



Atlantic Fleet Training and Testing Draft Environmental Impact Statement/ Overseas Environmental Impact Statement

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APPENDIX A ACTIVITY DESCRIPTIONS

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Draft

**Supplemental Environmental Impact Statement/
Overseas Environmental Impact Statement
Atlantic Fleet Training and Testing**

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A ACTIVITY DESCRIPTIONS

The Action Proponents have been conducting military readiness activities throughout the northwestern Atlantic Ocean, Gulf of Mexico, and inshore waters for decades. The tempo and types of military readiness activities have fluctuated within the Atlantic Fleet Training and Testing (AFTT) Study Area (Study Area) due to changing requirements, the introduction of new technologies, the dynamic nature of international events, advances in warfighting doctrine and procedures, and force structure changes. Such developments have influenced the frequency, duration, intensity, and location of required training and testing.

A.1 DESCRIPTION OF SONAR, MUNITIONS, TARGETS, AND OTHER SYSTEMS EMPLOYED IN ATLANTIC FLEET TRAINING AND TESTING ACTIVITIES

The Action Proponents use a variety of sensors, platforms, weapons, and other devices, including ones used to ensure the safety of Sailors and Marines, to meet its mission. Training and testing with these systems may have the potential to introduce acoustic (sound) energy and expended materials into the environment. The environmental impact of these activities was analyzed in [Chapter 3](#) (Affected Environment and Environmental Consequences) of this Supplemental Environmental Impact Statement (EIS)/Overseas Environmental Impact Statement (OEIS). This appendix presents and organizes sonar systems, munitions, targets, and other systems in a manner intended to facilitate understanding of both the activities that use them and the analysis of their environmental effects, described in [Chapter 3](#) (Affected Environment and Environmental Consequences) of this Supplemental EIS/OEIS.

A.1.1 SONAR SYSTEMS AND OTHER ACOUSTIC SOURCES

Sonar. Sonar, originally an acronym for “Sound Navigation and Ranging,” is a technique that uses underwater sound to navigate, communicate, or detect underwater objects (the term sonar is also used for the equipment used to generate and receive sound). There are two basic types of sonar: active and passive.

Active sonar emits sound waves that travel through the water, reflect off objects, and return to a receiver. Sonar is used to determine the distance to an underwater object by calculating the speed of sound in water and the time for the sound wave to travel to the object and back. For example, active sonar systems are used to track targets or to aid in vessel navigation by identifying known ocean floor features. Some whales, dolphins, and bats use echolocation, a similar technique, to identify their surroundings and to locate prey.

Passive sonar uses listening equipment, such as underwater microphones (hydrophones) and receiving sensors on ships, submarines, aircraft, or autonomous vehicles, to pick up underwater sounds. The advantage of passive sonar is that it places no sound in the water and, thus, does not reveal the location of the listening vessel. Passive sonar can indicate the presence, character, and direction of noise producing objects such as ships and submarines; however, passive sonar is increasingly ineffective as modern submarines become quieter. Passive sonar has no potential acoustic impact on the environment and, therefore, is not discussed further or analyzed within this Supplemental EIS/OEIS.

All sounds, including sonar, are categorized by frequency. For this Supplemental EIS/OEIS, active sonar is categorized into four frequency ranges: low-frequency¹, mid-frequency, high-frequency, and very high-frequency.

- Low-frequency active sonar emits sounds at frequencies less than 1 kilohertz (kHz). Low-frequency active sonar is useful for detecting objects at great distances because low-frequency sounds do not dissipate as rapidly as higher-frequency sounds.
- Mid-frequency active sonar emits sounds at frequencies from 1 to 10 kHz. Mid-frequency active sonar is the Navy's primary tool for detecting and identifying submarines. Active sonar in this frequency range provides a valuable combination of range and target accuracy.
- High-frequency active sonar emits sounds at frequencies from 10 kHz to 100 kHz. High-frequency sounds dissipate rapidly and have a small effective range; however, high-frequency sounds provide higher resolution of objects and are useful at detecting and identifying smaller objects such as sea mines.
- Very high-frequency sources are those that operate above 100 kHz but below 200 kHz. Very high-frequency sounds provide even higher resolution of objects and are sometimes used for underwater communication.

Modern sonar technology includes a variety of sonar sensor and processing systems. In concept, the simplest active sonar emits sound waves, or "pings," sent out in multiple directions, and the sound waves then reflect off of the target object in multiple directions (Figure A.1-1).

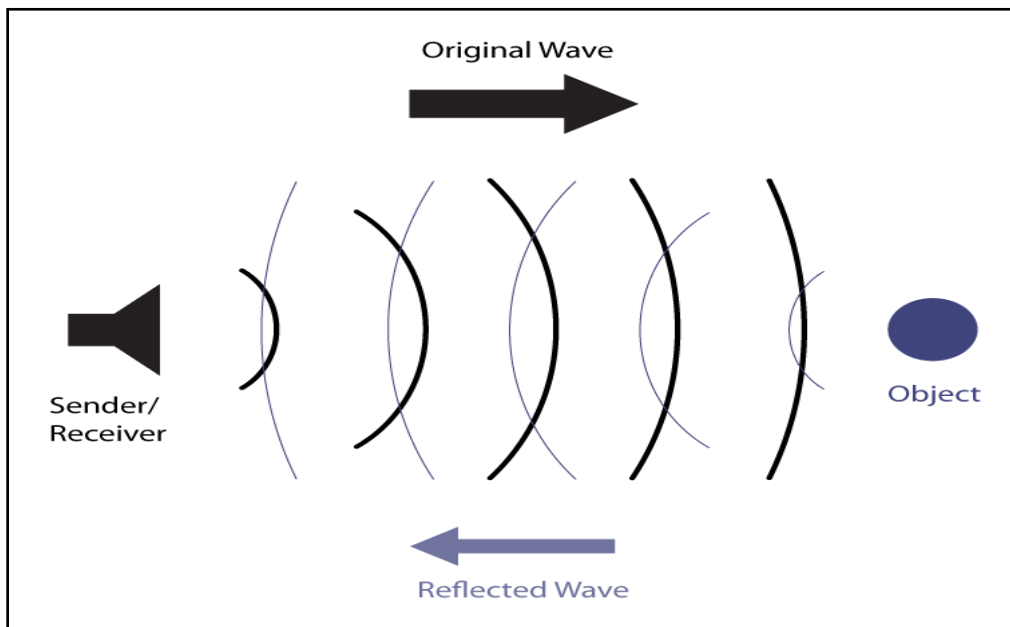


Figure A.1-1: Principle of an Active Sonar

The sonar source calculates the time it takes for reflected sound waves to return; this calculation determines the distance to the target object. More sophisticated active sonars emit a ping and then

¹ Surveillance Towed Array Sensor System (SURTASS) Low-Frequency Active sonar, which may be used in the Study Area, is not among the sources analyzed in this document. The potential environmental impacts from use of SURTASS Low-Frequency Active sonar are analyzed in separate analyses under the National Environmental Policy Act.

rapidly scan or listen to the sound waves in a specific area. This provides both distance to the target and directional information. Even more advanced sonars use multiple receivers to listen to echoes from several directions simultaneously and provide efficient detection of both direction and distance. It should be noted that active sonar is rarely used continuously throughout the listed activities. In addition, when sonar is in use, the sonar “pings” occur at intervals, referred to as a duty cycle, and the signals themselves are very short in duration. For example, a sonar that emits a 1-second ping every 10 seconds has a 10 percent duty cycle.

The Navy utilizes sonar systems and other acoustic sensors in support of a variety of mission requirements. Primary uses include detection of and defense against submarines (anti-submarine warfare) and mines (mine warfare), safe navigation and effective communications, and oceanographic surveys. Specific examples of how sonar systems are used for Navy activities are discussed in the following sections.

Anti-Submarine Warfare. Systems used in anti-submarine warfare include sonars, torpedoes, and acoustic countermeasure devices. These systems are employed from a variety of platforms (surface ships, submarines, helicopters, and fixed-wing aircraft). Surface ships conducting anti-submarine warfare are typically equipped with hull-mounted sonar (passive and active) for the detection of submarines (or submarine targets during training and testing activities). Helicopters use dipping sonar or sonobuoys (passive and active) to locate submarines (or targets). Fixed-wing aircraft deploy both active and passive expendable sonobuoys to assist in detecting and tracking submarines (or targets). Submarines are equipped with hull-mounted sonars to detect, localize, and track other submarines and surface ships. Submarines primarily use passive sonar; active sonar is used mostly for navigation. There are also unmanned vehicles currently being developed to deploy anti-submarine warfare systems.

Anti-submarine warfare activities often use mid-frequency (1 to 10 kHz) active sonar, though low-frequency and high-frequency active sonar systems are also used for specialized purposes.

Typical active sonar systems and acoustic sensors used during anti-submarine warfare sonar training and testing exercises include the following:

- **Surface Ship Sonar Systems:** A variety of surface ships operate hull-mounted or tethered mid-frequency active sonar during training exercises and testing activities (Figure A.1-2). Only cruisers and destroyers have surface ship sonar systems. The littoral combat ship and new frigate will have a tethered variable depth sonar system. Unmanned surface vessels can also include sonar systems, such as the variable depth sonar and minehunting sonar.

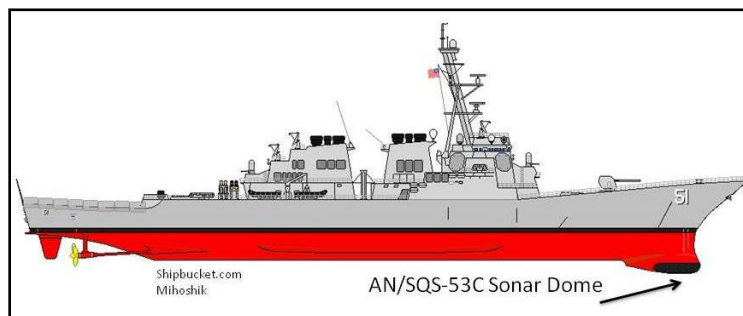


Figure A.1-2: Guided Missile Destroyer with an AN/SQS-53 Sonar

- **Submarine Sonar Systems:** Submarines are equipped with hull-mounted mid-frequency and high-frequency active sonar (Figure A.1-3) used to detect and target enemy submarines and surface ships. A submarine’s mission relies on its stealth; therefore, a submarine uses its active sonar sparingly because each sound emission gives away the submarine’s location.

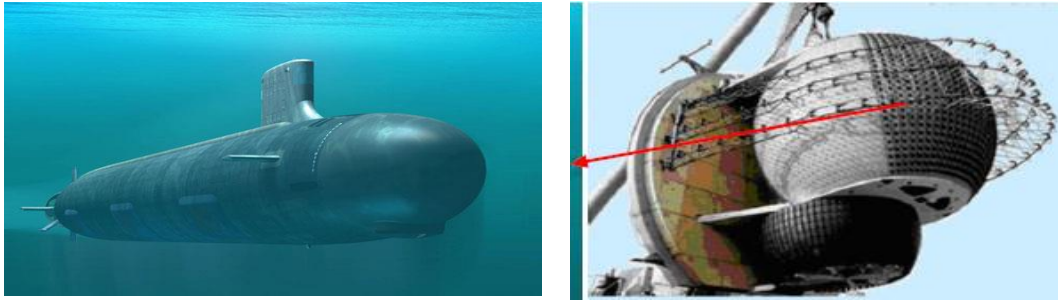


Figure A.1-3: Submarine AN/BQQ-10 Active Sonar Array

- **Aircraft Sonar Systems:** Aircraft sonar systems include sonobuoys and dipping sonars.
 - **Sonobuoys:** Active sonobuoys are expendable devices that contain a data transmitter and a hydrophone. The sounds collected by the sonobuoy are transmitted back to the operator (aboard ship or aircraft) for analysis. Sonobuoys are either active or passive and allow for short- and long-range detection of surface ships and submarines. These systems are deployed by ship, helicopter, and fixed-wing patrol aircraft (Figure A.1-4).



Figure A.1-4: Sonobuoy (e.g., AN/SSQ-62)

- **Dipping Sonars:** Dipping sonars are recoverable devices lowered into the water via cable from manned and unmanned helicopters (Figure A.1-5). The sonar detects underwater targets and determines the distance and movement of the target relative to the position of the helicopter.



Figure A.1-5: Helicopter Deploys Dipping Sonar

- **Exercise Torpedoes:** Some torpedoes used in military readiness activities may transmit active sonar signals. Surface ships, aircraft, and submarines primarily use torpedoes in anti-submarine warfare (Figure A.1-6). Recoverable, non-explosive torpedoes, categorized as either lightweight or heavyweight, are used during training and testing. Torpedoes operate autonomously, or in the case of heavyweight torpedoes, use a guidance system to operate the torpedo remotely through an attached wire (guidance wire). The autonomous guidance systems operate either passively (listening for sounds generated by the target) or actively (pinging to search for the target). Torpedo training in the Study Area is mostly simulated—solid masses that approximate the weight and shape of a torpedo are fired rather than fully functional torpedoes. Testing in the Study Area mostly uses fully functional exercise torpedoes.

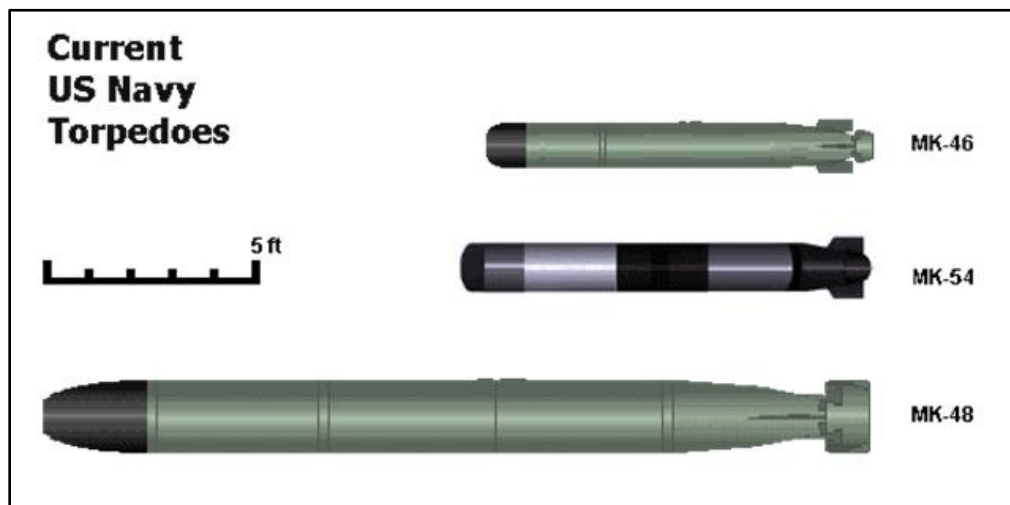


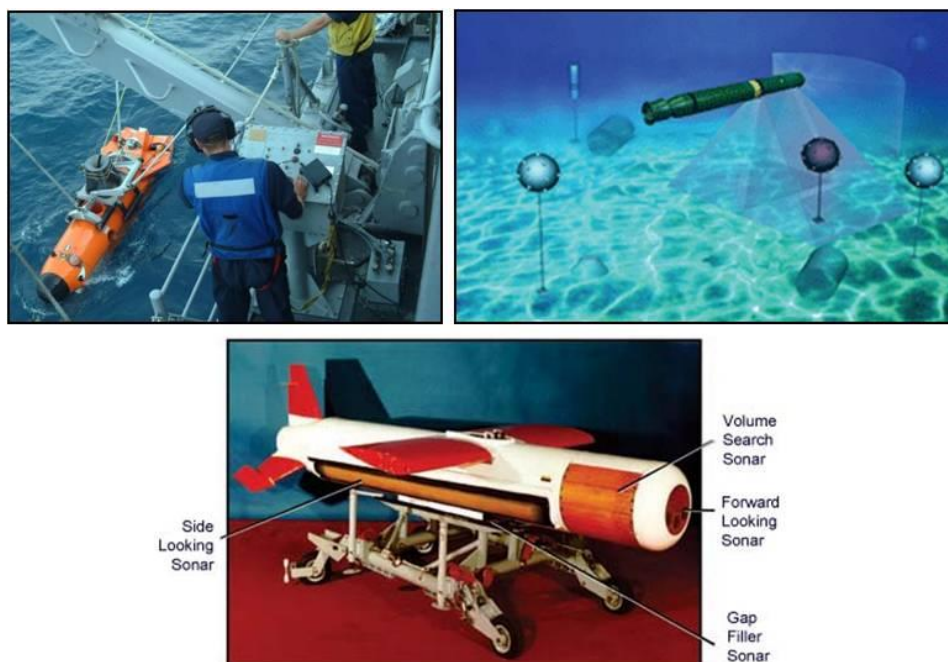
Figure A.1-6: Current U.S. Navy Torpedoes

- **Anti-Submarine Warfare Targets:** An anti-submarine warfare target is shown in (Figure A.1-7).



Figure A.1-7: Anti-Submarine Warfare Target

Mine Warfare. Mine warfare military readiness activities use a variety of different sonar systems that are typically high-frequency (10 kHz to 100 kHz) and very high-frequency (100 kHz to 200 kHz). These sonar systems are used to detect, locate, and characterize moored and bottom mines (Figure A.1-8). The majority of mine warfare sonar sensors can be deployed by more than one platform (e.g., helicopter, unmanned underwater vehicle, or surface ship) and may be interchangeable among platforms. Surface ships and submarines use sonar to detect mines and objects.



(Source: Graphic on right courtesy of Lockheed Martin)

Figure A.1-8: Mine Warfare Systems

Safety, Navigation, Communications, and Oceanographic Systems. Naval ships, submarines, and unmanned surface and sub-surface vehicles rely on equipment and instrumentation that use active sonar during both routine operations and training and testing activities. Sonar systems are used to gauge water depth; detect and map objects, navigational hazards, and the ocean floor; and transmit communication signals.

A.1.2 MUNITIONS

Most munitions used during training and testing activities fall into three basic categories: projectiles, missiles, and bombs. Munitions can be further defined by their net explosive weight, which is the actual weight in pounds of the explosive substance without the packaging, casings, bullets, etc. Net explosive weight is also the trinitrotoluene (TNT) equivalent of energetic material, which is the standard measure of strength of bombs and other explosives. For example, a 2,000-pound (lb.) bomb may have anywhere from 600 to 1,000 lb. of net explosive weight.

Projectiles. Projectiles are fired during gunnery exercises and testing activities from a variety of weapons, ranging from pistols and rifles to large-caliber, turret-mounted guns on the decks of Navy ships. Projectiles can be either high-explosive munitions (e.g., certain cannon shells), or non-explosive practice munitions (e.g., rifle/pistol bullets). Explosive rounds can be fused to either explode on impact or in the air (i.e., just prior to impact). Projectiles are broken down into three basic categories in this Supplemental EIS/OEIS:

- **Small-Caliber Projectiles:** These projectiles are up to and including 0.50 caliber. Small-caliber projectiles (e.g., bullets) are primarily fired from pistols, rifles, and machine guns (i.e., small arms) and mostly during training activities for an individual Sailor to become and remain proficient (Figure A.1-9).



Figure A.1-9: Shipboard Small Arms Training

- **Medium-Caliber Projectiles:** These projectiles are larger than 0.50 caliber but smaller than 57-millimeter (mm) (approximately 2- to 0.25-inch (in.) diameter). The most common size medium-caliber projectiles are 20 mm, 25 mm, and 40 mm. Medium-caliber projectiles are fired from machine guns operated by one to two crewman and mounted on the deck of a ship, wing-mounted guns on aircraft, and fully automated guns mounted on ships for defense against missile attack (Figure A.1-10). Medium-caliber projectiles also include 40-mm grenades, which can be fired from hand-held grenade launchers or crew-served deck-mounted guns. Medium-caliber projectiles can be non-explosive practice munitions or high-explosive projectiles. High-explosive projectiles are usually fused to detonate on impact; however, advanced high-explosive projectiles can detonate based on time, distance, or proximity to a target.



Figure A.1-10: Shipboard Medium-Caliber Guns

- **Large-Caliber Projectiles:** These include projectiles 57 mm and larger. The largest projectile currently in service has a 5-in. (12.7-centimeter) diameter. The most widely used large-caliber projectiles are 57 mm and 5 in. (Figure A.1-11). The most common 5-in. projectile is approximately 26 in. long and weighs 70 lb. Large-caliber projectiles are fired exclusively from turret-mounted guns located on ship decks and can be used to fire on surface ships and boats, in defense against missiles and aircraft, and against land-based targets. Large-caliber projectiles can be non-explosive practice munitions or explosive munitions. High-explosive projectiles can detonate on impact or in the air.



Figure A.1-11: Shipboard Large-Caliber Gun and Projectiles

Missiles. Missiles are rocket or jet-propelled munitions used to attack ships, aircraft, and land-based targets, as well as defend ships against other missiles. Guidance systems and advanced fusing technology ensure that missiles reliably impact on or detonate near their intended target. Missiles are categorized according to their intended target, as described below, and can be further classified according to net explosive weight. Rockets are included within the category of missiles.

- **Anti-Air Missiles:** Anti-air missiles are fired from ships and aircraft against enemy aircraft and incoming missiles (Figure A.1-12). Anti-air missiles are configured to explode in the air near, or on impact with, their intended target and are the primary ship-based defense against incoming missiles.



Figure A.1-12: Rolling Airframe Missile and Air-to-Air Missile

- **Anti-Surface Missiles:** Anti-surface missiles are fired from aircraft, ships, and submarines against surface ships (Figure A.1-13). Anti-surface missiles are typically configured to detonate on impact or just above the intended target.



Figure A.1-13: Anti-Surface Missile Fired from MH-60 Helicopter

- **Anti-Radiation Missiles:** The AGM-88 High-Speed Anti-Radiation Missile, used to destroy enemy radar sites, is fired at a floating seaborne target that replicates a land-based radar site.
- **Rockets:** Rockets are fired from helicopters against water and land-based targets. Rockets can either be laser guided or unguided, and while most contain inert warheads there are high-explosive variants that detonate on impact or flechette warheads that open at the conclusion of rocket motor burnout and contain approximately 1,180 60-grain flechettes.

Bombs. Bombs are unpowered munitions dropped from aircraft on land and water targets. The majority of bombs used during training and testing in the Study Area are non-explosive. However, explosive munitions are occasionally used for proficiency inspections and testing requirements. Bombs fall into two categories: general-purpose bombs and subscale practice bombs. Similar to missiles, bombs are further classified according to their net explosive weight.

- **General-Purpose Bombs:** General-purpose bombs consist of precision-guided and unguided full-scale bombs, ranging in size from 250 to 2,000 lb. (Figure A.1-14). Common bomb nomenclature used includes MK 80 series, which is the Navy's standard model; Guided Bomb Units and Joint Direct Attack Munitions, which are precision-guided (including laser-guided) bombs; and the Joint Standoff Weapon, which is a long-range "glider" precision weapon. General-purpose bombs can be either non-explosive practice munitions or high-explosive.



Figure A.1-14: F/A-18 Bomb Release and Loading General-Purpose Bombs

- **Subscale Bombs:** Subscale bombs (Figure A.1-15) are non-explosive practice munitions containing a spotting (smoke) charge to aid in scoring the accuracy of hitting the target during military readiness activities. Common subscale bombs are 25 lb. and less and are steel constructed. Laser-guided training rounds are another variation of a subscale practice bomb. They weigh approximately 100 lb. and are cost-effective non-explosive weapons used in training aircrew in laser-guided weapons employment.



Figure A.1-15: Subscale Bombs for Training

Other Munitions. There are other munitions used in naval at-sea training and testing activities that do not fit into one of the above categories and are discussed below:

- **Demolition Charges:** Divers place explosive charges in the marine environment during some military readiness activities. These activities may include the use of timed charges, in which the charge is placed, a timer is started, and the charge detonates at the set time. Munitions of up to 60-lb. blocks of composition 4 (C-4) plastic explosive, with the necessary detonators and cords, are used to support mine neutralization, demolition, and other warfare activities. The vast majority of underwater detonations involve explosive charges of 20 lb. or less in size. All demolition charges are further classified according to the net explosive weight of the charge.
- **Torpedoes:** Explosive torpedoes are required in some training and testing activities. Torpedoes are described as either lightweight or heavyweight and are further categorized according to the net explosive weight.

A.1.3 TARGETS

Training and testing require an assortment of realistic and challenging targets. Targets vary from items as simple and ordinary as an empty steel drum used for small-caliber weapons training from the deck of

a ship, to sophisticated, unmanned aerial drones used in air defense training. For this Supplemental EIS/OEIS, targets are organized by warfare area.

Air Warfare Targets: Air warfare targets, tow target systems, and aerial targets are used in training and testing activities that involve detection, tracking, defending against, and attacking enemy missiles and aircraft. Aerial tow target systems include textile (nylon banner) and rigid (fiberglass shapes) towed targets used for gunnery activities. Aerial targets include expendable ballistic targets and recoverable radio-controlled drones used for gunnery and missile exercises (Figure A.1-16). Parachute flares are used as air-to-air missile targets. Manned high-performance aircraft may be used as targets—to test ship and aircraft defensive systems and procedures—without the actual firing of munitions.



Figure A.1-16: Deployment and Recovery of Air Warfare Targets

Surface Warfare Targets: Floating, towed, and mobile targets are used as surface warfare targets during gunnery activities. Targets include floating steel drums, inflatable shapes or target balloons (e.g., Killer Tomato™) (Figure A.1-17), and towed sleds. High-speed targets, such as Jet Skis and motorboats, are also used (Figure A.1-18).



Figure A.1-17: Deploying a “Killer Tomato™” Floating Target



Figure A.1-18: Ship Deployable Surface Target and High-Speed Maneuverable Seaborne Target

Anti-Submarine Warfare Targets: Anti-submarine warfare uses multiple types of targets, including the following:

- **Submarines:** Submarines may act as tracking and detection targets during training and testing activities.
- **Motorized Autonomous Targets:** Motorized autonomous targets simulate the acoustic and magnetic characteristics of a submarine, providing realism for exercises when a submarine is not available. There are two types of mobile targets, one is designed for recovery and reuse, while the other is expendable.
- **Stationary Artificial Targets:** Stationary targets either resemble submarine hulls or are simulated systems with acoustic properties of enemy submarines. These targets either rest on the seafloor or are suspended at varying depths in the water column.

Mine Warfare Targets: Mine targets are used in training activities that involve the detection, location, and neutralization of mines in the water. There are a wide variety of mine targets that mimic floating, bottom, and moored mines. All mine targets are made out of inert material.

A.1.4 DEFENSIVE COUNTERMEASURES

Naval forces depend on effective defensive countermeasures to protect against missile and torpedo attack. Defensive countermeasures are devices designed to confuse, distract, and confound precision-guided munitions. Defensive countermeasures fall into five basic categories:

- **Chaff:** Chaff consists of reflective, aluminum-coated glass fibers used to obscure ships and aircraft from radar-guided systems. Chaff, which is stored in canisters, is either dispensed from aircraft or fired into the air from the decks of surface ships when an attack is imminent. The glass fibers create a radar cloud that masks the position of the ship or aircraft.
- **Flares:** Flares are pyrotechnic devices used to defend against heat-seeking missiles, where the missile seeks out the heat signature from the flare rather than the aircraft's engines. Similar to chaff, flares are also dispensed from aircraft and fired from ships.
- **Acoustic Countermeasures:** Acoustic countermeasures are used by surface ships and submarines to defend against torpedo attack (Figure A.1-19). Acoustic countermeasures are either released from ships and submarines or towed at a distance behind the ship.
- **Biodegradable Polymer:** Biodegradable polymer is a biodegradable vessel entanglement technology used to slow or stop specific maritime targets by entangling the propulsion mechanism.

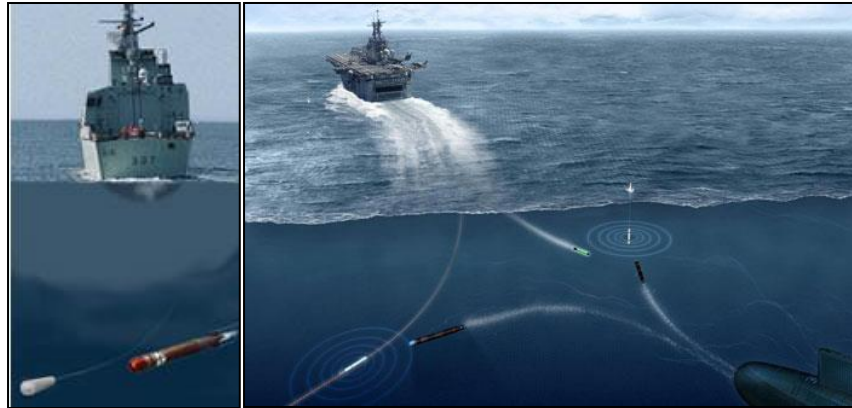


Figure A.1-19: Acoustic Countermeasures

A.1.5 MINE WARFARE SYSTEMS

Mine warfare systems fall into two broad categories: mine detection and mine neutralization.

Mine Detection Systems. Mine detection systems are used to locate, classify, and map suspected mines. Once located, the mines can either be neutralized or avoided. These systems are specialized to either locate mines on the surface, in the water column, or on the sea floor.

- **Towed or Hull-Mounted Mine Detection Systems:** These detection systems use acoustic and laser or video sensors to locate and classify suspect mines. Helicopters, ships, and unmanned vehicles deploy these systems, which can rapidly assess large areas (Figure A.1-20).



Figure A.1-20: Towed Mine Detection System

- **Airborne Laser Mine Detection Systems:** Airborne laser detection systems work in concert with neutralization systems. The detection system initially locates mines, and a neutralization system is then used to relocate and neutralize the mine (Figure A.1-21).

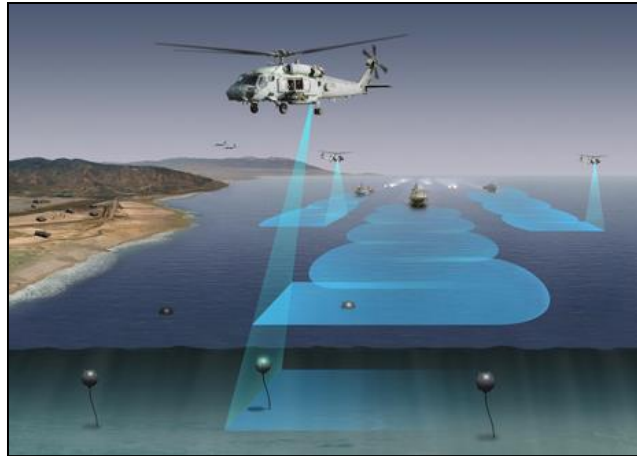


Figure A.1-21: AN/AES-1 Airborne Laser Mine Detection System

- **Unmanned/Remotely Operated Vehicles:** These vehicles use acoustic, video, or lasers, or combinations thereof, to locate and classify mines. Unmanned/remotely operated vehicles provide unique mine warfare capabilities in nearshore littoral areas, surf zones, ports, and channels.
- **Marine Mammal Systems:** Navy personnel and Navy marine mammals work together to detect specified underwater objects. The Navy deploys trained bottlenose dolphins and California sea lions as part of the marine mammal minehunting and object recovery system.
- **Mine Neutralization Systems.** These systems disrupt, disable, or detonate mines to clear ports and shipping lanes, as well as littoral, surf, and beach areas in support of naval amphibious operations. Mine neutralization systems can clear individual mines or a large number of mines quickly.
- **Towed Influence Mine Sweep Systems:** These systems use towed equipment that mimics a particular ship's magnetic and acoustic signature, triggering the mine and causing it to explode (Figure A.1-22).

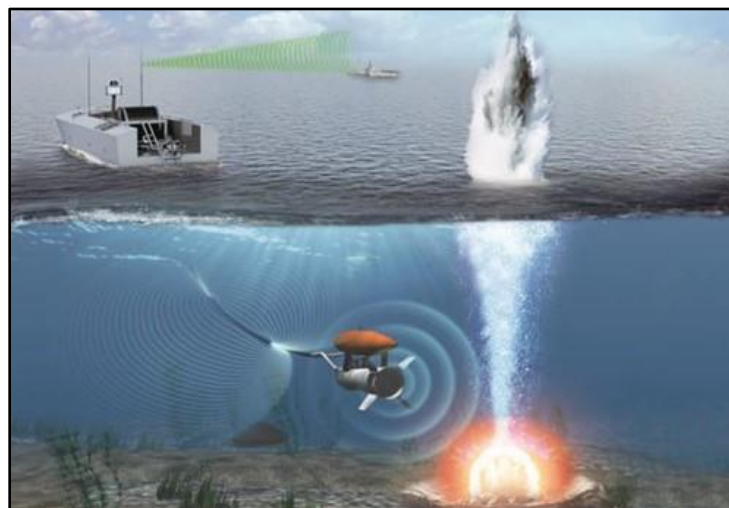


Figure A.1-22: Unmanned Influence Sweep Minehunting System

- **Towed Mechanical Mine Sweeping Systems:** These systems tow a sweep wire to snag the line that attaches a moored mine to its anchor and then uses a series of cables and cutters to sever those lines. Once these lines are cut, the mines float to the surface where explosive ordnance personnel can neutralize the mines.

- **Unmanned/Remotely Operated Mine Neutralization Systems:** Surface ship and helicopters operate these systems, which place explosive charges near or directly against mines to destroy the mine (Figure A.1-23).

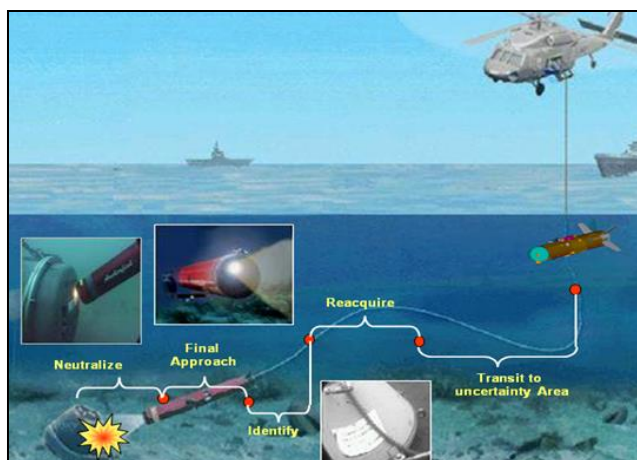


Figure A.1-23: Airborne Mine Neutralization System

- **Projectiles:** Small- and medium-caliber projectiles fired from surface ships or hovering helicopters are used to neutralize floating and near-surface mines.
- **Diver-Placed Explosive Charges:** Operating from small craft, divers place explosive charges, which may use time-delay fusing, near or on mines to destroy the mine or disrupt its ability to function.

A.1.6 MILITARY EXPENDED MATERIALS

Action Proponents' training and testing activities may introduce or expend various items, such as non-explosive munitions and targets, into the marine environment as a direct result of using these items for their intended purpose. In addition to the items described below, some accessory materials—related to the carriage or release of these items—may be released. These materials, referred to as military expended materials, are not recovered and potentially result in environmental impacts. These impacts are analyzed in detail in [Chapter 3](#) (Affected Environment and Environmental Consequences) of this Supplemental EIS/OEIS. This section includes descriptions of a representative sample of military expended materials. A more comprehensive discussion can be found in Chapter 3.

Military expended materials analyzed in this document include the following:

- **Sonobuoys:** Sonobuoys consist of decelerators/parachutes, wires, and the sonobuoys themselves.
- **Bathythermographs:** Bathythermographs as used by the Navy are similar to sonobuoys in that they consist of decelerators/parachutes, wires, and the buoy themselves. In the case of bathythermographs, the buoys are used to measure temperature information of the water column and transmit that information to the platform (usually a ship or aircraft) that deployed the bathythermograph.
- **Torpedo Launch Accessories:** Torpedoes are usually recovered; however, materials such as decelerators/parachutes used with air-dropped torpedoes, guidance wire used with submarine-launched torpedoes, and ballast weights are expended. Explosive-filled torpedoes expend torpedo fragments.
- **Projectiles and Bombs:** Non-explosive projectiles, non-explosive bombs, or fragments from explosive projectiles and bombs are expended during training and testing activities. These items

are primarily constructed of lead (most small-caliber projectiles) or steel (medium- and large-caliber projectiles and all bombs). Casings are expended as a result of firing either non-explosive or explosive projectiles. Most casings are recovered.

- **Blank Ammunition:** Blank ammunition is used in some training activities when the sound or flash of gunfire adds to the realism of the training activity but safety of personnel or nearby civilians is critical. Blank ammunition contains gunpowder, but no projectile is sent downrange upon firing the weapon. Casings are expended as a result of firing blank ammunition.
- **Missiles and Rockets:** Non-explosive missiles and missile fragments from explosive missiles are expended during training and testing activities. Propellant, and any explosive material involved, is consumed during firing/detonation. Rockets are similar to missiles and both non-explosive and fragments may be expended.
- **Countermeasures:** Countermeasures (acoustic, chaff, flares, and biodegradable polymer) are expended as a result of training or testing activities, with the exception of towed acoustic countermeasures. Chaff activities also include an expended canister, end caps, and pistons. Flares expend only end caps and pistons.
- **Targets:** Some targets are designed to be expended; other targets, such as aerial drones and remote-controlled boats, are recovered for reuse. Targets struck with munitions will result in target fragments.

A.1.7 STANDARD OPERATING PROCEDURES

For training and testing to be effective, personnel must be able to safely use their sensors, platforms, weapons, and other devices to their optimum capabilities and as intended for use in missions and combat operations. The Action Proponents have developed standard operating procedures through decades of experience to provide for safety and mission success. Because they are essential to safety and mission success, standard operating procedures are part of the Proposed Action and are considered in the [Chapter 3](#) (Affected Environment and Environmental Consequences) environmental analysis for applicable resources. Standard operating procedures recognized as providing a benefit to public safety or environmental resources are described below.

Airspace and sea space deconfliction allow for the necessary separation of multiple Action Proponents' units for safety and to prevent interference with equipment sensors. Deconfliction also allows for safe separation from non-participants within established commercial air traffic routes, commercial shipping lanes, and areas used for recreational activities. The Action Proponents evaluate the need to publish Notices to Airmen or Notices to Mariners to alert the public to stay clear of the area based on event locations and the activities involved. Some locations, such as those where explosive bombing activities routinely occur, have a standing Notice to Mariners. For other locations, such as ship shock trial boxes, the appropriate notices would be issued on an as-needed basis. Notices may also be issued prior to the use of unmanned surface vehicles, unmanned underwater vehicles, or unmanned aerial systems based on the event's scale, location, and timing. Additionally, when manned support vessels are already participating in activities involving unmanned vehicles, they will be responsible for ensuring safe operation of the vehicle, which may include ensuring (or requesting, if needed) clearance of non-participants from the event vicinity.

The Action Proponents do not typically conduct the activities listed in Table A.1-1 and Table A.1-2 in the coastal zone due to specific mission requirements. The coastal zone extends 3 nautical miles (NM) from shore everywhere in the Study Area except off Texas, the Florida Gulf coast, and Puerto Rico, where it extends 9 NM from shore.

Table A.1-1: Training Activities Typically Not Occurring in the Coastal Zone¹

<i>Air Warfare</i>	<i>Mine Warfare</i>
<ul style="list-style-type: none"> • Air Combat Maneuvers² • Air Defense Exercise • Gunnery Exercises <ul style="list-style-type: none"> ○ all Air-to-Air ○ all Surface-to-Air • Missile Exercises <ul style="list-style-type: none"> ○ Air-to-Air ○ Surface-to-Air 	<ul style="list-style-type: none"> • Mine Detection <ul style="list-style-type: none"> ○ Mine Countermeasure Exercise – Ship Sonar • Mine Laying <ul style="list-style-type: none"> ○ Aircraft ○ Submarine launched
<i>Amphibious Warfare</i>	<i>Surface Warfare</i>
<ul style="list-style-type: none"> • Naval Surface Fire Support Exercise-At Sea • Naval Surface Fire Support Exercise-Land-Based Target 	<ul style="list-style-type: none"> • Gunnery Exercises <ul style="list-style-type: none"> ○ All Air-to-Surface ○ All Surface-to-Surface • Missile Exercise <ul style="list-style-type: none"> ○ Air-to-Surface (Missile and Rocket) ○ Surface-to-Surface • Laser Targeting <ul style="list-style-type: none"> ○ Aircraft ○ Ship • Integrated Live Fire • Bombing Exercise • Sinking Exercise³
<i>Anti-Submarine Warfare</i>	<i>Major Training Exercise</i>
<ul style="list-style-type: none"> • Torpedo Exercise <ul style="list-style-type: none"> ○ Helicopter ○ Maritime Patrol Aircraft ○ Submarine ○ Ship • Tracking Exercise <ul style="list-style-type: none"> ○ Helicopter ○ Maritime Patrol Aircraft ○ Submarine ○ Ship 	<ul style="list-style-type: none"> • Composite Training Unit Exercise • Fleet Exercise/Sustainment Exercise
<i>Integrated/Coordinated Anti-Submarine Warfare</i>	<i>Other Training Activities</i>
<ul style="list-style-type: none"> • Anti-Submarine Warfare Tactical Development Exercise • Group Sail • Navy Undersea Warfare Training Assessment Course • Surface Warfare Advanced Tactical Training 	<ul style="list-style-type: none"> • Submarine Navigation • Submarine Under Ice Certification
	<i>Electronic Warfare</i>
	<ul style="list-style-type: none"> • Counter Targeting <ul style="list-style-type: none"> ○ Chaff-Aircraft ○ Chaff-Ship ○ Flare-Aircraft

¹ The coastal zone extends 3 NM from shore everywhere in the Study Area except off Texas, the Florida Gulf coast, and Puerto Rico, where it extends 9 NM from shore.

² Air Combat Maneuver typically occurs outside the coastal zone, with an exception in the Key West Range Complex.

³ This activity only occurs in a designated area, which is located outside of the coastal zone.

Table A.1-2: Testing Activities Typically Not Occurring in the Coastal Zone¹

<i>Air Warfare</i>	<i>Surface Warfare</i>
<ul style="list-style-type: none"> • Air Combat Maneuver Test • Air Platform Weapons Integration Test • Air Platform Vehicle Test • Air-to-Air Weapons System Test <ul style="list-style-type: none"> ○ Air-to-Air Gunnery Test – Medium-Caliber ○ Air-to-Air Missile Test • Intelligence, Surveillance, and Reconnaissance Test 	<ul style="list-style-type: none"> • Air-to-Surface Bombing Test • Air-to-Surface Gunnery Test • Air-to-Surface Missile Test • Air-to-Surface High-Energy Laser Test • Laser Targeting Test • Rocket Test • Gun Testing – Large-Caliber • Gun Testing – Medium-Caliber • Gun Testing – Small-Caliber • Missile and Rocket Testing • Maritime Security Operations
<i>Anti-Submarine Warfare</i>	
<ul style="list-style-type: none"> • Anti-Submarine Warfare Torpedo Test • Anti-Submarine Warfare Tracking Test – Rotary Wing • Kilo Dip • Sonobuoy Lot Acceptance Test 	

Table A.1-2: Testing Activities Typically Not Occurring in the Coastal Zone (continued)

<ul style="list-style-type: none"> • Torpedo (Explosive) Testing² • At-Sea Sonar Testing 	Other Testing Activities <ul style="list-style-type: none"> • Air Platform Shipboard Integration Test • Shipboard Electronic Systems Evaluation • Acoustic Component Testing • Simulant Testing • Non-Acoustic Component Testing
Electronic Warfare <ul style="list-style-type: none"> • Chaff Test • Electronic Systems Evaluation • Flare Test 	
Mine Warfare <ul style="list-style-type: none"> • Mine-Laying Test 	
Vessel Evaluation <ul style="list-style-type: none"> • Air Defense Testing • Propulsion Testing • Surface Warfare Testing • Small Ship Shock Trial² • Submarine Sea Trials – Propulsion Testing • Submarine Sea Trials – Weapons System Testing • Signature Analysis Operations 	Unmanned Systems <p>Underwater Search, Deployment, and Recovery</p> Acoustic and Oceanographic Science and Technology <ul style="list-style-type: none"> • Acoustic and Oceanographic Research • Electronic Systems Test • Large Displacement Unmanned Underwater Vehicle Testing

¹ The coastal zone extends 3 nautical miles from shore everywhere in the Study Area except off Texas, the Florida Gulf coast, and Puerto Rico, where it extends 9 nautical miles from shore.

² This activity only occurs in designated areas, which are located outside of the coastal zone.

Training and testing activities are carefully planned in advance and conducted under strict procedures that place the ultimate responsibility for safety on the officer conducting the exercise or civilian equivalent. If an unauthorized (i.e., non-participating) vessel, aircraft, or person is detected within an applicable safety distance, the activity would be temporarily halted until the area is cleared and secured. The U.S. Navy Dive Manual (U.S. Department of the Navy, 2011) prescribes safe distances for divers from active sonar sources and in-water explosions. Safety distances for weapon firing are based on the farthest firing range capability of the weapon being used. Safety distances for the use of electromagnetic energy are specified in Department of Defense Instruction 6055.11 (U.S. Department of Defense, 2021) and Military Standard 464D (U.S. Department of Defense, 2020) as the standard safety buffers for in-water energy to protect military divers. Laser systems are approved for fielding by the Action Proponents' Laser Safety Review Board or equivalent. Only properly trained and authorized personnel operate high-energy lasers within designated areas. In-water explosive activities are scheduled to occur in areas located away from popular recreational dive sites, primarily for human safety.

Most explosive activities are conducted during daylight hours. Weapon firing activities that involve small boats deploying or retrieving targets are typically conducted in Beaufort Sea state number 4 conditions or better to ensure safe operating conditions for the small boat operators. Aircrew are not authorized to deploy ordnance through extensive cloud cover where visual clearance for non-participants is not possible. The two exceptions to this requirement are (1) when operating in the open ocean, clearance for non-participating aircraft and vessels through radar surveillance is acceptable; and (2) when the officer conducting the exercise or civilian equivalent accepts responsibility for the safeguarding of airborne and surface traffic. During activities that involve recoverable targets, the Action Proponents recover the target and any associated decelerators or parachutes to the maximum extent practical consistent with personnel and equipment safety.

As a general policy for aircraft, aircrew do not intentionally generate sonic booms below 30,000 ft. of altitude unless over water and more than 30 miles from inhabited land areas or islands. The Action Proponents may authorize deviations from this policy for tactical missions, phases of formal training syllabus flights, or research, test, and operational suitability test flights. Aircraft will fly in accordance with Federal Aviation Administration Regulations (Part 91, General Operating and Flight Rules, Annex 2 Rules of the Air to the Convention of International Civil Aviation) or with due regard for the safety of all air traffic, which govern such flight components as operating near other aircraft, right-of-way rules, aircraft speed, and minimum safe altitudes. These rules include the use of tactical training and maintenance test-flight areas, arrival and departure routes, and airspace restrictions as appropriate to help control air operations. Aircrew make every attempt to avoid large flocks of birds to reduce the safety risk involved with a potential bird strike. Since 2011, the Navy has required that all Navy flying units report all bird strikes through the Web-Enabled Safety System Aviation Mishap and Hazard Reporting System. Unmanned aerial systems are operated in accordance with Federal Aviation Administration air traffic organization policy.

Vessels are required to operate in accordance with applicable navigation rules, including Inland Waters Navigation Rules (33 Code of Federal Regulations [CFR] section 83.01 et seq.) and International Regulations for Preventing Collisions at Sea (72 COLREGS). These rules and regulations were formalized in the Convention on the International Regulations for Preventing Collisions at Sea (1972) and implemented through the International Navigational Rules Act of 1977 (33 U.S.C. sections 1601–1608). Applicable navigation requirements specified in the Inland Navigation Rules include, but are not limited to, Rule 5 (Lookouts) and Rule 6 (Safe Speed). These rules require that vessels, at all times, proceed at a safe speed so proper and effective action can be taken to avoid collision and so vessels can be stopped within a distance appropriate to the prevailing circumstances and conditions. Surface ships transit at speeds that are optimal for fuel conservation, to maintain ship schedules, and to meet mission requirements. Vessel captains use the totality of the circumstances to ensure the vessel is traveling at appropriate speeds in accordance with navigation rules. Depending on the circumstances, this may involve adjusting speeds during periods of reduced visibility or in certain locations.

Underway surface ships operated by or for the Action Proponents have personnel assigned to stand watch at all times (day and night) for safety of navigation, collision avoidance, range clearance, and man-overboard precautions. Personnel on underway small boats (e.g., crewmembers responsible for navigation) fulfill similar watch standing responsibilities to those positioned on surface ships. Standard watch personnel, also referred to as “Lookouts,” include officers, enlisted personnel, and civilians operating in similar capacities. Following two ship collisions in 2017 that killed 17 Sailors, the Navy undertook a review of surface ship staffing, training, and personnel effectiveness. As a result, the Navy added additional Lookouts to watch teams for certain surface ship classes, increased the amount of time that Lookouts spend in bridge simulators, and developed watch rotations that align with the body’s natural circadian rhythms. Personnel are trained in accordance with the U.S. Navy Lookout Training Handbook or equivalent to use correct scanning procedures while monitoring assigned sectors, to estimate the relative bearing, range, position angle, and target angle of sighted objects, and to rapidly communicate accurate sightings reports. The handbook was updated in 2022 to include a more robust chapter on environmental compliance, mitigation, and marine species observation tools and techniques (NAVEDTRA 12968-E). Watch teams may use radios to communicate with other ships operating in the vicinity to coordinate safe maneuvering. After sunset and prior to sunrise, Lookouts employ night visual search techniques, which could include the use of night vision devices. Addressed in Chief of Naval Operations Instruction 3120.32D, the “Darken Ship Bill” requires darkened ships to ensure that white lights are not visible from outside surface ships. Lookouts monitor their assigned sectors for any indication of danger to the ship and the personnel on board, such as a floating or partially submerged object or piece of debris, periscope, surfaced submarine, wisp of smoke, flash of light, or surface disturbance. As a standard collision avoidance procedure for surface vessels, Lookouts also monitor for marine mammals that have the potential to be in the direct path of the vessel.

The Action Proponents also avoid known navigation hazards that appear on nautical charts, such as submerged wrecks and obstructions. With limited exceptions (e.g., amphibious vessels operating in designated locations, bottom-crawling vehicles), manned vessels and unmanned vehicles avoid contact with the seafloor as a standard collision avoidance procedure to prevent damage to the platforms.

Unmanned surface vehicles or unmanned underwater vehicles that operate autonomously may have embedded sensors designed for avoidance of large objects. For example, select unmanned vehicles have sensors, such as a forward-looking sonar, to perform obstacle avoidance. The forward-looking sonar makes detections at a sufficient range for the onboard processor to determine if there is a need for an avoidance maneuver. If there is a need for an avoidance maneuver, the onboard vehicle control system would insert a new maneuver (in place of the currently executing activity) and continue to introduce new maneuvers if detections continue to be made. There are a number of possible maneuvers that could be implemented, from adjusting heading to stopping or hovering the vehicle.

As an additional standard collision avoidance procedure during specific stages of training or testing (e.g., during an initial training and testing phases), manned support vessels may escort unmanned surface vehicles and unmanned underwater vehicles. Lookouts on the support vessels may use radios to communicate with other vessels operating in the vicinity to coordinate safe maneuvering (e.g., communicating the positioning and safety distances for avoiding collisions with unmanned vehicles).

As a standard collision avoidance procedure for in-water devices towed by surface vessels (or by unmanned surface vehicles or unmanned underwater vehicles under positive control by manned support vessels), the Action Proponents search the intended path of the towed in-water device for floating debris, concentrations of floating vegetation, floating objects, or animals with potential to obstruct, tangle, or damage the device.

A.2 TRAINING ACTIVITIES

The Action Proponents' training activities are organized generally into seven primary mission areas and a miscellaneous category ("Other Training") that includes those activities that do not fall within a primary mission area but are an essential part of Action Proponent training. The locations listed are the areas where the training typically takes place, but they can occur throughout the Study Area shown in Figure 2.1-1 (Atlantic Fleet Training and Testing Study Area) in [Chapter 2](#) (Description of Proposed Action and Alternatives). In addition, because the Navy conducts a number of activities within larger training exercises, descriptions of those larger exercises are also included here. It is important to note that these larger exercises are composed entirely of individual activities described in the primary mission areas.

A.2.1 MAJOR TRAINING EXERCISES

A major anti-submarine warfare training exercise comprises several "unit-level" range exercises conducted by several units operating together while commanded and controlled by a single commander. These exercises typically employ an exercise scenario developed to train and evaluate the strike group in naval tactical tasks. In a major training exercise, most of the operations and activities being directed and coordinated by the strike group commander are identical in nature to the operations conducted during individual, crew, and smaller-unit training events. In a major training exercise, however, these disparate training tasks are conducted in concert, rather than in isolation.

Major training exercises are listed in this Section A.2.1 (Major Training Exercises).

A.2.1.1 Composite Training Unit Exercise

Major Training Exercise - Large Integrated Anti-Submarine Warfare		
Composite Training Unit Exercise		
Short Description	Aircraft carrier and carrier air wing integrate with surface and submarine units in a challenging multi-threat operational environment that certifies them ready to deploy.	
Long Description	<p>The Composite Training Unit Exercise is an integration phase, at-sea, major training exercise, designed to forge the aircraft carrier strike group into a cohesive fighting team before deployment. Composite Training Unit Exercise normally consists of four-week, schedule of event-driven scenarios.</p> <p>An exercise typically consists of seven surface ships, multiple fixed-wing and rotary-wing aircraft, up to two submarines, and various unmanned vehicles. The exercise integrates the aircraft carrier and carrier air wing with surface and submarine units to achieve certification prior to deployment.</p> <p>Only the anti-submarine warfare activities were analyzed as a Composite Training Unit Exercise. Other warfare area training conducted during the Composite Training Unit Exercise is analyzed elsewhere as unit-level training (e.g., gunnery exercise, missile exercise, etc.). Coast Guard cutters and aircraft may participate in this activity.</p>	
Typical Components	<p>Platforms: Aircraft Carrier, Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Submarine, Surface Combatant, Unmanned Surface Vehicle, Unmanned Underwater Vehicle, Unmanned Aerial Vehicle</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed</p> <p>Munitions: Sonobuoys</p>	
Active Sonar	LFH, MFM, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources Manned surface vessels Towed in-water devices Unmanned vehicles</p>	
Parameters for Analysis	Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Navy Cherry Point Range Complex
	-	Jacksonville Range Complex
	Gulf of Mexico Range Complex	

A.2.1.2 Sustainment/Task Force Exercise

Included in the Fleet Response Training Plan is a requirement to conduct post-deployment training and maintenance. This ensures that the components of a strike group maintain an acceptable level of readiness after returning from deployment. A sustainment exercise is an exercise designed to challenge the strike group in all warfare areas. Marine mammal systems may be used during the exercise. This exercise is similar to a Composite Training Unit Exercise but is of shorter duration.

Major Training Exercise - Medium Integrated Anti-Submarine Warfare		
Sustainment/Task Force Exercise		
Short Description	Aircraft carrier and carrier air wing integrates with surface and submarine units in a challenging multi-threat operational environment to maintain ability to deploy.	
Long Description	<p>Sustainment Exercises are similar in scope to Composite Training Unit Exercises but shorter in duration and therefore fewer active sonar hours. Sustainment Exercises are conducted to ensure that a carrier strike group maintains an acceptable level of readiness after returning from deployment in order to maintain a surge capability. Marine mammal systems may be used during the exercise.</p> <p>Only the anti-submarine warfare activities were analyzed as a Sustainment Exercise. All other warfare area training conducted during a Sustainment Exercise was analyzed as unit-level training (e.g., bombing exercises, gunnery exercises, missile exercises, etc.).</p>	
Typical Components	<p>Platforms: Aircraft Carrier, Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Submarine, Surface Combatant, Unmanned Surface Vehicle, Unmanned Underwater Vehicle, Unmanned Aerial Vehicle</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed</p> <p>Munitions: Sonobuoys</p>	
Active Sonar	LFH, MFM, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources Manned surface vessels Towed in-water devices Unmanned vehicles</p>	
Parameters for Analysis	<p>Only the anti-submarine warfare activities were analyzed as a Sustainment Exercise. Other warfare area training conducted during the Sustainment Exercise was analyzed as unit-level training (gunnery exercise, missile exercise, etc.).</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.2 ANTI-SUBMARINE WARFARE TRAINING

Integrated or coordinated anti-submarine warfare training exercises are similar to major training exercises in that they are composed of several basic, unit-level exercises, training conducted by an individual unit, but are generally on a smaller scale, are of shorter duration, and use fewer hours of active sonar than a major training exercise.

A.2.2.1 Navy Undersea Warfare Training Assessment Course

Small Integrated Anti-Submarine Warfare Training		
Navy Undersea Warfare Training and Assessment Course		
Short Description	Multiple ships, aircraft, and submarines integrate the use of their sensors, including sonobuoys, to search for, detect, classify, localize, and track a threat submarine.	
Long Description	The Navy Undersea Warfare Training and Assessment Course is a tailored course of instruction designed to improve Sea Combat Commander and strike group integrated anti-submarine warfare warfighting skill sets. The Navy Undersea Warfare Training and Assessment Course is a coordinated training scenario that typically involves five surface ships, two to three embarked helicopters, a submarine, and one maritime patrol aircraft searching for, locating, and attacking one submarine. The scenario consists of two 12-hour exercises that occur five times per year. The submarine may practice simulated attacks against the ships while being tracked. Hull-mounted, towed array, and dipping sonar is employed by ships and helicopters. The submarine also periodically operates its sonar.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Submarine, Surface Combatant Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed Munitions: Sonobuoys	
Active Sonar	LFH, MFM, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Towed in-water devices	
Parameters for Analysis	Two MK-39 Expendable Mobile Anti-Submarine Warfare Training Targets may be used in place of an actual submarine target. Air deployed sonobuoys will have a decelerator/parachute. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.2.2 Surface Warfare Advanced Tactical Training

Small Integrated Anti-Submarine Warfare Training		
Surface Warfare Advanced Tactical Training		
Short Description	Multiple ships and aircraft coordinate the use of sensors, including sonobuoys, to search, detect, and track a threat submarine. Surface Warfare Advanced Tactical Training (SWATT) exercises are not dedicated anti-submarine warfare exercises and involve multiple warfare areas.	
Long Description	SWATT is an intermediate training exercise designed primarily to increase operator proficiency and exercise combined force responses to surface warfare, anti-submarine warfare, air warfare and electromagnetic spectrum operations. SWATT is conducted after a carrier strike group's first Group Sail, and before Composite Training Unit Exercise, and consists of multiple surface warfare, anti-submarine and air warfare live-fire activities. Multiple ships and aircraft search for, locate, and track one submarine. Occurs once per carrier strike group training cycle. Use of other munitions and explosives in SWATT are included in unit-level events.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Submarine, Surface Combatant Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed Munitions: Sonobuoys	
Active Sonar	LFH, MFM, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Towed in-water devices	
Parameters for Analysis	Only the anti-submarine warfare activities were analyzed as a SWATT. Other warfare area training conducted during SWATT was analyzed as unit-level training (gunnery exercises, missile exercises, etc.). Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.2.3 Anti-Submarine Warfare Tactical Development Exercise

Medium Coordinated Anti-Submarine Warfare Training		
Anti-Submarine Warfare Tactical Development Exercise		
Short Description	Multiple ships, aircraft, and submarines coordinate their efforts to search for, detect, and track submarines with the use of all sensors. Anti-Submarine Warfare Tactical Development Exercise is a dedicated anti-submarine warfare exercise.	
Long Description	Multiple ships, aircraft, and submarines coordinate their efforts to search for, detect, and track submarines with the use of all sensors. Anti-Submarine Warfare Tactical Development Exercise is a fleet training exercise involving surface ships, submarines, and aircraft. Active and passive sonar and sonobuoys are used to conduct anti-submarine warfare training exercises. The purpose of the exercise is to assess fleet anti-submarine warfare performance and capability among various units operating together in a specific threat environment.	
Typical Components	Platforms: Rotary-Wing Aircraft, Submarine, Surface Combatant Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed Munitions: Sonobuoys	
Active Sonar	MFM, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Towed in-water devices	
Parameters for Analysis	Only the anti-submarine warfare activities were analyzed as an Anti-Submarine Warfare Tactical Development Exercise. Other warfare area training conducted during the exercise was analyzed as unit-level training. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.2.4 Amphibious Ready Group Marine Expeditionary Unit Composite Training Unit Exercise

Small Coordinated Anti-Submarine Warfare Training		
Amphibious Ready Group Marine Expeditionary Unit Composite Training Unit Exercise		
Short Description	Navy and Marine Corps forces conduct advanced training at sea in preparation for deployment.	
Long Description	<p>Amphibious ships and embarked Marine Expeditionary Units train to a multitude of scenarios to test the capabilities of the amphibious force. Operations include ship to shore movement with tiltrotor aircraft and Landing Craft Air Cushion vessels. Marine Corps forces conduct more advanced amphibious operations to include small boat raids; visit, board, search, and seizure training; helicopter and mechanized amphibious raids; and non-combatant evacuation operations.</p> <p>This exercise generally occurs during an Expeditionary Strike Group Composite Training Unit Exercise. Surface combatants conduct anti-submarine warfare training to protect amphibious ships from underwater threats. All military expended materials, explosives, and use of other munitions in Amphibious Ready Group Marine Expeditionary Unit Exercise are included in unit-level events.</p>	
Typical Components	<p>Platforms: Amphibious Vehicles, Amphibious Warfare Ship, Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Surface Combatant, Tiltrotor Aircraft</p> <p>Targets: None</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Only the anti-submarine warfare activities were analyzed as Amphibious Ready Group Marine Expeditionary Unit training. Other warfare area training conducted during the exercise was analyzed as unit-level training.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.2.5 Group Sail

Small Coordinated Anti-Submarine Warfare Training		
Group Sail		
Short Description	Surface ships and helicopters integrate to search for, detect, and track threat submarines. Group Sails are not dedicated anti-submarine warfare exercises and involve multiple warfare areas.	
Long Description	<p>Multiple ships and helicopters integrate the use of their sensors, including sonobuoys, to search for, detect, classify, localize, and track threat submarines.</p> <p>While Group Sail is not a dedicated anti-submarine warfare exercise and involves multiple warfare areas, only the anti-submarine warfare activities were analyzed as a Group Sail. Other warfare area training conducted during a Group Sail is analyzed elsewhere as unit-level training.</p> <p>Group Sail is an intermediate training exercise primarily intended to introduce coordinated operations after unit-level training and prior to integrated training. This exercise stresses planning, coordination, and communications during multiple warfare training scenarios.</p> <p>Two or more ships and up to two helicopters search for, locate, and attack one submarine. Typically, one ship and helicopter are actively prosecuting while the other ship and helicopter are repositioning. Simultaneously, the submarine may practice simulated attacks against the ships. Multiple acoustic sources may be active at one time.</p>	
Typical Components	<p>Platforms: Rotary-Wing Aircraft, Submarine, Surface Combatant</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed</p> <p>Munitions: Sonobuoys</p>	
Active Sonar	MFM, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Towed in-water devices</p>	
Parameters for Analysis	<p>While the preference will be to train against an actual submarine or MK 30 recoverable target, assume only MK 39 expendable targets will be used.</p> <p>One MK 39 Expendable Mobile Anti-Submarine Warfare Training Target may be used in place of an actual submarine target.</p> <p>Only the anti-submarine warfare activities were analyzed as small coordinated Anti-Submarine Warfare training. Other warfare area training conducted during the exercise was analyzed as unit-level training.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.3 AIR WARFARE TRAINING

Air warfare is the primary mission area that addresses combat operations by air and surface forces against hostile aircraft. Navy ships contain an array of modern anti-aircraft weapon systems, including naval guns linked to radar-directed fire-control systems, surface-to-air missile systems, and radar-controlled cannon for close-in point defense. Strike/fighter aircraft carry anti-aircraft weapons, including air-to-air missiles and aircraft cannon. Air warfare training encompasses activities and exercises to train ship and aircraft crews in employment of these weapons systems against simulated threat aircraft or targets. Air warfare training includes surface-to-air gunnery, surface-to-air and air-to-air missile exercises, and aircraft force-on-force combat maneuvers.

A.2.3.1 Air Combat Maneuvers

Air Warfare		
Air Combat Maneuvers		
Short Description	Fixed-wing aircrews aggressively maneuver against threat aircraft to gain tactical advantage.	
Long Description	Basic flight maneuvers in which fixed-wing aircrew engage in offensive and defensive maneuvering against each other. No ordnance is expended during this training, however countermeasures such as chaff and flares may be used. These maneuvers typically involve two aircraft; however, based upon the training requirement, air combat maneuvers may involve over a dozen aircraft.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft Targets: None Systems being Trained/Tested: Captive Air Training Missile Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	No munitions are fired. Flares and chaff may be used. All flares and chaff are accounted for in flare exercise and chaff exercise.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	Key West Range Complex

A.2.3.2 Air Defense Exercise

Air Warfare		
Air Defense Exercise		
Short Description	Aircrew and ship crews conduct defensive measures against threat aircraft or simulated missiles.	
Long Description	Fixed-wing aircrew and ship personnel perform measures designed to defend against attacking threat aircraft or missiles or reduce the effectiveness of such attack. This exercise involves full detection through engagement sequence. Aircraft operate at varying altitudes and speeds. This exercise includes air intercept control exercises where aircraft controllers on ships, in fixed-wing aircraft, or at land-based locations, use search radars to track and direct friendly aircraft to intercept the threat aircraft. This exercise also includes detect-to-engage exercises, where personnel on ships use search radars to detect, classify, and track enemy aircraft or missiles up to the point of engagement. No ordnance is fired during this exercise, however countermeasures, such as chaff and flares, may be used. Coast Guard aircraft may participate in this activity.	
Typical Components	Platforms: Fixed Wing – Adversary Aircraft, Fixed Wing - Command and Control Aircraft, Fixed Wing – Strike Aircraft, Surface Combatant Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	No munitions are fired.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.3.3 Gunnery Exercise Air-to-Air Medium-Caliber

Air Warfare		
Gunnery Exercise Air-to-Air		
Short Description	Fixed-wing aircrews fire medium-caliber guns at air targets.	
Long Description	Fixed-wing aircrews maneuver aircraft in a gunnery pattern to achieve a firing solution with integrated medium-caliber guns. Typically involves two or more fixed-wing aircraft and a target banner towed by a contract aircraft (e.g., Lear jet). The target banner is recovered after the exercise.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft Targets: Air Targets - Other Systems being Trained/Tested: Medium-Caliber Gun Systems Munitions: Projectile - Medium-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	This activity is conducted at an altitude of 15,000 ft. and above, during the daytime, and approximately 40 NM from shore. A towed air target is a banner target and will be recovered. Only non-explosive munitions used.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	Key West Range Complex

A.2.3.4 Gunnery Exercise Air to Air - Small-Caliber

Air Warfare		
Gunnery Exercise Air-to-Air - Small-Caliber		
Short Description	Helicopter aircrews fire small-caliber guns at threat air targets.	
Long Description	Helicopter aircrews maneuver aircraft to engage a small airborne threat with crew-served weapons. Typically involves one helicopter and an airborne UAS or drone target.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: Air Targets - Drone Systems being Trained/Tested: None Munitions: Projectile - Small-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Jacksonville Range Complex

A.2.3.5 Gunnery Exercise Surface-to-Air Large-Caliber

Air Warfare		
Gunnery Exercise Surface-to-Air Large-Caliber		
Short Description	Surface ship crews fire large-caliber guns at air targets.	
Long Description	Surface ship and Coast Guard cutter crews defend against threat aircraft or missiles with large-caliber guns to disable or destroy the threat. An exercise involves one ship and a simulated threat aircraft or missile that is detected by the ship's radar. Large-caliber guns fire non-explosive projectiles at the threat before it reaches the ship. The target is towed by a contract air services jet.	
Typical Components	Platforms: Surface Combatant Targets: Air Targets - Other Systems being Trained/Tested: Large-Caliber Gun Systems Munitions: Projectile - Large-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Weapon firing noise	
Parameters for Analysis	The target is a fiberglass finned target that is towed approximately 3 NM behind the towing aircraft. For Navy exercises all projectiles are assumed to be non-explosive. USCG exercises may use explosive projectiles at medium altitudes. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore. This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.3.6 Gunnery Exercise Surface-to-Air Medium-Caliber

Air Warfare		
Gunnery Exercise Surface-to-Air Medium-Caliber		
Short Description	Surface ship crews fire medium-caliber guns at air targets.	
Long Description	Surface ship crews defend against threat aircraft or missiles with medium-caliber guns to disable or destroy the threat. An exercise involves one ship and a simulated threat aircraft or anti-ship missile that is detected by the ship's radar. Medium-caliber guns fire non-explosive projectiles to disable or destroy the threat before it reaches the ship. The target can be an unmanned aerial vehicle or be towed by a contract air services jet. This activity may include transportable Anti-Air weapon systems such as USMC Marine Air Defense Integrated System (MADIS) firing from ship or shore.	
Typical Components	Platforms: Aircraft Carrier, Surface Combatant Targets: Air Targets - Other Systems being Trained/Tested: Medium-Caliber Gun Systems Munitions: Projectile - Medium-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Weapon firing noise	
Parameters for Analysis	The target is a fiberglass finned target that is towed approximately 3 NM behind the towing aircraft. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.3.7 Missile Exercise – Man-Portable Air Defense System

Air Warfare		
Missile Exercise - Man-Portable Air Defense System		
Short Description	Personnel employ a shoulder fired surface-to-air missile at air targets.	
Long Description	<p>Personnel employ the Man-Portable Air Defense Systems, a shoulder fired surface-to-air missile, against threat missiles or aircraft.</p> <p>An exercise involves personnel firing the Man-Portable Air Defense System at remote piloted or ballistic aerial targets. Activity is typically conducted by combat forces firing from shore locations at targets over the water. Small boats are used to ensure range safety.</p>	
Typical Components	<p>Platforms: Fixed Range, Small Boat</p> <p>Targets: Air Targets - Drone</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Surface-to-Air Missiles</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>For analysis, all missiles are assumed to be explosive, although non-explosive practice munitions may be used. All missiles explode in-air at low altitude.</p> <p>All propellant and explosives are consumed.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.3.8 Missile Exercise Air-to-Air

Air Warfare		
Missile Exercise Air-to-Air		
Short Description	Fixed-wing aircrews fire air-to-air missiles at air targets.	
Long Description	An exercise involves two or more fixed-wing aircraft and a target. Missiles are either explosive warheads or non-explosive practice munitions. The target is an unmanned aerial target drone or a parachute suspended illumination flare. Target drones deploy parachutes and are recovered by small boat or rotary-wing aircraft; tactical air-launched decoys and illumination flares are expended and not recovered. These exercises typically occur at high altitudes.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft Targets: Air Targets - Drone, Air Targets - Flare Systems being Trained/Tested: Missile Firing/Launching Systems Munitions: Air-to-Air Missiles	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	For analysis, all missiles are assumed to be explosive, although non-explosive practice munitions may be used. All missiles explode at high altitude. All propellant and explosives are consumed. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex



Figure A.2-1: BQM-74 (Aerial Target)



Figure A.2-2: LUU-2B/B Illuminating Flare (Aerial Target)



Figure A.2-3: Tactical Air-Launched Decoy (Aerial Target)

A.2.3.9 Missile Exercise Surface-to-Air

Air Warfare		
Missile Exercise Surface-to-Air		
Short Description	Surface ship crews defend against threat missiles and aircraft with missiles.	
Long Description	Surface ship crews defend against threat missiles and aircraft with ship-launched surface-to-air missiles. The exercise involves an aerial target that simulates a threat aircraft, anti-ship missile, or land attack missile, which is detected by the ship's radar. Ship-launched surface-to-air missiles are fired to disable or destroy the threat. The target typically is either a sub-sonic remote-controlled drone or a supersonic target. Target drones deploy parachutes and are recovered by small boat or rotary-wing aircraft. Supersonic targets are not recovered.	
Typical Components	Platforms: Surface Combatant Targets: Air Targets - Drone Systems being Trained/Tested: Missile Firing/Launching Systems Munitions: Surface-to-Air Missiles	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	Assumes that all surface-to-air missiles are high-explosive. Missile explodes well above the water's surface at medium altitudes. All explosive and propellant are consumed. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.4 AMPHIBIOUS WARFARE TRAINING

Amphibious warfare is a type of naval warfare involving the utilization of naval firepower, logistics, and Marine Corps landing forces to project military power ashore. Amphibious warfare encompasses a broad spectrum of activities involving maneuver from the sea to objectives ashore, ranging from reconnaissance or raid missions involving a small unit to large-scale amphibious operations involving over 1,000 Marines and Sailors and multiple ships and aircraft embarked in a strike group.

Amphibious warfare training includes tasks at increasing levels of complexity, from individual, crew, and small unit events to large task force exercises. Individual and crew training include the operation of amphibious vehicles and naval gunfire support training. Small-unit training activities include shore assaults, boat raids, airfield or port seizures, and reconnaissance. Larger-scale amphibious exercises involve ship-to-shore maneuver, shore bombardment and other naval fire support, and air strike and close air support training.

A.2.4.1 Amphibious Assault

Amphibious Warfare		
Amphibious Assault		
Short Description	Large unit forces move ashore from amphibious ships at sea for the immediate execution of inland objectives.	
Long Description	<p>Large unit forces move ashore from amphibious ships at sea for the immediate execution of inland objectives. Amphibious assault is conducted for the purposes of prosecuting further combat operations, obtaining a site for an advanced naval or airbase, or denying the enemy use of an area.</p> <p>Unit-level training exercises involve one or more amphibious ships, and their associated watercraft and aircraft, to move personnel and equipment from ship to shore without the command and control and supporting elements involved in a full-scale exercise. The goal is to practice loading, unloading, and movement and to develop the timing required for a full-scale exercise.</p>	
Typical Components	<p>Platforms: Amphibious Vehicles, Amphibious Warfare Vessel, Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Tiltrotor Aircraft</p> <p>Targets: None</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Typical exercise: 1-3 amphibious ships (e.g., LHA or LHD, LPD, LSD); 2-8 landing craft (landing craft, air cushion; landing craft, utility); 4-14 amphibious assault vehicles; up to 22 aircraft (e.g., MH-53, H-46/MV-22, AH-1, UH-1, AV-8); a Marine Expeditionary Unit (2,200 Marines).</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.4.2 Amphibious Operations in a Contested Environment

Amphibious Warfare		
Amphibious Operations in a Contested Environment		
Short Description	Navy and Marine Corps forces conduct operations in coastal and offshore waterways against air, surface, and sub-surface threats.	
Long Description	USMC forces establish Expeditionary Advanced Bases on land and protect against air, surface, and sub-surface attacks. Systems employed, but not limited to, include Marine Air Defense Integrated System (MADIS), Navy Marine Expeditionary Ship Interdiction System (NMESIS), Long-Range Unmanned Surface Vehicle (LRUSV) employing unmanned aerial systems, high-energy laser systems, 155 mm Howitzer artillery, and High Mobility Artillery Rocket Systems.	
Typical Components	Platforms: Amphibious Warfare Vessel, Marine Corps Asset, Fixed Range, Small Boat, Small unit support vehicles, Unmanned Surface Vehicle Targets: Air Targets - Drone, Surface Targets - Maneuvering, Surface Targets - Towed Systems being Trained/Tested: High-Energy Laser Systems, Unmanned Vehicle Systems Munitions: Grenades, Projectile - Large-Caliber, Projectile - Medium-Caliber, Rockets, Surface-to-Surface Missiles	
Active Sonar	No	
In-Water Explosives	E1, E2, E3, E6, E9, E10	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Explosive gunnery Explosive missiles and rockets Towed in-water devices Unmanned vehicles Weapon firing noise	
Parameters for Analysis	This exercise includes in-air explosives at low altitudes. High-energy laser systems used in military readiness activities automatically shut down when target-lock is lost; meaning that if a high-energy laser beam aimed at a target on the surface, either from an aircraft or surface vessel, moves off the target, the system ceases projecting laser light, preventing any energy from striking the water or a nearby marine species.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex

A.2.4.3 Amphibious Raid

Amphibious Warfare		
Amphibious Raid		
Short Description	Small unit forces move from amphibious ships at sea for a specific short-term mission. These are quick operations with as few personnel as possible.	
Long Description	<p>Small unit forces swiftly move from amphibious vessels at sea into hostile territory for a specific mission, including a planned withdrawal. Raids are conducted to inflict loss or damage, secure information, create a diversion, confuse the enemy, or capture or evacuate individuals or material. Amphibious raid forces are kept as small as possible to maximize stealth and speed of the operation.</p> <p>An event may employ assault amphibian vehicle units, small boats, small unit live-fire and non-live-fire operations. Surveillance or reconnaissance unmanned surface and aerial vehicles may be used during this exercise.</p>	
Typical Components	<p>Platforms: Amphibious Vehicles, Amphibious Warfare Vessel, Rotary-Wing Aircraft, Unmanned Aerial Vehicle - Rotary Wing</p> <p>Targets: None</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Unmanned vehicles</p>	
Parameters for Analysis	Weapons firing during this exercise is discussed in appropriate unit-level training descriptions (e.g., surface-to-surface and air-to-surface small-caliber gunnery exercises).	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.4.4 Amphibious Ready Group Marine Expeditionary Unit Exercise

Amphibious Warfare		
Amphibious Ready Group Marine Expeditionary Unit Exercise		
Short Description	Amphibious Ready Group exercises are conducted to validate the Marine Expeditionary Unit's readiness for deployment and include small boat raids; visit, board, search, and seizure training; helicopter and mechanized amphibious raids; and non-combatant evacuation operations.	
Long Description	<p>Marine Corps amphibious forces move from amphibious ships at sea, by watercraft or aircraft, and introduce a landing force, establish a beachhead, and occupy the area or move further inland for an extended period.</p> <p>The amphibious assault conducted by a Marine Expeditionary Unit involves employment of the advance force, combat, combat support, and combat service support units in close coordination with the expeditionary strike group and carrier strike group. The landing is conducted in waves and is focused on concentrating forces quickly in order to establish the beachhead. A typical exercise involves two reinforced companies from the battalion landing team coming ashore via landing crafts and amphibious assault vehicles. Follow-on waves include fire support assets, armored units, and service support elements.</p>	
Typical Components	<p>Platforms: Amphibious Warfare Vessel, Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Submarine, Surface Combatant</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed</p> <p>Munitions: None</p>	
Active Sonar	LFH, MFM, MFH, MF1, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Towed in-water devices</p>	
Parameters for Analysis	Weapons firing during this exercise is discussed in appropriate unit-level exercise descriptions (e.g., surface-to-surface and air-to-surface small-caliber gunnery exercises).	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.4.5 Amphibious Squadron Marine Expeditionary Unit Integration Training

Amphibious Warfare		
Amphibious Squadron Marine Expeditionary Unit Integration Training		
Short Description	Navy and Marine Corps forces conduct integration training at sea in preparation for deployment.	
Long Description	Amphibious ships and Marine Expeditionary Unit integrate for the first time at sea to practice amphibious tactics, techniques, and procedures. Navy and Marine Corps forces conduct basic amphibious operations to include small boat raids; visit, board, search, and seizure training; helicopter and mechanized amphibious raids.	
Typical Components	Platforms: Amphibious Warfare Vessel, Rotary-Wing Aircraft, Small Boat, Surface Combatant, Tiltrotor Aircraft Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	Weapons firing during this exercise is discussed under descriptions of appropriate unit-level exercises (e.g., surface-to-surface and air-to-surface small-caliber gunnery exercises).	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.4.6 Amphibious Vehicle Maneuvers

Amphibious Warfare		
Amphibious Vehicle Maneuvers		
Short Description	Small boat crews practice the employment of amphibious vehicles.	
Long Description	Navy personnel train to learn handling characteristics of a variety of amphibious craft, to include air-cushioned, wheeled, and tracked vehicles. Training includes the driving of vehicles into the water, basic in-water vehicle maneuvers, and the driving of vehicles back to shore.	
Typical Components	Platforms: Amphibious Vehicles, Small Boat Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Jacksonville Range Complex Inshore
	-	JEB Little Creek Fort Story

A.2.4.7 Naval Surface Fire Support Exercise – At Sea

Amphibious Warfare		
Naval Surface Fire Support Exercise - At Sea		
Short Description	Surface ship crews fire large-caliber guns at a passive acoustic hydrophone scoring system.	
Long Description	<p>Surface ship crews use large-caliber guns to support forces ashore; however, the land target is simulated at sea. Rounds are scored by passive acoustic buoys or fixed hydrophones located at or near the target area.</p> <p>The portable scoring system is composed of buoys (Integrated Maritime Portable Acoustic Scoring and Simulation System) set in a pre-designed pattern at specific intervals, which are retrieved after the exercise. A scoring system provides a realistic presentation, such as a land mass with topography, to the vessel's combat system. This virtual land target area overlays the hydrophone array. The vessel fires its munitions into the target area and the acoustic noise resulting from the impact of the round landing in the water is detected by the hydrophones. The scoring system triangulates the exact point of impact of the round, allowing the exercise to be conducted as if the vessel were firing at an actual land target. Surface ship crews use large-caliber (main battery) guns to support forces ashore.</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Surface Targets - Floating</p> <p>Systems being Trained/Tested: Large-Caliber Gun Systems</p> <p>Munitions: Projectile - Large-Caliber</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Non-explosive gunnery</p> <p>Weapon firing noise</p>	
Parameters for Analysis	Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.4.8 Naval Surface Fire Support Exercise – Land-Based Target

Amphibious Warfare		
Naval Surface Fire Support Exercise - Land-Based Target		
Short Description	Surface ship crews fire large-caliber guns at land-based targets in support of forces ashore.	
Long Description	<p>Surface ship crews use large-caliber guns to support forces ashore. One or more ships position themselves from three to six NM from the target area and a land-based spotter relays type and exact location of the target. After observing the fall of the shot, the spotter relays any adjustments needed to reach the target. Once the rounds are on target, the spotter requests a sufficient number to effectively destroy the target. This exercise occurs on land ranges where explosive and non-explosive practice munitions are authorized and is often supported by target shapes such as tanks, trucks, trains, or aircraft on the ground.</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Land Targets</p> <p>Systems being Trained/Tested: Large-Caliber Gun Systems</p> <p>Munitions: Projectile - Large-Caliber</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations)</p> <p>Manned surface vessels</p> <p>Weapon firing noise:</p>	
Parameters for Analysis	<p>Projectile impact is on land and is not further analyzed. No land-based impacts are included in this document.</p> <p>Firing point from sea is Area 15B. Impact occurs at G-10 Impact Area, Camp Lejeune.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.4.9 Non-Combat Evacuation Operation

Amphibious Warfare		
Non-Combat Evacuation Operation		
Short Description	Military units evacuate non-combatants from hostile or unsafe areas or provide humanitarian assistance in times of disaster.	
Long Description	Military units evacuate non-combatants from hostile or unsafe areas to safe havens or to provide humanitarian assistance in times of disaster. Non-Combatant Evacuation Operation is conducted by military units (generally Marine Corps) usually operating in conjunction with Navy ships and aircraft. Non-combatants are evacuated when their lives are endangered by war, civil unrest, or natural disaster. Military units train for evacuations in hostile environments that require the use of force, though usually there is no opposition to evacuation from the host country. Helicopters and landing crafts could be expected to participate in this operation during day or night.	
Typical Components	Platforms: Amphibious Vehicles, Amphibious Warfare Vessel, Rotary-Wing Aircraft, Tiltrotor Aircraft Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	Previously called Humanitarian Assistance Operations. USCG may participate in this training.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex

A.2.5 ANTI-SUBMARINE WARFARE TRAINING

Anti-submarine warfare involves helicopter and maritime patrol aircraft, ships, and submarines. These units operate alone or in combination to locate, track, and neutralize submarines. Controlling the undersea battlespace is a unique naval capability and a vital aspect of sea control. Undersea battlespace dominance requires proficiency in anti-submarine warfare. Every deploying strike group and individual surface combatant must possess this capability.

Various types of active and passive sonar are used by the Navy to determine water depth, and identify, track, and target submarines. Passive sonar “listens” for sound waves by using underwater microphones, called hydrophones, which receive, amplify, and process underwater sounds. No sound is introduced into the water when using passive sonar. Passive sonar can indicate the presence, character, and movement of submarines. However, passive sonar provides only a bearing (direction) to a sound-emitting source; it does not provide an accurate range (distance) to the source. Active sonar is needed to locate objects because active sonar provides both bearing and range to the detected contact (such as an enemy submarine).

The Navy’s anti-submarine warfare training plan, including the use of active sonar in at-sea training scenarios, includes multiple levels of training. Individual-level anti-submarine warfare training addresses basic skills such as detection and classification of contacts; distinguishing discrete acoustic signatures including those of ships, submarines, and marine life; and identifying the characteristics, functions, and effects of controlled jamming and evasion devices.

More advanced, integrated anti-submarine warfare training exercises involving active sonar are conducted in coordinated, at-sea operations during training exercises involving submarines, ships, aircraft, and helicopters. This training integrates the full anti-submarine warfare continuum, from detecting and tracking a submarine to attacking a target using either exercise torpedoes or simulated weapons. Training activities include detection and tracking exercises against “enemy” submarine contacts, torpedo employment exercises against the target, and exercising command and control tasks in a multi-dimensional battlespace.

A.2.5.1 Anti-Submarine Warfare Torpedo Exercise – Helicopter

Anti-Submarine Warfare		
Anti-Submarine Warfare Torpedo Exercise - Helicopter		
Short Description	Helicopter crews search for, track, and detect submarines. Recoverable air-launched torpedoes are employed against submarine targets.	
Long Description	Helicopters using sonobuoys and dipping sonar search for, detect, classify, localize, and track a simulated threat submarine with the goal of determining a firing solution that could be used to launch a torpedo and destroy the submarine. Sonobuoys (both passive and active) are typically employed by a helicopter operating at altitudes below 3,000 ft. Dipping sonar (both passive and active) is employed from an altitude of about 50 ft. after the search area has been narrowed based on the sonobuoy search. The anti-submarine warfare target used for this exercise may be a MK-39 Expendable Mobile Anti-Submarine Warfare Training Target, a MK-30 target, or a live submarine. This exercise may involve a single aircraft, or occur during a coordinated larger exercise involving multiple aircraft and ships, including a major range event. Unmanned aerial systems, such as the MQ-8 Fire Scout, may also be used. The exercise torpedo is recovered by a special recovery helicopter or small craft. The preferred range for this exercise is an instrumented underwater range, but it may be conducted in other range complexes depending on training requirements and available assets.	
Typical Components	Platforms: Rotary-Wing Aircraft, Submarine, Unmanned Aerial Vehicle – Rotary Wing Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Sonar Systems – Dipping, Torpedo Launching Systems Munitions: Countermeasures, Sonobuoys Torpedoes – Exercise	
Active Sonar	MFM, MFH, HFH, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.5.2 Anti-Submarine Warfare Torpedo Exercise – Maritime Patrol Aircraft

Anti-Submarine Warfare		
Anti-Submarine Warfare Torpedo Exercise - Maritime Patrol Aircraft		
Short Description	Maritime patrol aircraft crews search for, track, and detect submarines. Recoverable air-launched torpedoes are employed against submarine targets.	
Long Description	<p>Fixed-wing maritime patrol aircraft employ sonobuoys to search for, detect, classify, localize, and track a simulated threat submarine with the goal of determining a firing solution that could be used to launch a torpedo and destroy the submarine.</p> <p>Sonobuoys (both passive and active) are typically employed by a maritime patrol aircraft operating at altitudes below 3,000 ft. Both sonobuoys and torpedoes (using the High Altitude Anti-Submarine Warfare Weapon Capability kit) may be delivered at high altitudes to remain clear of high threat areas. Sonobuoys are deployed in specific patterns based on the expected threat submarine and specific water conditions. Depending on these two factors, these patterns will cover many different size areas. For certain sonobuoys, tactical parameters of use may be classified. The anti-submarine warfare target used for this exercise may be a MK-39 Expendable Mobile Anti-Submarine Warfare Training Target, a MK-30 target, or a live submarine. This exercise may involve a single aircraft, or be undertaken in the context of a coordinated larger exercise involving multiple aircraft and vessels, including a major range event. The exercise torpedo is recovered by helicopter or small boat. The preferred range for this exercise is an instrumented underwater range, but it may be conducted in other OPAREAs depending on training requirements and available assets.</p>	
Typical Components	<p>Platforms: Fixed Wing – Patrol Aircraft, Submarine</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Torpedo Launching Systems</p> <p>Munitions: Countermeasures, Sonobuoys, Torpedoes – Exercise</p>	
Active Sonar	MFM, HFH, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Submarine may provide service as the target.</p> <p>If target is air-dropped, one parachute per target.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.5.3 Anti-Submarine Warfare Torpedo Exercise – Ship

Anti-Submarine Warfare		
Anti-Submarine Warfare Torpedo Exercise - Ship		
Short Description	Surface ship crews search for, track, and detect submarines. Exercise torpedoes are used during this exercise.	
Long Description	<p>Surface ships search for, detect, and track threat submarines to determine a firing position to launch a torpedo and attack the submarine. A surface ship operates at slow speeds while employing hull-mounted or towed array sonar. Passive or active sonar is employed depending on the type of threat submarine, the tactical situation, and environmental conditions. The anti-submarine warfare target used for this exercise is a MK-39 Expendable Mobile Anti-Submarine Warfare Training Target, MK-30 Target, or live submarine. This exercise may involve a single ship, or be undertaken in the context of a coordinated larger exercise involving multiple aircraft, ships, and submarines, including a major range event.</p> <p>The exercise torpedo is recovered by helicopter or small craft. The preferred range for this exercise is an instrumented underwater range, but it may be conducted in other range complexes depending on training requirements and available assets.</p>	
Typical Components	<p>Platforms: Submarine, Surface Combatant</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Sonar Systems - Hull Mounted, Torpedo Launching Systems</p> <p>Munitions: Countermeasures, Torpedoes - Exercise</p>	
Active Sonar	MF1, HFH, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Towed in-water devices</p>	
Parameters for Analysis	<p>Submarines may provide service as the target. Torpedoes are recovered.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.5.4 Anti-Submarine Warfare Torpedo Exercise – Submarine

Anti-Submarine Warfare		
Anti-Submarine Warfare Torpedo Exercise - Submarine		
Short Description	Submarine crews search for, track, and detect submarines. Exercise torpedoes are used during this exercise.	
Long Description	<p>Submarine crews search for, detect and track a threat submarine to develop firing position to launch a torpedo. A single submerged submarine operates at slow speeds and various depths while using its hull mounted or towed array sonar to track a threat submarine. Passive sonar is used almost exclusively. Non-explosive exercise torpedoes can be fired and active sonar can be used during this training exercise.</p> <p>This exercise may involve a single submarine, or be undertaken in the context of a coordinated larger exercise involving multiple aircraft, ships, and submarines, including a major range event. The exercise torpedo is recovered by helicopter or small craft. The preferred range for this exercise is an instrumented underwater range, but it may be conducted in other range complexes depending on training requirements and available assets.</p>	
Typical Components	<p>Platforms: Submarine</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Torpedo Launching Systems</p> <p>Munitions: Countermeasures, Torpedoes - Exercise</p>	
Active Sonar	HFH, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Towed in-water devices</p>	
Parameters for Analysis	<p>Torpedoes are recovered.</p> <p>Guidance wire has a low tensile strength and breaks easily. Weights and flex tubing sink rapidly.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.5.5 Anti-Submarine Warfare Tracking Exercise – Helicopter

Anti-Submarine Warfare		
Anti-Submarine Warfare Tracking Exercise - Helicopter		
Short Description	Helicopter crews search for, track, and detect submarines.	
Long Description	<p>Helicopters using sonobuoys and dipping sonar search for, detect, classify, localize, and track a simulated threat submarine with the goal of determining a firing solution that could be used to launch a torpedo and destroy the submarine.</p> <p>Sonobuoys (both passive and active) are typically employed by a helicopter operating at altitudes below 3,000 ft. Dipping sonar (both passive and active) is employed from an altitude of about 50 ft. after the search area has been narrowed based on the sonobuoy search.</p> <p>The anti-submarine warfare target used for this exercise may be a MK-39 Expendable Mobile Anti-Submarine Warfare Training Target, a MK-30 target, or a live submarine. This exercise may involve a single aircraft, or occur during a coordinated larger exercise involving multiple aircraft and ships, including a major range event. Unmanned aerial systems, such as the MQ-8 Fire Scout, may also be used. The preferred range for this exercise is an instrumented range, but it may be conducted in other range complexes depending on training requirements and available assets.</p>	
Typical Components	<p>Platforms: Rotary-Wing Aircraft, Unmanned Aerial Vehicle – Rotary Wing</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Sonar Systems - Dipping</p> <p>Munitions: Sonobuoys</p>	
Active Sonar	MFM, MFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Tracking exercise can occur in all locations.</p> <p>Submarines may provide service as the target.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	-	Other AFTT Areas

A.2.5.6 Anti-Submarine Warfare Tracking Exercise – Maritime Patrol Aircraft

Anti-Submarine Warfare		
Anti-Submarine Warfare Tracking Exercise - Maritime Patrol Aircraft		
Short Description	Maritime patrol aircraft crews search for, track, and detect submarines.	
Long Description	<p>Fixed-wing maritime patrol aircraft employ sonobuoys to search for, detect, classify, localize, and track a simulated threat submarine with the goal of determining a firing solution that could be used to launch a torpedo and destroy the submarine. Sonobuoys (both passive and active) are typically employed by a maritime patrol aircraft operating at altitudes below 3,000 ft. However, sonobuoys may be released at higher altitudes. Sonobuoys are deployed in specific patterns based on the expected threat submarine and specific water conditions. Depending on these two factors, these patterns will cover many different size areas. For certain sonobuoys, tactical parameters of use may be classified. The anti-submarine warfare target used for this exercise may be a MK-39 Expendable Mobile Anti-Submarine Warfare Training Target, a MK-30 target, or a live submarine. This exercise may involve a single aircraft, or be undertaken in the context of a coordinated larger exercise involving multiple aircraft and vessels, including a major range event.</p>	
Typical Components	<p>Platforms: Fixed Wing – Patrol Aircraft</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Sonobuoys</p>	
Active Sonar	LFM, LFH, MFM	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Tracking exercise can occur in all locations.</p> <p>Submarine may provide service as the target.</p> <p>If target is air-dropped, one parachute per target.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.5.7 Anti-Submarine Warfare Tracking Exercise – Ship

Anti-Submarine Warfare		
Anti-Submarine Warfare Tracking Exercise - Ship		
Short Description	Surface ship crews search for, track, and detect submarines.	
Long Description	<p>Surface ships search for, detect, and track threat submarines to determine a firing position to launch a torpedo and attack the submarine.</p> <p>A surface ship operates at slow speeds while employing sonobuoys, hull-mounted sonars, or towed array sonar. Passive or active sonar is employed depending on the type of threat submarine, the tactical situation, and environmental conditions. The target for this exercise is either a MK-39 Expendable Mobile Anti-Submarine Warfare Training Target, MK-30 Recoverable Training Target, or live submarine.</p> <p>This exercise may involve a single ship, or be undertaken in the context of a coordinated larger exercise involving multiple aircraft, ships, and submarines, including a major range event.</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Sonar Systems - Hull Mounted, Sonar Systems - Other, Sonar Systems - Towed</p> <p>Munitions: Countermeasures</p>	
Active Sonar	LFH, MFH, MF1, MF1C, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Towed in-water devices</p>	
Parameters for Analysis	<p>A submarine may provide service as the target.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex
	-	Other AFTT Areas

A.2.5.8 Anti-Submarine Warfare Tracking Exercise – Submarine

Anti-Submarine Warfare		
Anti-Submarine Warfare Tracking Exercise - Submarine		
Short Description	Submarine crews search for, track, and detect submarines.	
Long Description	<p>Submarine crews search for, detect, and track a threat submarine to develop firing position to launch a torpedo.</p> <p>A single submerged submarine operates at slow speeds and various depths while using its hull mounted sonar to track a threat submarine. Passive sonar is used almost exclusively. The target for this exercise is either an MK 39 Expendable Mobile Anti-Submarine Warfare Training Target, MK 30 recoverable training target, or live submarine. This exercise may involve a single submarine, or be undertaken in the context of a coordinated larger exercise involving multiple aircraft, ships, and submarines, including a major range event.</p>	
Typical Components	<p>Platforms: Moored Platform, Submarine, Surface Combatant</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Navigation Systems, Sonar Systems - Hull Mounted, Sonar Systems - Other</p> <p>Munitions: None</p>	
Active Sonar	LFH, MFH, HFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore. For biological resource analysis, vessel noise and vessel strike are only analyzed for the periods while the submarines are surfaced, typically brief in nature. Mitigation Involving Visual Observations for Marine Species related to vessel movement are only considered during the period of surfacing as well.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Other AFTT Areas

A.2.6 ELECTRONIC WARFARE

The mission of electronic warfare is to degrade the enemy's ability to use electronic systems, such as communication systems and radar, and to confuse or deny them the ability to defend their forces and assets. Electronic warfare is also used to detect enemy threats and counter their attempts to degrade the electronic capabilities of the Navy.

Typical electronic warfare activities include threat avoidance training, signals analysis for intelligence purposes, and use of airborne and surface electronic jamming devices (that block or interfere with other devices) to defeat tracking, navigation, and communications systems.

A.2.6.1 Counter Targeting Chaff Exercise – Aircraft

Electronic Warfare	
Counter Targeting Chaff Exercise - Aircraft	
Short Description	Fixed-winged aircraft and helicopter aircrews deploy chaff to disrupt threat targeting and missile guidance radars.
Long Description	Fixed-winged aircraft and helicopter aircrews deploy chaff to disrupt threat targeting and missile guidance radars. Fixed-winged aircraft and helicopter aircrews detect electronic targeting signals from threat radars or missiles, dispense chaff, and immediately maneuver to defeat the threat. The chaff cloud deceives the inbound missile and the aircraft clears away from the threat. Chaff is a radar reflector material made of thin, narrow, metallic strips cut in various lengths to elicit frequency responses, which deceive enemy radars. Chaff is employed to create a target that will lure enemy radar and weapons system away from the actual friendly platform.
Typical Components	Platforms: Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft Targets: None Systems being Trained/Tested: Chaff Dispensing Systems Munitions: Chaff Rounds
Active Sonar	No
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	None
Parameters for Analysis	Chaff is usually expended while conducting other training activities, such as air combat maneuvering. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.

Electronic Warfare		
Counter Targeting Chaff Exercise - Aircraft		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.2.6.2 Counter Targeting Chaff Exercise – Ship

Electronic Warfare		
Counter Targeting Chaff Exercise - Ship		
Short Description	Surface ship crews deploy chaff to disrupt threat targeting and missile guidance radars.	
Long Description	<p>Surface ship and Coast Guard cutter crews deploy chaff to disrupt threat targeting and missile guidance radars to defend against an attack.</p> <p>Surface ship crews detect electronic targeting signals from threat radars or missiles, dispense chaff, and immediately maneuver to defeat the threat. The chaff cloud deceives the inbound missile and the vessel clears away from the threat. The typical exercise duration is approximately 1.5 hours.</p> <p>Chaff is a radar reflector material made of thin, narrow, metallic strips cut in various lengths to elicit frequency responses, which deceive enemy radars. Chaff is employed create a target that will lure enemy radar and weapons system away from the actual friendly platform.</p> <p>Ships may also train with advanced countermeasure systems, such as the MK 53 Decoy Launching System (Nulka).</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: None</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Chaff rounds</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p> <p>This training activity is conducted by Navy and USCG.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.6.3 Counter Targeting Flare Exercise

Electronic Warfare		
Counter Targeting Flare Exercise		
Short Description	Fixed-winged aircraft and helicopter aircrews deploy flares to disrupt threat infrared missile guidance systems.	
Long Description	<p>Fixed-winged aircraft and helicopter aircrews deploy flares to disrupt threat infrared missile guidance systems.</p> <p>Aircraft detect electronic targeting signals from threat radars or missiles or a threat missile plume when launched and dispense flares and immediately maneuver to defeat the threat. This exercise trains aircraft personnel in the use of defensive flares designed to confuse infrared sensors or infrared homing missiles, thereby causing the sensor or missile to lock onto the flares instead of the real aircraft. Typically, an aircraft will expend five flares in an exercise while operating above 3,000 ft. Flare exercises are often conducted with chaff exercises, rather than as a stand-alone exercise.</p>	
Typical Components	<p>Platforms: Fixed Wing – Strike Aircraft, Fixed-Wing – Patrol Aircraft, Fixed-Wing – Electronic Aircraft, Rotary-Wing Aircraft</p> <p>Targets: None</p> <p>Systems being Trained/Tested: Flare Dispensing Systems</p> <p>Munitions: Flares</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	<p>Approximately five flares per aircraft are expended per exercise.</p> <p>All combustible material in flares is assumed to be consumed before contact of the casing with the water.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.2.6.4 Electronic Warfare Operations

Electronic Warfare		
Electronic Warfare Operations		
Short Description	Aircraft and surface ship crews control portions of the electromagnetic spectrum used by enemy systems to degrade or deny the enemy's ability to take defensive actions.	
Long Description	Aircraft and surface ship crews control the electromagnetic spectrum used by enemy systems to degrade or deny the enemy's ability to take defensive actions. Electronic Warfare Operations can be active or passive, offensive or defensive. Fixed-wing aircraft employ active jamming and deception against enemy search radars to mask the friendly inbound strike aircraft mission. Surface ships detect and evaluate enemy electronic signals from enemy aircraft or missile radars, evaluate courses of action concerning the use of passive or active countermeasures, then use ship maneuvers and either chaff, flares, active electronic countermeasures, or a combination of them to defeat the threat.	
Typical Components	Platforms: Fixed Wing - Electronic Warfare Aircraft, Surface Combatant Targets: Air Targets - Other Systems being Trained/Tested: Electronic Warfare Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	All chaff and flares involved in this exercise are covered under chaff exercises and flare exercises, respectively.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.6.5 High-Speed Anti-Radiation Missile Exercise

Electronic Warfare		
High-Speed Anti-Radiation Missile Exercise		
Short Description	Aircrews launch a High-Speed Anti-Radiation Missile against threat radar sites.	
Long Description	Aircrews detect radar signals from a simulated threat radar site and launch a High-Speed Anti-Radiation Missile (high-explosive) to destroy or disable the threat radar site. One or more fighter jets approach the threat radar site from high altitude. Once the target is located with onboard sensors, the aircrew launches a High-Speed Anti-Radiation Missile at the electronic signal. At-sea exercises involve training against a target vessel or a specially configured target barge that has a tower with an electronic emitter that the missile will seek after being fired from the launch aircraft.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft Targets: Electronic Warfare Targets Systems being Trained/Tested: None Munitions: Air-to-Surface Missiles	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Explosive missiles and rockets	
Parameters for Analysis	All chaff and flares involved in this exercise are covered under chaff exercises and flare exercises, respectively. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.7 EXPEDITIONARY WARFARE

The mission of expeditionary warfare is to provide security and surveillance in the littoral (at the shoreline), riparian (along a river), or coastal environments. Expeditionary warfare is wide ranging and includes defense of harbors, operation of remotely operated vehicles, defense against swimmers, and boarding/seizure operations.

Expeditionary warfare training activities include underwater construction team training, dive and salvage operations, and insertion/extraction via air, surface, and sub-surface platforms.

A.2.7.1 Dive and Salvage Operations

Expeditionary Warfare		
Dive and Salvage Operations		
Short Description	Navy divers perform dive operations and salvage training.	
Long Description	Navy divers will conduct a variety of salvage training to include debatching operations, underwater repairs to ships, underwater survey operations, and other underwater training as required.	
Typical Components	Platforms: Structure, Support Craft, Unmanned Bottom Crawler Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	The practice salvage platform can be sunk and then refloated and removed.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex
	-	Little Creek, VA
	-	NS Mayport

A.2.7.2 Personnel Insertion/Extraction – Air

Expeditionary Warfare		
Personnel Insertion/Extraction - Air		
Short Description	Personnel are inserted into and extracted from an objective area by fixed-wing aircraft or helicopters.	
Long Description	Personnel are inserted into a water objective via fixed-wing aircraft using parachutes or by helicopters via ropes or jumping into the water. They will conduct an infiltration to an objective (harbor, beach, moored vessel, etc.) and conduct a variety of tasks. The insertion/extraction activities are confined to in-water training. Upon completion of training objectives, personnel are extracted by helicopters or small boats.	
Typical Components	Platforms: Fixed Wing - Cargo and Transport Aircraft, Rotary-Wing Aircraft, Small Boat Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	Exercises are typically conducted in waters near land. USCG may also conduct this training.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex Inshore
	-	Gulf of Mexico Range Complex Inshore

A.2.7.3 Personnel Insertion/Extraction – Surface and Sub-Surface

Expeditionary Warfare		
Personnel Insertion/Extraction - Surface and Sub-Surface		
Short Description	Personnel are inserted into and extracted from an objective area by small boats or sub-surface platforms.	
Long Description	Utilizing both small surface and sub-surface platforms, personnel are inserted in the water. They will conduct an infiltration to an objective (harbor, beach, moored vessel, etc.) and conduct a variety of tasks. The insertion/extraction activities are confined to in-water training.	
Typical Components	Platforms: Small Boat, Small Manned Underwater Vehicle, Submarine, Unmanned Aerial Vehicle – Fixed Wing Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	Exercises are typically conducted in waters near land.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Northeast Range Complexes Inshore
	-	Virginia Capes Range Complex Inshore

A.2.7.4 Personnel Insertion/Extraction – Swimmer/Diver

Expeditionary Warfare		
Personnel Insertion/Extraction - Swimmer/Diver		
Short Description	Divers and swimmer infiltrate harbors, beaches, or moored vessels and conduct a variety of tasks.	
Long Description	Divers and swimmer infiltrate harbors, beaches, or moored vessels and conduct a variety of tasks. Activity may include Navy personnel learning advanced self-contained underwater breathing apparatus (scuba) diving to include tactics, techniques, and procedures and emergency procedures. Small boats are used for safety.	
Typical Components	Platforms: Small Boat Targets: None Systems being Trained/Tested: None Munitions: Signal, Underwater Sound Devices	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex Inshore

A.2.7.5 Port Damage Repair Training

Expeditionary Warfare		
Port Damage Repair Training		
Short Description	Navy Expeditionary forces train to repair critical port facilities.	
Long Description	Navy Expeditionary forces support fleet mission through expedient repair of critical port facilities. Training includes diving operations, pile driving and removal, salvage operations, expeditionary dredging, and repairs to piers, quay walls, and other waterfront infrastructure.	
Typical Components	Platforms: Small Boat, Structure, Support Craft, Unmanned Bottom Crawler Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Pile driving and pile removal	
Parameters for Analysis	Pile driving activities would be conducted over five days, up to four times per year (20 days total). Per event, round timber or plastic piles would be installed using impact methods and round timber or plastic, and steel sheet piles would be installed using vibratory methods. All piles or sheets would be removed after the training event using vibratory methods. During pile driving activities, due to the system design, the Action Proponent performs soft starts during impact installation of each pile to ensure proper operation of the diesel impact hammer. During a soft start, the Action Proponent performs an initial set of strikes from the impact hammer at reduced energy before it can be operated at full power and speed. The energy reduction of an individual hammer cannot be quantified because it varies by individual driver. The number of strikes at reduced energy varies because raising the hammer at less than full power and then releasing it results in the hammer “bouncing” as it strikes the pile, which results in multiple “strikes.”	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Gulfport, MS

A.2.7.6 Underwater Construction Team Training

Expeditionary Warfare		
Underwater Construction Team Training		
Short Description	Navy and Coast Guard divers conduct underwater repair and construction.	
Long Description	Navy and Coast Guard divers will perform cutting, welding, assembly, and installation of deep-water structures, mooring systems, underwater instrumentation, clearing of hazards, and other training as needed.	
Typical Components	Platforms: Small Boat, Unmanned Bottom Crawler Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex Inshore
	-	Gulfport, MS

A.2.8 MINE WARFARE

Mine warfare is the naval warfare area involving the detection, avoidance, and neutralization of mines to protect Navy ships and submarines and offensive mine laying in naval operations. A naval mine is a self-contained explosive device placed in water to destroy ships or submarines. Naval mines are deposited and left in place until triggered by the approach of an enemy ship or are destroyed or removed. Naval mines can be laid by purpose-built minelayers, other ships, submarines, or airplanes. Mine warfare training includes mine countermeasures exercises and mine-laying exercises.

A.2.8.1 Airborne Mine Countermeasure – Mine Detection

Mine Warfare	
Airborne Mine Countermeasures - Mine Detection	
Short Description	Helicopter aircrews detect mines using towed or laser mine detection systems.
Long Description	<p>Helicopter aircrews use towed and airborne devices to detect, locate, and classify potential mines. Towed devices employ active acoustic sources, such as high-frequency and side scanning sonar. These devices are similar in function to systems used to map the seafloor or locate submerged structures/items. Airborne devices utilize laser systems to locate mines located below the surface.</p> <p>Devices used include the AN/AQS-20/A, towed minehunting sonar used to detect and classify bottom and floating/moored mines in deep and shallow water, and the Airborne Laser Mine Detection System, developed to detect and classify floating and near-surface, moored mines.</p>
Typical Components	<p>Platforms: Rotary-Wing Aircraft</p> <p>Targets: Mine Targets</p> <p>Systems being Trained/Tested: Electromagnetic Systems, Sonar Systems - Mine Warfare, Sonar Systems - Other</p> <p>Munitions: None</p>
Active Sonar	HFH
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Towed in-water devices</p>
Parameters for Analysis	<p>Sonar mine detection systems towed from helicopters.</p> <p>Airborne laser systems used to detect mine shapes.</p> <p>Laser systems are similar to commercial Light Detection And Ranging (LIDAR) systems.</p> <p>The in-air energy stressor was used in analysis of potential impacts on human resources.</p> <p>Mine shapes may be deployed via ship and will be recovered.</p>

Mine Warfare		
Airborne Mine Countermeasures - Mine Detection		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex

A.2.8.2 Airborne Mine Countermeasure – Towed Mine Neutralization

Mine Warfare		
Airborne Mine Countermeasures - Towed Mine Neutralization		
Short Description	Helicopter aircrews tow systems through the water that are designed to disable or trigger mines.	
Long Description	<p>Helicopter vehicle operators use towed devices to trigger mines that are designed to detonate when they detect ships/submarines by engine/propeller sounds or magnetic (steel construction) signature. Towed devices can also employ cable cutters to detach floating moored mines. Training may be conducted with non-explosive training mine shapes.</p> <p>Devices used include the following: MK 105 sled, which creates a magnetic field used to trigger mines and can be used in conjunction with the MK 103 cable cutter system and the MK 104 acoustic countermeasure, and AN/SPU-1/W (Magnetic Orange Pipe), a magnetic pipe that is used to trigger magnetically influenced mines.</p>	
Typical Components	<p>Platforms: Rotary-Wing Aircraft</p> <p>Targets: Mine Targets</p> <p>Systems being Trained/Tested: Towed Mine Neutralization Systems</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Towed in-water devices</p>	
Parameters for Analysis	<p>Mechanical sweeping (cable cutting), acoustic and magnetic influence sweeping devices are towed from helicopters.</p> <p>Cable cutters utilize an insignificant charge (similar to a shotgun shell).</p> <p>Acoustic sweeps generate ship-type noise via a mechanical system.</p> <p>Towing systems through minefields (or without mines, to train to deploy, tow, and recover) may involve instrumented mines.</p> <p>Mine shapes are recovered.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex
	Virginia Capes Range Complex Inshore	Virginia Capes Range Complex Inshore

A.2.8.3 Airborne Mine Laying

Mine Warfare		
Airborne Mine Laying		
Short Description	Fixed-wing aircraft drop non-explosive mine shapes.	
Long Description	Fixed-winged aircraft lay offensive or defensive mines for a tactical advantage for friendly forces. Fixed-winged aircraft lay a precise minefield pattern for specific tactical situations. The aircrew typically makes multiple passes in the same flight pattern, and drop one or more training shapes per pass (four shapes total). Training shapes are non-explosive.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft Targets: None Systems being Trained/Tested: None Munitions: Bombs (non-explosive)	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Aerial-deployed mines and non-explosive bombs	
Parameters for Analysis	Mine laying is similar to non-explosive bombing exercises. These exercises primarily occur during major training exercises. Mine laying will typically take place in waters less than 100 ft. in depth. Assume 12 mine shapes are used per exercise. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.8.4 Civilian Port Defense – Homeland Security Anti-Terrorism/Force Protection Exercise

Mine Warfare	
Civilian Port Defense - Homeland Security Anti-Terrorism/Force Protection Exercise	
Short Description	Maritime security personnel train to protect civilian ports and harbors against enemy efforts to interfere with access to those ports.
Long Description	<p>Naval forces (including USCG) provide mine warfare capabilities to support Department of Homeland Security sponsored exercises. The three pillars of mine warfare, airborne (helicopter), surface (surface ships), and undersea (divers, marine mammals, and unmanned vehicles) mine countermeasures will be brought to bear in order to ensure strategic U.S. ports remain free of mine threats. Various mine warfare sensors, which utilize active acoustics, will be employed in the detection, classification, and neutralization of mines. Along with traditional mine warfare techniques, such as helicopter towed mine countermeasures, new technologies (unmanned vehicles) will be utilized. Marine mammal systems may be used during this exercise.</p> <p>Exercise locations and scenarios will vary according to Department of Homeland Security strategic goals and evolving world events. Coast Guard cutters, small boats, and aircraft may participate in this activity.</p>
Typical Components	<p>Platforms: Rotary-Wing Aircraft, Small Boat</p> <p>Targets: Mine Targets</p> <p>Systems being Trained/Tested: Acoustic Communications, Electromagnetic Systems, Sonar Systems - Mine Warfare, Unmanned Vehicle Systems</p> <p>Munitions: None</p>
Active Sonar	MFH, HFM, HFH
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources Manned surface vessels Towed in-water devices Unmanned vehicles</p>
Parameters for Analysis	<p>Non-permanent mine shapes will be laid in various places on the bottom and will be retrieved.</p> <p>Shapes are varied, from about 1 m circular to about 2.5 m long by 1 m wide. They will be recovered using normal assets, with diver involvement.</p> <p>Explosives may be used if required for scheduled mine neutralization exercises.</p> <p>While goal is to conduct once per year, alternating east/west coast, assume that an east coast exercise will occur every other year with a total of four per seven-year period.</p>

Mine Warfare		
Civilian Port Defense - Homeland Security Anti-Terrorism/Force Protection Exercise		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Boston, MA	Boston, MA
	Earle, NJ	Earle, NJ
	Delaware Bay, DE	Delaware Bay, DE
	Hampton Roads, VA	Hampton Roads, VA
	Morehead City, NC	Morehead City, NC
	Wilmington, NC	Wilmington, NC
	Savannah, GA	Savannah, GA
	Kings Bay, GA	Kings Bay, GA
	Mayport, FL	Mayport, FL
	Port Canaveral, FL	Port Canaveral, FL
	Tampa, FL	Tampa, FL
	Beaumont, TX	Beaumont, TX
	Corpus Christi, TX	Corpus Christi, TX

A.2.8.5 Coordinated Unit-Level Helicopter Airborne Mine Countermeasures Exercise

Mine Warfare		
Coordinated Unit-Level Helicopter Airborne Mine Countermeasures Exercise		
Short Description	A detachment of helicopters aircrews train as a unit in the use of airborne mine countermeasures, such as towed mine detection and neutralization systems.	
Long Description	Naval aircrews train, as a squadron, in the use of various airborne mine countermeasures. Systems employed include towed mine detection systems, mechanical (cable cutting) mine sweeps, magnetic and acoustic mine sweeps, and other airborne systems and sensors. Mine shapes will be used. If necessary, permanently placed mine shapes will be supplemented with approximately 24 additional, temporarily placed mine shapes. Training mine shapes could be bottom placed, moored, or floating.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: None Systems being Trained/Tested: Mine Detection Systems, Mine Neutralization Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Aerial-deployed mines and non-explosive bombs Towed in-water devices	
Parameters for Analysis	Multiple helicopters conduct airborne mine countermeasure training using an assortment of mine warfare gear similar to unit-level events, except that a squadron trains together. Assume up to 24 temporary mine shapes will be deployed to support each of these exercises.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex

A.2.8.6 Installation and Maintenance of Mine Training Areas

Mine Warfare		
Installation and Maintenance of Mine Training Areas		
Short Description	Inert mine shapes are installed, maintained, or removed from established mine training areas.	
Long Description	Mine warfare training is conducted in designated areas that contain inert mine shapes. These mine training areas will contain a variety of bottom and moored mine shapes. Target support vessels and divers routinely inspect these areas and will move and/or replace mine shapes for improved training scenarios. Coast Guard assets may assist in the installation and maintenance of these areas.	
Typical Components	Platforms: Support Craft Targets: Mine Targets Systems being Trained/Tested: Pinger Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	-	Jacksonville Range Complex
	-	Key West Range Complex
	-	Virginia Capes Range Complex Inshore

A.2.8.7 Mine Countermeasures – Mine Neutralization – Remotely Operated Vehicle

Mine Warfare		
Mine Countermeasures - Mine Neutralization - Remotely Operated Vehicles		
Short Description	Ship, small boat, and helicopter crews locate and disable mines using remotely operated underwater vehicles.	
Long Description	Ship, small boat, and helicopter crews utilize remotely operated vehicles to neutralize potential mines. Remotely operated vehicles will use sonar and optical systems to locate and target mine shapes. Explosive mine neutralizers may be used during live-fire activities.	
Typical Components	Platforms: Rotary-Wing Aircraft, Small Boat, Unmanned Underwater Vehicle Targets: Mine Targets Systems being Trained/Tested: Sonar Systems - Mine Warfare Munitions: Mine Warfare Devices	
Active Sonar	HFM	
In-Water Explosives	E4	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Explosive mine countermeasure and neutralization (no divers) Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex

A.2.8.8 Mine Countermeasures – Ship Sonar

Mine Warfare		
Mine Countermeasures - Ship Sonar		
Short Description	Ship crews detect and avoid mines while navigating restricted areas or channels using active sonar.	
Long Description	Surface ship crews detect and avoid mines or other underwater hazardous objects while navigating restricted areas or channels using active sonar. A Littoral Combat Ship utilizes unmanned surface vehicles and remotely operated vehicles to tow mine detection (hunting) equipment. Systems will operate from a shallow zone greater than 40 ft. to deep water. Exercises could be embedded within major training exercises.	
Typical Components	Platforms: Surface Combatant, Unmanned Surface Vehicle Targets: Mine Targets Systems being Trained/Tested: Sonar Systems - Mine Warfare Munitions: None	
Active Sonar	HFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Unmanned vehicles Towed in-water devices	
Parameters for Analysis	No explosives are used. It is assumed that the system will be operated in areas free of obstructions and will be towed well above the seafloor. Towed systems are always operated in a manner to avoid entanglement and damage. Exercises take place in water depths of 40 ft. and greater. Existing placed mine shapes to be used. There is the potential for temporary placement of mine shapes.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.8.9 Mine Neutralization – Explosive Ordnance Disposal

Mine Warfare		
Mine Neutralization Explosive Ordnance Disposal		
Short Description	Personnel place limpet mines or disable threat mines using explosive charges.	
Long Description	<p>Navy divers, typically explosive ordnance disposal personnel, disable threat mines with explosive charges to create a safe channel for friendly vessels to transit or placing or detonating limpet mines on steel structures.</p> <p>Personnel detect, identify, evaluate, and neutralize mines in the water with an explosive device and may involve detonation of one or more explosive charges from 4 to 60 pounds of TNT equivalent. These operations are normally conducted during daylight hours for safety reasons.</p> <p>Time-delay fuses may be used for these exercises. Personnel also identify and place limpet mine charges on a steel structure in the water and detonate an explosive charge of up to 2.5 pounds of TNT equivalent. These operations are normally conducted during daylight hours for safety reasons.</p>	
Typical Components	<p>Platforms: Small Boat</p> <p>Targets: Metal Plates and Frames, Mine Targets</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Demolition Devices</p>	
Active Sonar	No	
In-Water Explosives	E5, E6, E7	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Explosive mine neutralization (with divers)</p>	
Parameters for Analysis	<p>Time-delayed fuses may be used (up to 10 minutes) for charges up to 29 lb. net explosive weight in some locations. Charges are placed anywhere in water column, including bottom. For limpet mines, the detonation would be directed upwards towards the surface and away from the bottom with almost all acoustic energy released to the air.</p> <p>Some mine shapes and all of metal plates and frames will be recovered.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex
	Key West Range Complex Inshore	Key West Range Complex Inshore
	Virginia Capes Range Complex Inshore	Virginia Capes Range Complex Inshore

A.2.8.10 Submarine Mobile Mine and Mine Laying Exercise

Mine Warfare		
Submarine Mobile Mine and Mine-Laying Exercise		
Short Description	Submarine crews or UUVs deploy exercise mobile mines or mines.	
Long Description	Submarine crews or UUVs deploy exercise mobile mines or mines. Active sonar is used periodically. The UUV Mine-Laying Exercise involves an XLUUV deploying mines. During this event, an XLUUV transits to a designated mine deployment area and deploys mines. Mine training exercises may have a range support vessel (surface craft or a support helicopter) to recover mines. The exercise mines are recovered by helicopter or small craft.	
Typical Components	Platforms: Extra Large Unmanned Underwater Vehicle, Submarine Targets: Mine Targets Systems being Trained/Tested: Acoustic Communications, Pinger, Safety and Navigation, Unmanned Vehicle Systems Munitions: None	
Active Sonar	MFM, HFL, HFM, VHFL	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Jacksonville Range Complex

A.2.8.11 Surface Ship Object Detection

Mine Warfare		
Surface Ship Object Detection		
Short Description	Ship crews detect and avoid mines while navigating restricted areas or channels using active sonar.	
Long Description	Surface ship crews detect and avoid mines or other underwater hazardous objects while navigating restricted areas or channels using active sonar. Exercises could be embedded within major training exercises.	
Typical Components	Platforms: Surface Combatant Targets: Mine Targets Systems being Trained/Tested: Sonar Systems - Hull Mounted Munitions: None	
Active Sonar	MF1K	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Jacksonville Range Complex
	NS Norfolk	-
	NS Mayport	-

A.2.8.12 Underwater Mine Countermeasure Raise, Tow, Beach, and Exploitation Operations

Mine Warfare		
Underwater Mine Countermeasure Raise, Tow, Beach, and Exploitation Operations		
Short Description	Personnel locate mines, perform mine neutralization, raise and tow mines to the beach, and conduct exploitation operations for intelligence gathering.	
Long Description	Navy divers, typically explosive ordnance disposal personnel, locate mines using unmanned underwater vehicles, marine mammals, or other diver search techniques. Mines are then neutralized, or prevented from working as they are intended. Explosive ordnance disposal personnel ensure the neutralization measures are effective and the shapes are safe to bring to the beach. A lift balloon is attached to the line and slowly tows the shape to the beach. The final step, exploitation, is intelligence gathering, identifying the mine and how it works, and then disassembling it or disposing of it.	
Typical Components	Platforms: Rotary-Wing Aircraft, Small Boat, Unmanned Underwater Vehicles Targets: Mine Targets Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Unmanned vehicles	
Parameters for Analysis	Mine shapes are recovered as part of the exercise.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex Inshore

A.2.9 SURFACE WARFARE TRAINING

Surface warfare is a type of naval warfare in which aircraft, surface ships, and submarines employ weapons and sensors in operations directed against enemy surface ships or small boats. Aircraft-to-surface warfare is conducted by long-range attacks using air-launched cruise missiles, precision-guided munitions, or aircraft cannon. Surface warfare also is conducted by warships employing torpedoes, naval guns, and surface-to-surface missiles. Submarines attack surface ships using torpedoes or submarine-launched, anti-ship cruise missiles. Training in surface warfare includes surface-to-surface gunnery and missile exercises, air-to-surface gunnery and missile exercises, and submarine missile or torpedo launch activities. Gunnery and missile training generally involves expenditure of ordnance against a towed target. A sinking exercise is a specialized training exercise that provides an opportunity for ship, submarine, and aircraft crews to use multiple weapons systems to deliver high-explosive ordnance on a deactivated vessel, which is deliberately sunk.

Surface warfare also encompasses maritime security, that is, the interception of a suspect surface ship by an Action Proponent ship for the purpose of boarding-party inspection or the seizure of the suspect ship. Training in these tasks is conducted in visit, board, search and seizure exercises.

A.2.9.1 Bombing Exercise Air-to-Surface

Surface Warfare	
Bombing Exercise Air-to-Surface	
Short Description	Fixed-wing aircrews deliver bombs against surface targets.
Long Description	<p>Fixed-wing aircraft conduct bombing exercises against stationary floating targets (e.g., MK-58 smoke buoy), towed targets, or maneuvering targets. An aircraft clears the area, deploys a smoke buoy, and then delivers high-explosive or non-explosive practice bombs on the target. A range boat may be used to deploy towed or maneuvering targets for an aircraft to attack.</p> <p>Exercises for strike fighters typically involve a flight of two aircraft delivering unguided or guided munitions that may be either high-explosive or non-explosive. The following munitions may be employed by strike fighter aircraft in the course of bombing exercise: Unguided munitions including non-explosive subscale bombs (MK-76 and BDU-45), explosive and non-explosive general-purpose bombs (MK-80 series), and MK-20 cluster bombs (explosive, non-explosive). Precision-guided munitions include laser-guided bombs (explosive, non-explosive), laser-guided training rounds (non-explosive), Joint Direct Attack Munitions (explosive, non-explosive).</p>
Typical Components	<p>Platforms: Fixed Wing – Strike Aircraft</p> <p>Targets: Surface Targets - Floating, Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Bombs</p>
Active Sonar	No
In-Water Explosives	E9, E10, E12
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Aerial-deployed mines and non-explosive bombs</p> <p>Manned surface vessels</p> <p>Explosive bombs</p> <p>Towed in-water devices</p>

Surface Warfare		
Bombing Exercise Air-to-Surface		
Parameters for Analysis	Approximately 90 percent of non-explosive bombs are the sub-scale bombs such as the MK-76 and BDU-48. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.9.2 Gunnery Exercise Air-to-Surface Medium-Caliber

Surface Warfare		
Gunnery Exercise Air-to-Surface Medium-Caliber		
Short Description	Fixed-wing and helicopter aircrews fire medium-caliber guns at surface targets.	
Long Description	Navy, Marine Corps, and Coast Guard fixed-wing and helicopter aircrews engage surface targets with medium-caliber guns. Targets simulate enemy ships, boats, swimmers, and floating/near- surface mines. Fighter aircraft descend on a target firing high-explosive or non-explosive practice munitions medium-caliber projectiles. Helicopters will fly a racetrack pattern around an at-sea target. Aircrew will engage the target with medium-caliber weapons. Targets range from a smoke float, or an empty steel drum, to high-speed remote-controlled boats and Jet Skis.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft Targets: Surface Targets - Floating, Surface Targets - Maneuvering, Surface Targets - Towed Systems being Trained/Tested: Medium-Caliber Gun Systems Munitions: Projectile - Medium-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Non-explosive gunnery Towed in-water devices	
Parameters for Analysis	Most medium-caliber air-to-surface gunnery exercises will be with non-explosive training projectiles. High-explosive rounds will supplement when non-explosive training projectiles are not available. Fixed-wing projectile casings remain with aircraft and rotary-wing projectile casings are expended into the water. Two fixed-wing aircraft (400 rounds each) or one helicopter (400 rounds) per activity. One target used per exercise; expendable smoke floats (50 percent), stationary targets (45 percent), or remote-controlled targets (5 percent). De minimis explosives used during this activity are not quantitatively analyzed and, therefore, not included under munitions. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore. This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.9.3 Gunnery Exercise Air-to-Surface Small-Caliber

Surface Warfare		
Gunnery Exercise Air-to-Surface Small-Caliber		
Short Description	Helicopter and tiltrotor aircrews, use small-caliber guns to engage surface targets.	
Long Description	Navy, Marine Corps, and Coast Guard helicopters and tiltrotor aircraft, fly a racetrack pattern around an at-sea target. Targets simulate enemy ships, boats, and floating/near-surface mines. Each gunner will engage the target with small-caliber weapons. Targets range from a smoke float, an empty steel drum, to high-speed remote-controlled boats and Jet Skis.	
Typical Components	Platforms: Rotary-Wing Aircraft, Tiltrotor Aircraft Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: None Munitions: Projectile - Small-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Non-explosive gunnery	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.9.4 Gunnery Exercise Surface-to-Surface Boat Medium-Caliber

Surface Warfare		
Gunnery Exercise Surface-to-Surface Boat Medium-Caliber		
Short Description	Small boat crews fire medium-caliber guns at surface targets.	
Long Description	<p>Navy and Coast Guard small boat crews fire medium-caliber guns at surface targets. Boat crews may use high or low speeds to approach and engage targets simulating other boats, floating mines, or nearshore land targets with medium-caliber (up to and including 40 mm) weapons. A commonly used target is an empty steel drum.</p> <p>A number of different types of boats are used depending on the unit using the boat and their mission. Boats are most used to protect ships in harbors and high value units, such as: aircraft carriers, nuclear submarines, liquid natural gas tankers, etc., while entering and leaving ports, as well as to conduct riverine operations and various naval special warfare operations. The boats used by these units include small unit river craft, combat rubber raiding craft, rigid-hull inflatable boats, patrol craft, and many other versions of these types of boats. These boats use inboard or outboard diesel or gasoline engines with either propeller or water jet propulsion.</p>	
Typical Components	<p>Platforms: Small Boat</p> <p>Targets: Surface Targets - Floating, Surface Targets – Maneuvering, Surface Targets - Towed</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Grenades, Projectile - Medium-Caliber</p>	
Active Sonar	No	
In-Water Explosives	E1	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels Explosive gunnery Non-explosive gunnery Towed in-water devices</p>	
Parameters for Analysis	<p>Approximately 500 rounds expended per exercise.</p> <p>One target used per exercise, typically a stationary target such as a 50-liter steel drum.</p> <p>This training activity is conducted by Navy and USCG.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Key West Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.9.5 Gunnery Exercise Surface-to-Surface Boat Small-Caliber

Surface Warfare		
Gunnery Exercise Surface-to-Surface Boat Small-Caliber		
Short Description	Small boat crews fire small-caliber guns at surface targets.	
Long Description	<p>Navy and Coast Guard small boat crews fire small-caliber guns at surface targets. Boat crews may use high or low speeds to approach and engage targets simulating other boats, swimmers, floating mines, or nearshore land targets with small-caliber (up to and including 0.50 caliber) weapons. A commonly used target is an empty steel drum.</p> <p>A number of different types of boats are used depending on the unit using the boat and their mission. Boats are most used to protect ships in harbors and high value units, such as: aircraft carriers, nuclear submarines, liquid natural gas tankers, etc., while entering and leaving ports, as well as to conduct riverine operations, and various naval special warfare operations. The boats used by these units include small unit river craft, combat rubber raiding craft, rigid-hull inflatable boats, patrol craft, and many other versions of these types of boats. These boats use inboard or outboard, diesel or gasoline engines with either propeller or water jet propulsion.</p>	
Typical Components	<p>Platforms: Small Boat</p> <p>Targets: Surface Targets - Floating, Surface Targets – Maneuvering, Surface Targets - Towed</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Projectile - Small-Caliber</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels Non-explosive gunnery Towed in-water devices</p>	
Parameters for Analysis	<p>The majority of exercises will occur proximate to naval stations.</p> <p>Exercises will occur relatively nearshore due to short range of boats and safety concerns. Exercises mostly occur within 3 NM of the shoreline, but can occur further from shore. This training activity is conducted by Navy and USCG.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.9.6 Gunnery Exercise Surface-to-Surface Ship Large-Caliber

Surface Warfare	
Gunnery Exercise Surface-to-Surface Ship - Large-Caliber	
Short Description	Surface ship crews fire large-caliber guns at surface targets.
Long Description	<p>Navy and Coast Guard gun crews engage surface targets at sea with their main battery large-caliber (typically 57 mm, 76 mm, and 5-inch) guns. Targets include the QST-35 seaborne powered target, high-speed maneuverable surface target, or a specially configured remote-controlled watercraft. Some targets are expended during the exercise and are not recovered.</p> <p>The exercise proceeds with the target boat approaching from about 10-NM distance. The target is tracked by radar and when within a predetermined range, it is engaged first with large-caliber “warning shots.” As threats get closer all weapons may be used to disable the threat.</p> <p>This exercise may involve a single firing ship, or be undertaken in the context of a coordinated larger exercise involving multiple ships, including a major training exercise. Large-caliber guns will also be fired during weapon certification events and in conjunction with weapon maintenance.</p> <p>During all exercises, either high-explosive or non-explosive rounds may be used. High-explosive rounds can either be fused for detonation on impact (with water surface or targets), or for proximity to the target (in air detonation).</p>
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Surface Targets - Floating, Surface Targets – Maneuvering, Surface Targets - Towed</p> <p>Systems being Trained/Tested: Large-Caliber Gun Systems</p> <p>Munitions: Projectile - Large-Caliber</p>
Active Sonar	No
In-Water Explosives	E3, E5
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels Explosive gunnery Non-explosive gunnery Towed in-water devices Weapon firing noise</p>
Parameters for Analysis	<p>For analytical purposes assume all high-explosive rounds are fused to detonate upon impact with the water surface or target.</p> <p>After impacting the water, the high-explosive rounds are expected to detonate within 33 ft. of the surface. Non-explosive rounds, and fragments from the high-explosive rounds will sink to the bottom of the ocean.</p> <p>Assume each non-explosive projectile will be up to 5 in. in diameter and 30 in. in length, and each firing will also expend a metallic sleeve used to convey the projectile down the gun barrel.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p> <p>This training activity is conducted by Navy and USCG.</p>

Surface Warfare		
Gunnery Exercise Surface-to-Surface Ship - Large-Caliber		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Other AFTT Areas

A.2.9.7 Gunnery Exercise Surface-to-Surface Ship Medium-Caliber

Surface Warfare		
Gunnery Exercise Surface-to-Surface Ship Medium-Caliber		
Short Description	Surface ship crews fire medium-caliber guns at surface targets.	
Long Description	<p>Navy and Coast Guard crews fire medium-caliber guns at surface targets. Ships use medium-caliber weapons to practice defensive marksmanship, typically against a stationary floating target (a 10 ft. diameter red balloon [Killer Tomato]) and high-speed mobile targets. Some targets are expended during the exercise and are not recovered. Shipboard protection systems (Close-In Weapon System) utilizing medium-caliber projectiles would train against high-speed mobile targets.</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Surface Targets - Floating, Surface Targets – Maneuvering, Surface Targets - Towed</p> <p>Systems being Trained/Tested: Medium-Caliber Gun Systems</p> <p>Munitions: Projectile - Medium-Caliber</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels Non-explosive gunnery Towed in-water devices</p>	
Parameters for Analysis	<p>One target is used per exercise. Approximately 50 percent of targets are “Killer Tomatoes” (usually recovered). Approximately 35 percent are high-speed maneuvering targets, which are recovered. Approximately 15 percent of targets are other stationary targets such as a steel drum that are not recovered. The number of rounds per exercise varies depending on munitions used.</p> <p>This training activity is conducted by Navy and USCG.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Other AFTT Areas

A.2.9.8 Gunnery Exercise Surface-to-Surface Ship Small-Caliber

Surface Warfare		
Gunnery Exercise Surface-to-Surface Ship Small-Caliber		
Short Description	Surface ship crews fire small-caliber guns at surface targets.	
Long Description	<p>Navy and Coast Guard ship and boat crews fire small-caliber guns at surface targets. Ships use small-caliber weapons to practice defensive marksmanship, typically against stationary floating targets. The target may be a 10 ft. diameter red balloon (Killer Tomato, see Figure A.2-4, a 50-gallon steel drum, or other available target, such as a cardboard box. Some targets are expended during the exercise and are not recovered. Ship crew qualifications conducted at sea employ stationary targets on deck. Small-caliber projectiles fired during these exercises will be expended in the water. Shipboard protection systems utilizing small-caliber projectiles will train against high-speed mobile targets.</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Surface Targets – Floating, Surface Targets - Towed</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Projectile - Small-Caliber</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Non-explosive gunnery</p> <p>Towed in-water devices</p>	
Parameters for Analysis	<p>Small-caliber gun rounds per exercise: 1,000 to 3,000 non-explosive practice munitions. The majority of the activities will occur proximate to Navy homeports in Jacksonville, Florida and Norfolk, Virginia.</p> <p>This training activity is conducted by Navy and USCG.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complexes
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Other AFTT Areas



Figure A.2-4: “Killer Tomato” Stationary Floating Target

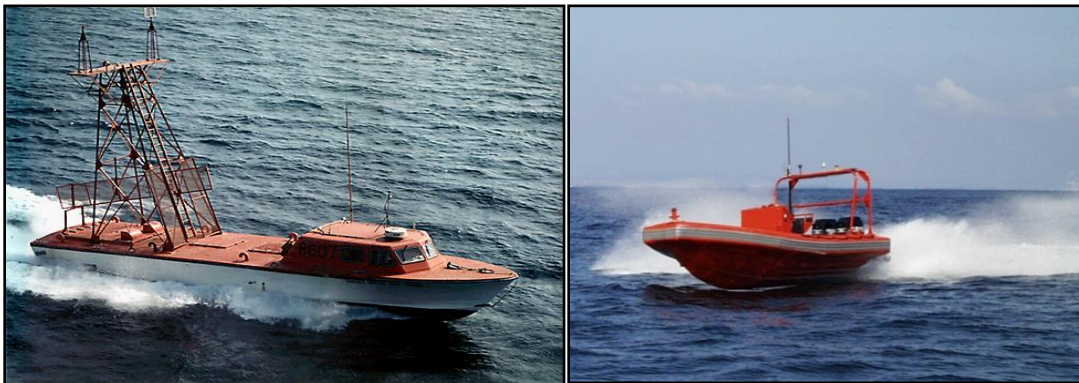


Figure A.2-5: QST-35 Seaborne Powered Target (on Left) and High-Speed Maneuvering Surface Target (on Right)

A.2.9.9 Integrated Live-Fire Exercise

Surface Warfare		
Integrated Live-Fire Exercise		
Short Description	Naval forces defend against a swarm of surface threats (ships or small boats) with bombs, missiles, rockets, and small-, medium-, and large-caliber guns.	
Long Description	<p>Naval forces use coordinated tactics and deliver high-explosive ordnance against a swarm of surface maritime threats. Strike fighter aircraft may deliver high-explosive unguided or guided munitions against surface targets. Strike fighter aircraft, helicopter aircrews, and ship crews fire high-explosive precision-guided missiles against surface targets. Helicopter-launched missiles (including rockets) typically detonate at or just below the water's surface. Strike fighter and helicopter aircrew may engage surface targets with small- and medium-caliber guns. Ships' gun crews engage surface targets with large-caliber (typically 57 mm and 5-inch) guns. This exercise may involve a single firing ship or be undertaken in the context of a coordinated larger exercise involving multiple ships. Coast Guard cutters and aircraft may participate in this activity.</p>	
Typical Components	<p>Platforms: Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Surface Combatant</p> <p>Targets: Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Large-Caliber Gun Systems, Medium-Caliber Gun Systems, Missile Firing/Launching Systems</p> <p>Munitions: Bombs, Large-Caliber Projectiles, Medium-Caliber Projectiles, Air-to-Surface Missiles, Rockets</p>	
Active Sonar	No	
In-Water Explosives	E10	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Aerial-deployed mines and non-explosive bombs</p> <p>Manned surface vessels</p> <p>Explosive bombs</p> <p>Explosive gunnery</p> <p>Explosive missiles and rockets</p> <p>Non-explosive gunnery</p> <p>Non-explosive missiles and rockets</p> <p>Weapon firing noise</p>	
Parameters for Analysis	Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore. Ordnance other than bombs modeled in unit-level training activities.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.9.10 Laser Targeting – Aircraft

Surface Warfare		
Laser Targeting - Aircraft		
Short Description	Fixed-wing and helicopter aircrews illuminate enemy targets with lasers.	
Long Description	Fixed-winged and helicopter aircrew illuminate enemy surface targets with lasers for engagement by aircraft with laser-guided bombs or missiles. This exercise may be conducted alone or in conjunction with other exercises utilizing precision-guided munitions, such as surface missiles and guided rockets. Exercises where weapons are fired are addressed in the appropriate activity (e.g., air-to-surface missile exercise). Lower powered lasers may also be used as non-lethal deterrents during maritime security operations (force protection).	
Typical Components	Platforms: Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft Targets: Surface Targets - Towed Systems being Trained/Tested: Laser Targeting Systems, Captive Air Training Missiles Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Towed in-water devices	
Parameters for Analysis	Laser targeting for missile/rocket guidance will occur in areas where these exercises also occur. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.9.11 Laser Targeting – Ship

Surface Warfare		
Laser Targeting - Ship		
Short Description	Surface ship crews illuminate and disable air and surface targets with high-energy laser systems.	
Long Description	Navy and Coast Guard ship crews employ high-power energy laser systems that are used to create critical failures in airborne and surface targets. The laser system directs an energy beam that can penetrate thin layers of metal at short distances (less than 1 nautical mile) that can render air and surface targets inoperative. Laser systems can also be used in a low power setting as non-lethal deterrent during maritime security operations (force protection). The low power capability would not be used against manned platforms during training.	
Typical Components	Platforms: Surface Combatant Targets: Air Targets - Drone, Surface Targets – Maneuvering, Surface Targets - Towed Systems being Trained/Tested: High Energy Laser System Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Towed in-water devices	
Parameters for Analysis	Laser targeting for missile/rocket guidance will occur in areas where these exercises also occur. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore. High-energy laser systems used in military readiness activities automatically shut down when target-lock is lost; meaning that if a high-energy laser beam aimed at a target on the surface, either from an aircraft or surface vessel, moves off the target, the system ceases projecting laser light, preventing any energy from striking the water or a nearby marine species. This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.9.12 Long-Range Unmanned Surface Vessel Training

Surface Warfare		
Long-Range Unmanned Surface Vessel Training		
Short Description	Amphibious ships employ unmanned surface vessel to engage surface targets.	
Long Description	Amphibious ships will launch an unmanned surface vessel that will employ unmanned aerial vehicles and engage surface threats.	
Typical Components	Platforms: Amphibious Warfare Vessel, Fleet Support Vessel, Unmanned Surface Vehicle Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: None Munitions: Projectile – Medium-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Jacksonville Range Complex

A.2.9.13 Maritime Security Operations

Surface Warfare	
Maritime Security Operations	
Short Description	Helicopter, surface ship, and small boat crews conduct a suite of maritime security operations at sea, to include visit, board, search and seizure; maritime interdiction operations; maritime infrastructure protection and harbor defense; ship force protection; anti-piracy operations; and drug interdiction by the Coast Guard.
Long Description	<p>Navy and Coast Guard helicopter and surface ship crews conduct a suite of maritime security operations. These activities involve training of boarding parties delivered by helicopters and surface ships to surface vessels for the purpose of simulating vessel search and seizure operations. Various training scenarios are employed and may include small arms with non-explosive blanks and surveillance or reconnaissance unmanned surface and aerial vehicles.</p> <p>Vessel Visit, Board, Search, and Seizure: Military personnel from ships and aircraft board suspect vessels, potentially under hostile conditions.</p> <p>Maritime Interdiction Operations: Ships and aircraft train in pursuing, intercepting, and ultimately detaining suspect vessels.</p> <p>Maritime Infrastructure Protection and Harbor Defense: Naval personnel train to defend oil platforms, similar at sea structures, harbors, piers, and other infrastructure.</p> <p>Warning Shot/Disabling Fire: Naval personnel train in the use of weapons to force fleeing or threatening small boats (typically operating at high speeds) to come to a stop.</p> <p>Ship Force Protection: Ship crews train in tracking multiple approaching, circling small craft, assessing threat potential, and communicating amongst crewmates and other vessels to ensure ships are protected against attack.</p> <p>Anti-Piracy Training: Naval personnel train in deterring and interrupting piracy activity. Training includes large vessels (pirate “mother ships”), and multiple small, maneuverable, and fast craft.</p> <p>Drug Interdiction: Coast Guard helicopter and surface ship crews train in the intercepting, boarding, and searching of suspected drug carrying vessels.</p>
Typical Components	<p>Platforms: Amphibious Warfare Vessel, Rotary-Wing Aircraft, Small Boat, Surface Combatant</p> <p>Targets: Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Grenades, Projectile – Small-Caliber</p>
Active Sonar	No
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Non-explosive gunnery</p> <p>Unmanned vehicles</p>

Surface Warfare		
Maritime Security Operations		
Parameters for Analysis	<p>Maritime Security Operations is a broad term used to describe activities intended to train naval forces in the skills necessary to protect naval vessels from small boat attack, counter piracy and drug operations (maritime interdiction operations and visit, board, search, and seizure), and protect key infrastructure (e.g. oil platforms). These exercises need to remain broad as naval forces need to be able to tailor training exercises to respond to emergent threats. Exercises typically do not involve live fire of weapons. All exercises involve vessel movement, sometimes at high rates of speed (naval vessels maneuvering to overtake suspect vessel and/or small boats [targets] closing in and maneuvering around naval vessels), and some activities involve helicopters and boarding parties. These training exercises are conducted proximate to naval homeports in Norfolk, Virginia, and Jacksonville, Florida, including during times of transit into and out of port, as well as during major training exercises.</p> <p>Firing of weapons during offshore exercises is accounted for in gunnery exercises, surface-to-surface activities. Inshore exercises include firing small-caliber blank ammunition.</p> <p>Other components associated with chaff and flare use are not expected to float and would sink to the seafloor.</p> <p>This training exercise is conducted by Navy and USCG. When USCG is performing this exercise, additional platforms may include cutters, boats, and air assets.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex
	-	Northeast Range Complexes Inshore
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex Inshore

A.2.9.14 Missile Exercise Air-to-Surface

Surface Warfare		
Missile Exercise Air-to-Surface		
Short Description	Fixed-wing and helicopter aircrews fire air-to-surface missiles at surface targets.	
Long Description	<p>Fighter, maritime patrol aircraft, and helicopter aircrews fire precision-guided missiles against surface targets. Aircraft involved may be unmanned.</p> <p>Fixed-wing aircraft (fighters or maritime patrol aircraft) approach an at-sea surface target from high altitude, and launch high-explosive precision-guided missiles.</p> <p>Helicopters designate at-sea surface targets with a laser or optics for a precision-guided high-explosive or non-explosive practice munitions missile. Helicopter-launched missiles typically pass through the target's "sail," and, if explosive, detonate at or just below, the water's surface.</p>	
Typical Components	<p>Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Patrol Aircraft, Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Unmanned Aerial Vehicle</p> <p>Targets: Surface Targets - Floating, Surface Targets - Towed</p> <p>Systems being Trained/Tested: Missile Firing/Launching Systems</p> <p>Munitions: Air-to-Surface Missiles</p>	
Active Sonar	No	
In-Water Explosives	E6, E8, E9	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Explosive missiles and rockets</p> <p>Non-explosive missiles and rocket</p> <p>Unmanned vehicles</p>	
Parameters for Analysis	<p>Assume one missile and one target are used per exercise.</p> <p>While missiles could explode above the water's surface after contacting targets, analysis assumes that all warheads explode at or just below the water's surface.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Key West Range Complex

A.2.9.15 Missile Exercise Air-to-Surface – Rocket

Surface Warfare		
Missile Exercise Air-to-Surface - Rocket		
Short Description	Helicopter aircrews fire both precision-guided and unguided rockets at surface targets.	
Long Description	Helicopters designate an at-sea surface target with a laser or optics for precision-guided high-explosive or non-explosive practice munitions rockets.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: Missile Firing/Launching Systems Munitions: Rockets	
Active Sonar	No	
In-Water Explosives	E3	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Explosive missiles and rockets Non-explosive missiles and rockets	
Parameters for Analysis	Assume all explosive rockets detonate in the water. Rockets may be used in conjunction with force protection activities. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore. Assume 5 percent of nonexplosive practice munitions in Virginia Capes Range Complex and Jacksonville Range Complex are flechette rockets.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.9.16 Missile Exercise Surface-to-Surface

Surface Warfare		
Missile Exercise Surface-to-Surface		
Short Description	Surface ship crews defend against surface threats (ships or small boats) and engage them with missiles.	
Long Description	<p>Surface ships launch missiles at surface maritime targets with the goal of destroying or disabling enemy ships or boats. After detecting and confirming a surface threat, the ship will fire a precision-guided surface missile.</p> <p>Activities with destroyers and cruisers will involve long-range (over the horizon) surface missiles. Activities with littoral combat ships certify ship's crew to defend against "close-in" surface threats and will use shorter range surface missiles such as Griffin or Hellfire. These exercises are live fire, meaning that a missile is fired down range. Surface missiles could be equipped with either high-explosive or non-explosive warheads.</p>	
Typical Components	<p>Platforms: Surface Combatant</p> <p>Targets: Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Missile Firing/Launching Systems</p> <p>Munitions: Surface-to-Surface Missiles</p>	
Active Sonar	No	
In-Water Explosives	E6, E9	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Explosive missiles and rockets</p> <p>Non-explosive missiles and rockets</p>	
Parameters for Analysis	<p>Assume one missile and one target used per exercise.</p> <p>While missile could explode above the water's surface after contacting target, analysis assumes all warheads explode at or just below the surface.</p> <p>Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.9.17 Sinking Exercise

Surface Warfare	
Sinking Exercise	
Short Description	Aircraft, ship, and submarine crews deliberately sink a seaborne target, usually a decommissioned ship made environmentally safe for sinking according to U.S. Environmental Protection Agency standards, with a variety of ordnance.
Long Description	<p>Ship personnel and aircrew deliver high-explosive ordnance on a seaborne target (large, deactivated vessel), which is deliberately sunk using multiple weapon systems. A sinking exercise is typically conducted by aircraft, surface vessels, and submarines to train in live ordnance delivery on a full-size ship target. The target is typically a decommissioned ship made environmentally safe for sinking according to U.S. Environmental Protection Agency standards. The location is greater than 50 nautical miles from shore and in water depths greater than 6,000 feet (ft.).</p> <p>Ship, aircraft, and submarine crews attack with coordinated tactics and deliver a variety of inert and high-explosive ordnance. Coast Guard cutters and aircraft may participate in this activity. Typically, the exercise lasts for 4 to 8 hours and possibly over 1 to 2 days, however it is unpredictable and ultimately ends when the target ship sinks.</p>
Typical Components	<p>Platforms: Fixed Wing – Strike Aircraft, Submarine, Surface Combatant</p> <p>Targets: Surface Targets - Floating</p> <p>Systems being Trained/Tested: Missile Firing/Launching Systems, Large-Caliber Gun Systems, Torpedo Launching System</p> <p>Munitions: Air-to-Surface Missiles, Bombs, Projectile - Large-Caliber, Torpedoes - HE</p>
Active Sonar	HFH
In-Water Explosives	E5, E8, E9, E11
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels SINKEX Weapon firing noise</p>
Parameters for Analysis	<p>USCG may participate in this training. Exercises occur greater than 50 NM from shore and in water depths greater than 6,000 ft. during daylight hours only. Due to the distance from shore, stressors to human resources were not analyzed for this activity. The participants and assets typically include:</p> <ul style="list-style-type: none"> • 1 full-size target ship hulk • 1-5 CG, DDG, or LCS ships • 1-10 F/A-18, or maritime patrol aircraft • 1 or 2 MH-60 helicopters • 1 E-2 aircraft for Command and Control • 1 submarine • 1-3 range clearance aircraft • 1-2 Harpoon surface-to-surface or air-to-surface missiles • 2-4 Maverick or Hellfire air-to-surface missiles • 2-12 MK-80 series general-purpose bombs • 200 rounds large-caliber projectiles • 1-2 MK-48 heavyweight submarine-launched torpedo

Surface Warfare		
Sinking Exercise		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes SINKEX Box	SINKEX Box

A.2.9.18 Small Boat Attack

Surface Warfare		
Small Boat Attack		
Short Description	Afloat units defend against small boat or personal watercraft attack.	
Long Description	For this activity, one or two small boats or personal watercraft conduct simulated attack activities on units afloat, training ship crews how to respond to small boat attack in harbors, restricted channels, and nearshore areas using non-lethal means or armament appropriate to the threat and location. Coast Guard small boats and aircraft may participate in this activity.	
Typical Components	Platforms: All Navy Ships and Boats Targets: Surface Targets - Maneuvering Systems being Trained/Tested: None Munitions: Small-Caliber Blanks	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels Non-explosive gunnery	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.10 OTHER TRAINING EXERCISES

A.2.10.1 Ship-to-Shore Fuel Transfer System Training

Other Training Activities		
Ship-to-Shore Fuel Transfer System Training		
Short Description	This activity trains personnel in the transfer of petroleum (though only sea water is used during training) from ship to shore.	
Long Description	The Navy uses either the Offshore Petroleum Discharge System or the Distributed Littoral Operational Fuel Transfer System to transfer fuel from a ship to the shore. For training purposes, only sea water is used. They systems consist of five training subcomponents including the beach termination unit, operation utility boat technicians, boat coxswain, dive boat operation technician, and single anchor leg moor training. This activity trains personnel in the transfer of petroleum (though only sea water is used during training) from ship to shore. From approximately one mile offshore, technicians and underwater construction team divers roll out conduit from a ship offshore, deploy the single anchor leg mooring which sinks to and settles on the ocean floor, and use anchors at various points along the conduit to secure it to the seafloor.	
Typical Components	Platforms: Fixed Range Targets: None Systems being Trained/Tested: Fuel Transfer Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Navy Cherry Point Range Complex
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex

A.2.10.2 Precision Anchoring

Other Training Activities		
Precision Anchoring		
Short Description	Releasing of anchors in designated locations.	
Long Description	Navy and Coast Guard ship crews choose the best available anchoring sites. The ship uses all means available to determine its position when anchor is dropped to demonstrate calculating and plotting the anchor's position within 100 yards of center of planned anchorage.	
Typical Components	Platforms: All Navy and Coast Guard Vessels Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.2.10.3 Search and Rescue

Other Training Activities		
Search and Rescue		
Short Description	Helicopter and ship crews rescue military personnel at sea.	
Long Description	Navy and Coast Guard helicopter, ship, and submarine crews practice the skills required to recover personnel lost at sea. Helicopters locate survivors and deploy rescue swimmer and rescue basket. Survivors are winched up to the hovering helicopter. Surface ships would conduct man-overboard drills and deploy a dummy figure in the water. Ship crews would launch a small boat, direct the recovery of the dummy, and recover the small boat. Submarine crews would maneuver the submarine to effect recovery of personnel.	
Typical Components	Platforms: All Navy Ships and Boats, Rotary-Wing Aircraft Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	Locations are typical, but ships may conduct man-overboard training throughout the Study Area. This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	-	Other AFTT Areas
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex Inshore

A.2.10.4 Submarine Navigation

Other Training Activities		
Submarine Navigation		
Short Description	Submarine crews operate sonar for navigation and detection while transiting into and out of port during reduced visibility.	
Long Description	Submarine crews train to operate sonar for navigation. The ability to navigate using sonar is critical for detection while transiting into and out of port during periods of reduced visibility. During this activity the submarine will be surfaced.	
Typical Components	Platforms: Submarine Targets: None Systems being Trained/Tested: Sonar Systems - Hull Mounted Munitions: None	
Active Sonar	MFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	For biological resource analysis, vessel noise and vessel strike are only analyzed for the periods while the submarines are surfaced, typically brief in nature. Mitigation Involving Visual Observations for Marine Species related to vessel movement are only considered during the period of surfacing as well. For human resource stressor analysis, physical disturbance and strike and physical interactions are only analyzed for the periods while the submarine are surfaced, typically brief in nature.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	-	Virginia Capes Range Complex
	-	Jacksonville Range Complex
	NS Norfolk	-
	NSB Kings Bay	-
	NS Mayport	-
	Port Canaveral, FL	-

A.2.10.5 Submarine Sonar Maintenance and Systems Checks

Other Training Activities		
Submarine Sonar Maintenance and Systems Checks		
Short Description	Maintenance of submarine sonar and other system checks are conducted pierside or at sea.	
Long Description	A submarine performs periodic maintenance on the AN/BQQ-10 and submarine high-frequency sonar systems while in port or at sea. Submarines conduct maintenance to their sonar systems in shallow water near their homeport, however, sonar maintenance could occur anywhere as the system's performance may warrant.	
Typical Components	Platforms: Submarine Targets: None Systems being Trained/Tested: Sonar Systems - Hull Mounted Munitions: None	
Active Sonar	MFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	"Other AFTT Areas" refers to areas outside of existing range complexes and testing ranges. Activities occurring within 12 NM are pierside.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Northeast Range Complexes Inshore	Northeast Range Complexes Inshore
	Virginia Capes Range Complex Inshore	Virginia Capes Range Complex Inshore
	Jacksonville Range Complex Inshore	Jacksonville Range Complex Inshore
	-	Other AFTT Areas
	-	NSB New London

A.2.10.6 Submarine Under Ice Certification

Other Training Activities		
Submarine under Ice Certification		
Short Description	Submarine crews operate sonar while transiting under ice. Ice conditions are simulated during training and certification events.	
Long Description	Submarine crews train to operate under ice. Ice conditions are simulated during training and certification exercises. A single exercise is comprised of 30 hours of training, spread out over 5 days in 6-hour training sessions.	
Typical Components	Platforms: Submarine Targets: None Systems being Trained/Tested: Sonar Systems - Hull Mounted Munitions: None	
Active Sonar	HFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.2.10.7 Surface Ship Sonar Maintenance and Systems Checks

Other Training Activities		
Surface Ship Sonar Maintenance and Systems Checks		
Short Description	Maintenance of surface ship sonar and other system checks are conducted pierside or at sea.	
Long Description	This scenario consists of surface ships performing periodic maintenance to the AN/SQS-53 sonar and other ship systems while in port or at sea. This maintenance takes up to 4 hours. Surface ships operate active sonar systems for maintenance while in shallow water near their homeport, however, sonar maintenance could occur anywhere as the system's performance may warrant.	
Typical Components	Platforms: Surface Combatant Targets: None Systems being Trained/Tested: Sonar Systems - Hull Mounted Munitions: None	
Active Sonar	MF1, MF1K	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	"Other AFTT Areas" refers to areas outside of existing range complexes and testing ranges. Activities occurring within 12 NM are pierside.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Other AFTT Areas
	-	NS Norfolk
	-	NS Mayport

A.2.10.8 Unmanned Aerial System Training Certification – Submarine

Other Training Activities		
Unmanned Aerial System Training and Certification - Submarine		
Short Description	Submarine deploys unmanned aerial system while submerged to conduct surveillance.	
Long Description	Submarine deploys unmanned aerial system while submerged to conduct surveillance. For submarine launched UASs, a negatively buoyant capsule is deployed underwater and descends to a programmed depth. The capsule then drops a weight, inflates a flotation collar, rises to the surface, and launches an unmanned aerial system. Submarine-launched UASs are not typically recovered.	
Typical Components	Platforms: Submarine, Unmanned Aerial Vehicle - Fixed Wing Targets: Air Targets - Drone Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	-	Jacksonville Range Complex

A.2.10.9 Unmanned Underwater Vehicle Training – Certification and Development

Other Training Activities		
Unmanned Underwater Vehicle Training - Certification and Development		
Short Description	Unmanned underwater vehicle certification involves training with unmanned platforms to ensure submarine crew proficiency. Tactical development involves training with various payloads, for multiple purposes to ensure that the systems can be employed effectively in an operational environment.	
Long Description	Unmanned underwater vehicle certification and tactical development involves the training with unmanned platforms on which various payloads are attached and used for different purposes. Unmanned underwater vehicles may be deployed by surface ships and Coast Guard cutters, small boats, submarines, aircraft, and target support vessels. Payload certification and development training assesses various systems that can be incorporated onto unmanned platforms for mine warfare, bottom mapping, and other missions. Training can range from basic remote control and autonomous navigation tests to deployment and activation of onboard systems which may include hydrodynamic instruments, launchers, and recovery capabilities. These vehicles are capable of expanding the communication and surveillance capabilities of submarines, and terrestrial commands.	
Typical Components	<p>Platforms: Fleet Support Vessel, Moored Platform, Small Boat, Fixed Structure, Submarine, Unmanned Underwater Vehicle</p> <p>Targets: Mine Targets, Sub-surface Targets - Stationary</p> <p>Systems being Trained/Tested: Acoustic Communications, Acoustic Releases, Fathometer, Pinger, Safety and Navigation, Sonar Systems - Other, Unmanned Vehicle Systems</p> <p>Munitions: None</p>	
Active Sonar	MFH, HFL, HFM, VHFL, VHFM, VHFH, Broadband (MF to HF), Broadband (HF to VHF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Unmanned vehicles</p>	
Parameters for Analysis	This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	-	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	-	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	-	Virginia Capes Range Complex Inshore

A.2.10.10 Waterborne Training

Other Training Activities		
Waterborne Training		
Short Description	Personnel launch, operate, and recover a variety of small boats to achieve certifications such as coxswain, crewman, and safety observer.	
Long Description	Waterborne Training includes qualification and certification as safety observer, safety swimmer, coxswain, and crewman utilizing a variety of Navy and Coast Guard small crafts. These craft include, but are not limited to, rigid-hull inflatables, aluminum chambered boats, patrol boats, stand-up paddleboards, kayaks, and Jet Skis. Small boat crews train to launch and recover, moor to buoys, anchor, and operate a variety of missions in shallow waters.	
Typical Components	Platforms: Small Boat Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	This training activity is conducted by Navy and USCG.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	-	Key West Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Northeast Range Complexes Inshore
	-	Virginia Capes Range Complex Inshore
	-	Jacksonville Range Complex Inshore
	-	Gulf of Mexico Range Complex Inshore
	-	NS Mayport
	-	Tampa, FL
	-	Pascagoula, MS
	-	Beaumont, TX

A.3 TESTING ACTIVITIES

A.3.1 NAVAL AIR SYSTEMS COMMAND TESTING ACTIVITIES

Naval Air Systems Command activities will generally fall under fleet primary mission areas, such as the testing of airborne mine warfare and anti-submarine warfare weapons and systems. Naval Air Systems Command activities include, but are not limited to, the testing of new aircraft platforms (e.g., the MQ-25 Joint Strike Fighter aircraft), weapons, and systems (e.g., newly developed sonobuoys) that will ultimately be integrated into fleet training activities. In addition to testing new platforms, weapons, and systems, Naval Air Systems Command also conducts lot acceptance testing of sonobuoys and follow-on testing and evaluation of updated systems in support of fleet operational units. In general, the potential environmental effects from most Naval Air Systems Command testing activities are similar to the associated fleet training exercises.

While many of these systems tested by Naval Air Systems Command will ultimately be used by the fleet, testing activities involving the same or similar systems may be conducted in different locations and manners than when conducted by the fleet. Because of these differences, the results of the analysis for testing activities may differ from the results for training activities.

A.3.1.1 Air Warfare

A.3.1.1.1 Air Combat Maneuvers Test

Air Warfare		
Air Combat Maneuvers Test		
Short Description	Aircrews engage in flight maneuvers designed to gain a tactical advantage during combat.	
Long Description	Air combat maneuver is the general term used to describe an air-to-air test event involving two or more aircraft, each engaged in continuous proactive and reactive changes in aircraft attitude, altitude, and airspeed. No weapons are fired during air combat maneuver activities.	
Typical Components	Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Strike Aircraft Targets: None Systems being Trained/Tested: Aircraft Platforms Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	All combustible material in flares is assumed to be consumed before contact of the casing with the water.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex

A.3.1.1.2 Air Platform Vehicle Test

Air Warfare		
Air Platform Vehicle Test		
Short Description	Testing performed to quantify the flying qualities, handling, airworthiness, stability, controllability, and integrity of an air platform or vehicle. No explosive weapons are released during an air platform/vehicle test.	
Long Description	The air platform/vehicle test describes the testing performed to quantify the flying qualities, handling, airworthiness, stability, controllability, and integrity of an air platform/vehicle. Integration of non-weapons system including aerial refueling tests are also conducted as part of an air platform/vehicle test. Test results are compared against design and performance specifications for compliance. The test results are also used to define stability and controllability characteristics and limitations and to improve and update existing analytical and predictive models. A wide variety of fixed-wing and rotary-wing aircraft, including unmanned aerial systems may undergo air platform/vehicle testing. No weapons are released during an Air Platform/Vehicle Test. Aircraft may employ laser detection for targeting systems and trailing antenna. Activities may involve two or more fighter jet aircraft and a towed target tractor by a contracted aircraft (e.g., Learjet for laser targeting tests).	
Typical Components	Platforms: Fixed Wing - Command and Control Aircraft, Fixed Wing – Other Aircraft, Fixed Wing – Strike Aircraft, Unmanned Aerial Vehicle - Fixed Wing Targets: None Systems being Trained/Tested: Aircraft Platform/Vehicle Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.3.1.1.3 Air Platform Weapons Integration Test

Air Warfare		
Air Platform Weapons Integration Test		
Short Description	Testing performed to quantify the compatibility of weapons with the aircraft from which they would be launched or released. Non-explosive weapons or shapes are used.	
Long Description	The air platform weapons integration test describes the testing performed to quantify the compatibility of weapons with the aircraft from which they would be released. Tests evaluate the compatibility of the weapon and its carriage, suspension, and launch equipment with the performance and handling characteristics of the designated aircraft. Additional tests assess the ability of the weapon to separate or launch safely from the aircraft at combat velocities, including at supersonic speeds. Test results are compared against design specifications for compliance. The test results are also used to define performance characteristics and to improve and update existing analytical and predictive models.	
Typical Components	Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Strike Aircraft, Unmanned Aerial Vehicle - Fixed Wing Targets: Air Targets - Drone, Surface Targets - Maneuvering Systems being Trained/Tested: Munitions Firing/Launching Systems Munitions: Air-to-Air Missiles, Air-to-Surface Missiles, Bombs	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Aerial-deployed mines and non-explosive bombs Non-explosive missiles and rockets	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Gulf of Mexico Range Complex

A.3.1.1.4 Air-to-Air Gunnery Test – Medium-Caliber

Air Warfare		
Air-to-Air Gunnery Test - Medium-Caliber		
Short Description	Test performed to evaluate the effectiveness of air-to-air guns against designated airborne targets. Fixed-wing aircraft may be used.	
Long Description	An air-to-air gunnery test involves the firing of guns from fixed-wing aircraft against a towed aerial banner that serves as the target. Non-explosive rounds are fired, and the targets fired upon are typically towed aerial banners.	
Typical Components	Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Strike Aircraft Targets: Air Targets - Decoy Systems being Trained/Tested: Medium-Caliber Gun Systems Munitions: Projectile - Medium-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	No	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex

A.3.1.1.5 Air-to-Air Missile Test

Air Warfare		
Air-to-Air Missile Test		
Short Description	Test performed to evaluate the effectiveness of air-launched missiles against designated airborne targets. Fixed-wing aircraft will be used.	
Long Description	These tests are a type of air-to-air weapons system test in which air-to-air missiles (non-explosive or in-air explosives) are fired from fixed-wing aircraft against unmanned aerial drones.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft Targets: Air Targets - Drone Systems being Trained/Tested: Missile Firing/Launching Systems Munitions: Air-to-Air Missiles	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	This activity includes missiles that explode in-air at medium altitudes.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex

A.3.1.1.6 Air-to-Air Weapons System Test

Air Warfare		
Air-to-Air Weapons System Test		
Short Description	Test to evaluate the effectiveness of air-launched weapons against designated air targets.	
Long Description	The air-to-air weapons systems test evaluates the performance of air-launched weapons systems against air targets. During an air-to-air weapons systems test, a strike fighter aircraft locates, tracks, and, in some tests, fires on an air target used to simulate another strike fighter aircraft using non-explosive ordnance. No testing of explosive weapons is planned.	
Typical Components	Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Strike Aircraft Targets: Air Targets - Decoy Systems being Trained/Tested: Munitions Firing/Launching Systems Munitions: Air-to-Air Missiles	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.1.1.7 Intelligence, Surveillance, and Reconnaissance Test

Air Warfare		
Intelligence, Surveillance, and Reconnaissance Test		
Short Description	Aircrews use all available sensors to collect data on threat vessels.	
Long Description	<p>An air warfare intelligence, surveillance, and reconnaissance (ISR) test involves evaluating communications capabilities of aircraft, including unmanned aerial systems that can carry cameras, sensors, communications equipment, or other payloads. New systems are tested at sea to ensure proper communications between aircraft and ships.</p> <p>ISR aircraft systems act as eyes in the sky, relaying raw imagery back to military personnel on the ground or to ships at-sea. The data is processed, analyzed, and shared with U.S. Navy or other U.S. military aircraft or vessels. New ISR technology systems provide combat identification (friend or foe) and are used for aircraft and ship-based communications.</p>	
Typical Components	<p>Platforms: Fixed Wing - Command and Control Aircraft, Unmanned Aerial Vehicle - Fixed Wing</p> <p>Targets: Air Targets - Drone</p> <p>Systems being Trained/Tested: ISR Systems</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	Surface targets consist of Navy vessels accounted for in unit-level training activities.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex

A.3.1.2 Anti-Submarine Warfare

Anti-submarine warfare activities involve fixed-wing and rotary-wing aircraft, ships, and submarines, conducting operations alone or in combination, to enhance or evaluate the ability to locate, track, and neutralize submarines. Anti-submarine warfare tests are intended to evaluate the capabilities of a variety of active and passive sonar systems. Some systems are used to characterize the environment by measuring water depth, for example, whereas others are designed to locate mines and identify, track, and target submarines. Passive sonar systems “listen” for sound by using underwater microphones, called hydrophones, which receive, filter, amplify, and process underwater sound in search of certain acoustic signatures. No sound is introduced into the water when using passive sonar. Passive sonar can indicate the presence, character, and movement of a submarine, to the extent that the submarine generates noise.

Active sonar is the most effective means for locating quiet, modern submarines because active sonar is not dependent on the sound being generated by the submarine. Active sonar transmits pulses of sound that travel through the water, reflect off objects, and return to a receiver. By knowing the speed of sound in water and the time taken for the sound wave to travel to the object and back, active sonar systems can quickly calculate direction and distance from the sonar platform to the underwater object. Being able to accurately track moving submarines is essential to U.S. ship survivability.

Advanced, large-scale anti-submarine warfare events (i.e., anti-submarine warfare coordinated events) involving active sonar are conducted in coordinated, at-sea activities during multidimensional fleet training events involving submarines, ships, fixed-wing aircraft, and helicopters. These integrated training events offer opportunities to conduct testing activities and to train aircrew in the use of new or newly enhanced systems during a large-scale, complex exercise. Coordinated anti-submarine warfare events often involve the full anti-submarine warfare continuum from detecting and tracking a submarine to attacking a target using either exercise torpedoes or simulated weapons. Training events include detection and tracking exercises against “enemy” submarine contacts, torpedo employment exercises against the target, and exercising command and control tasks in a multidimensional battlespace.

The torpedoes released during a torpedo employment exercise are non-explosive. No other weapons are fired during Naval Air Systems Command anti-submarine warfare tests. Anti-submarine warfare sonar systems are deployed from certain classes of surface ships, submarines, rotary-wing aircraft, and fixed-wing patrol aircraft. Helicopters equipped with dipping sonar or sonobuoys are utilized to locate suspect submarines or submarine targets within the training or testing area. In addition, fixed-wing patrol aircrafts are used to deploy both active and passive sonobuoys to assist in locating and tracking submarines during the duration of the test.

Anti-submarine warfare tests include sonobuoy lot acceptance tests, which evaluate the integrity of a series, or lot, of sonobuoys before the lot is turned over to the fleet; dipping sonar tests in both shallow and deep water; torpedo tests (non-explosive warhead); and sonobuoy tests with both coherent (acoustic) and incoherent (explosive) sonobuoys. The types of sound sources tested by Naval Air Systems Command during anti-submarine warfare sonar tests in the Study Area are identified in table that follows and descriptions of anti-submarine warfare tests are provided in the sections below.

A.3.1.2.1 Anti-Submarine Warfare Torpedo Test

Anti-Submarine Warfare		
Anti-Submarine Warfare Torpedo Test		
Short Description	Test evaluates anti-submarine warfare systems onboard rotary-wing and fixed-wing aircraft and the ability to search for, detect, classify, localize, track, and attack a submarine or similar target.	
Long Description	<p>An anti-submarine warfare torpedo test evaluates anti-submarine warfare systems onboard rotary-wing and fixed-wing aircraft and the ability to search for, detect, classify, localize, track, and attack a submarine or similar target. Both sonobuoys and torpedoes (using the High Altitude Anti-Submarine Warfare Weapon Capability kit) may be delivered at high altitudes to remain clear of high threat areas. The focus of the anti-submarine warfare torpedo test is the operation of non-explosive torpedoes, but other anti-submarine warfare systems are often used during the test. Targets simulate a submarine threat and are deployed at varying depths and speeds. If available, tests may be conducted using an actual submarine as the target. This activity can be conducted in shallow or deep waters and aircraft can originate from a land base or from a surface ship. The torpedo test culminates with the release of an exercise torpedo against the target and is intended to evaluate the targeting, release, and tracking process of deploying torpedoes from aircraft. All exercise torpedoes used in testing are either running (EXTORP) or non-running (REXTORP) and are non-explosive. 85 percent of torpedoes are recovered. A parachute assembly used for aircraft-launched torpedoes is jettisoned and sinks. Ballast (typically lead weights) may be released from the torpedoes to allow for recovery, leaving the ballast to sink to the bottom.</p>	
Typical Components	<p>Platforms: Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Torpedoes/Torpedo Launching Systems</p> <p>Munitions: Torpedoes - Exercise</p>	
Active Sonar	HFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p>	
Parameters for Analysis	<p>Assume one torpedo accessory package (ballast, etc.) per torpedo.</p> <p>Assume one target per torpedo.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.1.2.2 Anti-Submarine Warfare Tracking Test – Fixed-Wing

Anti-Submarine Warfare		
Anti-Submarine Warfare Tracking Test – Fixed-Wing		
Short Description	The test evaluates the sensors and systems used by fixed-wing aircraft to detect and track submarines and to ensure that aircraft systems used to deploy the tracking systems perform to specifications and meet operational requirements.	
Long Description	An Anti-Submarine Warfare Tracking Test Fixed -Wing evaluates the sensors and systems used to detect and track submarines and to ensure that platform systems used to deploy the tracking systems perform to specifications and meet operational requirements. Targets may also be employed during an anti-submarine warfare scenario. If available, tests may be conducted using an actual submarine as the target. This activity would be conducted in deep (typically beyond 100 ft.) waters. Some anti-submarine warfare fixed-wing aircraft tracking tests could be conducted as part of a coordinated event with fleet training activities.	
Typical Components	Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Patrol Aircraft Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Sonobuoys Munitions: None	
Active Sonar	LFM, LFH, MFM, HFM	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Explosive sonobuoys and other sub-surface explosives	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	SINKEX Box
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex
	-	Other AFTT Areas

A.3.1.2.3 Anti-Submarine Warfare Tracking Test – Rotary-Wing

Anti-Submarine Warfare		
Anti-Submarine Warfare Tracking Test – Rotary-Wing		
Short Description	The test evaluates the sensors and systems used to detect and track submarines and to ensure that rotary-wing aircraft systems used to deploy the tracking systems perform to specifications.	
Long Description	An Anti-Submarine Warfare Tracking Test–Rotary-Wing evaluates the sensors and systems used to detect and track submarines and to ensure that platform systems used to deploy the tracking systems perform to specifications. Targets may also be employed during an anti-submarine warfare tracking test event. If available, tests may be conducted using an actual submarine as the target. This activity would be conducted in shallow or deep waters and could initiate from a land base or from a surface ship. Rotary-Wing anti-submarine warfare tests are intended to evaluate the sensors and systems used to detect and track submarines and to ensure that platform systems used to deploy the tracking systems perform to specifications. Some anti-submarine rotary-wing tracking tests could be conducted as part of an anti-submarine tracking coordinated event with fleet training activities.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Sonar Systems - Dipping, Sonobuoys Munitions: None	
Active Sonar	MFM, MFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.3.1.2.4 Kilo Dip Test

Anti-Submarine Warfare		
Kilo Dip Test		
Short Description	Functional check of a rotary-wing aircraft-deployed dipping sonar system prior to conducting a testing or training event using the dipping sonar system.	
Long Description	A kilo dip is the operational term used to describe a functional check of a rotary-wing aircraft-deployed dipping sonar system. During a functional check, a single rotary-wing aircraft would deploy the sonar transducer assembly via a reel mechanism to a predetermined depth or series of depths while the rotary-wing aircraft hovers over the dip point. Once at the desired depth, the sonar transducer would be activated and would briefly transmit a pulsed, acoustic signal (i.e., ping) to check that all systems are functioning properly. After the check is completed, the sonar transducer assembly would be reeled in, and in some instances the rotary-wing aircraft would transit to a second dip point before the procedure is repeated. A kilo dip is a precursor to more comprehensive testing.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: None Systems being Trained/Tested: Sonar Systems - Dipping Munitions: None	
Active Sonar	MFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.3.1.2.5 Sonobuoy Lot Acceptance Test

Anti-Submarine Warfare		
Sonobuoy Lot Acceptance Test		
Short Description	Sonobuoys are deployed from surface vessels and aircraft to verify the integrity and performance of a lot or group of sonobuoys in advance of delivery to the fleet for operational use.	
Long Description	Sonobuoys are deployed from surface vessels and aircraft to verify the integrity and performance of a lot or group of sonobuoys in advance of delivery to the fleet for operational use. Lot acceptance testing would occur for multiple types of sonobuoys including non-impulsive and explosive.	
Typical Components	Platforms: Surface Vessel, Fixed Wing – Other Aircraft, Fixed Wing – Patrol Aircraft Targets: None Systems being Trained/Tested: Signal, Underwater Sound Buoys Sonobuoys Munitions: None	
Active Sonar	LFM, LFH, MFM, HFM	
In-Water Explosives	E1, E3	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Explosive sonobuoys and other sub-surface explosives	
Parameters for Analysis	Assume one parachute per sonobuoy	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Key West Range Complex	Key West Range Complex

A.3.1.3 Electronic Warfare

A.3.1.3.1 Chaff Test

Electronic Warfare	
Chaff Test	
Short Description	Chaff tests evaluate newly developed or enhanced chaff, chaff dispensing equipment, or modified aircraft systems against chaff deployment. Tests may also train pilots and aircrews in the use of new chaff dispensing equipment. Chaff tests are often conducted with flare tests and air combat maneuver activities, as well as other test activities, and are not typically conducted as standalone tests.
Long Description	Chaff tests are conducted to evaluate newly developed or enhanced chaff dispensing equipment, to ensure other newly developed or modified aircraft systems are compatible with chaff deployment, and to train pilots and aircrew in the use of new chaff dispensing equipment. Fixed-wing, rotary-wing, and tiltrotor aircraft deploy chaff to disrupt threat targeting and missile guidance radars and to defend against an attack (Electronic Protect deployment). Chaff tests are often conducted with flare tests or air combat maneuver activities, as well as other tests, rather than as a standalone test. Weapons are not typically fired during chaff tests. Chaff is employed for a number of different tactical reasons, but the end goal is to create a target that will distract enemy radar and weapon systems away from the friendly platform. Chaff may also be employed offensively (Electronic Attack deployment), such as before a major strike to "hide" inbound striking aircraft. Different chaff types are used by a variety of different Navy aircraft; however, all chaff consists of a radar reflector material made of thin, narrow, metallic strips cut in various lengths, and is intended to elicit frequency responses which deceive enemy radars. Defensive chaff tests are the most common type of chaff test. In most cases, the chaff test is conducted to evaluate systems on the aircraft deploying the chaff, but it is also critical to view the effect of the chaff from the "enemy" perspective so that radar system operators may practice corrective procedures to overcome the chaff jamming effect. Chaff tests are often designed to gain experience and data from both perspectives. Chaff is typically deployed from an aircraft as the aircraft makes evasive maneuvers to defeat a simulated threat missile or threat aircraft. The chaff deploys in a cloud of the highly reflective filaments and deceives the guidance system of an inbound missile, allowing the aircraft to escape the threat.
Typical Components	Platforms: Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Tiltrotor Aircraft Targets: None Systems being Trained/Tested: Chaff Munitions: None
Active Sonar	No
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	None
Parameters for Analysis	None

Electronic Warfare		
Chaff Test		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.1.3.2 Electronic Systems Test

Electronic Warfare		
Electronic Systems Test		
Short Description	Test that evaluates the effectiveness of electronic systems to control, deny, or monitor critical portions of the electromagnetic spectrum. In general, electronic warfare testing will assess the performance of three types of electronic warfare systems: electronic attack, electronic protect, and electronic support.	
Long Description	<p>Electronic systems evaluations are performed to determine the effectiveness of designated electronic warfare systems to control, deny, or monitor critical portions of the electromagnetic spectrum. In general, electronic warfare testing will assess the performance of three types of electronic warfare systems; specifically, electronic attack, electronic protect, and electronic support.</p> <p>Aircraft electronic attack systems are designed to confuse the enemy or deny the enemy the use of its electronically-targeted weapons systems. The suppression of enemy air defenses and active jamming against hostile aircraft and surface combatant radars are examples of the application of electronic attack. Aircraft electronic protect systems are designed to intercept, identify, categorize, and defeat threat weapons systems that are already targeting that or other friendly aircraft. Aircraft electronic support systems employ passive tactics to intercept, exploit, locate (target), collect, collate, and decipher information from the radio-frequency spectrum for the purpose of determining the intentions of the radiating source. Test results are compared against design specifications to evaluate the performance of the actually electronic warfare system. The test results are also used to define performance characteristics and to improve and update existing analytical and predictive models.</p>	
Typical Components	<p>Platforms: Fixed Wing - Command and Control Aircraft, Fixed Wing – Strike Aircraft</p> <p>Targets: Air Targets – Drone</p> <p>Systems being Trained/Tested: Electronic Warfare Systems</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.1.3.3 Flare Test

Electronic Warfare		
Flare Test		
Short Description	Flare tests evaluate newly developed or enhanced flares, flare dispensing equipment, or modified aircraft systems against flare deployment. Tests may also train pilots and aircrew in the use of newly developed or modified flare deployment systems. Flare tests are often conducted with chaff tests and air combat maneuver activities, as well as other test activities, and are not typically conducted as standalone tests.	
Long Description	<p>Flare tests are conducted to evaluate new flares, newly developed or modified flare deployment systems, to ensure that other newly enhanced aircraft systems are compatible with flare deployment, and to train pilots and aircrew in the use of newly developed or modified flare deployment systems. Flare tests are often conducted with chaff tests and air combat maneuver activities, as well as other test activities, and are not typically conducted as stand-alone tests. During a flare test, flares (and in some cases chaff) are deployed, but no weapons are typically fired. Flare dispensers may also be jettisoned during a flare test intended to assess the safe release of the dispenser in the event of an emergency.</p> <p>Rotary-wing and tiltrotor aircraft deploy flares as a defensive tactic (electronic protect deployment) to disrupt the infrared missile guidance systems used by heat-seeking missiles, thereby causing the missile to lock onto the flare instead of onto the aircraft and enabling the aircraft to avoid the threat. In a typical scenario, an aircraft may detect the electronic targeting signals emitted from threat radars or missiles, or aircrew may visually identify a threat missile plume when a missile is launched. At a strategically appropriate time, the pilot dispenses flares and immediately maneuvers the aircraft to distract and defeat the threat. During a typical flare test, an aircraft will dispense flares 3,000 ft. above mean sea level and flares are completely consumed while in the air. Aircraft flares use a magnesium extruded flare grain.</p>	
Typical Components	<p>Platforms: Rotary-Wing Aircraft, Tiltrotor Aircraft</p> <p>Targets: None</p> <p>Systems being Trained/Tested: Flare Dispensing Systems</p> <p>Munitions: Flares</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.1.4 Mine Warfare

Mine warfare involves the detection, avoidance, and neutralization of mines to protect Navy ships and submarines and offensive mine laying in naval operations. A naval mine is a self-contained, explosive device placed in the water at predetermined depths to destroy ships or submarines. Naval mines are deposited and left in place until triggered by the approach of or contact with an enemy ship or until removed or otherwise destroyed. Naval mines can be laid by minelayers, other ships, submarines, and aircraft. Naval Air Systems Command mine warfare testing activities include airborne mine countermeasures activities, mine-laying activities (similar to mine exercises), and mine neutralization activities. The AN/ASQ-235 airborne mine neutralization system was developed to destroy mines or otherwise rendering them non-functional. The Airborne Laser Mine Detection System test, airborne dipping sonar minehunting test, and airborne sonobuoy minehunting test evaluate the capabilities of mine warfare systems to detect, classify, and fix the location of floating, near-surface moored, and bottom moored mines.

A.3.1.4.1 Airborne Dipping Sonar Minehunting Test

Mine Warfare		
Airborne Dipping Sonar Minehunting Test		
Short Description	A minehunting dipping sonar system that is deployed from a rotary-wing aircraft and uses high-frequency sonar for the detection and classification of bottom and moored mines.	
Long Description	Tests of a minehunting dipping sonar system to evaluate the search capabilities of this rotary-wing aircraft-deployed, minehunting, detection, and classification system. The sonar identifies mine-like objects.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: Mine Targets Systems being Trained/Tested: Sonar Systems - Mine Warfare Munitions: None	
Active Sonar	HFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Active acoustic sources	
Parameters for Analysis	The activity uses an established mine warfare training range and does not require the placement of moored mines.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.1.4.2 Airborne Laser Mine Detection System Test

Mine Warfare		
Airborne Laser Mine Detection System Test		
Short Description	An Airborne Laser Mine Detection System test that is operated from a rotary-wing aircraft and evaluates the system's ability to detect, classify, and fix the location of floating and near-surface, moored mines. The system uses a low-energy laser to locate mines.	
Long Description	<p>During an airborne mine detection system test, a rotary-wing aircraft evaluates the search capabilities of the AN/AES-1 Airborne Laser Mine Detection System. The Airborne Laser Mine Detection System is a minehunting system designed to detect, classify, and localize floating and near-surface, moored sea mines using a laser system. The Airborne Laser Mine Detection System will be integrated into the rotary-wing aircraft to provide a rapid wide-area reconnaissance and assessment of mine threats in littoral zones, confined straits, choke points, and amphibious objective areas for Carrier and Expeditionary Strike Groups.</p> <p>The Airborne Laser Mine Detection System uses pulsed laser light to image the entire near-surface volume potentially containing mines. Airborne Laser Mine Detection System is capable of day or night operations without stopping to deploy or recover equipment and without towing any equipment in the water. With untethered operations, it can attain high area search rates. Airborne Laser Mine Detection System also provides accurate target geo-location to support follow-on neutralization of the detected mines.</p>	
Typical Components	<p>Platforms: Rotary-Wing Aircraft</p> <p>Targets: Mine Targets</p> <p>Systems being Trained/Tested: Low-Energy Laser Systems</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	The activity uses an established mine warfare training range and does not require the placement of moored mines.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.1.4.3 Airborne Mine Neutralization System Test

Mine Warfare		
Airborne Mine Neutralization System Test		
Short Description	A test of the airborne mine neutralization system evaluates the system's ability to detect and destroy mines from an airborne mine countermeasures capable rotary-wing aircraft. The airborne mine neutralization system uses up to four unmanned underwater vehicles equipped with high-frequency sonar, video cameras, and explosive and non-explosive neutralizers.	
Long Description	<p>Mine neutralization tests evaluate aircraft and aircraft systems intended to neutralize or otherwise destroy mines through the use of explosives or other munitions. For most neutralization tests, mine shapes or non-explosive mines are used to evaluate new or enhanced mine neutralization systems. The airborne mine neutralization system uses up to four unmanned underwater vehicles equipped with high-frequency sonar and video cameras to relocate previously detected submerged mines. The unmanned underwater vehicles are also equipped with explosives to neutralize the mines after they are located. Data from unmanned underwater vehicles are relayed to the operator in the rotary-wing aircraft through a fiber-optic cable enabling the operator to position the neutralizing charge onto the most vulnerable area of the mine. The explosive charge is then detonated to neutralize the mine. For most tests, recoverable non-explosive neutralizers are used. A mine shape, rather than an explosive mine, serves as the target and a range support vessel recovers the non-explosive neutralizer and the mine shape following the test. Testing scenarios include a non-explosive neutralizer against an inert mine shape, or an explosive neutralizer against an explosive mine.</p>	
Typical Components	<p>Platforms: Rotary-Wing Aircraft, Submarine</p> <p>Targets: Mine Targets</p> <p>Systems being Trained/Tested: Mine Warfare Devices</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	E4	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Explosive mine countermeasure and neutralization (no divers)</p>	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.1.4.4 Airborne Sonobuoy Minehunting Test

Mine Warfare		
Airborne Sonobuoy Minehunting Test		
Short Description	A minehunting system made up of sonobuoys is deployed from a rotary-wing aircraft. A field of sonobuoys, using high-frequency sonar, is used for detection and classification of bottom and moored mines.	
Long Description	Tests of minehunting sonobuoys to evaluate the search capabilities of this rotary-wing aircraft-deployed, minehunting, detection, and classification system. The sonar identifies mine-like objects.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: Mine Targets Systems being Trained/Tested: Sonobuoys Munitions: None	
Active Sonar	MFM	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.1.4.5 Mine-Laying Test

Mine Warfare		
Mine-Laying Test		
Short Description	Fixed-wing aircraft evaluate the performance of mine-laying equipment and software systems to lay mines. A mine test may also train aircrew in laying mines using a new or enhanced mine deployment system.	
Long Description	During a mine-laying test, fixed-wing aircraft evaluate the performance of aircraft mine laying equipment or associated software systems to lay mines using non-explosive mine shapes. A mine test may also train aircrew in the technique of laying mines and in using a new or enhanced mine deployment system. Aircrew typically drop a series of about four non-explosive mine shapes, making multiple passes in the same flight pattern and dropping one or more shapes each time. The non-explosive mine shapes are expendable and are typically not recovered after the test.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft Targets: None Systems being Trained/Tested: Mine-Laying Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Aerial-deployed mines	
Parameters for Analysis	When a test event occurs and aircrew receives training, the event will be analyzed as a testing event.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.1.5 Surface Warfare

Surface warfare is a type of naval warfare in which aircraft, surface ships, and submarines employ weapons, sensors, and operations directed against enemy surface vessels. Naval Air Systems Command surface warfare tests include air-to-surface missile, gunnery, and bombing tests, rocket tests, laser targeting tests, and high-energy laser weapons tests.

A sinking exercise is a specialized fleet training event that provides an opportunity for Naval Air Systems Command aircrew along with ship and submarine crews to deliver explosive ordnance on a deactivated vessel that has been cleaned and environmentally remediated. The vessel is deliberately sunk using multiple weapons systems. A Naval Air Systems Command testing event may take place in conjunction with a sinking exercise to test aircraft or aircraft systems in the delivery of explosive ordnance on a surface target.

A.3.1.5.1 Air-to-Surface Bombing Test

Surface Warfare		
Air-to-Surface Bombing Test		
Short Description	Fixed-wing aircraft test the delivery of bombs against surface maritime targets with the goal of evaluating the bomb, the bomb carry and delivery system, and any associated systems that may have been newly developed or enhanced.	
Long Description	Fixed-wing aircraft test the delivery of bombs against surface maritime targets with the goal of evaluating the bomb, the bomb carry and delivery system, and any associated systems that may have been newly developed or enhanced. Non-explosive bombs will be released during this type of test and typically include non-explosive general-purpose bombs and guided bomb units of various sizes. Surface targets may also be used.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft, Unmanned Aerial Vehicle - Fixed Wing Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: Bomb-Releasing Systems Munitions: Bombs	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Aerial-deployed mines and non-explosive bombs Explosive bombs	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex

A.3.1.5.2 Air-to-Surface Gunnery Test

Surface Warfare		
Air-to-Surface Gunnery Test		
Short Description	Fixed-wing and rotary-wing aircrews evaluate new or enhanced aircraft guns against surface maritime targets to test that the gun, gun ammunition, or associated systems meet required specifications or to train aircrew in the operation of a new or enhanced weapons system.	
Long Description	Fixed-wing and rotary-wing aircrews evaluate new or enhanced aircraft guns against surface maritime targets to test that the gun, gun ammunition, or associated systems meet required specifications or to train aircrew in the operation of a new or enhanced weapons system. Non-explosive practice munitions are typically used during this type of test; however, a small number of high-explosive rounds may be used during final testing. Rounds that may be used include 7.62 millimeter (mm), 20 mm, 30 mm, 0.30-caliber, and 0.50-caliber gun ammunition.	
Typical Components	Platforms: Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Tiltrotor Aircraft Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: Gunnery Systems Munitions: Projectile – Medium-Caliber, Projectile – Small-Caliber	
Active Sonar	No	
In-Water Explosives	E1	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels Explosive gunnery Non-explosive gunnery	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.1.5.3 Air-to-Surface Missile Test

Surface Warfare		
Air-to-Surface Missile Test		
Short Description	Test may involve both fixed-wing and rotary-wing aircraft launching missiles at surface maritime targets to evaluate the weapons system or as part of another systems integration test.	
Long Description	An air-to-surface missile test may involve both fixed-wing and rotary-wing aircraft launching missiles at surface maritime targets to evaluate the weapons system or as part of another systems integration test. Air-to-surface missile tests can include high explosive, non-explosive, or non-firing (captive air training missile) weapons. Laser targeting systems may also be used. Both stationary and mobile targets would be utilized during testing.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft, Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Tiltrotor Aircraft Targets: Air Targets - Decoy, Air Targets - Drone, Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: Missile Firing/Launching Systems Munitions: Air-to-Surface Missiles	
Active Sonar	No	
In-Water Explosives	E6, E9	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Aerial-deployed mines and non-explosive bombs Manned surface vessels Explosive missiles and rockets Non-explosive missiles and rockets	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.1.5.4 Air-to-Surface High-Energy Laser Test

Surface Warfare		
Air-to-Surface High-Energy Laser Test		
Short Description	High-energy laser tests would evaluate the specifications, integration, and performance of an aircraft mounted, approximately 25-kilowatt high-energy laser. The laser is intended to be used as a weapon to disable small surface vessels.	
Long Description	During a high-energy laser test, aircrew would evaluate the specifications, integration, and performance of an aircraft mounted, approximately 25-kilowatt high-energy laser that is intended to be used as a weapon against stationary and mobile, unmanned surface targets. The high-energy laser would be employed from a rotary-wing aircraft and is designed to disable the surface vessel, rendering it immobile. The high-energy laser would have a range of up to six kilometers. Unmanned surface targets would be used during the high-energy laser test.	
Typical Components	Platforms: Rotary-Wing Aircraft Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: High-Energy Laser System Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	High-energy laser systems used in military readiness activities automatically shut down when target-lock is lost; meaning that if a high-energy laser beam aimed at a target on the surface, either from an aircraft or surface vessel, moves off the target, the system ceases projecting laser light, preventing any energy from striking the water or a nearby marine species.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex

A.3.1.5.5 Laser Targeting Test

Surface Warfare		
Laser Targeting Test		
Short Description	Aircrews illuminate enemy targets with lasers.	
Long Description	During a laser targeting test, aircrew use laser targeting devices integrated into aircraft or weapons systems to evaluate targeting accuracy and precision and to train aircrew in the use of newly developed or enhanced laser targeting devices designed to illuminate designated targets for engagement with laser-guided weapons. No explosive munitions are released during a laser targeting test.	
Typical Components	Platforms: Unmanned Aerial Vehicle - Fixed Wing Targets: Surface Targets - Floating Systems being Trained/Tested: Laser Targeting Systems Munitions: Bombs	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Aerial-deployed mines and non-explosive bombs	
Parameters for Analysis	Military expended material may be non-explosive bombs or other guided munitions.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex

A.3.1.5.6 Maritime Security Operations

Surface Warfare		
Maritime Security Operations		
Short Description	Fixed-wing aircraft participate in maritime security activities and fleet training events. Aircraft identify, track, and monitor foreign merchant vessels suspected of non-compliance with United Nations-allied sanctions or conflict rules of engagement.	
Long Description	Crews from Navy fixed-wing aircraft identify, track, and monitor foreign merchant vessels suspected of not complying with United Nations-allied sanctions or conflict rules of engagement. This training event is non-firing. Naval Air Systems Command fixed-wing may participate in maritime security activities and training activities.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft Targets: None Systems being Trained/Tested: Radar Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	None	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.1.5.7 Rocket Test

Surface Warfare		
Rocket Test		
Short Description	Rocket tests are conducted to evaluate the integration, accuracy, performance, and safe separation of guided and unguided rockets fired from a hovering or forward flying rotary-wing aircraft or tiltrotor aircraft.	
Long Description	Rocket tests are conducted to evaluate the integration, accuracy, performance, and safe separation of laser-guided and unguided rockets fired from a hovering or forward flying rotary-wing aircraft. Rocket tests would involve the release of primarily live motor/non-explosive warhead rockets. Some explosive warhead rockets would be tested, and during a jettison test, rockets with a non-explosive motor and non-explosive warhead would be jettisoned along with the rocket launcher. Rocket tests are also conducted to train aircrew on the use of new or enhanced weapons systems. Non-explosive warhead rocket types also include flechette rockets. Some rocket tests may be conducted in conjunction with upgrades to or integration of the Forward-Looking Infrared targeting system.	
Typical Components	Platforms: Rotary-Wing Aircraft, Tiltrotor Aircraft, Vehicle Launch Platform Targets: Surface Targets - Floating, Surface Targets - Maneuvering Systems being Trained/Tested: Rocket Firing/Launching Systems Munitions: Rockets	
Active Sonar	No	
In-Water Explosives	E3	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Explosive missiles and rockets Non-explosive missiles and rockets	
Parameters for Analysis	Assume 25 percent of non-explosive practice munitions are flechette rockets.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.1.6 Other Testing Activities

A.3.1.6.1 Acoustic and Oceanographic Research

Other Testing Activities		
Acoustic and Oceanographic Research		
Short Description	Active transmissions within the band 10 hertz (Hz)-100 kilohertz (kHz) from sources deployed from ships and aircraft.	
Long Description	Active acoustic transmissions within the band 10 Hz-100 kHz used for engineering tests of acoustic sources, validation of ocean acoustic models, characterization of acoustic interactions with the ocean bottom and ocean surface.	
Typical Components	Platforms: Fixed Wing – Patrol Aircraft, Small Boat Targets: Surface Targets - Maneuvering Systems being Trained/Tested: Low-Energy Lasers, De Minimis Sonar Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.3.1.6.2 Air Platform Shipboard Integration Test

Other Testing Activities		
Air Platform Shipboard Integration Test		
Short Description	Aircraft are tested to determine operability from shipboard platforms, performance of shipboard physical operations, and to verify and evaluate communications and tactical data links.	
Long Description	The air platform shipboard integration test is performed to evaluate the compatibility of an aircraft to operate from designated shipboard platforms, perform shipboard physical operations, and to verify and evaluate communications and tactical data links. This test function also includes an assessment of carrier-shipboard suitability, such as hazards of electromagnetic radiation to ordnance, hazard of electromagnetic radiation to personnel, and high-energy radio frequency.	
Typical Components	Platforms: Aircraft Carrier, Fixed Wing - Command and Control Aircraft, Fixed Wing – Strike Aircraft, Rotary-Wing Aircraft, Surface Combatant, Tiltrotor Aircraft, Unmanned Aerial Vehicle - Fixed Wing, Unmanned Aerial Vehicle - Rotary Wing Targets: None Systems being Trained/Tested: Communication Systems Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	-	Key West Range Complex

A.3.1.6.3 Undersea Range System Test

Other Testing Activities		
Undersea Range System Test		
Short Description	Following installation of a Navy underwater warfare training and testing range, tests of the nodes (components of the range) will be conducted to include node surveys and testing of node transmission functionality.	
Long Description	The bottom-mounted bi-directional nodes are surveyed post-installation utilizing a range pinger and tested to establish system parameters and baseline hearing ranges. Each acoustic projector is activated at full power while listening is occurring on adjacent hydrophones. The nodes may also be activated during periodic operational and maintenance checks and following significant weather events to confirm that nodes are located correctly and functioning properly prior to ongoing training or testing.	
Typical Components	Platforms: Fixed Range, Support Craft, Unmanned Underwater Vehicle Targets: None Systems being Trained/Tested: Acoustic Communications, Signal, Underwater Sound Devices Munitions: None	
Active Sonar	MFM, HFM	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	The duration of the node survey varies. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Jacksonville Range Complex	Jacksonville Range Complex

A.3.2 NAVAL SEA SYSTEMS COMMAND TESTING ACTIVITIES

A.3.2.1 Amphibious Warfare

A.3.2.1.1 Amphibious Vessel Testing

Amphibious Warfare		
Amphibious Vessel Testing		
Short Description	Amphibious vessels evaluate performance of amphibious vessels and landing gear.	
Long Description	Amphibious vessels evaluate performance of amphibious vessels and landing gear. Testing is required to ensure amphibious vessels can land troops, equipment, and vehicles on a beach as designed. Testing would not occur above the mean high tide line.	
Typical Components	Platforms: Amphibious vessels Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels	
Parameters for Analysis	Testing locations would include beach landings on barrier islands, beaches on inland waterways, as well as beaches of the Gulf Coast. Current preferred locations would be within 50 NM of Mobile, Alabama.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Gulf of Mexico Range Complex Inshore

A.3.2.2 Anti-Submarine Warfare

A.3.2.2.1 Anti-Submarine Warfare Mission Package Testing

Anti-Submarine Warfare		
Anti-Submarine Warfare Mission Package Testing		
Short Description	Ships and their supporting platforms (e.g., rotary-wing aircraft and unmanned aerial systems) detect, localize, and prosecute submarines.	
Long Description	Ships conduct detect-to-engage operations against modern diesel-electric and nuclear submarines using airborne and surface assets (both manned and unmanned). Active and passive acoustic systems are used to detect and track submarine targets, culminating in the deployment of lightweight torpedoes to engage the threat.	
Typical Components	Platforms: Contracted Aircraft, Fleet Support Vessels, Rotary-Wing Aircraft, Fixed Structure, Surface Combatant Targets: Air Targets - Drone, Sub-surface Targets - Maneuvering Systems being Trained/Tested: Acoustic Communications, Countermeasures, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Towed Munitions: Surface-to-Air Missiles, Torpedoes – Exercise, Sonobuoys	
Active Sonar	LFM, LFH, MFM, MFH, MF1, HFH, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Towed in-water devices	
Parameters for Analysis	All sonobuoys have parachutes unless otherwise noted. Sub-surface targets are submarines. This activity includes missiles exploding at high altitudes.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Naval Undersea Warfare Center Division, Newport	-
	-	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	-	Bath, ME
	Newport, RI	-

A.3.2.2.2 At-Sea Sonar Testing

Anti-Submarine Warfare		
At-Sea Sonar Testing		
Short Description	At-sea testing to ensure systems are fully functional in an open ocean environment.	
Long Description	At-sea sonar testing is required to calibrate or document the functionality of sonar and torpedo systems while the ship or submarine is in an open ocean environment. Conduct detect-to-engage operations utilizing stationary targets as well as deployed expendable bathythermograph, passive sonobuoys and expendable mobile ASW training targets. At-sea sonar testing is conducted to verify the ship meets design acoustic specifications, define the underwater characteristics of the ship, determine effects of systems and equipment on ship's acoustic characteristics, and provide technical background necessary to initiate development of design improvements to reduce noise. Tests also consist of electronic support measurement, photonics, and sonar sensor accuracy testing. In some instances, a submarine's passive detection capability is tested when a second submarine utilizes its active sonar or is equipped with a noise augmentation system in order to replicate acoustic or electromagnetic signatures of other vessel types or classes.	
Typical Components	Platforms: Fixed Range, Submarine, Support Craft, Surface Combatant Targets: Sub-surface Targets - Maneuvering, Surface Targets - Maneuvering Systems being Trained/Tested: Acoustic Communications, Countermeasures, Pinger, Safety and Navigation, Sonar Systems - Hull Mounted, Sonar Systems - Other, Sonar Systems - Towed, Underwater Range Systems Munitions: Sonobuoys, Torpedoes - Exercise	
Active Sonar	MFL, MFM, MFH, MF1, MF1K, HFL, HFM, HFH, Broadband (LF to HF), Broadband (LF to MF), Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Towed in-water devices	
Parameters for Analysis	Active sonar use is intermittent throughout the duration of the event.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Naval Undersea Warfare Center Division, Newport	-
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	SFOMF	SFOMF
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex

A.3.2.2.3 Pierside Sonar Testing

Anti-Submarine Warfare	
Pierside Sonar Testing	
Short Description	Pierside testing to ensure systems are fully functional in a controlled pierside environment prior to at-sea test activities and complete any required troubleshooting.
Long Description	Ships and submarines would activate mid- and high-frequency tactical sonars, underwater communications systems, and navigational devices to ensure they are fully functional prior to at-sea test activities. Conduct required troubleshooting of above active sonar equipment to correct any noted system issues. Testing may also include the firing of inert torpedo shapes. Event duration varies; with average durations of 3 weeks, with active sonar used intermittently over 2 days during the total event duration. This also includes pierside sonar testing during surface combatant sea trials.
Typical Components	Platforms: All Navy Ships and Boats, Fixed Structure, Submarine, Surface Combatant Targets: None Systems being Trained/Tested: Acoustic Communications, Countermeasures, Fathometer, Navigation Systems, Safety and Navigation, Sonar Systems - Hull Mounted, Sonar Systems - Other Munitions: None
Active Sonar	MFM, MFH, HFM, HFH, Broadband (MF to HF)
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels
Parameters for Analysis	Event duration is 3 weeks with active sonar used intermittently. The facility platform may be a dock or other structure. Some testing may occur in the Navigation Tracks within the Range Complexes.

Anti-Submarine Warfare		
Pierside Sonar Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	-	Virginia Capes Range Complex
	-	Jacksonville Range Complex
	Gulf of Mexico Range Complex Inshore	Gulf of Mexico Range Complex Inshore
	Bath, ME	Bath, ME
	NSB New London	NSB New London
	PNS	PNS
	Newport, RI	Newport, RI
	NS Norfolk	NS Norfolk
	NS Kings Bay	NS Kings Bay
	-	NS Mayport
	Port Canaveral, FL	Port Canaveral, FL
	Pascagoula, MS	Pascagoula, MS

A.3.2.2.4 Surface Ship Sonar Testing/Maintenance

Anti-Submarine Warfare		
Surface Ship Sonar Testing/Maintenance		
Short Description	Pierside and at-sea testing of ship systems occurs periodically following major maintenance periods and for routine maintenance.	
Long Description	Following major and routine maintenance periods, pierside and at-sea testing and maintenance is required. Multiple systems with active and passive acoustic sources such as tactical sonar, navigation systems, fathometers, underwater communications systems, underwater distress beacons, range finders, and other similar systems will be tested.	
Typical Components	Platforms: Surface Combatant Targets: None Systems being Trained/Tested: Acoustic Communications, Countermeasures, Sonar Systems - Hull Mounted, Sonar Systems - Other Munitions: None	
Active Sonar	LFL, MFM, MF1, MF1K, Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	Sonar will not be continuously active for the duration of the test.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Norfolk, VA	-
	Mayport, FL	-

A.3.2.2.5 Torpedo (Explosive) Testing

Anti-Submarine Warfare		
Torpedo (Explosive) Testing		
Short Description	Air, surface, or submarine crews employ explosive and non-explosive torpedoes against artificial targets.	
Long Description	Non-explosive and explosive torpedoes (carrying a warhead) will be launched at a suspended target by a submarine and fixed- or rotary-wing aircraft or surface combatants. Event duration is 1 to 2 days during daylight hours.	
Typical Components	<p>Platforms: Fixed Wing – Other Aircraft, Fixed Wing – Patrol Aircraft, Moored Platform, Rotary-Wing Aircraft, Submarine, Support Craft, Surface Combatant</p> <p>Targets: Mine Targets, Sub-surface Targets - Maneuvering, Sub-surface Targets - Stationary, Surface Targets - Floating</p> <p>Systems being Trained/Tested: Countermeasures, Pinger, Signal, Underwater sound Devices, Sonar Systems - Dipping, Sonar Systems - Hull Mounted</p> <p>Munitions: Sonobuoys, Torpedoes - Exercise, Torpedoes - HE</p>	
Active Sonar	MFM, MFH, MF1, HFH, Broadband (MF to HF)	
In-Water Explosives	E8, E11	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Explosive torpedoes</p>	
Parameters for Analysis	<p>All sonobuoys have parachutes unless otherwise noted.</p> <p>Only one heavyweight torpedo test could occur in a single day; two heavyweight torpedo tests could occur on consecutive days. Two lightweight torpedo tests could occur in a single day.</p> <p>All non-explosive torpedoes are recovered.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	Key West Range Complex	Key West Range Complex

A.3.2.2.6 Torpedo (Non-Explosive) Testing

Anti-Submarine Warfare		
Torpedo (Non-Explosive) Testing		
Short Description	Air, surface, or submarine crews employ non-explosive torpedoes against targets, submarines, or surface vessels.	
Long Description	Aerial, surface, and subsurface assets fire exercise torpedoes against surface or subsurface targets or at no target and programmed with a particular run geometry. Torpedo testing evaluates the performance and the effectiveness of hardware and software upgrades of heavyweight or lightweight torpedoes. It also includes testing of experimental torpedoes. Not all torpedo tests involve acoustics. Exercise torpedoes are recovered, typically from surface ships and helicopters that are specifically crewed and outfitted for torpedo recovery. Event duration is dependent on number of torpedoes fired.	
Typical Components	<p>Platforms: Contracted Aircraft, Fixed Wing - Command and Control Aircraft, Fixed Wing – Other Aircraft, Fixed Wing – Patrol Aircraft, Moored Platform, Rotary-Wing Aircraft, Submarine, Support Craft, Surface Combatant</p> <p>Targets: Mine Targets, Sub-surface Targets - Maneuvering, Sub-surface Targets - Stationary, Surface Targets - Floating, Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Acoustic Communications, Countermeasures, Pinger, Safety and Navigation, Signal, Underwater sound Devices, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Underwater Range Systems</p> <p>Munitions: Sonobuoys, Torpedoes - Exercise</p>	
Active Sonar	MFL, MFM, MFH, MF1, HFM, HFH, VHFH, Broadband (LF to HF), Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>All torpedoes are recovered.</p> <p>Events can last up to two weeks and use up to 40 torpedoes. Typically, no more than eight torpedoes are fired per day during daylight hours.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	NUWC Newport Testing Range	NUWC Newport Testing Range
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	SFOMF
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Key West Range Complex

A.3.2.3 Electronic Warfare

A.3.2.3.1 Radar and Other System Testing

Electronic Warfare	
Radar and Other Systems Testing	
Short Description	Test may include use of military or commercial radar, communication systems (or simulators), passive and active EW systems, electro-optical / infrared systems, or high and low-energy lasers. Testing may occur aboard a ship against drones, small boats, rockets, missiles, or other targets.
Long Description	At-sea and docked testing may use military or commercial radar, communication systems (or simulators), passive and active EW systems, electro-optical/infrared systems, or high and low-energy lasers. No subsurface transmission will occur during this testing. Testing of various air and surface targets may include stationary targets, unmanned aerial systems, missiles or small craft (floating cardboard tri-walls, towed, anchored, or self-propelled vessels) or large ships. High-energy laser testing may include tracking, scoring, and neutralization runs with single or multiple targets.
Typical Components	<p>Platforms: Aircraft Carrier, Amphibious Warfare Vessel, Contracted Aircraft, Fixed Wing – Adversary Aircraft, Fixed Wing – Command and Control Aircraft, Fixed Wing – Patrol Aircraft, Fixed Wing – Strike Aircraft, Fleet Support Vessel, Patrol Combatant, Fixed Range, Rotary-Wing Aircraft, Small Boat, Fixed Structure, Submarine, Support Craft, Surface Combatant, Tiltrotor Aircraft, Unmanned Aerial Vehicle – Fixed Wing, Unmanned Bottom Crawler</p> <p>Targets: Air Targets – Drone, Air Targets – Other, Mine Targets, Sub-surface Targets – Maneuvering, Sub-surface Targets – Stationary, Surface Targets – Floating, Surface Targets – Maneuvering</p> <p>Systems being Trained/Tested: Echounders, High-Energy Laser Systems, Sonar Systems – Other</p> <p>Munitions: Projectile – Large-Caliber</p>
Active Sonar	No
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels Non-explosive gunnery Non-explosive missiles and rockets Towed in-water devices Unmanned vehicles Weapon firing noise</p>
Parameters for Analysis	<p>All explosive missiles detonate in air during this test event.</p> <p>High-energy lasers will not be tested pierside.</p> <p>High-energy laser systems used in military readiness activities automatically shut down when target-lock is lost; meaning that if a high-energy laser beam aimed at a target on the surface, either from an aircraft or surface vessel, moves off the target, the system ceases projecting laser light, preventing any energy from striking the water or a nearby marine species.</p>

Electronic Warfare		
Radar and Other Systems Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	NUWC Newport Testing Range	NUWC Newport Testing Range
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	SFOMF	-
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range
	Key West Range Complex	-
	Virginia Capes Range Complex Inshore	Virginia Capes Range Complex Inshore
	Groton, CT	-
	JEB Little Creek	-
	NS Norfolk	NS Norfolk

A.3.2.4 Mine Warfare

A.3.2.4.1 Mine Countermeasure and Neutralization Testing

Mine Warfare		
Mine Countermeasure and Neutralization Testing		
Short Description	Air, surface, and subsurface vessels neutralize threat mines and mine-like objects.	
Long Description	<p>Mine countermeasure-neutralization and mine system testing is required to ensure systems can effectively neutralize threat (live or inert) mines that will otherwise restrict passage through an area and to ensure U.S. Navy mines remain effective against enemy ships. These systems may be deployed with a variety of ships, aircraft, submarines, or unmanned autonomous vehicles and operate in water depths up to 6,000 feet. Mines are neutralized by cutting mooring cables of buoyant mines, producing acoustic energy that fires acoustic-influence mines, employing radar or laser fields, producing electrical energy to replicate the magnetic signatures of surface ships in order to detonate threat mines, detonation of mines using remotely operated vehicles, and using explosive charges to destroy threat mines.</p>	
Typical Components	<p>Platforms: Moored Platform, Rotary-Wing Aircraft, Unmanned Underwater Vehicle</p> <p>Targets: Mine Targets</p> <p>Systems being Trained/Tested: Mine Warfare Devices</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	E4	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Aerial-deployed mines and non-explosive bombs</p> <p>Manned surface vessels</p> <p>Explosive mine countermeasure and neutralization (no divers)</p>	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.2.4.2 Mine Countermeasure Mission Package Testing

Mine Warfare		
Mine Countermeasures Mission Package Testing		
Short Description	Vessels and associated aircraft conduct mine countermeasure operations.	
Long Description	Ships conduct mine detection using unmanned submersible and aerial vehicles, magnetic and acoustic sensor systems deployed by vessel or support helicopters, and high-energy laser systems. Mines are then neutralized using magnetic, acoustic, and supercavitating systems.	
Typical Components	Platforms: Rotary-Wing Aircraft, Surface Combatant, Unmanned Aerial Vehicle - Rotary Wing, Unmanned Surface Vehicle, Unmanned Underwater Vehicle Targets: Mine Targets Systems being Trained/Tested: Electromagnetic Systems, Mine Warfare Devices, Sonar Systems - Mine Warfare, Sonar Systems - Other, Unmanned Vehicle Systems Munitions: None	
Active Sonar	MFH, HFM, HFH	
In-Water Explosives	E4	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Aerial-deployed mines and non-explosive bombs Explosive mine countermeasure and neutralization (no divers) Unmanned vehicles	
Parameters for Analysis	Eight charges per event The in-air low-energy laser stressor was used in analysis of potential impacts on human resources.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	SFOMF	SFOMF
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.4.3 Mine Detection and Classification Testing

Mine Warfare	
Mine Detection and Classification Testing	
Short Description	Air, surface, and subsurface vessels and systems detect and classify mines and mine-like objects. Vessels also assess their potential susceptibility to mines and mine-like objects.
Long Description	Mine detection and classification systems require testing to evaluate the capability of generating underwater magnetic and acoustic signature fields as well as sonar systems that can detect, and classify a wide range of threat mines at tactically different water depths. Surface craft may deploy an underwater sensor system that uses ship signature to develop a susceptibility profile against mine-like objects. In order to develop better and safer methods of minesweeping, the Navy is currently testing new systems to detect locate, identify, and avoid mines including a laser airborne mine detection system that uses laser illumination coupled with sensitive electro-optic receivers to find mines in the upper part of the water column. This type of equipment has traditionally been designed for operation from a manned helicopter; however, the Navy is developing the capability to operate from unmanned aerial systems.
Typical Components	<p>Platforms: Fleet Support, Moored Platform, Fixed Range, Rotary-Wing Aircraft, Small Boat, Submarine, Support Craft, Surface Combatant, Unmanned Aerial Vehicle - Fixed Wing, Unmanned Aerial Vehicle - Rotary Wing, Unmanned Surface Vehicle, Unmanned Underwater Vehicle</p> <p>Targets: Mine Targets, Sub-surface Targets - Stationary, Surface Targets - Floating</p> <p>Systems being Trained/Tested: Safety and Navigation, Sonar Systems - Hull Mounted, Sonar Systems - Mine Warfare, Sonar Systems - Other</p> <p>Munitions: Torpedoes - Exercise</p>
Active Sonar	HFH
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Aerial-deployed mines and non-explosive bombs</p> <p>Unmanned vehicles</p>
Parameters for Analysis	<p>Some mine shapes could be deployed for a specific event, and then retrieved afterwards. However, some mine shapes are left in place so that multiple events can use the same shapes without needing to redeploy.</p> <p>The in-air low-energy laser stressor was used in analysis of potential impacts on human resources.</p>

Mine Warfare		
Mine Detection and Classification Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	-
	Navy Cherry Point Range Complex	-
	Jacksonville Range Complex	Jacksonville Range Complex
	SFOMF	-
	Gulf of Mexico Range Complex	-
	NSWC Panama City Testing Range	NSWC Panama City Testing Range
	-	Port Canaveral, FL

A.3.2.5 Surface Warfare

A.3.2.5.1 Gun Testing – Large-Caliber

Surface Warfare		
Gun Testing - Large-Caliber		
Short Description	Surface crews test large-caliber guns to defend against surface targets. Demonstration of large-caliber guns including the Mk45 5-inch gun and Mk41 Vertical Launch Systems using surface-to-air missiles.	
Long Description	Surface combatants conduct surface warfare by detecting, tracking, and prosecuting small-boat threats. Gun testing may also include the surface warfare mission package, which provides a layered strike-defensive capability by use of its embarked support aircraft, medium-range surface-to-surface missiles, and 57-millimeter gun weapon system. Demonstration of the Mk45 5-inch gun against a simulated target utilizing inert Blind Loaded and Plugged (BL&P) rounds.	
Typical Components	Platforms: Surface Combatant Targets: Air Targets - Drone, Air Targets - Other, Surface Targets - Floating, Surface Targets - Maneuvering, Surface Targets - Towed Systems being Trained/Tested: None Munitions: Projectile – Large-Caliber, Projectile – Small-Caliber	
Active Sonar	No	
In-Water Explosives	E3, E5	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Explosive gunnery Non-explosive gunnery Towed in-water devices Weapon firing noise	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	-
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	-
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.5.2 Gun Testing – Medium-Caliber

Surface Warfare		
Gun Testing - Medium-Caliber		
Short Description	Surface crews test medium-caliber guns to defend against surface targets. Demonstration of medium-caliber Mk15 Close-In Weapon System (CIWS).	
Long Description	Surface combatants conduct surface warfare by detecting, tracking, and prosecuting small-boat threats. Gun testing may also include the surface warfare mission package on the Littoral Combat Ship, which provides a layered strike-defensive capability by use of its embarked support aircraft, medium range surface-to-surface missiles, and 30-mm gun weapon system. Demonstration of the Mk15 Close-In Weapon System (CIWS) against a simulated target.	
Typical Components	Platforms: Aircraft Carrier, Contracted Aircraft, Fixed Wing – Patrol Aircraft, Fleet Support Vessel, Rotary-Wing Aircraft, Support Craft, Surface Combatant Targets: Air Targets - Other, Surface Targets - Floating, Surface Targets - Maneuvering, Surface Targets - Towed Systems being Trained/Tested: None Munitions: Projectile – Large-Caliber, Projectile – Medium-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Explosive gunnery Non-explosive gunnery Towed in-water devices Weapon firing noise	
Parameters for Analysis	50 or 1,400 rounds are expended per event. Events with 1,400 rounds have 700 explosive and 700 non-explosive rounds per event. This activity includes explosives detonated in-air at low altitudes.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	-
	Jacksonville Range Complex	-
	Key West Range Complex	-
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.5.3 Gun Testing – Small-Caliber

Surface Warfare		
Gun Testing - Small-Caliber		
Short Description	Surface crews test small-caliber guns to defend against surface targets.	
Long Description	Small-caliber guns are fired from surface vessels. This testing also includes anti-terrorism/force protection. During this event, surface craft surface targets will make threat profile approaches to the ship. Ship will demonstrate small-caliber gun testing with non-explosive rounds against the threat target. Small-caliber gun testing includes other class ship sea trials and surface warfare mission package testing.	
Typical Components	Platforms: Fleet Support Vessel, Rotary-Wing Aircraft, Small Boat, Surface Combatant Targets: Surface Targets - Floating, Surface Targets - Maneuvering, Surface Targets - Towed Systems being Trained/Tested: None Munitions: Projectile - Small-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Non-explosive gunnery Towed in-water devices	
Parameters for Analysis	500-1,000 rounds are expended per event. Ships may not be conducting tests consistently for the duration of the event	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	Key West Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.5.4 Missile and Rocket Testing

Surface Warfare		
Missile and Rocket Testing		
Short Description	Missile and rocket testing includes various missiles or rockets fired from submarines and surface combatants. Testing of the launching system and ship defense is performed.	
Long Description	Missile and rocket testing includes various missiles or rockets (standard missiles, Water Piercing Missile Launch) fired from submarines and surface combatants. Testing may occur during surface combatant sea trials and surface warfare mission package testing. This activity includes both air warfare and surface warfare activities.	
Typical Components	<p>Platforms: Aircraft Carrier, Fixed Wing - Electronic Warfare Aircraft, Fixed Wing – Patrol Aircraft, Fleet Support Vessel, Rotary-Wing Aircraft, Submarine, Support Craft, Surface Combatant, Unmanned Aerial Vehicle - Fixed Wing</p> <p>Targets: Air Targets - Decoy, Air Targets - Drone, Air Targets - Other, Land Targets, Surface Targets - Floating, Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Air-to-Surface Missiles, Projectile – Large-Caliber, Projectile – Medium-Caliber, Projectile – Small-Caliber, Rockets, Subsurface-to-Surface Missiles, Surface-to-Air Missiles</p>	
Active Sonar	No	
In-Water Explosives	E6, E7, E8, E10	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Explosive missiles and rockets</p> <p>Non-explosive missiles and rockets</p>	
Parameters for Analysis	<p>Targets used during non-explosive tests will be recovered.</p> <p>Explosive missiles will detonate either in the air (at low and medium altitudes) or at the water's surface.</p> <p>Ships will not be conducting test constantly for the duration of the allotted time.</p> <p>This activity includes both air warfare and surface warfare activities, but it captured under the Surface Warfare Protective Measures Assessment Protocol for simplicity.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	-
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	-
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.2.6 Unmanned Systems

A.3.2.6.1 Underwater Search, Deployment, and Recovery

Unmanned Systems		
Underwater Search, Deployment, and Recovery		
Short Description	Various underwater, bottom-crawling, or robotic vehicles are utilized in underwater search, recovery, installation, and scanning activities.	
Long Description	Subsurface activities include a variety of underwater vehicles, robotic or autonomous systems, and items placed on the seafloor. This includes remotely operated vehicles used to lay underwater communication cables and find existing cables for removal or repair. Diving activities and special operations training also occur. Other subsurface activities involve manned and unmanned underwater vehicles. All subsurface vehicles are retrieved after use, while most objects (e.g., non-explosive mines) remain for a period of time to be used as testing fixtures.	
Typical Components	Platforms: Fleet Support Vessel, Support Craft, Unmanned Underwater Vehicle Targets: Mine Targets Systems being Trained/Tested: Acoustic Releases, Pinger, Safety and Navigation, Sonar Systems - Hull Mounted, Sonar Systems - Other Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Unmanned vehicles Crewed vessels	
Parameters for Analysis	Mines and other objects may be placed on the bottom where they may remain for a period of time. They will eventually be retrieved.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	SFOMF	SFOMF

A.3.2.6.2 Unmanned Aerial System Testing

Unmanned Systems		
Unmanned Aerial System Testing		
Short Description	Unmanned aerial systems are launched from a platform (e.g., fixed platform, surface ship, or submerged submarine) to test the capability to extend the surveillance and communications range of unmanned underwater vehicles, manned and unmanned surface vehicles, and submarines.	
Long Description	Unmanned aerial systems are reusable, uncrewed vehicles capable of controlled, sustained, level flight. Anticipated scenarios of unmanned aerial system testing include both unmanned aerial system launcher testing and using unmanned aerial systems to extend the surveillance and communications range of distributed sensors, unmanned underwater vehicles, manned and unmanned surface vehicles, and submarines. To test unmanned aerial system launcher systems, a subsurface capsule release may be conducted. During testing, a negatively buoyant capsule is deployed underwater and descends to a programmed depth. The capsule then drops a weight, inflates a flotation collar, rises to the surface, and launches an unmanned aerial system. Personnel use radio-frequency communications to control and communicate with the unmanned aerial system during its flight. In the event of an extended communications test, an aerostat (helium filled balloon) may be tethered to either a stationary buoy or an unmanned surface vehicle to test the extended range of communications.	
Typical Components	Platforms: Fixed Structure, Submarine, Unmanned Aerial Vehicle - Fixed Wing Targets: Land Targets, Surface Targets - Maneuvering Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NUWC Newport Testing Range	NUWC Newport Testing Range
	Northeast Range Complexes	-
	Virginia Capes Range Complex	-

A.3.2.6.3 Unmanned Surface Vehicle System Testing

Unmanned Systems	
Unmanned Surface Vehicle System Testing	
Short Description	Testing involves the production or upgrade of unmanned surface vehicles. This may include testing of mine detection capabilities, evaluating the basic functions of individual platforms, or complex activities with multiple vehicles.
Long Description	Unmanned surface vehicle testing includes assessment of single-vehicle and multi-vehicle technical performance and functionality during mission operations. Most unmanned vehicle mission operations include launch, transit, mission profile execution, and recovery operations. Unmanned surface vehicles are generally remote-controlled, semi-autonomous, modular, multi-mission platforms. Unmanned surface vehicles include rigid hull-inflatable boats, cooperative autonomous research platform (autonomous kayaks), wave gliders, and remote-controlled Jet Skis. Unmanned surface vehicles may be launched from surface vessels, piers, or land. Once launched, the vehicles may be towed or self-propelled to the test area. Unmanned surface vehicles may deploy, tow, operate, or recover payload systems such as tow bodies containing multi-function sensors. Systems on the unmanned surface vehicle may be acoustically active or produce radio-frequency transmissions or provide laser illumination for electro-optical detection.
Typical Components	<p>Platforms: Support Craft, Unmanned Surface Vehicle</p> <p>Targets: Electronic Warfare Targets, Sub-surface Targets - Stationary, Surface Targets - Floating</p> <p>Systems being Trained/Tested: Echosounders, Fathometer, Oceanographic - Other, Unmanned Vehicle Systems</p> <p>Munitions: None</p>
Active Sonar	No
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p> <p>Unmanned vehicles</p>
Parameters for Analysis	None

Unmanned Systems		
Unmanned Surface Vehicle System Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NUWC Newport Testing Range	NUWC Newport Testing Range
	-	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	-	Jacksonville Range Complex
	-	Key West Range Complex
	-	Gulf of Mexico Range Complex
	-	Other AFTT Areas
	-	Gulf of Mexico Range Complex Inshore
	-	NS Norfolk
	-	NS Mayport
	-	Pascagoula, MS

A.3.2.6.4 Unmanned Underwater Vehicle Testing

Unmanned Systems	
Unmanned Underwater Vehicle Testing	
Short Description	Testing involves the production or upgrade of unmanned underwater vehicles. This may include testing of mine detection capabilities, evaluating the basic functions of individual platforms, or complex activities with multiple vehicles.
Long Description	Unmanned underwater vehicle testing ranges from single-vehicle tests to evaluate hydrodynamic parameters, to full mission, multiple vehicle functionality assessments. Most unmanned underwater vehicle operations include a launch, transit, mission profile execution, and recovery operations. Unmanned underwater vehicles include modular, multi-mission platforms and their payloads, and anti-submarine warfare targets. Unmanned underwater vehicles may be launched from aircraft, surface craft, submarines, piers, or land. Once launched, the vehicles are either towed or self-propelled to the test area. Unmanned underwater vehicles may also deploy, tow, operate, or recover remote sensors and payload systems. Systems on or towed by the unmanned vehicle may be acoustically active, produce radio-frequency transmissions or provide laser illumination for electro-optical detection. Vehicle development involves the production and upgrade of new unmanned platforms on which to attach various payloads used for different purposes. Platforms can include unmanned underwater vehicles, unmanned surface vehicles, and unmanned aerial systems. Payload testing assesses various systems that can be incorporated onto unmanned platforms for mine warfare, bottom mapping, mast antenna testing, and other missions. This type of test can also include multiple vehicles interacting in formations or acting as individual units and includes tests and demonstrations of unmanned underwater vehicles in detecting and classifying mine-like or other buried objects.
Typical Components	<p>Platforms: Extra Large Unmanned Underwater Vehicle, Large Displacement Unmanned Underwater Vehicle, Moored Platform, Patrol Combatant, Small Boat, Submarine, Support Craft, Surface Combatant, Unmanned Aerial Vehicle - Fixed Wing, Unmanned Surface Vehicle, Unmanned Underwater Vehicle</p> <p>Targets: Mine Targets, Sub-surface Targets - Maneuvering, Sub-surface Targets - Stationary, Surface Targets - Floating</p> <p>Systems being Trained/Tested: Acoustic Communications, Pinger, Safety and Navigation, Sonar Systems - Other, Unmanned Vehicle Systems</p> <p>Munitions: Sonobuoys, Torpedoes - Exercise</p>
Active Sonar	LFL, MFL, MFM, MFH, HFM, HFH, VHFH, Broadband (LF to HF), Broadband (MF to HF)
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources Manned surface vessels Towed in-water devices Unmanned vehicles</p>
Parameters for Analysis	None

Unmanned Systems		
Unmanned Underwater Vehicle Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NUWC Newport Testing Range	NUWC Newport Testing Range
	-	Virginia Capes Range Complex
	Jacksonville Range Complex	-
	SFOMF	SFOMF
	-	Key West Range Complex
	Gulf of Mexico Range Complex	-
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.7 Vessel Evaluation

A.3.2.7.1 Air Defense Testing

Vessel Evaluation		
Air Defense Testing		
Short Description	Tests the ship's capability to detect, identify, track, and successfully engage live and simulated targets. Gun systems are tested using non-explosive and explosive rounds.	
Long Description	Air Defense activities are conducted in clear and varied electronic attack environments, using a mix of missile firings to verify the ship's capability to detect, identify, track, and successfully engage live and simulated targets. The tests include testing the radar's track load in the presence of debris, long-range engagement processing, low-elevation detection and tracking, track load in the presence of electronic attack and chaff, and missile performance. Tests currently include firing of the 5-inch 0.62-caliber gun, and will potentially include a 155-millimeter gun.	
Typical Components	<p>Platforms: Aircraft Carrier, Amphibious Warfare Vessel, Contracted Aircraft, Fixed Wing – Adversary Aircraft, Fixed Wing – Electronic Warfare Aircraft, Fixed Wing – Patrol Aircraft, Fixed Wing – Strike Aircraft, Fleet Support Vessel, Surface Combatant</p> <p>Targets: Air Targets – Decoy, Air Targets – Drone, Air Targets – Other, Surface Targets – Maneuvering</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: Projectile – Large-Caliber, Projectile – Medium-Caliber, Rockets, Surface-to-Air Missiles</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels Explosive gunnery Explosive missiles and rockets Non-explosive gunnery Non-explosive missiles and rockets Weapon firing noise</p>	
Parameters for Analysis	Ships will not be conducting tests constantly for the duration of the allotted time. This activity incorporates components of both surface warfare and air defense activities. This activity includes in-air explosives detonated at low and medium altitudes.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	-
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	-

A.3.2.7.2 In-Port Maintenance Testing

Vessel Evaluation		
In-Port Maintenance Testing		
Short Description	Each combat system is tested to ensure they are functioning in a technically acceptable manner and are operationally ready to support at-sea testing.	
Long Description	Each combat system is tested to ensure they are functioning in a technically acceptable manner and are operationally ready to support at-sea Combat System Ship Qualification Trial events. The ship's test plans and procedures, Maintenance Repair/Requirements Cards, and computerized planned maintenance system are used in establishing testing standards for each system and pieces of equipment. Ship's crew, under supervision of subject matter experts, complete all actions and receive remedial training where required. Trouble Observation Reports are written on noted discrepancies.	
Typical Components	Platforms: All Navy Ships and Boats, Surface Combatant Targets: None Systems being Trained/Tested: Sonar Systems - Hull Mounted Munitions: None	
Active Sonar	MF1	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NS Norfolk	NS Norfolk
	NS Mayport	NS Mayport

A.3.2.7.3 Propulsion Testing

Vessel Evaluation		
Propulsion Testing		
Short Description	Ship is run at high speeds in various formations (straight-line and reciprocal paths).	
Long Description	The propulsion plant demonstration is a comprehensive test of the ship's main propulsion system. Propulsion testing is one part of the total sea trial activity. During this activity, the ship is tested for maneuverability, including full power and endurance runs. Additional testing will be performed involving the propulsion shafts, steering gear and reduction gears and countermeasure wash-down system. A sonar self-noise survey occurs during the trial and involves only passive monitoring of noise made by the ship at low to high speeds.	
Typical Components	Platforms: Aircraft Carrier, Amphibious Warfare Vessel, Fleet Support Vessel, Patrol Combatant, Small Boat, Surface Combatant Targets: Surface Targets - Floating Systems being Trained/Tested: None Munitions: Projectile - Medium-Caliber, Projectile - Small-Caliber	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	Ships will not be conducting test constantly for the duration of the allotted time. Ships may not be traveling in a straight line. Ships will operate across the full spectrum of capable speeds. During surface combatant sea trials full-power runs are conducted for a total of 4 hours, and endurance runs are conducted for a total of 2 hours. Testing may occur near Pascagoula, Mississippi when in the Gulf of Mexico.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	Key West Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	NSWC Panama City Testing Range
	-	Gulf of Mexico Range Complex Inshore
	-	New Orleans, LA

A.3.2.7.4 Signature Analysis Operations

Vessel Evaluation		
Signature Analysis Operations		
Short Description	Surface ship and submarine testing of electromagnetic, acoustic, optical, and radar signature measurements.	
Long Description	Signature analysis activities include electromagnetic, acoustic, optical, and radar signature measurements, recording, and post-run analyses of data of Navy surface and subsurface vessels. These activities include electromagnetic signature measurement, calibration, and detection of submarines, acoustic and magnetic signature detection of unmanned underwater vehicles and surface ships, radar, and optical detection of surface ships. Testing includes intelligence, surveillance, reconnaissance missions.	
Typical Components	Platforms: Amphibious Warfare Vessel, Moored Platform, Fixed Range, Fixed Structure, Submarine, Support Craft, Unmanned Bottom Crawler, Unmanned Underwater Vehicle Targets: None Systems being Trained/Tested: Acoustic Communications, Acoustic Releases, Pinger, Safety and Navigation, Sonar Systems - Other Munitions: Sonobuoys	
Active Sonar	LFM, LFH, MFM, HFM, Broadband (LF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Jacksonville Range Complex	-
	SFOMF	SFOMF
	-	Hampton Roads, VA

A.3.2.7.5 Small Ship Shock Trial

Vessel Evaluation		
Small Ship Shock Trial		
Short Description	Underwater detonations are used to test new ships or major upgrades.	
Long Description	Each new class (or major upgrade) of surface ships constructed for the Navy may undergo an at-sea shock trial. A shock trial is a series of underwater detonations that sends a shock wave through the ship's hull to simulate near misses during combat. A series of up to three underwater detonations per event will be conducted at various distances from the ship (charges are set closer to the ship as the trial progresses).	
Typical Components	Platforms: Fixed Wing - Other, Rotary-Wing Aircraft, Support Craft, Surface Combatant Targets: None Systems being Trained/Tested: None Munitions: Explosives	
Active Sonar	No	
In-Water Explosives	E16	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Ship shock trials	
Parameters for Analysis	One event may occur during the 7-year period, which will involve up to three 10,000-lb. charges with at least six full days between detonations. Testing will occur in waters deeper than 650 feet. The Action Proponent may conduct ship shock trials only within a designated ship shock trial area within the Study Area. Stressors to human resources were not analyzed for this activity since it occurs greater than 12 NM from shore.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex

A.3.2.7.6 Submarine Sea Trials – Propulsion Testing

Vessel Evaluation		
Submarine Sea Trials - Propulsion Testing		
Short Description	Submarine is run at high speeds in various formations, and at various depths.	
Long Description	Propulsion testing is one part of the total submarine sea trial activity. During this activity, submarines undergo a controlled deep dive to test depth, emergency surfacing, full-power operations, high-speed turns, and extreme depth changes.	
Typical Components	Platforms: Submarine Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels	
Parameters for Analysis	Subs will not be conducting test constantly for the duration of the allotted time. Subs may not be traveling in a straight line. Subs will operate across the full spectrum of capable speeds. For biological resource analysis, vessel noise and vessel strike are only analyzed for the periods while the submarines are surfaced, typically brief in nature. Mitigation Involving Visual Observations for Marine Species related to vessel movement are only considered during the period of surfacing as well. For human resource stressor analysis, airborne acoustics, physical disturbance and strike and physical interactions are only analyzed for the periods while the submarine are surfaced, typically brief in nature.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	-

A.3.2.7.7 Submarine Sea Trials – Weapons System Testing

Vessel Evaluation		
Submarine Sea Trials - Weapons System Testing		
Short Description	Submarine weapons and sonar systems are tested at-sea to meet the integrated combat system certification requirements.	
Long Description	Submarine weapons and sonar systems are tested at-sea to meet the integrated combat system certification requirements. This test involves subjecting the integrated combat system through rigorous testing which consists of passive and active sonar activities, launching “water slugs” and exercise torpedoes.	
Typical Components	Platforms: Moored Platform, Submarine, Support Craft Targets: Sub-surface Targets - Maneuvering Systems being Trained/Tested: Acoustic Communications, Safety and Navigation, Sonar Systems - Hull Mounted, Sonar Systems - Other, Underwater Range Systems Munitions: Torpedoes - Exercise	
Active Sonar	MFL, MFH, HFM, HFH, Broadband (LF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	Submarines will not be conducting test constantly for the duration of the allotted time.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	SFOMF	-
	-	Northeast Range Complexes Inshore
	-	NSB Kings Bay
	-	Port Canaveral, FL

A.3.2.7.8 Surface Warfare Testing

Vessel Evaluation	
Surface Warfare Testing	
Short Description	Tests the capabilities of shipboard sensors to detect, track, and engage surface targets. Testing may include ships defending against surface targets using explosive and non-explosive rounds, gun system structural test firing and demonstration of the response to Call for Fire against land-based targets (simulated by sea-based locations).
Long Description	Surface warfare activities are gun weapons system tests conducted in a clear environment to demonstrate the capability of shipboard and remote (helicopter) sensors to detect and track surface or land-based (simulated by sea-based locations) targets and engage targets with simulated and live gun and missile firings. The event may qualify the ship's surface warfare gun capability to receive track data from the sensors, filter it, calculate ballistics, recommend aimpoint corrections (spots), generate gun orders, select ammunition properly for targets at differing ranges, and deliver surface direct fire on the surface or land-based targets. Testing can also include structural test firing.
Typical Components	<p>Platforms: Amphibious Warfare Vessel, Contracted Aircraft, Fixed Wing – Adversary Aircraft, Fixed Wing - Electronic Warfare Aircraft, Fixed Wing – Patrol Aircraft, Rotary-Wing Aircraft, Support Craft, Surface Combatant</p> <p>Targets: Air Targets - Drone, Air Targets - Other, Surface Targets - Floating, Surface Targets - Maneuvering, Surface Targets – Towed</p> <p>Systems being Trained/Tested: High-Energy Laser Systems</p> <p>Munitions: Projectile – Large-Caliber, Projectile – Medium-Caliber, Surface-to-Air Missiles, Torpedoes - Exercise</p>
Active Sonar	HFH
In-Water Explosives	E3, E5, E6, E7, E8
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <ul style="list-style-type: none"> Active acoustic sources Manned surface vessels Explosive gunnery Explosive missiles and rockets Non-explosive gunnery Non-explosive missiles and rockets Towed in-water devices Weapon firing noise
Parameters for Analysis	Ships will not be conducting tests constantly for the duration of the allotted time. High-energy laser systems used in military readiness activities automatically shut down when target-lock is lost; meaning that if a high-energy laser beam aimed at a target on the surface, either from an aircraft or surface vessel, moves off the target, the system ceases projecting laser light, preventing any energy from striking the water or a nearby marine species.

Vessel Evaluation		
Surface Warfare Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	-
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	-
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.2.7.9 Undersea Warfare Testing

Vessel Evaluation	
Undersea Warfare Testing	
Short Description	Ships demonstrate capability countermeasure systems, underwater surveillance, weapons engagement, and communications systems. This tests ships' ability to detect, track, and engage undersea targets. Testing also includes assessing equipment vulnerability and ordnance lethality.
Long Description	Undersea warfare activities may be composed of tracking and firing activities or tests of hull-mounted sonar system capabilities to detect and avoid torpedo type targets. Tracking and firing activities ensure the operability of the undersea warfare suite and its interface with the rotary-wing helicopter. Tests include demonstrating the ability of the ship to search, detect and track a target and conduct attacks with exercise torpedoes. Detection and avoidance activities may use surface craft and underwater platforms to test the capability of mid- and high-frequency acoustic sources. Subsurface moving targets, rocket and air-dropped weapons, sonobuoys, towed arrays, and sub-surface torpedo-like devices may be used. Approximately 1 week of in-port training may precede the event. Undersea warfare activities also include equipment testing to assess equipment vulnerability to ordnance, which will use explosive demolition charges.
Typical Components	<p>Platforms: Fleet Support, Moored Platform, Rotary-Wing Aircraft, Small Boat, Submarine, Support Craft, Surface Combatant</p> <p>Targets: Air Targets - Other, Sub-surface Targets - Maneuvering, Surface Targets - Floating, Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Acoustic Communications, Countermeasures, Safety and Navigation, Sonar Systems - Dipping, Sonar Systems - Hull Mounted, Sonar Systems - Mine Warfare</p> <p>Munitions: Air-to-Surface Missiles, Demolition Devices, Sonobuoys, Torpedoes – Exercise</p>
Active Sonar	MFM, MFH, MF1, HFM, HFH, Broadband (LF to HF)
In-Water Explosives	E4, E7
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Explosive missiles and rockets</p> <p>Explosive sonobuoys and other sub-surface explosives</p> <p>Manned surface vessels</p> <p>Non-explosive missiles and rockets</p> <p>Towed in-water devices</p>
Parameters for Analysis	<p>Five targets are utilized per event.</p> <p>All sonobuoys have a parachute unless otherwise noted.</p> <p>Ships will not be conducting test constantly during the duration of the allotted time.</p>

Vessel Evaluation		
Undersea Warfare Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	SFOMF	SFOMF
	-	Key West Range Complex
	Gulf of Mexico Range Complex	-

A.3.2.7.10 Vessel Signature Evaluation

Vessel Evaluation		
Vessel Signature Evaluation		
Short Description	Surface ship, submarine, and auxiliary system signature assessments. This may include electronic, radar, acoustic, infrared and magnetic signatures.	
Long Description	Radar cross signature testing of surface ships and submarines is accomplished on new ships and periodically throughout a ship's life cycle to measure how detectable the ship is to radar. For example, Assessment Identification of Mine Susceptibility assessments are passive electromagnetic and acoustic measurements performed on mine countermeasure ships and on the Littoral Combat Ship mine countermeasure modules (i.e., auxiliary systems) to determine their mine susceptibility using seafloor deployed magnetometers and hydrophones, and a ship-board global positioning sensor tracking system. Signature testing of all surface ships and submarines verifies that each vessel's signature is within specifications, and may include the use of helicopter-deployed instrumentation, ship-mounted safety and navigation systems, fathometers, tracking devices, radar systems, and underwater communications equipment. Also included in this activity is the Shipboard Electronic Systems Evaluation Facility which conducts measurements of antenna radiation patterns, Federal Aviation Administration identification of Friend or Foe systems, and Tactical Air Navigation Systems.	
Typical Components	<p>Platforms: Aircraft Carrier, All Navy Ships and Boats, Amphibious Warfare Vessel, Fixed Wing - Cargo and Transport Aircraft, Moored Platform, Patrol Combatant, Rotary-Wing Aircraft, Fixed Structure, Submarine, Surface Combatant</p> <p>Targets: Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Acoustic Communications, Safety and Navigation, Sonar Systems - Hull Mounted</p> <p>Munitions: None</p>	
Active Sonar	MFM, HFM, HFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p>	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	NUWC Newport Testing Range
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	SFOMF
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	JEB Little Creek	-
	-	Hampton Roads, VA

A.3.2.8 Other Testing

A.3.2.8.1 Acoustic and Oceanographic Research

Other Testing		
Acoustic and Oceanographic Research		
Short Description	Research using active transmissions from sources deployed from ships, aircraft, and unmanned underwater vehicles. Research sources can be used as proxies for current and future Navy systems	
Long Description	Active acoustic transmissions used for engineering tests of acoustic sources, validation of ocean acoustic models, tests of signal processing algorithms, and characterization of acoustic interactions with the ocean bottom, fish and ocean surface. Standard oceanographic research sensing (acoustic Doppler current profiler, fathometer-like systems) also to be employed. Occurs year round, daytime only.	
Typical Components	Platforms: Fleet Support, Fixed Structure, Submarine, Support Craft Targets: Sub-surface Targets - Stationary Systems being Trained/Tested: Acoustic Releases, Countermeasures, Echosounders, Sonar Systems - Other Munitions: None	
Active Sonar	LFM, Broadband (LF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Northeast Range Complexes
	-	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex
	-	Key West Range Complex
	-	Other AFTT Areas

A.3.2.8.2 Acoustic Component Testing

Other Testing Activities		
Acoustic Component Testing		
Short Description	Various surface vessels, moored equipment, and materials are tested to evaluate performance in the marine environment.	
Long Description	Various surface activities utilizing the marine environment for testing and evaluation. Sample projects include buoy deployments, vessel entanglement systems, materials testing, and renewable energy devices. Other surface operations involve manned and unmanned surface vehicles. Miscellaneous types of equipment are deployed, including temperature, humidity, magnetic, acoustic, optical, and air quality instrumentation to measure, record, and analyze system effectiveness, dependability, operational parameters, and durability. Surface operations utilize a variety of vessels for deployment of test equipment and for the monitoring of the air, surface, subsurface.	
Typical Components	Platforms: Unmanned Surface Vehicle, Unmanned Underwater Vehicle Targets: None Systems being Trained/Tested: Acoustic Communications, Acoustic Releases, High-Energy Laser Systems, Pinger, Safety and Navigation, Sonar Systems - Other, Unmanned Vehicle Systems Munitions: None	
Active Sonar	LFL, MFL, MFH, HFM, HFH, VHFH, Broadband (LF to HF), Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Unmanned vehicles	
Parameters for Analysis	High-energy laser systems used in military readiness activities automatically shut down when target-lock is lost; meaning that if a high-energy laser beam aimed at a target on the surface, either from an aircraft or surface vessel, moves off the target, the system ceases projecting laser light, preventing any energy from striking the water or a nearby marine species.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	SFOMF	SFOMF

A.3.2.8.3 Countermeasure Testing

Other Testing	
Countermeasure Testing	
Short Description	Countermeasure testing involves the testing of systems that will detect, localize, track, and engage incoming weapons, including marine vessel targets and airborne missiles. Testing includes surface ship torpedo defense systems, marine vessel stopping payloads, and airborne decoys against air targets.
Long Description	Countermeasure testing involves the testing of systems that will detect, localize, track, and engage incoming weapons, including marine vessel targets and airborne missiles. At-sea testing of the Surface Ship Torpedo Defense systems includes towed acoustic systems, torpedo warning systems, and countermeasure anti-torpedo subsystems. Some countermeasure scenarios would employ non-explosive torpedoes against targets released by secondary platforms (helicopter or submarine). While surface vessels are in transit, countermeasure systems may be used to identify false alert rates. Testing of the maritime vessel stopping payloads will deliver the appropriate measure(s) to affect a target vessel's propulsion and associated control surfaces to significantly slow and potentially stop the advance of the vessel. At-sea testing of airborne decoys includes surface decoys as well as airborne countermeasure flight vehicles and payloads.
Typical Components	<p>Platforms: Aircraft Carrier, All Navy Ships and Boats, Rotary-Wing Aircraft, Small Boat, Fixed Structure, Support Craft, Surface Combatant, Unmanned Aerial Vehicle - Rotary Wing, Unmanned Surface Vehicle</p> <p>Targets: Air Targets - Other, Sub-surface Targets - Maneuvering, Surface Targets - Floating, Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Countermeasures, Biodegradable Polymer</p> <p>Munitions: Rockets, Torpedoes - Exercise</p>
Active Sonar	MFH, MFH, HFH, VHFH, Broadband (LF to HF), Broadband (MF to HF)
In-Water Explosives	No
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Manned surface vessels</p> <p>Unmanned vehicles</p>
Parameters for Analysis	Not all activities will include the use of sonar and other transducers

Other Testing		
Countermeasure Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	NUWC Newport Testing Range	NUWC Newport Testing Range
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Navy Cherry Point Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	Key West Range Complex	Key West Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Virginia Capes Range Complex Inshore
	-	JEB Little Creek Fort Story

A.3.2.8.4 Intelligence, Surveillance, Reconnaissance

Other Testing Activities		
Intelligence, Surveillance, Reconnaissance		
Short Description	Maritime patrol aircraft (MPA) and unmanned aerial systems use all available sensors to collect data on threat vessels.	
Long Description	MPA and unmanned aerial systems operators use all available sensors to collect data on threat vessels. Passive sonobuoys are used to collect and analyze acoustic data, and photographic equipment is used to document the vessel with visual information.	
Typical Components	Platforms: Moored Platform, Small Boat, Support Craft, Unmanned Underwater Vehicle Targets: Mine Targets Systems being Trained/Tested: Acoustic Communications, Acoustic Releases, Safety and Navigation, Sonar Systems - Other Munitions: None	
Active Sonar	MFM, Broadband (LF), Broadband (LF to HF), Broadband (MF to HF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	-	Virginia Capes Range Complex
	-	Jacksonville Range Complex

A.3.2.8.5 Simulant Testing

Other Testing Activities		
Simulant Testing		
Short Description	The capability of surface ship and aircraft defense systems to detect and protect against chemical and biological attacks are tested.	
Long Description	<p>The capabilities of surface ship defense systems to detect and protect in the event of chemical and biological attacks are tested. Testing involves the deployment of harmless compounds (i.e., simulants) as substitutes for chemical and biological warfare agents. Because chemical and biological warfare agents remain a security threat, the Department of Defense uses relatively harmless compounds (simulants) as substitutes for chemical and biological warfare agents to test equipment intended to detect their presence. Chemical and biological agent detectors monitor for the presence of chemical and biological warfare agents and protect military personnel and civilians from the threat of exposure to these agents. The simulants trigger a response by sensors in the detection equipment without irritating or injuring personnel involved in testing detectors. Navy Chemical Agent Simulant 82 (commonly referred to as NCAS-82), glacial acetic acid, triethyl phosphate, sulfur hexafluoride, 1,1,1,2 tetrafluoroethane (a refrigerant commonly known as R134), and 1,1-difluoroethane (a refrigerant commonly known as R-152a) are also referred to as gaseous simulants and can be released in smaller quantities in conjunction with glacial acetic acid or triethyl phosphate releases. The types of biological simulants that may be used include spore-forming bacteria, non-spore-forming bacteria, ovalbumin, bacteriophage MS2, and <i>Aspergillus niger</i>. The simulants are generally dispersed by hand at the detector or by aircraft as a fine mist or aerosol.</p>	
Typical Components	<p>Platforms: Fixed Wing – Other Aircraft, Surface Combatant</p> <p>Targets: None</p> <p>Systems being Trained/Tested: None</p> <p>Munitions: None</p>	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Manned surface vessels</p>	
Parameters for Analysis	<p>Examples of chemical simulants include glacial acetic acid and triethyl phosphate. Examples of biological simulants are spore-forming bacteria, non-spore-forming bacteria, the protein ovalbumin, MS2 bacteriophages, and the fungus <i>Aspergillus niger</i>.</p>	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	-
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	-
	Jacksonville Range Complex	-

A.3.2.8.6 Insertion/Extraction

Other Testing Activities		
Insertion/Extraction		
Short Description	Testing of submersibles capable of inserting and extracting personnel and payloads into denied areas from strategic distances.	
Long Description	Testing of submersibles capable of inserting and extracting personnel and payloads into denied areas from strategic distances. Testing could include the use of forces deployed from submerged submarines while at sea.	
Typical Components	Platforms: Fleet Support Vessel, Submarine, Support Craft Targets: None Systems being Trained/Tested: Acoustic Communications Munitions: Sonobuoys	
Active Sonar	LFH, HFM, Broadband (LF to MF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels	
Parameters for Analysis	Test will not occur constantly throughout duration of allotted time. For biological resource analysis, vessel noise and vessel strike are only analyzed for the periods while the submarines are surfaced, typically brief in nature. Mitigation Involving Visual Observations for Marine Species related to vessel movement are only considered during the period of surfacing as well. For human resource stressor analysis, airborne acoustics, physical disturbance and strike and physical interactions are only analyzed for the periods while the submarine are surfaced, typically brief in nature.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Key West Range Complex	Key West Range Complex
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.8.7 Line Charge Testing

Other Testing Activities		
Line Charge Testing		
Short Description	Surface vessels deploy line charges to test the capability to safely clear an area for expeditionary forces.	
Long Description	Line charges are tested to verify the capability to safely clear surf zone areas for sea-based expeditionary operations. Testing is performed on various surf zone clearing systems that use either line charges or explosive arrays to neutralize mine threats. This is a systems development test and only assesses the in-water components of testing. Line charges consist of a 350-ft. detonation cord with explosives lined from one end to the other end in a series of 5-lb. increments.	
Typical Components	Platforms: Moored Platform, Support Craft Targets: None Systems being Trained/Tested: None Munitions: Demolition Devices	
Active Sonar	No	
In-Water Explosives	E4	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Explosive line charges Manned surface vessels	
Parameters for Analysis	Test will not occur constantly over the duration of the allotted time.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NSWC Panama City Testing Range	NSWC Panama City Testing Range

A.3.2.8.8 Non-Acoustic Component Testing

Other Testing Activities		
Non-Acoustic Component Testing		
Short Description	Testing of towed or floating buoys for communications through radio-frequencies or two-way optical communications between an aircraft and underwater system(s). Also, includes testing of non-acoustic and de minimis sources.	
Long Description	Testing associated with radio-frequency communications could occur from towed antennas from surface vessels, from single-transmit buoys released from submarines, or tethered buoys from submarines for two-way communication. Optical communications tests may include communication between helicopter or fixed wing aircraft and manned or unmanned underwater systems, and may also include ground truth sensors mounted on surface craft. Also, includes testing of non-acoustic and de minimis sources.	
Typical Components	Platforms: All Navy Ships and Boats, Amphibious Warfare Vessel, Fleet Support Vessel, Rotary-Wing Aircraft, Small Boat, Support Craft Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations) : Manned surface vessels Towed in-water devices	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex
	-	Hampton Roads, VA

A.3.2.8.9 Payload Deployer Testing

Other Testing Activities		
Payload Deployer Testing		
Short Description	Decoy launcher systems are tested to evaluate performance.	
Long Description	Testing is conducted to evaluate the performance of current or future launchers, which are used to deploy objects (e.g., torpedoes, decoys, countermeasures, sensors, unmanned underwater vehicles, unmanned surface vehicles, and unmanned aerial vehicles). These tests may be performed from a fixed location or a mobile platform. The objects deployed may be operational equipment or mock equipment that is instrumented to evaluate the performance of the launcher system. Various methods may be employed to launch test items. The test items are typically recovered after the test and are usually equipped with an acoustic locator to aid in their recovery. Demonstration of the Mk36 Decoy Launcher System using inert concrete slugs.	
Typical Components	Platforms: Fleet Support Vessel, Large Displacement Unmanned Underwater Vehicle, Fixed Structure, Support Craft, Surface Combatant, Unmanned Surface Vehicle Targets: None Systems being Trained/Tested: None Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Manned surface vessels Unmanned vehicles	
Parameters for Analysis	Instrumented operational equipment or mock equipment will be recovered. Ships will not be conducting test constantly for the duration of the allotted time. Any acoustic sources used during this activity would be de minimis and not quantitatively analyzed and, therefore, are not included under systems. When chaff is used, 36 concrete slugs per event are expended. Other components associated with chaff and flare use are not expected to float and would sink to the seafloor.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	NUWC Newport Test Range	NUWC Newport Test Range
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.2.8.10 Semi-Stationary Equipment Testing

Other Testing Activities	
Semi-Stationary Equipment Testing	
Short Description	Semi-stationary equipment (e.g., hydrophones) is deployed to determine functionality.
Long Description	Semi-stationary equipment testing is performed from a fixed site, suspended over the side of a boat, moored to the bottom, suspended in the water column, or on the surface. Examples of semi-stationary equipment include moored hydrophones (i.e., devices to listen to underwater sound), line arrays (i.e., multiple hydrophones) deployed on the ocean bottom, acoustic countermeasures, a moored oceanographic sensor that moves vertically through the water column, and sonobuoys (i.e., expendable sonar systems). Some units produce sound in the water (e.g., acoustic countermeasures), while others only listen (e.g., passive sonobuoys, vector sensors that measure particle motion). Some tests could require deployment in an area that provides opportunistic data collection (e.g., placing a hydrophone near a shipping lane to collect shipping noise data), or with specific geographic or oceanographic requirements.
Typical Components	<p>Platforms: Moored Platform, Fixed Structure, Support Craft</p> <p>Targets: Air Targets - Drone, Electronic Warfare Targets, Land Targets, Sub-surface Targets - Maneuvering, Sub-surface Targets - Stationary, Surface Targets - Floating, Surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Acoustic Communications, Air Gun, Countermeasures, Distributed Systems, Echosounders, Sonar Systems - Other</p> <p>Munitions: Demolition Devices</p>
Active Sonar	MFM, HFM, HFH, VHFM, VHFH, Broadband (LF), Broadband (LF to HF), Broadband (MF to HF)
In-Water Explosives	E4, AG230
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Explosive mine countermeasure and neutralization (no divers)</p> <p>Manned surface vessels</p>
Parameters for Analysis	None

Other Testing Activities		
Semi-Stationary Equipment Testing		
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NUWC Newport Testing Range	NUWC Newport Testing Range
	NSWC Panama City Testing Range	NSWC Panama City Testing Range
	-	Virginia Capes Range Complex Inshore
	Newport, RI	Newport, RI
	-	NSB New London
	-	NS Norfolk
	-	NS Mayport
	-	Port Canaveral, FL
	-	Key West Range Complex Inshore

A.3.2.8.11 Towed Equipment Testing

Other Testing Activities		
Towed Equipment Testing		
Short Description	Surface vessels or unmanned surface vehicles deploy and tow equipment to determine functionality of towed systems.	
Long Description	Testing is conducted on equipment to evaluate hydrodynamic characteristics and control of a tow body, test fully functional items, or test a particular aspect of a system utilizing a mock-up of a functional item. A typical test operation for towed equipment testing involves a deployment, use, and recover scenario that requires range or commercial craft support. This equipment may be deployed from and towed by range craft or unmanned surface vehicles. The towed item may be underwater or floating on the surface. Equipment may be acoustically active or produce radio-frequency transmissions.	
Typical Components	Platforms: Support Craft, Unmanned Surface Vehicle Targets: Mine Targets, Sub-surface Targets - Stationary Systems being Trained/Tested: Acoustic Communications, Sonar Systems - Other, Underwater Range Systems Munitions: None	
Active Sonar	MFM, Broadband (LF)	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Manned surface vessels Towed in-water devices Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	NUWC Newport Testing Range	NUWC Newport Testing Range

A.3.3 OFFICE OF NAVAL RESEARCH TESTING ACTIVITIES

A.3.3.1 Acoustic and Oceanographic Science and Technology

A.3.3.1.1 Acoustic and Oceanographic Research

Acoustic and Oceanographic Science and Technology		
Acoustic and Oceanographic Research		
Short Description	Research involving passive acoustic and oceanographic sensing, as well as active transmissions from sources deployed from ships, aircraft, and unmanned underwater vehicles. Research sources serve as proxies for current and future Navy systems.	
Long Description	Active acoustic transmissions used for engineering tests of acoustic sources, validation of ocean acoustic models, tests of signal processing algorithms, and characterization of acoustic interactions with the ocean bottom, fish and ocean surface. Standard oceanographic research sensing (acoustic Doppler current profiler, fathometer-like systems) are also employed.	
Typical Components	<p>Platforms: Moored Platform, Small Boat, Support Craft, Unmanned Aerial Vehicle, Unmanned Surface Vehicle, Unmanned Underwater Vehicle</p> <p>Targets: Sub-surface Targets – Stationary, Sub-surface Targets - Maneuvering</p> <p>Systems being Trained/Tested: Air Gun, Oceanographic - Other, Signal, Underwater sound Devices</p> <p>Munitions: None</p>	
Active Sonar	LFM, LFH, MFM, MFH, HFM, HFH	
In-Water Impulsives	E1, E3, 3S3, AG232	
Mitigation Involving Visual Observations for Marine Species	<p>Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations):</p> <p>Active acoustic sources</p> <p>Explosive sonobuoys and other sub-surface explosives</p> <p>Manned surface vessels</p> <p>Unmanned vehicles</p>	
Parameters for Analysis	Research activities may take place anywhere in the Study Area. Range complexes below represent a geographic sample of the coastal area for conservative estimates of effects. Air guns are not to be used within 3 NM of land. Explosives not to be used within 12 NM of land. Activity in Stellwagen Bank limited to de minimis acoustic sources only.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	-	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.3.1.2 Large Displacement Unmanned Underwater Vehicle Testing

Acoustic and Oceanographic Science and Technology		
Large Displacement Unmanned Undersea Vehicle Testing		
Short Description	Autonomy testing and environmental data collection with Large Displacement Unmanned Undersea Vehicles (Originally Innovative Navy Prototype).	
Long Description	Large Displacement Unmanned Undersea Vehicle (LDUUV) testing includes launch, autonomous transit (up to 60 days), environmental data collection (e.g., bathymetry, water column properties, ocean surface properties), and retrieval. LDUUV testing throughout the study area will include de minimis acoustic sources (modems, imaging sonars and fathometers) for safe navigation and data collection.	
Typical Components	Platforms: Large Displacement Unmanned Underwater Vehicle Targets: Sub-surface Targets - Stationary Systems being Trained/Tested: Acoustic Communications, Pinger, Sonar Systems - Other Munitions: None	
Active Sonar	No	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Unmanned vehicles	
Parameters for Analysis	This activity may take place anywhere within the Study Area. Range complexes below are a sample of areas this activity may occur. Any acoustic sources used during this activity would be de minimis and not quantitatively analyzed and therefore are not included under systems.	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Navy Cherry Point Range Complex	-
	Jacksonville Range Complex	Jacksonville Range Complex
	Gulf of Mexico Range Complex	Gulf of Mexico Range Complex

A.3.3.1.3 Mine Countermeasure Technology Research

Acoustic and Oceanographic Science and Technology		
Mine Countermeasure Technology Research		
Short Description	Test involves the use of broadband acoustic sources on unmanned underwater vehicles.	
Long Description	Mine countermeasure system testing on unmanned underwater vehicles to take place offshore and in coastal waters. Broadband acoustic sources on unmanned underwater vehicles will use downward directed acoustic transmissions to characterize the ocean bottom. Inert objects will be placed on the bottom to test system performance.	
Typical Components	Platforms: Unmanned Underwater Vehicle Targets: Sub-surface Targets - Maneuvering, Surface Targets - Maneuvering Systems being Trained/Tested: Acoustic Communications, Acoustic Releases, Safety and Navigation, Sonar Systems - Other Munitions: None	
Active Sonar	MFH	
In-Water Explosives	No	
Mitigation Involving Visual Observations for Marine Species	Mitigation is required for the following stressors as described in Section 5.6 (Visual Observations): Active acoustic sources Unmanned vehicles	
Parameters for Analysis	None	
Location	Phase III Requirement 2018-2025	Phase IV Requirement 2025-2032
	Northeast Range Complexes	Northeast Range Complexes
	Virginia Capes Range Complex	Virginia Capes Range Complex
	Jacksonville Range Complex	Jacksonville Range Complex
	-	Gulf of Mexico Range Complex

References

- U.S. Department of Defense. (2020). *Electromagnetic Environmental Effects Requirements for Systems (MIL-STD-464D)*. Washington, DC: U.S. Department of Defense.
- U.S. Department of Defense. (2021). *Protecting Personnel from Electromagnetic Fields*. Washington, DC: Under Secretary of Defense for Acquisition, Technology, and Logistics.
- U.S. Department of the Navy. (2011). *U.S. Navy Dive Manual*. Washington, DC: Commander, Naval Sea Systems Command.

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APPENDIX B ACTIVITY STRESSOR MATRICES

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Draft

**Supplemental Environmental Impact Statement/
Overseas Environmental Impact Statement
Atlantic Fleet Training and Testing**

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B ACTIVITY STRESSORS

Table B-1: Stressors by Training Activity

Atlantic Fleet Training Activity	Biological Resources																Physical Resources						Human Resources											
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors				Entanglement Stressors		Ingestion Stressors		Air Quality Stressors		Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors			
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Major Training Exercise - Large Integrated Anti-Submarine Warfare																																		
Composite Training Unit Exercise	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Major Training Exercise - Medium Integrated Anti-Submarine Warfare																																		
Sustainment/Task Force Exercise	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Small Integrated Anti-Submarine Warfare Training																																		
Navy Undersea Warfare Training Assessment Course	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Surface Warfare Advanced Tactical Training	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Medium Coordinated Anti-Submarine Warfare Training																																		
Anti-Submarine Warfare Tactical Development Exercise	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Small Coordinated Anti-Submarine Warfare Training																																		
Amphibious Ready Group Marine Expeditionary Unit Composite Training Unit Exercise	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Group Sail	✓		✓	✓						✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓								
Air Warfare																																		
Air Combat Maneuvers				✓						✓			✓		✓						✓							✓	✓		✓		✓	✓
Air Defense Exercise			✓	✓						✓		✓	✓								✓													
Gunnery Exercise Air-to-Air Medium-Caliber				✓	✓					✓			✓	✓					✓		✓		✓		✓									

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources						Human Resources									
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors		Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors		
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Gunnery Exercise Air-to-Air – Small-Caliber				✓	✓					✓			✓	✓						✓		✓												
Gunnery Exercise Surface-to-Air Large-Caliber			✓		✓					✓		✓		✓						✓		✓			✓									
Gunnery Exercise Surface-to-Air Large-Caliber (USCG)			✓		✓		✓			✓		✓		✓						✓		✓	✓		✓	✓								
Gunnery Exercise Surface-to-Air Medium-Caliber			✓		✓					✓		✓		✓						✓			✓		✓									
Gunnery Exercise Surface-to-Air Medium-Caliber (USCG)			✓		✓					✓		✓		✓						✓			✓		✓									
Missile Exercise – Man-Portable Air Defense System				✓	✓			✓					✓	✓	✓					✓		✓	✓	✓	✓			✓	✓	✓	✓		✓	✓
Missile Exercise Air-to-Air				✓	✓			✓		✓			✓	✓				✓		✓		✓	✓	✓	✓									
Missile Exercise Surface-to-Air			✓		✓			✓		✓		✓		✓				✓		✓		✓	✓	✓	✓									
Amphibious Warfare																																		
Amphibious Assault			✓	✓						✓		✓	✓		✓						✓						✓	✓	✓	✓	✓	✓	✓	✓
Amphibious Operations in a Contested Environment			✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Amphibious Raid			✓	✓						✓		✓	✓		✓						✓						✓	✓	✓	✓	✓	✓	✓	✓
Amphibious Ready Group Marine Expeditionary Unit Exercise			✓	✓						✓		✓	✓		✓						✓							✓	✓	✓	✓	✓	✓	✓
Amphibious Squadron Marine Expeditionary Unit Integration Training			✓	✓						✓		✓	✓								✓													

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources						Human Resources									
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors		Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors		
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Amphibious Vehicle Maneuvers			✓									✓			✓						✓						✓	✓	✓	✓	✓	✓	✓	
Naval Surface Fire Support Exercise - At Sea			✓		✓				✓			✓		✓						✓	✓		✓	✓	✓									
Naval Surface Fire Support Exercise - Land-Based Target			✓		✓		✓		✓			✓		✓					✓		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	
Non-Combat Evacuation Operation			✓	✓					✓			✓	✓		✓						✓						✓	✓	✓	✓	✓	✓	✓	
Anti-Submarine Warfare																																		
Anti-Submarine Warfare Torpedo Exercise - Helicopter	✓			✓						✓		✓	✓	✓			✓	✓		✓	✓		✓	✓	✓									
Anti-Submarine Warfare Torpedo Exercise - Maritime Patrol Aircraft	✓			✓						✓		✓	✓	✓			✓	✓		✓	✓		✓	✓	✓									
Anti-Submarine Warfare Torpedo Exercise - Ship	✓		✓							✓		✓		✓			✓			✓	✓		✓	✓	✓									
Anti-Submarine Warfare Torpedo Exercise - Submarine	✓											✓		✓			✓				✓		✓	✓	✓									
Anti-Submarine Warfare Tracking Exercise - Helicopter	✓			✓						✓		✓	✓	✓			✓	✓		✓	✓		✓	✓	✓									
Anti-Submarine Warfare Tracking Exercise - Maritime Patrol Aircraft	✓			✓						✓		✓	✓	✓			✓	✓		✓	✓		✓	✓	✓									
Anti-submarine Warfare Tracking Exercise - Ship	✓		✓							✓		✓		✓			✓				✓		✓	✓	✓									
Anti-Submarine Warfare Tracking Exercise - Submarine	✓											✓		✓	✓		✓			✓	✓		✓	✓	✓									

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources						Human Resources									
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors		Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors		
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Electronic Warfare																																		
Counter Targeting Chaff Exercise - Aircraft				✓						✓			✓	✓						✓	✓		✓	✓	✓									
Counter Targeting Chaff Exercise - Ship			✓							✓		✓		✓						✓	✓		✓	✓	✓									
Counter Targeting Chaff Exercise - Ship (USCG)			✓							✓		✓		✓						✓	✓		✓	✓	✓									
Counter Targeting Flare Exercise				✓						✓			✓	✓						✓	✓		✓	✓	✓									
Electronic Warfare Operations				✓						✓			✓							✓														
High-Speed Anti-Radiation Missile Exercise				✓	✓		✓			✓			✓	✓					✓		✓	✓	✓	✓	✓									
Expeditionary Warfare																																		
Dive and Salvage Operations			✓									✓			✓						✓						✓	✓	✓	✓	✓	✓	✓	
Personnel Insertion/Extraction - Air			✓	✓	✓					✓		✓	✓	✓						✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
Personnel Insertion/Extraction - Surface and Subsurface			✓									✓								✓							✓	✓	✓	✓	✓	✓	✓	
Personnel Insertion/Extraction - Swimmer/Diver			✓				✓					✓		✓						✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Port Damage Repair		✓	✓									✓			✓					✓							✓	✓	✓	✓	✓	✓	✓	
Underwater Construction Team Training			✓									✓			✓					✓							✓	✓	✓	✓	✓	✓	✓	

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources						Human Resources									
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors				Cultural Resource Stressors	Socioeconomic Resource Stressors			Public Health and Safety Stressors				
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Mine Warfare																																		
Airborne Mine Countermeasures - Mine Detection	✓			✓					✓	✓			✓	✓	✓		✓				✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Airborne Mine Countermeasures - Towed Mine Neutralization				✓					✓	✓			✓								✓						✓	✓	✓	✓	✓	✓	✓	✓
Airborne Mine Laying				✓						✓			✓	✓							✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Civilian Port Defense - Homeland Security Anti-Terrorism/Force Protection Exercise	✓		✓	✓					✓	✓		✓	✓		✓						✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Coordinated Unit Level Helicopter Airborne Mine Countermeasures Exercise				✓						✓			✓								✓						✓	✓	✓	✓		✓	✓	✓
Installation and Maintenance of Mine Training Areas			✓							✓		✓		✓	✓		✓				✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Mine Countermeasures - Mine Neutralization - Remotely Operated Vehicles	✓		✓	✓			✓			✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mine Countermeasures - Ship Sonar	✓		✓						✓	✓		✓									✓						✓	✓	✓	✓	✓	✓	✓	✓
Mine Neutralization Explosive Ordnance Disposal			✓				✓					✓		✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Submarine Mine Laying	✓		✓									✓		✓							✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Surface Ship Object Detection	✓		✓							✓		✓									✓						✓	✓	✓	✓	✓	✓	✓	✓
Underwater Mine Countermeasure Raise, Tow, Beach, and Exploitation Operations			✓									✓		✓	✓		✓				✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources						Human Resources												
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors		Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors					
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions				
Surface Warfare																																					
Bombing Exercise Air-to-Surface			✓	✓			✓			✓		✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓											
Gunnery Exercise Air-to-Surface Medium-Caliber				✓	✓		✓			✓			✓	✓					✓	✓	✓	✓	✓	✓	✓	✓											
Gunnery Exercise Air-to-Surface Medium-Caliber (USCG)				✓	✓		✓			✓			✓	✓					✓	✓	✓	✓	✓	✓	✓	✓											
Gunnery Exercise Air-to-Surface Small-Caliber				✓	✓					✓			✓	✓					✓	✓	✓		✓	✓	✓	✓											
Gunnery Exercise Surface-to-Surface Boat Medium-Caliber			✓		✓		✓					✓		✓					✓	✓	✓	✓	✓	✓	✓												
Gunnery Exercise Surface-to-Surface Boat Medium-Caliber (USCG)			✓		✓		✓					✓		✓					✓	✓	✓	✓	✓	✓	✓	✓											
Gunnery Exercise Surface-to-Surface Boat Small-Caliber			✓		✓							✓		✓					✓	✓	✓		✓	✓	✓												
Gunnery Exercise Surface-to-Surface Boat Small-Caliber (USCG)			✓		✓							✓		✓					✓	✓	✓		✓	✓	✓												
Gunnery Exercise Surface-to-Surface Ship - Large-Caliber			✓		✓		✓			✓		✓		✓					✓		✓	✓	✓		✓	✓											
Gunnery Exercise Surface-to-Surface Ship Large-Caliber (USCG)			✓		✓		✓			✓		✓		✓					✓		✓	✓			✓	✓											
Gunnery Exercise Surface-to-Surface Ship Medium-Caliber			✓		✓		✓			✓		✓		✓					✓	✓	✓	✓	✓		✓	✓											
Gunnery Exercise Surface-to-Surface Ship Medium-Caliber (USCG)			✓		✓		✓			✓		✓		✓					✓	✓	✓		✓		✓	✓											
Gunnery Exercise Surface-to-Surface Ship Small-Caliber			✓		✓					✓		✓		✓					✓	✓	✓		✓		✓												
Gunnery Exercise Surface-to-Surface Ship Small-Caliber (USCG)			✓		✓					✓		✓		✓					✓	✓	✓		✓		✓												

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources						Human Resources										
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors		Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors			
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions		
Integrated Live Fire Exercise			✓	✓			✓			✓		✓	✓	✓					✓		✓	✓	✓	✓	✓	✓									
Laser Targeting - Aircraft				✓						✓			✓								✓						✓								
Laser Targeting - Ship			✓	✓						✓	✓	✓	✓								✓														
Laser Targeting - Ship (USCG)			✓							✓	✓	✓									✓														
Long Range Unmanned Surface Vessel Training			✓									✓		✓					✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓		✓	
Maritime Security Operations			✓	✓						✓		✓	✓								✓						✓	✓	✓	✓	✓	✓	✓	✓	
Maritime Security Operations (USCG)			✓	✓	✓					✓		✓	✓	✓					✓		✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Missile Exercise Air-to-Surface				✓	✓		✓			✓			✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓								
Missile Exercise Air-to-Surface - Rocket				✓			✓			✓			✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓								
Missile Exercise Surface-to-Surface			✓		✓		✓			✓		✓		✓					✓	✓	✓	✓	✓	✓	✓	✓	✓								
Sinking Exercise	✓		✓	✓	✓		✓			✓		✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓								
Small Boat Attack			✓		✓					✓		✓		✓					✓		✓		✓				✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Training Activities																																			
Precision Anchoring			✓							✓		✓			✓						✓		✓				✓	✓	✓	✓	✓	✓	✓	✓	
Precision Anchoring (USCG)			✓							✓		✓			✓						✓		✓				✓	✓	✓	✓	✓	✓	✓	✓	
Search and Rescue			✓	✓	✓					✓		✓	✓	✓						✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Search and Rescue (USCG)			✓	✓	✓					✓		✓	✓	✓						✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Submarine Navigation	✓											✓									✓						✓	✓	✓	✓	✓	✓	✓	✓	
Submarine Sonar Maintenance and Systems Checks	✓											✓									✓						✓	✓	✓	✓	✓	✓	✓	✓	
Submarine Under Ice Certification	✓											✓		✓			✓				✓		✓	✓	✓										
Surface Ship Sonar Maintenance and Systems Checks	✓		✓							✓		✓									✓						✓	✓	✓	✓	✓	✓	✓	✓	

Table B-1: Stressors by Training Activity (continued)

Atlantic Fleet Training Activity	Biological Resources																		Physical Resources					Human Resources									
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors					Entanglement Stressors		Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health & Safety Stressors		
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strike	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions
Unmanned Aerial System Training and Certification				✓					✓		✓	✓	✓							✓		✓	✓	✓									
Unmanned Aerial System Training and Certification (USCG)				✓					✓			✓								✓													
Unmanned Underwater Vehicle Training - Certification and Development	✓		✓						✓		✓		✓	✓			✓			✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Unmanned Underwater Vehicle Training - Certification and Development (USCG)	✓		✓								✓		✓	✓			✓			✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Waterborne Training			✓								✓									✓						✓	✓	✓	✓	✓	✓	✓	✓
Waterborne Training (USCG)			✓								✓									✓						✓	✓	✓	✓	✓	✓	✓	✓

Note: USCG = U.S. Coast Guard

Table B-2: Stressors by Testing Activity

Atlantic Fleet Testing Activity	Biological Resources																		Physical Resources					Human Resources													
	Acoustic Stressors						Explosive Stressors		Energy Stressors		Physical Disturbance and Strike Stressors				Entanglement Stressors			Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors			Cultural Resource Stressors	Socioeconomic Resource Stressors			Public Health and Safety Stressors									
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Biodegradable Polymers	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strikes	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions			
Acoustic and Oceanographic Science and Technology																																					
Acoustic and Oceanographic Research	✓		✓		✓	✓	✓			✓		✓		✓	✓					✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Large Displacement Unmanned Undersea Vehicle Testing			✓											✓								✓					✓	✓		✓	✓		✓		✓		
Mine Countermeasure Technology Research	✓		✓									✓										✓					✓	✓	✓	✓	✓	✓	✓	✓	✓		
Air Warfare																																					
Air Combat Maneuvers Test				✓						✓			✓	✓						✓		✓		✓	✓	✓											
Air Platform Vehicle Test				✓						✓			✓	✓						✓		✓		✓	✓	✓											
Air Platform Weapons Integration Test				✓	✓					✓		✓	✓	✓				✓				✓		✓	✓	✓											
Air-to-Air Gunnery Test – Medium-Caliber				✓	✓					✓			✓	✓						✓		✓		✓	✓	✓											
Air-to-Air Missile Test				✓	✓			✓		✓			✓	✓				✓		✓		✓	✓	✓	✓	✓											
Air-to-Air Weapons System Test				✓	✓					✓			✓	✓								✓		✓	✓	✓											
Intelligence, Surveillance, and Reconnaissance Test				✓						✓			✓									✓						✓	✓	✓	✓			✓	✓		
Amphibious Warfare																																					
Amphibious Vessel Testing			✓							✓		✓										✓						✓	✓	✓	✓	✓	✓	✓	✓		
Anti-Submarine Warfare																																					
Anti-Submarine Warfare Mission Package Testing	✓		✓	✓	✓			✓		✓		✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		
Anti-Submarine Warfare Torpedo Test	✓			✓						✓		✓	✓	✓			✓		✓		✓	✓		✓	✓	✓											
Anti-Submarine Warfare Tracking Test - Fixed-Wing	✓			✓			✓			✓		✓	✓	✓			✓		✓		✓	✓		✓	✓	✓											

Table B-2: Stressors by Testing Activity (continued)

Atlantic Fleet Testing Activity	Biological Resources																			Physical Resources					Human Resources											
	Acoustic Stressors						Explosive Stressors		Energy Stressors		Physical Disturbance and Strike Stressors				Entanglement Stressors			Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors				Cultural Resource Stressors	Socioeconomic Resource Stressors			Public Health and Safety Stressors							
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Biodegradable Polymers	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strikes	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions		
Anti-Submarine Warfare Tracking Test - Rotary Wing	✓			✓					✓		✓	✓	✓				✓		✓		✓	✓	✓	✓												
At-Sea Sonar Testing	✓		✓	✓					✓	✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓												
Kilo Dip Test	✓			✓						✓			✓									✓														
Pierside Sonar Testing	✓		✓							✓		✓			✓							✓				✓		✓	✓	✓	✓	✓	✓	✓	✓	
Sonobuoy Lot Acceptance Test	✓		✓	✓			✓			✓		✓	✓	✓			✓		✓		✓	✓	✓		✓	✓		✓								
Surface Ship Sonar Testing/Maintenance	✓		✓							✓		✓										✓						✓	✓	✓	✓	✓	✓	✓	✓	
Torpedo (Explosive) Testing	✓		✓	✓			✓			✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	✓									
Torpedo (Non-Explosive) Testing	✓		✓	✓						✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	
Electronic Warfare																																				
Chaff Test				✓						✓			✓	✓							✓	✓		✓	✓	✓										
Electronic Systems Test				✓						✓			✓	✓					✓			✓		✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	
Flare Test				✓						✓			✓	✓							✓	✓		✓	✓	✓										
Radar and Other Systems Testing			✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mine Warfare																																				
Airborne Dipping Sonar Minehunting Test	✓			✓						✓			✓									✓														
Airborne Laser Mine Detection System Test				✓						✓			✓									✓					✓	✓	✓	✓			✓	✓	✓	
Airborne Mine Neutralization System Test				✓			✓			✓		✓	✓	✓	✓		✓			✓		✓	✓	✓	✓	✓	✓									
Airborne Sonobuoy Minehunting Test	✓			✓						✓			✓	✓	✓		✓		✓		✓	✓		✓		✓										
Mine Countermeasure and Neutralization Testing	✓		✓	✓			✓			✓		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table B-2: Stressors by Testing Activity (continued)

Atlantic Fleet Testing Activity	Biological Resources																			Physical Resources					Human Resources										
	Acoustic Stressors						Explosive Stressors		Energy Stressors			Physical Disturbance and Strike Stressors				Entanglement Stressors			Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors				Cultural Resource Stressors		Socioeconomic Resource Stressors			Public Health and Safety Stressors				
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Biodegradable Polymers	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strikes	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Mine Countermeasure Mission Package Testing	✓		✓	✓			✓		✓	✓		✓	✓	✓	✓		✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mine Detection and Classification Testing	✓		✓	✓			✓		✓	✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mine Laying Test				✓						✓			✓	✓								✓		✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
Surface Warfare																																			
Air-to-Surface Bombing Test			✓	✓						✓		✓	✓	✓						✓	✓	✓		✓	✓	✓									
Air-to-Surface Gunnery Test			✓	✓	✓		✓			✓		✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									
Air-to-Surface High-Energy Laser Test			✓	✓						✓	✓	✓	✓	✓						✓	✓	✓			✓										
Air-to-Surface Missile Test			✓	✓	✓		✓			✓		✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓									
Gun Testing - Large-Caliber	✓		✓	✓	✓		✓			✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓								
Gun Testing - Medium-Caliber			✓	✓	✓		✓			✓		✓	✓	✓						✓	✓	✓	✓	✓		✓	✓								
Gun Testing - Small-Caliber			✓	✓	✓					✓		✓	✓	✓						✓	✓	✓		✓	✓	✓									
Laser Targeting Test				✓						✓			✓	✓							✓	✓		✓	✓	✓									
Maritime Security Operations				✓						✓			✓								✓														
Missile and Rocket Testing			✓	✓	✓		✓	✓		✓		✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓									
Rocket Test			✓	✓	✓		✓			✓		✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									
Unmanned Systems																																			
Underwater Search, Deployment, and Recovery			✓	✓						✓		✓	✓	✓	✓		✓					✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Unmanned Aerial System Testing			✓	✓						✓		✓	✓									✓					✓	✓	✓	✓	✓	✓	✓	✓	✓
Unmanned Surface Vehicle System Testing			✓							✓		✓		✓						✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Unmanned Underwater Vehicle Testing	✓		✓	✓			✓			✓		✓	✓	✓	✓		✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table B-2: Stressors by Testing Activity (continued)

Atlantic Fleet Testing Activity	Biological Resources																		Physical Resources						Human Resources												
	Acoustic Stressors						Explosive Stressors		Energy Stressors		Physical Disturbance and Strike Stressors				Entanglement Stressors			Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors				Cultural Resource Stressors	Socioeconomic Resource Stressors			Public Health and Safety Stressors								
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Biodegradable Polymers	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strikes	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions			
Vessel Evaluation																																					
Air Defense Testing			✓	✓	✓		✓	✓		✓		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓										
In-Port Maintenance Testing	✓		✓							✓		✓										✓						✓	✓	✓	✓	✓	✓	✓	✓		
Propulsion Testing			✓	✓	✓					✓		✓	✓	✓	✓					✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		
Signature Analysis Operations	✓		✓						✓	✓		✓		✓	✓		✓		✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		
Small Ship Shock Trial			✓	✓			✓			✓		✓	✓									✓	✓	✓	✓	✓	✓										
Submarine Sea Trials – Propulsion Testing												✓										✓															
Submarine Sea Trials – Weapons System Testing	✓		✓	✓			✓			✓		✓	✓	✓	✓		✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Surface Warfare Testing	✓		✓	✓	✓		✓	✓		✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓										
Undersea Warfare Testing	✓		✓	✓	✓		✓	✓		✓		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Vessel Signature Evaluation	✓		✓	✓					✓	✓		✓	✓		✓							✓						✓	✓	✓	✓	✓	✓	✓	✓		
Other Testing Activities																																					
Acoustic and Oceanographic Research	✓		✓	✓						✓		✓	✓	✓	✓							✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		
Acoustic Component Testing	✓		✓	✓			✓			✓	✓	✓	✓		✓							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Air Platform Shipboard Integration Test			✓	✓						✓		✓	✓									✓						✓	✓	✓	✓	✓	✓	✓	✓		
Simulant Testing			✓	✓						✓		✓	✓									✓															
Countermeasure Testing	✓		✓	✓					✓	✓		✓	✓	✓			✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		
Insertion/Extraction	✓		✓							✓		✓		✓			✓		✓			✓		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		
Intelligence, Surveillance, Reconnaissance	✓		✓	✓	✓	✓	✓			✓		✓	✓	✓	✓		✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		

Table B-2: Stressors by Testing Activity (continued)

Atlantic Fleet Testing Activity	Biological Resources																		Physical Resources					Human Resources											
	Acoustic Stressors						Explosive Stressors		Energy Stressors		Physical Disturbance and Strike Stressors				Entanglement Stressors			Ingestion Stressors		Air Quality Stressors	Sediments and Water Quality Stressors			Cultural Resource Stressors	Socioeconomic Resource Stressors			Public Health and Safety Stressors							
	Sonar and Other Transducers	Pile Driving	Vessel Noise	Aircraft Noise	Weapons Noise	Air Guns	Explosions in Water	Explosions in Air	In-Water Electromagnetic Devices	In-Air Electromagnetic Devices	High-Energy Lasers	Vessels and In-Water Device Strike	Aircraft and Aerial Target Strike	Military Expended Material	Seafloor Device	Pile Driving	Wires and Cables	Biodegradable Polymers	Decelerators/Parachutes	Military Expended Materials - Munitions	Military Expended Materials - Other than Munitions	Criteria Air Pollutants	Explosives and Explosive By-Products	Metals	Chemicals Other than Explosives	Other Materials	Explosives	Physical Disturbance and Strikes	Accessibility	Airborne Acoustics	Physical Disturbance and Strike	In-Water Energy	In-Air Energy	Physical Interactions	
Line Charge Testing			✓				✓			✓		✓			✓					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Non-Acoustic Component Testing			✓	✓					✓			✓	✓		✓							✓					✓	✓	✓	✓	✓	✓	✓	✓	✓
Payload Deployer Testing			✓						✓			✓		✓							✓	✓	✓		✓										
Semi-Stationary Equipment Testing	✓		✓		✓	✓	✓		✓			✓	✓	✓					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Towed Equipment Testing	✓		✓						✓			✓	✓	✓							✓		✓		✓										
Undersea Range System Test	✓		✓						✓			✓	✓	✓							✓		✓		✓										

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APPENDIX C

U.S. COAST GUARD SUPPORTING INFORMATION

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Draft

Supplemental Environmental Impact Statement/ Overseas Environmental Impact Statement Atlantic Fleet Training and Testing

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C U.S. COAST GUARD SUPPORTING INFORMATION

C.1 INTRODUCTION

This section provides more information about the United States (U.S.) Coast Guard (Coast Guard), its missions and assets, and the training and testing performed in support of these missions. This section will also explain how many Coast Guard missions are beneficial to the environment. Due to differing missions from the U.S. Navy (Navy), many of the of the Proposed Actions explained in [Chapter 2](#) (Description of Proposed Action and Alternatives) are not performed by the Coast Guard. The use of mid- or low-frequency sonar, missiles, and explosives are examples of actions that are not a part of the Coast Guard's mission requirements. Other training done by the Coast Guard which is as part of the Coast Guard's national defense training and testing mission, are also done in support of many of the other Coast Guard's statutory missions. For example, Coast Guard Search and Rescue training and operations not just related to our defense mission. The application of the Search and Rescue training in the real world may also be used to rescue boaters, perform law enforcement, perform drug or migrant interdiction, etc. Coast Guard locations within the Study Area are shown in Figure C.1-1.

The Coast Guard's purpose of and need for the Proposed Action, discussed in [Chapter 2](#) (Description of Proposed Action and Alternatives), is to ensure Coast Guard personnel can qualify and train jointly with, and independently of, the Navy and other services in the effective and safe operational use of Coast Guard vessels, aircraft, and weapons under realistic conditions. The Coast Guard has broad, multifaceted, jurisdictional authority for management of activities over all waters subject to jurisdiction of the United States. The Coast Guard's law enforcement and national defense mission authority is based in 14 United States Code (U.S.C.) § 102, requiring the Coast Guard to "maintain a state of readiness to function as a specialized service in the Navy in time of war, including the fulfillment of Maritime Defense Zone command responsibilities." The Coast Guard successfully achieves its missions in part by conducting training and testing within the Study Area of this Supplemental Environmental Impact Statement (EIS)/Overseas Environmental Impact Statement (OEIS) to develop, sharpen, and maintain tactics, coordination, and personnel readiness. As a multi-mission agency, all training the Coast Guard does in support of national defense also supports many of the Coast Guard's other statutory missions and vice versa.

C.1.1 SUMMARY OF COAST GUARD HISTORY

The Coast Guard was established in 1790 by Secretary of the Treasury Alexander Hamilton as the Revenue Marine Service. It later became the Revenue Cutter Service and, in 1915, was combined with the U.S. Lifesaving Service (formed 1878) to become the Coast Guard. Until Congress established the Navy Department in 1798 it served as the nation's only armed force afloat, making it the longest continuous sea service in the United States. It was under the (peacetime) jurisdiction of the Treasury Department until 1967, when it was transferred to the Department of Transportation. In 2003, the Coast Guard was placed under the jurisdiction of the newly created Department of Homeland Security.

The Coast Guard is a military service within the U.S. armed forces that is charged with the enforcement of maritime laws. It consists of approximately 44,000 officers and enlisted personnel, in addition to 7,000 civilians. The Coast Guard enforces all applicable federal laws on the high seas and waters within the jurisdiction of the United States. It administers laws and promulgates and enforces regulations for the promotion of safety of life and property along the entire U.S. coast. In time of war, it functions as part of the Navy.

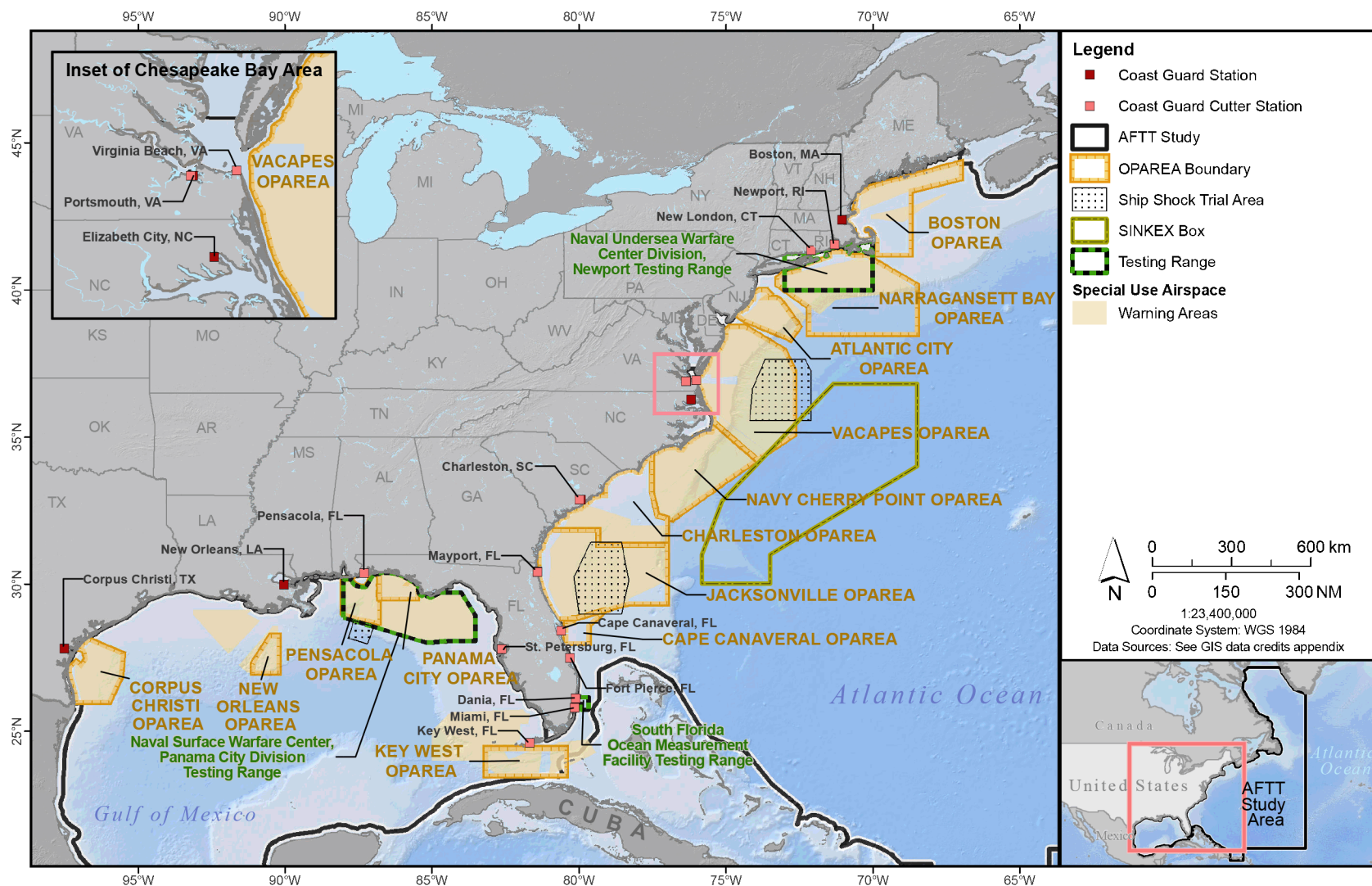


Figure C.1-1: Representative Coast Guard Locations within the Study Area

C.1.2 COAST GUARD MISSIONS

The Coast Guard manages six major operational mission programs: maritime law enforcement, maritime response, maritime prevention, marine transportation system management, maritime security operations, and defense operations. Within these 6 mission programs are 11 statutory missions. These statutory missions are:

1. **Marine Environmental Protection**—The Coast Guard regulates and inspects vessels and maritime facilities to reduce the risk of marine pollution incidents. The Marine Environmental Protection mission includes the planning, preparations, and operations to prevent, enforce, investigate, respond to, and mitigate the threat, frequency, and consequences of oil discharges and hazardous substance releases in U.S. waters. When spills occur, the Coast Guard leads response efforts to contain the damage.
2. **Living Marine Resources**—U.S. fisheries support over \$240 billion in economic activity annually, but nearly 20% are considered overfished. The Coast Guard is the lead federal agency for at-sea enforcement of U.S. fisheries laws. The Coast Guard’s legal authority to enforce fisheries laws flows from the Magnuson-Stevens Fisheries Conservation and Management Act of 1976. The Coast Guard enforces environmental laws that protect commercial and endangered species.
3. **Ports and Waterway Security**—The Coast Guard is responsible for the security of 361 U.S. ports and 95,000 statute miles (150,000 kilometers) of waterways. The local Coast Guard commander has legal authority over shipping in American waters as Captain of the Port. The Captain of the Port can declare inland waters in his jurisdiction to be “special security zones,” wherein commercial vessels must report their movements to the nearest Coast Guard station. The Coast Guard can direct ports closed or opened, and the Coast Guard’s vessel traffic managers direct ships on critical waterways.
4. **Other Law Enforcement**—The Coast Guard patrols America’s coasts and international waters using cutters, aircraft, and intelligence to detect, intercept, and disrupt dangerous and illegal activities such as drug smuggling and human trafficking.
5. **Drug Interdiction**—The Coast Guard is the lead agency in maritime drug interdiction, which is a shared legal responsibility with U.S. Customs and Border Protection. Coast Guard units coordinate their Caribbean Sea activities with the Navy.
6. **Migrant Interdiction**—The Coast Guard, especially its Florida-based Seventh District, enforces U.S. immigration law at sea. Many of these missions are also search-and-rescue missions since many migrants take to sea in unseaworthy vessels.
7. **Aids to Navigation**—Recreational and commercial boaters can safely navigate America’s waterways due to the Coast Guard’s managed and maintained network of buoys, lighthouses, and electronic aids.
8. **Ice Operations**—The effects of climate change have increased the Arctic’s scientific, economic, and national security importance. The Coast Guard has the only American-owned heavy icebreaker capable of supporting Arctic and Antarctic operations.
9. **Marine Safety**—Coast Guard personnel inspect commercial vessels, respond to pollution, investigate marine casualties and merchant mariners, manage waterways, and license merchant mariners.

10. **Search and Rescue**—Search and Rescue is one of the Coast Guard’s oldest missions. The National Search and Rescue Plan designates the Coast Guard as the federal agency responsible for maritime Search and Rescue operations in U.S. and international waters.
11. **Defense Readiness**—During wartime, by order of the President, the Coast Guard can fall under the operational orders of the Navy. Discussion of this mission is expanded below.

C.1.2.1 Coast Guard Defense Mission

Under Title 14 U.S.C. § 1, the Coast Guard is “at all times an armed force of the United States.” As part of the Joint Forces, the Coast Guard maintains its readiness to carry out military operations in support of the policies and objectives of the U.S. government. As an armed force, the Coast Guard trains and operates in the joint military arena at any time and functioning as a specialized service under the Navy in time of war or when directed by the President. Coast Guard service members are trained to respond immediately to support military operations and national security. As a member of the armed forces (10 U.S.C. § 101), the U.S. Coast Guard is purposefully embedded into different **national strategic level doctrines** that are used to guide the employment of the armed forces. These doctrinal pieces are:

1. **National Strategic Direction**—The National Strategic Direction is governed by the Constitution, federal laws, government policies, internationally recognized laws, and national interest (as represented by national security policies). This directional doctrine provides policy and planning to support the national strategic direction.
2. **National Strategic Strategy**—Issued by the President, the National Strategic Strategy provides a broad strategic context for employing military capabilities in concert with other instruments of national power.
3. **National Defense Strategy**—Issued by the Secretary of Defense, the National Defense Strategy outlines the Department of Defense’s (DoD) approach to implementing the President’s National Strategic Strategy.
4. **National Military Strategy**—Issued by the Chairman of the Joint Chiefs of Staff, the National Military Strategy supports the aims of the National Strategic Strategy and implements the National Defense Strategy. It describes the armed forces’ plan to achieve military objectives in the near term and provides a vision for maintaining a force capable of meeting future challenges.

Federal law created the framework for the relationship between the Navy and the Coast Guard.¹ To meet these statutory requirements, the Coast Guard must train in a realistic manner to ensure when they perform these similar activities in a “real-world” environment, they are doing so safely and effectively.

The Coast Guard has four major national defense missions:

- Maritime intercept operations
- Deployed port operations/security and defense
- Peacetime engagement
- Environmental defense operations (which includes oil and hazardous substance response)

¹ 10 U.S.C. § 101; 14 U.S.C. § 2 (7); 22 U.S.C.; 50 U.S.C.

These missions are essential military tasks assigned to the Coast Guard as a component of joint and combined forces in peacetime, crisis, and war. To effectively carry out these missions, the Coast Guard's air and surface units train using realistic scenarios, to include training with the Navy and the other armed services. Like the other services, the Coast Guard seeks to train in a realistic manner so that when the real-world missions arise, Coast Guard personnel are prepared to respond.

The Defense Readiness mission supports the National Military Strategy and DoD operations by ensuring Coast Guard assets are capable and equipped to deploy and conduct joint operations that support the most critical needs of combatant commanders in the major national-defense missions listed below. Every Coast Guard unit is trained to support all 11 statutory missions and, thus, trained to meet all mission requirements, which includes their defense mission requirements. Since all Coast Guard's missions generally entail the deployment of cutters or boats and either fixed-wing or rotary aircraft, the Coast Guard training requirements for one mission generally overlaps with the training requirements of other missions. Thus, when the Coast Guard is training for its defense mission, the same skill sets are utilized for its other statutory missions.

Table C.1-1 provides examples of how the training skills that assist the Coast Guard with conducting its Defense Readiness Mission are also used to assist the Guard in carrying out its other missions.

Table C.1-1: Coast Guard Mission Training Overlap with Defense Training

<i>Skill/Training Element</i>	<i>Defense Mission</i>	<i>Other Coast Guard Missions</i>
Stopping, boarding, searching, diverting, or redirecting vessel traffic	Maritime Interception/Interdiction	Drug interdiction; law enforcement; living marine resource protection; safety zone establishment; migrant interdiction
Flying helicopters, hovering, swimming in difficult seas	Search and Rescue. Recovering downed pilots, response to natural disasters	Search and rescue; law enforcement; drug interdiction; migrant interdiction; peacetime operations
Clearing battle space of oil and hazardous substances	Environmental Defense Operations. Clearing the sea of obstacles that may adversely affect other armed forces. It could include deployment of oil booms and establishing the National Command Center. Provides for efficient, coordinated, and effective response to discharges of oil and releases of hazardous substances, pollutants, and contaminants in accordance with the authorities of federal laws.	Marine safety; living marine resource protection; safety zone establishment; migrant interdiction; peacetime operations; aids to navigation. As the Vice-Chair of the multi-agency National Response Team and a leader of the National Contingency Plan, the Coast Guard (working with many other agencies to include the Navy) utilize many of the same tactics used while training for the defense mission to respond to oil spills in U.S. waters.
Ensuring port and harbor areas are free of hostile threats, terrorist actions, and safety deficiencies that would be a threat to the deployment of military resources	Port Operations, Security, and Defense	Law enforcement; drug interdiction; and safety zone establishment; port security; waterways management
Conducting humanitarian assistance (providing aid by air or by sea), professional exchanges, combined operations, training, exercises, and	Theater Security Cooperation	Responding to natural disasters; search and rescue; marine safety; waterways management; marine environmental protection; peacetime engagement

Table C.1-1: Coast Guard Mission Training Overlap with Defense Training (continued)

<i>Skill/Training Element</i>	<i>Defense Mission</i>	<i>Other Coast Guard Missions</i>
other diplomatic activities to foster international cooperation		
Protecting Offshore Strategic Assets by establishing and enforcing security zones	Maritime Interception Operations	Law enforcement; other law enforcement; marine safety; marine environmental protection; living marine resources
Conducting national air defense activities with helicopters	Rotary Wing Air Intercept, Port Security, Maritime Interception Operations	Surface and air training in support of the defense mission can be used in all Coast Guard statutory missions
Combatting terrorism—Providing special capabilities, such as training host nation forces and building the capacity of foreign maritime security forces that serve as a force multiplier to Department of Defense forces	Peacetime Engagement, Port Operations/Security and Defense; Coast Guard has relationships with many smaller navies/coast guards around the world and trains with these forces regularly	Surface and air training in support of the defense mission can be used in all Coast Guard statutory missions
Supporting Department of Defense response to maritime security threats, including terrorism, piracy, and other criminal or unlawful acts	Maritime Operational Threat Response/Defense	Surface and air training in support of the defense mission can be used in all Coast Guard statutory missions
Conducting offensive and defensive cyberspace operations to achieve military objectives and preserve system availability, integrity, and confidentiality	Military Cyberspace Operations	Cyberspace units in boat and cutter forces will most likely support maritime interception/interdiction operations, military environment response, and port operations, security, and defense

There are some Coast Guard similarities and differences with the Navy that are worth noting. These differences and similarities were considered in the analysis within the body of this Supplemental EIS/OEIS. Table C.1-2 highlights some of these contrasts/similarities.

Table C.1-2: Navy–Coast Guard Comparison

<i>Similarities</i>	<i>Differences</i>
Both Navy and Coast Guard are armed services of the United States.	Coast Guard reports to the Department of Homeland Security. Navy reports to the Secretary of Defense. Navy has approximately 320,000 personnel while the Coast Guard has approximately 40,000. Deployments by the Navy are normally measured in terms of months, whereas the Coast Guard generally measures time away from port in terms of days or weeks.
When joint or combined training occurs, Coast Guard generally falls under the Navy for purposes of the exercise. Coast Guard will follow the Navy’s exercise operations order which includes environmental mitigation.	Coast Guard training largely occurs at the unit level and at less intensity than the Navy.
Coast Guard trains using Navy procedures. Coast Guard borrows heavily from Shipboard Manuals published by Navy for many common standard operating procedures pertaining to watch stations,	Differences are minimal. Coast Guard draws its surface training requirements from the Navy’s Surface Force Training Manual. Coast Guard requires many of the same skills as Navy personnel.

Table C.1-2: Navy–Coast Guard Comparison (continued)

<i>Similarities</i>	<i>Differences</i>
and Navy-Type, Navy-Owned equipment such as Weapons Systems. Per Title 14 U.S.C., generally, Coast Guard weapons systems are Navy systems.	
Coast Guard systems and platforms are Navy systems and platforms.	Coast Guard has similar (or identical) weapons and communications systems to Navy assets, but their weapons and systems are significantly less impactful in terms of types and capabilities than the Navy. For example, the Coast Guard does not have mid-frequency or low-frequency sonar on any of its cutters or boats. Coast Guard explosive rounds are of much less weight and are less impactful.
Both Navy and Coast Guard have a global mission and reach.	Due to the size of Coast Guard cutters (and boats), Coast Guard training generally occurs close to the vessel homeport or close to shore, on established Navy ranges, or quite frequently, Coast Guard training commonly occurs enroute to a scheduled patrol/mission.
Both Navy and Coast Guard use Navy at-sea training ranges.	Navy maintains and schedules all usage of their at-sea training ranges. Coast Guard does not have their own at-sea ranges and regularly schedules usage of the Navy's at-sea ranges. Coast Guard meets with Navy annually to discuss necessary training in support of the Navy and the common defense mission. Access to Navy ranges and the procedures required on the range are also discussed.
Both Navy and Coast Guard may participate in a Sinking Exercise.	Sinking Exercise (SINKEX) is managed under the Navy's SINKEX program. There is a real-world scenario where the Coast Guard will sink a distressed vessel that is a hazard to navigation.
Both Navy and Coast Guard may participate in a law enforcement action.	The Navy cannot make arrests, but the Coast Guard can. Coast Guard crews with officers or petty officers assigned has law-enforcement authority (14 U.S.C. § 89) and can conduct armed boardings in support of defense or its law enforcement operation.
Both Navy and Coast Guard participate in dummy/inert mine shape placement.	Coast Guard does not perform a mine warfare mission but will at times assist the Navy with the placement of mine shapes for Navy training purposes. The Coast Guard's Aids to Navigation platforms may utilize their specialized equipment to place targets in the water.
Both Navy and Coast Guard work together as mission requirements dictate.	There are instances when the Navy will depend on the Coast Guard's unique capabilities not possessed by the Navy. For example, as part of Port and Waterway Security, the Coast Guard may escort Navy submarines in and out of harbors.

Notes: § = Section; SINKEX = Sinking Exercise; U.S.C. = United States Code

C.1.3 PLATFORMS, WEAPONS, ELECTRONIC WARFARE, AND COUNTERMEASURES

The platforms, weapons, electronic warfare, and countermeasures discussed below all exist within the Study Area and are utilized by the Coast Guard in the training and testing addressed in this

Supplemental EIS/OEIS. Since the Coast Guard trains the way it will operate, and many of its missions are emergent (akin to a firefighter responding immediately to a fire), often there is no time to consult with regulators or do environmental studies before responding to an emergent issue that may lead to the loss of life or property. The impacts to the environment caused by Coast Guard defense training and testing activities discussed in the body of this Supplemental EIS/OEIS are like those that would be caused by Coast Guard operations associated with responding to various emergent non-defense related issues such as a Search and Rescue for a fishing boat in distress, or a boarding done for law enforcement.

C.1.3.1 Cutters

Whereas the Navy has ships (that are much larger than the Coast Guard Cutters), carriers, fixed-wing aircraft, including fighter aircraft, rotary aircraft, and submarines, the Coast Guard deploys cutters, boats, fixed-wing, and rotary aircraft. A Coast Guard Cutter is any vessel which has a permanently assigned crew and accommodations for the extended support of that crew and includes all vessels of 65 feet (20 meters [m]) or more in length.

The Coast Guard currently operates approximately 240 cutters. Larger cutters are controlled by Area Commands—Atlantic Area (located in Portsmouth, Virginia) or Pacific Area (located in Alameda, California). Smaller cutters come under control of district commands. There are five districts within the Atlantic Area and four districts in the Pacific Area. Cutters usually carry a motor surf boat and/or a rigid-hulled inflatable boat. Polar-class icebreakers carry an Arctic survey boat and landing craft.

The endurance of a cutter to operate without provisioning is highly dependent upon several variables that change based on mission conditions. Coast Guard cutters are not designed to a specific endurance standard but rather to a set of performance requirements. The performance requirements are utilized to determine such parameters as maximum and cruising speeds, fuel capacity, water capacity, stores capacity, armament, crew size, and special mission characteristics (ice breaking, buoy handling, towing, defense etc.). The original performance requirements assume a specific set of operating conditions such as most economical speed. Actual endurance will vary depending on mission demands. Endurance is measured in days, whereas most Navy ships measure endurance in terms of months.

C.1.3.2 Boats

The Coast Guard operates approximately 1,400 boats, defined as any vessel less than 65 feet (20 m) in length, which generally operate near shore and on inland waterways. The most common is 25 feet (7.6 m) long, of which the Coast Guard has more than 350; the shortest is 13 feet (4 m). Boat training includes small boat crews engaging surface targets with small- and medium-caliber weapons. Boat crews may use high or low speeds to approach and engage targets simulating other boats, floating mines, or near shore land targets with up to 7.62-mm weapons. A commonly used target is an empty steel drum. Table C.1-3 describes different types of surface vessels.

Table C.1-3: List of Coast Guard Surface Platforms

<i>Type</i>	<i>Weapons</i>	<i>Length (Feet)</i>	<i>Notes</i>
Cutters			
Legend Class (replacing Hamilton Class)	MK 110 57-mm gun 20-mm Phalanx Close-In Weapons System Crew-served .50-caliber Browning M2 machine guns	Approximately 420	Known as National Security Cutter, there are approximately 12 in service or scheduled to be in service.

Table C.1-3: List of Coast Guard Surface Platforms (continued)

<i>Type</i>	<i>Weapons</i>	<i>Length (Feet)</i>	<i>Notes</i>
	Crew served 7.62-mm machine guns. Various small arms		
Famous-Class	76-mm/62-caliber naval gun 50-caliber (12.7-mm) machine guns Various small arms	> 250	Entered service in 1983, there are 13 in the inventory and they are being phased out as they reach their maximum service life.
Juniper-Class	.50-caliber (12.7 mm) machine guns Various small arms	Approximately 225	The Juniper-Class buoy tenders are responsible for maintaining short- and long-range aids to navigation such as fixed structures and buoys. Buoy tenders are multi-mission vessels and conduct maritime law enforcement, homeland security, and defense operations, as well as provide Search and Rescue (SAR) as needed. Entered service in 1996. Maximum Speed: 15 knots. Sixteen are in the inventory.
Reliance-Class	25-mm gun .50-caliber (12.7 mm) machine guns Various small arms	Approximately 210	Entered service in 1964.
Keeper-Class	None	Approximately 175	Entered service in 1997. Fourteen are in the inventory.
160-Foot-Class Island Construction Tender	None	Approximately 160	Entered service in 1976. Maximum Speed: 11 knots. Four are in the inventory.
Sentinel-Class	25-mm autocannon Crew-served Browning M2 machine guns	Approximately 150	Ultimately approximately 64 will be in service and will be multi-mission platforms capable of performing most of the USCG's statutory missions.
Bay-Class	M240 machine guns	140	Entered service in 1979. Up to 10 will be built.
Island-Class	25-mm chain gun .50-cal machine gun	110	(WPB): Entered service in 1985. These multi-mission platforms are being phased out and will be replaced by the Sentinel-Class cutters.
Marine Protector-Class	.50-caliber M2 Browning machine guns	87	Entered service in 1998. Approximately 70 are in the inventory.
Small Harbor Tug (WYTL)	None	65	These 65-foot tugs are multi-mission platforms.

Table C.1-3: List of Coast Guard Surface Platforms (continued)

<i>Type</i>	<i>Weapons</i>	<i>Length (Feet)</i>	<i>Notes</i>
Boats			
Aids to Navigation Boats	Small arms	Approximately 20–70	Varies in size
Screening Vessels	Small arms	Approximately 60	Multi-mission
Motor Lifeboat	Small arms	Approximately 50	Also known as “Special Purpose Craft – Heavy Weather (SPC-HWX).” Only located in Pacific Northwest.
Response Boat-Medium	None	Approximately 50	The Coast Guard has a contract for 180 Response Boat—Medium (RB-M) boats that were delivered starting in 2008 to replace the 41-foot utility boats. The RB-M is a multi-mission capable boat, operable from Coast Guard shore stations whose missions include PWCS, maritime law enforcement, and SAR.
Buoy Utility Stern Loading	None	Approximately 50	
Training Boats	None	Approximately 40	
Near-Shore Lifeboats	None	Approximately 40	
Boarding Team Delivery	Small arms	Approximately 40	
Long-Range Interceptor	Small arms	Approximately 40	Launched from National Security Cutters.
33-Foot Law Enforcement	Small arms	Approximately 30	
Response Boat-Small II	Replacement for Defender Class	Approximately 30	The Response Boat-Small II (RB-SII) is a multi-mission capable boat, operable from Coast Guard shore stations and designed to operate year-round in shallow waters. RB-S II missions include PWCS, maritime law enforcement, and SAR.
Cutter Boat Over the Horizon	Small arms	25	
Transportable Security Boats	Small arms	25	Used for Port Security.
Response Small Boat	None	25	To be replaced by a 29-foot boat.

Notes: > = greater than; cal = caliber; mm = millimeter; PWCS = Ports, Waterways, and Coastal Security; RB-M = Response Boat—Medium; RB-SII = Response Boat-Small II; SAR = Search and Rescue; SPC-HWX = Special Purpose Craft – Heavy Weather

C.1.3.3 Aircraft

The Coast Guard operates approximately 210 aircraft. Fixed-wing aircraft (such as Lockheed HC-130 Hercules turboprops) operate from air stations on long-duration missions. Helicopters (HH-65 Dolphin and Sikorsky HH-60J Jayhawk) operate from air stations, air facilities, and flight-deck equipped cutters, and can rescue people or intercept smuggling vessels or perform defense related missions. Some special MH-designated helicopters are armed with guns and some are equipped with armor to protect against small arms fire. Table C.1-4 describes different types of Coast Guard aircraft.

Table C.1-4: Aircraft

<i>Name</i>	<i>Quantity</i>	<i>Notes</i>
Lockheed HC-130 Hercules	Approximately 30	Multi-mission aircraft utilized in nearly all the Coast Guard statutory missions. No weapons.
HC-27J Spartan	Approximately 10	Fourteen on order.
CASA HC-144A Ocean Sentry	Approximately 20	-
Gulfstream C-37A	2	Aircraft used as a VIP transport for high-ranking Coast Guard and Homeland Security officials.
Airbus MH-65 Dolphin	Approximately 100	Helicopter used for most of the Coast Guard missions.
Sikorsky MH-60T Jayhawk	Approximately 40	Helicopter used for most of the Coast Guard missions.
RG-8A Condors	Unspecified number	-
Boeing Insitu ScanEagle	Unspecified number	-

Note: VIP = very important person

C.1.3.4 Pyrotechnics, Electronic Warfare, and Countermeasures

Table C.1-5, Table C.1-6, and Table C.1-7 list pyrotechnics, electronic warfare, and countermeasures used by the Coast Guard.

Table C.1-5: Pyrotechnics

<i>Item</i>
7.62-mm Grenade
Signal Kits
Flares
Marine Location Markers
Warning Flash Bang

Note: mm = millimeter

Table C.1-6: Electronic Warfare Systems

<i>Name</i>	<i>Notes</i>
Surface search and navigation radar	None of these systems is unique to the Coast Guard. Navy uses these same systems.
SCCS-Lite combat data system	-
AN/SLQ-32B(V)2 Electronic Warfare System	-
L-3 C4ISR suite	-
Sea Commander Aegis derived combat system	-
AN/SPS-50 surface search radar	-
AN/APX-123(V)1 IFF (ship automation system)	-

Table C.1-7: Decoys and Countermeasures

<i>Name</i>	<i>Notes</i>
Mark 36 SRBOC	Chaff countermeasures
Nulka	MK 53 Mod 10

C.1.4 COAST GUARD ACTIVITIES ANALYZED IN THIS DOCUMENT

Maritime Security Operations: Helicopter and surface ship crews conduct a suite of maritime security operations (e.g., visit, board, search and seizure, maritime interdiction operations, force protection, and anti-piracy operations). These activities involve training of boarding parties delivered by helicopters and surface ships to surface vessels for the purpose of simulating vessel search and seizure operations. Various training scenarios are employed and may include small arms with non-explosive blanks and surveillance or reconnaissance unmanned surface and aerial vehicles. The entire exercise may last 2 to 3 hours. This Coast Guard training is critical to all Coast Guard statutory missions.

Vessel Visit, Board, Search, and Seizure: Military personnel from ships and aircraft board suspect vessels, potentially under hostile conditions.

Maritime Interdiction Operations: Ships and aircraft train in pursuing, intercepting, and ultimately detaining suspect vessels.

Maritime Infrastructure Protection and Harbor Defense: Naval and Coast Guard personnel train to defend oil platforms, similar at-sea structures, harbors, piers, and other infrastructure.

Warning Shot/Disabling Fire: Coast Guard personnel train in the use of weapons to force fleeing or threatening small boats (typically operating at high speeds) to come to a stop.

Ship Force Protection: Coast Guard personnel train in tracking multiple approaching, circling small craft, assessing threat potential, and communicating among crewmates and other vessels to ensure ships are protected against attack.

Precision Anchoring: Ship crews choose the best available anchoring sites. The ship uses all means available to determine its position when anchor is dropped to demonstrate calculating and plotting the anchor's position within 100 yards of center of planned anchorage.

Waterborne Training: Waterborne training may include qualification and certification as safety observer, safety swimmer, coxswain, and crewman utilizing a variety of small crafts to include but not limited to rigid hull inflatables, aluminum chambered boat, stand-up paddleboards, kayaks, and jet skis. Boat crews train to launch and recover boats, operate crew-served unmanned vehicles, moor to buoys, anchor, and operate a variety of missions in shallow waters. Coast Guard may perform this training enroute to a scheduled patrol.

Civilian Port Defense—Homeland Security Anti-Terrorism/Force Protection Exercises: The Coast Guard provides close support to Naval forces Mine Warfare capabilities to support Department of Homeland Security-sponsored events. The Coast Guard is a component of the Department of Homeland Security. The three pillars of mine warfare, airborne (helicopter), surface (surface ships), and undersea (divers, marine mammals, and unmanned vehicles) mine countermeasures will be brought to bear to ensure strategic U.S. ports remain free of mine threats. Various mine warfare sensors, which utilize active acoustics, will be employed in the detection, classification, and neutralization of mines. Along with traditional mine warfare techniques, such as helicopter-towed mine countermeasures, new technologies (unmanned vehicles) will be utilized. Marine mammal systems may be used during this exercise. Event locations and scenarios will vary according to the Department of Homeland Security's strategic goals and evolving world events.

Humanitarian Assistance Operations: Military units evacuate noncombatants from hostile or unsafe areas to safe havens or to provide humanitarian assistance in times of disaster. The Coast Guard has a leadership role in many disaster relief operations, with their aircraft and surface vessels significantly contributing to the humanitarian assistance operations.

Search and Rescue: The Coast Guard maintains Search and Rescue facilities on the East, West and Gulf coasts, Hawaii, Alaska, Guam, and inland waterways. To maintain this perishable skill, the Coast Guard trains its helicopter and fixed-wing crews and Search and Rescue personnel in the air and on the water. Helicopter, ship, and submarine crews practice the skills required to recover personnel lost at sea. Helicopters locate survivors and deploy rescue swimmers and rescue baskets. Survivors are winched up to the hovering helicopter. Surface ships would conduct man overboard drills and deploy a dummy figure in the water. Ship crews would launch a small boat, direct the recovery of the dummy, and recover the small boat. Submarine crews would maneuver submarine to effect recovery of personnel.

Maritime Environmental Response: This defense mission in which the Coast Guard trains for by conducting spill response events that may prevent the Navy access to a beach or a port, is also an extremely important stand-alone mission. Coast Guard is a leader of the National Response Team that train to respond to events such as those that have occurred after ships run aground or oil wells are compromised and, thus, resulting in oil or hazardous materials releasing into the Waters of the U.S. Coast Guard as the Federal On-Scene Coordinator may deploy oil booms and setting up the National Command Center. Training for this inevitable mission directly supports its Defense Mission.

Gunnery Exercise: As an armed force, the Coast Guard may be called to perform gunnery operations as a part of its mission. This same training directly correlates to its law enforcement mission that may require a warning shot to get a vessel to stop or necessary for Coast Guard to board a vessel.

Small Boat Attacks: This defense mission is also a law enforcement mission, and the Coast Guard trains in a similar manner for both missions.

C.1.5 COAST GUARD AND THE PROTECTION OF MARINE RESOURCES

Many of the Coast Guard missions provide a direct and measurable positive impact on the marine environment, to include marine mammals, birds, coral reefs, and fishes. The inherent protective measures that the Coast Guard provides by conducting these missions are discussed below.

Through the Marine Environmental Protection program, the Coast Guard develops and enforces regulations to avert the introduction of invasive species into the maritime environment, stop unauthorized ocean dumping, and prevent oil and chemical spills. The Coast Guard serves as the Federal On-Scene Coordinator for oil spills and hazardous waste incidents in the marine environment. In this capacity, the Coast Guard oversees the clean-up of the marine environment, including authorizing wildlife operations to do reconnaissance and recovery of marine mammals (and other animals impacted). In a time of conflict, the Coast Guard would perform this function as a defense mission if there were oil spill, whether it be a result of the conflict or intentionally done by an adversary.

The Coast Guard spends tens of millions of dollars annually protecting living marine resources, to include an estimated \$65 million in fiscal year 2021 enforcing the Endangered Species Act. The Coast Guard is also a member of the National Marine Fisheries Service (NMFS) marine mammal stranding network and, in this capacity, assists NMFS and stranding response partners in aiding marine mammals in distress. Coast Guard assets have also been used to transport marine mammals to be taken in for rehabilitation or release.

Additionally, the Ports and Waterways Safety Act includes Coast Guard's responsibility in designating Traffic Separation Schemes for commercial vessels across the United States. The Coast Guard works with the National Oceanic and Atmospheric Administration's Office of National Marine Sanctuaries and NMFS to develop Traffic Separation Schemes that reduce the spatial overlap of commercial ships and large whales on the East Coast (to protect North Atlantic right whales) and off California (to protect blue, fin, and humpback whales). The Coast Guard provides marine mammal information to all mariners via a weekly notice to mariners (online) and broadcast notice to mariners (immediate information via very high frequency broadcasts). Both formats are used to convey information about whales, any closures

implemented by NMFS to reduce risk of strikes, and to raise general awareness of marine mammals in specific areas.

The Coast Guard protects our ocean environment and the marine life that inhabits it by enforcing domestic and international fisheries laws, as well as protects the U.S. Exclusive Economic Zone from foreign encroachment. The U.S. Exclusive Economic Zone is the largest in the world, comprising 3.4 million square miles of ocean and more than 90,000 miles of coastline. Keeping these waters clean and safe is critical to both our nation's economy and its environment. Using its law enforcement function, the Coast Guard enforces fisheries regulations from NMFS designed to reduce interactions with fisheries and marine mammals (e.g., patrols of groundfish fisheries in Alaska near Steller sea lion closed areas). Coast Guard auxiliaries help to raise awareness by providing information about protected species, including marine mammals, at various events. For example, Coast Guard is part of NMFS' "Be Whale Wise" campaign to promote safe vessel practices around endangered southern resident killer whales. This often entails the need for Coast Guard personnel to board a fishing vessel, which is also a requirement of the Coast Guard defense mission.

Protecting the integrity of the nation's maritime borders and ensuring the health of U.S. fisheries is a vital part of the Coast Guard mission. The Coast Guard also enforces international agreements to suppress illegal, unreported, and unregulated fishing activity in international waters. This provides a direct benefit to the marine environment and its resources.

Another important mission entrusted to the Coast Guard is the care and maintenance of maritime aids to navigation and the marine safety that this service provides. Much like drivers need stoplights, street signs, and universally accepted driving rules, boaters also need the nautical equivalent "rules of the road." The Coast Guard is responsible for ensuring this network of signs, symbols, buoys, markers, lighthouses, are functioning properly so recreational and commercial boaters can safely navigate the maritime environment. This function has a direct impact to safety of navigation and helps to prevent accidents that could harm the environment and its marine resources.

The United States has vital national interests in the polar regions. Polar security cutters enable the United States to maintain defense readiness in the Arctic and Antarctic regions; enforce treaties and other laws needed to safeguard both industry and the environment; provide ports, waterways, and coastal security; and provide logistical support—including vessel escort—to facilitate the movement of goods and personnel necessary to support scientific research, commerce, national security activities and maritime safety. Ice operations in areas like the Great Lakes and the Northeast Atlantic and rivers like the Hudson River facilitate the safe movement of ships delivering vital cargo in a safe manner, thus providing the added benefits of both marine safety, and preventing pollution through avoidance of accidents caused due to iced waterways.

To safely perform these statutory missions that provide direct benefits to the environment, the Coast Guard must provide its people realistic training. Defense training relating to aircraft and ship operations, and all the missions that relate to the usage of these assets, directly impact the ability of the Coast Guard to perform all their missions. The training utilized in support of defense readiness directly overlaps with many of the other Coast Guard missions that rely on ship and aircraft operations. Coast Guard personnel not only may perform these missions supporting the Navy and the Defense Readiness mission, but they also require the same skills for their law enforcement, marine protection, and other related missions.

APPENDIX D ACOUSTIC AND EXPLOSIVE IMPACTS SUPPORTING INFORMATION

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Draft
**Supplemental Environmental Impact Statement/
Overseas Environmental Impact Statement**
Atlantic Fleet Training and Testing

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D ACOUSTIC AND EXPLOSIVE IMPACTS SUPPORTING INFORMATION

D.1 ACOUSTIC AND EXPLOSIVE CONCEPTS/PRIMER

This appendix briefly explains the transmission of sound and explosive energy underwater and in air; introduces some of the basic mathematical formulas used to describe propagation; and defines acoustical terms, abbreviations, and units of measurement. Methods used to analyze hearing are also described.

For a more extensive background on acoustics, explosives, and marine bioacoustics the following resources are recommended:

- *Marine Mammals and Noise* (Richardson et al., 1995b)
- *Principles of Underwater Sound* (Urick, 1983)
- *Fundamentals of Acoustical Oceanography* (Medwin & Clay, 1998)
- *Principles of Marine Bioacoustics* (Au & Hastings, 2008)
- *Exploring Animal Behavior Through Sound: Volume 1 Methods* (Erbe & Thomas, 2022)
- *Discovery of Sound in the Sea* (<https://dosits.org/>)

D.1.1 TERMINOLOGY

The following terms are used in this document when discussing sound and the attributes of a sound source.

D.1.1.1 Sound

Sound is produced when an elastic medium (such as air or water) is set into motion, typically by a vibrating object within the medium. As the object vibrates, its motion is transmitted to adjacent “particles” of the medium. The motion of these particles is transmitted to adjacent particles, and so on. The result is a mechanical disturbance (the “sound wave”) that moves away from the source and propagates at a medium-dependent speed (the “sound speed”). As the sound wave travels through the medium, the individual particles of the medium oscillate about their original positions but do not actually move with the sound wave. This particle movement creates small changes in the medium’s density, pressure, and temperature.

Sound may be described by both physical and subjective attributes. Physical attributes, such as sound amplitude and frequency, may be directly measured. Subjective (or sensory) attributes like loudness depend on an animal’s perception of sound, and can vary between species and individuals.

D.1.1.2 Signal Versus Noise

When sound is purposely created to convey information, communicate, or obtain information about the environment, it is often referred to as a signal. Examples of signals include sonar pings, marine mammal vocalizations and echolocation clicks, tones used in hearing experiments, and small sonobuoy explosions used for submarine detection. Typically, signals have some type of known characteristics, for example, they could use a limited set of frequencies, have a specific set of harmonics, or be used such that the pulse context provides information to a receiver.

Noise is defined as any undesired sound (American National Standards Institute, 2013) that typically lacks the clear characteristics previously described. Sounds produced by naval aircraft and vessel propulsion are considered noise because they represent possible inefficiencies within the system and

increased detectability by adversaries. Whether a sound is perceived as noise depends on the receiver (i.e., the animal or system that detects the sound). For example, small explosions and sonar pings used to generate sounds to locate enemy submarines produce signals that are useful to sailors engaged in anti-submarine warfare, but are assumed to be noise when detected by marine species.

The combination of all sounds (including signals and noise) at a particular location, whether these sources are located near or far, is defined as ambient noise (American National Standards Institute, 2013). Ambient noise includes natural sources such as sound from crashing waves, rain, and animals (e.g., snapping shrimp), and anthropogenic sources such as seismic surveys and vessel noise. Every location in the marine environment contains some ambient noise, but how much depends on a multitude of factors. Characterizing the ambient noise level of a location is imperative to understanding potential impacts to marine life from anthropogenic sound.

D.1.1.3 Frequency and Wavelength

Frequency is the physical attribute associated with the subjective attribute “pitch”, the higher the frequency, the higher the pitch. Frequency is defined by the number of oscillations (i.e., cycles) in the sound pressure or particle motion per second. One hertz (Hz) is equal to one oscillation per second, and one kilohertz (kHz) is equal to 1,000 oscillations per second. “Bandwidth” refers to the range between the minimum and maximum frequency of a sound source or receiver.

Pure tones have energy at a constant, single frequency. Complex tones contain energy at multiple, discrete frequencies, rather than a single frequency. A harmonic of a sound at a particular frequency is a multiple of that frequency. For example, harmonic frequencies of a 2 kHz fundamental frequency tone (i.e., the lowest and most intense frequency of a complex tone) are 4 kHz, 6 kHz, 8 kHz. A source operating at a nominal frequency may emit several harmonic frequencies, but at lower amplitudes and higher frequencies. Some sources may also emit subharmonics which are lower in frequency than the fundamental frequency; however, these are typically many orders of magnitude less powerful than the fundamental frequency. Sounds with large bandwidths (“broadband” sounds) have energy spread across many frequencies.

In this document, sounds are generally described as either low- (less than 1 kHz), mid- (1 kHz to 10 kHz), high- (10 kHz to 100 kHz), or very high- (greater than 100 kHz) frequencies. Hearing ranges of marine animals (e.g., fishes, birds, sea turtles, and marine mammals) are variable and species dependent. For example, some fishes can detect sounds below 100 Hz and some species of marine mammals have hearing capabilities that extend above 100 kHz. Therefore, acoustic impact analyses must focus on the sound amplitude (i.e., pressure or particle motion, see Section D.1.1.4, Sound Amplitude), in addition to the sound frequency and animal sensory capabilities.

The wavelength of a sound is the distance between wave peaks. Wavelength decreases as frequency increases. The frequency multiplied by the wavelength equals the speed of sound in a medium, as shown in this equation:

$$\text{sound speed (m/s)} = \text{frequency} \left(\frac{1}{s} \right) \times \text{wavelength (m)}$$

The approximate speed of sound in sea water is 1,500 meters per second (m/s) and in air is 340 m/s, although speed varies depending on environmental conditions (e.g., pressure, temperature, and, in the case of sea water, salinity; see Section D.1.3.1, Speed of Sound).

D.1.1.4 Sound Amplitude

Sound amplitude is the physical attribute associated with the subjective attribute loudness. Amplitude is related to the amount that the medium particles oscillate about their original positions and can be thought of as the “strength” of a sound (as the amplitude increases, the loudness also increases). As the sound wave travels, the particles of the medium oscillate and transfer energy from one particle to

another but do not actually travel with the wave. The result is a mechanical disturbance (i.e., the sound wave) that propagates energy away from the sound source. Sound amplitude is typically characterized by measuring the acoustic pressure or particle motion.

D.1.1.5 Impulsive Versus Non-Impulsive Sounds

Although no standard definitions exist, sounds may be broadly categorized as impulsive or non-impulsive. Impulsive sounds have short durations, rapid rise-times, broad frequency content, and high peak pressures. Impulsive sounds are often produced by processes involving a rapid release of energy or mechanical impacts (Hamernik & Hsueh, 1991). Explosions and weapons firing are examples of impulsive sound sources analyzed in this document. In contrast, sonar, vessel operation, and underwater transducers lack the characteristics of impulsive sound sources and are thus examples of non-impulsive sound sources. Non-impulsive sounds can be essentially continuous, such as machinery noise, or intermittent, such as sonar pings. Impulsive signals, particularly at close range, are characterized as brief and broadband with rapid rise time and higher instantaneous peak pressure than other signal types. However, because of propagation effects, an impulsive signal can lose those characteristics, and at a variable distance it could be characterized as a non-impulsive signal (Hastie et al., 2019; Martin et al., 2020).

D.1.1.6 Acoustic Impedance

Acoustic impedance is a property of the propagation medium (air, water, sediment, or tissue) that can be simply described as the opposition to the flow of a pressure wave. Acoustic impedance is a function of the density and speed of sound in a medium. Sound transmits more readily through materials of similar acoustic impedance, such as water and animal tissue, since soft tissue is mainly comprised of water. When sound waves encounter a medium with different acoustic impedance (for example, an air-water interface), they reflect and refract (see Sections D.1.3.3.3, Refraction, and D.1.3.3.4, Reflection and Multipath Propagation), creating more complex propagation conditions. For example, sound traveling in air (low impedance) encountering the water surface (high impedance) will be largely reflected, preventing most sound energy in the air from being transmitted into the water. The impedance difference at the tissue-air interface in animals with gas-containing organs also makes these areas susceptible to damage when exposed to the shock wave near an explosion. Transmission from high-impedance to low-impedance can result in large motion at the boundary.

D.1.1.7 Duty Cycle

Duty cycle describes the portion of time that a source generates sound. It is defined as the ratio of time that a signal or system is on compared to the time it is off during an operational period. For example, if a sonar source produces a one-second ping once every 10 seconds, the duty cycle is 10 percent. Duty cycles vary within and between different acoustic sources; in general, a duty cycle of 20 percent or less is considered low, and a duty cycle of 80 percent or higher is considered high.

D.1.1.8 Resonance

Resonance occurs when an object is vibrated at a frequency near its “natural frequency” or resonant frequency. The resonant frequency can be considered the preferred frequency at which an object will oscillate at a greater magnitude than when exposed to other frequencies. In this document, resonance is considered in relation to the size of an air bubble or air cavity (e.g., lungs). Biological life exposed to high pressure waves from an outside source can lead to potential injury. Due to an inverse relationship, the smaller the bubble, the higher the resonant frequency. The natural frequency of biological life would vary based on the size of the bubbles trapped within them. For example, large whale lungs would have a lower resonant frequency than dolphin lungs. The natural frequencies of dolphin and beluga lungs near the surface are about 36 Hz and 30 Hz, respectively (Finneran, 2003). As an animal dives deep within the

water column, there is a corresponding increase in pressure. Hence, any air bubbles trapped within the animal would likely shrink as a result of the pressure change (Bostrom et al., 2008). Because of the change in bubble size, the resonant frequencies would tend to increase as an animal dives.

D.1.2 SOUND METRICS

The sound metrics described here are used to quantify exposure to a sound or explosion.

D.1.2.1 Pressure

Sound pressure is the incremental variation in a medium's static pressure (i.e., the ambient pressure without the added sound) as a sound wave travels through it. Sound pressure is typically expressed in units of micropascals (μPa), although explosive overpressure may also be described in pounds per square inch (psi).

Various sound pressure metrics are illustrated in Figure D.1-1 for (a) a non-impulsive sound (a pure tone in this illustration) and (b) an impulsive sound. As shown in Figure D.1-1, the non-impulsive sound has a relatively gradual rise in pressure from static pressure, while the impulsive sound has a near-instantaneous rise to a high peak pressure. The peak pressure shown on both illustrations is the maximum absolute value of the instantaneous sound pressure during a specified time interval ("zero-to-peak" or "peak"). "Peak-to-peak" pressure is the difference between the maximum and minimum sound pressures.

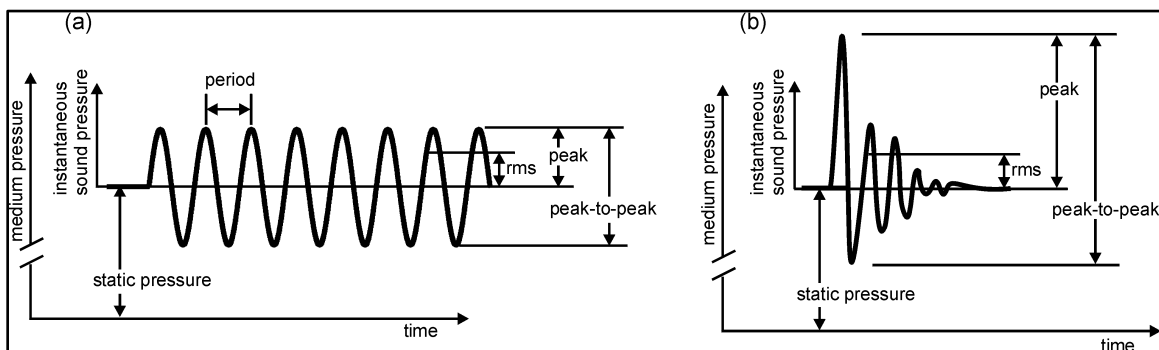


Figure D.1-1: Various Sound Pressure Metrics for a Hypothetical (a) Pure Tone (Non-Impulsive) and (b) Impulsive Sound

The root-mean-square (rms) value is often used to describe the average sound pressure level (SPL). SPLs provided in this Supplemental Environmental Impact Statement (EIS)/Overseas EIS (OEIS) are root-mean-square values unless otherwise specified. As the name suggests, this method takes the square root of the average squared sound pressure values over a time interval. The duration of this time interval can have a strong effect on the measured rms sound pressure for a given sound, especially where pressure levels vary significantly, as during an impulsive sound exposure. If the analysis duration includes a large portion of the waveform after the sound pressure has returned to zero, the rms pressure would be relatively low. If the analysis duration includes only the highest pressures of the impulsive exposure, the rms value would be comparatively high. For this reason, it is important to specify the duration used to calculate the rms pressure for impulsive sounds.

D.1.2.2 Sound Pressure Level

The most common sound level metric is SPL. Because many animals can detect very large pressure ranges and judge the relative loudness of sounds by the ratio of the sound pressures (a logarithmic behavior), SPL is described by taking the logarithm of the ratio of the sound pressure to a reference pressure. Use of a logarithmic scale compresses the wide range of measured pressure values into a more useful scale.

SPLs are normally expressed in decibels. A decibel is 1/10 of a bel, a unit of level when the logarithm is to the base ten and the quantities concerned are proportional to power (American National Standards Institute, 2013). SPL in decibels is calculated as follows:

$$SPL = 20 \log_{10} \left(\frac{P}{P_{ref}} \right)$$

where P is the sound pressure and P_{ref} is the reference pressure. Unless stated otherwise, the pressure (P) is the rms value of the pressure (American National Standards Institute, 2013). In some situations, SPL is calculated for the peak pressure rather than the rms pressure. On the occasions when rms pressure is not used, the pressure metric will be stated (e.g., peak SPL means an SPL calculated using the peak pressure rather than the rms pressure).

When a value is presented in decibels, it is important to also specify the value and units of the reference quantity. Normally the numeric value is given, followed by the text “re,” meaning “with reference to,” and the numeric value and unit of the reference quantity. For example, a pressure of 1 Pa, expressed in decibels with a reference of 1 micropascal (μ Pa), is written 120 dB re 1 μ Pa. The standard reference pressures are 1 μ Pa for water and 20 μ Pa for air. The reference pressure for air, 20 μ Pa, is the approximate lowest threshold of human hearing. It is important to note that because of the differences in reference units, the same sound pressures would result in different SPL values for each medium (the same sound pressure measured in water and in air would result in a higher SPL in water than in air, since the in-air reference is larger). Therefore, SPLs in air and in water cannot be directly compared.

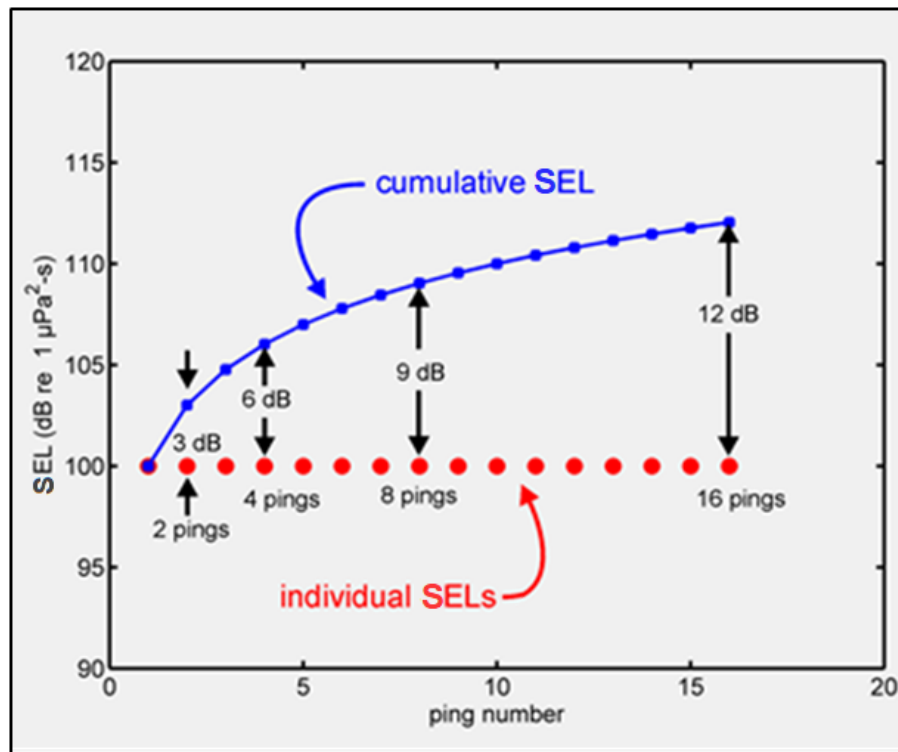
D.1.2.3 Sound Exposure Level

Sound exposure level (SEL) can be thought of as a composite metric that represents both the SPL of a sound and its duration. Individual time-varying noise events (e.g., a series of sonar pings or an impulsive sound) have two main characteristics: (1) a sound pressure that changes throughout the event and (2) a period during which a receiver is exposed to the sound. SEL can be provided for a single exposure (i.e., a single sonar ping or single explosive detonation) or for an entire acoustic event (i.e., multiple sonar pings or multiple explosive detonations). Cumulative SEL provides a measure of the net exposure of the entire acoustic event, but it does not directly represent the sound level at a given time. SEL is determined by calculating the decibel level of the cumulative sum-of-squared pressures over the duration of a sound, with units of dB re 1 micropascal squared seconds (re 1 μ Pa²s) for sounds in water, and dB re 20 micropascal squared seconds (re 20 μ Pa²s) for sounds in air.

Guidelines for SEL are as follows:

- The numeric value of SEL is equal to the SPL of a one-second sound that has the same total energy as the exposure event. If the sound duration is one second, SPL and SEL have the same numeric value (but not the same reference quantities). For example, a one-second sound with an SPL of 100 dB re 1 μ Pa has a SEL of 100 dB re 1 μ Pa²s.
- If the sound duration is constant but the SPL changes, SEL will change by the same number of decibels as the SPL.
- If the SPL is held constant and the duration (T) changes, SEL will change as a function of $10 \log_{10}(T)$:
 - $10 \log_{10}(10) = 10$, so increasing duration by a factor of 10 raises SEL by 10 dB.
 - $10 \log_{10}(0.1) = -10$, so decreasing duration by a factor of 10 lowers SEL by 10 dB.
 - $10 \log_{10}(2) \approx 3$, so doubling the duration increases SEL by 3 dB.
 - $10 \log_{10}(1/2) \approx -3$, so halving the duration lowers SEL by 3 dB.

Figure D.1-2 illustrates the summation of energy for a succession of sonar pings. In this hypothetical case, each ping has the same duration and SPL. The SEL at a particular location from each individual ping is 100 dB re 1 $\mu\text{Pa}^2\text{s}$ (red circles). The upper, blue curve shows the running total or cumulative SEL.

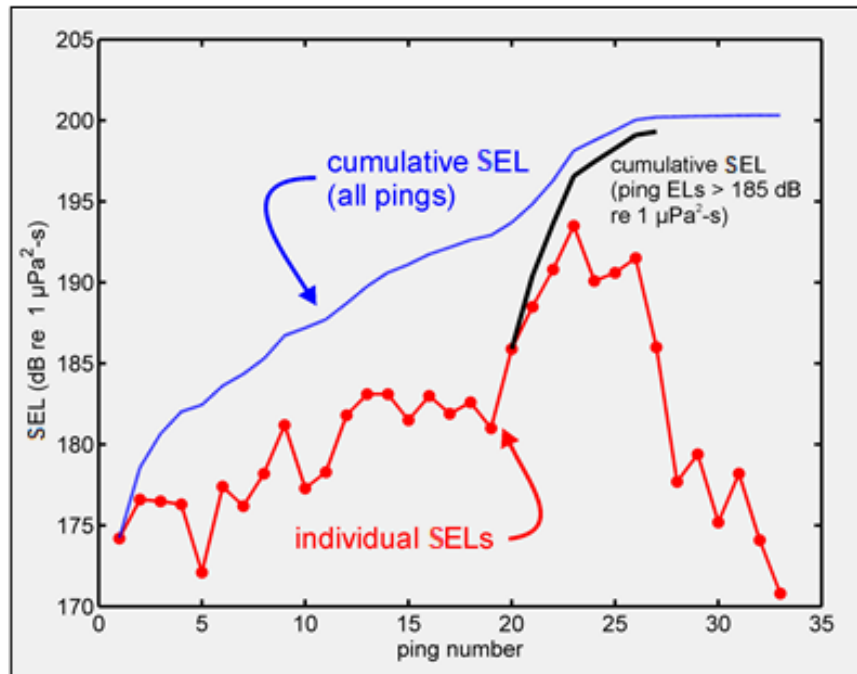


Note: dB = decibels; SEL = sound exposure level; dB re 1 $\mu\text{Pa}^2\text{s}$ = decibels with a reference of 1 micropascal (μPa) squared per second

Figure D.1-2: Summation of Acoustic Energy from a Hypothetical, Intermittently Pinging, Stationary Sound Source

After the first ping, the cumulative SEL is 100 dB re 1 $\mu\text{Pa}^2\text{s}$. Because each ping has the same duration and SPL, receiving two pings is the same as receiving a single ping with twice the duration. The cumulative SEL from two pings is therefore 103 dB re 1 $\mu\text{Pa}^2\text{s}$. The cumulative SEL from four pings is 3 dB higher than the cumulative SEL from two pings, or 106 dB re 1 $\mu\text{Pa}^2\text{s}$. Each doubling of the number of pings increases the cumulative SEL by 3 dB.

Figure D.1-3 shows a more realistic example where the individual pings do not have the same SEL. These data were recorded from a stationary hydrophone as a sound source approached, passed, and moved away from the hydrophone. As the source approached the hydrophone, the received SEL of each ping increased. After the source passed the hydrophone, the received SEL from each ping decreased as the source moved farther away (downward trend of red line), although the cumulative SEL increased with each additional ping received (slight upward trend of blue line). The main contributions are from those pings with the highest individual SELs. Individual pings with SELs 10 dB or more below the ping with the highest level contribute little (less than 0.5 dB) to the total cumulative SEL. This is shown in Figure D.1-3, where only a small error is introduced by summing the energy from the eight individual pings with SEL greater than 185 dB re 1 $\mu\text{Pa}^2\text{s}$ (black line), as opposed to including all pings (blue line).



Note: dB = decibels; ELs = exposure levels; SEL = sound exposure level; dB re 1 $\mu\text{Pa}^2\text{-s}$ = decibels with a reference of 1 micropascal (μPa) squared per second

Figure D.1-3: Cumulative SEL under Realistic Conditions with a Moving, Intermittently Pinging Sound Source

D.1.2.4 Particle Motion

The particles of a medium (e.g., water or air) oscillate around their original position as a sound wave passes through. Particle motion comprises particle displacement (m or dB re 1 μm), particle velocity (m/s or dB re 1 nm/s^2), and particle acceleration (m/s² or dB re 1 $\mu\text{m/s}^2$) (Nedelec et al., 2016a). Note that particle velocity is not the same as sound speed, which is how fast a sound wave moves through a medium. Particle motion is also directional, whereas sound pressure measurements are not (Nedelec et al., 2016a).

Near acoustic boundaries (e.g., the sea floor and sea surface) and in the shallow waters, the relationship between sound pressure and particle motion is complex and it is necessary to measure particle motion directly (Pierce, 1989). At distances far from a sound source (i.e., in the far field) and without boundary interactions that could cause wave interference, particle velocity is directly proportional to sound pressure. However, closer to a sound source (i.e., in the near field), the particle velocity component of the field contains more energy than the sound pressure component of the field. The rate of decline of particle velocity in the near field depends on the nature of the sound source and its movement pattern (Harris & van Bergeijk, 1962). The distance from a source at which the near field transitions to the far field is related to the wavelength of the signal, with a greater distance for lower frequencies.

D.1.2.5 Intensity

The intensity of a sound wave (I) is defined as the amount of energy per second (power in units Watts) propagating through 1 square meter of a medium (e.g., seawater). A propagating sound wave carries both kinetic energy of a medium's particles in motion (particle velocity [u]) and potential energy due to the acoustic impedance of the medium (sound pressure [p]) and is calculated as follows:

$$I = pu$$

Intensity and velocity are both vector quantities with a magnitude and direction. The motion of particles in a sound wave are generally oriented in the direction of propagation at a velocity equal to the velocity of sound (c). In a plane wave, the sound pressure is related to the particle velocity by:

$$p = \rho c u, \text{ or } u = \frac{p}{\rho c}$$

Where the fluid density (ρ) and velocity of sound (c) are known as the specific acoustic impedance of the medium. Therefore, for a plane wave, the instantaneous intensity is related to the instantaneous sound pressure by:

$$I = \frac{p^2}{\rho c}$$

D.1.2.6 Impulse

Impulse is a metric used to describe the pressure and time component of a pressure wave. Impulse is typically only considered for high-energy exposures to impulsive sources, such as exposures of marine species close to explosives. Specifically, pressure impulse is the time integral of the pressure with units of Pascal-seconds (Pa-s). Impulse is a measured quantity that is distinct from the term “impulsive,” which is not a measurement term, but rather describes a type of sound (see Section D.1.1.5, Impulsive Versus Non-Impulsive Sounds).

D.1.3 PREDICTING HOW SOUND TRAVELS IN WATER

While the concept of a sound wave traveling from its source to a receiver is straightforward, sound propagation is complex because of the simultaneous presence of numerous sound waves of different frequencies and source levels (i.e., the sound radiated by a projector). Waves undergo changes in direction (i.e., reflection, refraction, and diffraction) that can cause interferences (waves adding together or cancelling one another out). Ocean bottom types, water density, and surface conditions also affect sound propagation. While simple examples are provided here for illustration, the Navy Acoustic Effects Model used to quantify acoustic exposures to marine mammals and sea turtles considers the influence of multiple factors to predict acoustic propagation [see technical report *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase IV Training and Testing* (U.S. Department of the Navy, 2024b)].

D.1.3.1 Speed of Sound

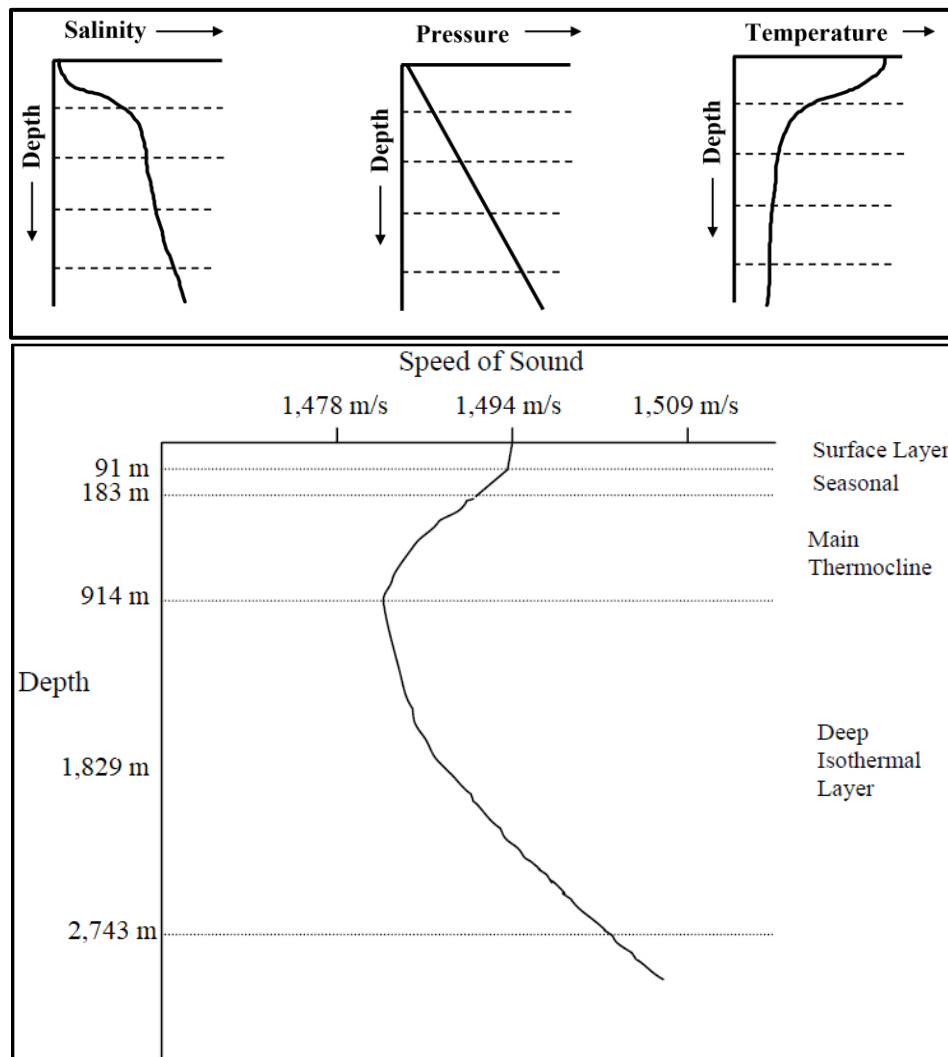
The speed of sound is not affected by the SPL or frequency of the sound, but depends wholly on characteristics of the medium through which it is passing. The speed of sound (c) is calculated using the bulk modulus (B), which describes resistance to compression, and density (ρ) of seawater, which are influenced by the pressure and temperature of the medium.

$$c = \sqrt{\frac{B}{\rho}}$$

Sound travels faster through a medium that is harder to compress. For example, water is more difficult to compress than air, and sound travels approximately 340 m/s in air and 1,500 m/s in seawater. The density of air is primarily influenced by temperature, relative humidity, and pressure, because these attributes affect the density and compressibility of air. Generally, the speed of sound in air increases as air temperature increases. The density of seawater is primarily influenced by temperature, pressure, and salinity. In general, the density is higher for colder temperatures, higher hydrostatic pressure, and higher

salinity. The speed of sound in seawater also increases with increasing temperature and, to a lesser degree, with increasing hydrostatic pressure and salinity.

The combination of effects from temperature, pressure, and salinity creates a sound velocity profile. Figure D.1-4 shows the independent relationship each of these three attributes have with depth. For most areas of the ocean, temperature decreases from the surface to the bottom, although there are many local variations. Shallow layers see the most variation with time and depth (e.g., surface mixing, solar heating, currents, seasonal variations), and at deeper layers the temperature becomes relatively constant at 4°C. Hydrostatic pressure makes the speed of sound increase with depth because of variations in the bulk modulus. Below 1,500 meters (m), the increasing hydrostatic pressure is the dominant factor on sound speed. The change in the mix of pure water and dissolved salts affects the speed of sound. Salinity has minimal variation with depth, but there can be stronger variations near areas with freshwater inputs such as river estuaries and melting ice. Inhomogeneities in seawater can also affect the speed of sound and include bubble layers close to the surface, mineral particles in suspension, and living organisms.



Note: m = meters; m/s = meters per second

Figure D.1-4: Sound Velocity Profile (Sound Speed) Is Related to Temperature, Salinity, and Hydrostatic Pressure of Seawater

Figure D.1-4 also shows an example of a standard sound velocity profile and its four distinctive layers. The surface layer tends to be irregular and is influenced by diurnal (i.e., daily) heating and cooling; mixing from currents, local wind action, and storms; and changes in salinity due to evaporation, precipitation, freezing, ice melt, and river runoff. The surface layer may contain a mixed layer of isothermal (i.e., nearly constant temperature) water that traps sound. Under prolonged calm and sunny conditions, the mixed layer does not exist and water temperature decreases with depth. The seasonal thermocline (i.e., temperature gradient) is influenced by seasonal heating and cooling and mixing from wind action and storms. The seasonal thermocline is characterized by temperature decreasing with depth. During the summer and fall when waters are warm, the seasonal thermocline is well defined. However, during winter and spring or in cold waters, the seasonal thermocline can be indistinguishable from the surface layer. The main, or permanent thermocline, is independent of the surface layer, is only slightly affected by seasonal changes within a localized area and is where the major temperature difference between the cold depths of the sea occurs. The main thermocline extends to about 300 m and marks the limit where temperature has the most influence on sound velocity due to less mixing at greater depths. The deep isothermal layer is defined by a nearly constant temperature and sound velocity is mainly influenced by pressure. At the inflection point where sound velocity decreases with depth in the main thermocline, and where sound velocity begins to increase in the deep isothermal layer, is where a sound velocity minimum occurs and sound at depth is focused by refraction.

D.1.3.2 Source Directivity

Most sonar and other active acoustic sources do not radiate sound in all directions, unlike noise from vessels and explosions for example. Rather, they emit sounds over a limited range of angles to focus sound energy on a specific area or object of interest. The specific angles are sometimes given as horizontal or vertical beam width. Some sources can be described qualitatively as “forward-looking,” when sound energy is radiated in a limited direction in front of the source, or “downward-looking,” when sound energy is directed toward the bottom.

D.1.3.3 Transmission Loss

As a sound wave passes through a medium, the sound level decreases with distance from the sound source. This phenomenon is known as transmission loss (TL). The transmission loss is used to relate the source SPL (SL), defined as the SPL produced by a sound source at 1 m, and the received SPL (RL) at a particular location, as follows:

$$RL = SL - TL$$

The main contributors to transmission loss are as follows (Urlick, 1983) and are discussed in detail below:

- Geometric spreading of the sound wave as it propagates away from the source
- Sound absorption (conversion of sound energy into heat)
- Scattering, diffraction, multipath interference, and boundary effects

D.1.3.3.1 Spreading Loss

Spreading loss is a geometric effect representing the regular weakening of a sound wave as it spreads out from a source. Spreading describes the reduction in sound pressure caused by the increase in surface area as the distance from a sound source increases. Spherical and cylindrical spreading are the simplest forms of spreading loss.

In the simple case of sound propagating from a point source without obstruction or reflection, the sound waves take on the shape of an expanding sphere. An example of spherical spreading loss is shown in Figure D.1-5. As spherical propagation continues, the sound energy is distributed over an ever-larger area following the inverse square law: the pressure of a sound wave decreases inversely with the square of the distance between the source and the receptor. For example, doubling the distance between the receptor and a sound source results in a reduction in the pressure of the sound to one-fourth of its initial value, tripling the distance results in one-ninth of the original pressure, and so on. Because the surface area of a sphere is $4\pi r^2$, where r is the sphere radius, the change in SPL with distance r from the source is proportional to the radius squared. This relationship is known as the spherical spreading law. The TL for spherical spreading between two locations is:

$$TL = 20\log_{10}(r)$$

- 2 x distance, 6 dB loss
- 3 x distance, 10 dB loss
- 10 x distance, 20 dB loss

In cylindrical spreading, spherical waves expanding from the source are constrained by the water surface and the seafloor and take on a cylindrical shape. In this case the sound wave expands in the shape of a cylinder rather than a sphere, and the transmission loss is:

$$TL = 10\log_{10}(r)$$

- 2 x distance, 3 dB loss
- 3 x distance, 5 dB loss
- 10 x distance, 10 dB loss

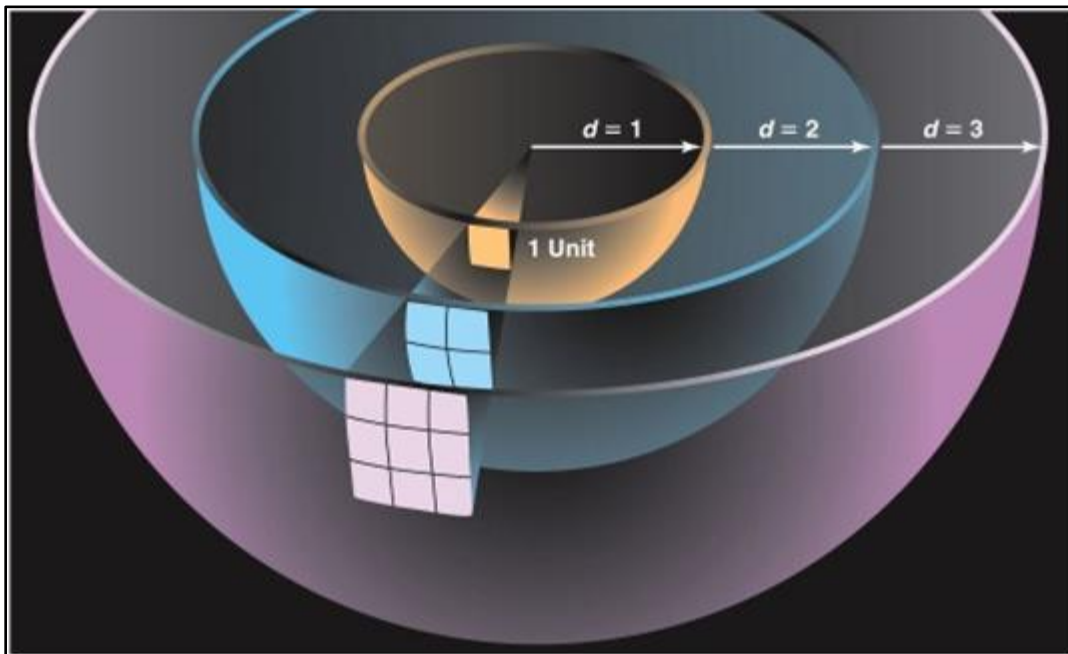


Figure D.1-5: Graphical Representation of the Inverse Square Relationship in Spherical Spreading with Increasing Distance from the Source (d)

The cylindrical and spherical spreading equations above represent two simple hypothetical cases. In reality, geometric spreading loss is more spherical near a source and more cylindrical with distance, and is better predicted using more complex models that account for environmental variables, such as the Navy Acoustic Effects Model [see technical report *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase IV Training and Testing* (U.S. Department of the Navy, 2024b)].

D.1.3.3.2 Absorption

Absorption loss is the conversion of acoustic energy to heat and kinetic energy and occurs when sound propagates through a medium (Urlick, 1983). Absorption is directly related to sound frequency, with higher frequencies (>10 kHz) having higher rates of absorption. The main cause of absorption in sea water occurs below 100 kHz and is due to ionic relaxation of dissolved salts (primarily magnesium sulfate). Therefore, absorption is the cause of an appreciable amount of attenuation for high- and very high-frequency sound sources, reducing the distance over which these sources may be perceived compared to mid- and low-frequency sound sources with the same source level.

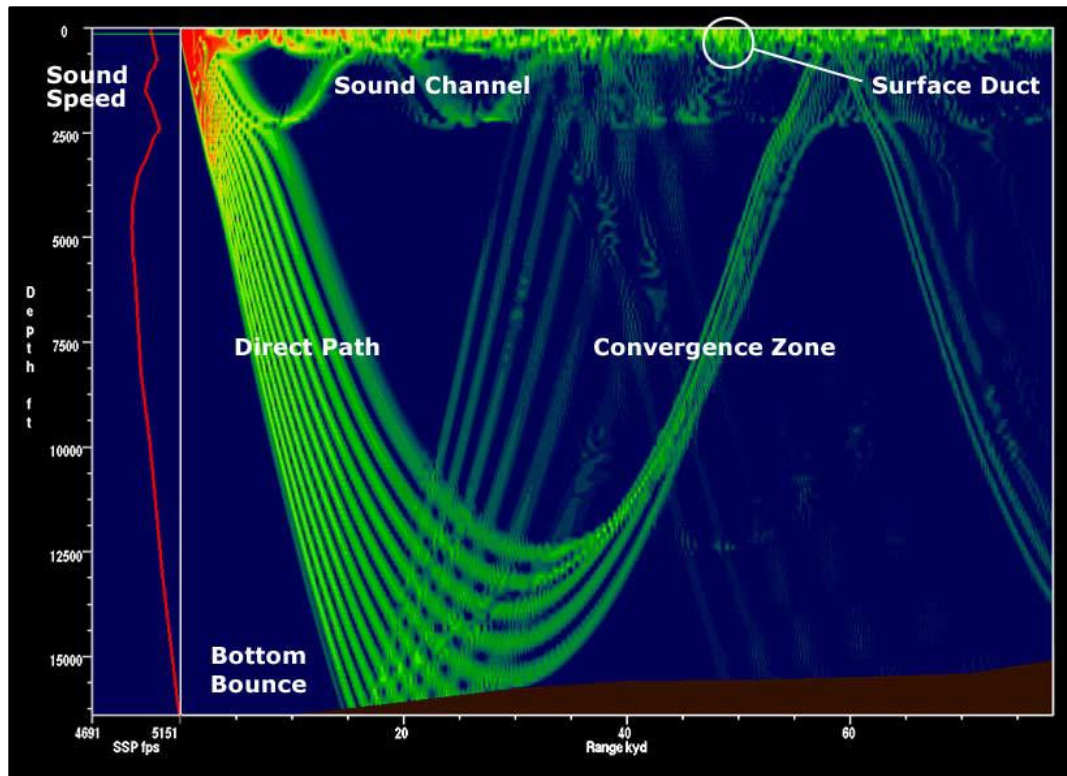
D.1.3.3.3 Refraction

When a sound wave propagating in a medium encounters a second medium with a different density (e.g., the air-water boundary), part of the incident sound will be reflected back into the first medium and part will be transmitted into the second medium (Kinsler et al., 1982). The propagation direction will change as the sound wave enters the second medium; this phenomenon is called refraction. Refraction may also occur within a single medium if the properties (e.g., temperature) of the medium change enough to cause a variation in the sound speed.

As discussed in Section D.1.3.1, Speed of Sound, the sound speed in the ocean primarily depends on hydrostatic pressure (i.e., depth) and temperature. Although the actual variations in sound speed are small, the existence of sound speed gradients in the ocean has an appreciable effect on the propagation of sound in the ocean. If one pictures sound as rays emanating from an underwater source, the propagation of these rays changes as a function of the sound speed profile in the water column. Specifically, the directions of the rays bend toward regions of slower sound speed. This phenomenon creates ducts in which sound becomes “trapped,” allowing it to propagate with high efficiency for large distances within certain depth boundaries. During winter months, the reduced sound speed at the surface due to cooling can create a surface duct that efficiently propagates sound such as commercial shipping noise (Figure D.1-6).

Sources located within this surface duct can have their sounds trapped, but sources located below this layer would have their sounds refracted downward. The deep sound channel, or sound frequency and ranging (SOFAR) channel is between 600 and 1,200 m deep at mid-latitudes and is where the slowest sound speed (i.e., sound speed minimum) occurs. The sound speed minimum creates a waveguide where sound waves are continually bent, or refracted, towards the region of lower sound speed which allows sound to travel long distances with minimal attenuation.

Similarly, the path of sound will bend toward regions of lower sound speed in air. Air temperature typically decreases with altitude. Since the speed of sound decreases in cooler temperatures, sounds produced in air tend to bend skyward. When an atmospheric temperature inversion is present, air is cooler near the earth’s surface than at altitude. In inversion conditions, sound waves near the earth’s surface will tend to refract downward.



Note: 1 kiloyard (kyd) = 0.9 km

Figure D.1-6: Sound Propagation Showing Multipath Propagation and Conditions for Surface Duct

D.1.3.3.4 Reflection and Multipath Propagation

In multipath propagation, sound may not only travel a direct path (with no reflection) from a source to a receiver, but also be reflected from the surface or bottom multiple times before reaching the receiver (Urick, 1983). Reflection is shown in Figure D.1-6 at the seafloor (bottom bounce) and at the water surface. At some distances, the reflected wave will be in phase with the direct wave (their waveforms add together and create a convergence zone), and at other distances the two waves will be out of phase (their waveforms cancel). The existence of multiple sound paths, or rays, arriving at a single point can result in multipath interference, a condition that permits the addition and cancellation between sound waves, resulting in the fluctuation of sound levels over short distances.

Reflection plays an important role in the pressures observed at different locations in the water column. Near the bottom, the direct path pressure wave may sum with the bottom-reflected pressure wave, increasing the exposure. Near the surface, however, the surface-reflected pressure wave may destructively interfere with the direct path pressure wave, by “cutting off” the wave and reducing exposure (called the Lloyd mirror effect). This can cause the sound level to decrease dramatically within the top few meters of the water column.

D.1.3.3.5 Diffraction, Scattering, and Reverberation

Diffraction, scattering, and reverberation are examples of what happens when sound waves interact with obstacles in the propagation path.

Diffraction may be thought as the change of direction of a sound wave as it passes around an obstacle. Diffraction depends on the size of the obstacle and the sound frequency. The wavelength of the sound

must be larger than the obstacle for notable diffraction to occur. If the obstacle is larger than the wavelength of sound, an acoustic shadow zone will exist behind the obstacle where the sound is unlikely to be detected. Common examples of diffraction include sound heard from a source around the corner of a building and sound propagating through a small gap in an otherwise closed door or window.

An obstacle or inhomogeneity (e.g., smoke, suspended particles, gas bubbles due to waves, and marine life) in the path of a sound wave causes scattering as these inhomogeneities reradiate incident sound in a variety of directions (Urlick, 1983). Reverberation refers to the prolongation of a sound, after the source has stopped emitting, caused by multiple reflections at water boundaries (surface and bottom) and scattering.

D.1.3.3.6 Surface and Bottom Effects

Because the sea surface reflects and scatters sound, it has a major effect on the propagation of underwater sound in applications where either the source or receiver is at a shallow depth (Urlick, 1983). If the sea surface is smooth, the energy from a reflected sound wave is nearly equal to the energy of an incident (i.e., incoming) sound wave; however, if the sea surface is rough, the amplitude of the reflected sound wave will be reduced. Sound waves in water reflected from a boundary with air (i.e., the sea surface) experience a phase reversal (i.e., a 180° change). When the surface-reflected waves interact with the direct path waves near the surface, a destructive interference pattern is created in which the two waves are out of phase by half a cycle and cancel each other out when added together. As a result, the amplitude of the two waves and the sound pressure become zero.

The sea bottom is also a reflecting and scattering surface, like the sea surface. Sound interaction with the sea bottom is more complex, primarily because the acoustic properties of the sea bottom are more variable, and the bottom is often layered into regions of differing density. As sound travels into the seafloor it reflects off these different density layers in complex ways. For sources in contact with the bottom, such as bottom-placed explosives, a ground wave is produced that travels through the bottom sediment and may refract back into the water column.

Sediment grain size, composition, and the measure of pore space (i.e., porosity) affect sound propagation and attenuation at the sea floor. In addition, sediments contain free or trapped gas and/or organic content which can affect the bulk properties of the sediment. For a hard bottom such as rock, the reflected wave will be approximately in phase with the incident wave. Thus, near the ocean bottom, the incident and reflected sound pressures may add together (constructive interference), resulting in increased sound pressure near the sea bottom. Soft bottoms such as mud or sediment absorb sound waves and reduce the level in the water column overall.

D.1.3.4 Air-Water Interface

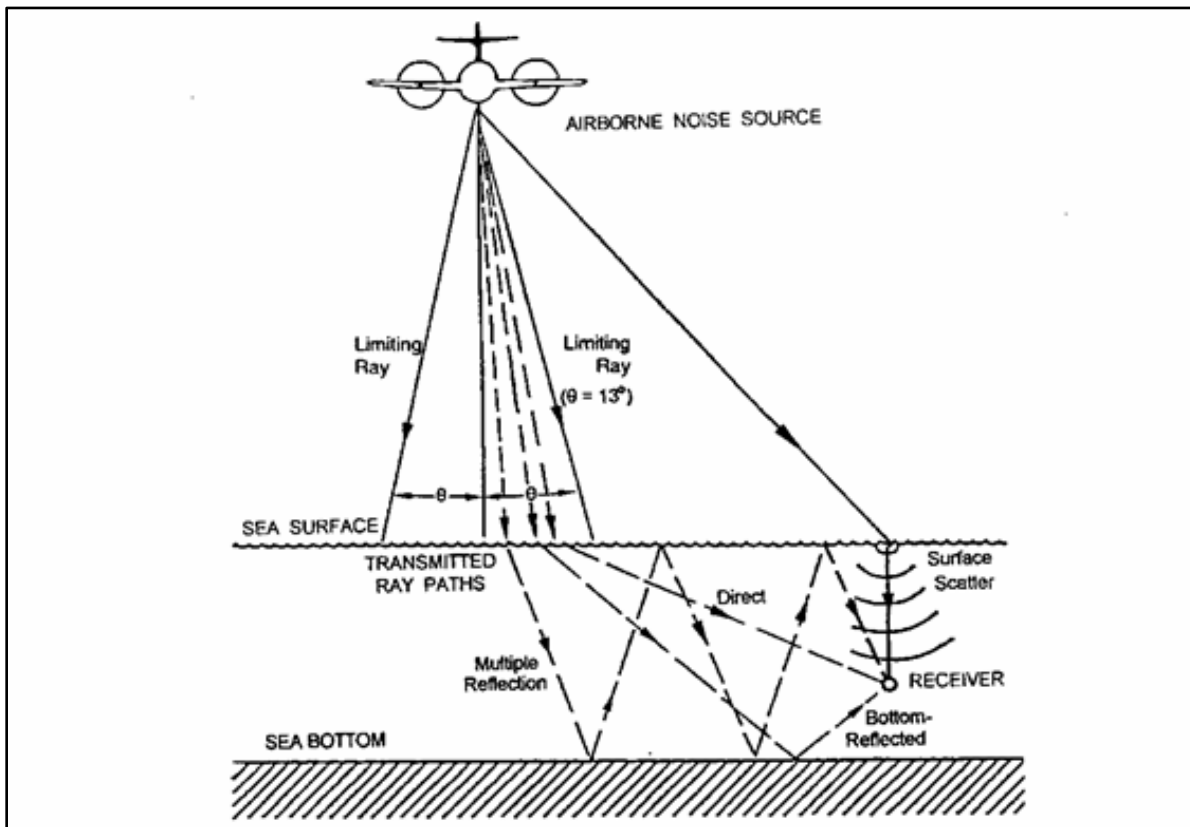
Sound from aerial sources such as aircraft and weapons firing may be transmitted into the water under certain conditions. The most studied of these sources are fixed-wing aircraft and helicopters, which create noise with most energy below 500 Hz. Underwater noise levels are highest at the surface and are highly dependent on the altitude of the aircraft, the angle at which the aerial sound encounters the water surface, and the amount of wave action and surface roughness. Transmission of the sound once it is in the water is identical to any other sound as described in the sections above.

Transmission of sound from a moving, airborne source to a receptor underwater is influenced by numerous factors and has been addressed by Young (1973), Urlick (1983), Richardson et al. (1995b), Eller and Cavanagh (2000), U.S. Department of the Air Force (2000), and others. Sound is transmitted from an airborne source to a receptor underwater by four principal means: (1) a direct path, refracted upon passing through the air-water interface; (2) direct-refracted paths reflected from the bottom in shallow

water; (3) evanescent transmission in which sound travels laterally close to the water surface; and (4) scattering from interface roughness due to wave motion.

At the air-water interface, sound can either be transmitted across the air-water boundary or reflected off the water surface. When sound waves meet the water at a perpendicular angle (e.g., straight down from an in-air source to a flat-water surface), the sound waves are both transmitted directly across the water surface in the same direction of travel and reflected 180 degrees back toward the original direction of travel. This can create a localized condition at the water surface where the incident and reflected waves sum, resulting in constructive interference, and doubling the in-air overpressure (+ 6 dB). As the incident angle of the in-air sound wave changes from perpendicular, this phenomenon is reduced, ultimately reaching the angle where sound waves are parallel to the water surface and there is no surface reflection.

The sound that enters the water is refracted due to the difference in sound velocity between air and water, as shown in Figure D.1-7. As the angle of the in-air incident wave moves away from perpendicular, the direction of travel of the underwater refracted waves becomes closer to parallel to the water surface. When the incident angle is reached, the underwater refracted sound wave is parallel to the water surface and all the sound is reflected into the air and no sound enters the water. This occurs at an angle of about 13 to 14 degrees. As a result, most of the acoustic energy is transmitted into the water through a relatively narrow cone extending vertically downward from the in-air source. The width of the footprint would be a function of the source altitude. Lesser amounts of sound may enter the water outside of this cone due to surface scattering (e.g., from water surface waves that can vary the angle of incidence over an area) and as evanescent waves that are only present very near the surface.



Source: (Richardson et al., 1995b)

Figure D.1-7: Characteristics of Sound Transmission Through the Air–Water Interface

If a sound wave is ideally transmitted into water (that is, with no surface transmission loss, due to foamy, wave conditions that could decrease sound entering the water), the SPL underwater is calculated by changing the pressure reference unit from 20 μPa in air to 1 μPa in water. For a sound with the same pressure in air and water, this calculation results in a +26 dB SPL in water compared to air. Sounds of equal intensity, however, will be 62 dB higher in water than in air. This is due not only to the difference in reference pressures, but also differences in impedance. For this reason, sound measurements in water and in air cannot be directly compared.

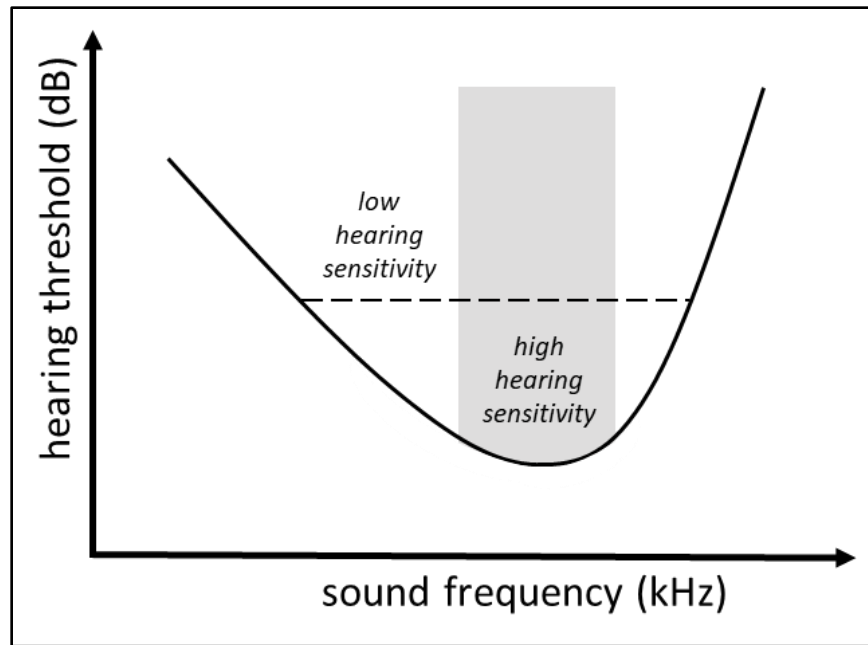
D.1.4 AUDITORY PERCEPTION

Animals with an eardrum or similar structure, including mammals, birds, and reptiles, detect the pressure component of sound. Some marine fishes also have specializations to detect pressure changes, although most invertebrates and many marine fishes do not have anatomical structures that enable them to detect the pressure component of sound and are only sensitive to the particle motion component of sound. This difference in acoustic energy sensing mechanisms limits the range at which fishes and invertebrates can detect most sound sources.

Because mammalian ears can detect large pressure ranges and humans judge the relative loudness of sounds by the ratio of the sound pressures (a logarithmic behavior), sound amplitude is described by the SPL, calculated by taking the logarithm of the ratio of the sound pressure to a reference pressure (see Section D.1.2.2, Sound Pressure Level). Use of a logarithmic scale compresses the wide range of pressure values into a more usable numerical scale. On the decibel scale, the smallest audible sound in air (near total silence) to a human is 0 dB re 20 μPa . If the sound intensity increases by a factor of 10, the SPL would increase to 10 dB re 20 μPa . If the sound intensity increases by a factor of 100, the SPL would increase to 20 dB re 20 μPa , and if the sound intensity increases by a factor of 1000, the SPL would be 30 dB re 20 μPa . A quiet conversation has an SPL of about 50 dB re 20 μPa , while a jet engine taking off 200 ft away is about 130 dB re 20 μPa (Cavanaugh & Tocci, 1998).

While sound pressure and frequency are physical measures of the sound, loudness is a subjective attribute that varies not only with sound pressure but also other attributes of the sound, such as frequency. For example, a human listener would perceive a 60 dB re 20 μPa sound at 2 kHz to be louder than a 60 dB re 20 μPa sound at 50 Hz, even though the SPLs are identical. This effect is most noticeable at lower SPLs; however, at very high SPLs, the difference in perceived loudness at different frequencies becomes smaller. This difference in perception for sounds having the same SPLs but different frequencies is related to the hearing capabilities of the individual or species.

The most accurate tests for determining the hearing capabilities of animals are direct measurements of auditory sensitivity. The two standard types of hearing tests are: 1) behavioral, where an animal is trained to provide a response to sound, and 2) physiological, where – without any training – the brain's responses to sound are measured (auditory-evoked potentials, or AEPs) (Finneran, 2015). During these tests, the sound is played at progressively lower levels until the animal can no longer hear it or until the brain's responses are no longer detected, and the hearing threshold in dB SPL is determined. The hearing threshold is the quietest audible sound, so a low hearing threshold indicates more sensitive hearing. When multiple frequencies are tested across the hearing range of an animal, a plot called an audiogram illustrates how hearing threshold changes as a function of sound frequency. An example of an audiogram is shown in Figure D.1-8.



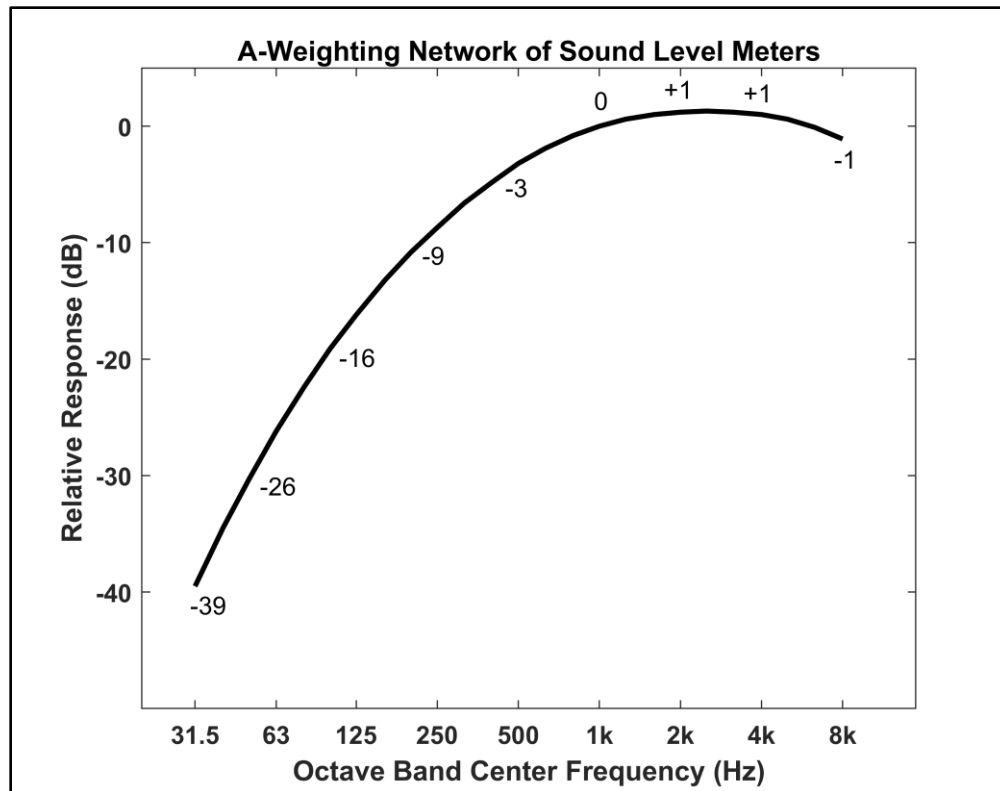
Notes: (dB = decibels; kHz = kilohertz) The area within the solid curve represents audible sounds. The dotted line illustrates that the listener is not as sensitive to frequencies on the tail ends of the curve as the frequencies that align with the bottom of the “U.” The shaded area is the frequency range with the lowest thresholds and highest hearing sensitivity, also called the region of best hearing. Marine mammal auditory sensitivity typically decreases more slowly at frequencies lower than the best frequency and decreases more quickly for frequencies higher than the best frequency.

Figure D.1-8: Example of an Audiogram

To account for differences in hearing sensitivity at various frequencies, acoustic risk analyses commonly use auditory weighting functions—mathematical functions that adjust (or “weight”) received sound levels with frequency based on how the listener’s sensitivity or susceptibility to sound changes at different frequencies. For humans, the most common weighting function is called “A-weighting” (see Figure D.1-9). A-weighted sound levels are specified in units of “dBA” (A-weighted decibels). For example, if the unweighted received level of a 500 Hz tone at a human receiver was 90 dB re 20 μ Pa, the A-weighted sound level would be 90 dB – 3 dB = 87 dBA because the A-weighting function amplitude at 500 Hz is -3 dB (Figure D.1-9). Many measurements of sound in air appear as A-weighted decibels in the literature because the intent of the authors is to assess noise impacts on humans.

The auditory weighting concept can be applied to other species. When used in analyzing the impacts of sound on an animal, auditory weighting functions adjust received sound levels to emphasize ranges of best hearing and de-emphasize ranges of less or no sensitivity. Auditory weighting functions were developed for marine mammals and sea turtles and are used to assess acoustic impacts. Additional information on auditory weighting functions and their derivation for this analysis are described in the *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase IV) technical report* (U.S. Department of the Navy, 2024a).

Masking occurs when noise interferes with the detection, discrimination, or recognition of the relevant sound or signal (Erbe et al., 2016). Auditory masking is defined as the amount in dB by which the threshold of hearing for one sound is raised by the presence of a masking sound (Acoustical Society of America, 2015). Masking occurs only in the presence of the masking noise and does not persist after the cessation of the noise.



Notes: (dB = decibels; Hz = hertz) The numbers along the curve indicate how a received sound level would be adjusted at that frequency.

Figure D.1-9: A-Weighting for Human Hearing of Sounds in Air (adapted from OSHA)

D.1.5 ACOUSTIC PROPAGATION IN SMALL TANKS

Although it is common to conduct bioacoustic research in small tanks with fishes, invertebrates, and other taxa, results from such experiments should be considered with caution due to the complicated acoustic fields that exist within small tank environments (Akamatsu et al., 2002). In a natural environment such as the open ocean, the particle velocity component of a signal contains more energy closer to the source (i.e., in the near field) compared to sound pressure. As sound propagates away from the source, this relationship shifts into a linear one as the two decay at the same rate in the far field. In a small tank, the acoustic field is complicated by boundaries, specifically the air-water interface at the walls and floor of the tank, and at the water surface (Akamatsu et al., 2002). These boundaries cause multiple overlapping reflections that alter the relationship between particle motion and sound pressure in the near field, attenuate the low-frequency components of the sound, and distort the directionality of the signal. As described in Section D.1.1.8, Resonance, it is known that small containers have resonant frequencies depending on their physical dimensions. When the acoustic signal used in an experiment overlaps that of the tank's resonant frequency, the sound is further distorted. Additionally, the physical dimensions of small tanks can be shorter than the wavelength of the signal used in bioacoustic experiments, further complicating the potential received signal. The placement of the sound source is also an important consideration as there is evidence that the source characteristics may vary at the receiver depending on whether the transducer is located in-water (within the tank) or in-air (adjacent to the tank) (Rogers et al., 2016). It is important for laboratory tests in small tanks to properly measure and characterize the sound field considering reverberations and refractions off the boundaries of the tank (Takahashi & Akamatsu, 2018), as well as the test subject itself (especially when using animals that

contain air filled organs). In the absence of such considerations, experiments conducted in small tanks may overestimate or mischaracterize the results.

D.1.6 EXPLOSIVES

Explosive materials used in Navy military readiness activities are either (1) high explosives (HE) material has a fast rate of detonation (exceeding the speed of sound), or (2) low explosives, which exhibit a relatively slow burn, or deflagration, such as black powder. Because low explosives are typically used in small quantities and have less destructive power, the below discussion focuses on high explosives.

The rate of detonation of a high explosive is supersonic and instantaneous, producing a steep, high-pressure shock wave that travels forward through explosive material. This shock front is produced by the supersonic expansion of the explosive products, but as the shock front travels away from the immediate area of the detonation, it begins to behave as an acoustic wave front travelling at the speed of sound.

The near-instantaneous rise from ambient to an extremely high peak pressure is what makes the explosive shock wave potentially damaging. Explosive exposures are usually characterized by the metrics of impulse and peak pressure. The positive impulse is calculated by integrating the positive pressure over the duration of the positive phase. The positive pressure produced by an explosion is also referred to as overpressure. As the shock front passes a location, the positive pressure exponentially decays, as shown in Figure D.1-10. As the shock front travels away from the detonation, the waveform is stretched—the peak pressure decreases while the positive duration increases. Both the reduction in peak pressure and stretching of the positive impulse reduce the potential for injury. In addition, absorption losses of higher frequencies over distance results in a softening of the shock front, such that the rise to peak pressure is no longer near instantaneous.

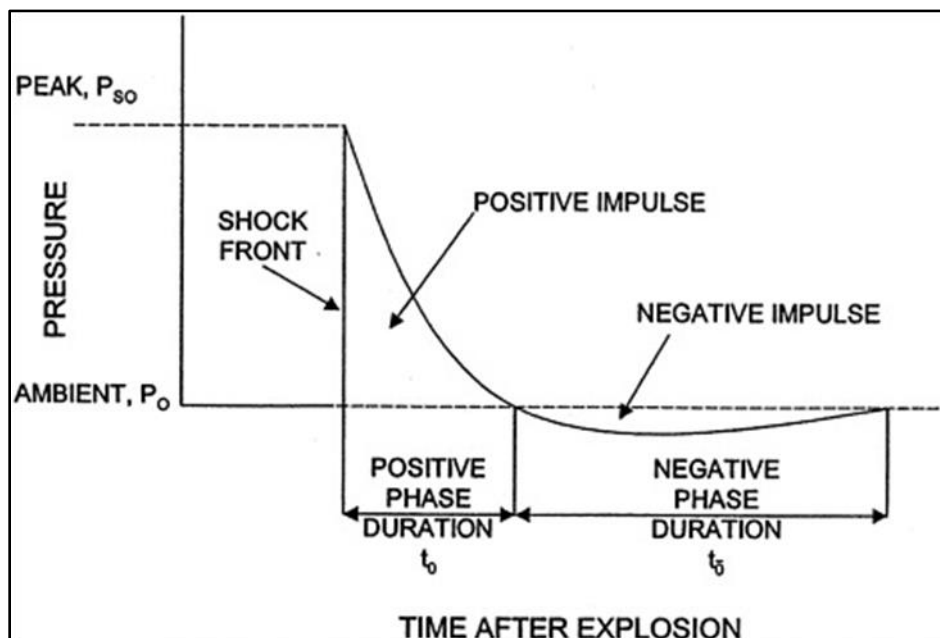


Figure D.1-10: Impulse Shown as a Function of Pressure over Duration at a Specific Location

The peak pressure experienced by a receptor (i.e., an animal) is a function of the explosive material, the net explosive weight (NEW), and the distance from the charge. NEW is a way to classify and compare quantities of different explosive compounds. The NEW for a given charge is the energetic equivalent

weight of trinitrotoluene (TNT). In general, shock wave effects near an explosive charge increase in proportion to the cube root of the explosive weight (Young, 1991). For example, shock wave impacts will double when the explosive charge weight is increased by a factor of eight (i.e., cube root of eight equals two). This cube root scaling relationship is known as the similarity principle and allows for a simple prediction of peak pressure in a uniform free field environment to estimate explosive effects in air and in water. However, at longer distances or in more complex environments with boundaries and variations in the propagation medium, explosive propagation modeling is preferred.

D.1.6.1 Explosions in Air

Pressure waves from explosions in air interact with the air-water boundary as previously described under Section D.1.3.4, Air-Water Interface. In certain explosive geometries, depending on the size of the explosive and its height of detonation, a combined shock wave, called a Mach stem, can be created when direct and reflected shock waves merge and form a single wave (Kinney & Graham, 1985). In instances where this specific geometry does not occur, only the direct path wave is experienced because there is no surface reflection (waves are parallel to or angled away from the water surface, such as would occur when an explosive is detonated at the water surface), or separate direct and reflected pressure waves may be experienced.

D.1.6.2 Explosions in Water

At the instant of explosion underwater, gas byproducts are generated at high pressure and temperature, creating a bubble. The heat causes a certain amount of water to vaporize, adding to the volume of the bubble. This action immediately begins to force the water in contact with the blast front in an outward direction, creating an intense, supersonic-pressure shock wave. As the high-pressure wave travels away from the source, it slows to the speed of sound and acts like an acoustic wave like other impulsive sources that lack a strong shock wave. Explosions have the greatest amount of energy at frequencies below 500 Hz, although energy is present at frequencies exceeding 10 kHz (Urlick, 1983). The higher frequency components exhibit more attenuation with distance due to absorption (see Section D.1.3.3.2, Absorption).

The shock wave caused by an explosion in deeper water may be followed by several bubble pulses in which the explosive byproduct gases expand and contract, with correlated high- and low-pressure oscillations. These bubble pulses lack the steep pressure front of the initial explosive pulse, but the first bubble pulse may still contribute to the total energy released at frequencies below 100 Hz (Urlick, 1983). Subsequent bubble pulses contribute little to the total energy released during the explosion (Urlick, 1983). If the detonation occurs at or just below the water surface, a portion of the explosive power is released into the air and a pulsating gas bubble is not formed.

The pressure waves from an explosive can constructively add or destructively cancel each other in ocean environments with multi-path propagation, as described for acoustic waves in Sections D.1.3.3.3, Refraction, and D.1.3.3.4, Reflection and Multipath Propagation. The received impulse is affected by the depth of the charge and the depth of the receiving animal. Pressure waves from the detonation may travel directly to the receiver or interact with the water surface or sea floor before arriving at the receiver. If a charge is detonated closer to the surface or if an animal is closer to the surface, the time between the initial direct path arrival and the following surface-reflected tension wave arrival is reduced, resulting in a steep negative pressure cut-off of the initial direct path positive impulse exposure. Two animals at similar distances from a charge, therefore, may experience the same peak pressure but different levels of impulse at different depths.

D.2 ACOUSTIC HABITAT

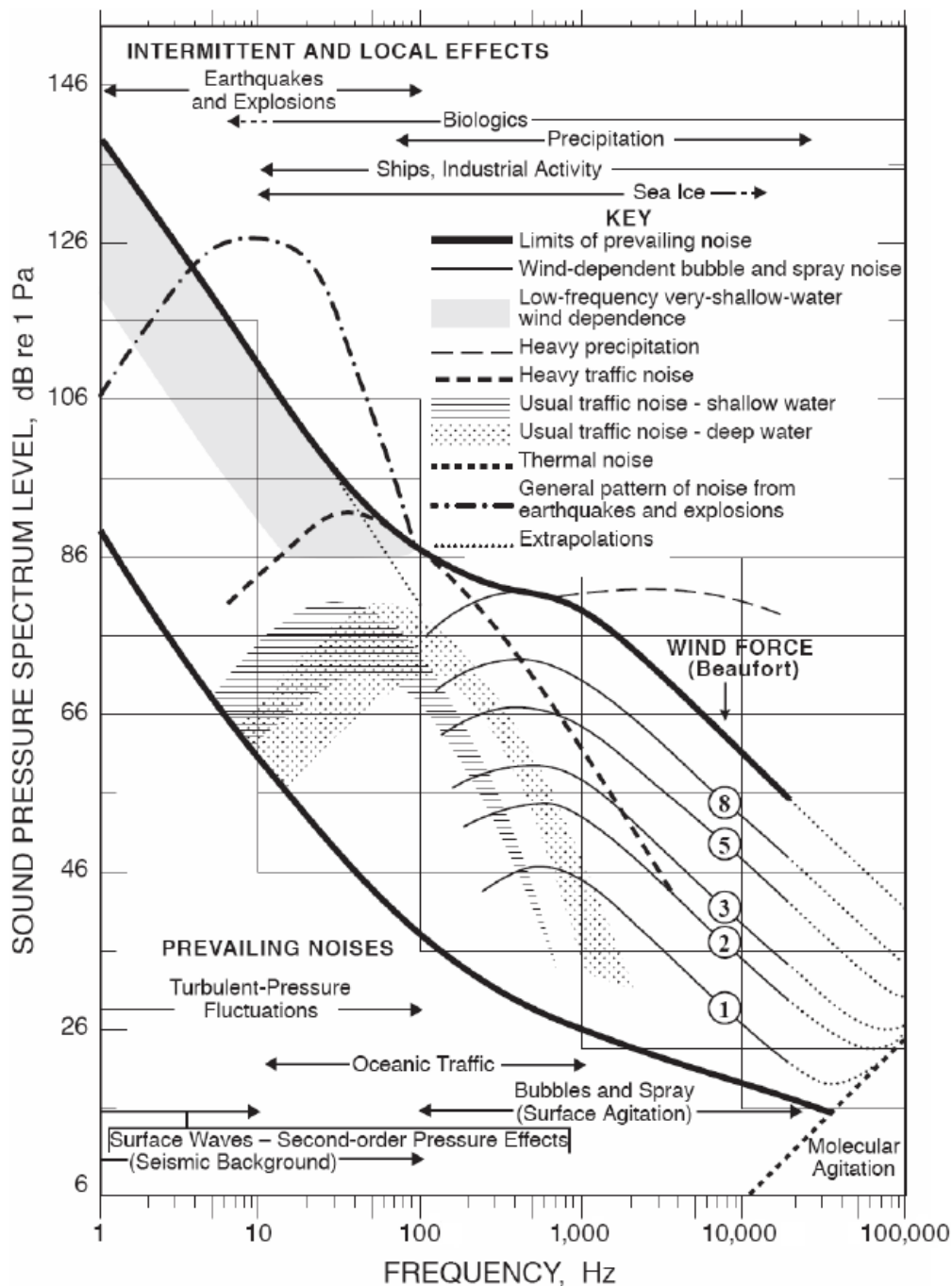
Ambient noise is defined as encompassing all noise at a specific location and time in the absence of a specified sound (International Organization for Standardization, 2017). Ambient noise is continuous and has considerable variation across time and space, varying by as much as 10 to 20 dB from day to day (Richardson et al., 1995b). The first systematic investigation of ambient noise was performed by Knudsen et al. (1948) and examined the relationship between noise level, wind speed, and sea state. Wenz (1962) expanded on the work by Knudsen et al. (1948) and described the spectra of natural and anthropogenic sources that contribute to noise in the ocean (Figure D.2-1). In general, the ambient noise spectrum can be broadly categorized into three frequency bands (Wenz, 1962). The low-frequency band (10 to 500 Hz) is dominated by shipping noise, the mid-frequency band (500 Hz to 25 kHz) is governed by surface agitation from wind and weather, and the high-frequency band (greater than 25 kHz) is influenced by thermal noise from molecular agitation of water molecules (particularly greater than 50 kHz). Despite changes in the ocean environment, the Knudsen Curves and Wenz Curves are still applicable and useful for understanding and estimating noise levels.

D.2.1 NATURAL NOISE

In underwater soundscape ecology, naturally occurring noise is categorized as geophony, which includes natural sounds of the earth (e.g., wind, waves, and earthquakes), and biophony, which includes sounds from living organisms (e.g., whales, fish, and snapping shrimp). Anthropophony (human generated signals) are not considered part of natural environmental noise. In the absence of distant shipping noise, natural sources dominate the long-term, time-averaged ocean noise across all frequencies. When distant shipping noise is present, natural sources continue to dominate time-averaged ocean noise spectra below 5 Hz and from around 500 Hz to over 200 kHz (National Research Council, 2003; Wenz, 1962). Prevalent sources of naturally occurring noise discussed in this section are generated by processes including wind, waves, rain, earthquakes, volcanoes, thermal noise, and biological sources.

D.2.1.1 Surface Interactions

Prevailing ambient noise associated with wind, waves, and rain has multiple contributing factors across a broad frequency range from below 1 Hz to at least 50 kHz (Figure D.2-1). Between 500 Hz and 25 kHz, ambient noise is governed by wind speed, sea state, and resulting surface agitation including air bubble cavitation and spray. At frequencies lower than 500 Hz, ambient noise is less correlated with wind speed and sea state, and as low as 50 to 100 Hz no relationship exists (Wenz, 1962). Noise from shipping and other anthropogenic activities become the prevalent sources of ambient noise at frequencies lower than 500 Hz and it is difficult to discern the impact of wind related noise at lower frequencies (Wenz, 1962). The wind-generated noise spectra for a given sea state (i.e., Beaufort 1, 2, 3, 5, and 8 in Figure D.2-1) have a slope of -5 dB/octave (e.g., a loss of 5 dB of sound energy for each doubled frequency range) or -18 dB/decade (e.g., a loss of 18 dB of sound energy for each tenfold frequency range) and a -29 dB in the spectra from 500 Hz to 25 kHz (Knudsen et al., 1948). Cavitating air bubbles that form near the surface and grow due to a process called rectified diffusion from pressure changes caused by waves, contribute to overall noise levels when bubbles collapse. Whitecaps and spray at the surface can increase estimated noise levels for a given Beaufort sea state in Figure D.2-1 by 4 to 5 dB when conditions are unusually windy, such as during a large storm (Knudsen et al., 1948). In contrast, estimated noise levels for a given Beaufort sea state may be lower than those in Figure D.2-1 when there is reduced spray and calm conditions.



Source: Wenz (1962)

Note: Hz = hertz; dB re 1 μ Pa = decibels with a reference of 1 micropascal (μ Pa)

Figure D.2-1: Wenz Curves Describing the Spectra of Ambient Ocean Noise

At frequencies below 10 Hz, surface gravity wave interactions create pressure fluctuations. First order pressure effects are due to the elevation and movement of water at the surface and causes subsurface pressure fluctuations below 0.3 Hz at less than 100 m depth (Wenz, 1962). Second order pressure effects occur when two surface waves with the same wavelength travel in opposite directions (e.g., from being reflected offshore). This magnifies the crests and troughs and form a standing wave with consistent

pressure across depth, and a frequency twice that of the two surface waves. The noise spectrum of a standing wave has a slope of -8 to -10 dB/octave in the frequency range from 1 to 10 Hz (Wenz, 1962).

Intermittent ambient noise from rain is affected by the rate of rainfall, droplet size, wind speed, and area covered. Together, these factors contribute to noise levels primarily above 500 Hz, however, noise levels can extend to lower frequencies (e.g., if heavy rainfall occurs with low wind speeds) (Wenz, 1962).

Underwater noise from rainfall is generated by the impact of droplets on the water surface, and by trapping a bubble underwater during a splash (Nystuen, 2001). Rain droplet size affects the underwater sound spectrum. Small droplets (0.8 to 1.2-millimeter [mm] diameter) have a strong signal in the spectrum from 13 to 25 kHz; medium droplets (1.2 to 2.0 mm diameter) have a signal from 1 to 30 kHz; large droplets (2.0 to 3.5-mm diameter) have a signal from 1-35 kHz with a peak in the spectrum at 2 to 5 kHz, and very large droplets (greater than 3.5-mm diameter) have a signal from 1-50 kHz with a peak in the spectrum from 1-2 kHz (Nystuen, 2001). During light rainfall, the ambient noise level can increase by 10 to 20 dB around 15 kHz (Nystuen & Farmer, 1987). In the 1 to 50 kHz range, heavy rainfall can increase the noise level up to 35 dB, and during extreme rainfall events (rate greater than 100 mm/hour) the noise level can increase up to 50 dB (Nystuen, 2001).

D.2.1.2 Biological Sources

Biological sources with an appreciable contribution to underwater ambient noise levels are briefly summarized here. Additional details on sounds from biological sources are provided in the sections below.

Marine mammal vocalizations cover a wide frequency range from less than 10 Hz to around 200 kHz. Broadband clicks and burst pulse signals produced by odontocetes can be used for echolocation, navigation, prey capture, and communication and have peak energy between approximately 10 and 150 kHz. Odontocetes also produce whistles for communication with fundamental frequencies between approximately 1 and 50 kHz. Vocalizations from mysticetes are lower frequency, from tens of Hertz to typically less than 10 kHz, and have the potential to be detected over long distances. For example, low-frequency blue whale calls can be heard by other whales up to 1,600 km away. An exception are humpback whales which can produce calls over 10 kHz (Zoidis et al., 2008) with harmonics up to 24 kHz (Au et al., 2006). Calls from mysticetes are diverse and complex in composition and are used for breeding, feeding, navigation, and communication. Depending on the timing and location, marine mammal vocalizations can be the dominant source of underwater noise in a region. For example, vocalizations produced by migrating mysticetes can seasonally increase ambient noise levels an average of 2 to 9 dB and up to 25 dB in the 15 to 22 Hz band (Curtis et al., 1999).

Many species of fish produce pulsed signals with most energy below 1 kHz for communication, courtship, mating, aggressive interactions, and when in distress (National Research Council, 2003). The occurrence of fish sounds can also exhibit diurnal, lunar, seasonal, and annual temporal variability. Sounds are produced by individuals, and collectively, many individuals produce choruses which can cause a sustained increase of 10-30 dB in ambient noise levels under 3 kHz (Cato, 1978; D'Spain & Batchelor, 2006).

Sounds from marine invertebrates are prolific in bays, harbors, estuaries, and coastal areas, and can be a major source of biological noise. Snapping shrimp produce high intensity, broadband impulses to communicate, deter predators, and stun prey. Sounds they produce have peak energy from 2 to 5 kHz with spectral components up to 250 kHz (Au & Banks, 1998) and can increase ambient noise levels up to 20 dB (Hildebrand, 2009). They occur in large aggregations in shrimp beds and are prevalent year-round in shallow and warm waters between +/- 40 degrees latitude (Knudsen et al., 1948). Snap rates are positively correlated with water temperature, and noise levels can vary up to 15 dB in the 1.5 to 20 kHz frequency band between winter and summer (Bohnenstiehl et al., 2015). Although sounds from snapping shrimp are the most prevalent, other marine invertebrates generate sounds as well. For example, sea urchins generate a scraping sound during feeding from 800 to 2,800 Hz (Radford et al.,

2008), and spiny lobsters generate broadband pulses called “antennal rasps,” potentially for intra-specific communication, with most energy below 1 kHz (Jezequel et al., 2022).

D.2.1.3 Geologic Activity

Geologic activity primarily contributes to ocean noise at frequencies less than 100 Hz. Earthquake generated acoustic waves in the ocean are called T-waves (tertiary waves) and produce intermittent sound at low frequencies. Earthquakes can occur under the ocean floor, or originate on land, and propagate between the land and ocean interface. Small earthquakes are more frequent and almost continuous in seismically active regions (e.g., the Mid-Atlantic Ridge and the East Pacific Rise). Recordings of earthquakes at the Mid-Atlantic Ridge have an estimated average source level between 199 and 234 dB re 1 μ Pa (Williams et al., 2006a), and a 20 dB increase in the ambient noise level has been observed in the 5 to 32 Hz band (McGrath, 1976). Active underwater volcanoes also generate low-frequency noise with most energy in the octave band centered near 10 Hz (Northrop, 1974).

D.2.1.4 Thermal Noise

Thermal noise is generated by pressure fluctuations from the thermal agitation (the movement of molecules due to energy transference) of water molecules. It is the remaining noise when all other sources are removed and provides a threshold on the minimum observable noise levels in the ocean. Thermal noise dictates the shape and level of ambient noise spectra above 50 to 100 kHz and causes an increase in ambient noise levels at rate of 6 dB/octave (Urick, 1983).

D.2.2 ANTHROPOGENIC NOISE

Marine species have existed, evolved, and adapted in the presence of naturally occurring noise for millions of years whereas the presence of anthropogenic noise is relatively recent, has intensified in the past century, and caused widespread alterations to the acoustic habitat (Duarte et al., 2021). Noise from human activities is often dynamic and few sources (e.g., shipping) have consistent inputs to the acoustic habitat. Anthropogenic noise varies widely in terms of frequency range, duration, and loudness and can have short-term and localized effects on acoustic habitats, as well as long-term effects over large areas. These characteristics strongly influence any potential impacts on marine species and their acoustic habitats. Prevalent sources of anthropogenic noise discussed in this section include vessel noise, sonar, explosions, and industrial activities.

D.2.2.1 Vessel Noise

Vessel noise is a major contributor to noise in the ocean. Radiated noise from ships varies depending on the size, hull design, type of propulsion, and speed. Ship-radiated noise increases with speed and primarily includes propeller blade tip and sheet cavitation (i.e., low pressure vortices shed by blade tips, and a sheet of bubbles on the back of the blade respectively), and broadband noise from water flowing across the hull (Richardson et al., 1995b; Urick, 1983). Based on these factors, vessel noise can contribute to ocean noise from 10 Hz to 10 kHz (Wenz, 1962). Different classes of vessels have unique acoustic signatures characterized by variances in dominant frequencies. Bulk carrier noise is predominantly near 100 Hz while container ship and tanker noise are predominantly below 40 Hz (McKenna et al., 2012). In comparison, small craft emit higher-frequency noise between 1 kHz and 5 kHz (Hildebrand, 2009).

Globally, commercial shipping is not uniformly distributed. Major shipping lanes typically follow great circle routes or coastlines and go to and from dozens of major ports, and hundreds of small harbors and ports. Most recreational boating occurs in shallow coastal waters whereas military, fishing, and scientific research vessels can be widely distributed (National Research Council, 2003).

Within the Study Area, commercial traffic is heaviest along the U.S. East Coast and the northern coast of the Gulf of Mexico, and follows distinct routes overseas and across the Gulf of Mexico (Mintz, 2012).

Figure D.2-2 highlights commercial routes along the East Coast of the U.S., the Bahamas, and great circle routes in the Atlantic Ocean. Navy vessel traffic in the Study Area (Figure D.2-3) is concentrated along the U.S. East Coast near port facilities, especially around and between the ports of Norfolk, Virginia and Jacksonville, Florida (Mintz, 2012; Mintz, 2016). Commercial traffic (and, therefore, broadband noise generated by it) is relatively steady throughout the year whereas Navy traffic occurs intermittently and is variable in duration. Within the Study Area, Navy vessels represent one percent of overall vessel traffic (Table D.2-1), with the other 99 percent of overall vessel traffic broken down by non-military vessel class in Table D.2-2. In terms of anthropogenic noise, Navy ships are engineered to be as quiet as possible given ship class limitations, and would contribute a correspondingly smaller amount of shipping noise compared to more common commercial shipping and boating (Mintz, 2012; Mintz & Filadelfo, 2011).

Table D.2-1: Overall Vessel Traffic in the Study Area

<i>Vessel Class</i>	<i>% of Traffic</i>
Non-Military	99%
U.S. Navy	1%
U.S. Coast Guard	< 1%
Foreign Military	< 1%

Source: Mintz (2016)

Note: % = percent; < = less than

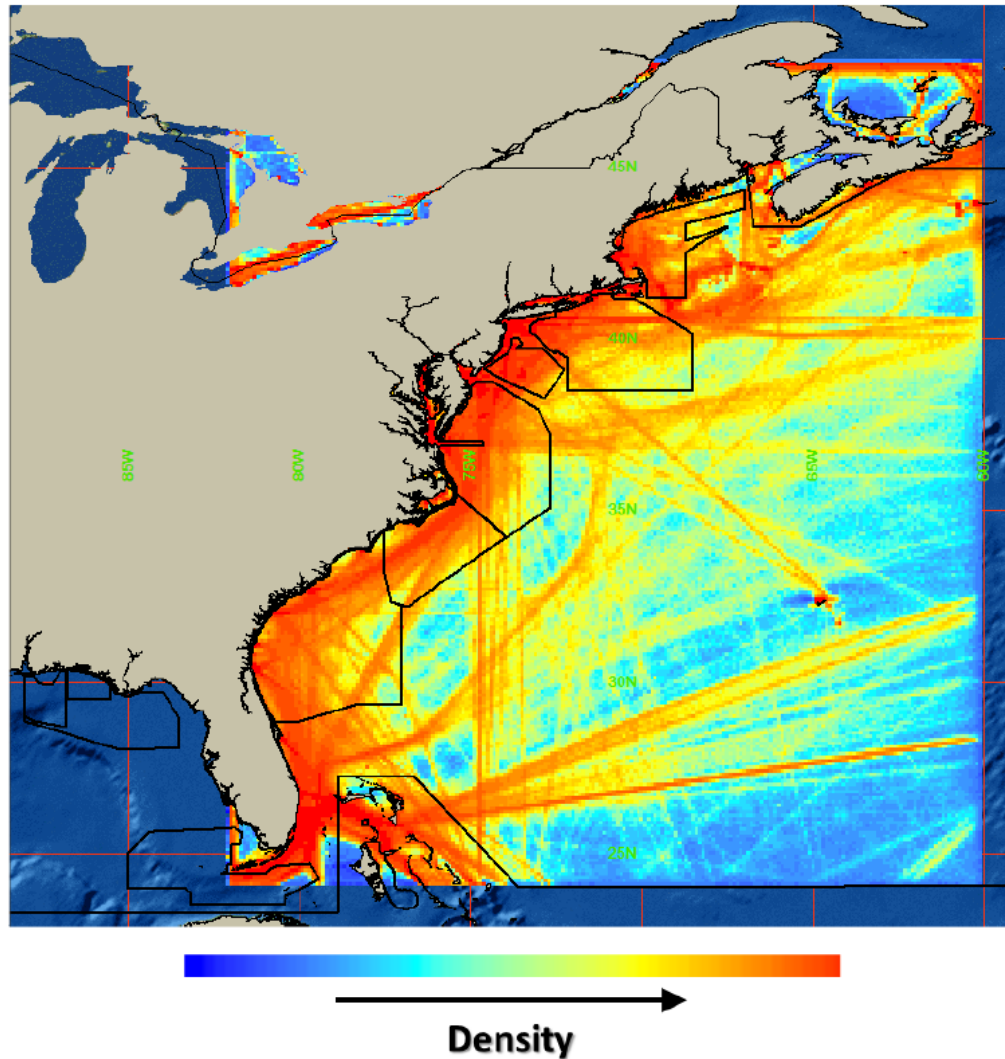
Table D.2-2: Non-Military Vessel Traffic in the Study Area

<i>Vessel Class</i>	<i>% of Traffic</i>
Tugs	24%
Cargo	17%
Other	14%
Fishing	11%
Tanker	11%
Bulk Carriers	9%
Passenger	8%
Service	5%
Research	1%

Source: Mintz (2016)

Notes: % = percent; < = less than

Spectral characteristics of individual ships can be observed at short ranges and in isolated environments. At long ranges, multiple vessels contribute to the overall background noise from ocean traffic in the 10 Hz to 1 kHz band (Figure D.2-1). In shallow water, vessel noise repeatedly interacts with the seafloor and surface and is attenuated by reflection, scattering, and absorption. In deep water, vessel noise propagates downward with fewer interactions with the seafloor and surface and undergoes less attenuation (Erbe et al., 2019). Low-frequency components of vessel noise can propagate long distances in deep water and can travel across ocean basins with minimal energy loss especially within the sound fixing and ranging (SOFAR) channel (Erbe et al., 2019). In areas with sloping bathymetry, vessel noise generated in shallow water can radiate into deeper water due to downward propagation and can couple into the SOFAR channel and propagate long distances (Erbe et al., 2019; Hildebrand, 2009). As a result, vessel noise generated in shallow nearshore waters can still be present in deep offshore waters many kilometers away from the source.

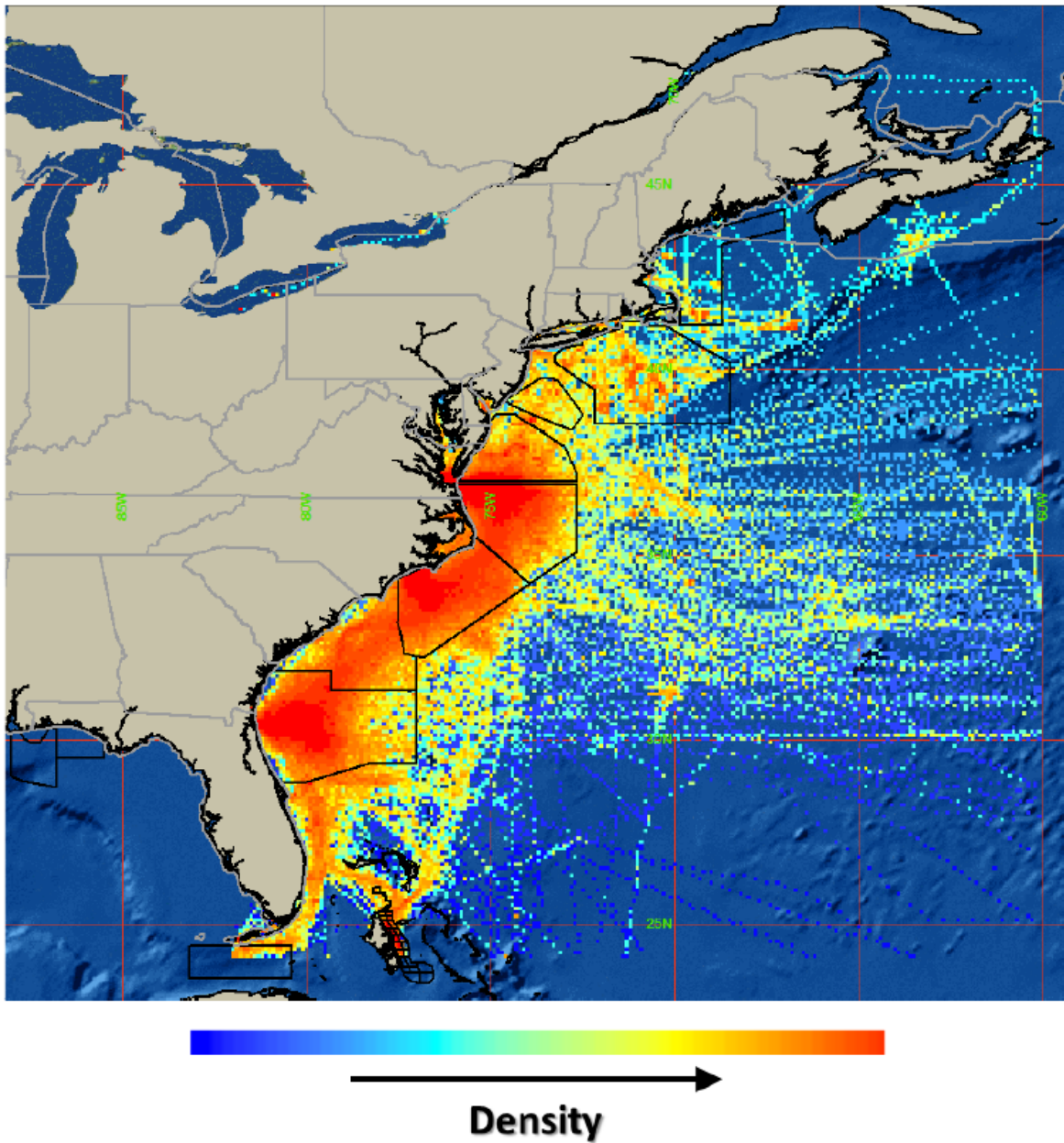


Source: Mintz (2016).

Figure D.2-2: Relative Distribution of Commercial Vessel Traffic in the Study Area

Commercial shipping's contribution to ambient noise in the ocean increased by as much as 12 dB between approximately the 1960s and 2005 and has been attributed to economic growth (Hildebrand, 2009; McDonald et al., 2008). Frisk (2012) confirmed the trend and reported that between 1950 and 2007 ocean noise in the 25 to 50 Hz frequency range has increased 3.3 dB/decade. Assuming a constant baseline level of 52 dB (decibels re $1 \mu\text{Pa}^2/\text{Hz}$) during this time results in a cumulative increase of approximately 19 dB. In areas with high levels of shipping traffic, daily average sound levels in the 63 and 125 Hz one-third octave bands were found to be near or higher than 100 dB re $1 \mu\text{Pa}$ (Haver et al., 2021). Daily average sound levels were between approximately 10 to 20 dB higher relative to areas with lower levels of shipping activity (Haver et al., 2021). Temporary reductions in vessel traffic following the events of September 11, 2001 showed an overall decrease of 6 dB (from 50 Hz to 20 kHz), with a notable decrease under 150 Hz (Rolland et al., 2012). Similarly, reduced vessel traffic at the onset of the COVID-19 pandemic resulted in a decrease of 1.5 to 1.7 dB (below 100 Hz) (Breeze et al., 2021; Dahl et al., 2021; Thomson, 2020). Reductions during the COVID-19 pandemic can be attributed to reduced economic activity and shipping (Thomson, 2020); however, noise levels were also subject to local

variations such as seasonal environmental conditions and the types of vessels active (Breeze et al., 2021; Dahl et al., 2021).



Source: Mintz (2016).

Figure D.2-3: Relative Distribution of U.S. Navy Vessel Traffic in the Study Area

D.2.2.2 Sonar

Active sonar and other transducers emit non-impulsive sound waves into the water to detect objects, safely navigate, and communicate. The contribution of sonar to the acoustic habitat is highly varied and depends on source characteristics (e.g., frequency, source level, directionality, and duty cycle) and factors that affect sound propagation (e.g., temperature, salinity, pressure, and bathymetry). Temporal and spatial usage are also highly varied and can range from minutes to approximately a month, and

from tens to hundreds of kilometers (National Research Council, 2003). Frequency ranges for categorizing sonars are relative, and generalized divisions that are commonly used include: low-frequency (less than 1 kHz), mid-frequency (1 to 10 kHz), high-frequency (10 to 100 kHz), and very high-frequency (greater than 100 kHz) (National Research Council, 2003). Given appreciable differences in usage and source characteristics, the contribution of sonar to the acoustic habitat is distinguished between military and commercial sonar systems.

Military sonar systems encompass all three frequency divisions and includes sources with wider beam widths and higher source levels compared with commercial sonar systems. Spatial and temporal usage is well defined both in terms of hours of operation, and the locations where activities occur. Activities are episodic and can last from hours, days to weeks, and over a month (National Research Council, 2003). Examples of military specific applications include low-frequency surveillance sonar, mid-frequency tactical sonar, and high-frequency sonar from weapons and countermeasures.

Compared with military sonar systems, commercial sonar systems use higher frequency signals, have lower source levels, narrower beam patterns that are downward directed, shorter pulse lengths, and are typically operated for minutes to days (National Research Council, 2003). Usage is widespread across locations and sectors including recreation, fishing, shipping, and research. Sources such as depth finders, multi-beam echosounders, and side-scan sonar are also utilized for military applications. Examples of common commercial sonar systems include depth finders and fish finding sonar (15 to 200 kHz) (Širović et al., 2020), both of which focus sound in a downward beam. Depth finders tend to be used in shallow and nearshore waters for navigation whereas fish finding sonar are operated in both shallow and deep waters. Sea floor mapping for seismic surveys and research utilize multi-beam echosounders (12 to 600 kHz) and side-scan sonar (65 to 500 kHz) (Crocker & Fratantonio, 2016; Ruppel et al., 2022).

D.2.2.3 Explosions

Underwater explosions generate broadband high intensity impulsive sounds that propagate equally in all directions. The spectral and amplitude characteristics of explosions vary with the weight of the charge and the depth of the detonation. Most energy is at lower frequencies from tens to hundreds of Hertz. Explosions are typically localized and propagate tens of kilometers, with the exception of acoustic tomography experiments that measure temperatures and currents over large regions of the ocean and can propagate hundreds to thousands of kilometers (National Research Council, 2003). Military applications of underwater explosives include bombs, mines, missiles, rockets, torpedoes, and projectiles. Spatial and temporal usage under the current action is well defined both in terms of counts of explosives, and the locations where activities occur. Commercial applications of underwater explosives include using explosives as an acoustic sound source for reflection seismology (i.e., rock/sediment penetration and determination) in geophysical exploration (i.e., oil and gas surveys) and for oceanographic research to study underwater acoustic tomography. The use of explosive sound sources for seismic surveys have largely been replaced by air guns due to environmental and handling safety concerns, as well as the lack of control when reproducing signals. Explosives are commonly used for decommissioning marine structures such as offshore oil and gas platforms by severing pilings and conductor pipes at the seafloor (Klima et al., 1988). In addition, small explosive charges known as seal bombs are commonly used by the fishing industry to protect fishing equipment and catch from predation by deterring marine mammals (Krumpel et al., 2021).

D.2.2.4 Industrial Activities

In many areas of the world, oil and gas seismic exploration in the ocean is undertaken using a group of air guns towed behind large research vessels. The air guns convert high-pressure air into very strong shock wave impulses that are designed to return information from the various buried layers of sediment under the seafloor. Most of the impulse energy (analogous to underwater explosions) produced by air guns is heard as low-frequency noise, which can travel long distances, especially in deep water. Most energy is below 200 Hz with additional energy extending to the kilohertz range (Greene & Richardson, 1988; Ruppel et al., 2022). Similar to air guns, other sources that generate an impulse for sub-bottom profiling include: boomers, which use an actuator to displace a near-surface and downward oriented metal plate; sparkers, which discharge a high voltage electric field to vaporize salt water; and bubble guns, which compress air within a plate or pair of plates (Crocker & Fratantonio, 2016; Ruppel et al., 2022). In the Study Area, seismic surveys are prevalent in the Gulf of Mexico Outer Continental Shelf, on the Atlantic Ocean Outer Continental Shelf from Delaware Bay to south of Cape Canaveral, and from the inner edge of federal waters to 403 miles offshore (Bureau of Ocean Energy Management, 2014). Seismic exploration surveys can encompass areas from tens of kilometers to over one hundred kilometers, and last from days to months (National Research Council, 2003).

The operation of offshore oil and gas extraction platforms produces nearly continuous noise primarily from 20 to 1,000 Hz (Greene & Richardson, 1988) and includes ancillary noise from support vessels and machinery. Oil and gas extraction is typically conducted on offshore platform rigs, drill ships, or artificial islands. Emplacement of permanent structures produces localized noise and lasts for weeks (National Research Council, 2003). Drill ships are generally the loudest with most broadband energy between 10 Hz and 10 kHz (Richardson et al., 1995b). This is because internal ship noise from machinery is effectively transmitted through the hull, and from the use of thrusters for dynamic positioning during drilling operations.

Pile driving is conducted for construction of nearshore structures such as piers, and for offshore structures including wind farm turbines and oil and gas platforms. Installing piles uses an impact hammer which results in an impulsive sound emanating from the length of the pile into the water column as well as from the bottom of the pile through the sediment. Because the impact wave travels through a steel pile at speeds faster than the speed of sound in water, a steep-fronted acoustic shock wave is formed in the water (Reinhall & Dahl, 2011). Piles can also be installed by vibratory pile driving and removed by vibratory extraction, which generates continuous non-impulsive noise with peak pressures lower than impact pile driving. Sound levels can vary depending on the size and power level of the equipment, pile material and diameter, and seafloor sediment type. Installation and removal can encompass areas from less than one kilometer to hundreds of kilometers, and near-continuous activity can last from days to months (National Research Council, 2003).

In the Study Area, the development of offshore wind farms is prevalent in waters between Massachusetts and North Carolina. The construction of offshore wind farms can take weeks to months to complete and produces localized low-frequency noise less than 2 kHz (Amaral, 2020). Most construction noise is produced from pile driving with ancillary noise from laying cable and support vessels. During operation, wind farms produce continuous low-frequency underwater noise primarily below 1 kHz, with tonals between 20 and 330 Hz (Pangerc et al., 2016).

D.3 VEGETATION

There is no evidence that underwater acoustic stressors impact marine vegetation under conditions they would experience with the Proposed Action. While there is at least one recent study (Solé et al., 2021) that documented a negative and non-trivial impact of sound on seagrass, the sound exposure was continuous for two hours at low frequencies and high intensities (157 to 175 dB re 1 μ Pa) in an artificial/tank environment (refer to Section D.1.5, Acoustic Propagation in Small Tanks, for context). The results of this study are not applicable to the proposed action due to either lack of proximity and/or duration of exposure. A prolonged exposure to sounds would only occur around highly modified pierside locations devoid of seagrass habitat. Elsewhere in the Study Area, seagrass may be exposed to distant and highly mobile sources of sound, but there would be no meaningful effects. Acoustic stressors were discounted for vegetation in the 2018 *Final Atlantic Fleet Training and Testing Environmental Impact Statement/Overseas Environmental Impact Statement* (hereinafter referred to as the 2018 Final EIS/OEIS) [Section 3.3.3.1](#) (Acoustic Stressors) and continue to be discounted for Section 3.4 (Vegetation).

D.4 INVERTEBRATES

The synthesis of information regarding acoustic stressors effects on marine invertebrates has not changed appreciably from what is described in the 2018 Final EIS/OEIS. The key synthesis papers recently published (Ferrier-Pages et al., 2021; Murchy et al., 2019; Solé et al., 2023c; Wale et al., 2021) mention most of the same studies referenced in the 2018 Final EIS/OEIS [Section 3.4.3.1](#) (Acoustic Stressors), and there is no recent research that suggests an escalation of noise effects on marine invertebrates under the mostly temporary and localized exposure they would experience from the Proposed Action stressors. Most of the studies were conducted on bivalves, cephalopods, and crustaceans. Relative few were conducted on gastropods, bryozoans, echinoderms, cnidarians, tunicates, and zooplankton.

Despite claims that anthropogenic noise effects on invertebrates are a direct indicator of ocean health (Solé et al., 2023c), the presentation of information does not support the claim. The synthesis papers often neglect to report the duration of exposures and ranges at which the stated effects occurred. They also mostly neglect to report details about the recovery of invertebrates from the stated effects. To address this deficiency, a summary and evaluation of the updated literature is presented under the following subsections: Sound Sensing and Production, Hearing Loss and Auditory Injury, and Masking.

With regards to Endangered Species Act (ESA)-listed or ESA-proposed invertebrates, recent literature was published for the taxonomic group that includes queen conch (gastropods). The information for acoustic and explosive stressor effects on corals in the 2018 Final EIS/OEIS remains valid for this Supplemental EIS/OEIS.

D.4.1 HEARING LOSS AND AUDITORY INJURY

The following studies provided updated information regarding the potential for temporary hearing loss among invertebrates exposed to acoustic stressors.

- Solé et al. (2021) investigated the effect of sinusoidal wave sweeps on a gastropod (apple snail, *Pomacea maculate*) and found damage to the statocysts. However, the experiment was conducted in tanks with exposures to 40 to 400 Hz sweeps at 157 dB plus or minus 5 dB re 1 μ Pa with peak SPL up to 175 dB re 1 μ Pa for two hours.
- Solé et al. (2023a) investigated the effect of artificial sound on the sea anemone (*Calliactis parasitica*) and its host the red hermit crab (*Dardanus calidus*) and found damage to statocysts.

However, the experiment was conducted in tanks with exposures to continuous 50 to 400 Hz frequencies at 157 plus or minus 5 dB re 1 μPa^2 with peak levels up to 175 dB re μPa^2 for two hours.

- Solé et al. (2023b) investigated the effect of natural sounds and sinusoidal wave sweeps on blue crabs and found some damage to sensory statocysts. However, the experiment was conducted in a tank maze with exposures to continuous 100 to 500 Hz sinusoidal wave sweeps at 171 dB re 1 μPa with peak levels up to 180 dB re 1 μPa for two hours.

These experiments and their results are consistent with the studies on squid, octopus, crabs, zooplankton, and jellyfish presented in the 2018 Final EIS/OEIS. The effects were from prolonged noise exposure at mostly very close ranges (e.g., tank dimensions) and attributable primarily to particle motion. Noise exposure experiments in small tanks and at a close distance are complicated (see Section D.1.5, Acoustic Propagation in Small Tanks). Small tanks are not representative of the natural environment because of how noise travels and interacts within the walls of the tank. While it is believed that invertebrates primarily detect particle motion (see Section D.1.4 Auditory Perception), an individual has to be in the near field of the sound source (see Section D.1.2.4, Particle Motion) to be impacted by the noise. In reality, very few individuals will be close enough to the sound source for them to be impacted in the ways suggested by these experiments. Not to mention that the small tanks may even amplify the effects well beyond what would be realistic in the natural environment.

D.4.2 MASKING

The following studies provided updated information regarding the masking effect of acoustic stressors on invertebrates.

- Anderson et al. (2021) evaluated the premature settlement response of reef-associated sessile invertebrate larvae to simulated anthropogenic noise at 1, 10, 25, 50, 100, 200, and 500 m. The noise source characteristics were recordings of pure tones of known frequency (100, 500, 1,000, 1,500, and 2,000 Hz) amplified to 180 dB re 1 μPa and played for 30 minutes at each distance. The After five consecutive nights of collecting invertebrate larvae settling on the bottom in otherwise quiet shallow-water reef environment, the effect of anthropogenic sound was considered not ecologically significant by the principal investigators. The results provide support for the general conclusion in the 2018 Final EIS/OEIS that the masking effect of Proposed Action sounds reaching shallow-water reef environments is likely negligible.
- Jézéquel et al. (2021) evaluated the sound production response of caged American lobsters to actual vessel noise. The noise was recorded in close proximity to their cages. The result indicates that lobsters significantly increase their call rate in the presence of shipping noise. The recordings included both periods of ambient soundscape properties (1 to 2 kHz with a mean SPL of 102.3 plus or minus 4 dB re 1 μPa) and periods of vessel activity (up to 146.2 dB re 1 μPa). Masking was assumed to some degree for lobster and other sound producing invertebrates in the 2018 Final EIS/OEIS, but the effect of the new information on the qualitative analysis is negligible.

D.4.3 BEHAVIORAL REACTIONS

The following studies provided updated information regarding the behavioral reaction of invertebrates to acoustic stressors.

- Charifi et al. (2018) investigated the effect of cargo ship noise and uptake of trace metal contaminants on Pacific oysters (*Magallana gigas*) and found decreased valve activity, resulting in lower metal contamination and decreased growth, with exposure to ship noise relative to no

ship noise. However, the study was conducted in a tank environment with recorded vessel noise (see Section D.1.5, Acoustic Propagation in Small Tanks). The noises recorded and played back were from cargo vessels approximately 500 m away that exposed the test organisms to 92 replicates of 12-minute noise exposures per day for 3 days.

- Hudson et al. (2022) investigated the effect of vessel noise and mid-frequency sonar on blue crabs (*Callinectes sapidus*) and found changes in competitive behavior. However, the experiment was conducted in tanks with exposures of 50 minutes to either sonar noise of 1.67 and 2.5 to 4 kHz at 177 to 182 dB re 1 μ Pa or vessel noise of 60 Hz to 1 kHz at 169 to 172 dB re 1 μ Pa.
- Jézéquel et al. (2022) evaluated the response of giant scallops (*Placopecten magellanicus*) to pile driving noise. The pile driving noise employed mimicked what happens during construction of off-shore wind turbines and induced repeated valve closure in giant scallops located 8 to 50 m from the driven pilings. The tested individuals returned to normal behavior after negligible acclimation to the episodic noises. Valve closure with pile driving was referenced in the 2018 Final EIS/OEIS, though little was said about the acclimation and return to normal behavior after the noise stopped.
- Solé et al. (2023b) investigated the effect of natural sounds and sinusoidal wave sweeps on blue crabs and found no impact on behavior from either treatment. However, the experiment was conducted in a tank maze with exposures of two hours to 100 to 500 Hz sinusoidal wave sweeps at 171 dB re 1 μ Pa with peak levels up to 180 dB re 1 μ Pa.

These experiments and their results are consistent with the studies on various crustaceans, squid, bivalves, and sea stars presented in the 2018 Final EIS/OEIS. The effects were from prolonged exposure at mostly very close ranges (e.g., tank dimensions) and attributable primarily to particle motion.

D.4.4 PHYSIOLOGICAL RESPONSE

The following studies provide updated information regarding the physiological responses of invertebrates to acoustic stressors.

- Charifi et al. (2018) investigated the effect of cargo ship noise and uptake of trace metal contaminants on Pacific oysters (*Magallana gigas*) and found lower growth rates (2.6 times slower) with exposure to ship noise relative to no ship noise. However, the study was conducted in a tank environment with recorded vessel noise. The noises recorded and played back were from cargo vessels approximately 500 m away that exposed the test organisms to 92 replicates of 12-minute noise exposure per day for 3 days.
- Wale et al. (2019) investigated the effect of ship noise playbacks on blue mussels and found higher breaks in the deoxyribonucleic acid (DNA), lower algal clearance rates and higher oxygen consumption rates. However, the study was conducted in a tank environment with recorded vessel noise. The noises recorded and played back were from ships approximately 200 to 300 m away that exposed the test organisms to a peak SPL of 150 to 155 dB re 1 μ Pa² relative to 85 to 95 dB re 1 μ Pa² during control conditions. The duration of passing vessel noise during the six hours of treatment exposure was not specified.
- Vazzana et al. (2020a) investigated the effect of linear chirp playback on Mediterranean mussel (*Mytilus galloprovincialis*) and found changes in biochemical and immunological parameters in their digestive glands. However, the experiment was conducted in tanks with continuous exposures of three hours to 100 to 200 kHz chirps at 145 to 160 dB re 1 μ Pa rms.

- Vazzana et al. (2020b) investigated the effect of playback noise on blue mussels (*Mytilus edulis*) and found changes in biochemical and immunological parameters in their digestive gland. However, the experiment was conducted in tanks with continuous exposures of three hours to 100 to 200 kHz noise at 145 to 160 dB re 1 μ Pa.
- Zhao et al. (2021) evaluated the effect of 10 days of simulated pile driving noise at received sound intensities of approximately 70 and 100 dB re 1 μ Pa on blue mussel attachment tissue. The results document a significant reduction in the secretion of attachment tissue and resulting strength of shell attachments. Whereas this may seem to contradict the observations reported in Horton (2016) that healthy shellfish populations exist around Navy piers subjected to regular piling replacement, the effects were observed after more continuous pile driving than is being proposed; the simulated noise was played on a loop for 10 days which does not simulate the sporadic nature of actual pile driving noise.
- Hudson et al. (2022) evaluated the response of blue crabs (*Callinectes sapidus*) and American lobsters (*Homarus americanus*) to simulated vessel and sonar noise. After 50-minute exposures to less than 1 kHz simulated vessel noise at 169 to 172 dB re 1 μ Pa (receptor exposure at less than 500 m from mid-sized container vessel), there was no effect on blue crab or lobster mortality and stress chemicals returned to normal level after 48 hours. However, there was evidence of elevated stress chemicals for seven days after blue crabs were exposed to simulated sonar for the same duration. The exposures were to one-second 1.67 kHz continuous wave pulses following by 2.5 to 4 kHz one-second chirps at 177 to 182 dB re 1 μ Pa (receptor exposure at some unspecified distance from Navy sonar). The results expand upon those of Dossot et al. (2017) that is referenced already in the 2018 Final EIS/OEIS, but they are not substantively different in terms of the qualitative factors employed for analysis.
- Olivier et al. (2023) investigated the effect of pile driving and drilling playback on king scallop (*Pecten maximus*) and found less than four percent mortality rates without any noise influence and an interactive impact on postlarval growth between trophic environment and noise level/spectra and no change in fatty acid profiles. However, the experiment was conducted in tanks with 6- and 19-hour exposures to continuous pile driving and drilling noise, respectively. The intensity of treatment sounds ranged from 147 to 187 dB re 1 μ Pa p-p for pile driving and 107 to 175 dB re 1 μ Pa rms for drilling.

These experiments and their results are consistent with the studies on various crustaceans and bivalves presented in the 2018 Final EIS/OEIS. The effects were from prolonged exposure and mostly at very close ranges (e.g., tank dimensions) and attributable primarily to particle motion.

D.4.5 LONG-TERM CONSEQUENCES

The following studies provide updated information regarding the long-term consequences of acoustic stressors on invertebrates.

- Hubert et al. (2022) evaluated the long-term response of blue mussels (*Mytilus edulis*) to repeated exposure with simulated impulsive noise. The results suggested habituation or sensory adaptation to the stressor. Habituation to noise was not referenced specifically in the 2018 Final EIS/OEIS, but the possibility of habituation was already included in the qualitative analysis.
- Jézéquel et al. (2023) exposed groups of longfin squid (*Doryteuthis pealeii*) in cages at multiple distances from consecutive pile driving events and quantified responses. Whereas there as a short-term alarm response to sound levels of 112 to 123 decibels referenced to 1 micrometer

per second squared ($\text{dB re } 1 \mu\text{ms}^{-2}$) (zero-peak), the individual rate of response quickly decreased within and across pile driving events. This is consistent with the information presented in the 2018 Final EIS/OEIS for long-term consequences.

D.5 FISHES

D.5.1 HEARING AND VOCALIZATIONS

All fishes have two sensory systems that can detect sound in the water (Popper et al., 2019; Popper & Schilt, 2008; Schulz-Mirbach et al., 2020). The first system discussed herein is the lateral line, which consists of a series of neuromasts (i.e., receptors) along the body that are directly exposed to the environment. When a vibration occurs within the water column that reaches the fish, the receptors along the lateral line move and this movement is transferred through the nervous system to the brain, where it is interpreted. These receptors are sensitive to external particle motion, specifically at frequencies up to 400 Hz (Coombs & Montgomery, 1999; Hastings & Popper, 2005; Higgs & Radford, 2013; Webb et al., 2008), created by sources within a few body lengths of an animal (i.e., in the near field, see Section D.1.2.4, Particle Motion, for additional information).

The second sensory system is the inner ear. The inner ear in fishes functions similarly to the inner ear in other vertebrates. Generally, the inner ears of bony fishes contain three dense otoliths (i.e., small calcareous bodies, although some fishes may have more) that sit atop many delicate mechanoelectrical hair cells within the inner ear. Underwater sound waves pass through the fish's body due to different structural densities (i.e., soft tissue versus bone) and vibrate the otoliths. As a result, sound waves cause relative motion between the dense otoliths and the surrounding tissues, causing movement of the hair cells back and forth, which is sensed by the nervous system like the stimulation of the receptors along the lateral line. Note, the inner ears are directly sensitive to acoustic particle motion like sensory receptors along the lateral line rather than acoustic pressure. However, some fishes possess morphological adaptations or specializations that can enhance their sensitivity to sound pressure, such as a gas-filled swim bladder (Astrup, 1999; Popper & Fay, 2010). The swim bladder can enhance sound detection by converting acoustic pressure into localized particle motion, which may then be detected by the inner ear (Radford et al., 2012). Fishes with a swim bladder generally have greater auditory sensitivity and can detect higher frequencies than fishes without a swim bladder (Popper & Fay, 2010; Popper et al., 2014). In addition, some fishes contain small horn-like projections that can either partially or fully connect the swim bladder and the inner ear increasing sensitivity and allowing for higher frequency detection (up to a few kilohertz or higher for some species) and better sound pressure detection (e.g., Vetter & Sisneros, 2020). For simplicity and consistency with terminology used in other taxa sections within this SEIS, and peer-reviewed research, acoustic detection capabilities by either sensory system will generally be described as 'hearing' throughout this discussion.

Propagating sound waves contain pressure and particle motion components but, particle motion is most prominent at low frequencies and is most detectable at high-sound pressures or very close to a sound source. Historically, studies have investigated acoustic detection (e.g., hearing research) and its effects on fishes. However, when exposed to a sound, often only sound pressure is measured and not particle motion. Although particle motion may be the more relevant exposure metric, few data are available that actually measure particle motion due to a lack of standard methodology and experience with particle motion detectors (Hawkins et al., 2015; Martin et al., 2016). In these instances, particle motion can be estimated from pressure measurements (Nedelec et al., 2016a). Similarly, although the lateral line likely plays a significant role in a fish's auditory capabilities, this portion of the sensory system is not always included in

hearing experiments. Due to the limited research on lateral line sound detection, the remainder of this section will be focusing on inner ear sound detection.

Although many researchers have investigated acoustic detection in fishes (Ladich & Fay, 2013; Popper et al., 2014), hearing data (i.e., audiograms) only exist for just over 100 of the estimated 36,000 species of fish worldwide (Fricke et al., 2020). Therefore, fish categories are defined by species that possess a similar continuum of anatomical features, which result in varying degrees of estimated acoustic detection capabilities (Popper & Fay, 2010; Popper & Hastings, 2009b; Schulz-Mirbach et al., 2020; Stanley et al., 2020; Wiernicki et al., 2020). Specifically, fishes with specialized adaptations connecting the swim bladder to the inner ear have traditionally been categorized as “hearing specialists,” while fishes that do not possess specialized structures or swim bladders have been referred to as “hearing generalists” (Popper et al., 2003). Specialists can detect a wide range of frequencies at lower sound levels (i.e., auditory thresholds) compared to generalists that typically detect a much narrower range of frequencies at higher sound levels. Categories and descriptions of the general acoustic detection capabilities for these groups are further defined in Table D.5-1 (modified from Popper et al., 2014). Additional research is still needed to better understand species-specific frequency detection capabilities and continues to help clarify how various anatomical features interact within the auditory system and influence overall sensitivity to sound.

Table D.5-1: Fish Hearing Groups and Categories

<i>Hearing Group</i>	<i>Fish Category</i>	<i>Description</i>
Hearing Generalists	Fishes without a swim bladder	Acoustic detection capabilities are limited to particle motion detection at frequencies well below 2 kHz (e.g., sharks, rays, and halibut).
	Fishes with a swim bladder not involved in hearing	Fishes lack notable anatomical specializations and primarily detect particle motion at frequencies below 2 kHz (e.g., salmonids, sturgeon, and groupers).
Hearing Specialists	Fishes with a swim bladder involved in hearing	Fishes can detect frequencies below 2 kHz, possess anatomical specializations to enhance hearing, and are capable of sound pressure detection up to a few kHz (e.g., herring, sardines, anchovy).
	Fishes with a swim bladder and with high-frequency hearing	Fishes possess anatomical specializations and are capable of sound pressure detection at frequencies up to 10 kHz, or over 100 kHz in some species (shad and menhaden).

Note: kHz = kilohertz

Data suggest that most species of marine fish are hearing generalists and either lack a swim bladder (e.g., sharks and flatfishes) or have a swim bladder not involved in acoustic detection (e.g., sturgeon and codfishes) and can only detect sounds below 2 kHz. Fewer marine fishes (Clupeiformes) are hearing specialists (i.e., those with a swim bladder involved in hearing). These species can detect sounds up to about 4 kHz (Colley et al., 2016; Mann et al., 2001; Mann et al., 1997; Mickle & Higgs, 2021). One subfamily of clupeids (i.e., Alosinae or shads) can detect high- and very high-frequency sounds (i.e., frequencies from 10 to 100 kHz, and frequencies above 100 kHz, respectively), although sensitivity at these higher frequencies are elevated and the range of best sensitivity is still in the low-frequency range (below 1 kHz) like other fishes. It was theorized that this subfamily may have evolved the ability to hear relatively high sound levels at these higher frequencies to detect echolocation signals of nearby foraging dolphins

(Mann et al., 1998; Mann et al., 1997). For fishes that have not had their hearing tested, such as deep sea fishes, the suspected hearing capabilities are based on the structure of the ear, the relationship between the ear and the swim bladder, and other potential adaptations such as the presence of highly developed areas of the brain related to inner ear and lateral line functions (Buran et al., 2005; Deng et al., 2011, 2013). It is believed that most fishes have their best sensitivity from 100 to 400 Hz (Popper et al., 2003). Seasonal variations in auditory sensitivity have been reported in some fishes, such as the plainfish midshipman, which have likely evolved to aid in reproductive behaviors (i.e., detection of suitable mates) (e.g., Rogers et al., 2022; Sisneros & Bass, 2003).

Bony fishes can produce sounds in several ways and use them for a variety of behavioral functions (Kasumyan, 2009; Ladich, 2008, 2014). The most common mechanism for sound production is when the swim bladder and other structures (often muscles that are associated with the swim bladder wall) vibrate and radiate sound into the water (Zelick et al., 1999). Additional mechanisms include, but are not limited to, muscular vibrations, rubbing, or plucking of pectoral fins (including the girdle, spines, or tendons) and grinding or rubbing of teeth, jaw apparatuses, or even bones in the skull (Kasumyan, 2008; Ladich, 2008). Over 30 families of fishes are known to produce acoustic signals in aggressive interactions, and over 20 families of fishes vocalize during courtship or mating (Ladich, 2008). Sounds generated by fishes as a means of communication are generally narrow band and below 500 Hz, though some acoustic signals have been recorded at frequencies up to 5,000 Hz (Kasumyan, 2008; Ladich, 2000; McCauley & Cato, 2000; Slabbekoorn et al., 2010). Acoustic signals may vary in source level depending on factors such as the sound production mechanism, species, size of fish, behaviors associated with the signal, and even environmental factors (Kasumyan, 2009). Some of the loudest recorded vocalizations are from fish choruses with approximate source levels up to 170 dB re 1 μ Pa (Erisman & Rowell, 2017; McCauley & Cato, 2000; McIver et al., 2014; Sisneros & Bass, 2003; Sprague & Luczkovich, 2004).

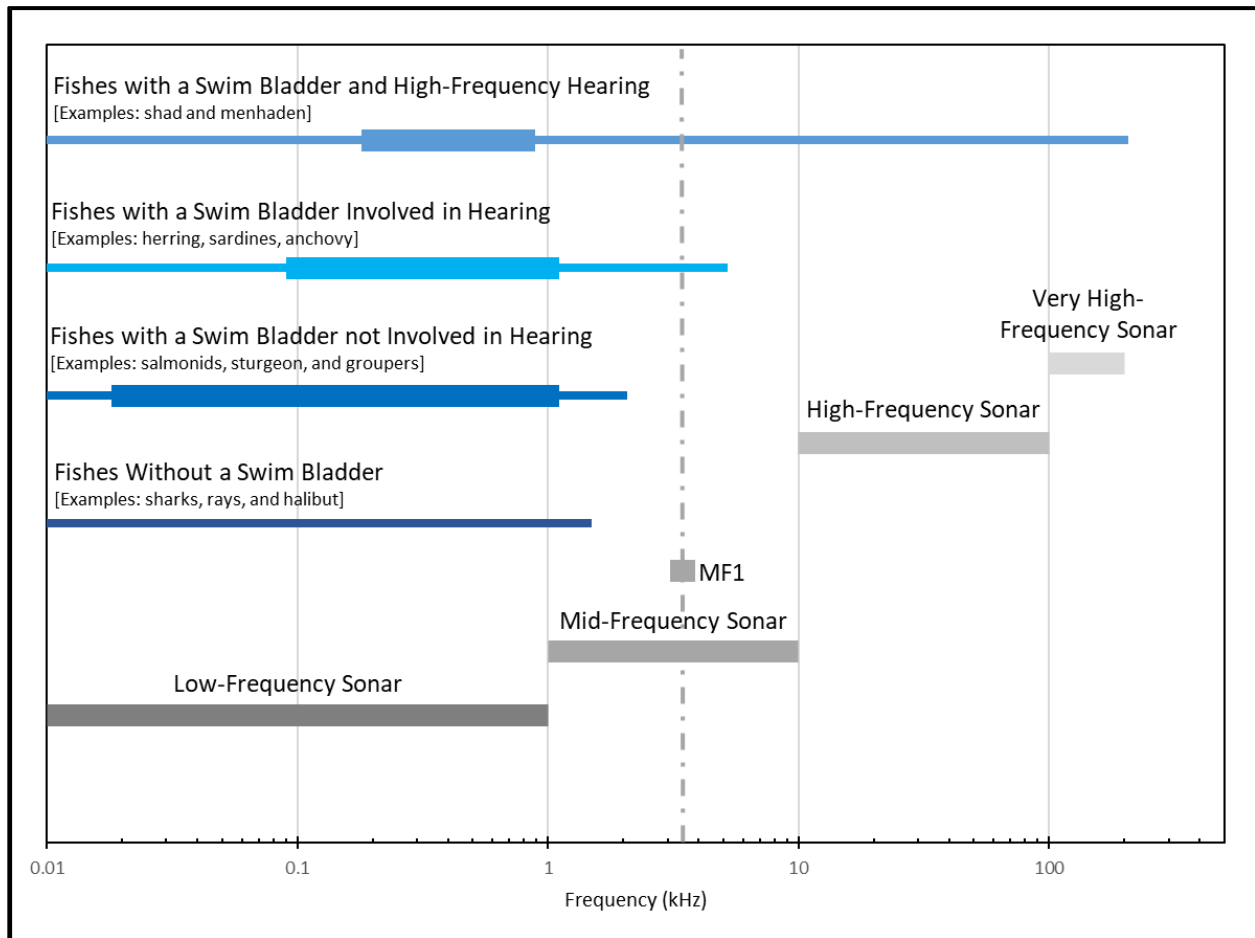
Combined research methods that utilize visual surveys (such as baited underwater video and monitoring by divers) and passive acoustic monitoring continue to reveal new sounds produced by fishes both in the marine and freshwater environments. Such experiments allow for specific behaviors to be paired with recorded signals, the identification of sex-specific vocalizations, and may be useful in determining more approximate estimates of the total number of soniferous (e.g., sound producing) fishes in a given habitat (Bussmann, 2020; Parmentier et al., 2021; Radford et al., 2018; Rountree et al., 2018; Rowell et al., 2020; Rowell et al., 2018).

D.5.1.1 Detection of Navy Sonars

As described above, fishes are not equally sensitive to noise at all frequencies. Figure D.5-1 provides a general summary of hearing threshold data from available literature (Casper & Mann, 2006; Deng et al., 2013; K  ver et al., 2014; Mann et al., 2001; Ramcharitar et al., 2006) to demonstrate the potential overlap of frequency detection for each fish category with Navy sonars. Fishes from all categories can detect broadband sound sources such as explosives or vessel noise. But, as displayed, not all fishes would detect some frequency-limited sources, such as high-frequency sonar.

Due to data limitations, these estimated ranges of frequency detection may be overly conservative in that they may extend beyond what some species within a given fish hearing category may detect. For example, although many sharks are most sensitive to lower frequencies, well below 1 kHz, the bull shark (*Carcharhinus leucas*) can detect frequencies up to 1.5 kHz (Kritzer & Wood, 1961; Myrberg, 2001), representing the uppermost known limit of frequency detection for this hearing category. These upper bounds of each fish category's frequency range are outside of the range of best

sensitivity for most fishes within that category. As a result, fishes within each group would only be able to detect those upper frequencies at close distances to the source, and from sources with relatively high source levels.



Notes: Thin blue lines represent the estimated minimum and maximum range of frequency detection for each fish category. All groups are assumed to detect frequencies down to 10 Hz regardless of available data. Thicker portions of each blue line represent the estimated minimum and maximum range of best sensitivity for that group. Not all fishes within a given category would be able to detect all the displayed frequencies. For example, flatfish such as halibut can only detect frequencies up to 270 Hz, although other fishes in the same hearing group can detect much higher frequencies (e.g., bull sharks can detect up to 1,500 Hz, the upper limit of the hearing group). Each sonar source class that occurs in the Study Area is represented graphically by the horizontal grey bars. Not all sources within each class would operate at all the displayed frequencies and may not overlap all fish hearing groups as demonstrated by the dotted grey line. kHz = kilohertz, MF1 = center frequency of 3.5 kHz.

Sources: Casper and Mann (2006); Chapman and Hawkins (1973); Chapman and Sand (1974); Hawkins and Johnstone (1978); Mann et al. (2005); Popper (2008); Popper et al. (2007); Tavalga and Wodinsky (1963)

Figure D.5-1: Fish Categories and Navy Sonars

D.5.2 HEARING LOSS AND AUDITORY INJURY

Impairment of auditory detection (more commonly referred to as hearing loss) or auditory injury will have an immediate effect on an animal's ability to detect certain frequencies. For this reason, hearing loss and auditory injury are often discussed together. However, the sensory hair cells of the inner ear and lateral line in fishes are regularly replaced over time when they are damaged, unlike in mammals

where sensory hair cells loss is permanent (Lombarte et al., 1993; Popper et al., 2014; Smith et al., 2006). Consequently, PTS has not been known to occur in fishes, and any hearing loss in a fish may be as temporary as the timeframe required to repair or replace the sensory cells that were damaged or destroyed (Popper et al., 2014; Popper et al., 2005; Smith et al., 2006).

Available data for some terrestrial mammals have shown signs of auditory injury in the form of nerve damage after severe threshold shifts (e.g., Kujawa & Liberman, 2009; Lin et al., 2011). In fishes, studies have observed cellular changes in hearing structures after long-term sound exposures (Sapozhnikova et al., 2020), as well as hair cell damage and tearing of the epithelial lining after exposure to underwater detonations at close range (Smith et al., 2022). However, it is not known if physical damage such as those described here would be recoverable in fishes (like hair cell regeneration noted in other studies), or if there would be hearing impairment. One of the few studies to look at both auditory sensitivity (measured by threshold shifts) and potential physical damage to the inner ear include research using zebrafish (*Danio rerio*, a freshwater hearing specialist) (Breitzler et al., 2020). The experiment demonstrated a lack of damage to sensory receptors when temporary threshold shift (TTS) occurred though this has not been investigated in marine species (for additional details on the results of this experiment, see D.5.2.2, Threshold Shift due to Vessel Noise).

D.5.2.1 Threshold Shift due to Sonar and Other Transducers

Several studies have examined the effects of the sound exposures from low-frequency sonar on fish hearing (Halvorsen et al., 2013; Kane et al., 2010; Popper et al., 2007). Hearing was measured both immediately post exposure and for up to several days thereafter (Halvorsen et al., 2013; Kane et al., 2010; Popper et al., 2007). Maximum SELs were 218 or 220 dB re 1 $\mu\text{Pa}^2\text{s}$ at frequencies ranging from 170 to 320 Hz (Kane et al., 2010; Popper et al., 2007) and 215 dB re 1 $\mu\text{Pa}^2\text{s}$ in a follow-on study (Halvorsen et al., 2013). Two hearing generalists, the largemouth bass (*Micropterus salmoides*) and yellow perch (*Perca flavescens*), showed no loss in detection sensitivity from sound exposure immediately after the test or 24 hours later. Channel catfish (*Ictalurus punctatus*), a hearing specialist, and some specimens of rainbow trout (*Oncorhynchus mykiss*), a hearing generalist, showed a threshold shift (up to 10–20 dB) immediately after exposure to the low-frequency sonar when compared to baseline and control animals. Small thresholds shifts were detected for up to 24 hours after the exposure in some channel catfish. Although some rainbow trout in one test group showed signs of TTS, rainbow trout in another group showed no TTS. Catfish hearing returned to normal within about 24 hours after exposure to low-frequency sonar. Examination of the inner ears of the fish during necropsy revealed no differences from the control groups in ciliary bundles or other features indicative of hearing loss.

The same investigators examined the potential effects of mid-frequency active sonar on rainbow trout and channel catfish hearing (Halvorsen et al., 2012c; Kane et al., 2010). The maximum received cumulative SEL was 220 dB re 1 $\mu\text{Pa}^2\text{s}$. No significant TTS was observed in rainbow trout. Of the catfish tested, only the group tested in October experienced TTS (6.35 dB), which recovered within 24 hours, but fish tested in December showed no TTS (Halvorsen et al., 2012c; Kane et al., 2010).

Some studies have suggested that there may be some loss of sensory hair cells due to high intensity sources, indicating a possible loss in hearing sensitivity; however, none of those studies investigated the subjects' actual hearing range after exposure to these sources. Enger (1981) found loss of ciliary bundles of the sensory cells in the inner ears of Atlantic cod (*Gadus morhua*), hearing specialists, following one to five hours of exposure to pure tone sounds between 50 and 400 Hz with a SPL of 180 dB re 1 μPa .

Hastings (1995) found auditory hair-cell damage in goldfish (*Carassius auratus*), a freshwater hearing specialist. Goldfish were exposed to 250 Hz and 500 Hz continuous tones with maximum peak SPLs of 204 dB re 1 μ Pa and 197 dB re 1 μ Pa, respectively, for about two hours. Similarly, Hastings et al. (1996) demonstrated damage to some sensory hair cells in oscars (*Astronotus ocellatus*) observed one to four days following a one-hour exposure to a pure tone at 300 Hz with an SPL of 180 dB re 1 μ Pa. Both studies found a relatively small percentage of total hair cell loss from hearing organs despite long-duration exposures. Effects from long-duration noise exposure studies are generally informative; however, they are not necessarily representative of effects from intermittent, short-duration exposures produced during Navy activities involving sonar and other transducers.

As noted in the *American National Standards Institute (ANSI) Sound Exposure Guideline* technical report (Popper et al., 2014), some hearing specialists may be more susceptible to TTS from high-intensity, non-impulsive sound sources, such as sonar and other transducers, depending on the duration and frequency content of the exposure. Fishes that are hearing specialists may exhibit TTS from exposure to low- and mid-frequency sonar, specifically at cumulative SELs above 215 dB re 1 μ Pa²s. However, hearing generalists would be unlikely to detect mid- or other high-frequency sonars and would likely require a much higher SEL to exhibit the same effect from exposure to low-frequency active sonar.

D.5.2.2 Threshold Shift due to Vessel Noise

There are only a few studies on the effects of vessel noise on hearing in fishes. For example, Rogers et al. (2020) examined the effects of vessel noise playbacks on the oyster toadfish, a hearing generalist. Toadfish were exposed to one of three noise conditions and hearing thresholds were measured before and multiple days (up to 9) after exposure. Two groups of fish were exposed to recorded boat noise (30 to 12,000 Hz frequency range) for either 1 or 12 hours continuously, and a third group was exposed to 12 hours of biological noise (male toadfish vocalizations, called boatwhistles, with a fundamental frequency of 180 Hz). SPLs for all noise conditions were maintained at approximately 150 dB re 1 μ Pa and fell within the oyster toadfish frequency sensitivity of 80-550 Hz. Exposures to biological signals, even for a duration of 12 hours, did not result in any hearing impairment. However, significant TTS of up to 8 and 20 dB was observed after exposures of 1 and 12 hours of vessel noise, respectively. More often, TTS has been studied in captive fishes exposed to elevated background noise and other non-impulsive, broadband¹ sources such as white noise (e.g., Breitzler et al., 2020; Scholik & Yan, 2002b; Smith et al., 2004b; Wysocki & Ladich, 2005).

Caged studies on hearing specialists show some hearing loss after several days or weeks of exposure to increased background sounds, although the hearing loss seems to recover (e.g., Breitzler et al., 2020; Scholik & Yan, 2002a; Smith et al., 2006; Smith et al., 2004a). Smith et al. (2006) and Smith et al. (2004a) exposed goldfish to noise with a SPL of 170 dB re 1 μ Pa and found a clear relationship between the amount of hearing loss and the duration of exposure until maximum hearing loss occurred 24 hours after exposure. A 10-minute exposure resulted in 5 dB of TTS, whereas a three-week exposure resulted in a 28 dB TTS that took over two weeks to return to pre-exposure levels (Smith et al., 2004a). Recovery times were not measured by investigators for shorter exposure durations.

Scholik and Yan (2001) demonstrated TTS in a hearing specialist, the fathead minnow (*Pimephales promelas*), after a 24-hour continuous exposure to white noise (0.3–2.0 kHz) at 142 dB re 1 μ Pa that took up to 14 days post-exposure to recover. This is the longest recorded time for a threshold shift to

¹ A sound or signal that contains energy across multiple frequencies.

recover in a fish. The same authors also found that the bluegill sunfish (*Lepomis macrochirus*), a generalist, did not show significant elevations in auditory thresholds when exposed to the same stimulus (Scholik & Yan, 2002b). This evidence supports that fishes that are hearing specialists may be more sensitive to hearing loss when exposed to noise than fishes that are hearing generalists.

Breitzler et al. (2020) exposed zebrafish (a freshwater hearing specialist) to 24 hours of white noise at various frequencies and sound levels. TTS was observed at frequencies that were within the fish's best hearing sensitivity. Recovery took up to 14 days for fish exposed to the highest SPL (150 dB re 1 μ Pa). The highest threshold shifts recorded (up to 33 dB) also resulted in significant hair cell loss, whereas lower exposure levels did not. Like the other effects measured in this study, hair cell loss attributed to the highest exposure level returned to baseline levels within 7 days post-exposure. This demonstrates the ability for fish to regenerate hair cells and for hearing thresholds to recover to baseline levels (lacking evidence of PTS).

Wong et al. (2022) exposed zebrafish to 24 hours of white noise with four different temporal patterns (continuous fast and slow, regular and irregular intermittent). Impacts from white noise at SPLs of approximately 150 dB re 1 μ Pa included noise induced hearing loss, physical damage, and behavioral responses (discussed further in Section D.5.4.1). Auditory evoked potentials were used to measure significant threshold shifts (an average of approximately 13 dB across all tested frequencies) for all four temporal patterns. Although significant hair cell loss was not found, other indications of physical damage were reported including decreased Ribeye b protein and splaying of inner ear epithelial. Wong et al. (2022) proposed that the total acoustic energy of a given signal may play a larger role in observed effects than the temporal patterns of the signal.

Although TTS has been reported in larval zebrafish as early as five days post fertilization exposed to white noise at frequencies below 1.5 kHz with a SPL of 150 dB re 1 μ Pa, the actual duration of the exposure was not reported (Lara et al., 2022). Unlike the previous study, an analysis of the change in hair cell numbers, epithelia area, and general hair cell density showed varying responses to the sound source. Overall, there were no significant reductions in hair cell density between noise and control groups.

A direct comparison of results from these studies to fishes exposed to continuous sound sources in natural settings should be treated with caution due to differences between laboratory and open ocean or coastal environments. For example, fishes that are exposed to noise produced by a vessel passing by in their natural environment, even in areas with high levels of vessel movement, would only be exposed for short durations (e.g., seconds or minutes) and therefore relatively low SELs by transiting vessels. Fishes used in laboratory experiments are often held in a tank during exposures without any possibility to avoid the noise source and test species are often freshwater hearing specialists (e.g., goldfish or zebrafish) due to ease of availability from commercial sources. Furthermore, small aquariums present issues when transmitting acoustic signals as there may be excessive particle motion not accurately measured and accounted for during the experiment (e.g., Okumura et al., 2002). As evidence suggests that fish can recover from hearing loss (both threshold sensitivity and actual physical damage) even after long duration exposures in a confined space, it also indicates similar results to lower level and shorter duration exposures. Therefore, overall effects would not likely rise to the level of impact demonstrated in the summarized laboratory studies.

As noted in the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014), hearing specialists may be more susceptible to TTS from long duration continuous noise, such as broadband white noise,

depending on the duration of the exposure (thresholds are proposed based on continuous exposure of 12 hours). However, it is less likely that TTS would occur in fishes that are hearing generalists.

D.5.2.3 Threshold Shift due to Impulsive Sound Sources

Popper et al. (2005) examined the effects of a seismic air gun array on a hearing specialist, the lake chub (*Couesius plumbeus*); and two hearing generalists, the northern pike (*Esox lucius*) and the broad whitefish (*Coregonus nasus*), a salmonid. In this study, fish were placed in pens in a shallow river (with water depths of 1.9 m) and exposed to either five or 20 shots from a nearby small air gun array (eight air guns total). Effects were noted at a cumulative SEL of 186 dB re 1 $\mu\text{Pa}^2\text{s}$, based on an exposure of five shots with a mean single strike SEL of 177 dB re 1 $\mu\text{Pa}^2\text{s}$ (Popper et al., 2014). Like most air gun signals, each shot lasted a few milliseconds with the 5 shot exposure likely lasting a few minutes based on the 15 minutes it took to expose fish to 20 shots (pulse length and pulse interval was not reported). TTS was reported in the lake chub and northern pike, but not in the broad whitefish. Approximately 20 to 25 dB of TTS was reported at some, but not all tested frequencies for both species, and full recovery from threshold shifts took place within 18 hours after sound exposure. Examination of the sensory surfaces of the ears after allotted recovery times (one hour for five shot exposures, and up to 18 hours for 20 shot exposures) showed no damage to sensory hair cells in any of the fish from these exposures (Song et al., 2008).

A small percent (2-15% depending on the region and test group) of sensory hair cells in the inner ear was observed in caged fishes exposed to multiple passes of a towed air gun array at distances from five to several hundred meters (McCauley et al., 2003; McCauley & Kent, 2012). Pink snapper (*Chrysophrys auratus*), a hearing generalist, were exposed to multiple air gun shots for up to one and one-half hours (McCauley et al., 2003) where the maximum received SELs exceeded 180 dB re 1 $\mu\text{Pa}^2\text{s}$. Though there were no long-term controls to compare to, the loss of sensory hair cells continued to increase for up to at least 58 days post exposure to 2.7 percent of the total cells. Gold band snapper (*Pristipomoides multidens*) and sea perch (*Lutjanus kasmira*), both hearing specialists, were also exposed to a towed air gun array simulating a passing seismic vessel (McCauley & Kent, 2012). Although received levels for these exposures have not been published, hair cell damage increased as the range of the exposure (i.e., distance to the source) decreased. Again, the amount of damage was considered small in each case (McCauley & Kent, 2012). It is not known if this hair cell loss would result in TTS since fish have tens or even hundreds of thousands of sensory hair cells in the inner ear and only a small portion were affected by the sound (Lombarte & Popper, 1994; Popper & Hoxter, 1984). A reason McCauley and Kent (2012) found damage to sensory hair cells, while Popper et al. (2005) did not, may be in their distinct methodologies. Their studies had many differences, including species and the precise sound source characteristics.

Hastings et al. (2008) exposed a hearing specialist, the pinecone soldierfish (*Myripristis murdjan*), and three hearing generalists, the blue green damselfish (*Chromis viridis*), the saber squirrelfish (*Sargocentron spiniferum*), and the bluestripe seaperch (*Lutjanus kasmira*) to a nearby active seismic survey. Fish were located at one of three test sites that varied in distance from the actual survey (approximately 45 m to several kilometers). Fish in cages were exposed to multiple air gun shots with a cumulative SEL of 190 dB re 1 $\mu\text{Pa}^2\text{s}$. The authors found no TTS in any fish examined up to 12 hours after the exposures.

In an investigation of another impulsive source, Casper et al. (2013b) found that some fishes may actually be more susceptible to barotrauma (e.g., swim bladder ruptures, herniations, and hematomas)

than effects to the auditory system when exposed to simulated impact pile driving. Hybrid striped bass (white bass *Morone chrysops* x striped bass *M. saxatilis*) and Mozambique tilapia (*Oreochromis mossambicus*), both hearing generalists, were exposed to SELs between 213 and 216 dB re 1 $\mu\text{Pa}^2\text{s}$. The subjects exhibited barotrauma, and although researchers began to observe signs of inner ear hair cell loss, these effects were small compared to the other non-auditory injuries that occurred. Smith et al. (2022) observed physical damage in the inner ear of a hearing generalist, Pacific mackerel (*Scomber japonicus*), exposed to underwater explosions starting at received peak to peak SPLs of 220 dB re 1 μPa . Though there are no direct measurements of TTS in fishes exposed to explosive sources, it is assumed that fish would demonstrate similar effects on auditory detection as those exposed to other impulsive sources such as those described above. These received sound levels likely represent thresholds at which hearing effects may occur.

PTS has not been known to occur in fishes tested to date. Any hearing loss in fish may be as temporary as the timeframe required to repair or replace the sensory cells that were damaged or destroyed (Popper et al., 2014; Popper et al., 2005; Smith et al., 2006). The lowest SEL at which TTS has been observed in fishes with hearing specializations exposed to air gun signals is 186 dB re 1 $\mu\text{Pa}^2\text{s}$. As reviewed in the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014), hearing generalists would be less susceptible to TTS than specialists, even at higher levels and longer durations. Fishes that are hearing specialists may be susceptible to TTS within very close ranges to an explosive.

D.5.3 MASKING

Masking is likely to occur in most fishes due to varying levels of ambient or natural noise in the environment, such as wave action, precipitation, or other animal vocalizations (Popper et al., 2014). Ambient noise during higher sea states in the ocean has resulted in masking in several fish species (Chapman & Hawkins, 1973; Ramcharitar & Popper, 2004). Although the overall intensity or loudness of ambient or human-generated noise may result in masking effects in fishes, masking is most problematic when human-generated signals or ambient noise levels overlap the frequencies of biologically important signals (Buerkle, 1968, 1969; Popper et al., 2014; Tavalga, 1974).

Auditory sensitivity can be hindered by masking noise. Wysocki and Ladich (2005) investigated the influence of continuous white noise on the auditory thresholds of two hearing specialists, the goldfish and the lined Raphael catfish (*Platydoras costatus*) as well as a hearing generalist, the pumpkinseed sunfish (*Lepomis gibbosus*). Experiments were conducted in aquariums. Continuous white noise with an SPL of approximately 130 dB re 1 μPa at 1 m resulted in 23–44 dB of masking within the goldfish and catfish region of best sensitivity between 500 and 1,000 Hz. The sunfish experienced only 11 dB of masking during the same noise treatment. In a similar study, meagre (*Argyrosomus regius*) exposed to boat noise at relative SPLs of 130 dB re 1 μPa showed a masking effect of up to 20 dB during presentation of the noise stimulus (Vieira et al., 2021). As seen in previous studies, fish calls were masked by up to 20 dB. Masked auditory thresholds were also measured in the croaking gourami (*Trichopsis vittata*, Osphronemidae) during playbacks of white noise at a relative SPL of 110 dB re 1 μPa (Maiditsch & Ladich, 2022). The experiment revealed a significant increase in auditory thresholds during noise presentations. Specifically, the largest effect was noted at frequencies that overlap with female pre-spawning purring vocalizations.

Masking could lead to potential fitness costs depending on the severity of the reaction and the animal's ability to adapt or compensate during an exposure (e.g., de Jong et al., 2020; Krahforst et al., 2016; Radford et al., 2014; Slabbekoorn et al., 2010). For example, masking could result in changes in

predator-prey relationships, potentially inhibiting a fish's ability to detect predators and therefore increase its risk of predation, or limiting a fish's ability to classify and locate prey items, reducing foraging success (e.g., Astrup, 1999; Mann et al., 1998; McCormick et al., 2018; Simpson et al., 2015; Simpson et al., 2016; Voellmy et al., 2014). Alternatively, if the masking noise overlaps the hearing range of fish predators (e.g., marine mammals) or their prey, this could be beneficial if the masking signal prevents predators from finding them or increases their chance of capturing prey items.

Masking may also limit the distance over which fish can communicate or detect important signals, including conspecific vocalizations such as those made during reproductive phases or sounds emitted from a reef for navigating larvae (Alves et al., 2016; Codarin et al., 2009; de Jong et al., 2020; Higgs, 2005; Krahforst et al., 2016; Neenan et al., 2016; Ramcharitar et al., 2006; Ramcharitar et al., 2001; Stanley et al., 2017; Vieira et al., 2021). If the masking signal is brief (a few seconds or less), biologically important signals may still be detected, resulting in little effect to the individual. If the signal is longer in duration (minutes or hours) or overlaps with important frequencies for a particular species, more severe consequences may occur such as the inability to attract a mate and reproduce. The Lombard effect has been reported in fishes (both in a laboratory setting and in situ) in an increasing number of experiments (e.g., Holt & Johnston, 2014; Luczkovich et al., 2016b; Somogyi & Rountree, 2023). The Lombard effect is defined as a potentially compensatory behavior where an animal increases the source level of its vocalizations in response to elevated noise levels. The Lombard effect is currently understood to be a reflex that may be unnoticeable to the animal, or it could lead to increased energy expenditure during communication.

Passive acoustic monitoring was conducted during several phases of an offshore windfarm installation project (Siddagangaiah et al., 2021). Installation and active use of the windfarm resulted in increased background noise levels as well as changes in fish chorusing patterns compared to baseline conditions in the Study Area. For example, type 1 choruses occurred for longer durations and at a lower intensity compared to pre-construction monitoring. Type 2 choruses showed an increase in intensity but no change in overall call duration during the same portion of the project installation. After construction was complete, residual effects on call duration and intensity were evident for Type 1 chorusing (increased call duration and intensity) though Type 2 chorusing did not seem affected and returned to baseline levels. Changes in fish vocal behavior may be affected to masking (the Lombard effect) or other factors such as disrupted group cohesion during periods of noise presentation. Although the construction noise included impact pile driving, it is difficult to distinguish whether these impacts were a result of the impulsive signals alone, or if noise from other parts of the activity (vessel movements, dredging, windmill operations) contributed changes in fish chorusing behavior. Additional research has shown that some, but not all species, respond to sound exposures with the Lombard effect (e.g., Brown et al., 2021; Maiditsch & Ladich, 2022).

The *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014) highlights the lack of data for masking by sonar but suggests that the narrow bandwidth and intermittent nature of most sonar signals would result in only a limited probability of any masking effects. In addition, most sonars (mid-, high-, and very high-frequency) are above the hearing range of most marine fish species (see Figure D.5-1), eliminating the possibility of masking for these species. In most cases, the probability of masking would further decrease with increasing distance from the sound source.

In addition, few data are available for masking by impulsive signals (e.g., impact pile driving and air guns) (Popper et al., 2014; Siddagangaiah et al., 2021). Impulsive sounds are typically brief, lasting only fractions of a second, where masking could occur only during that brief duration of sound. Biological

sounds can typically be detected between pulses within close distances to the source unless those biological sounds are like the masking noise, such as impulsive or drumming vocalizations made by some fishes (e.g., cod or haddock). Masking could also indirectly occur because of repetitive impulsive signals where the repetitive sounds and reverberations over distance may create a more continuous noise exposure. Currently there are no direct observations of masking in fishes due to explosives. The *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014) highlights a lack of data that exist for masking by explosives but suggests that the intermittent nature of explosions would result in very limited probability of any masking effects, and if masking were to occur it would only occur during the duration of the sound. Potential masking from explosives is likely to be like masking studied for other impulsive sounds such as air guns.

Although there is evidence of masking because of exposure to vessel noise, the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014) does not present numeric thresholds for this effect. Instead, relative risk factors are considered, and it is assumed the probability of masking occurring is higher at near to moderate distances from the source (up to hundreds of meters) but decreases with increasing distance (Popper et al., 2014).

D.5.4 BEHAVIORAL REACTIONS

Behavioral reactions of fishes have been observed across many types of sound sources. Most research has been performed using air guns (including large-scale seismic surveys), sonar, and vessel noise. Fewer observations have been made on behavioral reactions to impact pile driving noise and there are no data available on reactions to explosives, although fish are likely to show similar behavioral reactions to any impulsive noise.

Fish studies have identified the following behavioral reactions to sound: alteration of natural behaviors (e.g., startle or alarm), and avoidance (LGL Ltd Environmental Research Associates et al., 2008; McCauley et al., 2000b; Pearson et al., 1992). In the context of this Supplemental EIS/OEIS, and to remain consistent with available behavioral reaction literature, the terms “startle,” “alarm,” “response,” and “reaction” will be used synonymously. In addition, observed behavioral reactions to sound can include disruption to or alteration of swimming, schooling, feeding, breeding, and migrating. Sudden changes in sound level can cause fish changes in depth and swimming direction. However, some fish either do not respond, or learn to tolerate or habituate to the noise exposure (e.g., Brintjes et al., 2016; Currie et al., 2020; Hubert et al., 2020b; Nedelec et al., 2016b; Radford et al., 2016).

Research on behavioral reactions can be difficult to understand and interpret. For example, behavioral responses often vary depending on the type of exposure and sound source. Changes in sound intensity may be more important to a fish’s behavior than the maximum sound level. Some studies show that sounds that fluctuate in sound pressure level or have intermittent pulse rates tend to elicit stronger responses from fish than even stronger sounds with a continuous level (Currie et al., 2020; Neo et al., 2014; Schwarz & Greer, 1984). It has also been suggested that unpredictable sounds that last for long durations may have the largest impact on behavioral responses (de Jong et al., 2020). Interpreting behavioral responses can also be difficult due to species-specific behavioral tendencies, motivational state (e.g., feeding or mating), an individual’s previous experience, how resilient a species is to changes in their environment, and whether the fish are able to avoid the sound source (e.g., caged versus free-swimming subjects). Results from caged studies may not provide a representative understanding of how free-swimming fishes may react to the same or similar sound exposures (Hawkins et al., 2015),

especially when the experimental population consists of those species bred and raised in captivity (e.g., generations of captive zebrafish used in biological studies).

D.5.4.1 Behavioral Reactions to Sonar and Other Transducers

Behavioral reactions to sonar have been studied both in caged and free-swimming fish, although results can often-times be difficult to interpret depending on the species tested and the study environment. Jorgensen et al. (2005) showed that caged cod and spotted wolffish (*Anarhichas minor*) lacked any response to simulated sonar between 1 and 8 kHz. However, within the same study, reactions were seen in juvenile herring. It is likely that the sonar signals were inaudible to the cod and wolf fish (species that lack notable hearing specializations) but audible to herring (a hearing specialist).

Several experiments studied the reactions of both wild and captive Atlantic herring (*Clupea harengus*) to the Royal Netherlands Navy's experimental mid-frequency active sonar ranging from 1 to 7 kHz with maximum cumulative SELs of 184 dB re 1 $\mu\text{Pa}^2\text{s}$ (Doksaeter et al., 2009; Doksaeter et al., 2012; Sivle et al., 2015a; Sivle et al., 2012a). No avoidance or escape reactions were observed when herring were exposed to sonar sources and the authors concluded that the use of naval sonar poses little risk to populations of herring. Instead, significant reactions were noted at lower received sound levels of different non-sonar sound types. For example, dive responses (i.e., escape reactions) were observed when herring were exposed to killer whale feeding sounds at received SPLs of approximately 150 dB re 1 μPa (Sivle et al., 2012a). Startle responses were seen when the cages for captive herring were hit with a wooden stick and with the ignition of an outboard boat engine at a distance of one meter from the test pen (Doksaeter et al., 2012). It is possible that the herring were not disturbed by the sonar because they were more motivated to continue other behaviors such as feeding, or did not associate the sound as a threatening stimulus as they likely did for the killer whale and outboard motorboat signals.

Short et al. (2020) studied the effect of a broadband, pulsed, acoustically random noise exposure (60–2,000 Hz) on the swimming behavior of a captive freshwater shoaling species (Eurasian minnows, *Phoxinus phoxinus*, hearing specialists). In response to the noise exposure, group responses were more consistent in their escape behavior (e.g., startled, consistent speed, less erratic path, stronger group cohesion, more synchronized orientation) compared to fish tested individually. Although the pulsed tones were broadband, unlike most sonar sources that have a limited center frequency, the study provides insight into the differences in group versus individual reactions particularly for shoaling species.

There is evidence that elasmobranchs (cartilaginous fish including sharks and rays) also respond to human-generated sounds. A number of researchers conducted experiments in which they played back sounds (e.g., pulsed tones below 1 kHz) and attracted a number of different shark species to the sound source (e.g., Casper et al., 2012a; Myrberg et al., 1976; Myrberg et al., 1969; Myrberg et al., 1972; Nelson & Johnson, 1972). The results of these studies showed that sharks, hearing generalists, were attracted to irregularly pulsed low-frequency sounds (below several hundred Hz), in the same frequency range of sounds that might be produced by struggling prey. However, abrupt and irregularly pulsed human-generated noise (0.02–10 kHz, with most energy below 1 kHz) resulted in withdrawal responses of certain shark species (Chapuis et al., 2019). Sharks are not known to be attracted to continuous signals or higher frequencies that they presumably cannot hear (Casper & Mann, 2006; Casper & Mann, 2009).

Only a few species of marine fishes can detect sonars above about 2 kHz, meaning that most fishes would not detect most mid-, high-, or very high-frequency Navy sonars. The few marine species that can

detect above 2 kHz and have some hearing specializations may be able to better detect the sound and would therefore be more likely to react. However, researchers have found little reaction by adult fish in the wild to sonars within the animals' auditory detection range (Doksaeter et al., 2009; Doksaeter et al., 2012; Sivle et al., 2012a). The *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014) suggests that fish able to hear sonars would have a low probability of reacting to the source within near or intermediate distances (within tens to hundreds of meters) and a decreasing probability of reacting at increasing distances.

D.5.4.2 Behavioral Reactions to Vessel Noise

Vessel traffic contributes to the amount of noise in the ocean and has the potential to affect fishes. Several studies have reported and reviewed avoidance responses by fishes (e.g., herring and cod) to vessels or playbacks of vessel noise (De Robertis & Handegard, 2013; Engås et al., 1995; Handegard et al., 2003; Waddell & Sirovic, 2023). For example, Misund (1997) found fish showed avoidance reactions at ranges of 50 to 150 m ahead of the ship. When the vessel passed over them, some species of fish responded with sudden escape reactions that included lateral avoidance or downward compression of the school. In some rare cases, there have also been reports of fish attraction to traditional and unmanned underwater vessels (Fernandes et al., 2000; Rostad et al., 2006). Though the mechanism for this response is still unknown it is likely related to the type of fish (i.e., predators) and the way they interpret their environment. It is important to note that vessel noise alone may not be the only mechanism for some of these observed responses (De Robertis & Handegard, 2013). Rather, it is likely that other cues (e.g., visual cues, water displacement) play a large role in observed responses of fishes to passing vessels.

As mentioned above, behavioral reactions are variable depending on a number of factors such as (but not limited to) the type of fish, its life history stage, behavior, time of day, location, the sound source (e.g., type of vessel or motor vs. playback of broadband sounds), and the sound propagation characteristics of the water column (Popper et al., 2014; Schwarz & Greer, 1984). Reactions to playbacks of continuous noise or passing vessels generally include basic startle and avoidance responses. Other widely observed responses include: changes in vocalizations; modifications in movement patterns such as changes in vertical distribution in the water column, swim speeds, distance traveled or changes to group cohesion; modified attention or evidence of distractions; effects on foraging success and antipredator responses (e.g., Bracciali et al., 2012; Gendron et al., 2020; Handegard et al., 2015; Jimenez et al., 2020; Krahforst et al., 2016; Luczkovich et al., 2016a; Luczkovich et al., 2016b; Magnhagen et al., 2017; Mauro et al., 2020; Mills et al., 2020; Nedelec et al., 2017a; Neo et al., 2015; Roberts et al., 2016a; Simpson et al., 2015; Stasso et al., 2022; Vieira et al., 2021; Voellmy et al., 2014). Both playbacks and actual noise conditions from nearby boats have also resulted in alterations in reproductive and nesting behaviors; signaling and aggression towards potential mates, competitors, and conspecifics; diminished territorial interactions; and reduced parental care behaviors (Amorim et al., 2022; Butler & Maruska, 2020; McCloskey et al., 2020).

Behavioral responses may be dependent on the type of vessel to which a fish is exposed. For example, juvenile damselfish (*Pomacentrus wardi*) exposed to sound from a two-stroke engine resulted in startle responses, reduction in boldness (increased time spent hiding, less time exhibiting exploratory behaviors) and space use (maximum distance ventured from shelter or traveled within the test enclosure). However, damselfish exposed to sound from a four-stroke engine generally displayed similar responses as control fish exposed to ambient noise (e.g., little or no change in boldness) (McCormick et al., 2019). Although the two sound sources were very similar, the vessels powered by the four-stroke

engine were of lower intensity (i.e., less energy across all frequencies) compared to vessels powered by the two-stroke engine, which may explain the overall reduced response to this engine type.

Vessel noise may also lead to changes in anti-predator response, but these responses vary by species. During exposures to vessel noise, juvenile Ambon damselfish (*Pomacentrus amboinensis*) and European eels showed slower reaction times and lacked startle responses to predatory attacks. Subsequently these fish showed signs of distraction and increased their risk of predation during both simulated and actual predation experiments (Simpson et al., 2015; Simpson et al., 2016). However, it is not known if these responses would decrease over time as repeated measures were not performed. Juvenile Ambon damselfish showed a reduction in learned anti-predator behaviors likely because of distraction (Ferrari et al., 2018). Spiny chromis (*Acanthochromis polyacanthus*) exposed to chronic (12 consecutive days) boat noise playback spent less time feeding and interacting with offspring and displayed increased defensive acts. In addition, offspring survival rates were lower at nests exposed to chronic boat noise playback versus those exposed to ambient playback (Nedelec et al., 2017b). This suggests that chronic or long-term exposures could have more severe consequences.

In contrast to results from the previous study, larval Atlantic cod showed a stronger anti-predator response and was more difficult to capture during simulated predator attacks (Nedelec et al., 2015). There are also observations of a general lack of response to shipping noise (e.g., Higgs & Humphrey, 2019; Roberts et al., 2016b). Mensinger et al. (2018) found that Australian snapper located in a protected area showed no change in feeding behavior or avoidance during boat passes. Conversely, snapper in areas where fishing occurs startled and ceased feeding behaviors during boat presence suggesting that location and experience have a strong influence on whether fishes react.

Although behavioral responses such as those listed above were often noted during the onset of most sound presentations, most behaviors did not last long, and animals quickly returned to baseline behavior patterns. In fact, in one study with zebrafish, when given the chance to move from a noisy tank (with SPLs reaching 120–140 dB re 1 μ Pa) to a quieter tank (110 dB re 1 μ Pa SPL), there was no evidence of avoidance. The fish did not seem to prefer the quieter environment and continued to swim between the two tanks comparable to control sessions (Neo et al., 2015). However, many of these reactions are difficult to extrapolate to real-world conditions due to the captive environment in which testing occurred.

To investigate potential avoidance on a larger scale, Ivanova et al. (2020) tagged Arctic cod and recorded movement and behavior during exposure to noise produced by cargo and cruise ship traffic. Overall, cod increased their horizontal movement outside of their estimated home range when vessels were either present or moving, compared to periods where vessels were absent, indicating periods of potential avoidance. Changes in feeding, travel, and search behaviors were also observed when comparing each sound treatment. The authors note that future studies should continue to investigate whether these observed effects are prolonged or how quickly fish may return to their home range and baseline behaviors.

Most fish species should be able to detect vessel noise due to its low-frequency content and their hearing capabilities. The *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014) suggests that fishes have a high to moderate probability of reacting to nearby vessel noise (i.e., within tens of meters) with decreasing probability of reactions as distance from the source increases (hundreds or more meters).

D.5.4.3 Behavioral Reactions to Impulsive Noise

It is assumed that most species would show similar behavioral responses across all impulsive sounds, regardless of the source (e.g., weapons noise and explosions). Data on fish behavioral reactions exposed to impulsive sound sources is mostly limited to studies using caged fishes and seismic air guns and impact pile driving. General reactions include startle or alarm responses and increased swim speeds at the onset of impulsive sounds (Fewtrell & McCauley, 2012; Løkkeborg et al., 2012; Pearson et al., 1992; Roberts et al., 2016a; Spiga et al., 2017).

Several species of caged rockfish (*Sebastes* species), white trevally (*Pseudocaranx dentex*) and pink snapper (all hearing generalists) exhibited startle or alarm reactions to seismic air gun pulses between 180 dB re 1 μ Pa and 205 dB re 1 μ Pa peak-to-peak SPL (Pearson et al., 1992). More subtle behavioral changes were noted at lower SPLs, including changes in swim speeds. At the presentation of the sound, all three species moved to the bottom of the experimental enclosure. Both white trevally and pink snapper also exhibited changes in schooling behaviors including changes in group cohesion when exposed to air gun noise (Fewtrell & McCauley, 2012). These behavioral responses were seen during SELs as low as 147 and up to 161 dB re 1 μ Pa²s but habituation occurred in all cases, either within a few minutes or within 30 minutes after the final air gun shot (Fewtrell & McCauley, 2012; Pearson et al., 1992).

A study by a research group in the Netherlands conducted an in situ experiment and exposed tagged Atlantic cod to a simulated seismic survey event (Hubert et al., 2020a). Thirty six air guns were utilized in the array and the seismic event was conducted continuously over three-and-a-half days. The location was selected due to high site fidelity of cod in the areas immediately surrounding windfarm turbines in the North Sea and allowed the research group to monitor general movements patterns and overall behavior before, during, and after the survey. Cod were more likely to be inactive during sound exposures and immediately following the surveys, compared to baseline movement patterns (van der Knaap et al., 2021).

Some studies have shown a lack of behavioral reactions to air gun noise. The same research group in the Netherlands exposed cod to playbacks of an air gun in a large net pen (Hubert et al., 2020a). Unlike the study conducted in the North Sea, cod exposed in a net pen showed very little change in behavior or overall use of space within the pen. Herring exposed to an approaching air gun survey (from 27 to 2 km over 6 hours), resulting in single pulses of 125 to 155 dB re 1 μ Pa²s SEL, did not react (Pena et al., 2013). Although these levels are similar to those tested in other studies that exhibited responses (Fewtrell & McCauley, 2012), the distance of the exposure to the test enclosure, the slow onset of the sound source, and potential motivation for feeding may have affected the observed response (Pena et al., 2013).

Wardle et al. (2001) observed marine fish on an inshore reef before, during, and after air gun surveys at varying distances. The air guns were calibrated at a peak level of 210 dB re 1 μ Pa at 16 m and 195 dB re 1 μ Pa at 109 m from the source. Other than observed startle responses and small changes in the position of adult pollack (*Pollachius pollachius* [a hearing generalist]), when the air gun was located within 10 m of the test site, they found no substantial or permanent changes in the behavior of the fish on the reef (including juvenile saithe [*Pollachius virens*] and cod) throughout the course of the study. A similar study monitored species abundance, composition, behavior and movement patterns over the course of several months to capture long-term responses to a five-day seismic survey (Meekan et al., 2021). This study utilized multiple methods such as underwater baited cameras, tagging, and passive acoustic monitoring to understand each variable under investigation. Overall, the results suggested that

there was little, if any, short- or long-term impacts on the demersal fishes (i.e., those that hover slightly above the bottom) from exposure to the full-scale survey.

McQueen et al. (2022) tagged Atlantic cod (*Gadus morhua* L.) to analyze potential responses to a nearby seismic survey. Tagging and analysis was conducted over multiple years (2019–2021) in known spawning locations. Hydrophones and acoustic receivers were placed in two locations; the test site located close to the ‘racetrack’ where the seismic survey event occurred, and a control site in a nearby area but separated from the racetrack by islands and other features to prevent any sound exposure at this portion of the Study Area. Exposures consisted of a three-hour treatment period with active seismic signals present, and a three-hour control period where no seismic activity was detectable. These periods were repeated in random order over the course of a week in a given test year. SELs varied from 120 to 145 dB re 1 $\mu\text{Pa}^2\text{s}$ at the closest point at the treatment site to the seismic survey. Overall, spawning cod did not avoid the noise from the seismic survey and remained at the spawning site despite elevated sound levels. It is likely the cod’s preference for the spawning location motivated them to remain in the area despite the presence of the noise.

In contrast, other research on the effects of impulsive seismic survey sound that can last weeks to months has indicated that this level of behavioral response is unlikely (McQueen et al. 2022; Meeken et al. 2021). For example, Meekan et al. (2021) observed no short-term (days) or long-term (months) effects of exposure to the composition, abundance, size structure, behavior, or movement to assemblages of tropical demersal fishes, including hearing specialist species (e.g., Lutjanidae sp.), in Western Australia exposed to noise from a commercial-scale seismic air gun survey with received SELs of up to approximately 180 dB re 1 $\mu\text{Pa}^2\text{s}$. McQueen et al. (2022) examined the responses of spawning cod in the North Sea exposed to seismic air gun noise over two 1-week periods, with fluctuating SELs of up to 145 dB re 1 $\mu\text{Pa}^2\text{s}$, comparable to a full-scale industrial survey 5 to 40 km away (Handegard et al. 2003). Tagged cod in this study were not displaced from spawning grounds (McQueen et al. 2022). McQueen et al. (2022) speculated that strong affinity to selected spawning sites overcame the behavioral effects of stressor exposure. Although the sound source (i.e., seismic air guns) is not analogous to pile driving, they both produce high-intensity, impulsive sound primarily in the 100-Hz or lower frequency bands that overlap the spectral range of cod communication and hearing sensitivity and are informative in the absence of studies assessing the impacts of pile driving to Atlantic cod. Overall, these findings suggest that, although noise exposure during sensitive life stages is a potential concern, disturbances resulting from impulsive sound sources, such as pile driving or seismic air guns, may not necessarily result in adverse effects, such as the complete abandonment of an area for the duration of a spawning season versus temporary displacement or disturbance of Atlantic cod or other hearing specialist species.

Unlike the previously described studies, Slotte et al. (2004) used fishing sonar (38 kHz echo sounder) to monitor behavior and depth of blue whiting (*Micromesistius poutassou*) and Norwegian spring herring (hearing generalists) spawning schools during air gun exposures. They reported that fishes near the air guns appeared to move to greater depths after the air gun exposure compared to their vertical position prior to the air gun usage. Moreover, the abundance of animals 30–50 km away from the air guns increased during seismic activity, suggesting that migrating fish left the zone of seismic activity and did not re-enter the area until the activity ceased. It is unlikely that either species was able to detect the fishing sonar. However, it should be noted that these behavior patterns may have also been influenced by other variables such as motivation for feeding, migration, or other environmental factors (e.g., temperature, salinity).

Alterations in natural behavior patterns due to exposure to pile driving noise reported noted thus far are like those seen in response to seismic surveys. These changes in behavior include startle responses, changes in depth (in both caged and free-swimming subjects), swim speeds, group cohesion, and in attention and anti-predator behaviors, breaching, and directional avoidance (e.g., Hawkins et al., 2014; Kok et al., 2021; Mueller-Blenkle et al., 2010; Neo et al., 2015; Roberts et al., 2016a; Spiga et al., 2017). The severity of responses varies greatly by species and received SPL. For example, Neo et al. (2014) observed slower recovery times in fishes exposed to intermittent sounds (similar to pile driving) compared to continuous exposures. However, at some higher SPLs (152 - 157 dB re 1 μ Pa) some free-swimming fishes avoided pile driving noise (Iafrate et al., 2016). Using a baited remote underwater video Roberts et al. (2016a) showed that although multiple species of free swimming fish responded to simulated pile driving recordings, not all responded consistently. In some cases, only one fish would respond while the others continued feeding. In other instances, various individual fish would respond to different strikes. Similar results were reported at an existing windfarm in the Belgian part of the North Sea where tagged free-range Atlantic cod (*Gadus morhua*) showed no significant avoidance response to a largescale pile driving effort and a high variance in measured behavioral responses (van der Knaap et al., 2022). As part of the same experiment, echosounders also indicated that fish abundance and group cohesion changed when pelagic fishes were exposed to pile driving and seismic activities. However, the location of schooling fishes in the water column differed by sound source type, and some of these effects were also noted at the control site (i.e., no sound exposure) which may be explained by other abiotic factors such as seasonality (Kok et al., 2021). The repetition rate of pulses during an exposure may also influence what behaviors are observed during many of these experiments and how quickly these behaviors recovered as opposed to the overall sound pressure or exposure level (Neo et al., 2014).

As summarized in the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014), species may react differently to the same sound source depending on a number of variables, such as the animal's life stage or behavioral state (e.g., feeding, mating). Without specific data, it is assumed that fishes with similar hearing capabilities react similarly to all impulsive sounds outside the zone for hearing loss and injury. Observations of fish reactions to large-scale air gun surveys are informative, but not necessarily directly applicable to analyzing impacts from the short-term, intermittent use of all impulsive sources. It is assumed that fish have a high probability of reacting to an impulsive sound source within near and intermediate distances (tens to hundreds of meters), and a decreasing probability of reaction at increasing distances.

D.5.5 PHYSIOLOGICAL RESPONSE

Fishes naturally experience stress within their environment and as part of their life histories. To simulate physiological stress, it is common to test subjects using a variety of stimuli, such as predator vocalizations and anthropogenic noise exposures. The stress response in an animal is a suite of physiological changes that are meant to help an animal mitigate the impact of a stressor. However, if the magnitude and duration of the stress response is too great or too long, then it can have negative consequences to the animal (e.g., decreased immune function, decreased reproduction, increased likelihood of predation). The initial response to a stimulus is a rapid release of stress hormones into the circulatory system, which may cause other responses such as elevated heart rate and blood chemistry changes. A sudden increase in SPL (i.e., presentation of a sound source or acute/short-term exposure), increase in overall background noise levels, or long-duration or continuous exposures have been shown to cause stress, including measurements of biochemical responses and alteration of metabolic rates indicative of a stress response such as increased ventilation and oxygen consumption (e.g., Goetz et al.,

2015; Guh et al., 2021; Lara & Vasconcelos, 2021; Madaro et al., 2015; Pickering, 1981; Popper & Hastings, 2009a; Radford et al., 2016; Remage-Healey et al., 2006; Simpson et al., 2015; Simpson et al., 2016; Smith et al., 2004a; Smith et al., 2004b; Spiga et al., 2017; Wysocki et al., 2007; Wysocki et al., 2006). However, results from these studies have varied in part this is due the variety of stimuli used in a study as well as the complicated physiological responses each individual undergoes.

A common response that has been observed in fishes involves the production of cortisol (a stress hormone) when exposed to sounds such as boat noise, tones, or predator vocalizations. For example, Nichols et al. (2015) exposed the giant kelpfish (*Heterostichus rostratus*), a hearing generalist, to intermittent boat noise and found increased cortisol levels with increased sound levels. Cod exposed to a short-duration upsweep (a tone that sweeps upward) across 100–1,000 Hz showed increases in cortisol levels, which returned to normal one hour post-exposure (Sierra-Flores et al., 2015). Remage-Healey et al. (2006) found elevated cortisol levels in Gulf toadfish (*Opsanus beta* [a hearing generalist]), when exposed to low-frequency bottlenose dolphin sounds, but observed no cortisol change when exposed to low-frequency “pops” produced by snapping shrimp. Butler and Maruska (2020) exposed mouth-brooding freshwater female African cichlids (hearing specialist) to noise within their hearing range (0.1–2.0 kHz) for three hours and then measured the effects of sound on several factors, including cortisol levels. Like other findings, cortisol levels were higher immediately after exposure, in fish exposed to noise.

While studies have explored the impacts of vessel noise on hormones, results varied in that some fish species demonstrated increases in cortisol levels (Remage-Healey et al., 2006) and others showed no evidence of change (Mills et al., 2020). One study did show a change in androgen hormone levels in both male and female fish (Mills et al., 2020), however, the impacts of this change are unknown.

Smith et al. (2004b) found no increase in corticosteroid (a class of stress hormones) in goldfish exposed to a continuous, band-limited noise (0.1–10 kHz) at 170 dB re 1 μ Pa SPL for one month. Wysocki et al. (2007) exposed rainbow trout to continuous band-limited noise with an SPL of about 150 dB re 1 μ Pa for nine months with no observed stress effects (i.e., growth rates and secondary stress measures via blood samples). Growth rates and effects on the trout’s immune systems were not significantly different from control animals exposed to 110 dB re 1 μ Pa SPL. In addition, although there was a difference of 10 dB in overall background level and boat activity between test sites, reef fish (*Halichoeres bivittatus*) showed similar levels of whole-body cortisol (Staatterman et al., 2020). This suggests that boat noise, in this context, was not as stressful as handling of the fish for this experiment and contradicts previous conclusions that follow similar study designs.

Kusku (2020) measured respiratory changes as secondary indicators of stress in Nile tilapia (*Oreochromis niloticus*) to determine potential effects of long-term exposure to underwater sound playback, including shipping noise. Fish exposed to noise showed as much as a two-fold increase in respiratory indicators (opercular beat rate and pectoral wing rate) after 10 minutes of sound exposure as compared to controls and pre-exposure rates. Over the next 120 days of continuous sound exposure, respiratory indicators declined steadily and returned to baseline. The authors conclude that the data support habituation of fish to chronic noise exposure.

Zhang et al. (2022) studied the effects of simulated ship noise on liver metabolite production and gene expression of hybrid sturgeon (*Acipenser baerii* \times *A. schrenckii*). During continuous exposure to underwater noise (12 hours), cell motility increased, while protein synthesis (the process of creating protein in the body) and several metabolic pathways were inhibited. Results suggested that immune

response was initiated when exposed to underwater noise stress and that immune-related pathways were activated to protect the normal activities of the fish, despite evidence that underwater noise may have caused some inflammatory responses.

Factors such as early-stage development or survival rates as indicators of stress from a given noise exposure have also been investigated. For example, reef fish embryos exposed to boat noise have demonstrated changes in morphological development and increases in heart rate, another indication of a physiological stress response, although survival rates were unchanged (Fakan & McCormick, 2019; Jain-Schlaepfer et al., 2018). Faria et al. (2022) found evidence of detrimental effects of chronic boat noise on wild Lusitanian toadfish (*Halobatrachus didactylus*) development, and of increased physiological stress assessed by oxidative stress and energy metabolism biomarkers. It has been shown that chronic or long-term (days or weeks) exposures of continuous man-made sounds can also lead to a reduction in embryo viability, decreased growth rates, and early mortality including in larvae and fishes infected with parasites (Lara & Vasconcelos, 2021; Masud et al., 2020; Nedelec et al., 2015; Sierra-Flores et al., 2015). Furthermore, Masud et al. (2020) found that guppies exposed to 24 hours of broadband white noise showed increased disease susceptibility compared to those exposed for longer durations (up to 7 days).

Contrary to previous findings, meagre larvae and embryos showed little change in development after exposure to playbacks of boat noise. Specifically, eggs were either provided with either a silent treatment (the controls) or exposed to playbacks of boat noise. On average, playback levels were 25 dB higher than control conditions. Overall, boat noise did not affect measured stress or development responses such as hatching rate, larval size, and yolk sack area. Effects that were noted, such as the size of the lipid droplet area, were small and should be verified with additional data (Trabulo et al., 2023).

Research on physiological stress in fishes due to exposure to explosive sources is limited. Sverdrup et al. (1994) studied levels of stress hormones in Atlantic salmon after exposure to multiple detonations in a laboratory setting. Increases in cortisol and adrenaline were observed following the exposure, with adrenaline values returning to within normal range within 24 hours.

In summary, fishes may have physiological stress reactions to sounds that they can hear. Generally, stress responses are more likely to occur in the presence of potentially threatening sound sources, such as predator vocalizations, or the sudden onset of impulsive signals rather than from non-impulsive or continuous sources such as vessel noise or sonar. If an exposure is short, the stress responses are typically brief (a few seconds to minutes). In addition, research shows that fishes may habituate to (i.e., learn to tolerate) the noise that is being presented after multiple exposures or longer duration exposures that prove to be non-threatening. However, exposure to chronic noise sources can lead to more severe impacts over time, such as reduced growth rates which can lead to reduced survivability for an individual. It is assumed that any physiological response (e.g., hearing loss or injury) or significant behavioral response is also associated with a stress response.

D.5.6 DIRECT INJURY

Injury to fishes refers to the direct effects on the tissues or organs of a fish. Auditory injuries are generally discussed above in Section D.5.2. No research on the potential injuries from moderate- to low-level noise from vessels, aircraft, and weapons firing is available. However, these sound sources lack the amplitude and energy to cause any direct injury and are not discussed further.

D.5.6.1 Injury due to Sonar and Other Transducers

Non-impulsive sound sources (e.g., sonar, acoustic modems, and sonobuoys) have not been known to cause direct injury or mortality to fish under wild conditions (Halvorsen et al., 2012a; Kane et al., 2010; Popper et al., 2007). Potential direct injuries (e.g., barotrauma, hemorrhage or rupture of organs or tissue) from non-impulsive sound sources, such as sonar, are unlikely because of slow rise times, lack of a strong shock wave such as that associated with an explosive, and relatively low peak pressures.

The effects of mid-frequency sonar-like signals (1.5–6.5 kHz) on larval and juvenile Atlantic herring, Atlantic cod, saithe, and spotted wolffish (*Anarhichas minor*) were examined by Jorgensen et al. (2005). Researchers investigated potential effects on survival, development, and behavior in this study. Among fish kept in tanks and observed for one to four weeks after sound exposure, no significant differences in mortality or growth-related parameters between exposed and unexposed groups were observed. Examination of organs and tissues from selected herring experiments did not reveal obvious differences between unexposed and exposed groups. However, two (out of 42) of the herring groups exposed to continuous wave of 189 dB re 1 μ Pa and 179 dB re 1 μ Pa SPL had a post-exposure mortality of 19 and 30 percent, respectively. It is not clear if this increased mortality was due to the received level or to other unknown factors, such as exposure to the resonance frequency of the swim bladder (see Section D.1.1.8 for discussion of resonance). Jorgensen et al. (2005) estimated a resonant frequency of 1.8 kHz for herring and saithe ranging in size from 6.3 to 7.0 centimeters, respectively, which lies within the range of frequencies used during sound exposures and, therefore, may explain some of the noted mortalities. Frequency-modulated sonar signals of the same frequency range and intensities did not cause mortality.

Past research has demonstrated that fish species, size, and depth influence the resonant frequency (defined in Section D.1.1.8) of the swim bladder (Løvik & Hovem, 1979; McCartney & Stubbs, 1971). For example, lower frequencies (i.e., generally below 1 kHz) are expected to produce swim bladder resonance in adult fishes from about 10 to 100 centimeters (McCartney & Stubbs, 1971); higher frequencies, greater than 1 kHz, could produce swim bladder resonance in smaller fishes. At resonance, the swim bladder may absorb much of the acoustic energy in the impinging sound wave. It was hypothesized that the resulting oscillations may cause mortality or harm the auditory organs or the swim bladder (Jorgensen et al., 2005; Kvadsheim & Sevaldsen, 2005). However, damage to the swim bladder and to tissues surrounding the swim bladder was not observed in fishes exposed to multiple sonar pulses from approximately 165–195 dB re 1 μ Pa at their presumed swim bladder resonant frequency (Jorgensen et al., 2005). Fishes may be more susceptible to injury from swim bladder resonance when exposed to continuous signals within the resonant frequency range; although, based on the above studies, injury or mortality from swim bladder resonance under real-world conditions is unlikely.

Hastings (1991); (1995) tested the limits of acoustic exposure on two freshwater fish species. Hastings found “acoustic stunning” (loss of consciousness) in blue gouramis (*Trichogaster trichopterus*) following an eight-minute continuous exposure in captivity to a 150 Hz pure tone of 198 dB re 1 μ Pa SPL (1995). This species of fish has an air bubble in the mouth cavity directly adjacent to the animal’s braincase that may have caused this injury. Hastings (1991); (1995) also found that goldfish, exposed to a 250 Hz continuous wave sound with peak pressures of 204 dB re 1 μ Pa for two hours, and blue gourami exposed to a 150 Hz continuous wave sound at an SPL of 198 dB re 1 μ Pa for 0.5 hour did not survive.

To investigate potential injury to the auditory system in fishes, Sapozhnikova et al. (2020) exposed freshwater fish (peled, *Coregonus peled*) to tonal, 300 Hz sound at 176–186 dB re 1 μ Pa SPL (peak to peak), for up to 18 days. After exposure, cellular changes to hearing structures were assessed. Hair cell bundles of the saccule (one of three otolithic organs in the inner ear) were significantly less dense in sound-exposed fish compared to untreated controls, and changes were only observed for fish exposed longer than five days. Changes to otolith crystal structure and fusion of stereocilia (“hair-like” structures within the inner ear) like that observed after ototoxic antibiotic exposure were also observed after sound exposure, but no direct measurements of hearing loss were taken. The exposure was intended to simulate conditions of common aquaculture systems and therefore may not be applicable to exposures in other environments. Additionally, freshwater fishes are known to have better hearing than marine species, making them more susceptible to auditory impacts. This study does demonstrate some of the more severe physical impacts to the auditory system that could result from extremely long duration exposures to low-frequency tonal signals.

Although these studies (Hastings, 1991; Hastings, 1995; Sapozhnikova et al., 2020) illustrate some of the highest known exposures (long duration exposures to moderately high sound levels) of tonal signals on freshwater fishes with enhanced hearing capabilities, direct comparisons of these results to impacts from transitory signals (e.g., sonar or vessels) should be treated with caution. The conditions of the exposures (e.g., exposure duration, fish’s inability to avoid the source) are not synonymous with conditions to an open ocean or coastal environment. Stunning and mortality due to exposure to non-impulsive sound exposure has not been observed in other studies.

Three freshwater species of fish, the rainbow trout, channel catfish, and the hybrid sunfish (*Lepomis* sp.), were exposed to both low- (170 to 320 Hz) and mid-frequency (2.8 to 3.8 kHz) sonar (Kane et al., 2010; Popper et al., 2007). Low-frequency exposures with received SPLs of 193 dB re 1 μ Pa occurred for either 324 or 648 seconds. Mid-frequency exposures of 210 dB re 1 μ Pa SPL occurred for 15 seconds. No fish mortality resulted from either experiment. During examination after test exposures, both studies found that none of the subjects showed signs of tissue damage related to exposure (Kane et al., 2010; Popper et al., 2007). As summarized in the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014), although fish have been injured and killed due to intense, long-duration, non-impulsive sound exposures, fish exposed under more realistic conditions have shown no signs of injury. In the absence of other proxies to rely upon, those species tested to date can be used as surrogates for estimating injury in other species exposed to similar sources.

D.5.6.2 Injury due to Impulsive Sound Sources

Non-explosive impulsive sounds, such as those produced by seismic air guns and impact pile driving, may cause injury or mortality in fishes. Mortality and potential damage to the cells of the lateral line have been observed in fish larvae, fry, and embryos after exposure to single shots from a seismic air gun within close proximity to the sound source (0.1–6 m) (Booman et al., 1996; Cox et al., 2012). However, exposure of adult pallid sturgeon (*Scaphirhynchus albus*) and paddlefish (*Polyodon spathula*) to a single shot from an air gun array (four air guns) within similar ranges (6 m) did not result in any signs of mortality within seven days after exposure (Popper et al., 2016). Although injuries occurred in adult fishes, they were like injuries seen in control subjects so there is little evidence that the air gun exposure solely contributed to the observed effects.

Injuries, such as ruptured swim bladders, hematomas, and hemorrhaging of other gas-filled organs, have been reported in fish exposed to a large number of simulated impact pile driving strikes with cumulative

SELs up to 219 dB re 1 $\mu\text{Pa}^2\text{s}$ under highly controlled settings where fish were unable to avoid the source (Casper et al., 2013a; Casper et al., 2012b; Casper et al., 2013b; Halvorsen et al., 2012a; Halvorsen et al., 2011, 2012b). However, it is important to note that these studies exposed fish to 900 or more strikes as the studies aimed to evaluate the equal energy hypothesis, which suggests that the effects of a large single pulse of energy is equivalent to the effects of energy received from many smaller pulses (as discussed in Smith & Gilley, 2008). Halvorsen et al. (2011) and Casper et al. (2017) propose that the equal energy hypothesis does not apply to effects of pile driving. Specifically, Casper et al. (2017) found the amount of energy in each pile strike had a larger influence on resulting injuries than the number of strikes even when the SEL was equal. For example, hybrid striped bass (white bass x striped bass) exposed to fewer strikes with higher single strike sound exposure values resulted in a higher number of, and more severe, injuries than bass exposed to an equivalent cumulative SEL that contained more strikes with lower single strike sound exposure values. This is important to consider when comparing data from pile driving studies to potential effects from an explosion. Although single strike peak SPLs were measured during these experiments (at average levels of 207 dB re 1 μPa), the injuries were only observed during exposures to multiple strikes; therefore, it is anticipated that a peak value much higher than the reported values would be required to lead to injury in fishes exposed to a single strike or explosion.

The studies discussed in the paragraph above included species both with and without swim bladders. Most fishes that exhibited injuries were those with swim bladders. Lake sturgeon (*Acipenser fulvescens*), a physostomous fish, was found to be less susceptible to injury from impulsive sources than Nile tilapia or hybrid striped bass, both of which are physoclistous fishes (Casper et al., 2017; Halvorsen et al., 2012a). Halvorsen et al. (2012a) proposed that the difference in results is likely due to the type of swim bladder present in each species. Physostomous fishes have an open duct connecting the swim bladder to their esophagus and may be able to quickly adjust the amount of gas in their body by gulping or releasing air. Physoclistous fishes do not have this duct; instead, special tissues or glands regulate gas pressure in the swim bladder and are unable to react quickly enough to reduce pressure appreciably in response to an impulsive sound stressor. There were no mortalities reported during these experiments, and in the studies where recovery was observed, most exposure related injuries healed within a few days in a laboratory setting. In many of these controlled studies, neutral buoyancy was determined in the fishes prior to exposure to the simulated pile driving. However, fishes with similar physiology to those described in these studies that are exposed to actual pile driving activities may not be neutrally buoyant at the onset of an exposure and therefore may show varying levels of injury depending on their state of buoyancy.

By exposing caged juvenile European sea bass (*Dicentrarchus labrax*) to actual pile driving operations, Debusschere et al. (2014) confirmed the results discussed above. No differences in mortality were found between control and experimental groups (215–222 dB re 1 $\mu\text{Pa}^2\text{s}$ SEL), and many of the same types of injuries occurred (Casper et al., 2013a; Casper et al., 2012b; Casper et al., 2013b; Halvorsen et al., 2012a; Halvorsen et al., 2011, 2012b).

Other potential effects from exposure to impulsive sound sources include bubble formation and neurotrauma. It is speculated that high SPLs may cause bubbles to form from micronuclei in the blood stream or other tissues of animals, possibly causing embolism damage (Hastings & Popper, 2005). Fishes have small capillaries where these bubbles could be caught, leading to vessel rupture and internal bleeding. It has also been speculated that this phenomena could take place in the eyes of fish due to potentially high gas saturation within the eye tissues (Popper & Hastings, 2009b). Additional research is

necessary to verify if these speculations apply to exposures to non-impulsive sources such as sonars. These phenomena have not been well studied in fishes and are difficult to recreate under real-world conditions.

As summarized in the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014), exposure to high intensity and long duration impact pile driving or air gun shots has not caused mortality, and fishes typically recovered from injuries in controlled laboratory settings. Barring other proxies to rely upon, species tested to date can be used as surrogates for investigating injury in other species exposed to similar sources (Popper et al., 2014).

D.5.6.3 Injury due to Explosions

The blast wave from an explosion is lethal to fishes at close range, causing massive organ and tissue damage (Keevin & Hempen, 1997). At greater distance from the detonation point, the extent of mortality or injury depends on many factors including fish size, body shape, depth, physical condition of the fish, and, perhaps most importantly, the presence of a swim bladder. In general, fishes without swim bladders have been shown to be more resilient to explosives compared to those with swim bladders (Gaspin, 1975; Gaspin et al., 1976; Goertner et al., 1994). At the same distance from the source, larger fishes and those with elongated forms that are round in cross-section were generally less susceptible to death or injury than smaller fishes and deep-bodied forms, and fishes oriented sideways to the blast suffer the greatest impact (O'Keeffe, 1984; O'Keeffe & Young, 1984; Wiley et al., 1981; Yelverton et al., 1975).

If a fish is close to an explosive detonation, the exposure to rapidly changing high pressure levels can cause barotrauma. Barotrauma is injury due to a sudden difference in pressure between an air space inside the body and the surrounding water and tissues. Rapid compression followed by rapid expansion of airspaces, such as the swim bladder, can damage surrounding tissues and result in the rupture of the airspace itself. The swim bladder is the primary site of damage from explosives (Dahl et al., 2020; Wright, 1982; Yelverton et al., 1975). Gas-filled swim bladders resonate at different frequencies than surrounding tissue and can be torn by rapid oscillation between high- and low-pressure waves (Goertner, 1978). Swim bladders are a characteristic of most bony fishes, with the notable exception of some flatfishes (e.g., halibut). Sharks and rays are examples of cartilaginous fishes which lack a swim bladder. Small airspaces, such as micro-bubbles that may be present in gill structures, could also be susceptible to oscillation when exposed to the rapid pressure increases caused by an explosion. This may have caused the bleeding observed on gill structures of some fish exposed to explosions (Goertner et al., 1994). Sudden very high pressures can also cause damage at tissue interfaces due to the way pressure waves travel differently through tissues with different densities. Rapidly oscillating pressure waves might rupture the swim bladder, kidney, liver, and spleen and cause venous hemorrhaging (Dahl et al., 2020; Jenkins et al., 2022; Keevin & Hempen, 1997).

Several studies have exposed fish to explosives and examined various metrics in relation to injury susceptibility. Sverdrup et al. (1994) exposed Atlantic salmon in a laboratory setting to repeated shock pressures of around 2 megapascals (300 psi or 246 dB re 1 μ Pa peak) without any immediate or delayed mortality after a week. Hubbs and Rechnitzer (1952) exposed fish to underwater detonations placed either on the seafloor or buried at various depths along an underwater canyon in La Jolla, California. Data from this experiment showed that when near the surface, fishes began to exhibit injuries around peak pressure exposures of 40–70 psi (229 to 234 dB re 1 μ Pa peak). However, near the bottom (all water depths were less than 100 feet [ft.]) fish exposed to pressures over twice as high exhibited no sign

of injury. Yelverton et al. (1975) found that peak pressure was not correlated to injury susceptibility; instead, injury susceptibility of swim bladder fish at shallow depths (10 ft. or less) was correlated to the metric of positive impulse (pascal seconds [Pa-s]), which takes into account the positive peak pressure, the duration of the positive pressure exposure, and fish mass, with smaller fish being more susceptible than larger fishes.

Two experiments reported the effects of underwater explosions on Pacific sardines (*Sardinops sagax*) and Pacific mackerel (*Scomber japonicus*) to underwater detonations of C4 explosives at the same general test site off the coast of California, though the experiments took place during different years (Dahl et al., 2020; Jenkins et al., 2022). In both efforts, fish were stationed at various distances (out to approximately 800 m) prior to the explosion, in addition to a control group that was not exposed. Necropsies following explosions observed significant injuries, including fat hematoma, kidney rupture, swim bladder rupture, and reproductive blood vessel rupture. Injuries decreased with increasing distance from the explosion, and swim bladder injuries were the most prevalent. While most significant injuries were consistently present at close range (less than 50 m, approximately 240 dB re 1 μ Pa peak) with decreasing proportion of injury farther from the source in both studies, Dahl et al. (2020) found inconsistent findings at the 50–125 m range (approximately 240 – 232 dB re 1 μ Pa peak). The inconsistency in observed physical damage at this distance from the detonation was due to possible acoustic refraction effects, including waveform paths that were bottom reflected, surface reflected, or a combination of both. Some fish mortality was observed during the Jenkins et al. (2022) experiment, in a portion of cages at or within 157 m (received level of 231 dB re 1 μ Pa peak) of the explosion. Additionally, unique video footage from a subset of treatment groups showed most fish at or within 257 m (a peak SPL of 224 dB re 1 μ Pa) were stunned (immobilized) immediately following exposure. Unlike Yelverton et al. (1975), the statistical model demonstrated that while all three acoustic measures were good predictors of injury, peak pressure and SEL were better predictors of injury than pressure impulse.

Multiple fishes with a swim bladder were exposed to explosions of varying sizes across a variety of depths (Gaspin, 1975; Gaspin et al., 1976). Subsequently, a swim bladder oscillation model was developed, which showed that the severity of injury observed in those tests could be correlated to the extent of swim bladder expansion and contraction predicted to have been induced by exposure to the explosive blasts (Goertner, 1978; Wiley et al., 1981). Per this model, the degree of swim bladder oscillation is affected by ambient pressure (i.e., depth of fish), peak pressure of the explosive, duration of the pressure exposure, and exposure to surface rarefaction (negative pressure) waves. The maximum potential for injury is predicted to occur where the surface reflected rarefaction (negative) pressure wave arrives coincident with the moment of maximum compression of the swim bladder caused by exposure to the direct positive blast pressure wave, resulting in a subsequent maximum expansion of the swim bladder. Goertner (1978) and Wiley et al. (1981) found that their swim bladder oscillation model explained the injury data in the Yelverton et al. (1975) exposure study and that the Yelverton and Richmond (1981) impulse parameter was applicable only to fishes at shallow enough depths to experience less than one swim bladder oscillation before being exposed to the following surface rarefaction wave.

O'Keefe (1984) provides calculations and contour plots that allow estimation of the range to potential effects of explosions at or near the surface of the water on fish possessing swim bladders using the damage prediction model developed by Goertner (1978). O'Keefe (1984) parameters include the charge weight, depth of burst, and the size and depth of the fish, but the estimated ranges do not consider

unique propagation environments that could reduce or increase the range to effect. Based on these calculations, it was suggested that fish at greater depths and near the surface are predicted to be less likely to be injured because geometries of the exposures would limit the amplitude of swim bladder oscillations. In contrast, detonations at or near the surface, like most proposed activities that utilize bombs, missiles, and gunfire, would result in surface blow off (i.e., loss of energy into the air), resulting in lower overall ranges to effects.

Studies that have documented caged fishes killed during planned underwater explosions indicate that most fish that die do so within one to four hours, after exposure and almost all die within 24-hours (Yelverton et al., 1975). Mortality in free-swimming (uncaged) fishes may be higher due to increased susceptibility to predation. Fitch and Young (1948) found that the type of free-swimming fish killed changed when blasting was repeated at the same location within 24 hours of previous blasting. They observed that most fish killed on the second day were scavengers, presumably attracted by the victims of the previous day's blasts.

Fitch and Young (1948) also investigated whether a significant portion of fish killed would have sunk and not been observed at the surface. Comparisons of the numbers of fish observed dead at the surface and at the bottom in the same affected area after an explosion showed that fish found dead on the bottom comprised less than 10 percent of the total observed mortality. Gitschlag et al. (2000) conducted a more detailed study of both floating fishes and those that were sinking or lying on the bottom after explosive removal of nine oil platforms in the northern Gulf of Mexico. Results were highly variable. They found that 3–87 percent (46 percent average) of the red snapper killed during a blast might float to the surface. Currents, winds, and predation by seabirds or other fishes may be some of the reasons that the magnitude of fish mortality may not have been accurately captured.

There have been few studies of the impact of underwater explosives on early life stages of fish (eggs, larvae, juveniles). Fitch and Young (1948) reported mortality of larval anchovies scooped opportunistically during underwater blasting off the coast of California. Detonations used during these operations varied in size (from 10 to 160 pounds), with some explosives placed just beneath the water's surface and others buried under the seafloor. Although the authors mention observations of live fish within the "lethal range" of these detonations, specific distances and search patterns were not provided. Another experiment reported dead anchovy and smelt larvae within approximately 50 m of buried charges weighing from 90 to 180 pounds in a shallow water channel during a pipeline construction project (Nix & Chapman, 1985). Although this provides useful insight into potential impacts to fishes from explosives, acoustic measures were not taken during either of these studies to correlate mortality with received levels. Similar to adult fishes, the presence of a swim bladder contributes to shock wave-induced internal damage in larval and juvenile fish (Settle et al., 2002). Explosive shock wave injury to internal organs of larval pinfish (*Lagodon rhomboids*) and spot (*Leiostomus xanthurus*) exposed at shallow depths was documented at impulse levels similar to those predicted by Yelverton et al. (1975) for very small fish and provide the lowest measured received level that injuries have been observed in larval fish (peak SPLs of 220 dB re 1 μ Pa) (Govoni et al., 2003; Govoni et al., 2008; Settle et al., 2002). Researchers have suggested that egg mortality may be correlated with peak particle velocity exposure [i.e., the localized movement or shaking of water particles, as opposed to the velocity of the blast wave (Faulkner et al., 2006; Faulkner et al., 2008; Jensen, 2003)], although sufficient data from direct explosive exposures is not available.

Observations of the inner ear and lateral line across fishes exposed to explosives are lacking. Smith et al. (2022) provide the first examination of the physical effects of underwater explosions on the inner ear of Pacific mackerel (*Scomber japonicus*). Results showed varying amounts of hair cell loss as well as evidence of hair cell shearing and even holes in the epithelial tissue along the saccule related to the explosive exposure. Significant impacts were observed starting at peak SPLs of 220 dB re 1 μ Pa. Additional impacts on these sensory system organs have been observed during exposure to other impulsive sources such as air guns and playbacks of impact pile driving noise, which would indicate that similar effects may be possible in fishes exposed to explosions (Booman et al., 1996; Casper et al., 2013a; McCauley et al., 2003). Rapid pressure changes could cause mechanical damage to sensitive ear structures due to differential movements of the otolithic structures. Bleeding near otolithic structures was the most commonly observed injury in non-swim bladder fish exposed to a close explosive charge (Goertner et al., 1994). Additional research is needed to understand the potential for sensory cell damage from explosive exposures, the severity and implication of such affects for individual fish, and at what sound levels these impacts may occur.

As summarized by the *ANSI Sound Exposure Guideline* technical report (Popper et al., 2014), exposure to explosive energy poses the greatest potential threat for injury and mortality in marine fishes. Fishes with a swim bladder are more susceptible to injury than fishes without a swim bladder. The susceptibility also probably varies with size and depth of both the detonation and the fish. Fish larvae or juvenile fish may be more susceptible to injury from exposure to explosives.

D.5.7 LONG-TERM CONSEQUENCES

Mortality removes an individual fish from the population and injury can reduce the fitness of an individual. Fishes with injuries from any sound exposure may not survive in the wild due to harsher conditions and risk of predation. They may also have long-term competitive disadvantages for prey and mates, relative to uninjured individuals of the same species. Few studies have been conducted on any long-term consequences from repeated hearing loss, stress, or behavioral reactions in fishes due to exposure to loud sounds (Hawkins et al., 2015; Popper & Hastings, 2009a; Popper et al., 2014).

Repeated exposures of an individual to multiple sound-producing activities over a season, year, or life stage could cause reactions with costs that can accumulate over time to cause long-term consequences for the individual. These long-term consequences may affect the survivability of the individual, or if impacting enough individuals may have population-level effects, including alteration from migration paths, avoidance of important habitat, or even cessation of foraging or reproductive behavior (Hawkins et al., 2015). For example, Soudijn et al. (2020) attempted to design a theoretical population consequences model without quantitative data on SELs. Atlantic cod energy expenditure, food intake, mortality rate, and reproductive output were analyzed to assess cod's potential impacts from sound exposure. The model predicted decreased food intake, increased energy expenditure, and decreased population growth rate because of increased continuous noise. Models such as these are common among other taxa and often come to similar conclusions. Conversely, some animals may habituate to or become tolerant of repeated exposures over time, learning to ignore a stimulus that in the past has not accompanied any overt threat. In fact, Sivle et al. (2016a) and Sivle et al. (2015a) predicted that exposures to sonar at the maximum levels tested would only result in short-term disturbance and would not likely affect the overall population in sensitive fishes such as Atlantic herring. Additional research is needed to understand the complex relationship of sound exposure to potential long-term consequences to individuals and populations.

D.6 MARINE MAMMALS

This section describes general effects to marine mammals from exposure to acoustic sources.

D.6.1 HEARING

The typical mammalian ear has an outer ear that collects and transfers sound to the eardrum and then to the middle ear (Fay & Popper, 1994; Rosowski, 1994). The middle ear contains bones that amplify and transfer acoustic energy to the inner ear, which contains sensory cells (called hair cells) that transform acoustic energy into electrical signals. Those electrical signals are then carried by the auditory nerve to the brain (Møller, 2013).

All marine mammals display some modifications to the typical mammalian ear; furthermore, there are differences between the hearing of marine mammals that are fully aquatic and those that are amphibious – or live partially out of the water (Wartzok & Ketten, 1999). Marine mammals with an amphibious ear include the marine carnivores: pinnipeds, sea otters, and polar bears (Ghoul & Reichmuth, 2014b; Owen & Bowles, 2011; Reichmuth et al., 2013). Outer ear adaptations in this group include outer ears that are reduced or absent, and in seals, specialized tissues that act as valves to seal off water from entering the ear canal when submerged (Wartzok & Ketten, 1999). In marine mammals with a fully aquatic ear (cetaceans and sirenians), bone and fat channels in the head conduct sound to the ear; while the ear canal still exists, it is narrow and sealed, and outer ears are absent (Castellini et al., 2016; Ketten, 1998) (see Figure D.6-1). These adaptations reflect specializations for hearing in both air and water for amphibious marine mammals, and for hearing in water for fully aquatic marine mammals.



Notes: The amphibious California sea lion outer ear is reduced compared to terrestrial mammals, while the harbor seal lacks an outer ear and has specialized valve-like tissue to close off the ear canal from water. The aquatic bottlenose dolphin lacks an outer ear and has a drastically reduced pinhole-like ear canal yet has specialized hearing for underwater sounds.

Source: <https://pediaa.com/difference-between-seal-and-sea-lion>, <https://www.shutterstock.com/pic.mhtml?id=69136297>

Figure D.6-1: Examples of Marine Mammal Ears

Marine mammal audiograms, like those of terrestrial mammals, typically have a “U-shape,” with a frequency region of best hearing sensitivity at the bottom of the “U” and a progressive decrease in sensitivity outside of the range of best hearing (Southall et al., 2019c) (see Figure D.1-8).

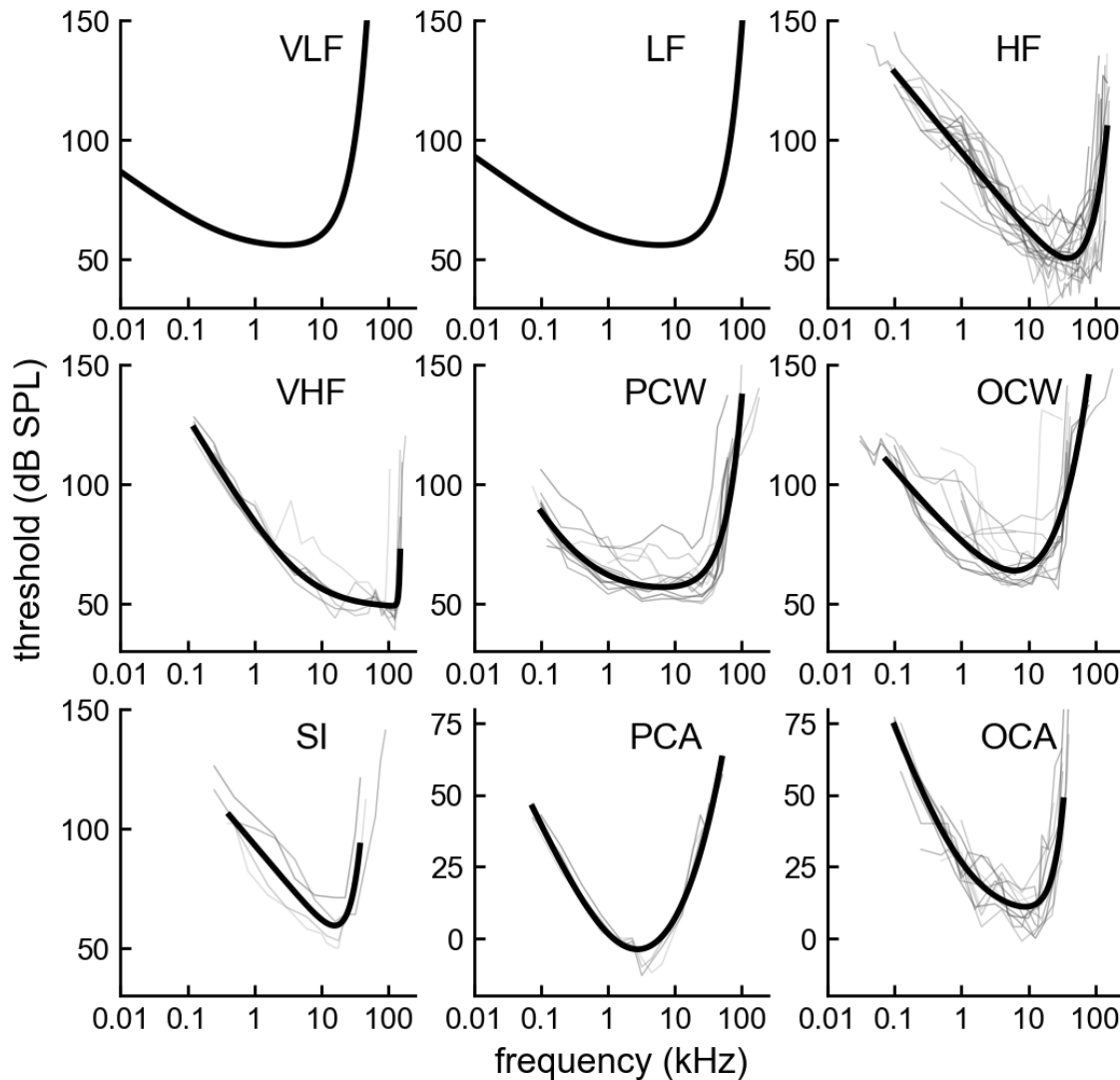
Direct measurements of hearing sensitivity exist for about a quarter of the nearly 130 species of marine mammals. Marine mammals are arranged into the following functional hearing groups based on their

generalized hearing sensitivities: very high-frequency cetaceans (VHF group: porpoises, *Kogia* spp.), high-frequency cetaceans (HF group: delphinids, beaked whales, sperm whales), low-frequency cetaceans (LF group: mysticetes), sirenians (SI group: manatees), otariids and other non-phocid marine carnivores in water and air (OCW and OCA groups: sea lions, otters), and phocids in water and air (PCW and PCA groups: true seals) (Southall et al., 2019c). Representative composite audiograms (U.S. Department of the Navy, 2024a) have been created for each functional hearing group using audiograms from published literature (see Figure D.6-2).

Since the composite audiograms were developed for this analysis, Houser et al. (2022) published new AEP audiograms for stranded odontocetes of six species for which no audiograms had previously existed: dwarf sperm whale (*Kogia sima*), pygmy sperm whale (*Kogia breviceps*), northern right whale dolphin (*Lissodelphis borealis*), melon-headed whale (*Peponocephala electra*), long-beaked common dolphin (*Delphinus capensis*), and Atlantic spotted dolphin (*Stenella frontalis*). Hearing data was also provided on the pygmy killer whale (*Feresa attenuata*). The audiograms had frequency ranges, shapes, and upper frequency limits that were generally consistent with the hearing groups in which these species are categorized (see Table 2 in U.S. Department of the Navy, 2024a).

For marine mammals that are impractical to test or have limited hearing data (e.g., mysticete whales and rare species), some aspects of hearing can be estimated from anatomical structures, frequency content of vocalizations, behavioral responses to sound and inferences from related species (U.S. Department of the Navy, 2024a). For example, behavioral responses of gray whales suggests that they can hear 21 - 25 kHz signals (Frankel & Stein, 2020). The only hearing measurement in a mysticete (minke whale) suggests that LF cetaceans have a upper-frequency limit of hearing between 45 and 90 kHz (Houser et al., 2024). Although there have been no direct measurements of hearing sensitivity in larger mysticetes (VLF hearing group), an audible frequency range of approximately 10 Hz to 30 kHz has been estimated from measured vocalization frequencies, observed reactions to playback of sounds, and anatomical analyses of the auditory system (Cranford & Krysl, 2015; Houser et al., 2001a). See the technical report titled Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase IV) (U.S. Department of the Navy, 2024a) for a complete description of marine mammal composite audiograms.

Research has shown that hearing in marine mammals is directional: the relative angle between the sound source location and the animal's position affects the hearing threshold. This is important because how an animal perceives sound is dependent on the hearing threshold. For example, a sound presented from directly in front of an animal might be heard clearly, while the same sound presented from directly behind an animal might not be heard. For bottlenose dolphins, hearing sensitivity becomes more directional as the sound frequency increases, with the greatest sensitivity to sounds presented in front and below the dolphin (Accomando et al., 2020; Au & Moore, 1984). Hearing sensitivity is asymmetrical in the vertical and horizontal planes, which might be beneficial for localizing a sound source. Harbor porpoises and belugas exhibit direction-dependent hearing, but to a lesser degree than the dolphin (Kastelein et al., 2019b; Kastelein et al., 2005a; Popov & Supin, 2009). Based on experiments in harbor seals, phocids likely have well-developed directional hearing for biologically relevant sounds (Byl et al., 2016; Byl et al., 2019). Directional hearing is important to consider when assessing masking effects.



Notes: For hearing in water (top two rows) and in air (bottom row, phocids and otariids only). VLF = very low frequency; LF = low frequency; HF = high frequency; VHF = very high frequency; PCW = phocids in water; OCW = otariids and other non-phocid marine carnivores in water; SI = sirenians in water; OCA = otariids and other non-phocid marine carnivores in air; PCA = phocids in air

Figure D.6-2: Composite Audiograms used in Marine Mammal Hearing Criteria and Thresholds

D.6.2 ACOUSTIC SIGNALING

Like the diversity of hearing capabilities among species, the wide variety of acoustic signals used in communication and echolocation is reflective of the diverse characteristics of marine mammal species. Detailed reviews of sounds generated by marine mammals are available, see Chapter 7 of Richardson et al. (1995b) and Table 4-1 in Wartzok and Ketten (1999). A general division can be drawn between lower frequency communication signals including vocalizations that are produced by all marine mammals, and the specific, high-frequency echolocation (i.e., biosonar) signals that are used by odontocetes to sense their environment. The general types and frequency characteristics of marine mammal vocalizations are described in Table D.6-1.

Table D.6-1: Marine Mammal Vocalizations

<i>Signal type</i>	<i>Description</i>	<i>Marine mammal group(s)</i>	<i>Frequency range¹</i>
Echolocation	Broadband, short-duration, high-source level clicks serving a primarily sensory function with a secondary communication function ² .	HF & VHF cetaceans	20 – 160 kHz
Communication	Tonal (e.g., whistles) and non-tonal (e.g., grunts) with a wide variety of durations and source levels and serving primarily for communication (e.g., mating, mother-calf contact, group cohesion/coordination, and other social functions).	VLF cetaceans	0.01 – 0.4 kHz
		LF cetaceans	0.1 – 4 kHz
		HF & VHF cetaceans	4 – 30 kHz
		Sirenians	0.6 – 16 kHz
		Pinnipeds (phocids, otariids)	0.1 – 30 kHz
		Otters	3 – 5 kHz
		Polar bears	0.2 – 1 kHz

¹The frequencies near maximum energy based on Table 4-1 in Wartzok and Ketten (1999).

² Sperm whales use clicks to echolocate and specific click patterns primarily to communicate. Some other species might also use click patterns that function primarily to communicate.

D.6.2.1 Communication

Communication sounds have crucial functions including social (e.g., mating), maintaining mother-calf contact, group cohesion, feeding, and other purposes. Communication signals include calls (i.e., vocalizations) and sounds produced by non-vocal behaviors such as tail/fluke slaps on the water surface or clapping the jaw. Vocalizations might have a tonal quality or pitch resulting from a prominent fundamental frequency, such as whistles in some odontocetes and sirenian calls (Brady et al., 2021), or they might be less tonal because of energy distributed across a wide frequency range such as grunts produced by marine carnivores like pinnipeds. Aerial vocalizations are produced by pinnipeds, otters, and polar bears. The acoustic characteristics of communication signals of marine mammals are quite diverse but can be generally classified as having dominant energy at frequencies between approximately 20 Hz and 30 kHz (Richardson et al., 1995b; Wartzok & Ketten, 1999).

Of note are the lower frequency calls of mysticete whales that range from tens of Hz to several kHz and have source levels of approximately 150–200 dB re 1 µPa. Typically, mysticete calls have fundamental frequencies below 200 Hz. Fin whales and blue whales make exceptionally low frequency calls (10 -16 Hz), while humpback whales make higher frequency calls having harmonics that exceed 20 kHz, (Au et al., 2006; Cummings & Thompson, 1971; Edds-Walton, 1997; Širović et al., 2007; Stimpert et al., 2007; Wartzok & Ketten, 1999). These calls most likely serve social functions such as interspecific attraction or detection over long distances but could serve an orientation function as well (Frazer & Mercado, 2000; Green, 1994; Green et al., 1994; Mercado, 2021; Richardson et al., 1995b).

D.6.2.2 Echolocation

Odontocete cetaceans generate short-duration (50–200 microseconds), high-frequency (10 – 200 kHz peak frequency), specialized echolocation clicks (e.g., biosonar) used to detect, localize, and characterize underwater objects (Au, 1993; Wartzok & Ketten, 1999). This process is essential for hunting, including

searching, tracking, and capturing prey. Echolocation clicks are often more intense than communicative signals, with reported source levels as high as 229 dB re 1 μ Pa peak-to-peak (Au et al., 1974). The echolocation clicks of very high-frequency cetaceans (e.g., porpoises) are narrower in bandwidth (i.e., the difference between the upper and lower frequencies in a sound) and higher in frequency than those of high-frequency cetaceans (Madsen et al., 2005; Villadsgaard et al., 2007). The specific characteristics of echolocation signals such as their repetition patterns and peak frequency can be used to identify species (Baumann-Pickering et al., 2013).

Echolocation can serve communicative functions even though clicks are not usually produced for this purpose by most odontocetes. For example, eavesdropping animals may hear rapid echolocation clicks and other sounds associated with feeding to find food or avoid predators, and sperm whale clicks may reveal the size or general characteristics of the clicking individual. However, some types of clicks or patterns of clicks are thought to be produced for the purpose of communication. For example, click patterns called codas are communicative vocalizations produced by sperm whales (Jacobs et al., 2024; Richardson et al., 1995b; Watkins & Schevill, 1977).

D.6.2.3 Relationship between Hearing and Vocalization

In general, frequency ranges of sounds produced by a species lie within the audible frequency range for that species (i.e., animals vocalize within their audible frequency range). However, auditory frequency range and vocalization frequencies do not perfectly align. For example, odontocete echolocation clicks contain a broad range of frequencies, and not all the frequency content is necessarily heard by the individual that emitted the click. The frequency range of vocalization in a species can therefore be used to infer some characteristics of their hearing capabilities; however, caution must be taken when considering vocalization frequencies alone in predicting the hearing capabilities of species for which data are absent or limited such as mysticete whales.

Aspects of vocalization and hearing sensitivity are subject to evolutionary pressures that are not solely related to communication within the species. For example, hearing and vocalization is influenced by the need to detect or avoid threats such as predators (e.g., Deecke et al., 2002) and listening for prey-generated sounds. Additionally, high-frequency hearing is advantageous to animals with small heads because it facilitates sound localization based on differences in sound levels at each ear (Heffner & Heffner, 1982). These factors might be partially responsible for the difference in best hearing thresholds and dominant vocalization frequencies in some species of marine mammals (e.g., Steller sea lions, Mulsow & Reichmuth, 2010).

D.6.3 HEARING LOSS AND AUDITORY INJURY

All mammals experience normal age-related hearing loss (presbycusis), which is a progressive reduction in the ability to hear higher frequencies that spreads to lower frequencies over time. This type of hearing loss is due to the loss of sensory cells in the inner ear and degeneration of the pathways that connect the ear to the brain. Age-related hearing loss occurs over a lifetime and is distinct from acute noise-induced hearing loss (Møller, 2013).

Noise-induced hearing loss can be temporary (i.e., temporary threshold shift, or TTS) or permanent (i.e., permanent threshold shift, or PTS), and higher-level sound exposures are more likely to cause PTS or other auditory injury. For marine mammals, auditory injury (AINJ) is considered to be possible when sound exposures are sufficient to produce 40 dB of TTS measured approximately four minutes after exposure (U.S. Department of the Navy, 2024a).

Numerous studies have directly examined noise-induced hearing loss in marine mammals. In these studies, hearing thresholds were measured in marine mammals before and after exposure to intense sounds. The difference between the post-exposure and pre-exposure hearing thresholds is used to determine the amount of TTS in dB that was produced as a result of the sound exposure. The data from these studies is detailed in (U.S. Department of the Navy, 2024a) and the major findings are outlined in Table D.6-2 Table D.6-2.

Table D.6-2: Major Findings from Studies of Threshold Shift in Marine Mammals

<i>Major Finding</i>	<i>Supporting Scientific Studies</i>
Hearing test method	
The method used to test hearing may affect the resulting amount of measured temporary threshold shift (TTS), with auditory evoked potential measures producing larger amounts of TTS compared to behavioral measures.	Finneran (2015); Finneran et al. (2007)
Effect of frequency and sound pressure level (SPL)	
Sound exposures of a narrow frequency range can produce TTS over a large frequency range.	Finneran et al. (2007); Kastelein et al. (2020a); Kastelein et al. (2019d); Kastelein et al. (2019f); Mooney et al. (2009a); Nachtigall et al. (2004); Popov et al. (2013); Popov et al. (2011); Reichmuth et al. (2019); Schlundt et al. (2000)
As the exposure SPL increases, the frequency at which the maximum TTS occurs also increases.	Finneran et al. (2007); Kastelein et al. (2020a); Kastelein et al. (2019d); Kastelein et al. (2019f); Kastelein et al. (2014a); Mooney et al. (2009a); Nachtigall et al. (2004); Popov et al. (2013); Popov et al. (2011); Reichmuth et al. (2019); Schlundt et al. (2000)
Sounds at frequencies well below the region of best sensitivity are generally less hazardous than those near the region of best sensitivity.	Finneran and Schlundt (2013); Kastelein et al. (2020a); Kastelein et al. (2019d); Kastelein et al. (2019f); (Gransier & Kastelein, 2024)
Effect of exposure duration, sound exposure level (SEL), and multiple exposures	
The amount of TTS increases with exposure SPL and duration and is correlated with SEL, but duration of the exposure has a more significant effect on TTS than would be predicted based on SEL alone. As the exposure duration increases, the relationship between TTS and SEL begins to break down.	Finneran et al. (2010b); Kastak et al. (2007); Kastak et al. (2005); Kastelein et al. (2014a); Mooney et al. (2009a); Popov et al. (2014); (Gransier & Kastelein, 2024)
TTS can accumulate across multiple exposures, but the resulting TTS will be less than the TTS from a single, continuous exposure with the same SEL. This means that TTS predictions based on the total, cumulative SEL will overestimate the amount of TTS from intermittent exposures such as sonars and impulsive sources ¹ .	Finneran et al. (2010b); Finneran et al. (2000); Finneran et al. (2002); Kastelein et al. (2015a); Kastelein et al. (2018a); Kastelein et al. (2014a); Mooney et al. (2009b); Reichmuth et al. (2016)
Growth of TTS and occurrence of permanent threshold shift (PTS)	
Gradual growth of TTS with increased levels of SEL typically occurs before onset of PTS. However, it is possible for PTS to occur without observing gradual growth of TTS or behavioral changes.	Reichmuth et al. (2019)

Table D.6-2: Major Findings from Studies of Threshold Shift in Marine Mammals (continued)

<i>Major Finding</i>	<i>Supporting Scientific Studies</i>
Recovery from TTS over time	
The time required for complete recovery of hearing depends on the magnitude of the initial shift; for relatively small shifts recovery may be complete in a few minutes, while large shifts may require several days for recovery. Recovery times are consistent for similar-magnitude TTS, regardless of the type of sound exposure (impulsive, continuous noise band, or sinusoidal wave).	Finneran et al. (2010a, 2010b); Finneran and Schlundt (2013); Kastelein et al. (2012a); Kastelein et al. (2012b); Kastelein et al. (2013a); Kastelein et al. (2019e); Kastelein et al. (2014a); Kastelein et al. (2014b); Kastelein et al. (2014c); Popov et al. (2014); Popov et al. (2013); Popov et al. (2011).
Under many circumstances TTS recovers linearly with the logarithm of time.	Finneran et al. (2010a, 2010b); Finneran and Schlundt (2013); Kastelein et al. (2012a); Kastelein et al. (2012b); Kastelein et al. (2013a); Kastelein et al. (2014a); Kastelein et al. (2014b); Kastelein et al. (2014c); Popov et al. (2014); Popov et al. (2013); Popov et al. (2011).

¹ In most acoustic impact assessments, the scenarios of interest involve shorter duration exposures than the marine mammal experimental data from which impact thresholds are derived; therefore, use of SEL tends to over-estimate the amount of TTS. Despite this, SEL continues to be used in many situations because it is relatively simple, more accurate than SPL alone, and lends itself easily to scenarios involving multiple exposures with different SPL and multiple sources. Notes: PTS = permanent threshold shift; SEL = sound exposure level; SPL = sound pressure level; TTS = temporary threshold shift

The data from studies of hearing (i.e., composite audiograms, Figure D.6-2) and hearing loss in marine mammals were used to generate exposure functions – or predictions of hearing loss based on sound frequency, level, and type (continuous or impulsive) – for each hearing group (U.S. Department of the Navy, 2024a).

D.6.3.1 TTS Growth and Recovery

SEL is used to predict TTS in marine mammals based on available data (U.S. Department of the Navy, 2024a). These predictions likely hold true for shorter duration exposures, but for longer-duration exposures, SEL likely overestimates TTS (see Table D.6-2). In general, TTS increases with SEL in a non-linear fashion (Finneran, 2015). For lower SEL exposures, TTS will increase at a steady rate, but at higher SELs, TTS will either increase more rapidly or plateau (see U.S. Department of the Navy, 2024a).

Small amounts of TTS (a few dB) typically begin to recover immediately after the sound exposure and may fully recover in minutes, while larger amounts of TTS take longer to recover. Studies have also found substantial individual variation both in the amount of TTS produced by similar SELs (Kastelein et al., 2012a; Popov et al., 2013), and in recovery from similar TTS (Finneran, 2015; Kastelein et al., 2019e). For example, one harbor seal began recovering immediately after a 34 dB TTS, while a 45 dB TTS in another harbor seal only began recovering 4 - 24 hours after the exposure ended and complete recovery was observed after four days (Kastelein et al., 2020b). In general, recovery from TTS occurs linearly with the logarithm of time (Finneran, 2015).

Most of these findings are from studies that used continuous sound exposures, but intermittent, impulsive sound exposures have also been tested. The sound resulting from an explosive detonation is considered an impulsive sound and shares important qualities (i.e., short duration and fast rise time) with other impulsive sounds such as those produced by air guns, although explosive signals are

characterized by sharper rises and higher peak pressures. There are no direct measurements of hearing loss in marine mammals due to exposure to explosive sources. Few studies using impulsive sounds have produced enough TTS to make predictions about hearing loss due to this source type (see U.S. Department of the Navy, 2024a). In general, predictions of TTS based on SEL for this type of sound exposure is likely to overestimate TTS because some recovery from TTS may occur in the quiet periods between impulsive sounds – especially when the duty cycle is low. Peak SPL (unweighted) is also used to predict TTS due to impulsive sounds (Southall et al., 2007; Southall et al., 2019c; U.S. Department of the Navy, 2024a).

D.6.3.2 Self-Mitigation of Hearing Sensitivity

Several studies have shown that certain odontocete cetaceans (toothed whales) may learn to reduce their hearing sensitivity (presumably to protect their hearing) when warned of an impending intense sound exposure or the duty cycle is predictable (Finneran, 2018; Finneran et al., 2024; Nachtigall & Supin, 2013, 2014, 2015; Nachtigall et al., 2015; Nachtigall et al., 2016a, 2018; Nachtigall et al., 2016b). The effect has been demonstrated in the false killer whale (*Pseudorca crassidens*) (Nachtigall & Supin, 2013), bottlenose dolphin (*Tursiops truncatus*) (Finneran, 2018; Nachtigall & Supin, 2014, 2015; Nachtigall et al., 2016b), beluga (*Delphinapterus leucas*) (Nachtigall et al., 2015), and harbor porpoise (*Phocoena phocoena*) (Nachtigall et al., 2016a).

Based on these experimental measurements with captive odontocetes, it is possible that wild odontocetes would also suppress their hearing if they could anticipate an impending, intense sound, or during a prolonged exposure (even if unanticipated). Based on results from these conditioned hearing sensitivity experiments, odontocetes participating in some previous TTS experiments could have been protecting their hearing during exposures (Finneran, 2018; Finneran et al., 2024; Finneran et al., 2023). A better understanding of the mechanisms responsible for the observed hearing changes is needed for proper interpretation of some existing TTS data, particularly for TTS due to short-duration, unpredictable exposures.

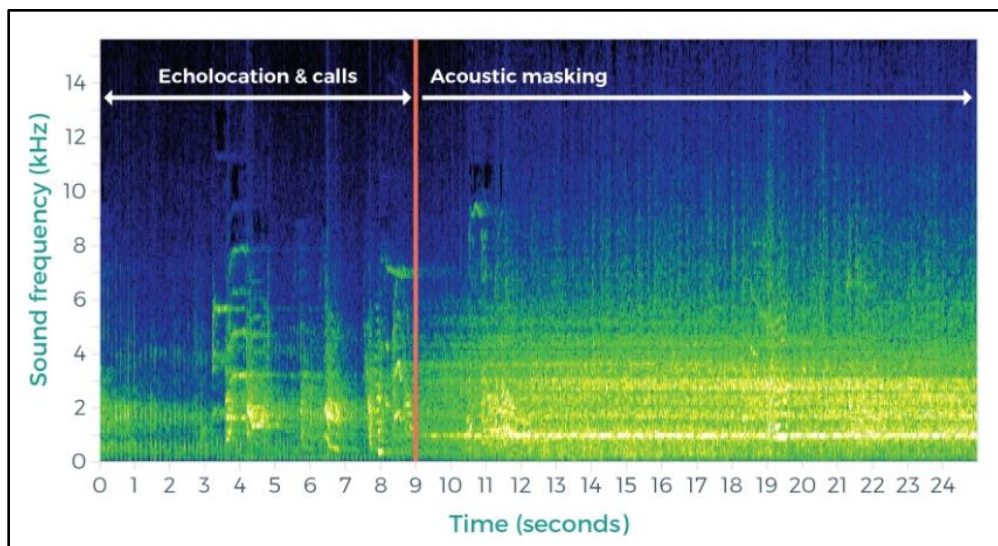
D.6.4 MASKING

This section provides an overview of masking in marine mammals, discusses the potential impacts of masking including communication space reduction and vocalization changes in response to noise, and reviews scientific literature specific to masking by anthropogenic sources. Detailed reviews and analysis of masking in marine mammals are provided by Clark et al. (2009), Erbe et al. (2016), and Branstetter and Sills (2022).

Most research on auditory masking measures the ability of the listener to detect a signal in noise. This is also called “energetic” masking. Energetic masking has been measured for pinnipeds (Sills et al., 2014, 2015; Southall et al., 2000, 2003), odontocetes (Au & Moore, 1990; Branstetter et al., 2021; Branstetter et al., 2017; Johnson et al., 1989; Kastelein & Wensveen, 2008; Lemonds et al., 2011; Thomas et al., 1990a), sirenians (Gaspard et al., 2012), and sea otters (Ghoul & Reichmuth, 2014b). These measurements allow predictions of masking if the spectral density of noise is known (Branstetter et al., 2017). Although energetic masking is typically estimated in controlled laboratory conditions using white noise, results can vary considerably depending on the noise type (Branstetter et al., 2013; Trickey et al., 2010). These fundamental measurements of the ability of marine mammals to detect different signal types under different masking noise conditions are useful for prediction of masking in real-world scenarios.

The frequency overlap between the signal and masker is perhaps the most important consideration when assessing the potential effect of noise. For example, higher frequency noise is more effective at masking higher frequency signals, (Au & Moore, 1990; Lemonds et al., 2011). Signal type (e.g., whistles, burst-pulse, echolocation clicks) and spectral characteristics (e.g., frequency modulation and/or harmonics) may further influence masked detection thresholds (Branstetter et al., 2016; Branstetter & Finneran, 2008; Branstetter et al., 2013; Cunningham et al., 2014). Figure D.6-3 shows an example of lower-frequency ship noise masking communication calls.

Much emphasis has been placed on signal detection in noise and, as a result, most masking studies and models have used masked signal detection thresholds. However, from a fitness perspective, signal detection does not equate to the ability to determine the sound source location and recognize “what” is producing the sound. Marine mammals use sound to recognize conspecifics, prey, predators, or other biologically significant sources. Masked recognition thresholds for whistle-like sounds, have been measured for bottlenose dolphins (Branstetter et al., 2016) and are approximately 4 dB above detection thresholds (signal detection masking) for the same signals. It should be noted that the term “threshold” typically refers to the listener’s ability to detect or recognize a signal 50 percent of the time. For example, human speech communication, where only 50 percent of the words are recognized, would result in poor communication. Likewise, recognition of a conspecific call or the acoustic signature of a predator at only the 50 percent level could have severe impacts (Branstetter et al., 2016). Masking that may not result in a loss of signal detection, but results in loss of a signal’s meaning is called informational masking.



Notes: Spectrogram showing killer whale communication calls and echolocation sounds in the first nine seconds, which are then masked by the passing of a ship. The ship’s masking noise is predominant at 1.5 kHz and extends up to about 6 kHz. Some communication calls can be seen at 11 and 19 seconds. Echolocation calls (small vertical stripes) extend to much higher frequencies and are not masked as much as communication calls in this example. Figure from Kathy Heise and Tracy Saxby, Coastal Ocean Research Institute, <https://oceanwatch.ca/bccoast/wp-content/uploads/sites/4/2018/10/OceanWatch-BC-Coast-underwater-noise.pdf>

Figure D.6-3: Masking of Killer Whale Calls by a Passing Ship

Marine mammals use sound to recognize predators (Allen et al., 2014; Cummings & Thompson, 1971; Curé et al., 2015; Fish & Vania, 1971). Auditory recognition may be reduced in the presence of a masking noise, particularly if it occurs in the same frequency band. Therefore, the occurrence of masking may prevent marine mammals from responding appropriately to the acoustic cues produced by their predators. For example, studies have shown that for marine mammals that are preyed upon by killer

whales, some recognition of predator cues might be missed if the killer whale vocalizations were masked (Curé et al., 2016; Curé et al., 2015; Deecke et al., 2002; Isojunno et al., 2016; Visser et al., 2016). This possibility depends on the duration of the masking and the likelihood of encountering a predator during the time that detection and recognition of predator cues are impeded. Relatively little data exists on informational masking in marine mammals despite its potential importance in models of how noise affects communication.

D.6.4.1 Masking Concepts

D.6.4.1.1 Release from Masking

Masking is less likely or is expected to be less impactful when the noise is intermittent, such as low-duty cycle sonars or impulsive noise, compared to when the noise is continuous, such as vessel noise, high-duty cycle sonar, or continuous active sonar. This is because for intermittent noise, the signal of interest can be detected during the quiet periods between noise events. This is often called “dip” or “gap” listening. The effect of masking on communication space is often modeled using constant-amplitude noise, whereas many anthropogenic sources contain gaps or fluctuations in the noise. Studies have shown that the signal duration, duty cycle, masker level, and fluctuations should be considered when modeling the effect of noise on signal detection (Branstetter & Finneran, 2008; Branstetter et al., 2013; Kastelein et al., 2021; Sills et al., 2017; Trickey et al., 2010).

Spatial release from masking (SRM) occurs when a noise and signal are separated in space, resulting in a reduction or elimination of masking (Holt & Schusterman, 2007; Popov et al., 2020). The relative position of sound sources can act as one of the most salient cues that allow the listener to segregate multiple sounds in a complex auditory scene. Many sounds are emitted from a directional source that is spatially separated from biologically relevant signals. Under such conditions, minimal masking will occur, and existing models of masking will overestimate the amount of actual masking. Marine mammals have excellent sound source localization capabilities (Branstetter & Mercado, 2006; Byl et al., 2019; Renaud & Popper, 1975) and directional hearing (Accomando et al., 2020; Au & Moore, 1984; Mooney et al., 2008; Popov & Supin, 2009) which likely combine to aid in separating auditory events and improving detection. Spatial release from masking has been empirically demonstrated using behavioral methods in a harbor seal a California sea lion, three harbor porpoises, and a bottlenose dolphin (Holt & Schusterman, 2007; Kastelein et al., 2021; Popov et al., 2020), where maximal spatial release from masking was 19, 12, 14.5, and 24 dB for each species respectively. The spatial positions of the receiver and noise source are often considered in terms of distance but the relative angles between the vocalizing and/or listening animal and the noise source are also important to consider when estimating masking effects.

D.6.4.1.2 Communication Space Models of Masking

Communication space models estimate how the distance at which animals can communicate is reduced in noise. The term “communication space” typically means the distance an animal’s call can travel and feasibly be heard and interpreted by a listener. Since the range of available communication space varies widely with species and habitat, reduction in communication space is usually quantified as a percentage loss or a percentage of space available during increased anthropogenic and ambient noise.

Models typically include the source level and frequency characteristics of both the animal of interest’s vocalization and the noise, and the spatial relationship between the noise source and the calling animal and/or the listener. The listener (i.e., receiver) is considered in the best available communication space models, which use the listener’s hearing characteristics when data are available. Models vary in their implementation of propagation modeling – or how the sound (signal and noise) levels are reduced with

distance. Some use simple spherical spreading loss while others employ more sophisticated location-specific estimates, and these choices are related both to the specific research question and the availability of empirical data or existing propagation models.

Clark et al. (2009) estimated masking effects on communication signals for three species of calling mysticete whales (LF cetaceans), including calculating the cumulative impact of multiple noise sources. For example, the model estimates that a right whale's optimal communication space (around 20 km) is decreased by as much as 84 percent when two commercial ships pass by. When one ship passed, communication space for singing fin and humpback whales briefly decreased by approximately 20 and 8 percent respectively when the ship passed close to the whales. For the same ship passage, right whale communication space was reduced by approximately 77 percent. These differences were due to the call repetition rate, source level, and call frequency differences between species. Notably, the right whale calls had a much lower repetition rate in comparison to humpback and fin whale calls. In another study, Hatch et al. (2012) found that North Atlantic right whale communication space was reduced by 67 percent during exposure to vessel noise.

An experiment in a shallow water environment (less than 50 m depth) investigating humpback whale sounds (vocalizations and surface-generated sounds) determined that, in typical ambient (wind) noise, their communication range extends to approximately 2 - 4 km (Dunlop, 2018). Considering this baseline space restricted by ambient noise, Dunlop (2019) used vocalization and whale interactions to show a reduction in humpback whale communication space in vessel noise. This study concluded that the physical presence of the vessel could possibly explain changes in social behavior. This example illustrates the overall concept that changes in behavior observed in the field, including vocalization, often cannot be ascribed solely to masking noise, but also to the physical presence of the noise source.

Results from additional scientific studies on communication space, primarily from vessel noise are listed in Table D.6-3.

Table D.6-3: Communication Space Models of Masking in Marine Mammals

<i>Species</i>	<i>Location</i>	<i>Anthropogenic Noise Source</i>	<i>Communication Space Reduction</i>	<i>Call Type</i>	<i>Study</i>
North Atlantic right whale (<i>Eubalaena glacialis</i>)	Stellwagen Bank National Sanctuary, USA	Passing vessels	77% (single vessel) 84% (two vessels)	71 – 224 Hz contact call	Clark et al. (2009)
		AIS ¹ , fishing, and whale-watching vessels	5%	36 – 891 Hz “gunshot” call	Cholewiak et al. (2018)
Humpback whale (<i>Megaptera novaeangliae</i>)	Stellwagen Bank National Sanctuary, USA	Single vessel passing	8%	224 – 708 Hz song	Clark et al. (2009)
		AIS, fishing, and whale-watching vessels	80 – 99% ²	36 – 355 Hz song and social sounds	Cholewiak et al. (2018)
	Glacier Bay National Park, USA	AIS vessel traffic, summer season	13 – 28% (song) 18 – 51% (calls)	224 – 708 Hz song, 50 – 700 Hz “whup” calls	Gabriele et al. (2018) ²
	Peregian Beach, Australia	Vessel-dominated noise	25 – 50%	Low-frequency calls (≤ 126 Hz min., ≤ 159 Hz center frequency) and	Dunlop (2019)

Table D.6-3: Communication Space Models of Masking in Marine Mammals (continued)

<i>Species</i>	<i>Location</i>	<i>Anthropogenic Noise Source</i>	<i>Communication Space Reduction</i>	<i>Call Type</i>	<i>Study</i>
				high-frequency calls (> 159 Hz center frequency)	
	Colombian Pacific	Vessel (whale-watching/ecotour)	63%	350 Hz peak frequency	Rey-Baquero et al. (2021)
Fin whale (<i>Balaenoptera physalus</i>)	Stellwagen Bank National Sanctuary, USA	Single vessel passing	20%	18 -28 Hz song	Clark et al. (2009)
		AIS ¹ , fishing, and whale-watching vessels	80 – 99% ²	18 – 22 Hz song	Cholewiak et al. (2018)
Bryde’s whale (<i>Balaenoptera edeni</i>)	Hauraki Gulf, New Zealand	AIS ¹ vessels	≤ 87%	23.5 – 207.8 Hz calls	Putland et al. (2018)
Minke whale (<i>Balaenoptera acutorostrata</i>)	Stellwagen Bank National Sanctuary, USA	AIS ¹ , fishing, and whale-watching vessels	≥ 80%	56 – 355 Hz pulse trains	Cholewiak et al. (2018)
Killer whale (<i>Orcinus orca</i>)	Haro Strait, USA	Vessels	62 – 97%	1.5 – 3.5 kHz	Williams et al. (2014a)
	Salish sea	Vessels and wind	50 – 90%	1 – 50 kHz	Burnham et al. (2023)
Beluga whale (<i>Delphinapterus leucas</i>)	Saguenay - St. Lawrence Marine Park, Canada	Car ferries, whale watching vessels, small vessels	70 – 85%	2.5 kHz center frequency	Gervaise et al. (2012)
	St. Lawrence Estuary, Canada	Vessels	53 – 57%	Adult, sub-adult, and calf communication calls	Vergara et al. (2021)
Bottlenose dolphin (<i>Tursiops</i> sp.)	Tenerife, Canary Islands, Spain	Vessels	26%	4 – 10 kHz whistles	Jensen et al. (2009)
Short-finned pilot whale (<i>Globicephala macrorhynchus</i>)			58%	2 – 12.5 kHz tonal sounds	
Harbor seal (<i>Phoca vitulina</i>)	Glacier Bay National Park, USA	AIS ¹ vessel traffic, summer season	32 – 61%	4 – 500 Hz “roar”	Gabriele et al. (2018)

¹AIS = Automatic Identification System, certain types of vessels are outfitted with transponders that provide position information.

² This communication space reduction value is based on increase in anthropogenic noise and ambient (natural) background noise increases combined

Notes: % = percent; < = less than; > = greater than; ≤ = less than or equal to; ≥ = greater than or equal to; AIS = Automatic Identification System; Hz = Hertz; kHz = kilohertz; sp. = species;

These studies demonstrate that anthropogenic sounds – especially broadband vessel noise – can reduce the communication space available to marine mammals. Existing models tend to simplify the noise

characteristics such as how the sound propagates away from the noise source, and the auditory capabilities of the listener (e.g., do not consider directional hearing). Additionally, as pointed out by Branstetter and Sills (2022), many of these models are based on an assumed signal detection and recognition threshold – usually a 10 dB signal-to-noise ratio (Clark et al., 2009).

D.6.4.1.3 Noise-Induced Vocal Modifications

Masking noise can result in vocal modifications or other acoustic signaling behaviors that might reduce or compensate for the overall effect of masking. These noise-induced vocal modifications (NIVM) include increasing the source level (Lombard effect), modifying the frequency, increasing the repetition rate of vocalizations, or ceasing to vocalize in the presence of increased noise (Hotchkiss & Parks, 2013). With increased natural background (ambient) noise levels, a switch from vocal communication to physical, surface-generated sounds such as pectoral fin slapping or breaching has been observed in mysticete whales (Dunlop et al., 2010).

Vocalization changes have been reported from exposure to anthropogenic noise sources such as sonar, vessel noise, and seismic surveying (Gordon et al., 2003; Holt et al., 2011; Holt et al., 2008; Lesage et al., 1999; McDonald et al., 2009; Nowacek et al., 2007; Rolland et al., 2012) as well as changes in the natural acoustic environment (Brumm & Slabbekoorn, 2005). It is often difficult to discriminate NIVM from potential effects of context, measurement tools, and analysis methods. For example, vocalizations may be masked from the recorder, or confounded by other behavioral responses of the marine mammal such as moving away from the noise and recorder or increasing dive duration (Castellote et al., 2012; Cerchio et al., 2014). The ability to observe NIVM might also depend on the methods used to quantify baseline behavior and timescale over which recordings are analyzed (Casey et al., 2024). Table D.6-4 details some examples of the best available scientific observations of noise-induced vocal modifications in marine mammals due to anthropogenic and ambient noise.

Table D.6-4: Examples of Noise-Induced Vocal Modifications in Marine Mammals

Species	Study	Noise source	Vocalization Change			
			Rate	Duration	Frequency	Amplitude
Blue whale (<i>Balaenoptera musculus</i>)	Di Lorio and Clark (2010)	Seismic survey (sparker pulses, average received SELs of 131 dB re 1 μ Pa ² s)	↑			
	Shabangu et al. (2022)	Vessel (10 – 500 Hz)	↑			
		Wind (1 – 4 kHz)	↓ ² masked			
North Atlantic right whale (<i>Eubalaena glacialis</i>)	Parks et al. (2011); Parks et al. (2009).	Ambient (20 Hz – 8 kHz)	↓		↑ ¹	↑ Lombard
Humpback whale (<i>Megaptera novaeangliae</i>)	Girola et al. (2023)	Wind				↑ Lombard, 0.5 dB for every 1 dB increase
		Vessels				NC

Table D.6-4: Examples of Noise-Induced Vocal Modifications in Marine Mammals (continued)

Species	Study	Noise source	Vocalization Change			
			Rate	Duration	Frequency	Amplitude
	Shabangu et al. (2022)	Wind				↑ Lombard
	Laute et al. (2022)	Vessels	↓			
	Dunlop et al. (2014)	Ambient wind noise				↑ Lombard, 0.9 dB for every 1 dB noise increase
	Dunlop (2016)	Vessels		NC	NC	↓ Masked ²
	Fournet et al. (2018)	Vessels and ambient	↓ 9% for every 1 dB noise increase			↑ Lombard, 0.8 dB for every 1 dB noise increase
	Fristrup et al. (2003); Miller et al. (2000),	Low-frequency active sonar		↑ overall song length		
Bowhead whale (<i>Balaena mysticetus</i>)	Blackwell et al. (2015); Blackwell et al. (2017)	Seismic survey (air gun pulses) and large-scale drilling operation (tonal drilling, vessels)	↑ Noise levels < 127 dB ↓ Noise levels > 127 dB X Noise level 170 dB			
Beluga (<i>Delphinapterus leucas</i>)	Lesage et al. (1999)	Small vessels	↓ overall ↑ certain call types		↑ bandwidth	
Beluga (<i>Delphinapterus leucas</i> , St. Lawrence Estuary)	Scheifele et al. (2005)	Vessels				↑ Lombard
Killer whale (<i>Orcinus orca</i>)	Foote et al. (2004)	Vessels	NC	↑		
Killer whale	Wieland et al. (2010)	Vessels		↑14 call types		

Table D.6-4: Examples of Noise-Induced Vocal Modifications in Marine Mammals (continued)

Species	Study	Noise source	Vocalization Change			
			Rate	Duration	Frequency	Amplitude
(Orcinus orca, Southern Resident)				↓ 2 call types		
	Holt et al. (2011); (2008)	Vessels				↑ Lombard
Bottlenose dolphin (Tursiops sp.)	Buckstaff (2004)	Vessels	↑ Vessel approach	NC	NC	
	Luís et al. (2014)	Vessels	↓			
	Gospić and Picciulin (2016)	Vessels (low-frequency noise)			↑	
	Antichi et al. (2022)	Vessels (single small vessel passages)			Coastal dolphins ↑, Oceanic dolphins ↓ (after approach)	
Delphinids (multiple species)	Papale et al. (2015)	Anthropogenic and ambient noise			↑ min/max frequency	
Dugong (Dugong dugon)	Ando-Mizobata et al. (2014)	Vessels (within 400 m)	NC	↑	↑ bandwidth	
Harbor seal (Phoca vitulina, pups, 1 – 3 weeks old)	Torres Borda et al. (2021)	Broadband recorded ambient noise playback	NC	NC	↓ fundamental frequency	↑ Lombard in three of eight seals
Bearded seal (Erignathus barbatus)	Fournet et al. (2021)	Ambient (below 900 Hz)				↑ Lombard

¹ Call frequency and Lombard effect are often interrelated.

² In many studies, decreases in call amplitude or detections (calling rates) can result from masking of the recording hydrophone (receiver) rather than a change in the animal's vocal behavior.

Notes: ↑ = increase; ↓ = decrease; % = percent; < = less than; > = greater than; $\mu\text{Pa}^2\text{s}$ = micropascal squared seconds; dB = decibel; Hz = Hertz; kHz = kilohertz; NC = no change; SEL = sound exposure level; X = ceased calling

In some scenarios, depending on the capability of the individual animal to adjust the frequency and/or source levels of their calls and the characteristics of anthropogenic noise, vocal modifications might not compensate for masking. For example, Fournet et al. (2021) showed that estimated source levels of seal calls increased with ambient noise up to approximately 100 to 105 dB rms, above which no further Lombard effect was observed. This suggests that masking of bearded seal mating calls may occur in the presence of noise that exceeds 100 dB.

Vocal and other behavioral changes in response to masking noise might have fitness consequences, such as those that could result from an increase in metabolic rates and oxygen consumption, as was found for bottlenose dolphins when increasing their call amplitude (Holt et al., 2015). Some species might avoid changing the source levels or frequencies of their vocalizations to avoid predation or suffer increased risks of predation due to these vocal modifications. For example, beaked whales that modify their vocalizations might compromise otherwise cryptic foraging strategies which function to avoid predation by killer whales (Aguilar de Soto et al., 2006; Brumm & Slabbekoorn, 2005).

D.6.4.2 Masking by Anthropogenic Noise Sources

This section summarizes the predicted effects of masking by each type of anthropogenic noise source on marine mammals based on the information presented above. Examples of studies specific to vessel noise, sonar, and impulsive sounds are also discussed. The most important considerations for potential masking are the source level, frequency, duty cycle, and range (distance between masker and listening or calling animal).

D.6.4.2.1 Masking by Vessel Noise

Masking of marine mammal vocalizations is most likely to occur in the presence of broadband, relatively continuous noise sources such as vessels. This type of noise overlaps in frequency with many marine mammal sounds and can effectively reduce their communication space. Both signal detection and informational masking are likely to occur in the presence of vessel noise (Erbe et al., 2016). Models of communication space reduction (Table D.6-3) have predicted substantial decreases in communication space for a variety of species. When there is persistent vessel noise such as in a busy harbor, this effect is likely to be pervasive in nearby habitats as compared to intermittent when vessels pass through a habitat with lower ambient noise levels.

It is also possible that high source level vessel noise could mask marine mammal echolocation sounds. Hermannsen et al. (2014) estimated that broadband vessel noise could extend up to 160 kHz at ranges from 60 to 1,200 m, and that the higher frequency portion of that noise might mask harbor porpoise clicks. However, masking might not occur in practice, since harbor porpoises may avoid vessels and therefore may not be close enough to have their clicks masked (Dyndo et al., 2015; Polacheck & Thorpe, 1990; Sairanen, 2014). Liu et al. (2017) found that broadband shipping noise could cause masking of humpback dolphin whistles within 1.5 to 3 km, and masking of echolocation clicks within 0.5 to 1.5 km. Williams et al. (2014a) found that killer whale echolocation clicks (18 to 60 kHz) in Haro Strait were not masked by vessel noise over a 2 km distance. Gervaise et al. (2012) showed that the echolocation frequency range of belugas in the Saguenay-St. Lawrence Marine Park was masked by car ferry noise.

Overall, vessel noise has a substantial probability of masking marine mammal communication sounds and can also mask echolocation sounds in some cases. However, many studies of vessel noise masking do not consider spatial release from masking [e.g., (Brewer et al., 2023)], which is likely to reduce the effect of masking if the vessel is spatially separated from the signal of interest; this is especially relevant for situations where avoidance behavior is also exhibited. The overall potential effects of masking by vessel noise are (1) a reduction in the ability of marine mammals to communicate, detect, or interpret biologically relevant sounds, (2) costs associated with noise-induced vocal modifications such as the Lombard effect, or (3) costs associated with other behavioral responses to masking noise or the physical presence of vessels (see Behavioral Reactions D.6.5).

D.6.4.2.2 Masking by Sonar

Because military sonars typically have low duty cycles, relatively short duration, and narrow bandwidth that does not overlap with vocalizations for most marine mammal species, masking would be limited as compared to continuous sources (e.g., vessel noise). Dolphin whistles and mid-frequency active sonar are similar in frequency, so masking is possible but less likely due to the low-duty cycle and short durations of most sonars and the probability that dip listening would occur. For similar reasons, masking caused by low-frequency active sonar may be limited where it overlaps in frequency with some mysticete vocalizations (e.g., minke and humpback whales) (Fristrup et al., 2003; Miller et al., 2000).

High-duty cycle or continuous active sonars have the potential to mask marine mammal vocalizations. These sonars transmit more frequently than intermittent sonars, but at substantially lower source levels.

While the lower source levels limit the range of impact compared to other systems, animals close to the sonar source are likely to experience masking on a much longer time scale than those exposed to intermittent sonars. Continuous noise at the same frequency of communicative vocalizations may cause disruptions to communication, social interactions, and acoustically mediated cooperative behaviors (Sørensen et al., 2023) such as foraging and mating. Similarly, because the high-duty cycle or continuous active sonar are mid-frequency, there is the potential for the sonar signals to mask important environmental cues like predator vocalizations (e.g., killer whales), possibly affecting prey (including other marine mammals). Spatial release from masking may occur with higher duty cycle or continuous active sonars.

von Benda-Beckmann et al. (2021) modeled the effect of pulsed and continuous 1-2 kHz active sonar on sperm whale echolocation clicks and found that the presence of upper harmonics in the sonar signal increased masking of clicks produced in the search phase of foraging compared to buzz clicks produced during prey capture. Different levels of sonar caused intermittent to continuous masking (120 to 160 dB re 1 μPa^2 , respectively), but varied based on click level, whale orientation, and prey target strength. Continuous active sonar resulted in a greater percentage of time that echolocation clicks were masked compared to pulsed active sonar. This means that sonar sounds could reduce the ability of sperm whales to find prey under certain conditions. However, echoes from prey are most likely spatially separated from the sonar source, and so spatial release from masking would be expected.

Overall, sonar has the potential to mask marine mammal communication sounds and echolocation clicks. Continuous active sonar is more likely to mask vocalizations than intermittent sonar, and in general, sonar is less likely than vessel noise to have masking effects on sounds that are biologically relevant to marine mammals.

D.6.4.2.3 Masking by Impulsive Sound Sources

Impulsive sound sources, including explosions, are intense and short in duration (see D.1.1.5). Since impulsive noise is intermittent, the length of the gap between sounds (duty-cycle) and received level are pertinent when considering the potential for masking. Impulsive sounds with lower duty cycles or lower received levels are less likely to result in masking than higher duty cycles or received levels. There are no direct observations of masking in marine mammals due to exposure to explosive sources. Potential masking from explosive sounds or weapon noise is likely similar to masking studied for other impulsive sounds, such as air guns or pile-driving.

Masking of mysticete calls could occur due to the overlap between their low-frequency vocalizations and the dominant frequencies of impulsive sources (Castellote et al., 2012; Nieukirk et al., 2012). For example, blue whale feeding/social calls increased when seismic exploration was underway (Di Lorio & Clark, 2010), indicative of a possible compensatory response to masking effects of the increased noise level. However, mysticetes that call at higher rates are less likely to be masked by impulsive noise with lower duty cycles (Clark et al., 2009) because of the decreased likelihood that the noise would overlap with the calls, and because of dip listening. Field observations of masking effects such as vocal modifications are difficult to interpret because when recordings indicate that call rates decline, this could be caused by (1) animals calling less frequently (actual noise-induced vocal modifications), (2) the calls being masked from the recording hydrophone due to the noise (e.g., animals are not calling less frequently but are being detected less frequently), or (3) the animals moving away from the noise, or any combination of these causes (Blackwell et al., 2013; Cerchio et al., 2014).

Masking of pinniped communication sounds at 100 Hz center frequency is possible when vocalizations occur at the same time as an air gun pulse (Sills et al., 2017). This might result in some percentage of vocalizations being masked if an activity such as a seismic survey is being conducted in the vicinity, even

when the sender and receiver are near one another. Release from masking due to “dip listening” is likely in this scenario.

While a masking effect of impulsive noise can depend on the received level (Blackwell et al., 2015) and other characteristics of the noise, the vocal response of the affected animal to masking noise is an equally important consideration for inferring overall impacts to an animal. As illustrated in Table D.6-4, it is possible that the receiver would increase the rate and/or level of calls to compensate for masking; or, conversely, cease calling.

In general, impulsive noise has the potential to mask sounds that are biologically important for marine mammals, reducing communication space or resulting in noise-induced vocal modifications that might impact marine mammals. Masking by close-range impulsive sound sources is most likely to impact marine mammal communication.

D.6.5 BEHAVIORAL REACTIONS

Any stimulus in the environment can cause marine mammals to react, including noise from anthropogenic sources such as vessels, sonar, or aircraft, as well as the physical presence of a vessel or aircraft. Marine mammal responses to anthropogenic sound were reviewed by Richardson et al. (1995b). Other reviews (Nowacek et al., 2007; Southall et al., 2007) addressed studies conducted since 1995 and focused on observations where the received sound level was known or could be estimated, and discussed the role of context. Southall et al. (2007) synthesized data from many past behavioral studies and observations to determine the likelihood of behavioral reactions at specific sound levels, and Southall et al. (2016) reviewed the range of experimental field studies that have been conducted to measure behavioral responses of cetaceans to sonar.

Considerable variability has been observed in marine mammal responses to sound. Methods have been developed and refined to categorize and assess the severity of acute responses, considering impacts to individuals that may consequently impact populations (Southall et al., 2007; Southall et al., 2021). These severity scales assess immediate discrete responses in relation to behaviors affecting vital rates, including survival, reproduction, and foraging. Using these scales, a behavioral response by a wild (non-captive) marine mammal may range from low severity (e.g., detectable interruptions in foraging, diving, or courtship behavior) to moderate severity (e.g., avoidance, sustained foraging reduction) to high severity (e.g., separation of mother-offspring, prolonged displacement from foraging habitat, repeated breeding disruption leading to reduced reproductive success). Captive animal behavior studies allow for controlled, repeated exposures with very precise measures, but captive marine mammals may have training and motivational contexts that make their responses difficult to compare to free-ranging, non-captive animals (Southall et al., 2021). Therefore, behavioral severity scales developed for captive marine mammals consider other factors such as trained behaviors, use of rewards, and habituation.

While in general, the louder the sound source, the more intense the behavioral response, it was clear that the proximity of a sound source and the animal’s experience, motivation, and conditioning were also critical factors influencing the response (Southall et al., 2007; Southall et al., 2016). Ellison et al. (2011) submit that “exposure context” greatly influences the type of behavioral response exhibited by an animal and outlined an approach to assessing the effects of sound on marine mammals that considers not just the received level of sound, but also in what activity the animal is engaged, the nature and novelty of the sound (i.e., is this a new sound from the animal’s perspective), and the distance between the sound source and the animal. Other variables and contextual factors that may affect the probability and magnitude of a behavioral response include subject-specific factors (e.g., age, sex,

presence of a calf, and group size and composition), characteristics of the sound (frequency, duration, similarity to predator sounds, and whether it is continuous or intermittent); whether the sound is approaching or moving away; the presence of predators, prey, or conspecifics; and navigational constraints on the animal (Ellison et al., 2011; Southall et al., 2021; Wartzok et al., 2003).

Extensive research programs have and are investigating the responses of free-ranging marine mammals to anthropogenic sounds, including actual and simulated tactical sonars both on and off military ranges (Southall et al., 2016). These behavioral response studies include controlled exposure studies, in which detailed acoustic dose and behavioral data are obtained from tags on focal animals, as well as data obtained from longer-term tags and passive acoustic monitoring during opportunistic exposures to actual sonar on naval training and testing ocean ranges with bottom-mounted hydrophones (Harris et al., 2018). Table D.6-5 provides an overview of current and past efforts as background to the findings presented in the taxa-specific sections below.

Table D.6-5: Major Non-Captive Behavioral Response Studies

<i>Project/ Location</i>	<i>Focal Species</i>	<i>Sound source</i>	<i>Studies</i>
Opportunistic Studies on Navy instrumented Ranges			
AUTEC, Bahamas	Blainville's beaked whale	Navy hull-mounted sonar	Joyce et al. (2019); McCarthy et al. (2011); Moretti et al. (2014); Tyack et al. (2011)
SOCAL Anti-Submarine Warfare Range	Goose-beaked whale ¹	Navy hull-mounted and dipping sonar	Falcone et al. (2017)
Pacific Missile Range Facility, Hawaii	Minke whale Humpback whale Blainville's beaked whale	Navy hull-mounted sonar	Durbach et al. (2021); Harris et al. (2019b); Henderson et al. (2019); Henderson et al. (2016); Manzano-Roth et al. (2016); Martin et al. (2015)
BRS with Controlled Exposure Experiments			
AUTEC-BRS (Bahamas)	Blainville's beaked whales	Simulated tactical sonar	Tyack et al. (2011)
3S1 ² (Norway)	Killer whale Long-finned pilot whale Sperm whale	Simulated tactical sonar (1 – 2 kHz or 6 – 7 kHz, intermittent)	Antunes et al. (2014); Curé et al. (2016); Isojunno et al. (2016); Isojunno et al. (2017); Miller (2012); Miller et al. (2014); Sivle et al. (2012b); Visser et al. (2016)
3S2 ² (Norway)	Humpback whale Minke whale Northern bottlenose whale	Simulated tactical sonar (1 – 2 kHz or 6 – 7 kHz, intermittent)	Curé et al. (2021); Kvadsheim et al. (2017); Miller et al. (2015); Sivle et al. (2015b); Sivle et al. (2016b); Wensveen et al. (2019); Wensveen et al. (2017)
3S3 ² (Norway)	Sperm whale Long-finned pilot whale	Simulated tactical sonar (1 – 2 kHz continuous and intermittent)	Curé et al. (2021); Isojunno et al. (2021); Isojunno et al. (2020)
SOCAL BRS	Blue whale Fin whale Minke whale Baird's beaked whale Goose-beaked whale ¹ Risso's dolphin	Simulated tactical sonar (3.5 – 4 kHz intermittent)	DeRuiter et al. (2013b); Friedlaender et al. (2016); Goldbogen et al. (2013); Kvadsheim et al. (2017); Southall et al. (2019b); Stimpert et al. (2014); Southall et al. (2023)

Table D.6-5: Major Non-Captive Behavioral Response Studies (continued)

<i>Project/ Location</i>	<i>Focal Species</i>	<i>Sound source</i>	<i>Studies</i>
Atlantic BRS ³	Goose-beaked whale ¹ Short-finned pilot whale	Simulated tactical sonar (3 – 4 kHz, intermittent) and Navy hull-mounted sonar	

¹ Formerly Cuvier's beaked whale

² 3S = Sea mammals and Sonar Safety

³ This is the most recent BRS efforts; thus, peer-reviewed publications of findings are not yet available.

Notes: AUTECH = Atlantic Undersea Test and Evaluation Center; BRS = Behavioral Response Studies; kHz = kilohertz; SOCAL = Southern California

For most species, little or no data exist on behavioral responses to any sound source. For the below synthesis of best available science on marine mammal behavioral responses, all species have been grouped into broad taxonomic groups from which general response information can be inferred.

D.6.5.1 Behavioral Reactions of Mysticetes

D.6.5.1.1 Sonar and Other Transducers

The responses of mysticetes to sonar and other duty-cycled tonal sounds depend on the characteristics of the signal, behavioral state of the animal, sensitivity and previous experience of an individual, and other contextual factors including distance of the source, movement of the source, physical presence of vessels, time of year, and geographic location (Goldbogen et al., 2013; Harris et al., 2019a; Harris et al., 2015; Martin et al., 2015; Sibley et al., 2015b). Behavioral response studies have been conducted over a variety of contextual and behavioral states, helping to identify which factors, beyond the received level of the sound, may lead to a response. Observed reactions during behavioral response studies have not been consistent across individuals based on received sound levels alone, and likely were the result of complex interactions between these contextual factors.

In the SOCAL BRS, tagged surface feeding blue whales did not show a change in behavior in response to mid-frequency simulated and incidental Navy sonar sources with received levels between 90 and 179 dB re 1 μ Pa, but deep feeding and non-feeding whales showed temporary reactions including cessation of feeding, reduced initiation of deep foraging dives, generalized avoidance responses, and changes to dive behavior. The behavioral responses were generally brief, of low to moderate severity, and highly dependent on exposure context (behavioral state, source-to-whale horizontal range, and prey availability), with a return to baseline behavior shortly after the end of the exposure (DeRuiter et al., 2017; Goldbogen et al., 2013; Southall et al., 2019c). When the prey field (krill) was mapped and used as a covariate in models looking for a response in the 2011–2013 SOCAL BRS data set, the response in deep-feeding blue whales was even more apparent, reinforcing the need for contextual variables, such as feeding state, to be included when assessing behavioral responses (Friedlaender et al., 2016). The probability of a moderate behavioral response increased when the range to source was closer for these foraging blue whales, although there was a high degree of uncertainty in that relationship (Southall et al., 2019b). None of the tagged fin whales in the SOCAL BRS demonstrated more than a brief or minor response regardless of their behavioral state (Harris et al., 2019a). The fin whales were exposed to both mid-frequency simulated sonar and pseudorandom noise of similar frequency, duration, and source level. They were less sensitive to disturbance than blue whales, with no significant differences in response between behavioral states or signal types. The authors rated responses as low-to-moderate severity with no negative impact to foraging success (Southall et al., 2023).

Similarly, humpback whale behavioral responses to sonar have been influenced by foraging state. During sonar exposure of tagged whales in the 3S2 study, the rates of foraging lunges generally decreased, but responses varied across individuals (e.g., ceasing or starting to forage); most of the non-foraging humpback whales did not respond to any approaches at all (Sivle et al., 2016b). For foraging whales, lunges decreased (although not significantly) during a no-sonar control vessel approach prior to the sonar exposure, and lunges decreased less during a second sonar approach than during the initial approach. There was also variability in humpback avoidance responses. Some tagged whales in the 3S2 study avoided the sonar vessel only during the first or second exposure, and only one whale avoided both (Sivle et al., 2016b). This suggests that there may have been responses to the vessel or habituation to the sonar and vessel after repeated approaches. Almost half of the animals with avoidance responses were foraging before the exposure; the non-feeding whales that avoided responded at a slightly lower received level and greater distance than those that were feeding (Wensveen et al., 2017). When responses did occur the animals quickly returned to their previous behavior after the sound exposure ended (Sivle et al., 2015b). Changes in foraging duration during mammal-eating killer whale playbacks and mid-frequency sonar were positively correlated across multiple species in the 3S Norwegian studies, including humpback whales, suggesting that tolerance of predation risk may play a role in sensitivity to sonar disturbance (Miller et al., 2022), with the humpback whales responding more severely to the killer whale vocalization playbacks than they did to the sonar playbacks (Curé et al., 2015; Sivle et al., 2015b).

The most severe baleen whale response in any behavioral response study was observed in a minke whale in the 3S2 study, which responded to simulated naval sonar at a received level of 146 dB re 1 μ Pa by strongly avoiding the sound source (Kvadsheim et al., 2017; Sivle et al., 2015b). Although the minke whale increased its swim speed, directional movement, and respiration rate, none of these were greater than rates observed in baseline behavior, and its dive behavior remained similar to baseline dives. A minke whale tagged in the SOCAL behavioral response study also responded by increasing its directional movement, but maintained its speed and dive patterns, and so did not demonstrate as strong of a response (Kvadsheim et al., 2017). In addition, the 3S2 minke whale demonstrated some of the same avoidance behavior during the controlled ship approach with no sonar, indicating at least some of the response was to the vessel (Kvadsheim et al., 2017).

In addition to behavioral response studies, responses by humpback and minke whales to actual training activities on Navy ranges have been monitored. Several humpback whales have been observed during aerial or visual surveys during Navy training events involving sonar; no avoidance or other behavioral responses were ever noted, even when the whales were observed within 5 km of a vessel with active sonar and maximum received levels were estimated to be between 135 and 161 dB re 1 μ Pa (Mobley, 2011; Mobley & Milette, 2010; Mobley & Pacini, 2012; Mobley et al., 2012; Smultea et al., 2009). In fact, one group of humpback whales approached a vessel with active sonar so closely that the sonar was shut down and the vessel slowed; the animals continued approaching and swam under the bow of the vessel (U.S. Department of the Navy, 2011a). Another group of humpback whales continued heading towards a vessel with active sonar as the vessel was moving away for almost 30 minutes, with an estimated median received level of 143 dB re 1 μ Pa. This group was observed producing surface active behaviors such as pec slaps, tail slaps, and breaches; however, these are very common behaviors in competitive pods during the breeding season and were not considered to have occurred in response to the sonar (Mobley et al., 2012).

Monitoring at the Pacific Missile Range Facility off Kaua'i has provided data on humpback and minke responses to naval anti-submarine warfare sonars in actual training conditions. Henderson et al. (2019)

examined the dive and movement behavior of tagged humpback whales, including whales incidentally exposed to sonar during Navy training activities. Tracking data showed that individual humpbacks spent limited time, no more than a few days, in the vicinity of Kaua'i, even without sonar exposure. Potential behavioral responses to sonar exposure were limited and may have been influenced by engagement in breeding and social behaviors. Martin et al. (2015) found that the density of calling minke whales was reduced during periods of Navy training involving sonar relative to the periods before training and increased again in the days after training was completed. The responses of individual whales could not be assessed, so in this case it is unknown whether the decrease in calling animals indicated that the animals left the range or simply ceased calling. Harris et al. (2019b) utilized acoustically generated minke whale tracks to statistically demonstrate changes in the spatial distribution of minke whale acoustic presence before, during, and after surface ship mid-frequency active sonar training. The spatial distribution of probability of acoustic presence was different in the "during" phase compared to the "before" phase, and the probability of presence at the center of ship activity during mid-frequency active sonar training was close to zero for both years. The "after" phases for both years retained lower probabilities of presence suggesting the return to baseline conditions may take more than five days. The results show a clear spatial redistribution of calling minke whales during surface ship mid-frequency active sonar training, however a limitation of passive acoustic monitoring is that one cannot conclude if the whales moved away, went silent, or a combination of the two.

Building on this work, Durbach et al. (2021) used the same data and determined that individual minke whales tended to be in either a fast or slow movement behavior state while on the range, where whales tended to be in the slow state in baseline or before periods but transitioned into the fast state with more directed movement during sonar exposures. They also moved away from the area of sonar activity on the range, either to the north or east depending on where the activity was located; this explains the spatial redistribution found by Harris et al. (2019b). Minke whales were also more likely to stop calling when in the fast state, regardless of sonar activity, or when in the slow state during sonar activity (Durbach et al., 2021). Similarly, minke whale detections made using Marine Acoustic Recording Instruments off Jacksonville, Florida, were reduced or ceased altogether during periods of sonar use (Norris et al., 2012; U.S. Department of the Navy, 2013), especially with an increased ping rate (Charif et al., 2015).

Other opportunistic passive acoustic based studies have also detected behavioral responses of blue and humpback whales to sonar, although definitive conclusions are harder to draw. Blue whales exposed to mid-frequency sonar in the Southern California Bight were less likely to produce low-frequency calls usually associated with feeding behavior, beginning at received levels of 110 to 120 dB re 1 μ Pa (Melcón et al., 2012); however, without visual observations it is unknown whether there was another factor that contributed to the reduction in foraging calls, such as the presence of conspecifics. In another example, Risch et al. (2012, 2014) determined that humpback whale song produced in the Stellwagen Bank National Marine Sanctuary was reduced while an Ocean Acoustic Waveguide Remote Sensing experiment was occurring 200 km away. They concluded that the reduced song was a result of the Ocean Acoustic Waveguide Remote Sensing. However, Gong et al. (2014) analyzed the same data set while also looking at the presence of herring in the region, and found that the singing humpbacks were actually located on nearby Georges Bank and not on Stellwagen, and that the song rate in their data did not change in response to Ocean Acoustic Waveguide Remote Sensing, but could be explained by natural causes.

Baleen whales have also been exposed to lower frequency sonars, with the hypothesis that they may react more strongly to lower frequency sounds that overlap with their vocalization range. One series of studies was undertaken in 1997–1998 pursuant to the Navy's Low Frequency Sound Scientific Research Program. The frequency bands of the low-frequency sonars used were between 100 and 500 Hz, with

received levels between 115 and 150 dB re 1 μ Pa, and the source was always stationary. Fin and blue whales were targeted on foraging grounds, singing humpback whales were exposed on breeding grounds, and gray whales were exposed during migratory behavior. These studies found only short-term responses to low-frequency sound by some fin and humpback whales, including changes in vocal activity and avoidance of the source vessel, while other fin, humpback, and blue whales did not respond at all. When the source was in the path of migrating gray whales they changed course up to 2 km to avoid the sound, but when the source was outside their path, little response was observed although received levels were similar (Clark & Fristrup, 2001; Croll et al., 2001; Fristrup et al., 2003; Miller et al., 2000; Nowacek et al., 2007). Low-frequency signals of the Acoustic Thermometry of Ocean Climate sound source were also not found to affect dive times of humpback whales in Hawaiian waters (Frankel & Clark, 2000).

In contrast to actual or simulated naval sonar, some studies have examined responses to underwater tones or alarms intended to serve as deterrents (Table D.6-6). Migrating mysticetes sometimes responded by changing their route away from the deterrent (Dunlop et al., 2013; Frankel & Stein, 2020; Watkins & Schevill, 1975) or not at all (Harcourt et al., 2014; Morton & Symonds, 2002; Pirotta et al., 2016). Other behavioral responses caused by acoustic alarms and deterrents include reduced foraging dives, path predictability and reoxygenation rates, as well as increased swim speeds and dive durations (Boisseau et al., 2021; Nowacek et al., 2004a).

Table D.6-6: Major Findings from Studies of Acoustic Alarms and Acoustic Deterrent Devices (ADDs) in Mysticetes

<i>Species</i>	<i>Major Finding</i>	<i>Supporting Studies</i>
Humpback whales – wild	Changed migration course away from the deterrent (more offshore) and surfaced more frequently during 2 kHz tones.	Dunlop et al. (2013); Watkins and Schevill (1975)
Gray whales – wild	Changed migration course away from the deterrent (towards shore) during stationary sonar transmissions (21 – 25 kHz, 148 dB re 1 μ Pa).	Frankel and Stein (2020)
Humpback whales – wild	No change in migration route or behavioral response (even within 500 m) during 2 – 5 kHz fisheries deterrents.	Harcourt et al. (2014); Morton and Symonds (2002); Pirotta et al. (2016)
North Atlantic right whales - wild	Interrupted foraging dives during particularly long acoustic alarm (0.5 – 4.5 kHz, several minute long).	Nowacek et al. (2004a)
Minke whales - wild	Increased speed, dive duration, path predictability (straighter paths), and decreased reoxygenation rates while foraging during ADD (15 kHz, 198 dB rms). Path predictability had strong relationship with received level. Speed and dive duration more influenced by the presence of the exposure signal instead of the received sound level.	Boisseau et al. (2021)

Notes: ADD = acoustic deterrent device; dB = decibel; kHz = kilohertz; m = meters; μ Pa = micropascal; rms = root mean square

Although some strong responses have been observed in mysticetes to sonar and other transducers (e.g., the single minke whale), for the most part mysticete responses appear to be fairly moderate across all received levels. While some responses such as cessation of foraging or changes in dive behavior could carry short-term impacts, in all cases behavior returned to normal after the signal stopped. Mysticete responses also seem to be highly mediated by behavioral state, with no responses occurring in some behavioral states, and contextual factors and signal characteristics having more impact than received level alone. Many of the contextual factors resulting from the behavioral response studies (e.g., close

approaches by multiple vessels or tagging) would never be introduced in real Navy training scenarios. While data are lacking on behavioral responses of mysticetes to continuous active sonars, these species are known to be able to habituate to novel and continuous sounds (Nowacek et al., 2004a), suggesting that they are likely to have similar responses to high-duty cycle sonars. Therefore, mysticete behavioral responses to Navy sonar will likely be a result of the animal's behavioral state and prior experience rather than external variables such as ship proximity; thus, if significant behavioral responses occur they will likely be short term. In fact, no significant behavioral responses such as panic, stranding, or other severe reactions have been observed during monitoring of actual training exercises (Smultea et al., 2009; U.S. Department of the Navy, 2011b, 2014; Watwood et al., 2012).

D.6.5.1.2 Vessel Disturbance

Behavioral responses to vessels can be caused by multiple factors. It is difficult for researchers and analysts to separate the effects of vessel noise and vessel presence; therefore, this section will cover both aspects. Baleen whales demonstrate a variety of responses to vessel traffic and noise, including not responding at all to approaching vessels, as well as both horizontal (swimming away) and vertical (increased diving) avoidance (Baker et al., 1983; Fiori et al., 2019; Gende et al., 2011; Watkins, 1981). Avoidance responses can include changes in swim patterns, speed, or direction (Jahoda et al., 2003), staying submerged for longer periods of time (Au & Green, 2000), or performing shallower dives accompanied by more frequent surfacing. Smaller-scale responses to vessels include changes such as altered breathing patterns (e.g., Baker et al., 1983; Jahoda et al., 2003), and larger-scale changes such as a decrease in apparent presence (Anderwald et al., 2013). Other common behavioral reactions include changes in vocalizations, surface time, feeding and social behaviors (Au & Green, 2000; Dunlop, 2019; Fournet et al., 2018; Machernis et al., 2018; Richter et al., 2003; Williams et al., 2002a).

Certain vessel types come with additional associated sound, other than engine and propeller cavitation noise (e.g., icebreakers). Bowhead whales avoided the area around icebreaker ship noise and increased their time at the surface and number of blows (Richardson et al., 1995a). However, bowhead whales showed no discernable long-range (greater than 8 km) behavioral reaction to various types of vessel traffic, similar to their close relative, North Atlantic right whales (Martin et al., 2023b).

Studies show that North Atlantic right whales demonstrate little if any reaction to sounds of vessels approaching or the presence of the vessels themselves. They continue to use habitats in high vessel traffic areas (Nowacek et al., 2004a). This lack of response may be due to habituation to the presence and associated noise of vessels in right whale habitat or may be due to propagation effects that may attenuate vessel noise near the surface (Nowacek et al., 2004a; Terhune & Verboom, 1999). However, right whales have been reported to increase the amplitude or frequency of their vocalizations or call at a lower rate in the presence of increased vessel noise (Parks et al., 2007; Parks et al., 2011), and these vocalization changes may persist over long periods if background noise levels remained elevated.

Other species of mysticetes seem to lack obvious reactions to vessel disturbance as well, but it may be for lack of research or variables studied. Sei whales have been observed ignoring the presence of vessels entirely and even pass close to vessels (Reeves et al., 1998). Historically, fin whales tend to ignore vessels at a distance (Watkins, 1981) or habituate to vessels over time (Watkins, 1986), but still demonstrate vocal modifications (e.g., decreased frequency parameters of calls) during boat traffic. Fin whale calls in Ireland were less likely to be detected for every 1 dB re 1 μ Pa/minute increase in shipping noise levels as well (Ramesh et al., 2021). In the presence of tour boats in Chile, fin whales were changing their direction of movement more frequently, with less linear movement than occurred before the boats arrived; this behavior may represent evasion or avoidance of the boats (Santos-Carvalho et al., 2021). The increase in travel swim speeds after the boats left the area may be related to the rapid

speeds at which the boats left the area, sometimes in front of the animals, leading to more avoidance behavior after the boats have left.

The likelihood of any behavioral response may be driven by the density, distance or approach of vessel traffic, the animal's behavioral state, or by the prior experience of the individual or population. If the threshold of disturbance is not met for a species or group of mysticetes, there may be no behavioral reaction, as seen during a study on fin and humpback whales that largely ignored vessels that remained 100 m or more away (Watkins, 1981). When a fishing vessel conducting an acoustic survey of pelagic fisheries began moving around six whales (species unknown) at close distances (50 to 400 m), whales only slightly changed swim direction (Bernasconi et al., 2012). In areas with high motorized vessel traffic, gray whales were likely to continue feeding when approached by a vessel, but in areas with less motorized vessel traffic they were more likely to change behaviors, either indicating habituation to vessels in high traffic area, or indicating possible startle reactions to close-approaching non-motorized vessels (e.g., kayaks) in quieter areas (Sullivan & Torres, 2018).

Changes in humpback whale behavior were also affected by vessel behavior (e.g., approach type, speed), in addition to time of day and season (Di Clemente et al., 2018; Fiori et al., 2019). Avoidance responses occurred most often after "J" type vessel approaches (i.e., traveling parallel to the whales' direction of travel, then overtaking the whales by turning in front of the group) compared to parallel or direct approaches. Mother humpbacks were particularly sensitive to direct and J type approaches and spent significantly more time diving in response (Fiori et al., 2019). The presence of a passing vessel did not change the behavior of resting humpback whale mother-calf pairs, but fast vessels with louder low-frequency weighted source levels of 173 dB re 1 μ Pa, equating to weighted received levels of 133 dB re 1 μ Pa at an average distance of 100 m, led to a decrease in resting behavior and increase in dives, swim speeds, and respiration rates (Sprogis et al., 2020). Humpback whale reactions to vessel disturbance were dependent on their behavioral state. When vessels came within 500 m humpbacks would continue to feed, but were more likely to start traveling if they were surface active when approached (Di Clemente et al., 2018).

Humpback whales changed their dive times, respiration rates, and social behavior when vessels were present. In a study of large Navy vessels in Hawaii, humpback whale avoidance behaviors included increasing dive times and decreasing respiration rates at the surface when vessels were within 0.5 to 2 km (Smultea et al., 2009). Social interactions between migrating males and mother-calf pairs were reduced in the presence of vessels towing seismic air gun arrays, regardless of whether the air guns were active or not; this indicates that it was the presence of ships (rather than the active air guns) that impacted humpback behavior (Dunlop et al., 2020).

The vocal behavior and communication space for humpback whales is also impacted by vessel disturbance. In one study, whales increased the source level of their calls with increased ambient noise levels that include vessel noise (Fournet et al., 2018) and in another humpback whale call rates increased in association with high vessel noise (Doyle et al., 2008). However, there are several studies demonstrating that the probability of humpback whale calls and detections decrease when vessel noise becomes a larger part of the soundscape (Fournet et al., 2018; Laute et al., 2022). When the number of whale watching trips decreased by nearly 70 percent in an Icelandic humpback whale feeding ground, the number of humpback whale calls doubled, even though the median ambient SPL did not change (Laute et al., 2022). Humpback song activity also decreased due to boat traffic near Brazil (Sousa-Lima & Clark, 2008), and in Australia their communication area was reduced by half in average vessel-dominated noise (105 dB re 1 μ Pa). However the physical presence of vessels was the major contributing factor to decreased social interactions (Dunlop, 2019).

Examples of mysticete responses to tourism vessels, with an emphasis on humpback whale responses, are detailed in Table D.6-7.

Table D.6-7: Examples of Behavioral Responses to Vessel Disturbance in Mysticetes

Species	Study	Boat type	Behavioral Change					
			Feeding or foraging	Surface behaviors	Resting	Respiration Rates	Diving duration	Horizontal avoidance (Δ direction or speed)
Humpback whales – Hawaii	Baker et al. (1983)	Tour					↑ when < 2,000 m away	↑ when 2,000 – 4,000 m away
Humpback whales – Australia	Stamation et al. (2010)	Tour		↓		NC	↑	↑ or ↓ (avoid or approach)
Humpback whales – Alaska	Schuler et al. (2019); Toro et al. (2021)	Tour		↓		↑		↑
Minke whales – Iceland	Christiansen et al. (2013)	Tour	↓			↑ (↓ IBI)		
Blue whales – Canada	Lesage et al. (2017)	Tour	↓	↓		↓	↓	
Fin whales – Chile	Santos-Carvalho et al. (2021)	Tour						↑
Sperm whales – Portugal	Oliveira et al. (2022)	Tour	NC		↓ (↑ movement)			↑ speed of ascent
Southern right whales – Australia	Sprogis et al. (2023)	Tour			↓	NC		

Notes: ↑ = increase; ↓ = decrease; < = less than; Δ = change in; IBI = Inter-breath interval; m = meters; NC = no change

Blue whale response to vessel disturbance varies from increasing the likelihood of producing certain types of calls when vessels pass (Melcón et al., 2012), to general avoidance behavior (Lesage et al., 2017; Szesciorka et al., 2019). In an area of high whale watch activity, vessels were within 2,000 m of blue whales 70 percent of the time, with a maximum of 8 vessels observed within 400 m of one whale at the same time. In response to repeated exposures to vessels, blue whales decreased time at the surface, had fewer breaths at the surface, shorter dive times and less time foraging as a result (Lesage et al., 2017). In response to an approaching large commercial vessel in an area of high ambient noise levels (125–130 dB re 1 μ Pa), a tagged female blue whale turned around mid-ascent and descended perpendicular to the ship's path (Szesciorka et al., 2019). The whale did not respond until the ship's closest point of approach (100 m distance, 135 dB re 1 μ Pa), which was 10 dB above the ambient noise levels. After the ship passed, the whale ascended to the surface again with a three-minute delay.

Minke whale negative, neutral, or positive response to vessels may be influenced by vessel speed and boat traffic density. In the Antarctic minke whales did not show any apparent response to a survey vessel moving at normal cruising speeds (about 12 knots) at a distance of 5.5 NM. However, when the vessel drifted or moved at very slow speeds (about 1 knot), many whales approached it (Leatherwood et al., 1982). Larger-scale negative changes like habitat displacement was found during a construction

project in the United Kingdom, when fewer minke whales were observed as vessel traffic increased (Anderwald et al., 2013). Likewise, minke whales on feeding grounds in Iceland responded to increased whale watching vessel traffic with a decrease in foraging, both during deep dives and at the surface (Christiansen et al., 2013). They also increased their avoidance of the boats while decreasing their respiration rates, likely leading to an increase in their metabolic rates. Christiansen and Lusseau (2015) and Christiansen et al. (2014) followed up this study by modeling the cumulative impacts of whale watching boats on minke whales, but found that although the boats cause temporary feeding disruptions, there were not likely to be long-term consequences as a result. This suggests that short-term responses may not lead to long-term consequences and that over time animals may habituate to the presence of vessel traffic.

Longitudinal studies on vessel noise have been conducted, but the consequences of chronic vessel noise are not well understood. Using historical records, Watkins (1986) showed that the reactions of four species of mysticetes to vessel traffic and whale watching activities in Cape Cod had changed over 25 years (1957–1982). Reactions of minke whales changed from initially more positive reactions, such as coming towards the boat or research equipment to investigate, to more uninterested reactions towards the end of the study. Fin whales, the most numerous species in the area, showed a trend from initially more negative reactions, such as swimming away from the boat with limited surfacing, to more uninterested reactions (ignoring), allowing boats to approach within 30 m. Right whales showed little change over the study period, with a roughly equal number of reactions judged to be negative and uninterested; no right whales were noted as having positive reactions to vessels. Humpback whales showed a trend from negative to positive reactions with vessels during the study period. The author concluded that the whales had habituated to the human activities over time (Watkins, 1986).

Overall baleen whale responses to vessel noise and traffic are varied, and habituation or changes to vocalization are predominant long-term responses. When baleen whales do avoid ships, they do so by altering their swim and dive patterns to move away from the vessel. In many cases the whales do not appear to change their behavior at all. This may result from habituation by the whales but may also result from reduced received levels near the surface due to propagation, or due to acoustic shadowing of the propeller cavitation noise by the ship's hull. Although a lack of response in the presence of a vessel may minimize potential disturbance from passing ships, it does increase the whales' vulnerability to vessel strike, which may be of greater concern for baleen whales than vessel noise.

D.6.5.1.3 Aircraft Disturbance

Mysticetes either ignore or occasionally dive in response to aircraft overflights (Koski et al., 1998). Richardson et al. (1985); Richardson et al. (1995b) found no evidence that single or occasional aircraft flying above mysticetes causes long-term displacement of these mammals. However, bowhead whales in the Beaufort Sea exhibited a short-term behavioral response to fixed-wing aircraft and vessels. Reactions were frequently observed at less than 1,000 ft. above sea level, infrequently observed at 1,500 ft., and not observed at all at 2,000 ft. (Richardson et al., 1985).

Bowhead whales reacted to helicopter overflights by diving, breaching, changing direction or behavior, and altering breathing patterns. Behavioral reactions decreased in frequency as the altitude of the helicopter increased to 150 m or higher. The bowheads exhibited fewer behavioral changes than did the odontocetes in the same area (Patenaude et al., 2002). It should be noted that bowhead whales in this study may have more acute responses to anthropogenic activity than many other marine mammals since these animals were presented with restricted egress due to limited open water between ice floes.

Additionally, these animals are hunted by Alaska Natives, which could lead to animals developing additional sensitivity to human noise and presence.

Studies on unmanned aerial systems have not found significant behavioral responses from mysticetes so far. These devices are much smaller and quieter than typical aircraft, and so are less likely to cause a behavioral response, although they may fly at much lower altitudes (Smith et al., 2016). Acevedo-Whitehouse et al. (2010) maneuvered a remote-controlled helicopter over large baleen whales to collect samples of their blows, with no more avoidance behavior than noted for typical photo-identification vessel approaches. Bowhead whales did not respond to an unmanned system flying at altitudes between 120 and 210 m above the ocean's surface (Koski et al., 2015; Koski et al., 1998). While collecting humpback photogrammetry and fitness data, Christiansen et al. (2016) did not observe any responses to their unmanned aerial vehicle flown 30–120 m above the water either. Even 10 southern right whale mother-calf pairs showed no change in swim speed, respiration rate, turning angle, or interbreath interval in response to an unmanned aerial vehicle (Christiansen et al., 2020). Some of the animals were equipped with DTAGs to measure the sound of the unmanned aerial vehicle; the received levels in the 100–1,500 Hz band were 86 ± 4 dB re $1 \mu\text{Pa}$, very similar to ambient noise levels measured at 81 ± 7 dB in the same frequency band.

D.6.5.1.4 Impulsive Noise

Baleen whales have shown a variety of responses to impulsive sound sources, including avoidance, aggressive directed movement towards the source, reduced surface intervals, altered swimming behavior, and changes in vocalization rates (Gordon et al., 2003; McCauley et al., 2000a; Richardson et al., 1985; Southall et al., 2007). Studies have been conducted on many baleen whale species, including gray, humpback, blue, fin and bowhead whales; it is assumed that these responses are representative of all baleen whale species. The behavioral state of the whale seems to be an integral part of whether the animal responds and how they respond, as does the location and movement of the sound source, more than the received level of the sound.

Migratory behavior seems to lead to a higher likelihood of response, with some species demonstrating more sensitivity than others do. For example, migrating gray whales showed avoidance responses to seismic vessels at received levels between 164 and 190 dB re $1 \mu\text{Pa}$ (Malme et al., 1986, 1988). Similarly, migrating humpback whales showed avoidance behavior at ranges of 5–8 km from a seismic array during observational studies and controlled exposure experiments in one Australian study (McCauley et al., 1998), and in another Australian study decreased their dive times and reduced their swimming speeds (Dunlop et al., 2015). However, when comparing received levels and behavioral responses using ramp-up versus a constant noise level of air guns, humpback whales did not change their dive behavior but did deviate from their predicted heading and decreased their swim speeds (Dunlop et al., 2016). In addition, the whales demonstrated more course deviation during the constant source trials but reduced travel speeds more in the ramp-up trials; in either case there was no dose-response relationship with the received level of the air gun noise, and similar responses were observed in control trials with vessel movement but no air guns so some of the response was likely due to the presence of the vessel and not the received level of the air guns. Similar results were found in migrating humpback whales (Dunlop et al., 2020). Social interactions between males and mother-calf pairs were reduced in the presence of vessels towing seismic air gun arrays, regardless of whether the air guns were active or not; this indicates that it was the presence of ships (rather than the active air guns) that impacted humpback behavior (Dunlop et al., 2020).

When looking at the relationships between proximity, received level, and behavioral response, Dunlop et al. (2017) used responses to two different air guns and found responses occurred more towards the smaller, closer source than to the larger source at the same received level, demonstrating the importance of proximity. Responses were found to be more likely when the source was within 3 km or above 140 dB re 1 μ Pa, although responses were variable and some animals did not respond at those values while others responded below them. In addition, responses were generally small, with short term course deviations of only around 500 m (Dunlop et al., 2017). McDonald et al. (1995) tracked a blue whale with seafloor seismometers and reported that it stopped vocalizing and changed its travel direction at a range of 10 km from the seismic vessel (estimated received level 143 dB re 1 μ Pa peak-to-peak). Bowhead whales seem to be the most sensitive species. While most bowhead whales did not show active avoidance until within 8 km of seismic vessels (Richardson et al., 1995b), some whales avoided vessels by more than 20 km at received levels as low as 120 dB re 1 μ Pa. Additionally, Malme et al. (1988) observed clear changes in diving and breathing patterns in bowheads at ranges up to 73 km from seismic vessels, with received levels as low as 125 dB re 1 μ Pa. Bowhead whales may also avoid the area around seismic surveys, from 6 to 8 km (Koski and Johnson 1987, as cited in Gordon et al., 2003) out to 20 or 30 km (Richardson et al., 1999). However, work by Robertson et al. (2013) supports the idea that behavioral responses are contextually dependent, and that during seismic operations bowhead whales may be less “available” for counting due to alterations in dive behavior but that they may not have left the area after all.

In contrast, noise from seismic surveys was not found to impact feeding behavior or exhalation rates in western gray whales while resting or diving off the coast of Russia (Gailey et al., 2007; Yazvenko et al., 2007); however, the increase in vessel traffic associated with the surveys and the proximity of the vessels to the whales did affect the orientation of the whales relative to the vessels and shortened their dive-surface intervals (Gailey et al., 2016). They also increased their speed and distance from the noise source, and will even travel towards shore to avoid an approaching seismic vessel, as shown in one case study (Gailey et al., 2022). Todd et al. (1996) found no clear short-term behavioral responses by foraging humpbacks to explosions associated with construction operations in Newfoundland but did see a trend of increased rates of net entanglement closer to the noise source, possibly indicating a reduction in net detection associated with the noise through masking or TTS. Distributions of fin and minke whales were modeled with a suite of environmental variables along with the occurrence or absence of seismic surveys, and no evidence of a decrease in sighting rates relative to seismic activity was found for either species (Vilela et al., 2016). Their distributions were driven entirely by environmental variables, particularly those linked to prey including warmer sea surface temperatures, higher chlorophyll-a values, and higher photosynthetically available radiation (a measure of primary productivity). Sighting rates based on over 8,000 hours of baleen and toothed whale survey data were compared on regular vessel surveys versus both active and passive periods of seismic surveys (Kavanagh et al., 2019). Models of sighting numbers were developed, and it was determined that baleen whale sightings were reduced by 88 and 87 percent during active and inactive phases of seismic surveys, respectively, compared to regular surveys. These results seemed to occur regardless of geographic location of the survey; however, when only comparing active versus inactive periods of seismic surveys the geographic location did seem to affect the change in sighting rates.

Vocal and other behavioral responses to seismic surveys have been observed in a number of baleen whale species, including a cessation of calling, a shift in frequency, increases in amplitude or call rate, leaving the area, or a combination of these strategies (Blackwell et al., 2013; Blackwell et al., 2015; Blackwell et al., 2017; Di Lorio & Clark, 2010). For example, responses by fin whales to a 10-day seismic survey in the Mediterranean Sea included possible decreased call production and movement away from

the area (Castellote et al., 2012). Models of humpback whale song showed a decrease in the number of singers with increasing received levels of air gun pulses, indicating either a vocal modification or that whales left the area (Cerchio et al., 2014).

Mysticetes seem to be the most behaviorally sensitive taxonomic group of marine mammals to impulsive sound sources, with possible avoidance responses occurring out to 30 km and vocal changes occurring in response to sounds over 100 km away. However, they are also the most studied taxonomic group, yielding a larger sample size and greater chance of finding behavioral reactions to impulsive noise. Also, their responses appear to be behavior-dependent, with most avoidance responses occurring during migration behavior and little observed response during feeding behavior. These response patterns are likely to hold true for Navy impulsive sources; however, Navy impulsive sources would largely be stationary (e.g., explosives fired at a fixed target), and short term (on the order of hours rather than days or weeks) than were found in these studies and so responses would likely occur in closer proximity or not at all.

D.6.5.2 Behavioral Reactions of Odontocetes

D.6.5.2.1 Sonar and Other Transducers

D.6.5.2.1.1 Beaked Whales

Following several beaked whale strandings in which military mid-frequency active sonar was identified as a contributing cause or factor, the scientific community hypothesized that these deep-diving species may be more susceptible to behavioral disturbance or behaviorally mediated physiological consequences. Subsequently, behavioral response studies in which beaked whales were intentionally or incidentally exposed to real or simulated sonar, in some cases on military ranges, found that beaked whales are likely more sensitive to disturbance than most other cetaceans. Observed reactions by Blainville's beaked whales, goose-beaked whales, and Baird's beaked whales, as well as northern bottlenose whales (the largest of the beaked whales), to mid-frequency sonar sounds include cessation of clicking, decline in group vocal periods, termination of foraging dives, changes in direction to avoid the sound source, slower ascent rates to the surface, longer deep and shallow dive durations, and other unusual dive behaviors (DeRuiter et al., 2013b; Hewitt et al., 2022; Jacobson et al., 2022; McCarthy et al., 2011; Miller et al., 2015; Moretti et al., 2014; Southall et al., 2011; Stimpert et al., 2014; Tyack et al., 2011).

Research on beaked whales includes detailed response data from exposures of focal, tagged animals, as well as wide-scale analyses of changes in group vocal behaviors across instrumented ranges. Many of the exposures to tagged animals occurred within 1–8 km of the focal animal, within a few hours of tagging the animal, and with one or more boats within a few kilometers to observe responses and record acoustic data. Thus, while tagged animal data is precise and detailed, the animal's behavior may be influenced by the experimental context. In addition, individual variability can only be assessed with many tagged individuals. In contrast, group vocal behavior observations from instrumented ranges do not provide fine-scale movement and behavior data for individuals but allow for assessing responses across a range-wide population in real-world military training conditions.

Beaked whales have been tagged and exposed to sonar across multiple efforts (e.g., AUTECH, 3S2, SOCAL BRS, Atlantic BRS). During the SOCAL BRS, a tagged Baird's beaked whale exposed to simulated mid-frequency active sonar within 3 km increased swim speed and modified its dive behavior (Stimpert et al., 2014). One goose-beaked whale (formerly Cuvier's beaked whale) was also incidentally exposed to real Navy sonar located over 100 km away in addition to the source used in the controlled exposure study, and the authors did not detect similar responses at comparable received levels. Received levels from the

mid-frequency active sonar signals from the controlled (3.4 to 9.5 km) and incidental (118 km) exposures were calculated as 84 to 144 and 78 to 106 dB re 1 μ Pa, respectively, indicating that context of the exposures (e.g., source proximity, controlled source ramp-up) may have been a significant factor in the responses to the simulated sonars (DeRuiter et al., 2013b).

Long-term tagging work on the SOCAL BRS has demonstrated that the longer duration dives considered a behavioral response by DeRuiter et al. (2013b) fell within the normal range of dive durations found for eight tagged goose-beaked whales on the Southern California Offshore Range (Schorr et al., 2014). However, the longer inter-deep dive intervals found by DeRuiter et al. (2013b), which were among the longest found by Schorr et al. (2014) and Falcone et al. (2017), could indicate a response to sonar. In addition, Williams et al. (2017) note that in normal deep dives or during fast swim speeds, beaked whales and other marine mammals use strategies to reduce their stroke rates, including leaping or wave surfing when swimming, and interspersing glides between bouts of stroking when diving. They determined that in the post-exposure dives by the tagged goose-beaked whales described in DeRuiter et al. (2013b), the whales ceased gliding and swam with almost continuous strokes. This change in swim behavior was calculated to increase metabolic costs about 30.5 percent and increase the amount of energy expending on fast swim speeds from 27 to 59 percent of their overall energy budget. This repartitioning of energy was detected in the model up to 1.7 hours after the single sonar exposure. Therefore, while the overall post-exposure dive durations were similar, the metabolic energy calculated by Williams et al. (2017) was higher. However, Southall et al. (2019a) found that prey availability was higher in the western area of the Southern California Offshore Range where goose-beaked whales preferentially occurred, while prey resources were lower in the eastern area and moderate in the area just north of the Range. This high prey availability may indicate that fewer foraging dives are needed to meet metabolic energy requirements than would be needed in another area with fewer resources.

During the 3S2 Project, the roles of sound source distance and received level in northern bottlenose whales were analyzed in an environment without frequent sonar activity using controlled exposure experiments (von Benda-Beckmann et al., 2019; Wensveen et al., 2019). Researchers observed behavioral avoidance of the sound source over a wide range of distances (0.8 to 28 km) and estimated avoidance thresholds ranging from received SPLs of 117 to 126 dB re 1 μ Pa. The behavioral response characteristics and avoidance thresholds were comparable to those previously observed in beaked whale studies; however, they did not observe an effect of distance on behavioral response and found that onset and intensity of behavioral response were better predicted by received SPL. One northern bottlenose whale did approach the ship and circle the source, then resumed foraging after the exposure, but the source level was only 122 dB re 1 μ Pa. A northern bottlenose whale conducted the longest and deepest dive on record for that species after sonar exposure and continued swimming away from the source for over seven hours (Miller et al., 2015; Siegal et al., 2022; Wensveen et al., 2019).

On the AUTEK range, Blainville's beaked whales located on-range appear to move off-range during sonar use and return only after the sonar transmissions have stopped, sometimes taking several days to do so (Boyd et al., 2009; Henderson et al., 2015; Jones-Todd et al., 2021; Manzano-Roth et al., 2022; Manzano-Roth et al., 2016; McCarthy et al., 2011; Tyack et al., 2011). For example, five Blainville's beaked whales that were estimated to be within 2 to 29 km of the AUTEK range at the onset of sonar were displaced a maximum of 28–68 km from the range after moving away from the range, although one whale approached the range during the period of active sonar. Researchers found a decline in deep dives at the onset of the training and an increase in time spent on foraging dives as individuals moved away from the range. Predicted received levels at which presumed responses were observed were comparable to

those previously observed in beaked whale studies. Acoustic data indicated that vocal periods were detected on the range within 72 hours after training ended (Joyce et al., 2019). However, Blainville's beaked whales remain on the range to forage throughout the rest of the year (Henderson et al., 2016), possibly indicating that this a preferred foraging habitat regardless of the effects of the noise, or it could be that there are no long-term consequences of the sonar activity. Similarly, photo-identification studies in the SOCAL Range Complex have identified approximately 100 individual goose-beaked whale individuals, with 40 percent having been seen in one or more prior years, with re-sightings up to seven years apart, indicating a possibly resident population on the range (Falcone & Schorr, 2014; Falcone et al., 2009).

The probability of Blainville's beaked whale group vocal periods on the Pacific Missile Range Facility were modeled during periods of no naval activity, naval activity without hull-mounted mid-frequency active sonar, and naval activity with hull-mounted mid-frequency active sonar (Jacobson et al., 2022). At a received level of 150 dB re 1 μ Pa rms (root mean square), the probability of group vocal period detection decreased by 77 percent compared to periods when general training activity was ongoing and by 87 percent compared to baseline conditions. This study found a greater reduction in probability of a group vocal period with mid-frequency active sonar than observed in a prior study of Blainville's beaked whales at AUTECH (Moretti et al., 2014). The authors suggest that this may be due to the baseline period in the AUTECH study including naval activity without mid-frequency active sonar, potentially lowering the baseline group vocal period activity in that study, or due to differences in the residency of the populations at each range. Along the edge of the Scotian Shelf off eastern Canada, baseline activity from both prior to a period of naval sonar use and a prior year with no known naval activity were used to assess changes in beaked whale detections. Goose-beaked and Mesoplodont beaked whale detection rates dropped both during and after an eight-day, multi-platform anti-submarine warfare training exercise, and remained low seven days after the exercise (Stanistreet et al., 2022).

On the Southern California Anti-Submarine Warfare Range, deep and shallow dive durations, surface interval durations, and inter-deep dive intervals of goose-beaked whales were modeled against predictor values that included helicopter dipping, mid-power mid-frequency active sonar and hull-mounted, high-power mid-frequency active sonar along with other, non-mid-frequency active sonar predictors (Falcone et al., 2017). They found both shallow and deep dive durations increased as the proximity to both mid- and high-powered sources decreased, and found that surface intervals and inter-deep dive intervals increased in the presence of both types of sonars, although surface intervals shortened during periods of no mid-frequency active sonar. The responses to the mid-power mid-frequency active sonar at closer ranges were comparable to the responses to the higher source level ship sonar, again highlighting the importance of proximity. This study also supports context as a response factor, as helicopter dipping sonars are shorter duration and randomly located, so more difficult for beaked whales to predict or track and therefore potentially more likely to cause a response, especially when they occur at closer distances (6 to 25 km in this study). Sea floor depths and quantity of light are also important variables to consider in goose-beaked whale behavioral response studies, as their foraging dive depth increased with sea floor depth up to sea floor depths of 2,000 m. The fraction of time spent at foraging depths and likely foraging was greater at night, although they spent more time near the surface during the night as well, particularly on dark nights with little moonlight, likely avoiding predation by staying deeper during periods of bright lunar illumination (Barlow et al., 2020). Sonar occurred during 10 percent of the dives studied and had little effect on the resulting dive metrics. Watwood et al. (2017) found that helicopter dipping events occurred more frequently but with shorter durations than periods of hull-mounted sonar, and also found that the longer the duration of a sonar

event, the greater reduction in detected goose-beaked whale group dives. Therefore, when looking at the number of detected group dives there was a greater reduction during periods of hull-mounted sonar than during helicopter dipping sonar. Similar results were found by DiMarzio et al. (2019).

Echosounders

Beaked whales may respond similarly to shipboard echosounders, commonly used for navigation, fisheries, and scientific purposes, with frequencies ranging from 12 to 400 kHz and source levels up to 230 dB re 1 μ Pa but typically a very narrow beam (Cholewiak et al., 2017). During a scientific cetacean survey, an array of echosounders was used in a one-day-on, one-day-off paradigm. Beaked whale acoustic detections occurred predominantly (96 percent) when the echosounder was off, with only 4 detections occurring when it was on. Beaked whales were sighted fairly equally when the echosounder was on or off, but sightings were further from the ship when the echosounder was on (Cholewiak et al., 2017). These findings indicate that the beaked whales may be avoiding the area and may cease foraging near the echosounder. Another study also found that echosounders contributed to fewer beaked whale observations, but ultrasonic antifouling devices elicited an even stronger avoidance response (Trickey et al., 2022).

In contrast, goose-beaked whale group vocal periods during multibeam echosounder activity recorded in the Southern California Antisubmarine Warfare Range did not decrease during the echosounder survey (Varghese et al., 2020). The whales did not leave the range or cease foraging, and group vocal periods increased during and after multibeam echosounder surveys. Since echosounders are highly directional and the sound doesn't propagate horizontally, the difference in these results may be due to the locations of beaked whales relative to the echosounder. In fact, one of the surveys by Varghese et al. (2020) was largely conducted on a portion of the range little used by goose-beaked whales. A subsequent analysis suggested that the observed spatial shifts were most likely due to prey dynamics (Varghese et al., 2021).

Predator Sounds

Tyack et al. (2011) hypothesized that beaked whale responses to sonar may represent an anti-predator response. To test this idea, vocalizations of a potential predator—a killer whale—were played back to a Blainville's beaked whale at AUTC. The killer whale vocalization recording was from a stock of mammal-eating killer whales that are not present at AUTC. This exposure resulted in a similar but more pronounced reaction than that elicited by sonar playback, which included longer inter-dive intervals and a sustained straight-line departure of more than 20 km from the area (Allen et al., 2014; Tyack et al., 2011). Similarly, De Soto et al. (2020) hypothesized that the high degree of vocal synchrony in beaked whales during their deep foraging dives, coupled with their silent, low-angled ascents, have evolved as an anti-predator response to killer whales. Since killer whales do not dive deep when foraging and so may be waiting at the surface for animals to finish a dive, these authors speculated that by diving in spatial and vocal cohesion with all members of their group, and by surfacing silently and up to 1 km away from where they were vocally active during the dive, they minimize the ability of killer whales to locate them when at the surface. This may lead to a trade-off for the larger, more fit individuals that can conduct longer foraging dives, such that all members of the group remain together and are better protected by this behavior. The authors speculate that this may explain the long, slow, silent, and shallow ascents that beaked whales make when sonar occurs during a deep foraging dive. However, these hypotheses are based only on the dive behavior of tagged beaked whales, with no observations of predation attempts by killer whales, and "anti-predator response" theory needs to be tested further to be validated. This anti-predator hypothesis was also tested by playing back killer whale vocalizations to

northern bottlenose whales and several other odontocetes to determine responses by both potential prey and conspecifics (Miller, 2012; Miller et al., 2011). Results varied in other odontocetes, from no response to an increase in group size and attraction to the source (Curé et al., 2012). Changes in foraging duration during killer whale playbacks and mid-frequency sonar were positively correlated across four species in the 3S Norwegian studies, including northern bottlenose whales, suggesting that tolerance of predation risk may play a role in sensitivity to sonar disturbance (Miller et al., 2022).

D.6.5.2.1.2 Harbor Porpoises

There are very few behavioral response studies on harbor porpoise reactions to sonar, but there are many reports of porpoise responding to other tonal sounds such as acoustic harassment devices (AHDs) and acoustic deterrent devices (ADDs). AHDs and ADDs, which transmit sound into the acoustic environment like Navy sources, have been used to deter marine mammals from fishing gear both to prevent entanglement and to reduce depredation (taking fish). These devices have been used successfully to deter harbor porpoises and beaked whales from getting entangled in fishing nets. See Table D.6-8 for a summary of the major findings from studies of the effects of AHDs and ADDs in harbor porpoises.

Table D.6-8: Major Findings from Studies of Acoustic Harassment Devices (AHDs) and Acoustic Deterrent Devices (ADDs) in Harbor Porpoises

<i>Major Finding</i>	<i>Supporting Studies</i>
High-frequency acoustic alarms with varied duration, interval, and sweep characteristics can prove to be effective deterrents for harbor porpoises.	Kastelein et al. (2006); Kastelein et al. (2001); Kastelein et al. (2017)
Detection rates were reduced by ADDs, especially in close proximity (< 100 m away, limited to a few 100 m at most). Tested with many pinger parameters (e.g., 10 kHz tone with and without 30 to 60 kHz sweep, 50 – 120 kHz).	Findlay et al. (2024); Kindt-Larsen et al. (2019); Kyhn et al. (2015); Omeyer et al. (2020)
Simulated AHD (12 kHz, 165 dB re 1 µPa) caused avoidance (physically moved away) from the source up to 525 m.	Mikkelsen et al. (2017)
Detection rates within 100 m were reduced by banana pingers designed to avoid pinniped responses, but had no effect at 400 m.	Königson et al. (2021)
Habituation to short-term exposures (2 to 4 exposures).	Kyhn et al. (2015)
No habituation (remained avoidant/silent) while pingers were on, especially over longer-term exposures (28+ days).	Kyhn et al. (2015); Omeyer et al. (2020)
Habituation to a pinger may occur with single tones but is less likely with a mixture of signals.	Kindt-Larsen et al. (2019)
When pinger was shut off, clicking returned to normal levels (no long-term displacement).	Omeier et al. (2020)
Modeled results found that when pingers were used alone (in the absence of gillnets or time-area closures), caused enough habitat displacement for 21% population-level reduction.	van Beest et al. (2017)
Net pingers are successful at reducing entanglements for harbor porpoise and beaked whales since these species are not depredating from the nets but are getting entangled when foraging in the area and are unable to detect the net.	Carretta et al. (2008); Schakner and Blumstein (2013)
Lower broadband source SPL, SEL, and duty cycle “startle sounds” compared to other ADDs resulted in avoidance behaviors for duration of exposure (+ 31 minutes minimum). Travelled at least 1 km (> 3 km maximum) within 15 minutes of exposure, increased group cohesion and swim speed away from the transducer.	Hiley et al. (2021)

Table D.6-8: Major Findings from Studies of Acoustic Harassment Devices (AHDs) and Acoustic Deterrent Devices (ADDs) in Harbor Porpoises (continued)

<i>Major Finding</i>	<i>Supporting Studies</i>
Avoided high-frequency ADDs (60 – 150 kHz, 172 dB re 1 μ Pa rms) up to 2.5 km away. Reduced occurrence by 30 to 100% at 750 m.	Voß et al. (2023)
Swam quickly away from low received level AHDs (14 kHz, 98-132 dB re 1 μ Pa), decreased echolocation rate, and either increased or decreased heart rate. Waited 15 – 42 minutes to resume feeding behavior.	Elmegaard et al. (2023) Elmegaard et al. (2021)

Notes: % = percent; > = greater than; < = less than; ADD = acoustic deterrent device; AHD = acoustic harassment device; dB = decibel; kHz = kilohertz; km = kilometer; m = meters; μ Pa = micropascal; SEL = sound exposure level; SPL = sound pressure level

Behavioral responses by harbor porpoises to a variety of sound sources other than acoustic alarms have been studied (Kastelein et al., 2006; Kastelein et al., 2001), including emissions for underwater data transmission (Kastelein et al., 2005b), and tones such as 1 to 2 kHz and 6 to 7 kHz sweeps with and without harmonics (Kastelein et al., 2014c), 25 kHz tones with and without sidebands (Kastelein et al., 2015e; Kastelein et al., 2015f), and mid-frequency sonar tones at 3.5 to 4.1 kHz at 2.7 percent and 96 percent duty cycles (e.g., one tone per minute versus a continuous tone for almost a minute) (Kastelein et al., 2018b). Responses include increased respiration rates, swim speed, jumping, swimming further from the source, or decreasing echolocation rate which increases risk of wild harbor porpoise becoming by-catch (Elmegaard et al., 2021). However, responses were different depending on the source. For example, harbor porpoises responded to the 1 to 2 kHz upswEEP at 123 dB re 1 μ Pa, but not to the downswEEP or the 6 to 7 kHz tonal at the same level (Kastelein et al., 2014c). When measuring the same sweeps for a startle response, the 50 percent response threshold was 133 and 101 dB re 1 μ Pa for 1 to 2 kHz and 6 to 7 kHz sweeps, respectively, when no harmonics were present, and decreased to 90 dB re 1 μ Pa for 1 to 2 kHz sweeps with harmonics present (Kastelein et al., 2014c).

Kastelein et al. (2019a) examined the potential masking effect of high sea state ambient noise on captive harbor porpoise perception of and response to high duty cycle playbacks of AN/SQS-53C sonar signals by observing their respiration rates. Results indicated that sonar signals were not masked by the high sea state noise, and received levels at which responses were observed were similar to those observed in prior studies of harbor porpoise behavior. However, in another study sonar sweeps did not elicit a startle response in captive harbor porpoises; instead initial exposures induced bradycardia (slowing of the heart rate), with subsequent habituation that was conserved for at least three years (Elmegaard et al., 2021).

Harbor porpoises did not respond to the low-duty cycle mid-frequency tones at any received level, but one did respond to the high-duty cycle signal with more jumping and increased respiration rates (Kastelein et al., 2018b). Harbor porpoises responded to seal scarers with broadband signals up to 44 kHz with a slight respiration response at 117 dB re 1 μ Pa and an avoidance response at 139 dB re 1 μ Pa, but another scarer with a fundamental (strongest) frequency of 18 kHz did not have an avoidance response until 151 dB re 1 μ Pa (Kastelein et al., 2015d). Exposure of the same acoustic pinger to a striped dolphin under the same conditions did not elicit a response (Kastelein et al., 2006), again highlighting the importance in understanding species differences in the tolerance of underwater noise, although sample sizes in these studies was small so these could reflect individual differences as well.

D.6.5.2.1.3 Other Odontocetes

While there has been a focus on beaked whale (and to a lesser extent harbor porpoise) response to sonar and similar transducers, other species have been studied during behavioral response studies as

well, including pilot whales, killer whales, sperm whales, false killer whales, melon-headed whales, bottlenose dolphins, rough-toothed dolphins, Risso's dolphins, Pacific white-sided dolphins, and Commerson's dolphins. Responses by these species include horizontal avoidance, reduced breathing rates, changes in behavioral state, and changes in dive behavior (Antunes et al., 2014; Isojunno et al., 2018; Isojunno et al., 2017; Isojunno et al., 2020; Miller, 2012; Miller et al., 2011; Miller et al., 2014). Some species like pilot whales, false killer whales and Risso's dolphins will also respond by mimicking the sound of the sonar with their whistles (Alves et al., 2014; DeRuiter et al., 2013a; Smultea et al., 2012).

More severe behavioral responses, such as separation of a killer whale calf from its group, have been observed during exposure to mid-frequency sonar playbacks (Miller et al., 2011). However, it is difficult to tease this response to sonar apart from the animals' response to the perusing research vessel in an environment with limited egress. Received level thresholds at the onset of avoidance behavior were generally lower for killer whales (mean 129 dB re 1 μ Pa) compared to pilot whales (mean 150 dB re 1 μ Pa) and sperm whales (mean 140 dB re 1 μ Pa) (Antunes et al., 2014; Curé et al., 2021; Miller, 2012; Miller et al., 2014). Tagged odontocetes (e.g., pilot whales, rough-toothed dolphins, bottlenose dolphins, and false killer whales) did not have an avoidance response to sonar on or near the Pacific Missile Range Facility before Navy training events (Baird et al., 2014; Baird et al., 2017; Baird et al., 2013). In some cases, odontocetes even traveled towards areas of higher noise levels, while estimated received SPLs varied from 130 to 168 dB re 1 μ Pa and distances from sonar sources ranged between 3.2 and 94.4 km.

Not all responses to sonar cause avoidance responses or deleterious changes in behavior. Navy exercises involving sonar on large ships may also attract odontocetes or cause no reaction, depending on the species. While most of the published literature involving bowriding odontocete observations does not involve sonar, certain species (e.g., bottlenose, spotted, spinner, Clymene, Pacific white sided, rough-toothed dolphins) will sometimes approach vessels to bow ride, indicating either that these species are less sensitive to vessels or that the behavioral drive to bow ride supersedes any impact of the associated noise (Würsig et al., 1998). During aerial and visual monitoring of Navy training events, rough-toothed dolphins and unidentified dolphins were observed approaching the vessel with active sonar as if to bow ride. Spotted dolphins were observed nearby but did not avoid or approach the vessel (Mobley, 2011; U.S. Department of the Navy, 2011a; Watwood et al., 2012). During small boat surveys near the Southern California Offshore Range in southern California, more dolphins were encountered in June compared to a similar survey conducted the previous November after seven days of mid-frequency sonar activity; it was not investigated if this change was due to the sonar activity or was due to the poor weather conditions in November that may have prevented animals from being seen (Campbell et al., 2010). There were also fewer passive acoustic dolphin detections during and after longer sonar activities in the Mariana Islands Range Complex, with the post-activity absence lasting longer than the mean dolphin absence of two days when sonar was not present (Munger et al., 2014; Munger et al., 2015).

Controlled experiments have also been conducted on captive animals to estimate received levels at which behavioral responses occur. In one study, bottlenose dolphin behavioral responses were recorded when exposed to 3 kHz sonar-like tones between 115 and 185 dB re 1 μ Pa (Houser et al., 2013a), and in another study bottlenose dolphins and beluga whales were presented with one-second tones up to 203 dB re 1 μ Pa to measure TTS (Finneran et al., 2003a; Finneran et al., 2001; Finneran et al., 2005; Finneran & Schlundt, 2004; Schlundt et al., 2000). During these studies, responses included changes in respiration rate, fluke slaps, and a refusal to participate or return to the location of the sound stimulus. This refusal included what appeared to be deliberate attempts to avoid a sound exposure or to avoid the location of the exposure site during subsequent tests (Finneran et al., 2002; Schlundt et al., 2000). In the behavioral response study, bottlenose dolphins demonstrated a 50 percent probability of response at 172 dB re 1 μ Pa over 10 trials. In the TTS experiment, bottlenose dolphins exposed to one-second

intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 μ Pa; beluga whales did so at received levels of 180 to 196 dB re 1 μ Pa and above. In some instances, animals exhibited aggressive behavior toward the test apparatus (Ridgway et al., 1997; Schlundt et al., 2000). While animals were commonly reinforced with food during these studies, the controlled environment provided insight on received levels at which animals behaviorally respond to noise sources.

There are opportunistic observations of behavioral responses to sonar as well, although in those cases it is difficult to attribute observed responses directly to the sonar exposure, or to know exactly what form the response took. For example, both sperm and pilot whales potentially ceased sound production during the Heard Island feasibility test, with transmissions centered at 57 Hz and up to 220 dB re 1 μ Pa (Bowles et al., 1994b), although it could not be determined whether the animals ceased sound production or left the area. Killer whales in Haro Strait exhibited what were believed by some observers to be aberrant behaviors, during a time that the USS Shoup was in the vicinity and engaged in mid-frequency active sonar operations. Sound fields modeled for the USS Shoup transmissions (Fromm, 2009; National Marine Fisheries Service, 2005; U.S. Department of the Navy, 2004) estimated a mean received SPL of approximately 169 dB re 1 μ Pa at the location of the killer whales at the closest point of approach between the animals and the vessel (estimated received SPLs ranged from 150 to 180 dB re 1 μ Pa). However, attributing the observed behaviors to any one cause is problematic given there were six nearby whale watch vessels surrounding the pod, and subsequent research has demonstrated that “Southern Residents modify their behavior by increasing surface activity (breaches, tail slaps, and pectoral fin slaps) and swimming in more erratic paths when vessels are close” (National Oceanic and Atmospheric Administration, 2014).

Opportunistic sightings of several other odontocete species (i.e., bottlenose dolphins, Risso’s dolphins, Pacific white-sided dolphins, common dolphins) have been observed near the Southern California Offshore Range during periods of mid-frequency active sonar. Responses included changes in or cessation of vocalizations, changes in behavior, and leaving the area, and at the highest received levels animals were not present in the area at all (Henderson et al., 2014). However, these opportunistic observations were conducted from a vessel off-range, and so any observed responses could not be attributed to the sonar with any certainty. Similarly, research on sperm whales in the Caribbean in 1983 coincided with the U.S. intervention in Grenada, where animals were presumed to scatter and leave the area because of military sonar (Watkins et al., 1985; Watkins & Schevill, 1975). They also reported similar reactions from noise generated by banging on their boat hull; therefore, it was unclear if the sperm whales were reacting to the sonar signal itself or to a potentially new unknown sound in general.

Behavioral responses by odontocetes to sonar and other transducers appear to range from no response at all to responses that could potentially lead to long-term consequences for individual animals (e.g., mother-calf separation). This is likely in part because this taxonomic group is so broad and includes some of the most sensitive species (e.g., beaked whales and harbor porpoise) as well as some of the least sensitive species (e.g., bottlenose dolphins). This is also the only group for which both field behavioral response studies and captive controlled exposure experiments have been conducted, leading to the assessment of both contextually driven responses as well as dose-based responses. This wide range in both exposure situations and individual- and species-sensitivities makes reaching general conclusions difficult. However, it does appear as though exposures in close proximity, with multiple vessels that approach the animal lead to higher-level responses in most odontocete species regardless of received level or behavioral state. In contrast, in more “real-world” exposure situations, with distant sources moving in variable directions, behavioral responses appear to be driven by behavioral state, individual experience, or species-level sensitivities. These responses may also occur more in-line with received level such that the likelihood of a response would increase with increased received levels. However, these “real-world” responses are more likely to be short term, lasting the duration of the

exposure or even shorter as the animal assesses the sound and (based on prior experience or contextual cues) determines a threat is unlikely. Therefore, while odontocete behavioral responses to Navy sonar will vary across species, populations, and individuals, long-term consequences or population-level effects will depend on the frequency and duration of the disturbance and resulting behavioral response.

Responses by Specific Odontocete Species

Killer Whales

A close examination of the tag data from the Norwegian killer whales indicated that responses were mediated by behavior, signal frequency, or received sound energy. Killer whales changed their dive behavior during deep foraging dives at the onset of low-frequency active sonar (1 to 2 kHz, sweeping across frequencies) but did not change their dive behavior if they were deep diving during mid-frequency active sonar (6 to 7 kHz, sweeping across frequencies). Nor did they change their dive behavior if they were conducting shallow dives at the onset of either type of sonar (Sivle et al., 2012b). Killer whale sighting data from the same region in Norway as the behavioral response study in the 3S Project were used to compare the presence or absence of whales from other years against the period with sonar. The authors found a strong relationship between the presence of whales and the abundance of herring, and only a weak relationship between the whales and sonar activity (Kuningas et al., 2013).

Sperm Whales

The behavioral context and parameters of sonar exposure are important variables in sperm whale behavioral response to sonar as well. While there was no change in foraging (deep dive) behavior during mid-frequency active sonar, sperm whales were more responsive to low frequency active sonar (e.g., reduced dive depth, foraging, and vocalization) (Sivle et al., 2012b). In another study, (Harris et al., 2015; Quick et al., 2017) sperm whales were exposed to low frequency active pulsed active sonar at moderate source levels and high source levels, as well as continuous active sonar at moderate source levels for which the summed energy (SEL) equaled the summed energy of the high source level pulsed active sonar (Isojunno et al., 2020). Foraging behavior did not change during exposures to moderate source level sonar, but non-foraging behavior increased during exposures to high source level sonar and to the continuous active sonar, indicating that the SEL was a better predictor of response than SPL. Other studies also demonstrate that higher SELs reduced sperm whale buzzing (i.e., foraging) (Isojunno et al., 2021). The time of day of the exposure and order effects (e.g., the SEL of the previous exposure) were also important covariates in determining the amount of non-foraging behavior (Isojunno et al., 2020). Curé et al. (2021) also found that sperm whales exposed to continuous and pulsed active sonar were more likely to produce low or medium severity responses with higher cumulative SEL. Specifically, the probability of observing a low severity response increased to 0.5 at approximately 173 dB SEL and observing a medium severity response reached a probability of 0.35 at cumulative SELs between 179 and 189 dB.

One study opportunistically observed sperm whale vocalizations during an eight-day multi-platform naval exercise off the Scotian Shelf of Canada. During long bouts of sonar (various waveforms, both pulsed and continuous) lasting up to 13 consecutive hours (median and maximum SPL = 120 dB and 164 dB), sperm whales substantially reduced how often they produced clicks during sonar, indicating a decrease or cessation in foraging behavior (Stanistreet et al., 2022). Few previous studies have shown sustained changes in sperm whales, but there was an absence of sperm whale clicks for six consecutive days of sonar activity.

Melon-Headed Whales

Melon-headed whales responded to each 6–7 kHz signal with “minor transient silencing” (a brief, non-lasting period of silence), and (in a different oceanographic region) pilot whales had no apparent response (DeRuiter et al., 2013a). In a passive acoustic study using Marine Autonomous Recording Units in the Jacksonville Range Complex, the probability of detecting delphinid vocalizations (whistles, clicks, and buzzes) increased during periods of active sonar use (compared to the period prior to its use), while there was no change in the probability of detecting sperm whale clicks (Charif et al., 2015; HDR EOC, 2012).

Common Dolphins

Durban et al. (2022) observed long-beaked common dolphins via land-based observation platform coupled with a drone and multiple acoustic recorders for the first time. Vocal behavior, group cohesion, group size, and group behavior were observed before, during, and after a simulated mid-frequency sonar exposure. The number of whistles and sub-groups increased during the exposure, but the directivity and speed of the tracked subgroup was less affected.

Pilot Whales

Sonar frequency content and behavioral context are important variables in pilot whale behavioral response to sonar. While there was no change in foraging (deep dive) behavior during mid-frequency active sonar, pilot whales had fewer deep dives during low frequency active sonar (Sivle et al., 2012b). Their behavior at the onset of low frequency active sonar was especially important. If they were deep dive foraging at sonar onset, they were more likely to stop feeding and switch to shallow diving, signifying a switch to travel or rest behavior. If they were shallow diving at low frequency active sonar onset, they would not change dive type and would continue to travel or rest (Sivle et al., 2012b). In another study, pilot whales initially reduced foraging time and increased travel behavior during both low frequency active and mid-frequency active sonar exposures, but foraging increased again during subsequent exposures (Isojunno et al., 2017). This kind of behavioral reaction may indicate habituation to sonar or be driven by prey availability. Pilot whales exposed to a 38 kHz downward-facing echosounder did not change their foraging behavior during exposure periods, but their heading variance increased and fewer deep dives were conducted (Quick et al., 2017).

Diving pilot whales are also sensitive to the received level of sonar (around 170 dB re 1 μ Pa; Antunes et al., 2014). Cessation of foraging appeared to occur at a lower received level (145–150 dB re 1 μ Pa) than had been observed previously for avoidance behavior (around 170 dB re 1 μ Pa; Antunes et al., 2014). Pilot whales reduced breathing rates relative to their diving behavior when low frequency active sonar levels were high (180 dB re 1 μ Pa), but only on the first sonar exposure. On subsequent exposures their breathing rates increased (Isojunno et al., 2018), indicating a change in response tactic with additional exposures (Isojunno et al., 2018). Other behavioral responses to sonar include the synchronization of pilot whale surfacing's with sonar pulses during one exposure, possibly as a means of mitigating the sound (Wensveen et al., 2015), and pilot whales mimicking the sound of the sonar with their whistles (Alves et al., 2014).

None of the tagged pilot whales near sonar activities in Hawaii demonstrated a large-scale avoidance response as they moved on or near the range; estimated received SPLs varied from 130 to 168 dB re 1 μ Pa and distances from sonar sources ranged between 3.2 and 94.4 km (Baird et al., 2014; Baird et al., 2017; Baird et al., 2013). However, one pilot whale did have reduced dive rates (from 2.6 dives per hour before to 1.6 dives per hour during) and deeper dives (from a mean of 124 m to 268 m) during a period of sonar exposure. Baird et al. (2016) also tagged four short-finned pilot whales from both the resident island-associated population and from the pelagic population. The core range for the pelagic population

was over 20 times larger than for the resident population, leading Baird et al. (2016) to hypothesize that that likelihood of exposure to mid-frequency active sonar, and therefore the potential for response, would be very different between the two populations. These diverse examples demonstrate that responses can be varied, are often context- and behavior-driven, and can be species- and even exposure-specific.

These results demonstrate that the behavioral state and environment of the animal mediates the likelihood of a behavioral response, as do the characteristics (e.g., frequency, energy level) of the sound source itself. The highly flexible activity time budgets observed for pilot whales, with a large amount of time spent resting at the surface, may indicate context-dependency on some behaviors, such as the presence of prey driving periods of foraging. That time may be more easily re-allocated to missed foraging opportunities (Isojunno et al., 2017).

Odontocete Responses to Other Sound Sources

Responses to Killer Whale Playbacks

The anti-predator hypothesis tested on beaked whaled was also assessed with other odontocetes. Scientists played recordings of the same mammal-eating killer whale vocalizations to pilot whales, sperm whales, Risso's dolphins, and even other killer whales, to determine responses by both potential prey and conspecifics (Mobley, 2011; Read et al., 2022; U.S. Department of the Navy, 2011a; Watwood et al., 2012). Results varied, from no response by killer whales to an increase in group size and attraction to the source in pilot whales; rarely does a species have strong aversions as seen in beaked whales (Allen et al., 2014; Tyack et al., 2011), except for the instance of stampeding Risso's dolphins in Southern California (Read et al., 2022). In this case study, when a group of 20 Risso's dolphins were exposed to mammal-eating orca calls (30 sec), they became quiet, swam away at a moderate pace, and at a further distance began to porpoise and swim rapidly away (greater than 12 knots) with quick direction changes, rapid surfacings, and increased synchrony and group cohesion. Two similar sized groups of Risso's followed suite close behind them. They slowed to 5 knots after about 1 hour and 10 km away from their original point of exposure (Read et al., 2022). Changes in foraging duration during killer whale playbacks and mid-frequency active sonar were positively correlated across four species in the 3S Norwegian studies, including long-finned pilot whale and sperm whales, suggesting that tolerance of predation risk may play a role in sensitivity to sonar disturbance (Miller et al., 2022). An alternative explanation to the anti-predator response in odontocete species that respond to sonar is a startle response. Startle responses in bottlenose dolphins occurred at moderate received levels and mid-frequencies, and the relationship between rise time and startle response was more gradual than expected for an odontocete (Gotz et al., 2020).

Responses to Acoustic Harassment and Deterrent Devices

The characteristics of deterrents and the motivation of the animal play a role in the effectiveness of acoustic harassment devices (Schakner & Blumstein, 2013). Deterrents that are strongly aversive or simulate a predator or are otherwise predictive of a threat are more likely to be effective, unless the animal habituates to the signal or learns that there is no true threat associated with the signal. While sperm whales in the Caribbean stopped vocalizing when presented with sounds from nearby acoustic pingers (Watkins & Schevill, 1975), killer whales rapidly habituated to pingers (6.5 kHz, 195 dB re 1 μ Pa) that were installed to stop them from depredating long lines or aquaculture enclosures. Two groups fled over 700 m away during the first exposure, but they began depredating again after the third and seventh exposures, demonstrating that acoustic harassment devices may be more successful at deterring marine mammals based on their species and context (i.e., prey availability). In some cases, net pingers may even create a "dinner bell effect," where marine mammals have learned to associate the signal with the

availability of prey (Jefferson & Curry, 1996; Schakner & Blumstein, 2013). See Table D.6-9 for a summary of findings from additional studies on these sources.

Table D.6-9: Major Findings from Studies of Acoustic Harassment Devices (AHDs) and Acoustic Deterrent Devices (ADDs) in Other Odontocetes

<i>Species</i>	<i>Major Finding</i>	<i>Supporting Studies</i>
Sperm whales – wild	Stopped vocalizing when pingers were present.	Watkins and Schevill (1975)
Killer whales – wild	Decreased occurrence when four AHDs deployed on salmon farms. No reduction in occurrence at adjacent location without AHDs. When AHDs removed, whale abundance near farms returned to baseline.	Morton and Symonds (2002)
Killer whales – wild	Habituated to pingers (6.5 kHz, 195 dB re 1 μ Pa) quickly when next to desired prey species. Fled > 700 m during the first exposure but began depredating again after the third and seventh exposures.	Tixier et al. (2014)
Bottlenose dolphins – captive	Increased surfacing, distance relative to transducer, and reduced clicks when exposed to different deterrent parameters (e.g., pulsed, and continuous tonal signals). Some acclimatization was observed during daily tests, but no habituation was observed over the full duration of the study.	Niu et al. (2012)
Bottlenose dolphins – captive	Different species had different responses to a gillnet pinger (attached to a fishing net and anchor). Bottlenose spent significantly less time in the area when it was present.	Bowles and Anderson (2012)
Bottlenose dolphins – wild	Predated significantly less on commercial fishing catches with pingers nearby (n=2) compared to catches without pingers (n=16).	Ceciarini et al. (2023)
Pacific white-sided dolphins – captive	Approached the gillnet without a pinger but avoided it when the pinger was added.	Bowles and Anderson (2012)
Commerson's dolphins – captive	Increased high-energy behavioral responses (e.g., increased swim speed, use of a refuge pool and rate of vocalization) in response to pinger. Did not habituate to pingers but instead sensitized/ demonstrated even stronger aversive behaviors over time.	Bowles and Anderson (2012)
Franciscana dolphins – wild	Avoided active banana pinger (300 ms, 50 – 120 kHz frequency modulated, 145 dB +/- 3 dB at 1 m SL) within 100 m but not at 400 m. No habituation during length of the experiment (64 days).	Paitach et al. (2022)

Notes: % = percent; > = greater than; < = less than; ADD = acoustic deterrent device; AHD = acoustic harassment device; dB = decibel; kHz = kilohertz; km = kilometer; m = meters; rms = root mean square; μ Pa = micropascal; n = number; SL = sound level

D.6.5.2.2 Vessel Disturbance

Behavioral responses to vessels can be caused by multiple factors. The type of vessel, approach, and speed of approach can impact the probability of a negative behavioral response (Ng & Leung, 2003). Even the way research vessels approach or move away from cetaceans can cause varied reactions in group structure and vocal behavior (Guerra et al., 2014). One research group made an effort to distinguish behavioral (e.g., nursing and resting) reactions to vessel noise from vessel presence (Arranz et al., 2021). The short-finned pilot whale mother-calf pairs were approached by the same tour boat with either two quiet electric or noisy petrol engines installed. Approach speed, distance, and vessel features other than engine noise remained the same between the two experimental conditions. While mother pilot whales rested less, and calves nursed less, in response to both types of boat engines

compared to control conditions, only the louder petrol engine caused significant impacts (29 percent and 81 percent, respectively) to these behaviors. However, in most field studies the influence of vessel sound exposure cannot be decoupled from the physical presence of a surface vessel, complicating interpretations of the relative contribution of each stimulus to the response. This section will cover both aspects (vessel noise and presence) in publications that specifically aim to target response to noise.

Most odontocetes react neutrally to vessels, although both avoidance and attraction behavior have been observed (Hewitt, 1985; Würsig et al., 1998). Würsig et al. (1998) found that Kogia whales and beaked whales were the most sensitive species to vessels and reacted by avoiding marine mammal survey vessels in 73 percent of sightings, more than any other odontocetes. Avoidance reactions include a decrease in resting behavior or change in travel direction (Bejder et al., 2006a). Incidents of attraction include common, rough-toothed, and bottlenose dolphins bow riding and jumping in the wake of a vessel (Norris & Prescott, 1961; Ritter, 2002; Shane et al., 1986; Würsig et al., 1998). Hudson Bay belugas spent most of their time interacting favorably (e.g., glided under, rubbed against, and swam along) with nearby seasonal tour boats that practiced sustainable whale watching practices (Westdal et al., 2023). A study of vessel reactions by dolphin communities in the eastern tropical Pacific found that populations that were often the target of tuna purse-seine fisheries (spotted, spinner, and common dolphins) show evasive behavior when approached; however, populations that live closer to shore (within 100 NM; coastal spotted and bottlenose dolphins), and are not set on by purse-seine fisheries, tend to be attracted to vessels (Archer et al., 2010). Reactions to vessels may also be context-specific. In some studies, the presence of vessels has been shown to interrupt feeding behavior in delphinids (Meissner et al., 2015; Pirotta et al., 2015b). However, in an important foraging area, bottlenose dolphins (a comparatively less sensitive species of odontocete) may continue to forage and socialize even while constantly exposed to high vessel traffic (Mills et al., 2023).

Smaller vessels (e.g., research and tour boats) generate more noise in higher frequency bands, are more likely to approach odontocetes directly and spend more time near an individual whale. Tour boat activity can cause short-term (Carrera et al., 2008) and longer term or repetitive displacement of dolphins due to chronic vessel noise (Haviland-Howell et al., 2007). Delphinid behavioral states also change in the presence of tourist boats that often approach animals, with travel and resting increasing, foraging and social behavior decreasing, and animals reducing the space between each other (e.g., “group dispersal”) (Cecchetti et al., 2017; Clarkson et al., 2020; Kassamali-Fox et al., 2020; Meissner et al., 2015). Most bottlenose dolphin studies on the behavioral reactions to vessel traffic have documented at least short-term changes in behavior, activities, or vocalization patterns when vessels are nearby (Acevedo, 1991; Arcangeli & Crosti, 2009; Berrow & Holmes, 1999; Fumagalli et al., 2018; Gregory & Rowden, 2001; Janik & Thompson, 1996; Lusseau, 2004; Marega et al., 2018; Mattson et al., 2005; Perez-Ortega et al., 2021; Puszka et al., 2021; Scarpaci et al., 2000). Table D.6-10 provides some examples of behavioral responses to different vessel types, with a focus on small recreational vessels and tour boats.

Northern and Southern resident killer whales are sought after by numerous small whale watching vessels in the Pacific Northwest and live in a high traffic area with many different types of vessels. For many years (1998 – 2012) these populations had an average of 20 vessels within 0.5 miles of their location during daytime hours every month (Clark, 2015; Eisenhardt, 2014; Erbe et al., 2014). These vessels had source levels that ranged from 145 to 169 dB re 1 μ Pa and produced broadband noise up to 96 kHz. Received levels of vessel noise did not decrease with the implementation of new policy on vessel distance. Instead noise levels increased as more and faster moving vessels were introduced (Holt et al., 2017). These noise levels can result in behavioral disturbance, interfere with communication, and affect the killer whales’ hearing capabilities via masking (Erbe, 2002; Veirs et al., 2015). Factors other than

vessel noise that contribute to the severity of killer whales behavioral response to vessels include seasonal data (e.g., year and month), a whale's prior experience with vessels (e.g., age and sex), and the number of other vessels present (Williams et al., 2014a).

Table D.6-10: Examples of Behavioral Responses to Vessels by Odontocetes

Species	Study	Boat type	Behavioral Change				
			Feeding or foraging	Group dispersal	Resting	Diving duration	Traveling or fleeing
Common dolphins	Stockin et al. (2008)	Tour	↓		↓		
Bottlenose dolphin	Steckenreuter et al. (2011)	Tour	↓	↓			↑ when approached to 50 m (vs 150 m)
Bottlenose dolphin	Toro et al. (2021)	Tour					↑ (avoid vessel and ↓ surface activity)
Indo-Pacific humpback dolphins	Ng and Leung (2003)	Fishing	↑				
Indo-Pacific humpback dolphins	Ng and Leung (2003)	High-speed				↑ in heavy or oncoming traffic	↑
Killer whales	Kruse (1991); Lusseau et al. (2009); Trites and Bain (2000); Williams et al. (2002a); Williams et al. (2009); Williams et al. (2002b)	Tour	↓ when boats < 100 m				↑ when boats < 100 m
Killer whales (esp. females)	Holt et al. (2021)	Tour	↓ (stop) when boats < 400 m				↑ (start) when boats < 400 m
Pilot whales	Arranz et al. (2021)	Tour	↓ nursing		↓		
Beluga whales	Martin et al. (2023b)	Various ¹				Δ dive behavior	↑ speed (< 13 km) and Δ bearing
Beluga whales	Westdal et al. (2023)	Tour	↓				↓ (↑ interactions with boat < 25 m away)
Harbor porpoises	Frankish et al. (2023)	Large tankers				↑ depth at night	↑ distance during day, especially < 300 m

¹Various ships = tankers, cargo ships, research vessels, fishing, tug boats

Notes: ↑ = increase; ↓ = decrease; < = less than; Δ = change in; km = kilometer; m = meters

Sperm whales generally only react to vessels approaching within several hundred meters. Some individuals are prone to avoidance behavior, such as quick diving (Magalhães et al., 2002; Würsig et al., 1998) or less time spent at the surface (Isojunno & Miller, 2015). When vessels were present, sperm whales were quicker to emit their first click after diving (Richter et al., 2006). Sperm whales have also been observed reducing clicks while a vessel passes by, as well as up to a half hour after the vessel passed (Azzara et al., 2013). It is unknown whether these whales left the area, ceased to click, or

surfaced during this period. However, some of the reduction in click detections may be due to masking of the clicks by the vessel noise, particularly during the closest point of approach.

Little information is available on the behavioral impacts of vessel disturbance on beaked whales (Cox et al., 2006), but it seems like most beaked whales react negatively to vessels with abrupt diving and other avoidance maneuvers (Würsig et al., 1998). There is some evidence that suggests beaked whales respond to all anthropogenic noise (including vessel and sonar) at similar sound levels (Aguilar de Soto et al., 2006; Tyack et al., 2011; Tyack, 2009). A vocalizing goose-beaked whale was disrupted from foraging when a large, noisy vessel passed, which suggests that some types of vessel traffic may disturb foraging beaked whales (Aguilar de Soto et al., 2006). Exposure to broadband ship noise (received level of 135 dB re 1 μ Pa) does not change the duration of whale foraging dives, but may restrict the movement of a group (Pirodda et al., 2012).

Small dolphins and porpoises are also sensitive to vessel noise. Both finless porpoises (Li et al., 2008) and harbor porpoises (Polacheck & Thorpe, 1990) routinely avoid and swim away from large motorized vessels. A study in the Baltic Sea found that harbor porpoises were more likely to horizontally avoid large commercial ships during the day but vertically avoid them at night (Frankish et al., 2023). Near ships, harbor porpoises respond with fewer clicks (Sairanen, 2014), decreased feeding and behavioral bout durations in general (Akkaya Bas et al., 2017). Specifically, foraging harbor porpoises have fewer prey capture attempts and have disrupted foraging when vessels pass closely and noise levels are higher (Wisniewska et al., 2018). A resident population of harbor porpoise that was regularly near vessel traffic (10 m to 1 km away) had no response in 74 percent of interactions and an avoidance response in 26 percent of interactions. Most avoidance responses were observed in groups of 1 to 2 animals, and were the result of fast-moving or steady plane-hulling motorized vessels (Oakley et al., 2017). Larger groups reacted less often, and few responses were observed to non-motorized or stationary vessels (Oakley et al., 2017). Another study of responses to fast moving vessels found that when the vessels were within 50 m, harbor porpoises had an 80 percent probability of changing their swimming direction, but only a 40 percent probability when vessels were beyond 400 m (Akkaya Bas et al., 2017). A study on harbor porpoise in the Baltic Sea found that porpoises were most likely to avoid close ships (< 300 m), but that 5-10% of the time they would also respond to ships > 2 km away, signifying that were not just attuning to ship presence but ship noise as well (Frankish et al., 2023). Although most vessel noise is constrained to lower frequencies below 1 kHz, at close ranges, vessel noise can extend into mid- and high frequencies (into the tens of kHz) (Hermannsen et al., 2014; Li et al., 2015). These frequencies are what harbor porpoises are likely responding to; the mean M-weighted received SPL threshold for a response at these frequencies is 123 dB re 1 μ Pa (Dyndo et al., 2015). Hermannsen et al. (2019) estimated that noise in the 16 kHz frequency band resulting from small recreational vessels not equipped with an Automatic Identification System and therefore not included in most vessel noise impact models could be elevated up to 124 dB re 1 μ Pa and raise ambient levels up to 51 dB; these higher levels were associated with vessel speed and range. These authors determined that the threshold levels found by Dyndo et al. (2015) and Wisniewska et al. (2018) were exceeded by 49 to 85 percent of events with high levels of boat noise, and that recreational vessel noise in the 16 kHz band could cause behavioral responses in harbor porpoises.

Naïve populations of bottlenose dolphins (exposed to lower levels of vessel traffic) had stronger and longer lasting reactions to vessel approaches (Bejder et al., 2006b). Fewer reactions in populations of dolphins regularly subjected to high levels of vessel traffic could be a sign of habituation, or it could be that the more sensitive animals in this population previously abandoned the area of higher human activity.

Odontocetes have been shown to make short-term changes to their vocalizations as an immediate response to vessel noise (see Table D.6-4). For example, bottlenose dolphins in Portuguese waters

decrease their call rates and change the frequency parameters of whistles in the presence of boats, while dolphin groups with calves increase their whistle rates when tourist boats are within 200 m and when the boats increase their speed (Guerra et al., 2014). Foraging Lahille's bottlenose dolphins in Brazil increase the duration of their whistles when there is an increase in the speed or number of boats within 250 m; they also increase the frequency parameters of their whistles, especially when group size or calf presence increased. Likewise, modification of multiple vocalization parameters was shown in belugas residing in an area known for high levels of commercial traffic. These animals decreased their call rate, increased certain types of calls, and shifted upward in frequency content in the presence of small vessel noise (Lesage et al., 1999). An increase in the amplitude of vocalizations (Lombard effect) has also been observed when ships were present (Scheifele et al., 2005).

Long-term modifications to vocalizations may be indicative of a learned response to chronic noise, or of a genetic or physiological shift in the populations. This type of change has been observed in killer whales off the northwestern coast of the United States between 1973 and 2003. This population increased the duration of primary calls once a threshold in observed vessel density (e.g., whale watching) was reached, which is suggested as being a long-term response to increased masking noise produced by the vessels (Foote et al., 2004).

The long-term and cumulative implications of vessel noise on odontocetes is largely unknown (National Academies of Sciences Engineering and Medicine, 2017; National Marine Fisheries Service, 2007) although some long-term consequences have been reported (Lusseau & Bejder, 2007). Repeated exposure to acoustic and other anthropogenic stimuli has been studied in several cases, especially as related to vessel traffic and whale watching. Many authors speculate that repeated interruption of foraging behaviors could lead to long-term implications for odontocete populations (Stockin et al., 2008), and in many contexts their localized and coastal home ranges do make them less resilient than mysticetes to this kind of chronic stressor (Southall et al., 2021). The long-term and cumulative implications of ship sound on odontocetes is largely unknown (National Academies of Sciences Engineering and Medicine, 2017; National Marine Fisheries Service, 2007) although some long-term consequences have been reported (Lusseau & Bejder, 2007). Repeated exposure to acoustic and other anthropogenic stimuli has been studied in several cases, especially as related to vessel traffic and whale watching. Many authors speculate that repeated interruption of foraging behaviors could lead to long-term implications for odontocete populations (Stockin et al., 2008), and in many contexts their localized and coastal home ranges do make them less resilient than mysticetes to this kind of chronic stressor (Southall et al., 2021).

Like mysticetes, odontocete responses to vessel noise are varied. Although many odontocete species seem to be more sensitive to vessel presence and noise, these two factors are difficult to tease apart. Some species (e.g., killer whales and porpoises) may be sensitized to vessels and respond at further distances and lower received levels than other delphinids. In contrast, other species (e.g., bottlenose, spotted, spinner, Clymene, and Pacific white sided dolphins) will approach vessels to bow ride, indicating either that these species are less sensitive to vessels or that the behavioral drive to bow ride supersedes any impact of the associated noise (Würsig et al., 1998). With these broad and disparate responses, it is difficult to assess the impacts of vessel noise on odontocetes.

D.6.5.2.3 Aircraft Disturbance

Behavioral responses to aircraft can be caused by multiple factors. It is difficult for researchers and analysts to separate the effects of aircraft noise and aircraft presence; therefore, this section will cover both aspects in publications that specifically aim to target response to noise.

Variable responses to aircraft have been observed in toothed whales, though overall little change in behavior has been observed during flyovers. Some toothed whales dove, slapped the water with their

flukes or flippers, or swam away from the direction of the aircraft during overflights; others did not visibly react (Richardson et al., 1995b). Würsig et al. (1998) found that beaked whales were the most sensitive cetacean and reacted by avoiding marine mammal survey aircraft in 89 percent of sightings and at more than twice the rate as Kogia whales, which was the next most reactive of the odontocetes in 39 percent of sightings. These are the same species that were sensitive to vessel traffic.

During standard marine mammal surveys at an altitude of 750 ft., some sperm whales remained on or near the surface the entire time the aircraft was in the vicinity, while others dove immediately or a few minutes after being sighted. Other authors have corroborated the variability in sperm whales' reactions to fixed-wing aircraft or helicopters (Green et al., 1992; Richter et al., 2006; Richter et al., 2003; Smultea et al., 2008; Würsig et al., 1998). Whale watching aircraft (fixed-wing airplanes and helicopters) apparently caused sperm whales to turn more sharply but did not affect blow interval, surface time, time to first click, or the frequency of aerial behavior (Richter et al., 2003).

A group of sperm whales responded to a circling fixed-wing aircraft (altitude of 800 to 1,100 ft.) by moving closer together and forming a defensive fan-shaped semicircle, with their heads facing outward. Several individuals in the group turned on their sides, apparently to look up toward the aircraft (Smultea et al., 2008). Smaller delphinids generally react to overflights either neutrally or with a startle response (Würsig et al., 1998). A change in travel direction was noted in a group of pilot whales as the a fixed-wing aircraft circled while conducting monitoring (HDR, 2011). No changes in group cohesion or orientation behavior were observed for groups of Risso's dolphins, common dolphins, or killer whales when a survey airplane flew at altitudes of 213–610 m, but this may be due to the plane maintaining lateral distances greater than 500 m in all (Smultea & Lomac-MacNair, 2016).

Helicopters may elicit a greater reaction in odontocetes. Beluga whales reacted to helicopter overflights by diving, breaching, changing direction or behavior, and altering breathing patterns to a greater extent than mysticetes in the same area (Patenaude et al., 2002). These reactions increased in frequency as the altitude of the helicopter dropped below 150 m. Sperm whales showed no reaction to a helicopter until they encountered the downdrafts from the rotors (Richardson et al., 1995b).

Much like mysticetes, odontocetes have demonstrated no responses to unmanned aerial systems at altitudes over 30 m. For example, Durban et al. (2015) conducted photogrammetry studies of killer whales using a small helicopter flown 35 to 40 m above the animals with no disturbance noted. However, odontocete responses have been reported with use at reduced altitudes. St. Lawrence belugas responded to drones below 23 m with evasive dive responses; their alert surface active reactions (e.g., tail slap) also increased in larger groups or while socializing (Aubin et al., 2023). These impacts may be species-specific, and could be due either to noise or the shadows created by the vehicle (Smith et al., 2016). Bottlenose dolphins responded to a small portion of unmanned aerial vehicles by briefly orienting when the vehicle was relatively close (10 to 30 m high), but in most cases did not respond at all (Ramos et al., 2018).

D.6.5.2.4 Impulsive Noise

Impulsive signals, particularly at close range, have a rapid rise time and higher instantaneous peak pressure than other signal types, making them more likely to cause startle responses or avoidance responses. However, at long distances the rise time increases as the signal duration lengthens (similar to a “ringing” sound), making the impulsive signal more similar to a non-impulsive signal (Hastie et al., 2019; Martin et al., 2020). Behavioral reactions from explosive sounds are likely to be similar to reactions studied for other impulsive sounds, such as those produced by air guns and impact pile driving. Data on behavioral responses to impulsive sound sources are limited across all marine mammal groups, with only a few studies available for mysticetes and odontocetes. Most data have come from seismic

surveys that occur over long durations (e.g., on the order of days to weeks), and typically utilize large multi-air gun arrays that fire repeatedly. While seismic data provide the best available science for assessing behavioral responses to impulsive sounds by marine mammals, it is likely that these responses represent a worst-case scenario compared to responses to explosives used in Navy activities, which would typically consist of single impulses or a cluster of impulses, rather than long-duration, repeated impulses.

Few data are available on odontocete responses to impulsive sound sources, with only a few studies on responses to seismic surveys, pile driving and construction activity available. However, odontocetes appear to be less sensitive to impulsive sound than mysticetes, with responses occurring at much closer distances. This may be due to the predominance of low-frequency sound associated with these sources that propagates long distances and overlaps with the range of best hearing for mysticetes but is below that range for odontocetes. The exception to this is the harbor porpoise, which has been shown to be highly sensitive to most sound sources, avoiding both stationary (e.g., pile driving) and moving (e.g., seismic survey vessels) impulsive sound sources out to approximately 20 km (e.g., Haelters et al., 2014; Pirotta et al., 2014). However, even this response is short term, with porpoises returning to the area within hours after the cessation of the noise.

There are even fewer direct observations of behavioral reactions from marine mammals due to exposure to explosive sounds. Lammers et al. (2017) recorded dolphin detections near naval mine neutralization exercises and found that although the immediate response (within 30 seconds of the explosion) was an increase in whistles relative to the 30 seconds before the explosion, there was a reduction in daytime acoustic activity during the day of and the day after the exercise within 6 km. However, the nighttime activity did not seem to be different than that prior to the exercise, and two days after there appeared to be an increase in daytime acoustic activity, indicating a rapid return to the area by the dolphins (Lammers et al., 2017).

Ferguson et al. (2006) and Miller et al. (2009) tagged and monitored eight sperm whales in the Gulf of Mexico exposed to seismic air gun surveys. Sound sources were from approximately 2 to 7 NM away from the whales, and received levels were as high as 162 dB SPL re 1 μ Pa (Madsen et al., 2006). The whales showed no horizontal avoidance, however one whale rested at the water's surface for an extended period of time until air guns ceased firing (Miller et al., 2009). While the remaining whales continued to execute foraging dives throughout exposure, tag data suggested there may have been subtle effects of noise on foraging behavior (Miller et al., 2009). Similarly, Weir (2008) observed that seismic air gun surveys along the Angolan coast did not significantly reduce the encounter rate of sperm whales during the 10-month survey period, nor were avoidance behaviors to air gun impulsive sounds observed. In contrast, Atlantic spotted dolphins did show a significant, short-term avoidance response to air gun impulses within approximately 1 km of the source (Weir, 2008). The dolphins were observed at greater distances from the vessel when the air gun was in use, and when the air gun was not in use they readily approached the vessel to bow ride. Kavanagh et al. (2019) also found that toothed whales were more averse to active air guns, as sightings of several species of odontocetes were reduced by 53 and 29 percent during active and inactive phases of seismic surveys, respectively, compared to baseline surveys. Narwhals exposed to air guns in an Arctic fjord were even more sensitive (Heide-Jorgensen et al., 2021). Even though small and large air gun sources reached ambient noise levels around 3 and 10 km (air gun source levels = 231 and 241 dB re 1 μ Pa at 1 m), respectively, narwhals still changed their swimming direction away from the source and towards shore when seismic vessels were in line of sight over 11 km away. Swimming speed was context-dependent; whales usually increased speed in the presence of vessels but would reduce speed ("freeze") in response to closely approaching air gun pulses. Other behaviors, like feeding, also ceased when the active air gun noise was less than 10 km away,

although received SELs were below 130 dB re 1 $\mu\text{Pa}^2 \text{ s}$ for either air gun at this distance. Due to study research methods and criteria, even these long-distance reactions of narwhals may be conservatively estimating narwhals' range to behavioral response.

Captive bottlenose dolphins sometimes vocalized or were reluctant to return to the test station after exposure to single impulses from a seismic water gun (Finneran et al., 2002). When exposed to multiple impulses from a seismic air gun, some dolphins turned their heads away from the sound source just before the impulse, showing that they could anticipate the timing of the impulses and perhaps reduce the received level (Finneran et al., 2015). During construction (including the blasting of old bastions) of a bridge over a waterway commonly used by the Tampa Bay, Florida stock of bottlenose dolphins, the use of the area by females decreased while males displayed high site fidelity and continued using the area, perhaps indicating differential habitat uses between the sexes (Weaver, 2015).

Harbor porpoises seem to have an avoidance response to seismic surveys. A study using aerial surveys and C-PODs (an autonomous recording device that counts odontocete clicks) found that harbor porpoises appeared to leave the area of the survey, and decreased their foraging activity within 5 to 10 km, as evidenced by both a decrease in vocalizations near the survey and an increase in vocalizations at a distance (Pirrotta et al., 2014; Thompson et al., 2013a). However, the animals returned within a day after the air gun operation ceased, and the decrease in occurrence over the survey period was small relative to the observed natural seasonal decrease compared to the previous year.

Harbor porpoises have a similar response to pile driving as well. A similar study using C-PODs at two offshore windfarms to examine differences in harbor porpoises presence and foraging activity between baseline (102 to 104 dB) and construction periods (155 to 161 dB) found decreased presence (8 to 17 percent) and foraging (41 to 62 percent) during construction periods. More porpoises were displaced up to 12 km away from pile driving and 4 km from construction vessels (Benhemma-Le Gall et al., 2021). A number of studies also found strong avoidance responses by harbor porpoises out to 20 km during pile driving; however, animals returned to the area after the activity stopped (Brandt et al., 2011; Dähne et al., 2014; Haelters et al., 2014; Thompson et al., 2010; Tougaard et al., 2005; Tougaard et al., 2009). When bubble curtains were deployed around pile driving, the avoidance distance appeared to be reduced to half that distance (12 km), and the response only lasted about five hours rather than a day before the animals returned to the area (Dähne et al., 2017).

However, not all harbor porpoise behavioral response studies ended in habitat displacement. Bergström et al. (2014) found that although there was a high likelihood of acoustic disturbance during wind farm construction (including pile driving), the impact was short term. In another pile driving study, Graham et al. (2019) found that the distance at which behavioral responses were probable decreased over the course of the construction project, suggesting habituation to pile-driving noise in the local harbor porpoise population. When C-PODs were placed near oil and gas platforms and control sites 15 km away, there was a dose-response effect with the lowest amount of porpoise activity closest to the seismic vessel ($\text{SEL}_{\text{single shot}} = 155 \text{ dB re } 1 \mu\text{Pa}^2 \text{ s}$) and then increasing porpoise activity out to 8 to 12 km, outside of which levels were similar to baseline. Distance to the seismic vessel was a better model predictor of porpoise activity than sound level. Despite these smaller-scale responses, a large-scale response was not detected, and overall porpoise activity in the seismic area was similar to the control stations; this may indicate that the porpoises were moving around the seismic area to avoid the ship, but not leaving the area entirely (Sarnocińska et al., 2020).

According to a 10-year boat-based line-transect survey in an area which included the preconstruction, construction, and postconstruction of offshore wind farm, harbor porpoises were observed throughout the area during all three phases. However, they were not detected within the footprint of the windfarm and were overall less frequent throughout the study area during the construction phase. They returned

after the construction was completed at a slightly higher level than in the preconstruction phase. There was no large-scale displacement of harbor porpoises during construction, and their avoidance behavior only occurred out to about 18 km, in contrast to the approximately 25 km avoidance distance found in other windfarm construction and pile driving monitoring efforts.

A five-year study (2015-2020) found that harbor porpoise detections significantly decreased at the beginning of a pile driving project (SEL at 750 m was 160 to 164 dB re 1 $\mu\text{Pa}^2\text{s}$) for an oil and gas platform, but detections appeared to return to baseline levels within five months (Todd et al., 2022). The lack of significant trend over years indicated that porpoises did not experience habitat displacement for the entire five-year period. However, it is important to note that the oil and gas platform construction did not take five years, and the type of sources changed over this five-year period.

When exposing a captive harbor porpoise to impact pile driving sounds, Kastelein et al. (2013b) found that above 136 dB re 1 μPa (zero-to-peak) the animal's respiration rates increased, and at higher levels it jumped more frequently. Swim speed, respiration rate, distance from the transducer, and jumping may also increase in response to pile driving sounds, as long as those sounds have higher frequencies present (i.e., above 6 kHz) (Kastelein et al., 2022).

The occurrence of bottlenose dolphins and harbor porpoises over different area and time scales were assessed with and without impact and vibratory pile driving. While there were fewer hours with bottlenose dolphin detections and reduced detection durations within the pile driving area and increased detection durations outside the area, the magnitude of the effects were small, and the reduced harbor porpoise encounter duration was attributed to seasonal changes outside the influence of the pile driving. However, received levels in this area were lower due to propagation effects than in the other areas described above, which may have led to the lack of or reduced response.

Odontocete behavioral responses to impulsive sound sources are likely species- and context-dependent, with most species demonstrating little to no apparent response. Responses might be expected close to a noise source, under specific behavioral conditions such as females with offspring, or for sensitive species such as harbor porpoises.

D.6.5.3 Behavioral Reactions of Pinnipeds

The pinnipeds consist of phocids ("earless" seals) and otariids (sea lions and fur seals), as well as walruses. The below summary will address best available science regarding responses by phocids, followed by otariids. Although not all species are present in the Study Area, information on their responses to acoustic stressors augment the limited knowledge of behavioral responses by pinnipeds.

D.6.5.3.1 Sonar and Other Transducers

Studies of pinniped behavioral responses to sonar and other transducers are limited. Observed responses seem to be mediated by the contextual factors of the exposure, including the characteristics of the signal (e.g., Hastie et al., 2014) and the behavioral state of the animal. However, all studies of pinniped behavioral response to sonars (not including fisheries deterrents) have been conducted in captivity, so application to real-world exposure situations must be done with caution. Based on exposures to other sound sources in the wild (e.g., impulsive sounds and vessels), pinnipeds may only respond strongly to Navy sonar that is near or approaching.

Different responses displayed by captive and wild phocid seals to sound judged to be "unpleasant" or threatening have been reported, including habituation by captive seals (they did not avoid the sound) and avoidance behavior by wild seals (Götz & Janik, 2010). Captive seals received food (reinforcement) during sound playback, while wild seals were exposed opportunistically. These results indicate that motivational state (e.g., reinforcement via food acquisition) can be a factor in whether an animal

tolerates or habituates to novel or unpleasant sounds. Another study found that captive hooded seals reacted to 1 to 7 kHz sonar signals, in part with displacement (i.e., avoidance) to the areas of least SPL, at levels between 160 and 170 dB re 1 μ Pa (Kvadsheim et al., 2010b); however, the animals adapted to the sound and did not show the same avoidance behavior upon subsequent exposures. Captive harbor seals responded differently to three signals at 25 kHz with different waveform characteristics and duty cycles. The seals responded to the frequency modulated signal at received levels over 137 dB re 1 μ Pa by hauling out more, swimming faster, and raising their heads or jumping out of the water, but did not respond to the continuous wave or combination signals at any received level (up to 156 dB re 1 μ Pa) (Kastelein et al., 2015c). Low-frequency signals of the Acoustic Thermometry of Ocean Climate sound source centered at 75 Hz, with received levels between 118 and 137 dB re 1 μ Pa, were not found to overtly affect elephant seal dives (Costa et al., 2003). However, they did produce subtle effects that varied in direction and degree among the individual seals, again illustrating the equivocal nature of behavioral effects and consequent difficulty in defining and predicting them.

Harbor seals exposed to seal scarers (i.e., acoustic harassment devices used to deter seals from fishing nets or salmon farms) did not respond in any biologically significant way in several studies (Kastelein et al., 2015b; Mikkelsen et al., 2017; Morton & Symonds, 2002), but did demonstrate minor responses by occasionally hauling out at 128 to 138 dB re 1 μ Pa (Kastelein et al., 2015b). Pingers have also been used to deter marine mammals from fishing nets. One study exposed species to novel objects, including a fishing net and anchor with line, both with and without a gillnet pinger. Captive harbor seals, California sea lions and Northern elephant seals avoided a fishing net and anchor with line with a gillnet pinger but did not avoid the same net without a pinger (Bowles & Anderson, 2012). In some cases, pingers on nets lead to the “dinner bell effect,” where the pinger becomes an attractant rather than a deterrent (Carretta & Barlow, 2011).

To better understand otariid responses to tactical mid-frequency sonar, captive California sea lions were exposed to mid-frequency sonar at various received levels (125 to 185 dB re 1 μ Pa) during a repetitive task (Houser et al., 2013a). Behavioral responses included a refusal to participate, hauling out, an increase in respiration rate, and an increase in the time spent submerged. Young animals (less than two years old) were more likely to respond than older animals. Dose-response curves were developed both including and excluding those young animals. Most responses below 155 dB re 1 μ Pa were changes in respiration, whereas over 170 dB re 1 μ Pa more severe responses began to occur (such as hauling out or refusing to participate); many of the most severe responses came from the younger animals. In another study investigating potential deterrent sounds, captive Steller sea lions were exposed to a variety of sounds for two minutes, at a maximum source level of 165 dB re 1 μ Pa for non-impulsive sounds (Akamatsu et al., 1996). Killer whale vocalizations (whether these were from fish-eating or mammal-eating killer whales is not stated), 1-4 kHz sweeps, and low source level impulses were least effective at causing adults to respond by hauling out, whereas juveniles were more likely to haul out in response to sweeps and low-level impulses. The intermittent pure tone at 8 kHz was most likely to elicit responses in adults and juveniles, although not consistently. The addition of prey items to the test pool greatly reduced the likelihood of hauling out during a sound exposure.

D.6.5.3.2 Vessel Disturbance

Behavioral responses to vessels can be caused by multiple factors. It is difficult for researchers and analysts to separate the effects of vessel noise and vessel presence; therefore, this section will cover both aspects in publications that specifically aim to target response to noise. Pinniped reactions to vessels are variable and reports include a wide spectrum of possibilities including vigilance, avoidance, alerting, and reduced time feeding, resting, or nursing (Martin et al., 2023a; Martin et al., 2022; Mikkelsen et al., 2019; Richardson et al., 1995b). On the opposite end of the spectrum, some pinnipeds

demonstrate in-water attraction or a lack of significant reaction when hauled out, suggesting habituation to or tolerance of vessels (Richardson et al., 1995b). Specific case reports in Richardson et al. (1995b) vary based on factors such as routine anthropogenic activity, distance from the vessel, engine type, wind direction, and ongoing subsistence hunting. As with reactions to sound reviewed by Southall et al. (2007), pinniped responses to vessels are affected by the context of the situation and by the animal's experience. Social variables such as animal density and reproductive context may play a role in degree of responsiveness as well. For example, Cape fur seals were less responsive to vessel noise in sites with lower seal abundances compared to a site with a large breeding colony (Martin et al., 2023a).

Increasing numbers of vessels in coastal areas have reduced haul-out time and increase heart rate for harbor seals in certain contexts. The most harbor seal haul outs on Alaskan tidewater glaciers occur during pupping season, and the presence of any vessel reduced this haul out time, with cruise ships and other large vessels having the strongest effect (Blundell & Pendleton, 2015). Another study in Alaska found that hauled out harbor seals were more likely to flush and enter the water when cruise ships approached the ice within 500 m, and were four times more likely to flush when the cruise ship approaches within 100 m (Jansen et al., 2010). Harbor seal heart rates increased when vessels were present during haul out periods and increased further when vessels approached and animals re-entered the water (Karpovich et al., 2015). Harbor seals responded more to vessels passing by haul out sites in areas with less overall vessel activity, and the model best predicting their flushing behavior included the number of boats, type of boats, and distance to boats. More flushing occurred to non-motorized vessels (e.g., kayaks), likely because they tended to occur in groups rather than as single vessels, and tended to pass closer (25 to 184 m) to the haul out sites than motorized vessels (55 to 591 m) (Cates & Acevedo-Gutiérrez, 2017).

Other behaviors not associated with haul-out time and flushing are impacted by vessel disturbance as well. Long-term biologgers (DTAGs) were attached to harbor seals and grey seals to opportunistically examine behaviors over several weeks (Mikkelsen et al., 2019). The data showed that seals were exposed to vessel noise between 2.2 and 20.5 percent of their time in water. Potential responses to vessels, coinciding with increasing or peak vessel noise on the tags, included interruption of resting and foraging behaviors. Although there were no behavioral differences between hauled-out wild cape fur seals exposed to low (60-64 dB re 20 μ Pa RMS SPL), medium (64-70 dB) and high-level (70-80 dB) vessel noise playbacks, mother-pup pairs spent less time nursing (15-to 31 percent) and more time awake (13 to 26 percent), vigilant (7 to 31 percent), and mobile (2to 4 percent) during boat noise conditions compared to control conditions (Martin et al., 2022).

Impact to pinnipeds may differ based on the location or species, as some populations may be more tolerant to vessel disturbance or have a lower degree of overlap with boat traffic. Walrus reaction to vessel noise in the Arctic remains inconclusive (Taylor et al., 2023). Grey seal reactions to increasing vessel traffic off Ireland's coast in association with construction activities suggest that the number of vessels had an indeterminate effect on the seals' presence (Anderwald et al., 2013). Modeling of harbor seals and grey seals in the UK found that they were most likely to overlap with vessel traffic within 50 km of the coast, which included around half of the seals' Special Areas of Conservation (Jones et al. (2017). While there was no evidence of reduced population size in any of these high overlap areas, estimated received levels of shipping noise and maximum daily M-weighted cumulative SEL values ranged from 170 to 189 dB, with the upper confidence intervals of those estimates sometimes exceeding TTS values.

D.6.5.3.3 Aircraft Disturbance

Richardson et al. (1995b) noted that responsiveness to aircraft overflights generally was dependent on the range (altitude and distance) of the aircraft, the abruptness of the associated aircraft sound, and life

cycle stage (breeding, molting, etc.). Pinnipeds may startle, orient towards the sound source, increase vigilance, or briefly re-enter the water, but, in general, they are unresponsive to overflights and typically remain hauled out or immediately return to their haul out location (Blackwell et al., 2004; Gjertz & Børset, 1992). Reactions of walruses on land varied in severity and included minor head raising at a distance of 2.5 km, orienting toward, or entering the water at less than 150 m and 1.3 km in altitude, to full flight reactions at horizontal ranges of less than 1 km at altitudes as high as 1,000–1,500 m (Richardson et al., 1995b).

Helicopters are used in studies of several species of seals hauled out and are considered an effective means of observation (Bester et al., 2002; Gjertz & Børset, 1992), although they have been known to elicit behavioral reactions such as fleeing (Hoover, 1988). For California sea lions and Steller sea lions at a rocky haulout off Crescent City in northern California, helicopter approaches to landing sites typically caused the most severe response of diving into the water (National Oceanic and Atmospheric Administration, 2010). Responses were also dependent on the species, with Steller sea lions being more sensitive and California sea lions more tolerant. Depending on the time between subsequent approaches, animals hauled out in between and fewer animals reacted upon subsequent exposures (National Oceanic and Atmospheric Administration, 2010).

Pinnipeds may respond to unmanned aerial systems, especially those flying at low altitudes, due to their possible resemblance to predatorial birds (Smith et al., 2016), which could lead to flushing behavior (Olson, 2013). Responses may also vary by species, age class, behavior, and habituation to other anthropogenic noise, as well as by the type, size, and configuration of unmanned aerial vehicle used (Pomeroy et al., 2015). However, in general pinnipeds have demonstrated little to no response to unmanned aerial systems, with some orienting towards the vehicle, other alerting behavior, or short-term flushing possible (Laborie et al., 2021; Moreland et al., 2015; Sweeney et al., 2015).

D.6.5.3.4 Impulsive Noise

Pinnipeds may be the least sensitive marine mammal group to noise sources in this document. Some species may be more sensitive than others and are likely to only respond to loud impulsive sound sources at close ranges by startling, jumping into the water when hauled out, or ceasing foraging, but only for brief periods before returning to their previous behavior (e.g., Southall et al., 2007). Pinnipeds may even experience hearing effects before exhibiting a behavioral response (Southall et al., 2007). A review of behavioral reactions by pinnipeds to impulsive noise can be found in Richardson et al. (1995b) and Southall et al. (2007).

Blackwell et al. (2004) observed that ringed seals exhibited little or no reaction to pile-driving noise with mean underwater levels of 157 dB re 1 μ Pa and in-air levels of 112 dB re 20 μ Pa, suggesting that the seals had habituated to the noise. On the other hand, harbor seals were displaced from areas surrounding wind farm pile driving (average pile driving duration 6 hours) at estimated received levels between 166 and 178 dB re 1 μ Pa SPL (peak to peak), with presence returning to baseline within two hours of cessation of pile driving (Russell et al., 2016). Similarly, harbor and grey seals avoided a seismic air gun by rapidly swimming away and ceasing foraging, then returned to normal behavior afterwards (Thompson et al. 1998, cited in Gordon et al., 2003).

Captive California sea lions avoided sounds from an underwater impulsive source at levels of 165 to 170 dB re 1 μ Pa (Finneran et al., 2003b). However, few responses were observed by New Zealand fur seals to a towed air gun array operating at full power; rather, when responses were observed it seemed to be to the physical presence of the vessel and tow apparatus, and these only occurred when the vessel was within 200 m and sometimes as close as 5 m (Lalas & McConnell, 2016). Captive Steller sea lions were exposed to a variety of tonal, sweep, impulsive and broadband sounds to determine what might

work as a deterrent from fishing nets (Akamatsu et al., 1996). An impulsive sound at a source level of 210 dB re 1 μ Pa at 1 m was more likely to cause both adults and juveniles to haul out and refuse to eat fish presented in a net compared to other exposures. Fewer instances of juvenile haul outs and no adult haul outs were observed in response to the same impulse sound at a source level of 165 dB re 1 μ Pa, including with and without the food item in the test pool. Steller sea lions exposed to in-air explosive blasts increased their activity levels and often re-entered the water when hauled out (Demarchi et al., 2012). However, these responses were short-lived and, within minutes, the animals had hauled out again, and there were no lasting behavioral impacts in the days following the blasts.

Hastie et al. (2021) studied how the number and severity of avoidance events may be an outcome of marine mammal cognition and risk assessment. Five captive grey seals were given the option to forage in a high- or low-density prey patch while continuously exposed to silence, pile driving or tidal turbine playbacks (148 dB re 1 μ Pa at 1 m). One prey patch was closer to the speaker, so had a higher received level in experimental exposures. Overall, seals avoided both anthropogenic noise playback conditions with higher received levels when the prey density was limited but would forage successfully and for as long as control conditions when the prey density was higher, demonstrating that noise has the potential to impact seal foraging decisions if the level is high enough. Experimentally, Götz and Janik (2011) tested underwater startle responses to a startling sound (sound with a rapid rise time and a 93 dB sensation level [the level above the animal's hearing threshold at that frequency]) and a non-startling sound (sound with the same level, but with a slower rise time) in wild-captured gray seals. The animals exposed to the startling treatment avoided a known food source, whereas animals exposed to the non-startling treatment did not react or habituated during the exposure period. The results of this study highlight the importance of the characteristics of the acoustic signal in an animal's response of habituation.

D.6.5.4 Behavioral Reactions of Sirenians

D.6.5.4.1 Sonar and Other Transducers

Few data exist on manatee responses to sonar; however, there has been some work using side-scan and fish-finding sonar to detect manatees (Gonzalez-Socoloske & Olivera-Gomez, 2012; Gonzalez-Socoloske et al., 2009; Niezrecki, 2010). These are typically very-high-frequency systems, with frequencies over 200 kHz, although in some cases frequencies of 50 kHz were used. The response of the manatees to the sonar was not the focus of these studies, but, when reported, the authors stated that no response was observed. Studies have also been conducted on the efficacy of using pingers to warn manatees about the presence of vessels or fishing gear. Bowles et al. (2001) observed brief startle responses to pingers sweeping 10 to 80 kHz in two of nine manatees tested. However, the captive manatees appeared to be attracted to the fishing gear, and did not avoid it even in the presence of pingers (Bowles et al., 2001). Dugongs in Australia were exposed to 3.5 and 10 kHz pingers with source levels around 133 dB re 1 μ Pa, with no significant responses observed and continued foraging throughout the experiment (Hodgson & Marsh, 2007). In contrast, wild dugongs in Thailand exposed to 3.5 kHz tones at 141 dB re 1 μ Pa did not approach the source within 100 m, while playbacks of dugong calls elicited approaches within 10 m (Ichikawa et al., 2009).

These limited data may indicate that sirenians are relatively robust to sonar and other active acoustic sources; however, with the lack of focused studies on these sound sources it is difficult to draw any conclusions.

D.6.5.4.2 Vessel Disturbance

Behavioral responses to vessels can be caused by multiple factors. It is difficult for researchers and analysts to separate the effects of vessel noise and vessel presence; therefore, this section will cover

both aspects in publications that specifically aim to target response to noise. The West Indian manatee responds to vessel movement via acoustic and possibly visual cues by moving away from the approaching vessel, increasing its swimming speed, and moving toward deeper water (Miksis-Olds et al., 2007; Nowacek et al., 2004b). When vessels pass within 10 m, manatees respond by fluking, changing their heading or depth, or rolling (Rycyk et al., 2018). The degree of response varies with the individual manatee and may be more pronounced in deeper water, where they are more easily able to determine the direction of the approaching vessel (Nowacek et al., 2004b). Similar responses were observed for slow- and fast-moving vessels (Rycyk et al., 2018). However, they were more likely to change their behavior to boat passes of longer durations, and the longer they had to change their behavior (e.g., slower moving boats) that behavior change occurred earlier relative to the boat's closest approach. In other words, slower moving vessels allowed manatees a greater opportunity to move out of the way of the vessel. This disturbance is a temporary response to the approaching vessel. West Indian manatees have also been shown to seek out areas with a lower density of vessels (Buckingham et al., 1999). West Indian manatees exhibit a clear behavioral response to vessels within distances of 25 to 50 m, but it is unclear at what distance the manatees first detect the presence of vessels (Nowacek et al., 2004b). Vessel traffic and recreation activities that disturb West Indian manatees may cause them to leave preferred habitats and may alter biologically important behaviors, such as feeding, suckling, or resting (Haubold et al., 2006).

In manatees, call rates and call amplitude were affected by noise that shared dominant frequencies of watercraft, with call rates decreasing during feeding and socializing. Differential effects were also seen on call type based on the presence or absence of calves (Miksis-Olds & Tyack, 2009). Similarly, call rates in dugongs did not change in the presence of vessels, but call durations were longer and more harmonics were present when boats passed within 400 m (Ando-Mizobata et al., 2014). These changes in vocalizations varied with the frequency of the noise, the type of call being produced, and the behavioral or social context; taken together, these changes may indicate that responses to vessel noise are dependent on behavioral and environmental contexts.

D.6.5.4.3 Aircraft Disturbance

There are few data on the effects of aircraft overflight on sirenians. Rathbun (1988) studied the reaction of West Indian manatees to both fixed-wing aircraft and helicopters used during census surveys. The manatees did not react to a fixed-wing aircraft moving at approximately 130 km per hour at 160 m altitude. However, animals did react to a helicopter below approximately 100 m moving at speeds of 0 (hovering) to 20 km per hour by startling from rest and diving to deeper waters. This again demonstrates that distance to the aircraft impacts if and how an animal may respond.

Hodgson et al. (2013) conducted a pilot study to conduct aerial surveys of dugongs using an unmanned aerial vehicle flown at altitudes of 500, 750 and 1,000 ft.; no behavioral responses were mentioned but noise levels were much lower than for a typical fixed-wing aircraft. Similarly, manatees were not disturbed by a fixed-wing unmanned vehicle flying at 100 m (Jones IV et al., 2006; Smith et al., 2016).

D.6.5.4.4 Vessel Disturbance

Sea otters that live far inshore and may be exposed to noise from recreational boats and commercial and military ships transiting in and out of port areas. Sea otters have similar in-air hearing sensitivities as pinnipeds (Miksis-Olds et al., 2007; Nowacek et al., 2004b), and may react in a similar fashion when approached by vessels. However, underwater hearing sensitivities are significantly reduced compared to pinnipeds (Ghoul & Reichmuth, 2014a, 2014b). While reactions to underwater vessel noise may occur, they will have lower overall severity to those of pinnipeds. Sea otters in Monterey, CA that were living in areas of disturbance from human activity such as recreational boating spent more time engaged in

travel than resting (Curland, 1997). Sea otters in undisturbed areas spent 5 percent of their time travelling; otters in areas of disturbance due to vessels were shown to spend 13 percent of their time travelling (Curland, 1997). While this may not appear to be a large change in behavior, sea otter dives are very costly and require twice the metabolic energy that phocid seals need to dive; therefore sea otters may not dive or travel far in response to disturbance, as they already require long periods of rest at the surface to counterbalance the high cost of foraging at sea (Yeates et al., 2007). For example, when a single air gun vessel passed a large raft of otters, several otters were mildly alarmed (e.g., rolled over on their sides or bellies and looked intently at the vessel as it approached) but did not leave the raft. However, they reacted to the vessel every time it passed, even though the air gun was only operational for two of the four passes. This indicates that otters were either responding to the loud airborne sounds of the boat engines and compressor, or to the close approach of the vessel itself, rather than the seismic sounds (Reidman, 1983). However, sea otters may habituate quickly. Even when purposefully harassed in an effort to cause a behavioral response, sea otters generally moved only a short distance (100 to 200 m) before resuming normal activity, and nearby boats, nets, and floating oil containment booms were sometimes an attractant (Davis et al., 1988). Although Barrett (2019) found that sea otters have a high metabolic rate and are at risk of increased energetic costs when disturbed, there was less than a 10 percent chance of disturbance when small vessels were more 54 m away from sea otters.

D.6.5.4.5 Aircraft Disturbance

Sea otters spend approximately 80 percent of their time on the surface of the water (Curland, 1997) with their heads above the surface, and will most likely be exposed to noise from aircraft. Recordings of underwater noise produced by helicopter overflights did not appear to affect sea otter foraging behavior, foraging success, or daily activity patterns when projected underwater 1 to 1.5 km from a group of otters in Lobos Cove (Reidman, 1983). Sea otters have similar in-air hearing sensitivities as pinnipeds (Ghoul & Reichmuth, 2014a, 2014b), and may react in a similar fashion when exposed to aircraft noise. Pinnipeds in general are unresponsive but may react depending on the altitude of the aircraft or the abruptness of the associated sound (Richardson et al., 1995b), with reactions ranging from unresponsiveness to flushing into the water location (Blackwell et al., 2004; Gjertz & Børset, 1992). Sea otters may dive below the surface of the water or flush into the water to avoid aircraft noise. However, sea otter dives are very costly and require twice the metabolic energy that phocid seals need to dive; therefore sea otters may not dive or travel so readily in response to disturbance, as they already require long periods of rest at the surface to counterbalance the high cost of foraging at sea (Yeates et al., 2007). So far, there has been no evidence that any aircraft has had adverse effects on a well-monitored translocated colony of sea otters at San Nicolas Island, which has a landing field operated by the U.S. Navy (U.S. Fish and Wildlife Service, 2012, 2015).

D.6.5.4.6 Impulsive Noise

There are few available studies on responses of sea otters to impulsive sounds. A playback study of multiple and single air guns had no significant impact on sea otters in California. During the multiple air gun exposures, otters rested 1 percent more and foraged 1 percent less. They were successful at obtaining prey during 84 percent of their foraging dives when the air gun vessel was 50 NM away, and the success rate only decreased by 5 percent when the multiple air gun vessel moved closer (0.5 NM away). Overall, foraging and dive behaviors remained undisturbed, as did the density and distribution of sea otters in the area. This study caveats that the data were collected under rough weather conditions which could have affected the otters' perception of the seismic sounds. In addition, otters kept close to shore in relatively sheltered coves (Reidman, 1983).

During the single air gun experiment, the air gun ship approached a raft of otters (at a minimum of 730 m), and several otters were mildly alarmed (e.g., rolled over on their sides or bellies and looked

intently at the vessel as it approached) but did not leave the raft. Of the four times the vessel passed the group of otters, the air gun was operational during only two of the transects. However, the otters reacted to the vessel every time it passed, indicating that otters were either responding to the loud airborne sounds of the boat engines and compressor, or to the close approach of the vessel itself, rather than the seismic sounds (Reidman, 1983).

In a follow-up study, Riedman (1984) monitored sea otter reactions to drilling platform sounds and air gun firing projected from a source vessel 0.9 to 1.6 km away from groups of sea otters. No behavioral reactions or movements were observed in 14 days of observations with 15–38 individual sea otters present on any given day. Sound pressure levels from the air gun were reported as 166 dB re 1 μ Pa at 1.1 km, which means that two otters may have been subjected to levels greater than this at ranges of 900 m on the one day the pair foraged closer to the air gun ship for one hour. Most of the otters would have been subjected to just under this level, since the majority of otters foraged 1.3 to 1.6 m away from the sound sources, and propagation loss due to distance and the kelp environment needs to be considered. In a survey of the local coastline, no change in numbers of sea otters was evident between just prior to the sound stimuli and on day 10 of the emissions. No changes in feeding dive times or feeding success was seen during the study either.

When conducting impact and vibratory pile driving for the Parsons Slough estuarine restoration, the Elkhorn Slough National Estuarine Research Reserve (2011) recorded the abundance and behavior of sea otters in the area. Disturbances within 30 m of the pile driving site included otters raising their heads, swimming away without startling, or startle diving. Usually only single adult males with an established territory that included the construction site traveled within 30 m. Otters further away (> 180 m) were observed swimming away with startling, including mother-pup pairs. However, sea otter behavioral disturbances 30–180 m away from the pile driving site were difficult to tease apart from the impacts of pedestrian vessels and other construction activities.

Sea otters spend approximately 80 percent of their time on the surface of the water (Curland, 1997) with their heads above the surface, which reduces their exposure to underwater sounds. They require long periods of undisturbed rest at the surface to counterbalance high metabolic costs associated with foraging at sea (Yeates et al., 2007). If reactions to Navy impulsive noise were to occur, they may be similar to those of pinnipeds, which show temporary avoidance responses or cessation of foraging behavior (Gordon et al., 2003; Thompson et al., 1998). However, underwater hearing sensitivities are significantly reduced in sea otters when compared to pinnipeds (Ghoul & Reichmuth, 2014a, 2014b), so reactions may not be as strong, if they occur at all.

D.6.6 PHYSIOLOGICAL RESPONSE

The growing field of conservation physiology relies in part on the ability to monitor stress hormones in populations of animals, particularly those that are threatened or endangered. Physiological stress is an adaptive process that helps an animal cope with changing conditions. The ability to make predictions from stress hormones about impacts on individuals and populations exposed to various forms of stressors, natural and human-caused, relies on understanding the linkages between changes in stress hormones and resulting physiological impacts. Currently, the sound characteristics that correlate with specific stress responses in marine mammals are poorly understood, as are the ultimate consequences of these changes. Navy-funded efforts have improved the understanding of and the ability to predict how stressors ultimately affect marine mammal populations (e.g., King et al., 2015; New et al., 2013a; Pirota et al., 2015a; Pirota et al., 2022b). This includes not only determining how and to what degree various types of anthropogenic sound cause stress in marine mammals, but what factors can mitigate those responses. Factors potentially affecting an animal's response to a stressor include the mammal's

life history, sex, age, reproductive status, overall physiological and behavioral plasticity, and whether they are naïve or experienced with the sound (e.g., prior experience with a stressor may result in a reduced response due to habituation)(Finneran & Branstetter, 2013; St. Aubin & Dierauf, 2001). Because there are many unknowns regarding the occurrence of acoustically induced stress responses in marine mammals, any physiological response (e.g., hearing loss or injury) or significant behavioral response is assumed to be associated with a stress response.

Marine mammals naturally experience stressors within their environment and as part of their life histories. Changing weather and ocean conditions, exposure to disease and naturally occurring toxins, lack of prey availability, and interactions with predators all contribute to the stress a marine mammal experiences (Atkinson et al., 2015). Breeding cycles, periods of fasting, social interactions with members of the same species, and molting (for pinnipeds) are also stressors, although they are natural components of an animal's life history. Anthropogenic activities have the potential to provide additional stressors beyond those that occur naturally (Fair et al., 2014; Meissner et al., 2015; Rolland et al., 2012). Anthropogenic stressors potentially include such things as fishery interactions, pollution, tourism, and ocean noise.

Relatively little information exists on the linkage between anthropogenic sound exposure and stress in marine mammals, and even less information exists on the ultimate consequences of sound-induced stress responses (either acute or chronic). Most studies to date have focused on acute responses to sound either by measuring catecholamines or heart rate as an assumed proxy for an acute stress response.

D.6.6.1 Heart Rate Response

Increases in heart rate were observed in captive bottlenose dolphins to which known calls of other dolphins were played, although no increase in heart rate was observed when background tank noise was played back (Miksis et al., 2001). Unfortunately, it cannot be determined whether the increase in heart rate was due to stress or social factors, such as expectation of an encounter with a known conspecific. Similarly, a young captive beluga's heart rate increased during exposure to noise, with increases dependent upon the frequency band of noise and duration of exposure, and with a sharp decrease to normal or below normal levels upon cessation of the exposure (Lyamin et al., 2011). Spectral analysis of heart rate variability corroborated direct measures of heart rate (Bakhchina et al., 2017). This response might have been in part due to the conditions during testing, the young age of the animal, and the novelty of the exposure; a year later the exposure was repeated at a slightly higher received level and there was no heart rate response, indicating the beluga whale had potentially habituated to the noise exposure.

Kvadsheim et al. (2010a) measured the heart rate of captive hooded seals during exposure to sonar signals and found an increase in the heart rate of the seals during exposure periods versus control periods when the animals were at the surface. When the animals dove, the normal dive-related heart rate decrease was not impacted by the sonar exposure. Similarly, Thompson et al. (1998) observed a rapid but short-lived decrease in heart rates in wild harbor and grey seals exposed to seismic air guns (cited in Gordon et al., 2003).

Two captive harbor porpoises showed significant bradycardia (reduced heart rate), below that which occurs with diving, when they were exposed to pinger-like sounds with frequencies between 100-140 kHz (Teilmann et al., 2006). The bradycardia was found only in the early noise exposures and the porpoises acclimated quickly across successive noise exposures. Elmegaard et al. (2021) also found that initial exposures to sonar sweeps produced bradycardia but did not elicit a startle response in captive harbor porpoises. As with Teilmann et al. (2006), the cardiac response disappeared over several repeat

exposures suggesting rapid acclimation to the noise. In the same animals, 40-kHz noise pulses induced startle responses but without a change in heart rate. Bakkeren et al. (2023) found no change in the heart rate of a harbor porpoise during exposure to masking noise (1/3rd octave band noise, centered frequency of 125 kHz, maximum received level of 125 dB re 1 μ Pa) during an echolocation task but showed significant bradycardia while blindfolded for the same task. The authors attributed the change in heart rate to sensory deprivation, although no strong conclusions about acoustic masking could be made since the animal was still able to perform the echolocation task in the presence of the masking noise.

Williams et al. (2022) observed periods of increased heart rate variability in narwhals during seismic air gun impulse exposure, but profound bradycardia was not noted. Conversely, Williams et al. (2017) found that a profound bradycardia persisted in narwhals, even though exercise effort increased dramatically as part of their escape response following release from capture and handling.

Limited evidence across several different species suggests that increased heart rate might occur as part of the acute stress response of marine mammals that are at the surface. However, the decreased heart rate typical of diving marine mammals can be enhanced in response to an acute stressor, suggesting that the context of the exposure is critical to understanding the cardiac response. Furthermore, in instances where a cardiac response was noted, there appears to be rapid habituation when repeat exposures occur. Additional research is required to understand the interaction of dive bradycardia, noise-induced cardiac responses, and the role of habituation in marine mammals.

D.6.6.2 Stress Hormone and Immune Response

What is known about the function of the various stress hormones is based largely upon observations of the stress response in terrestrial mammals. The endocrine response of marine mammals to stress may not be the same as that of terrestrial mammals because of the selective pressures marine mammals faced during their evolution in an ocean environment (Atkinson et al., 2015). For example, due to the necessity of breath-holding while diving and foraging at depth, the physiological role of epinephrine and norepinephrine (the catecholamines) might be different in marine versus other mammals.

Catecholamines increase during breath-hold diving in seals, co-occurring with a reduction in heart rate, peripheral vasoconstriction (constriction of blood vessels), and an increased reliance on anaerobic metabolism during extended dives (Hance et al., 1982; Hochachka et al., 1995; Hurford et al., 1996); the catecholamine increase is not associated with increased heart rate, glycemic release, and increased oxygen consumption typical of terrestrial mammals. Captive belugas demonstrated no catecholamine response to the playback of oil drilling sounds (Thomas et al., 1990b) but showed a small but statistically significant increase in catecholamines following exposure to impulsive sounds produced from a seismic water gun (Romano et al., 2004). A captive bottlenose dolphin exposed to the same sounds did not demonstrate a catecholamine response, but did demonstrate a statistically significant elevation in aldosterone (Romano et al., 2004), however, the increase was within the normal daily variation observed in this species (St. Aubin et al., 1996) and was likely of little biological significance. Aldosterone has been speculated to not only contribute to electrolyte balance, but possibly also the maintenance of blood pressure during periods of vasoconstriction (Houser et al., 2011). In marine mammals, aldosterone is thought to play a role in mediating stress (St. Aubin & Dierauf, 2001; St. Aubin & Geraci, 1989).

Yang et al. (2021) measured cortisol concentrations in two captive bottlenose dolphins and found significantly higher concentrations after exposure to 140 dB re 1 μ Pa impulsive noise playbacks. Two out of six tested indicators of immune system function underwent acoustic dose-dependent changes, suggesting that repeated exposures or sustained stress response to impulsive sounds may increase an

affected individual's susceptibility to pathogens. Unfortunately, absolute values of cortisol were not provided, and it is not possible from the study to tell if cortisol rose to problematic levels (e.g., see normal variation and changes due to handling in Houser et al. (2021) and Champagne et al. (2018)). Exposing dolphins to a different acoustic stressor yielded contrasting results. Houser et al. (2020) measured cortisol and epinephrine obtained from 30 captive bottlenose dolphins exposed to simulated U.S. Navy mid-frequency sonar and found no correlation between SPL and stress hormone levels, even though sound exposures were as high as 185 dB re 1 μ Pa. In the same experiment (Houser et al., 2013b), behavioral responses were shown to increase in severity with increasing received SPLs. These results suggest that behavioral reactions to sonar signals are not necessarily indicative of a hormonal stress response.

Whereas a limited amount of work has addressed the potential for acute sound exposures to produce a stress response, almost nothing is known about how chronic exposure to acoustic stressors affects stress hormones in marine mammals, particularly as it relates to survival or reproduction. In what is probably the only study of chronic noise exposure in marine mammals associating changes in a stress hormone with changes in anthropogenic noise, Rolland et al. (2012) compared the levels of cortisol metabolites in North Atlantic right whale feces collected before and after September 11, 2001. Following the events of September 11, shipping was significantly reduced in the region where fecal collections were made, and regional ocean background noise declined. Fecal cortisol metabolites significantly decreased during the period of reduced ship traffic and ocean noise (Rolland et al., 2012). Rolland et al. (2017) also compared acute (death by ship strike) to chronic (entanglement or live stranding) stressors in North Atlantic right whales and found that whales subject to chronic stressors had higher levels of glucocorticoid stress hormones (cortisol and corticosterone) than either healthy whales or those killed by ships. It was presumed that whales subjected to acute stress may have died too quickly for increases in fecal glucocorticoids to be detected.

Considerably more work has been conducted in an attempt to determine the potential effect of vessel disturbance on smaller cetaceans, particularly killer whales (Bain, 2002; Erbe, 2002; Lusseau, 2006; Noren et al., 2009; Pirodda et al., 2015b; Read et al., 2014; Rolland et al., 2012; Williams et al., 2009; Williams et al., 2014a; Williams et al., 2014b; Williams et al., 2006b). Most of these efforts focused primarily on estimates of metabolic costs associated with altered behavior or inferred consequences of boat presence and noise but did not directly measure stress hormones. However, Ayres et al. (2012) investigated Southern Resident killer whale fecal thyroid hormone and cortisol metabolites to assess two potential threats to the species' recovery: lack of prey (salmon) and impacts from exposure to the physical presence of vessel traffic (but without measuring vessel traffic noise). Ayres et al. (2012) concluded from these stress hormone measures that the lack of prey overshadowed any population-level physiological impacts on Southern Resident killer whales due to vessel traffic. Lemos et al. (2022) investigated the potential for vessel traffic to affect gray whales. By assessing gray whale fecal cortisol metabolites across years in which vessel traffic was variable, Lemos et al. (2022) found a direct relationship between the presence/density of vessel traffic and fecal cortisol metabolite levels. Unfortunately, no direct noise exposure measurements were made on any individual making it impossible to tell if other natural and anthropogenic factors could also be related to the results. Collectively, these studies indicate the difficulty in determining which factors are primarily influence the secretion of stress hormones, including the separate and additive effects of vessel presence and vessel noise. While vessel presence could contribute to the variation in fecal cortisol metabolites in North Atlantic right whales and gray whales, there are other potential influences on fecal hormone metabolites, so it is difficult to establish a direct link between ocean noise and fecal hormone metabolites.

D.6.7 DIRECT INJURY

D.6.7.1 Injury due to Sonar

An object exposed to its resonant frequency will tend to amplify its vibration at that frequency, a phenomenon called acoustic resonance. Acoustic resonance has been proposed as a mechanism by which a sonar or sources with similar operating characteristics could damage tissues of marine mammals. In 2002, NMFS convened a panel of government and private scientists to investigate the potential for acoustic resonance to occur in marine mammals (National Oceanic and Atmospheric Administration, 2002). They modeled and evaluated the likelihood that Navy mid-frequency sonar caused resonance effects in beaked whales that eventually led to their stranding. The conclusion of the group was that resonance in air-filled structures did not likely cause the Bahamas stranding in 2000. The frequency at which resonance was predicted to occur in the animals' lungs was 50 Hz, well below the frequencies used by the mid-frequency sonar systems associated with the Bahamas event. Furthermore, air cavity vibrations, even at resonant frequencies, were not considered to be of sufficient amplitude to cause tissue damage, even under the unrealistic scenario in which air volumes would be undamped (unrestrained) by surrounding tissues and the amplitude of the resonant response would be greatest. These same conclusions would apply to other training activities involving acoustic sources. Therefore, the Action Proponents conclude that acoustic resonance would not occur under real training conditions. The potential impact of acoustic resonance is not considered further in this analysis.

D.6.7.1.1 Acoustically Induced Bubble Formation

A suggested cause of injury to marine mammals is rectified diffusion (Crum & Mao, 1996), the process of increasing the size of a microscopic gas bubble by exposing it to a sound field. The process is dependent upon several factors including the SPL and duration. Under this hypothesis, microscopic bubbles assumed to exist in the tissues of marine mammals may experience one of three things: (1) bubbles grow to the extent they become emboli or cause localized tissue trauma, (2) bubbles develop to the extent that a complement immune response is triggered or the nervous tissue is subjected to enough localized pressure that pain or dysfunction occurs (a stress response without injury), or (3) the bubbles are cleared by the lung without negative consequence to the animal.

Rectified diffusion is facilitated if the environment in which the ensonified bubbles exist is supersaturated with gas. As discussed above, repetitive diving by marine mammals can cause the blood and some tissues to become supersaturated (Ridgway & Howard, 1979). The dive patterns of some marine mammals (e.g., beaked whales) are predicted to induce greater supersaturation (Houser et al., 2001b). If rectified diffusion were possible in marine mammals exposed to high-level sound, conditions of tissue supersaturation could theoretically speed the rate and increase the size of bubble growth. Subsequent effects due to tissue trauma and emboli would presumably mirror those observed in humans suffering from decompression sickness.

It is unlikely that the short duration of sonar pulses would be long enough to drive bubble growth to any substantial size, if such a phenomenon occurs. However, an alternative but related hypothesis has also been suggested: stable microbubbles could be destabilized by high-level sound exposures such that bubble growth then occurs through static diffusion of gas out of supersaturated tissues. In such a scenario, the marine mammal would need to be in a gas-supersaturated state for a long enough time for bubbles to become a problematic size. The phenomena of bubble growth due to a destabilizing exposure was shown by Crum et al. (2005) by exposing highly supersaturated ex vivo bovine tissues to a 37 kHz source at 214 dB re 1 μ Pa. Although bubble growth occurred under the extreme conditions created for the study, these conditions would not exist in the wild because the levels of tissue supersaturation in the study (as high as 400 to 700 percent) are substantially higher than model

predictions for marine mammals (Fahlman et al., 2009; Fahlman et al., 2014; Houser et al., 2001b; Saunders et al., 2008), and such high exposure levels would only occur in very close proximity to the most powerful sonars. For these reasons, it is improbable that this mechanism is responsible for stranding events or traumas associated with beaked whale strandings.

There has been considerable disagreement among scientists as to the likelihood of this phenomenon (Evans & Miller, 2003; Piantadosi & Thalmann, 2004). Although it has been argued that traumas from beaked whale strandings are consistent with gas emboli and bubble-induced tissue separations (Fernandez et al., 2005; Jepson et al., 2003), nitrogen bubble formation as the cause of the traumas has not been verified. The presence of bubbles postmortem, particularly after decompression, is not necessarily indicative of bubble pathology (Bernaldo de Quiros et al., 2012; Bernaldo de Quiros et al., 2013a; Bernaldo de Quiros et al., 2013b; Dennison et al., 2012; Moore et al., 2009), and other mechanisms by which bubble emboli might occur once animals are rapidly stranded (e.g., cardiovascular collapse preventing tissue off-gassing) have not been ruled out (Houser et al., 2009).

D.6.7.2 Behaviorally Mediated Injury

Marine mammals mitigate nitrogen gas accumulation in their blood and other tissues, which is caused by gas exchange from the lungs under conditions of increased hydrostatic pressure during diving, through anatomical, behavioral, and physiological adaptations (Hooker et al., 2012).

Although not an injury caused by the interaction of sound with tissues, variations in marine mammal diving behavior or avoidance responses in response to sound exposure have been hypothesized to result in the off-gassing of nitrogen super-saturated tissues, possibly to the point of deleterious vascular and tissue bubble formation (Hooker et al., 2012; Jepson et al., 2003; Saunders et al., 2008) with resulting symptoms similar to decompression sickness (also known as “the bends”).

Whether marine mammals can produce deleterious gas emboli has been under debate in the scientific community (Hooker et al., 2012; Saunders et al., 2008), although various lines of evidence have been presented in support of the phenomenon. Some of these postulations are described below.

- Analyses of bycaught animals demonstrated that nitrogen bubble formation occurs in drowned animals when they are brought to the surface (Bernaldo de Quiros et al., 2013b; Moore et al., 2009). Since gas exchange with the lungs no longer occurs once drowned, tissues become supersaturated with nitrogen due to the reduction in hydrostatic pressure near the surface. This demonstrates that the phenomenon of bubble formation is at least physically possible.
- The presence of osteonecrosis (bone death due to reduced blood flow) in deep-diving sperm whales has been offered as evidence of impacts due to chronic nitrogen supersaturation and a lifetime of decompression insults (Moore & Early, 2004).
- Dennison et al. (2012) investigated dolphins stranded in 2009–2010. Using ultrasound, they identified gas bubbles in kidneys of 21 of the 22 live-stranded dolphins and in the liver of two of the 22. The authors postulated that stranded animals were unable to recompress by diving, and thus retained bubbles that would have otherwise re-absorbed in animals that continued to dive. However, the researchers concluded that the minor bubble formation observed could be tolerated since most stranded dolphins released did not re-strand.
- A fat embolic syndrome (out-of-place fat particles, typically in the bloodstream) was identified by Fernandez et al. (2005) coincident with the identification of bubble emboli in stranded beaked whales. The fat embolic syndrome was the first pathology of this type identified in marine mammals and was thought to possibly arise from the formation of bubbles in fat bodies, which subsequently resulted in the release of fat emboli into the blood stream.

- Findings of gas and fat emboli in a few stranded Risso's dolphin, and in which sonar exposure was ruled out as a cause of stranding, suggested that other factors, in this case struggling with a prey item, might cause significant variations in dive behavior such that emboli formation could occur (Fernandez et al., 2017).

Only one study has attempted to find vascular bubbles in a freely diving marine mammal (Houser et al., 2009). In that study, no vascular bubbles were imaged by ultrasound in a bottlenose dolphin that repeatedly dove to a 100 m depth and maintained a dive profile meant to maximize nitrogen gas uptake. Thus, although lines of evidence suggest that marine mammals manage excessive nitrogen gas loads, most of the evidence for the formation of bubble and fat emboli come from stranded animals in which physiological compromise due to the stranding event is a potential confounding factor. To validate decompression sickness observations in certain stranded cetaceans found coincident with naval activities, a study used rabbits as an experimental pathological model and found that rabbit mortalities during or immediately following decompression showed systematically distributed gas bubbles (microscopic and macroscopic), as well as emphysema and hemorrhages in multiple organs, similar to observations in the stranded cetacean mortalities (Velazquez-Wallraf et al., 2021). Similar findings were not found in almost half the rabbits that survived at least one hour after decompression, revealing individual variation has an essential role in this condition.

Researchers have examined how dive behavior affects tissue supersaturation conditions that could put an animal at risk of gas bubble embolism. An early hypothesis was that if exposure to a startling sound elicits a rapid ascent to the surface, tissue gas saturation sufficient for the evolution of nitrogen bubbles might result (Fernandez et al., 2005; Jepson et al., 2003). However, modeling suggested that even unrealistically rapid rates of ascent from normal dive behaviors are unlikely to result in supersaturation to the extent that bubble formation would be expected in beaked whales (Zimmer & Tyack, 2007). Instead, emboli observed in animals exposed to mid-frequency active sonar (Fernandez et al., 2005; Jepson et al., 2003) could stem from a behavioral response that involves repeated dives, shallower than the depth of lung collapse (Aguilar de Soto et al., 2006; Hooker et al., 2012; Tyack et al., 2006; Zimmer & Tyack, 2007). Longer times spent diving at mid-depths above lung collapse would allow gas exchange from the lungs to continue under high hydrostatic pressure conditions, increasing potential for supersaturation; below the depth of lung collapse, gas exchange from the lungs to the blood would likely not occur (Costidis & Rommel, 2016; Fahlman et al., 2014). To estimate risk of decompression sickness, Kvadsheim et al. (2012) modeled gas exchange in the tissues of sperm, pilot, killer, and beaked whales based on actual dive behavior during exposure to sonar in the wild. Results predicted that venous supersaturation would be within the normal range for these species, which would presumably have naturally higher levels of nitrogen gas loading. Nevertheless, deep-diving whales, such as beaked whales, have also been predicted to have higher nitrogen gas loads in body tissues for certain modeled changes in dive behavior, which might make them more susceptible to decompression sickness (Fahlman et al., 2014; Fernandez et al., 2005; Hooker et al., 2012; Jepson et al., 2003). Bernaldo de Quirós et al. (2019) summarized discussions from a 2017 workshop on potential sonar impacts on beaked whales, suggesting that the effect of mid-frequency active sonar on beaked whales varies among individuals or populations and that predisposing conditions such as previous exposure to sonar and individual health risk factors may contribute to individual outcomes (such as decompression sickness) as well.

Modeling has suggested that the long, deep dives performed regularly by beaked whales over a lifetime could result in the saturation of long-halftime tissues (i.e., tissues that take longer to give off nitrogen, e.g., fat and bone lipid) to the point that they are supersaturated when the animals are at the surface (Fahlman et al., 2014; Hooker et al., 2009; Saunders et al., 2008). Proposed adaptations for prevention

of bubble formation under conditions of persistent tissue saturation have been suggested (Fahlman et al., 2006; Hooker et al., 2009), and because of the time it takes for tissue offloading, it is feasible that long-halftime tissues are not a concern for decompression insults under normal ventilation or dive (recompression) conditions. However, for beaked whale strandings associated with sonar use, one proposed hypothesis is that observed bubble formation may be caused by compromised blood flow due to stranding-related cardiovascular collapse. This would reduce the ability to remove nitrogen from tissues following rapid sonar-induced stranding and could preclude typical management of nitrogen in supersaturated, long-halftime tissues (Houser et al., 2009).

Predictive modeling conducted to date has been performed with many unknowns about the respiratory physiology of deep-diving breath-hold animals. For example, Denk et al. (2020) found intra-species differences in the compliance of tracheobronchial structures of post-mortem cetaceans and pinnipeds under diving hydrostatic pressures, which would affect depth of alveolar collapse. Although, as hypothesized by Garcia Parraga et al. (2018) and reviewed in (Fahlman et al., 2021), mechanisms may exist that allow marine mammals to create a pulmonary shunt without the need for hydrostatic pressure-induced lung collapse, i.e., by varying perfusion to the lung independent of lung collapse and degree of ventilation. If such a mechanism exists, then assumptions in prior gas models require reconsideration, the degree of nitrogen gas accumulation associated with dive profiles needs to be re-evaluated, and behavioral responses potentially leading to a destabilization of the relationship between pulmonary ventilation and perfusion should be considered. Costidis and Rommel (2016) suggested that gas exchange may continue to occur across the tissues of air-filled sinuses in deep diving odontocetes below the depth of lung collapse if hydrostatic pressures are high enough to drive gas exchange across into non-capillary veins.

If feasible, kinetic gas models would need to consider an additional gas exchange route that might be functional at great depths within the odontocetes. Other adaptations potentially mitigating and defending against deleterious nitrogen gas emboli have been proposed (Blix et al., 2013). Researchers have also considered the accumulation of carbon dioxide produced during periods of high activity by an animal, theorizing that accumulating carbon dioxide, which cannot be removed by gas exchange below the depth of lung collapse, might also facilitate the formation of bubbles in nitrogen-saturated tissues (Bernaldo de Quiros et al., 2012; Fahlman et al., 2014). In all these cases, the hypotheses have received little in the way of experimentation to evaluate whether they are supported, thus leaving many unknowns as to the predictive accuracy of modeling efforts.

The appearance of extensive bubble and fat emboli in beaked whales was unique to a small number of strandings associated with certain high-intensity sonar events; the phenomenon has not been observed to the same degree in other stranded marine mammals, including other beaked whale strandings not associated with sonar use. It is uncertain as to whether there is some more easily triggered mechanism for this phenomenon specific to beaked whales or whether the phenomenon occurs only following rapidly occurring stranding events (i.e., when whales are not capable of sufficiently decompressing). Nevertheless, based on the rarity of observations of bubble pathology, the potential for nitrogen decompression sickness due to exposure to the Action Proponents' sound sources is considered discountable.

D.6.7.3 Strandings Associated with Sonar

A stranding occurs when a marine mammal is found dead, either ashore or in the water, or is found alive, but is unable to return to the water, needs medical attention, or is unable to return to its natural habitat without assistance. Marine mammals face many threats in their environment, and many of these factors, both natural and anthropogenic, may cause or contribute to a stranding. These include disease, vessel strike, entanglement, marine debris, algal blooms, pollution, starvation, weather events, and

oceanographic changes (National Marine Fisheries Service, 2019). Decomposition, buoyancy, scavenging by other marine species, wave damage, and other oceanic conditions complicate the assessment of marine mammal carcasses (Moore et al., 2020). In most instances, even for the more thoroughly investigated strandings involving post-stranding data collection and necropsies, the cause (or causes) for strandings remains undetermined.

Strandings of deep diving odontocetes, specifically beaked whales, have been correlated with naval anti-submarine warfare sonar use. D'Amico et al. (2009) reviewed global beaked whale mass strandings (two or more marine mammals of the same species other than a mother/calf pair) occurring between 1950 and 2004. The review suggested that 12 of 126 of the strandings could be considered to have coincided in space and time with naval activity that may have included mid-frequency active sonar use. Sonar use during exercises involving the U.S. Navy has been identified as a contributing cause or factor in five specific mass stranding events: Greece in 1996; the Bahamas in March 2000; Madeira Island, Portugal in 2000; the Canary Islands in 2002, and Spain in 2006 (Cox et al., 2006; Fernandez, 2006), as described in the Navy's technical report titled *Marine Mammal Strandings Associated with U.S. Navy Sonar Activities* (U.S. Department of the Navy, 2017b). These five mass strandings have resulted in about 40 known cetacean deaths consisting mostly of beaked whales and with close linkages to mid-frequency active sonar activity. Two minke whales also stranded in shallow water after the U.S. Navy training event in the Bahamas in 2000, although these animals were successfully returned to deep water with no physical examinations; therefore, no final conclusions were drawn on whether the sonar led to their stranding (Filadelfo et al., 2009a; Filadelfo et al., 2009b; U.S. Department of Commerce & U.S. Department of the Navy, 2001). Factors that were associated with these strandings included steep bathymetry, multiple hull-mounted platforms using sonar simultaneously, constricted channels, and acoustic propagation conditions that trapped sound near the sea surface (i.e., strong surface ducts). While no other beaked whale strandings have since been correlated to U.S. Navy sonar use, Simonis et al. (2020) claimed a correlation between sonar and beaked whale strandings in the Mariana Islands between 2007 and 2019. This analysis, however, relied on incomplete or inaccurate assumptions about actual U.S. Navy sonar use around the Mariana Islands, such as news reports about Navy activities rather than actual records of sonar use. In a subsequent analysis, the Center for Naval Analysis found no statistically significant correlation of beaked whale strandings around the Mariana Islands with actual use of U.S. Navy sonar based on the complete classified record of all U.S. Navy sonar used (Center for Naval Analysis, 2020).

Sonar was considered a plausible cause in other stranding investigations for other species: coastal bottlenose dolphins in California (Danil et al., 2021) and melon-headed whales in Hawaii (Southall et al., 2006). It should be noted that other factors were considered plausible causes in these investigations, such as a fisheries interaction for the bottlenose dolphins in California or lunar cycles for the melon-headed whales in Hawaii. In Alaska, Savage et al. (2021) suggested that historical Stejneger's beaked whale strandings could have co-occurred with Navy sonobuoy use but present no evidence of correlation.

Multiple hypotheses regarding the relationship between non-impulsive sound exposure and stranding have been proposed (see Bernaldo de Quirós et al., 2019). These range from direct impact of the sound on the physiology of the marine mammal, to behavioral reactions contributing to altered physiology (e.g., "gas and fat embolic syndrome") (Fernandez et al., 2005; Jepson et al., 2003; Jepson et al., 2005), to behaviors directly contributing to the stranding (e.g., beaching of fleeing animals). Unfortunately, without direct observation of not only the event but also the underlying process, and given the potential for artefactual evidence (e.g., chronic condition, previous injury) to complicate conclusions from the post-mortem analyses of stranded animals (Cox et al., 2006), it has not been possible to determine with certainty the exact mechanism underlying these strandings. Based on examination of the above

sonar-associated strandings, Bernaldo de Quirós et al. (2019) list diagnostic features, the presence of all of which suggest gas and fat embolic syndrome for beaked whales stranded in association with sonar exposure. Bernaldo de Quirós et al. (2019) observed that, to date, strandings which have a confirmed association with naval exercise have exhibited all seven of the following diagnostic features:

1. Individual or multiple animals stranded within hours or a few days of an exercise in good body condition
2. Food remnants in the first gastric compartment ranging from undigested food to squid beaks
3. Abundant gas bubbles widely distributed in veins (subcutaneous, mesenteric, portal, coronary, subarachnoid veins, etc.) composed primarily of nitrogen in fresh carcasses
4. Gross subarachnoid and/or acoustic fat hemorrhages
5. Microscopic multi-organ gas and fat emboli associated with bronchopulmonary shock
6. Diffuse, mild to moderate, acute, monophasic myonecrosis (hyaline degeneration) with "disintegration" of the interstitial connective tissue and related structures, including fat deposits, and their replacement by amorphous hyaline material (degraded material) in fresh and well-preserved carcasses
7. Multi-organ microscopic hemorrhages of varying severity in lipid-rich tissues such as the central nervous system, spinal cord, and the coronary and kidney fat when present

Historically, stranding reporting and response efforts have been inconsistent, although they have improved considerably over the time. Although reporting forms have been standardized nationally, data collection methods, assessment methods, detail of reporting, and procedures vary by region and are not yet standardized across the United States. Conditions such as weather, time, location, and decomposition state may also affect the ability to thoroughly examine a specimen (Carretta et al., 2016b; Moore et al., 2013). Because of this, the current ability to interpret long-term trends in marine mammal stranding is limited. While the investigation of stranded animals provides insight into the types of threats marine mammal populations face, investigations are only conducted on a small fraction of the total number of strandings that occur, limiting the understanding of the causes of strandings (Carretta et al., 2016a).

D.6.7.3.1 Direct Injury due to Explosives

Explosive injury to marine mammals would consist of primary blast injury, which refers to those injuries that result from the compression of a body exposed to a blast wave and is usually observed as barotrauma of gas-containing structures (e.g., lung and gut) and structural damage to the auditory system (Greaves et al., 1943; Office of the Surgeon General, 1991; Richmond et al., 1973). The near instantaneous high magnitude pressure change near an explosion can injure an animal where tissue material properties significantly differ from the surrounding environment, such as around air-filled cavities in the lungs or gastrointestinal tract. Large pressure changes at tissue-air interfaces in the lungs and gastrointestinal tract may cause tissue rupture, resulting in a range of injuries depending on degree of exposure. The lungs are typically the first site to show any damage, while the solid organs (e.g., liver, spleen, and kidney) are more resistant to blast injury (Clark & Ward, 1943). Odontocetes can also incur hemorrhaging in the acoustic fats in the melon and jaw (Siebert et al., 2022). Recoverable injuries would include slight lung injury, such as capillary interstitial bleeding, and contusions to the gastrointestinal tract. More severe injuries, such as tissue lacerations, major hemorrhage, organ rupture, or air in the chest cavity (pneumothorax), would significantly reduce fitness and likely cause death in the wild. Rupture of the lung may also introduce air into the vascular system, producing air emboli that can cause a stroke or heart attack by restricting oxygen delivery to critical organs.

If an animal is exposed to an explosive blast underwater, the likelihood of injury depends on the charge size, the geometry of the exposure (distance to the charge, depth of the animal and the charge), and the size of the animal. In general, models predict that an animal would be less susceptible to injury near the water surface because the pressure wave reflected from the water surface would interfere with the direct path pressure wave, reducing positive pressure exposure (Goertner, 1982; Yelverton & Richmond, 1981). This is shown in the records of humans exposed to blast while in the water, which show that the gastrointestinal tract was more likely to be injured than the lungs, likely due to the shallower exposure geometry of the lungs (i.e., closer to the water surface) (Lance et al., 2015). Susceptibility would increase with depth, until normal lung collapse (due to increasing hydrostatic pressure) and increasing ambient pressures again reduce susceptibility (Goertner, 1982).

The only known occurrence of mortality or injury to a marine mammal due to a Navy training event involving explosives occurred in March 2011 in nearshore waters off San Diego, California, at the Silver Strand Training Complex. This area had been used for underwater demolitions training for at least three decades without prior known incident. On this occasion, however, a group of approximately 100 to 150 long-beaked common dolphins entered the mitigation zone surrounding an area where a time-delayed firing device had been initiated on an explosive with a NEW of 8.76 pounds (lb.) (3.97 kg) placed at a depth of 48 ft. (14.6 m). Approximately one minute after detonation, three animals were observed dead at the surface. The Navy recovered those animals and transferred them to the local stranding network for necropsy. A fourth animal was discovered stranded and dead 42 NM to the north of the detonation three days later. It is unknown exactly how close those four animals were to the detonation. Upon necropsy, all four animals were found to have sustained typical mammalian primary blast injuries (Danil & St Leger, 2011).

Relatively little is known about auditory system trauma in marine mammals resulting from explosive exposure, although it is assumed that auditory structures would be vulnerable to blast injuries. Auditory trauma was found in two humpback whales that died following the detonation of a 5,000 kg explosive used off Newfoundland during demolition of an offshore oil rig platform (Ketten et al., 1993), but the proximity of the whales to the detonation was unknown. Eardrum rupture was examined in submerged terrestrial mammals exposed to underwater explosions (Richmond et al., 1973; Yelverton et al., 1973); however, results may not be applicable to the anatomical adaptations for underwater hearing in marine mammals. In this discussion, primary blast injury to auditory tissues is considered gross structural tissue damage distinct from threshold shift or other auditory effects.

Controlled tests with a variety of lab animals (mice, rats, dogs, pigs, sheep, and other species) are the best data sources on actual injury to mammals due to underwater exposure to explosions. In the early 1970s, the Lovelace Foundation for Medical Education and Research conducted a series of tests in an artificial pond at Kirtland Air Force Base, New Mexico, to determine the effects of underwater explosions on mammals, with the goal of determining safe ranges for human divers. The resulting data were summarized in two reports (Richmond et al., 1973; Yelverton et al., 1973). Specific physiological observations for each test animal are documented in Richmond et al. (1973). Gas-containing internal organs, such as lungs and intestines, were the principle damage sites in submerged terrestrial mammals; this is consistent with earlier studies of mammal exposures to underwater explosions in which lungs were consistently the first areas to show damage, with less consistent damage observed in the gastrointestinal tract (Clark & Ward, 1943; Greaves et al., 1943).

In the Lovelace studies, the first positive acoustic impulse was found to be the metric most related to degree of injury, and size of an animal's gas-containing cavities was thought to play a role in blast injury

susceptibility. For these shallow exposures of small terrestrial mammals (masses ranging from 3.4 to 50 kg) to underwater detonations, Richmond et al. (1973) reported that no blast injuries were observed when exposures were less than 6 pounds per square inch per millisecond (psi-ms) (40 pascal seconds [Pa-s]), no instances of slight lung hemorrhage occurred below 20 psi-ms (140 Pa-s), and instances of no lung damage were observed in some exposures at higher levels up to 40 psi-ms (280 Pa-s). An impulse of 34 psi-ms (230 Pa-s) resulted in about 50 percent incidence of slight lung hemorrhage. About half of the animals had gastrointestinal tract contusions (with slight ulceration, i.e., some perforation of the mucosal layer) at exposures of 25–27 psi-ms (170–190 Pa-s). Lung injuries were found to be slightly more prevalent than gastrointestinal tract injuries for the same exposure. The anatomical differences between the terrestrial animals used in the Lovelace tests and marine mammals are summarized in Fetherston et al. (2019). Goertner (1982) examined how lung cavity size would affect susceptibility to blast injury by considering both marine mammal size and depth in a bubble oscillation model of the lung; however, the Goertner (1982) model did not consider how tissues surrounding the respiratory air spaces would reflect shock wave energy or constrain oscillation (Fetherston et al., 2019).

Goertner (1982) suggested a peak overpressure gastrointestinal tract injury criterion because the size of gas bubbles in the gastrointestinal tract are variable, and their oscillation period could be short relative to primary blast wave exposure duration. The potential for gastrointestinal tract injury, therefore, may not be adequately modeled by the single oscillation bubble methodology used to estimate lung injury due to impulse. Like impulse, however, high instantaneous pressures may damage many parts of the body, but damage to the gastrointestinal tract is used as an indicator of any peak pressure-induced injury due to its vulnerability.

Because gas-containing organs are more vulnerable to primary blast injury, adaptations for diving that allow for collapse of lung tissues with depth may make animals less vulnerable to lung injury with depth. Adaptations for diving include a flexible thoracic cavity, distensible veins that can fill space as air compresses, elastic lung tissue, and resilient tracheas with interlocking cartilaginous rings that provide strength and flexibility (Ridgway, 1972). Denk et al. (2020) found intra-species differences in the compliance of tracheobronchial structures of post-mortem cetaceans and pinnipeds under diving hydrostatic pressures, which would affect depth of alveolar collapse. Older literature suggested complete lung collapse depths at approximately 70 m for dolphins (Ridgway & Howard, 1979) and 20 to 50 m for phocid seals (Falke et al., 1985; Kooyman et al., 1972). Follow-on work by Kooyman and Sinnett (1982), in which pulmonary shunting was studied in harbor seals and sea lions, suggested that complete lung collapse for these species would be about 170 m and about 180 m, respectively. Evidence in sea lions suggests that complete collapse might not occur until depths as great as 225 m; although the depth of collapse and depth of the dive are related, sea lions can affect the depth of lung collapse by varying the amount of air inhaled on a dive (McDonald & Ponganis, 2012). This is an important consideration for all divers who can modulate lung volume and gas exchange prior to diving via the degree of inhalation and during diving via exhalation (Fahlman et al., 2009); indeed, there are noted differences in pre-dive respiratory behavior, with some marine mammals exhibiting pre-dive exhalation to reduce the lung volume (e.g., phocid seals Kooyman et al., 1973).

D.6.8 POPULATION CONSEQUENCES TO MARINE MAMMALS FROM ACOUSTIC STRESSORS

This section summarizes the best available science on consequences to marine mammal populations from exposure to acoustic sources.

D.6.8.1 Long-Term Consequences to Populations

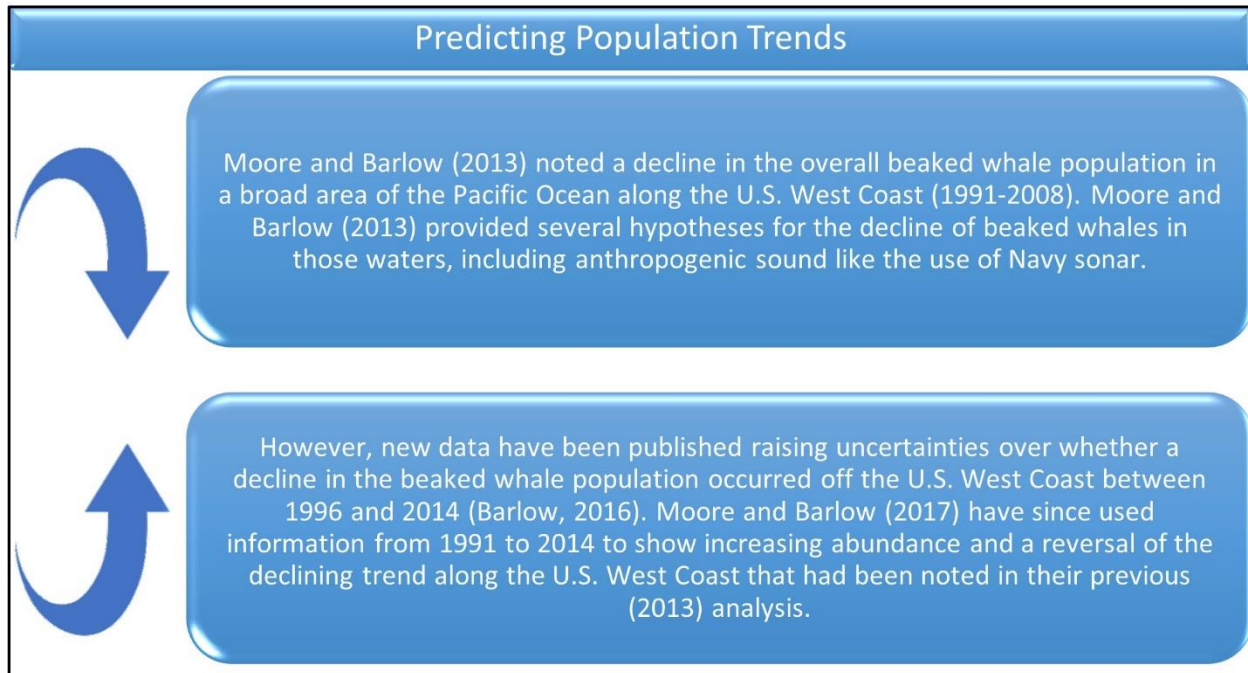
The long-term consequences of disturbance (anthropogenic or environmental), hearing loss, chronic masking, and short-term or chronic physiological stress are difficult to predict because of the different factors experienced by individual animals, such as context of stressor exposure, underlying health conditions, and other environmental or anthropogenic stressors. Linking these non-lethal effects on individuals to changes in population growth rates requires long-term data, which is lacking for many populations.

An important variable to consider is duration of disturbance. Severity scales used to assess behavioral responses to acute sound exposures are not appropriate to apply to sustained or repeated (chronic) exposures, as the focus has shifted from the immediate impacts to an individual to the health of a population over time (Southall et al., 2021). For example, short-term costs experienced over the course of a week by an otherwise healthy individual may be recouped over time after exposure to the stressor ends. These short-term costs would be unlikely to result in long-term consequences to that individual or to that individual's population. Comparatively, long-term costs accumulated by otherwise healthy individuals over an entire season, year, or throughout a life stage would be less easily recouped and more likely to result in long-term consequences to that individual or population.

Marine mammals exposed to frequent or intense human activities may leave the area, habituate to the activity, or tolerate the disturbance and remain in the area (Wartzok et al., 2003). Highly resident or localized populations may also stay in an area of disturbance because the cost of displacement may be higher than the cost of remaining (Forney et al., 2017). An apparent lack of response (e.g., no displacement or avoidance of a sound source) may not necessarily mean there is no cost to the individual or population, as some resources or habitats may be of such high value that animals may choose to stay, even when experiencing the consequences of stress, masking, or hearing loss (Forney et al., 2017).

Longer term displacement can lead to changes in abundance or distribution patterns of the species in the affected region (Bejder et al., 2006b; Blackwell et al., 2004; Teilmann et al., 2006). For example, gray whales in Baja California abandoned a historical breeding lagoon in the mid-1960s due to an increase in dredging and commercial shipping operations, and only repopulated the lagoon after shipping activities had ceased for several years (Bryant et al., 1984). Mysticetes in the northeast tended to adjust to vessel traffic over a number of years, trending towards more neutral behavioral responses to passing vessels (Watkins, 1986), indicating that some animals may habituate to high levels of human activity. A study on bottlenose dolphin responses to vessel approaches found that lesser reactions in populations of dolphins regularly subjected to high levels of vessel traffic could be a sign of habituation, or it could be that the more sensitive animals in this population previously abandoned the area of higher human activity (Bejder et al., 2006a).

Population characteristics such as if a population is open or closed to immigration and emigration can influence sensitivity to disturbance as well; closed populations could not withstand a higher probability of disturbance compared to open populations with no limitation on food (New et al., 2020). Still, predicting population trends or long-term displacement patterns due to anthropogenic disturbance is challenging due to limited information and survey data for many species over sufficient temporal and spatial scales, as well as a full understanding of how other factors, such as oceanographic oscillations and climate change, affect presence (e.g., see Figure D.6-4).



Sources: (Barlow, 2016; Moore & Barlow, 2017; Moore & Barlow, 2013)

Note: Real-world displacement trends are complicated. This example demonstrates how the abundance, and the implied trend of habitat displacement, of beaked whales in an area changed depending on the years analyzed.

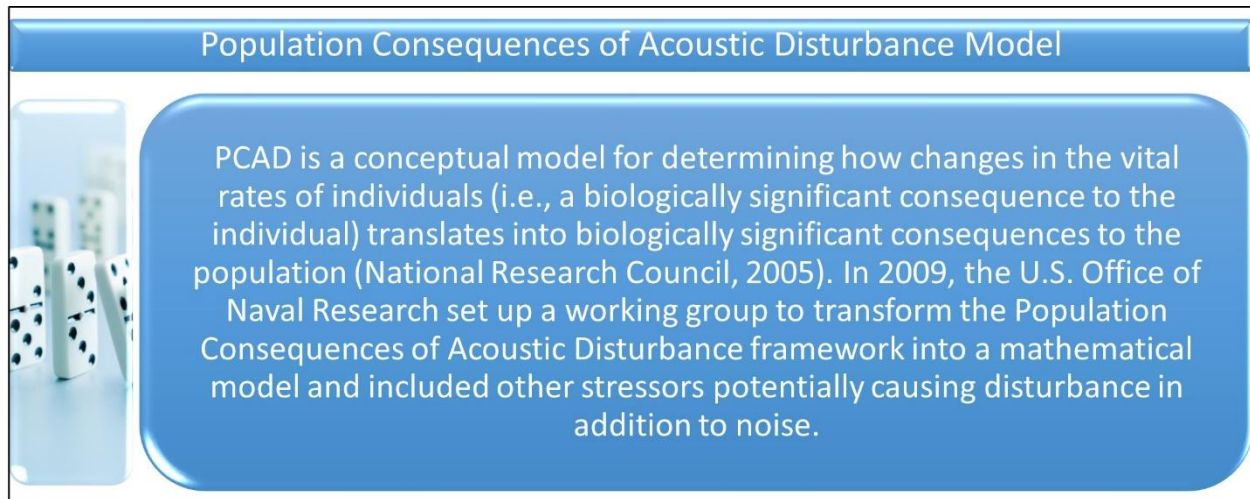
Figure D.6-4: Predicting Population Trends

D.6.8.2 Population Consequences of Disturbance Models

Scientists link short-term effects to individuals from disturbance (anthropogenic impacts or environmental change) to long-term population consequences using population models. Population models accept inputs for the population size and changes in vital rates of the population, such as the mean values for survival age, lifetime reproductive success, and recruitment of new individuals into the population (i.e., raising self-sufficient pups and calves past the weaning stage), to predict changes in population dynamics (e.g., population growth rate). These efforts often rely on bioenergetic models, or energy budget models, which analyze energy intake from food and energy costs for life functions, such as maintenance, growth, and reproduction, either at the individual or population level (Pirodda, 2022). There is high uncertainty around many parameters in these models (Hütt et al., 2023). Model sensitivity analyses have identified the most consequential parameters, including prey characteristics, feeding processes, energy expenditure, body size, energy storage, and lactation capability (Pirodda, 2022).

The National Research Council committee on Characterizing Biologically Significant Marine Mammal Behavior developed an initial conceptual model to link acoustic disturbance to population effects and inform data and research needs (National Research Council, 2005) (Figure D.6-5). This Population Consequences of Acoustic Disturbance, or PCAD, conceptual model linked parameters as illustrated in Figure D.6-6.

In its report, the committee found that the relationships between vital rates and population effects were relatively well understood, but that the relationships between the other components of the model were not well-known or easily observed.



Source: (National Research Council, 2005)

Figure D.6-5: Population Consequences of Acoustic Disturbance (PCAD) Model Definition

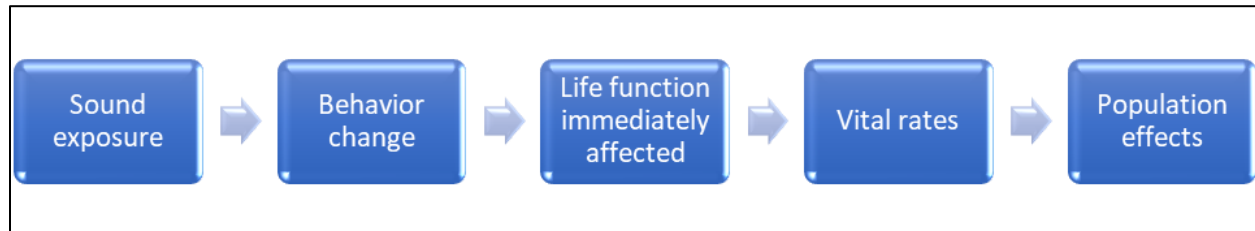
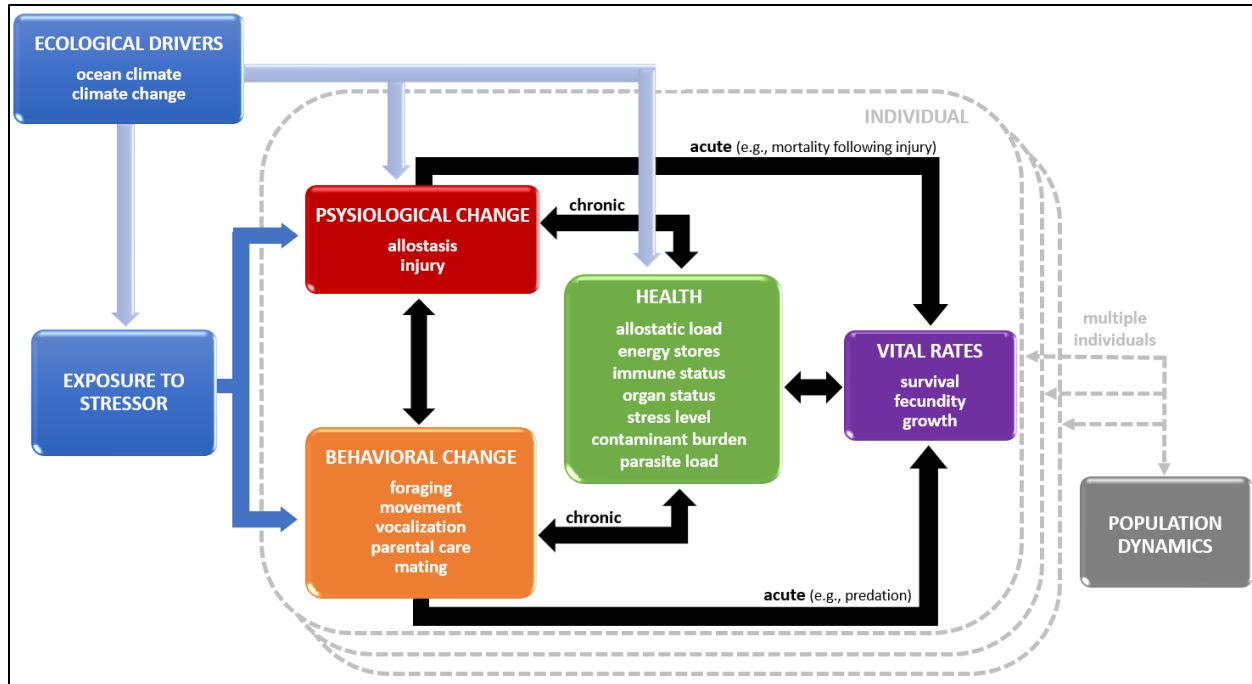


Figure D.6-6: PCAD Model Parameters Flowchart

Building on the PCAD framework, the PcoD conceptual model was developed by an Office of Naval Research working group. The PCOD model considers all types of disturbance, not solely anthropogenic or acoustic, and incorporates physiological changes, such as stress or injury, along with behavioral changes as a direct result of disturbance (National Academies of Sciences Engineering and Medicine, 2017). It also links these changes to both acute effects on vital rates (e.g., survival, fecundity) and chronic effects on health (e.g., energy stores, stress, immunity) (New et al., 2014; Pirotta et al., 2018a). Examples of acute effects include immediate injury, such as vessel strike; immediate health impacts, such as toxic algae exposure; or behavioral responses that increase predation risk (National Academies of Sciences Engineering and Medicine, 2017). Examples of chronic effects include exposure to persistent contaminants and permanent hearing loss (National Academies of Sciences Engineering and Medicine, 2017). These relationships are shown in Figure D.6-7.



Sources: Adapted from Pirotta et al. (2018a), National Academies of Sciences Engineering and Medicine (2017), New et al. (2014), and Keen et al. (2021)

Figure D.6-7: The Population Consequences of Disturbance Conceptual Model

The Population Consequences of Disturbance (PcoD) model identifies the types of data that would be needed to assess population-level impacts. These data are lacking for many marine mammal species (Booth et al., 2020). Southall et al. (2021) states that future modeling and population simulation studies can help determine population-wide long-term consequences and impact analysis. However, the method to do so is still developing, as there are gaps in the literature, possible sampling biases, and results are rarely ground-truthed, with a few exceptions (Booth et al., 2022; Schwarz et al., 2022). Nowacek et al. (2016) reviewed technologies such as passive acoustic monitoring, tagging, and the use of unmanned aerial vehicles which can improve scientists' abilities to study these model inputs and link behavioral changes to individual life functions and ultimately population-level effects. Relevant data needed for improving analyses of population-level consequences resulting from disturbances will continue to be collected during projects funded by the Navy's marine species monitoring program.

Multiple case studies across marine mammal taxonomic groups have been conducted following the PcoD framework (see Table D.6-11). From these studies, Keen et al. (2021) identified themes and contextual factors relevant to assessing impacts to populations due to disturbance (see Figure D.6-8).

life-history traits	movement ecology	<ul style="list-style-type: none"> – resident: individuals occupy small home ranges compared to population's range, year-round and prolonged exposure potential – nomadic: individuals move over population's range without spatial or temporal consistency, year-round and unpredictable exposure potential – migratory: individuals undertake annual or seasonal movements between sites within population's range, seasonal exposure potential – demographic: age, sex, and reproductive status influence spatial and temporal movements
	reproductive strategy	<ul style="list-style-type: none"> – income breeder: feeds during lactation, vulnerable to prolonged foraging loss during lactation – capital breeder: stores energy prior to parturition for lactation, vulnerable to prolonged foraging loss during gestation
	body size	<ul style="list-style-type: none"> – body size: a larger body size may buffer against periods of reduced prey availability – life stage: juveniles and young mothers may be more sensitive to reduced food availability due to physiological constraints related to body size
	pace of life	<ul style="list-style-type: none"> – fast pace of life: reproduction is more sensitive to reduced or lost foraging, but populations will be quicker to recover due to high reproductive rates and short generation times – slow pace of life: reproduction is more resilient to reduced or lost foraging, but populations will be slower to recover, particularly if adult survival is impacted, due to low reproductive rates and long generation times
disturbance source characteristics	overlap with biologically important habitats	<ul style="list-style-type: none"> – the effect of disturbance is strongly influenced by whether it overlaps with biologically important habitats when individuals are present – avoiding biologically important habitats will provide opportunities for individuals to compensate for reduced or lost foraging if large portions of their range are disturbed
	duration and frequency	<ul style="list-style-type: none"> – continuous disruption will have a greater impact than intermittent disruption – reducing the duration and frequency of disturbance or incorporating breaks between disturbance events may allow individuals to recover – energy loss can be translated into days of disturbance to inform area- or population-specific disturbance caps
	nature and context	<ul style="list-style-type: none"> – the probability and severity of individual responses depends on the interactions between the type and nature of the disturbance source and the context of the exposure – incorporating context into risk assessments can significantly reduce the uncertainty in managing populations and mitigating effects
environmental conditions	natural variability in prey availability	<ul style="list-style-type: none"> – sensitivity to disturbance strongly depends on the availability of prey in the environment – avoiding periods of low productivity and increased energy intake can reduce the potential for interactive and cumulative effects
	climate change	<ul style="list-style-type: none"> – climate vulnerability assessments can help identify populations most vulnerable to climate change and the factors contributing to their vulnerability – climate change coupled with disturbance may have interactive and cumulative effects that affect reproductive success and survival

Source: Table from Keen et al. (2021)

Figure D.6-8: Emerging Themes in PcoD Models that Should Be Considered When Assessing the Likelihood and Duration of Exposure and the Sensitivity of a Population to Disturbance Identified by Keen et al. (2021)

Table D.6-11: Published Models using the Population Consequences of Disturbance Framework

<i>Species</i>	<i>Disturbance/ PcoD Variables¹</i>	<i>Findings</i>
Minke whale	Whale watching activities/ M, R, D	Whale watching interactions decreased (42%) feeding and increased (7%) non-feeding activity, but cumulative bioenergetic cost remained low (88,018 kJ) even for the most exposed whale which resulted in a minor decrease in body condition safely below the threshold which would impact fetal growth. Impacts would be larger if vessels interacted with whales significantly more during the feeding season (Christiansen & Lusseau, 2015).
Blue whale	Simulated seismic survey/ M, B, D, N	Migrating blue whales are more likely to go long periods without exposure but are more likely to be exposed to seismic during seasonal presence, like in the California Current feeding grounds. Time and proportion of whales exposed increased (< 19%) as stressor increased (Costa et al., 2016a).
	Five scenarios of natural (El Nino or unprecedented change) and unspecified anthropogenic disturbances modeled as lost foraging time (i.e., 0%, habitat displacement, or 50%)/ M, R, B, D, N, V	Short environmental changes like El Nino reduced calf recruitment a little, but unprecedented climate changes impacted fecundity much more (i.e., increased abortions). Weak anthropogenic disturbances over a diffuse area (e.g., ship traffic, whale watching) had little effect on fecundity. Impact from intense, continuous noise (e.g., seismic, pile driving) depended on females' response. If they stayed in the area, body condition decreased and rate of abortions and starvation increased; if they moved to feed elsewhere there was no long-term effect (Pirodda et al., 2018b).
	Natural and unspecified anthropogenic disturbances modeled as lost foraging time/ M, R, S, P, B, D, N, V, C	Blue whale model above was expanded to encompass females' entire lives. Increased frequency of climate change decreased fecundity gradually (e.g., calves weaned early). High levels of anthropogenic disturbance only impacted vital rates if disturbance occurred for 1 year in all locations of the home range, or if disturbance was localized in summer feeding grounds. Repeated disturbance decreased reproductive success and survival of young whales (Pirodda et al., 2019).
	Sonar/ M, N, V	Activity budgets, lunging rates and ranging pattern caused variability in the predicted cost of sonar disturbance. With disturbance, whale reproductive strategies resulted in lower fitness (Pirodda et al., 2021).
Gray whale	Unspecified "anthropogenic disturbance"/ M, R, P, D	Western gray whales had greater energetic requirements during the longer migration to Baja California and China, compared to the shorter migration of Eastern gray whales, so were more sensitive to energy lost through disturbance (Villegas-Amtmann et al., 2017).
	Seismic surveys/ M, R, S, P, B, N, V	Direct disturbance or displacement from nearshore (less energy-rich) areas had little impact on population abundance, but females deprived access to energy-rich offshore summer feeding grounds decreased reproductive success and adult survival, leading to long-term consequences on population abundance (McHuron et al., 2021).
Long-finned pilot whale	Unspecified disturbance modeled as "lost foraging days" for mother-calf pairs (e.g., habitat displacement)/ R, S, P, D, V	Short disturbances increased mortality of calves born to young mothers, and longer disturbances increased calf mortality (born to older mothers) and decreased the life expectancy for mothers, including starvation during lactation periods. Disturbance impacted whales faster in winter (5+ days) than in summer (20+ days) (Hin et al., 2019).

Table D.6-11: Published Models using the Population Consequences of Disturbance Framework (continued)

<i>Species</i>	<i>Disturbance/ PcoD Variables¹</i>	<i>Findings</i>
	Unspecified “anthropogenic disturbance”/ R, S, P, D, V	Modeled disturbance decreased reproductive strategies and fitness. When resources were not evenly distributed, cautious strategies and knowledge of resource variation was advantageous (Pirodda et al., 2020).
	Unspecified disturbance modeled as “lost foraging days” (e.g., habitat displacement)/ R, S, P, D, V	Disturbance decreased population density (e.g., young lactating females) and increased prey availability, which resulted in improved body condition in the population overall and no net impact on lifetime reproductive output, suggesting that fitness markers may not indicate population effects (Hin et al., 2021).
Humpback whale	Simulated seismic survey/ M, B, D, N	Whale populations that foraged for krill over wide areas (West Antarctic Peninsula) were exposed to seismic less, resulting in less disturbed foraging behavior. In contrast, Bering Sea humpback whales hunted fish over a much smaller/ localized area, and have a limited range for foraging where more whales (90%) were exposed to seismic and interrupted while foraging (Costa et al., 2016a).
	Seismic surveys/ M, R, S, P, N	PcoD models can be used for predicting population consequences or making management decisions, depending if forwards or backward approach is used (Dunlop et al., 2021).
North Atlantic Right Whale	Fishing gear entanglements/ D, N, V, C	Entanglement and limited prey availability can be considered continuous stressors (e.g., prey density changes throughout range and entanglement level), and compounded impacts as entanglement decreases foraging success. When there isn’t enough empirical information, a mechanistic model can be used to simulate the interaction between varying levels of entanglement, feeding rate and maximum prey intake (Pirodda et al., 2022b).
Beaked whale	Unspecified “non-lethal” disturbance/ R, S, P, B, V	Different assumptions for duration of gestation and lactation can alter model results for mother and calf mortality. Six beaked whale species were very sensitive, Baird’s had a quick time to weaning, and Longman’s needed higher quality habitat. Consistent long-term disturbance with minor reduction in energy intake may have same effect as strong, short-term disturbance that halts energy intake. Many conservative assumptions were used for this model since many parameters were unknown for 21 beaked whale species (New et al., 2013b).
	Sonar/ M, B, D, N	Beaked whales at SOAR and AUTC ranges exposed to MFA navy sonar could have outcomes ranging from slight increase in population abundance to population extinction, depending on the interaction of sonar use, habitat quality, and the whales’ behavioral response to sonar (i.e., displacement, cessation of feeding, both, or no response) (Hin et al., 2023)
Killer whale	Vessel strike, vessel noise, polychlorinated biphenyls contamination/ R, P, B, V	Both Northern and Southern killer whale populations were impacted by the interaction of low prey abundance with vessel strike, vessel noise, and contaminants, but more research is needed to validate the mechanisms of all non-prey variables (Murray et al., 2021).
Harbor porpoise	Wind turbine noise, ship noise/ M, R, S, P, N	Even assuming a 10% reduction in population size, if prey is impacted up to two days, the presence of ships and wind turbines did not deplete the population (Nabe-Nielsen et al., 2014).

Table D.6-11: Published Models using the Population Consequences of Disturbance Framework (continued)

<i>Species</i>	<i>Disturbance/ PcoD Variables¹</i>	<i>Findings</i>
	Pile driving/ M, R, S, P, D, V	Predicted a < 0.5% decline in harbor porpoise population size from wind farm construction in worst case scenario (King et al., 2015).
	Seismic surveys/ M, R, S, P, N, V	Seismic activity in May had less impact on porpoise health and reproduction, and seismic in September had more impact (Gallagher et al., 2021).
Sperm whale	Oil spill, seismic survey/ M, R, S, P, B, D, N	10-year model projected population reductions from the oil spill and further declines when compounded with exposure to seismic surveys. Amount of additional population decline due to seismic noise depended on modeling method (i.e., single step-functions had more impacts than functions with multiple steps and frequency weighting). Resilient populations (e.g., able to make up reserves through increased foraging) mediate impacts from both disturbances (Farmer et al., 2018a).
	Unspecified “anthropogenic disturbance” associated with reduced foraging efficiency/ R, S, P, D	Mothers with calves were most vulnerable to foraging disruptions due to high energetic cost of lactation (Farmer et al., 2018b).
Bottlenose dolphin	Climate change, ship noise, fisheries bycatch, epizootic (morbillivirus)/ R, S, P, D, B, V, C	5-year model predicted that epizootic and climate change scenarios would have the largest impact on population size and fecundity. Fisheries interactions and shipping noise disturbance had little overall impact on population abundances in either location, even in the most extreme impact scenarios modeled (Reed et al., 2020).
Northern elephant seal	Unspecified “environmental change” or “anthropogenic disturbance”/ M, R, P, D	Predicted that populations of elephant seals are relatively robust even with > 50% reduction in foraging trips (only a 0.4% population decline in the following year) (New et al., 2014).
	Continuous acoustic disturbance/ M, R, N	Elephant seals would be less impacted than California sea lions since their foraging range and transit area is more expansive. Negligible impacts on reproduction and pup survival rates (Costa et al., 2016b).
Harbor seal	Pile driving/ M, R, S, P, D	Worst-case scenario PCAD model predicted that the 18% of harbor seals with PTS from wind farm construction noise exposure could translate to higher mortality rates or lower reproductive rates for the population (Thompson et al., 2013b).
California sea lion	Continuous acoustic disturbance/ M, R, N	California sea lions were disturbed for a longer period than elephant seals because the sea lions’ range (foraging and transit area) is more limited. However, even animals exposed for the longest periods had negligible modeled impacts on their reproduction and pup survival rates (Costa et al., 2016b).
	Generalized disturbance/ M, R, S, P, D	Very short duration disturbances/responses led to little change, particularly if the disturbance was a single event, and changes in the timing of the event in the year had little effect. Relatively short disturbances or mild responses, when a disturbance was modeled as recurring, resulted in a fewer number of adults and pups. The effects weren’t noticeable for several years, as the impacts on pup survival did not affect the population until those pups were mature (McHuron et al., 2018a).

Table D.6-11: Published Models using the Population Consequences of Disturbance Framework (continued)

<i>Species</i>	<i>Disturbance/ PcoD Variables¹</i>	<i>Findings</i>
11 mysticete and odontocete species ²	Sonar/ M, S, P, V	Short-term energetic cost was influenced more by lost foraging opportunities than increased locomotor effort during avoidance. Mysticetes incurred more energetic costs than odontocetes, even during mild behavioral responses to mid-frequency active sonar (Czapanskiy et al., 2021).

¹If an anthropogenic disturbance was modeled it is included, along with the variables included in the PcoD model, such as life-history traits (M= movement ecology, R= reproductive strategy, S= body size, P= pace of life), disturbance of source characteristics (B= overlap with biologically important habitats, D= duration and frequency, N= nature and context), and environmental conditions (V= natural variability in prey, C= climate change). Notation adapted from Keen et al. (2021).

²11 species studied: harbor porpoise, Risso's dolphin, Bainville's beaked whale, short-finned pilot whale, long-finned pilot whale, goose-beaked whale, minke whale, sperm whale, humpback whale, fin whale, and blue whale (Czapanskiy et al., 2021).

Notes: % = percent; > = greater than; kJ = kilojoule; PCAD = Population Consequences of Acoustic Disturbance; PcoD = Population Consequences of Disturbance; PTS = permanent threshold shift

D.6.8.3 Movement Ecology

A population's movement ecology determines the potential for temporal and spatial overlap with a disturbance. Resident populations or populations that rely on spatially limited habitats for critical life functions, such as foraging or breeding, would be at greater risk of repeated or chronic exposure to disturbances than populations that are wide-ranging relative to the footprint of a disturbance (Keen et al., 2021). Even for the same species, differences in habitat use between populations can result in different potential for repeated exposure to individuals for a similar stressor (Costa et al., 2016a). The location and radius of disturbance can impact how many animals are exposed and for how long (Costa et al., 2016b). While some models have shown the advantages of populations with larger ranges, namely the decreased chance of being exposed (Costa et al., 2016b), it's important to consider that for some species, the energetic cost of a longer migration could make a population more sensitive to energy lost through disturbance (Villegas-Amtmann et al., 2017). In addition to ranging patterns, a species' activity budgets and lunging rates can cause variability in their predicted cost of disturbance as well (Pirotta et al., 2021).

D.6.8.4 Resource Dependence

Bioenergetics frameworks that examine the impact of foraging disruption on body reserves of individual whales found that rates of daily foraging disruption can predict the number of days to terminal starvation for various life stages (Farmer et al., 2018b). Similarly, when a population is displaced by a stressor, and only has access to areas of poor habitat quality (i.e., low prey abundance) for relocation, bioenergetic models may be more likely to predict starvation, longer recovery times, or extinction (Hin et al., 2023). There is some debate over the use of blubber thickness as a metric of cetacean energy stores and health, as marine mammals may not use their fat stores in a similar manner to terrestrial mammals (Deros et al., 2020).

Resource limitation can impact population growth rate regardless of additional anthropogenic disturbance. Stochastic Dynamic Programming models have been used to explore the impact declining prey species has on focal marine mammal predators (McHuron et al., 2023a; McHuron et al., 2023b). A Stochastic Dynamic Programming model determined that a decrease in walleye pollock availability increased the time and distance northern fur seal mothers had to travel offshore, which negatively

impacted pup growth rate and wean mass, despite attempts to compensate with longer recovery time on land (McHuron et al., 2023b).

Prey is an important factor in long-term consequence models for many species of marine mammals. In disturbance models that predict habitat displacement or otherwise reduced foraging opportunities, populations are being deprived of energy dense prey or “high quality” areas which can lead to long-term impacts on fecundity and survival (Czapanskiy et al., 2021; Hin et al., 2019; McHuron et al., 2023a; New et al., 2013b).

Prey density limits the energy available for growth, reproduction, and survival. Some disturbance models indicate that the immediate decrease in a portion of the population (e.g., young lactating mothers) is not necessarily detrimental to a population, since as a result, prey availability increases and the population’s overall improved body condition reduces the age at first calf (Hin et al., 2021).

The timing of a disturbance with seasonally available resources is important. If a disturbance occurs during periods of low resource availability, the population-level consequences are greater and occur faster than if the disturbance occurs during periods when resource levels are high (Hin et al., 2019). When resources are not evenly distributed, populations with cautious strategies and knowledge of resource variation have an advantage (Pirotta et al., 2020).

Even when modeled alongside several anthropogenic sources of disturbance (e.g., vessel strike, vessel noise, chemical contaminants, sonar), several species of marine mammals are most influenced by lack of prey (Czapanskiy et al., 2021; Murray et al., 2021). Some species like killer whales are especially sensitive to prey abundance due to their limited diet (Murray et al., 2021). The short-term energetic cost of eleven species of cetaceans and mysticetes exposed to mid-frequency active sonar was influenced more by lost foraging opportunities than increased locomotor effort during avoidance (Czapanskiy et al., 2021). Additionally, the model found that mysticetes incurred more energetic cost than odontocetes, even during mild behavioral responses to sonar. These results may be useful in the development of future Population Consequences of Multiple Stressors and Population Consequences of Disturbance models since they should seek to qualify cetacean health in a more ecologically relevant manner.

D.6.8.5 Harbor Porpoises and Non-Military Disturbance Consequences

Studies have investigated the potential consequences of fasting for harbor porpoises because their high metabolic rate may leave them especially vulnerable to disturbances that prevent them from feeding. Four stranded harbor porpoises were able to consume 85–100 percent of their daily food mass intake in a short time period with no physical problems, suggesting that they can compensate for periods of missed feeding if food is available (Kastelein et al., 2019c). Harbor porpoises are also capable of recovering from lost foraging opportunities, largely because of their varied diet, high foraging rates, and high prey capture success (Booth, 2019). By modeling their foraging behavior and known prey species and sizes, the porpoises’ generalist feeding behavior, in most scenarios, would enable them to obtain more than 100 percent of their energetic needs through typical foraging behavior, and therefore would largely be robust to short-term disturbances to foraging.

Seasonality is an important predictor of disturbance for harbor porpoises. Movement and foraging behavior were modeled in seasons, and seismic activity in May had a much smaller impact on harbor porpoise health and reproduction, due to the porpoises having greater energy stores that time of year and females having already weaned their calves (Gallagher et al., 2021). In contrast, seismic surveys in September had a much greater impact due to lower energy reserves at that time, while females were lactating and possibly pregnant as well.

Different stressors and models have generated different long-term consequences within the same species. Even when high and frequent exposure levels are included, some harbor porpoise models result in few long-term consequences from sound exposure (e.g., wind farms, pile driving), but have costly results in others (e.g., pile driving, seismic surveys) (King et al., 2015). For example, the impact of noise from wind farms on harbor porpoises predicted that even when assuming a 10 percent reduction in population size if prey is impacted up to two days, the presence of ships and wind turbines did not deplete the population. Similarly, even under the worst case scenarios, King et al. (2015) model of wind farm impacts on harbor porpoises predicted less than a 0.5 percent decline in harbor porpoise populations. De Silva et al. (2014) analyzed the long-term impacts of a different stressor (pile driving and construction noise) on harbor porpoises and bottlenose dolphins. Despite including the extreme and unlikely assumptions that 25 percent of animals that received PTS would die, and that behavioral displacement from an area would lead to breeding failure, the model only found short-term impacts on the population size and no long-term effects on population viability. In contrast, Heinis et al. (2015) used the Population Consequences of Disturbance framework to estimate impacts from both pile driving and seismic exploration on harbor porpoises and found a 23 percent decrease in population size over six years, with an increased risk for further reduction with additional disturbance days. These seemingly contradictory results demonstrate that refinements to models need to be investigated to improve consistency and interpretation of model results.

D.6.8.6 Multiple Stressors and Cumulative Effects

Population consequences of disturbance models have been used to assess the impacts of multiple and recurring stressors. A marine mammal population that is already subject to chronic stressors like climate change will likely be more vulnerable to acute disturbances. Models that have looked at populations of cetaceans who are exposed to multiple stressors over several years have found that even one major chronic stressor (e.g., climate change, epizootic disease, oil spill) has severe impacts on population size. A layer of one or more stressor (e.g., seismic surveys) in addition to a chronic stressor (like an oil spill) can yield devastating impacts on a population. These results may vary based on species and location, as one population may be more impacted by chronic shipping noise, while another population may not. However, just because a population doesn't appear to be impacted by one chronic stressor (e.g., shipping noise), does not mean they aren't affected by others, such as climate change or disease (Reed et al., 2020). Recurring or chronic stressors can impact population abundance even when instances of disturbance are short and have minimal behavioral impact on an individual (Farmer et al., 2018a; McHuron et al., 2018b; Pirotta et al., 2019). Some changes to response variables like pup recruitment (survival to age one) aren't noticeable for several years, as the impacts on pup survival does not affect the population until those pups are mature but impacts to young animals will ultimately lead to population-wide declines. The severity of the repeated disturbance can also impact a population's long-term reproductive success. Scenarios with severe repeated disturbance (e.g., 95 percent probability of exposure, with 95 percent reduction in feeding efficiency) can severely reduce fecundity and calf survival, while a weaker disturbance (25 percent probability of exposure, with 25 percent reduction in feeding efficiency) had no population-wide effect on vital rates (Pirotta et al., 2019). An expanded version of the Population Consequences of Multiple Stressors framework in Figure D.6-7 would include multiple "exposure to stressor" buttons to signify the many stressors an individual and population faces, as well as multiple layers of physiological and behavioral responses per individual (National Academies of Sciences Engineering and Medicine, 2017).

The study that modeled an oil spill led to chronic declines in a sperm whale population over 10 years, and if models included even one more stressor (i.e., behavioral responses to air guns), the population declined even further (Farmer et al., 2018a). However, the amount of additional population decline due

to acoustic disturbance depended on the way the dose-response of the noise levels were modeled. A single step-function led to higher impacts than a function with multiple steps and frequency weighting. In addition, the amount of impact from both disturbances was mediated when the metric in the model that described animal resilience was changed to increase resilience to disturbance (e.g., able to make up reserves through increased foraging).

Not all stressors have the same impact for all species and all locations. Another model analyzed the effect of a number of chronic disturbances on two bottlenose dolphin populations in Australia over 5 years (Reed et al., 2020). Results indicated that disturbance from fisheries interactions and shipping noise had little overall impact on population abundances in either location, even in the most extreme impact scenarios modeled. At least in this area, epizootic and climate change scenarios had the largest impact on population size and fecundity.

Recurring stressors can impact population abundance even when individual instances of disturbance are short and have minimal behavioral impact on an individual. A model on California sea lions introduced a generalized disturbance at different times throughout the breeding cycle, with their behavior response being an increase in the duration of a foraging trip by the female (McHuron et al., 2018b). Very short duration disturbances or responses led to little change, particularly if the disturbance was a single event, and changes in the timing of the event in the year had little effect. However, with even relatively short disturbances or mild responses, when a disturbance was modeled as recurring there were resulting reductions in population size and pup recruitment (survival to age one). Often, the effects weren't noticeable for several years, as the impacts on pup survival did not affect the population until those pups were mature.

D.6.8.7 PcoD Models as Tools for Management

PcoD models may also have application for species management. One model used for migrating humpback whale mother-calf pair responses to seismic surveys used both a forwards and backward approach (Dunlop et al., 2021). While a typical forwards approach can determine if a stressor would have population-level consequences, authors demonstrated that working backwards through a Population Consequences of Disturbance model can be used to assess the worst-case scenario for an interaction of a target species and stressor. This method may be useful for future management goals when appropriate data becomes available to fully support the model.

D.6.8.8 Long-Term Consequences on Navy Ranges

D.6.8.8.1 Blue Whales on Navy Ranges in Southern California

The U.S. Navy funds research on blue whale sonar disturbance on Navy ranges. Pirotta et al. (2018b) modeled one reproductive cycle of a female North Pacific blue whale, starting with leaving the breeding grounds off Baja California to begin migrating north to feeding grounds off California, and ending with her returning to the breeding grounds, giving birth, and lactating. They modeled this scenario with no disturbance and found 95 percent calf recruitment (the successful growth and weaning of a calf); under a "normal" environmental perturbation (El Niño-Southern Oscillation) there was a very small reduction in recruitment, and, under an "unprecedented" environmental change, recruitment was reduced to 69 percent. An intense, localized anthropogenic disturbance was modeled (although the duration of the event was not provided); if the animals were not allowed to leave the area, they did not forage, and recruitment dropped to 63 percent. However, if animals could leave the area of the disturbance, then there was almost no change to the recruitment rate. A weak but broader spatial disturbance, where foraging was reduced by 50 percent, caused only a small decrease in calf recruitment to 94 percent.

Pirotta et al. (2022a) investigated the potential long-term effects of changing environmental conditions and military sonar by modeling vital rates of Eastern North Pacific blue whales. Previous work from Pirotta et al. (2021) was used as a foundation for incorporating the best available science into the 2022 vital rate model. Using data and underlying models of behavioral patterns, energy budgets, body condition, contextual responses to noise, and prey resources, the model predicted female vital rates including survival (age at death), and reproductive success (number of female calves). The model simulation results showed that environmental changes were more likely to affect vital rates, “while the current regime of sonar activities was not ” (Pirotta et al., 2022a). The case study used an annual sonar regime in Southern California Range Complex based on the description of the action in the Navy’s 2018 Hawaii-Southern California Training and Testing EIS/OEIS. Additional military sonar scenarios were modeled, and only a ten-fold increase in sonar activity combined with a shift in geographical location to overlap with main feeding areas of blue whales resulted in a moderate decrease in lifetime reproductive success (Cohen’s $d = 0.47$), but there was no effect on survival (Cohen’s $d = 0.05$).

D.6.8.8.2 Beaked Whales on Navy Ranges

The Navy has funded sonar research on three instrumented ranges that contribute to understanding long-term effects on beaked whale populations exposed to sonar: Southern California Anti-Submarine Warfare Range, Atlantic Undersea Test and Evaluation Center, and the Pacific Missile Range Facility. Long-term impacts to sensitive beaked whale populations on Navy testing and training grounds is a heavily researched topic, and the residency on the range may play a role. Studies on the AUTECH instrumented range in the Bahamas have shown that some Blainville’s beaked whales may be residents during all or part of the year in the area. Individuals may move off the range for several days during and following a sonar event but return within a few days (Joyce et al., 2019; McCarthy et al., 2011; Tyack et al., 2011).

A study by Benoit-Bird et al. (2020) demonstrated that differences in prey distribution could be a substantial factor for beaked whale habitat preference in the Bahamas. Photo-identification studies in the SOCAL Range Complex have identified approximately 100 individual goose-beaked whales, with 40 percent having been seen in one or more prior years and re-sightings up to seven years apart (Falcone & Schorr, 2014; Falcone et al., 2009). These results indicate long-term residency by individuals in an intensively used Navy training area, which may suggest a lack of long-term consequences from exposure to Navy training activities but could also be indicative of high-value resources that exceed the cost of remaining in the area. Long-term residency by itself does not mean there has been no impact on population growth rates and there are no data on the reproductive rates of populations inhabiting the Navy range area around San Clemente Island compared to beaked whales from other areas. In that regard however, results from photo-identification efforts can provide critically needed calving and weaning rate data for resident animals on the Navy’s Southern California range. Three adult females that had been sighted with calves in previous years were again sighted in 2016, one of these was associated with her second calf, and a fourth female that was first identified in 2015 without a calf, was sighted in 2016 with a calf (Schorr et al., 2017). Resident females documented with and without calves from year to year will provide data on growth rate for this population.

Beaked whales may routinely move hundreds of kilometers as part of their normal pattern. While at least some beaked whales are residents of a particular area, more than three beaked whales in the SOCAL Range Complex have been documented traveling hundreds of kilometers after being tagged (Falcone & Schorr, 2012, 2014). Out of eight goose-beaked whales, five made journeys of approximately 250 km from their tag deployment location, and one of these five made an extra-regional excursion over 450 km south to Mexico and back again (Schorr et al., 2014).

D.6.8.8.3 Ongoing Research and Monitoring

The best assessment of long-term consequences from Navy training activities will be to monitor the populations over time within the Study Area. A U.S. workshop on Marine Mammals and Sound (Fitch et al., 2011) indicated a critical need for baseline biological data on marine mammal abundance, distribution, habitat, and behavior over sufficient time and space to evaluate impacts from human-generated activities on long-term population survival. The Navy has implemented comprehensive monitoring plans since 2009 for protected marine mammals on Navy ranges with the goal of assessing the impacts of training activities on marine species and the effectiveness of the Navy's mitigation measures. The results of this long-term monitoring are continually being compiled and analyzed for trends in occurrence or abundance over time (e.g., Martin et al., 2017).

Preliminary results of this analysis at Pacific Missile Range Facility off Kauai, Hawaii indicate no changes in detection rates for several species over the past decade, demonstrating that Navy activities may not be having long-term population-level impacts. This type of analysis can be expanded to the other Navy ranges, such as in the Pacific Northwest. Continued analysis of this 15-year dataset and additional monitoring efforts over time are necessary to fully understand the long-term consequences of exposure to military readiness activities.

It should be noted that, in all the population consequence models discussed above, many assumptions were made, and many input variables were unknown and so were estimated using data when available. It is not possible to estimate long-term or population-level effects from individual short-term behavioral responses alone.

D.7 REPTILES

D.7.1 HEARING AND VOCALIZATION

Sea turtle ears are adapted for hearing underwater and in air, with auditory structures that may receive sound via bone conduction (Lenhardt et al., 1985), resonance of the middle ear cavity (Willis et al., 2013), or the standard tympanic middle ear path (Hetherington, 2008). In-water hearing in sea turtles is typically between 50 and 1,600 Hertz (Hz). Maximum hearing sensitivity is between 100 and 400 Hz, and sensitivity rapidly drops off at higher frequencies (Bartol & Ketten, 2006; Martin et al., 2012; Piniak et al., 2012b; Piniak et al., 2016). Sea turtles are also limited to low-frequency hearing in-air, with juveniles hearing between 50 and 800 Hz, with a maximum hearing sensitivity around 300–400 Hz (Bartol & Ketten, 2006; Piniak et al., 2016). Hearing abilities have primarily been studied with sub-adult, juvenile, and hatchling subjects in four sea turtle species, including green (Bartol & Ketten, 2006; Ketten & Moein-Bartol, 2006; Piniak et al., 2016; Ridgway et al., 1969; Yudhana et al., 2010), olive ridley (Bartol & Ketten, 2006), loggerhead (Bartol et al., 1999; Lavender et al., 2014; Martin et al., 2012), and leatherback (Piniak et al., 2012a). Only one study examined the auditory capabilities of an adult sea turtle (Martin et al., 2012); the hearing range of the adult loggerhead turtle was similar to other measurements of juvenile and hatchling sea turtle hearing ranges.

The role of underwater hearing in sea turtles is unclear. Sea turtles may use acoustic signals from their environment as guideposts during migration and as cues to identify their natal beaches (Lenhardt et al., 1983). However, they may rely more on other senses, such as vision and magnetic orientation, to interact with their environment (Arens, 2003; Lohmann & Lohmann, 2019; Narazaki et al., 2013; Putman et al., 2015). Hearing may also be used for intra-specific communication in water (Charrier et al., 2022) and in air, including hatching synchronization and nest emergence (Cook & Forrest, 2005; Ferrara et al., 2014; Ferrara et al., 2019; McKenna et al., 2019; Mrosovsky, 1972).

All best-available underwater sea turtle AEP and behavioral hearing threshold data from the scientific literature were considered to develop a composite sea turtle audiogram for underwater hearing (Figure D.7-1). An overview of the data used, and the methods to develop a composite sea turtle audiogram for underwater hearing are described in the *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase IV) technical report* (U.S. Department of the Navy, 2024a).

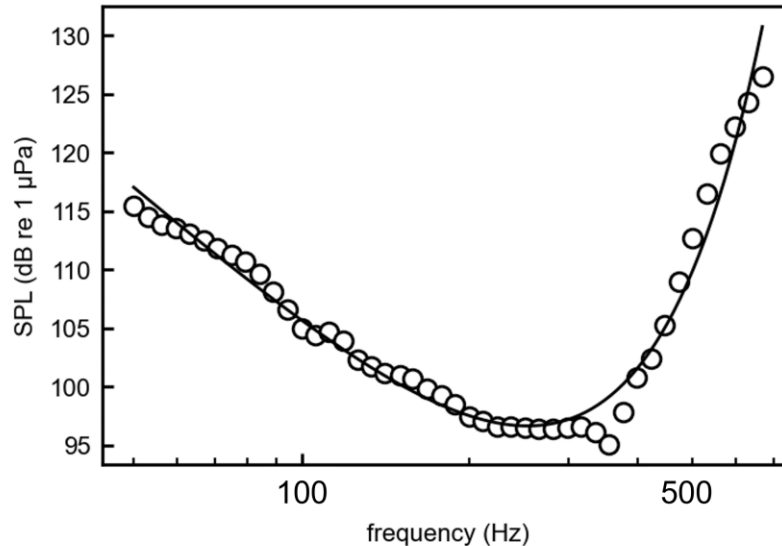


Figure D.7-1: Composite Audiogram used in Sea Turtle Criteria and Thresholds (U.S. Department of the Navy, 2024a)

Some in-air sounds have been recorded during nesting activities ashore, including belch-like sounds and sighs, exhale/inhales, gular pumps, and grunts by female leatherback turtles, and low-frequency pulsed and harmonic sounds by hawksbill, Olive Ridley, Kemp's Ridley, leatherback, and green sea turtle embryos in eggs and hatchlings (Cook & Forrest, 2005; Ferrara et al., 2014; Ferrara et al., 2019; McKenna et al., 2019; Mrosovsky, 1972). Underwater vocalizations from juvenile green turtles have been characterized as pulses, low amplitude calls, frequency modulated sounds, and squeaks (Charrier et al., 2022). Croaks and squeaks have components that are outside the known frequency bandwidth of green turtle hearing and may only be partially detectable (Charrier et al., 2022). These vocalizations were not associated with a specific behavior or the presence of another sea turtle, but there are similarities in vocalizations from freshwater turtles and hatchling Kemp's ridley turtles (Ferrara et al., 2019; Giles et al., 2009).

Crocodylians (e.g., crocodiles and alligators), like other amphibious species, have both in-air and underwater hearing capabilities. However, crocodylians appear to be structurally adapted for detection of airborne sound based on the similarities between crocodylian and avian ear morphology and the corresponding auditory brainstem structures (Gleich & Manley, 2000). Crocodylians detect airborne sound via the tympanic membrane, while sounds in water appear to be detected via bone conduction (Higgs et al., 2002). Crocodylians have external muscular flaps both above and below the opening of the external auditory canal that reflexively close to seal off the canal when submerged and relax to open above/out of the water (Saunders et al., 2000; Shute & Bellairs, 1955).

Crocodylian hearing is most sensitive at low frequencies, both in air and in water. Hearing abilities have not been studied for adult crocodylians but have been studied in juveniles. Best hearing range in air was found between 1 and 1.5 kilohertz (kHz), with poor sensitivity above 2 kHz (Higgs et al., 2002; Wever,

1971). In water, best sensitivity was observed at 800 Hz, with no responses to exposures at 4 kHz (Higgs et al., 2002). The hearing range for crocodilians was observed to extend to higher frequencies in air than in water (Higgs et al., 2002). Crocodilians use hearing for prey detection and social communication, but also rely on good vision, scent, and touch for interacting with their environment (Grigg & Gans, 1993; Wever, 1971). Regarding sound production, crocodilian calls are typically low-frequency (i.e., below 1 kHz), short, and repetitive. Adult calls include courtship bellows at the air-water interface with a notable in-water component, grunts, hisses during threat displays, and coughs (Garrick et al., 1978; Vergne et al., 2009; Vliet, 1989). Hatchling and juvenile American alligators have a more restricted communication repertoire (Higgs et al., 2002). Sound production includes contact calls, hisses, and snarls (Bierman et al., 2014).

No definitive research is available to ascertain how terrapins use sound in the environment. Hearing may be used to locate food or mates, avoid predators, navigate, or communicate (Lester, 2012). Lester et al. (2012) determined that diamondback terrapins can hear a limited range of low-frequency tones less than 1,000 Hz. Terrapins responded to in-air sounds from 100 to 1,000 Hz, with the range of best hearing from 400 to 600 Hz with mean lowest threshold of 64 dB re 20 μ Pa SPL (Lester, 2012). In-water, terrapins responded to sounds from 50 to 800 Hz with mean lowest threshold of 86 dB re 1 μ Pa SPL (Lester, 2012).

Sea turtles, crocodilians, and terrapins have similar hearing capabilities, mechanisms, and likely usage. Therefore, the types of impacts to crocodilians and terrapins are assessed to be comparable to those for sea turtles.

D.7.2 HEARING LOSS AND AUDITORY INJURY

A Working Group organized under the ANSI-Accredited Standards Committee S3, Subcommittee 1, Animal Bioacoustics, developed sound exposure guidelines for fishes and sea turtles (Popper et al., 2014), hereafter referred to as the *ANSI Sound Exposure Guideline Technical Report*. The guidelines do not include numeric sound exposure thresholds for auditory effects on sea turtles rather, they qualitatively estimate that sea turtles are less likely to incur TTS or AINJ with increasing distance from various sound sources. Sea turtle hearing is most sensitive around 100–400 Hz in-water and is limited over 1 kHz (Bartol & Ketten, 2006; Martin et al., 2012; Piniak et al., 2012b; Piniak et al., 2016). Therefore, sound exposures from most mid-frequency and all high-frequency sound sources are not anticipated to affect sea turtle hearing, and sea turtles are likely only susceptible to auditory impacts when exposed to very high levels of sound within their limited hearing range. No studies have measured TTS or AINJ in sea turtles, however, TTS in freshwater turtles has been examined (Salas et al., 2023, 2024). Onset values of TTS for freshwater turtles (Salas et al., 2023, 2024) were extrapolated to determine a TTS onset level for non-impulsive sources in sea turtles (U.S. Department of the Navy, 2024a). Consistent with methods from prior analyses, (U.S. Department of the Navy, 2017c) TTS onset levels for non-impulsive sources were used to determine AINJ for non-impulsive sound sources, and onset levels for impulsive sources (U.S. Department of the Navy, 2024a).

D.7.3 MASKING

Reptiles likely use their hearing to detect broadband low-frequency sounds in their environment so the potential for masking would be limited to sound exposures that have similar characteristics (i.e., frequency, duration, and amplitude). Continuous and near-continuous human-generated sounds that have a significant low-frequency component, are not brief, and are of sufficient received level, are most likely to result in masking (e.g., proximate vessel noise and high-duty cycle or continuous active sonar). Other intermittent, short-duration sound sources with low-frequency components (e.g., air guns, pile driving, aircraft noise, weapons noise, and explosives) would have limited potential for masking.

Because reptiles may rely primarily on senses other than hearing for interacting with their environment, any effect of masking may be mediated by reliance on other environmental inputs.

D.7.4 BEHAVIORAL REACTIONS

Behavioral responses fall into two major categories: Alterations in natural behavioral patterns and avoidance. These types of reactions are not mutually exclusive, and reactions may be combinations of behaviors or a sequence of behaviors. The response of a sea turtle to an anthropogenic sound would likely depend on the frequency, duration, temporal pattern, and amplitude of the sound as well as the animal's prior experience with the sound and the context in which the sound is encountered (i.e., what the animal is doing at the time of the exposure) (Ellison et al., 2011; Southall et al., 2021; Wartzkow et al., 2003). Distance from the sound source and whether it is perceived as approaching or moving away may also affect a sea turtle's response.

In the *ANSI Sound Exposure Guideline Technical Report* (Popper et al., 2014), qualitative risk factors were developed to assess the potential for sea turtles to respond to various underwater sound sources. The guidelines state that there is a low likelihood that sea turtles would respond within tens of meters of low-frequency sonars, and that it is highly unlikely that sea turtles would respond to mid-frequency sources. The risk that sea turtles would respond to other broadband sources, such as shipping, is considered high within tens of meters of the sound source, but moderate to low at farther distances.

D.7.4.1 Behavioral Reactions to Sonar and Other Transducers

Studies of reptile responses to sonar and other transducers are limited and all data are from studies with sea turtles. Lenhardt (1994) used very low-frequency vibrations (less than 100 Hz) coupled to a shallow tank to elicit swimming behavior responses by two loggerhead sea turtles in which turtles swam to the surface and remained at the surface or slightly submerged. The limitations of conducting acoustic experiments in shallow tanks are discussed in Section D.1.5, Acoustic Propagation in Small Tanks. Watwood et al. (2016) tagged green sea turtles with acoustic transponders and monitored them using acoustic telemetry arrays in Port Canaveral, Florida. Sea turtles were monitored before, during, and after a routine pier-side submarine sonar test that utilized typical source levels, signals, and duty cycle. The authors concluded that no significant long-term displacement was exhibited by the sea turtles in this study. The authors note that Port Canaveral is an urban marine habitat and that resident sea turtles may be less likely to respond than naïve populations.

Kastelein et al. (2023) exposed two green and two hawksbill sea turtles to a wide variety of potential acoustic deterrent signals (> 200 Hz) including Helicopter Long-Range Active Sonar (HELRAS) down sweeps (1.3 to 1.44 kHz). The authors concluded that no behavioral responses were observed to the HELRAS, pure tones, impulsive sounds, or killer whale vocalizations, at levels of approximately 173 dB re 1 μ Pa. Behavioral responses were observed to eighteen different sounds with various spectro-temporal characteristics, duty cycles and received levels. Of those, four sound types with Navy-relevant signal characteristics (frequency modulated and upsweep). However, no consistent relationship between signal level and behavioral response was observed, and contextual factors appeared to explain some of these responses. The baseline behavioral state of the sea turtle appeared to influence the likelihood of a response, with bottom-resting sea turtles exhibiting little to no responses. The reverberant, shallow environment of the testing pool, minimal controls in the experimental design, and absence of behavioral responses to impulsive sounds suggests that the results of this study should be interpreted with caution, and do not necessitate any changes to the criterion for sonar.

According to the qualitative risk factors developed in the *ANSI Sound Exposure Guideline Technical Report* (Popper et al., 2014), the likelihood of sea turtles responding to low- and mid-frequency sonar is low and highly unlikely, respectively. Based on the limited behavioral response data discussed above,

behavioral responses to non-impulsive sounds could consist of temporary avoidance, increased swim speed, or no observable response.

D.7.4.2 Behavioral Reactions to Vessel Noise

There is limited information on reptile behavioral responses to vessel noise. Diaz et al. (2023) quantified the behavioral responses of free-ranging green turtles to vessel noise using audio, video, and positional data from devices mounted to the carapace. Data were collected in the presence and absence of vessel noise while turtles were either traveling or resting on the sea floor. During exposures to vessel noise, existing behaviors were amplified, and the time spent traveling or at the sea floor increased. In addition, more time was spent scanning during traveling when vessel noise was present, which may indicate increased vigilance to detect potential threats. This supports the findings from Hazel et al. (2007) in which turtles avoided vessels more quickly when there was good visibility. In contrast, the amount of time spent scanning while at the sea floor did not significantly increase when vessel noise was present. While at the sea floor vessels may not be perceived as an immediate threat or vessel noise may not be detectable.

Based on the limited behavioral response data discussed above, behavioral responses to vessel noise could include amplification of existing behaviors, increased vigilance, or no observable response.

D.7.4.3 Behavioral Reactions to Aircraft Noise

Behavioral reactions due to aircraft noise, including hovering helicopters, are likely to be brief and minor, if they occur at all. Reptile reactions to aircraft noise have not been studied like marine mammals. For marine mammals, aircraft noise would cause only small temporary changes in behavior. Since reptile hearing is less sensitive than marine mammals, conservatively, it is likely that reptiles could exhibit temporary changes in behavior to aircraft noise as well.

D.7.4.4 Behavioral Reactions to Impulsive Sound Sources

There are limited studies of reptile responses to sounds from impulsive sound sources, and all data come from sea turtles exposed to seismic air guns. These exposures consist of multiple air gun shots, either in close proximity or over long durations, so it is likely that observed responses may over-estimate responses to single or short-duration impulsive exposures. Studies of responses to air guns are used to inform reptile responses to other impulsive sounds (e.g., weapon noise and explosions).

O'Hara and Wilcox (1990) attempted to create a sound barrier at the end of a canal using seismic air guns. They reported that loggerhead turtles kept in a 300 m by 45 m enclosure in a 10-m deep canal and maintained a minimum standoff range of 30 m from air guns fired simultaneously at intervals of 15 seconds with strongest sound components in the 25 to 1,000 Hz frequency range. McCauley et al. (2000a) estimated that the received SPL at which turtles avoided sound in the O'Hara and Wilcox (1990) experiment was 175 to 176 dB re 1 μ Pa.

Moein Bartol et al. (1995) investigated the use of air guns to repel juvenile loggerhead sea turtles from hopper dredges. Sound frequencies of the air guns ranged from 100 to 1,000 Hz at three source SPLs: 175, 177, and 179 dB re 1 μ Pa at 1 m. The turtles avoided the air guns during the initial exposures (mean range of 24 m), but additional exposures on the same day and several days afterward did not elicit avoidance behavior that was statistically significant. They concluded that this was likely due to habituation.

McCauley et al. (2000a) exposed a caged green and a caged loggerhead sea turtle to an approaching-departing single air gun to gauge behavioral responses. The trials showed that above a received SPL of 166 dB re 1 μ Pa, the turtles noticeably increased their swimming activity compared to

nonoperational periods, with swimming time increasing as air gun SPLs increased during approach. Above 175 dB re 1 μ Pa, behavior became more erratic, possibly indicating the turtles were in an agitated state. The authors noted that the point at which the turtles showed more erratic behavior and exhibited possible agitation would be expected to approximate the point at which active avoidance to air guns would occur for unrestrained turtles.

No obvious avoidance reactions by free-ranging sea turtles, such as swimming away, were observed during a multi-month seismic survey using air gun arrays, although fewer sea turtles were observed when the seismic air guns were active than when they were inactive (Weir, 2007). Weir (2007) noted that sea state and the time of day affected both air gun operations and sea turtle surface basking behavior, making it difficult to draw conclusions from the data. However, DeRuiter and Doukara (2012) noted several possible startle or avoidance reactions to a seismic air gun array in the Mediterranean by loggerhead turtles that had been motionlessly basking at the water surface.

Based on the limited behavioral response data discussed above, reptile behavioral responses to impulsive sounds could consist of temporary avoidance, increased swim speed, or changes in depth; or there may be no observable response.

D.7.5 PHYSIOLOGICAL RESPONSE

A stress response is a suite of physiological changes meant to help an organism mitigate the impact of a stressor. If the magnitude and duration of the stress response is too great or too long, then it can have negative consequences to the animal (e.g., decreased immune function, decreased reproduction). Physiological stress is typically analyzed by measuring stress hormones, other biochemical markers, or vital signs. Physiological stress (e.g., corticosterone, glucose, total white blood cell count, and heterophil/lymphocyte ratio) has been measured for sea turtles during nesting (Arango et al., 2022; Flower et al., 2015; Valverde et al., 1999; Vasquez-Bultron et al., 2021), capture and handling (Flower et al., 2015; Gregory & Schmid, 2001; Usategui-Martin et al., 2021), transport (Hunt et al., 2019; Hunt et al., 2020), rehabilitation (Caliani et al., 2019), and when caught in entanglement nets (Hoopes et al., 2000; Miguel et al., 2020; Snoddy et al., 2009) and trawls (Stabenau et al., 1991). However, the stress caused by acoustic exposure has not been studied for sea turtles. Therefore, the stress response in sea turtles in the Study Area due to acoustic exposures is considered to be consistent with general knowledge about physiological stress responses described in the Conceptual Framework for Assessing Effects from Acoustic and Explosive Activities.

Marine animals naturally experience stressors within their environment and as part of their life histories. Changing weather and ocean conditions, exposure to diseases and naturally occurring toxins, lack of prey availability, social interactions with members of the same species, nesting, and interactions with predators all contribute to stress (Atkinson et al., 2015). Anthropogenic sound-producing activities have the potential to provide additional stressors beyond those that naturally occur (Fair et al., 2014; Meissner et al., 2015; Rolland et al., 2012).

Due to the limited information about acoustically induced stress responses for reptiles, the Action Proponents conservatively assume in its effects analysis that any physiological response (e.g., hearing loss or injury) or significant behavioral response is also associated with a stress response.

D.7.6 DIRECT INJURY DUE TO SONAR

The high peak pressures close to some non-impulsive underwater sound sources may be injurious, although there are no reported instances of injury to reptiles caused by these sources. Lacking any data on non-auditory sea turtle injuries due to sonar, *ANSI Sound Exposure Guideline Technical Report* (Popper et al., 2014) estimated the risk to sea turtles from low-frequency sonar to be low and mid-

frequency sonar to be non-existent. Additionally, sea turtle carapaces (i.e., shells) may protect against non-auditory injury due to exposures to high peak pressures (Popper et al., 2014), which can also be assumed for terrapins.

Mechanisms for non-auditory injury due to acoustic exposure have been hypothesized for diving breath-hold animals. Acoustically induced bubble formation, rectified diffusion, and acoustic resonance of air cavities are considered for their similarity to pathologies observed in marine mammals stranded coincident with sonar exposures but were found to not be likely causal mechanisms, and findings are applicable to reptiles.

Nitrogen decompression due to modifications to dive behavior in response to sonar exposures has never been observed in sea turtles. Sea turtles are thought to deal with nitrogen loads in their blood and other tissues, caused by gas exchange from the lungs under conditions of high ambient pressure during diving, through anatomical, behavioral, and physiological adaptations (Lutcavage & Lutz, 1997). Although diving sea turtles experience gas supersaturation, gas embolism has only been observed in sea turtles bycaught in fisheries, including loggerhead sea turtles (Garcia-Parraga et al., 2014), as well as leatherback, green, and olive ridley sea turtles (Crespo-Picazo et al., 2020). Therefore, nitrogen decompression due to changes in diving behavior in response to sonar exposures is not considered a potential consequence to diving reptiles.

D.7.7 DIRECT INJURY DUE TO EXPLOSIVES

Data on observed injuries to reptiles from explosions is generally limited to animals found following explosive removal of offshore structures (Viada et al., 2008), which can attract reptiles for feeding or shelter (Klima et al., 1988; Viada et al., 2008). Klima et al. (1988) observed a turtle mortality subsequent to an oil platform removal blast, although sufficient information was not available to determine the animal's exposure. Klima et al. (1988) also placed small sea turtles (less than 7 kg) at varying distances from piling detonations. Some of the turtles were immediately knocked unconscious or exhibited vasodilation (i.e., expansion of blood vessels), but others at the same exposure distance exhibited no effects. Vasodilation was present around the throat and flippers for 2-3 weeks and the increase in blood flow helped to repair damaged cells and tissue. Unconsciousness renders a turtle more susceptible to predation and may result in sinking to the bottom. Although resting turtles can remain submerged for hours, the effects of submergence on stunned turtles are unknown. These data also verified that explosions could result in both near- and far- field injuries to turtles.

Incidental injuries to sea turtles due to military explosions have been documented in a few instances. In one incident, a single 1,200 lb. trinitrotoluene (TNT) underwater charge was detonated off Panama City, Florida, in 1981. The charge was detonated at a mid-water depth of 120 ft. Although details are limited, the following were recorded: at a distance of 500–700 ft., a 400 lb. sea turtle was killed; at 1,200 ft., a 200 to 300 lb. sea turtle experienced “minor” injury; and at 2,000 ft. a 200 to 300 lb. sea turtle was not injured (O'Keeffe & Young, 1984). In another incident, two “immature” green sea turtles (size unspecified) were killed when 100 to 150 ft. away from detonation of 20 lb. of C-4 in a shallow-water environment. This illustrates that the likelihood and types of injuries from underwater explosives depends on the charge size, the geometry of the exposure (distance to the charge, depth of the animal and the charge), and the size of the animal.

D.7.8 LONG-TERM CONSEQUENCES

For reptiles present in the Study Area, long-term consequences to individuals and populations due to acoustic exposures have not been studied. For this analysis it is assumed that long term-consequences to reptiles are consistent with general knowledge about long-term consequences to other marine species.

Long-term consequences to reptile populations due to disturbances, whether anthropogenic or environmental, are difficult to assess. Linking non-lethal effects on individuals to changes in population growth rates requires long-term data, which is lacking for many populations. The long-term consequences of hearing loss, chronic masking, and short-term or chronic physiological stress are especially difficult to predict because of the different factors experienced by individual animals, such as context of stressor exposure, underlying health conditions, and other environmental or anthropogenic stressors.

An important variable to consider is duration of disturbance. Severity scales used to assess behavioral responses to acute sound exposures are not appropriate to apply to sustained or repeated (chronic) exposures, as the focus has shifted from the immediate impacts to an individual to the health of a population over time (Southall et al., 2021). For example, short-term costs experienced over the course of a week by an otherwise healthy individual may be recouped over time after exposure to the stressor ends. These short-term costs would be unlikely to result in long-term consequences to that individual or to that individual's population. Comparatively, long-term costs accumulated by otherwise healthy individuals over an entire season, year, or throughout a life stage would be less easily recouped and more likely to result in long-term consequences to that individual or population.

Reptiles exposed to frequent or intense human activities may leave the area, habituate to the activity, or tolerate the disturbance and remain in the area (Wartzok et al., 2003). Highly resident or localized populations may also stay in an area of disturbance because the cost of displacement may be higher than the cost of remaining (Forney et al., 2017). An apparent lack of response (e.g., no displacement or avoidance of a sound source) may not necessarily mean there is no cost to the individual or population, as some resources or habitats may be of such high value that animals may choose to stay, even when experiencing the consequences of stress, masking, or hearing loss (Forney et al., 2017).

Longer term displacement can lead to changes in abundance or distribution patterns of the species in the affected region (Bejder et al., 2006b; Blackwell et al., 2004; Teilmann et al., 2006). Predicting population trends or long-term displacement patterns due to anthropogenic disturbance is challenging due to limited information and survey data for many species over sufficient temporal and spatial scales, as well as a full understanding of how other factors, such as oceanographic oscillations and climate change, affect presence.

D.8 BIRDS AND BATS

This section presents a review of existing literature on acoustic impacts to birds and bats. Assessing whether sounds may disturb or injure an animal involves understanding the characteristics of the acoustic sources and the effects that sound may have on the physiology and behavior of those animals. Impacts could depend on other factors besides the received level of sound, such as the animal's physical condition and prior experience with the sound. Additional explanation of the acoustic terms and sound energy concepts used in this section is found in Section D.1 (Acoustic and Explosive Concepts/Primer).

Following a review of recent literature, the data on acoustic impacts to birds has not changed appreciably. As such, the information presented in the 2018 Final EIS/OEIS [Section 3.9.3.1](#) (Acoustic Stressors) remains valid. Studies since that time generally support conclusions and those have been added to the sections below as appropriate.

D.8.1 HEARING AND VOCALIZATION

D.8.1.1 Birds

Although hearing range and sensitivity has been measured for many land birds, fewer studies have focused on seabird hearing and most published literature on bird hearing focuses on terrestrial birds

and their ability to hear in air. A review of 32 terrestrial and marine species indicates that birds generally have the greatest hearing sensitivity between 1 and 4 kHz (Beason, 2004; Dooling, 2002). Very few can hear below 20 Hz, most have an upper frequency hearing limit of 10 kHz, and none exhibit hearing at frequencies higher than 15 kHz (Dooling, 2002; Dooling & Popper, 2000). Hearing capabilities have been studied for several seabirds (Beason, 2004; Beuter et al., 1986; Crowell et al., 2015; Johansen et al., 2016; Thiessen, 1958; Wever et al., 1969); these studies show that seabird hearing ranges and sensitivity in air are consistent with what is known about bird hearing in general. Several studies of seabird hearing have been published since the 2018 Final EIS/OEIS and support previous work. These newer studies of long-tailed duck, common eider, and surf scoter (McGrew et al., 2022); and Atlantic puffin and common murre (Mooney et al., 2019) support previous conclusions that birds generally have greatest hearing sensitivity between 1 and 4 kHz. Two field studies (Mooney et al., 2020; Mooney et al., 2019) of wild captured Atlantic puffin produced auditory curves between 0.5 and 6 kHz, similar to measurements for other seabirds. Smith et al. (2023) measured the same range in marbled murrelet. Hansen et al. (2017) studied great cormorants and found maximum sensitivity at 2 kHz and Larsen et al. (2020) found that great cormorants have underwater hearing sensitivity that is at least as good as their aerial sensitivity along with anatomical adaptations to underwater hearing (thickened eardrum).

Crowell et al. (2015) also compared the vocalizations of the same ten diving bird species to the region of highest sensitivity of in-air hearing. Of the birds studied, vocalizations of only eight species were obtained due to the relatively silent nature of two of the species. The peak frequency of the vocalizations of seven of the eight species fell within the range of highest sensitivity of in-air hearing. Crowell et al. (2015) suggested that the colonial nesters tested had relatively reduced hearing sensitivity because they relied on individually distinctive vocalizations over short ranges. Additionally, Crowell et al. (2015) observed that the species with more sensitive hearing were those associated with freshwater habitats, which are quieter compared to marine habitats with wind and wave noise.

Although important to seabirds in air, it is unknown if seabirds use hearing or vocalizations underwater for foraging, communication, predator avoidance or navigation (Crowell, 2016; Dooling & Therrien, 2012).

Diving birds may not hear as well underwater, compared to other (non-avian) species, based on adaptations to protect their ears from pressure changes (Dooling & Therrien, 2012). Because reproduction and communication with conspecifics occurs in air, adaptations for diving may have evolved to protect in-air hearing ability and may contribute to reduced sensitivity underwater (Hetherington, 2008). Hansen et al. (2020) observed that common murre (*Uria aalge*) consistently reacted to sounds produced by underwater sound bursts and mid-frequency sonar signals. There are many anatomical adaptations in diving birds that may reduce sensitivity both in air and underwater. Anatomical ear adaptations include cavernous tissue in the meatus and middle ear that may fill with blood during dives to compensate for increased pressure on the tympanum, active muscular control of the meatus to prevent water entering the ear, and interlocking feathers to create a waterproof outer covering (Crowell et al., 2015; Rijke, 1970; Sade et al., 2008). Zeyl et al. (2022) used nano-CT scanning of the ears of 127 bird species to measure the morphological adaptations to aerial and underwater hearing. Pursuit and deep diving species have heavily modified middle ears including smaller tympanic membranes and columella footplate of the middle ear middle ear; shorter extrastapedius, as well as reduced cranial air volume and connectivity. These likely facilitating hearing underwater and provide baroprotection, while potentially constraining the sensitivity of aerial hearing.

The northern gannet, a plunge diver, has unique adaptations to hitting the water at high speeds, including additional air spaces in the head and neck to cushion the impact and a thicker tympanic

membrane than similar sized birds (Crowell et al., 2015). All these adaptations could explain the measured higher thresholds of diving birds.

D.8.1.2 Bats

The hearing range of insect-eating bats in North America is 10 to 100 kHz. The most sensitive frequency band is 20 to 50 kHz, where bats can detect sounds at approximately 20 dB re 20 μ Pa (Bohn et al., 2006; Koay et al., 1997). Bats are generally unable to hear frequencies below 500 Hz. While hearing is the primary sense used by echolocating bats to forage and avoid obstacles, they use a combination of auditory and visual landmark recognition (Denzinger & Schnitzler, 2013; Gonzalez-Terrazas et al., 2016; Jensen et al., 2005; Schnitzler et al., 2003), magneto-reception (Holland et al., 2008; Holland et al., 2006; Wang et al., 2007), and spatial memory for long-distance navigation (Barchi et al., 2013; Ulanovsky & Moss, 2008, 2011; William & Williams, 1970; Williams et al., 1966). The variety of vocalizations produced by bats can be separated into two general categories: ultrasonic echolocation sounds and communication sounds. Echolocation is used while foraging, in which bats listen for received echoes from insect targets. Sound detection levels are somewhat dependent on ambient noise, and bats increase the loudness of their calls when they encounter noise (Hage et al., 2013; Hotchkiss & Parks, 2013; Luo & Wiegand, 2016).

D.8.2 HEARING LOSS AND AUDITORY INJURY

Exposure to intense sound may result in hearing loss which persists after cessation of the noise exposure. Hearing loss may be temporary or permanent, depending on factors such as the sound's frequency, received SPL, and duration. Hearing loss could impair a bird's or a bat's ability to hear biologically important sounds within the affected frequency range. Biologically important sounds include communication with social groups, potential mates, offspring, and parents as well as environmental sounds and sounds made by prey and predators.

Studies of in-air noise induced hearing loss and recovery are limited (e.g., quail, budgerigars, canaries, and zebra finches) (Ryals et al., 1999). There are no studies of bird hearing loss from underwater sound exposures. The frequencies affected by hearing loss would vary depending on the exposure frequency. The limited data on hearing loss in birds show that the frequency of exposure is the hearing frequency most likely to be affected (Saunders & Dooling, 1974).

Hearing loss can result from tissue damage. Tissue damage can include damage to the auditory hair cells and their underlying support cells. Hair cell damage has been observed in birds exposed to long-duration sounds that resulted in initial threshold shifts greater than 40 dB (Niemi et al., 1994; Ryals et al., 1999). Birds can regenerate hair cells in the ear, usually resulting in considerable anatomical, physiological, and behavioral recovery within several weeks (Rubel et al., 2013; Ryals et al., 1999). Still, intense exposures are not always fully recoverable, even over periods up to a year after exposure, and damage and subsequent recovery vary significantly by species (Ryals et al., 1999). Birds may be able to protect themselves against damage from sustained sound exposures by reducing middle ear pressure, an ability that may protect ears while in flight (Ryals et al., 1999) and from injury due to pressure changes during diving (Dooling & Therrien, 2012).

Studies in mammals have revealed that noise exposures resulting in high levels of TTS (greater than 40 dB) may also result in neural injury without any permanent hearing loss (Kujawa & Liberman, 2009; Lin et al., 2011). It is unknown if a similar effect would be observed for birds.

D.8.2.1 Hearing Loss due to Non-Impulsive Sounds

D.8.2.1.1 Birds

Behavioral studies of threshold shift in birds within their frequencies of best hearing (between 2 and 4 kHz) due to long-duration (30 minutes to 72 hours) continuous, non-impulsive, high-level sound exposures in air have shown that susceptibility to hearing loss varies substantially by species, even in species with similar auditory sensitivities, hearing ranges, and body size (Niemic et al., 1994; Ryals et al., 1999; Saunders & Dooling, 1974). For example, Ryals et al. (1999) conducted the same exposure experiment on quail and budgerigars, which have very similar audiograms. A 12-hour exposure to a 2.86 kHz tone at 112 dB re 20 μ Pa SPL (cumulative SEL of 158 dB re 20 μ Pa²s) resulted in a 70 dB threshold shift measured after 24 hours of recovery in quail, but a substantially lower 40 dB threshold shift measured after just 12 hours of recovery in budgerigars which recovered to within 10 dB of baseline after three days and fully recovered by one month (Ryals et al., 1999). Whereas the 158 dB re 20 μ Pa²s SEL tonal exposure to quail discussed above caused 20 dB of PTS (Ryals et al., 1999), a shorter (four-hour) tonal exposure to quail with similar SEL (157 dB re 20 μ Pa²s) caused 65 dB of threshold shift that fully recovered within two weeks (Niemic et al., 1994).

Data on threshold shift in birds due to relatively short-duration sound exposures that could be used to estimate the onset of threshold shift is limited. Saunders and Dooling (1974) provide the only threshold shift growth data measured for birds. Saunders and Dooling (1974) exposed young budgerigars to four levels of continuous 1/3-octave band noise (76, 86, 96, and 106 dB re 20 μ Pa) centered at 2.0 kHz and measured the threshold shift at various time intervals during the 72-hour exposure. The earliest measurement found 7 dB of threshold shift after approximately 20 minutes of exposure to the 96 dB re 20 μ Pa SPL noise (127 dB re 20 μ Pa²s SEL). Generally, onset of TTS in other species has been considered 6 dB above measured threshold (Finneran, 2015), which accounts for natural variability in auditory thresholds. The Saunders and Dooling (1974) budgerigar data is the only bird data showing low levels of threshold shift. Because of the observed variability of threshold shift susceptibility among bird species and the relatively long duration of sound exposure in Saunders and Dooling (1974), the observed onset level cannot be assumed to represent the SEL that would cause onset of TTS for other bird species or for shorter-duration exposures (i.e., a higher SEL may be required to induce TTS for shorter-duration exposures).

Since the goal of most bird hearing studies has been to induce hair cell damage to study regeneration and recovery, exposure durations were purposely long. Studies with other non-avian species have shown that long-duration exposures tend to produce more threshold shift than short-duration exposures with the same SEL (e.g., see Finneran (2015)). The SELs that induced TTS and PTS in these studies likely over-estimate the potential for hearing loss due to any short-duration sound of comparable SEL that a bird could encounter outside of a controlled laboratory setting. In addition, these studies were not designed to determine the exposure levels associated with the onset of any threshold shift or to determine the lowest SEL that may result in PTS.

With insufficient data to determine PTS onset for birds due to a non-impulsive exposure, data from other taxa are considered. Studies of terrestrial mammals suggest that 40 dB of threshold shift is a reasonable estimate of where PTS onset may begin (Southall et al., 2009). Similar amounts of threshold shift have been observed in some bird studies with no subsequent PTS. Of the birds studied, the budgerigars showed intermediate susceptibility to threshold shift; the budgerigars exhibited threshold shifts in the range of 40 dB to 50 dB after 12-hour exposures to 112 dB and 118 dB re 20 μ Pa SPL tones at 2.86 kHz (158 to 164 dB re 20 μ Pa²s SEL), which recovered to within 10 dB of baseline after three days and fully recovered by one month (Ryals et al., 1999). These experimental SELs are a conservative estimate of the SEL above which PTS may be considered possible for birds.

All of the above studies were conducted in air. There are no studies of hearing loss to diving birds due to underwater exposures.

D.8.2.1.2 Bats

Bats exposed to loud noise have not been shown to exhibit TTS (Hom et al., 2016; Simmons et al., 2015; Simmons et al., 2016). Recently, Hom et al. (2016) exposed four big brown bats (*Eptesicus fuscus*) to intense broadband noise (10 to 100 kHz with SEL 152 dB re 20 $\mu\text{Pa}^2\text{s}$ over one hour) and found no effect on the bats' vocalizations (which could indicate a change in hearing) or psychophysical thresholds 20 minutes, 24 hours, or 48 hours after exposure (Hom et al., 2016; Simmons et al., 2016). Another study on the Japanese house bat (*Pipistrellus abramus*) measured physiological (auditory brainstem response) thresholds immediately after a noise exposure (10 to 80 kHz, 90 dB re 20 μPa SPL, 30-minute duration) and also did not find evidence of TTS (Simmons et al., 2015). This may be because bats are adapted to hear in an acoustic environment where they are likely to experience loud sounds (110 to 140 dB re 20 μPa SPL) continuously for several hours while hunting near other bats that are also echolocating (Jakobsen et al., 2013; Simmons et al., 2001). It is also possible that the stimuli used in these experiments were not loud enough to induce TTS or that measurements of hearing sensitivity took place outside the time window where TTS might be observed.

D.8.2.2 Hearing Loss due to Impulsive Sounds

The only measure of hearing loss in a bird due to an impulsive noise exposure was conducted by Hashino et al. (1988), in which budgerigars were exposed to the firing of a pistol with a received level of 169 dB re 20 μPa peak SPL (two gunshots per each ear); SELs were not provided. While the gunshot frequency power spectrum had its peak at 2.8 kHz, threshold shift was most extensive below 1 kHz. Threshold shift recovered at frequencies above 1 kHz, while a 24 dB PTS was sustained at frequencies below 1 kHz. Studies of hearing loss in diving birds exposed to impulsive sounds underwater do not exist.

Because there is only one study of hearing loss in birds due to an impulsive exposure and no studies of hearing loss in bats due to an impulsive exposure, the few studies of hearing loss in birds and bats due to exposures to non-impulsive sound are the only other data upon which to assess bird and bat susceptibility to hearing loss from an impulsive sound source. Data from other taxa (U.S. Department of the Navy, 2017a) indicate that, for the same SEL, impulsive exposures are more likely to result in hearing loss than non-impulsive exposures. This is due to the high peak pressures and rapid pressure rise times associated with impulsive exposures.

D.8.3 MASKING

Masking occurs when one sound interferes with the detection or recognition of another sound. The quantitative definition of masking is the amount in decibels an auditory detection or discrimination threshold is raised in the presence of a masker (Erbe et al., 2016). As discussed in [Section 3.0.3.7.1](#) (Conceptual Framework for Assessing Effects from Acoustic and Explosive Activities), masking can effectively limit the distance over which an animal can communicate and detect biologically relevant sounds. Masking only occurs in the presence of the masking noise and does not persist after the cessation of the noise.

D.8.3.1 Birds

Critical ratios are the lowest ratio of signal-to-noise at which a signal can be detected. When expressed in decibels, critical ratios can easily be calculated by subtracting the noise level (in dB re 1 $\mu\text{Pa}^2/\text{Hz}$) from the signal level (in dB re 1 μPa) at detection threshold. A signal must be received above the critical ratio at a given frequency to be detectable by an animal. Critical ratios have been determined for a variety of bird species (e.g., Crowell, 2016; Dooling, 1980; Dooling & Popper, 2000; Noirot et al., 2011) and inter-

species variability is evident. Some birds exhibit low critical ratios at certain vocal frequencies, perhaps indicating that hearing evolved to detect signals in noisy environments or over long distances (Dooling & Popper, 2000).

The effect of masking is to limit the distance over which a signal can be perceived. An animal may attempt to compensate in several ways, such as by increasing the source level of vocalizations (the Lombard effect), changing the frequency of vocalizations, or changing behavior (e.g., moving to another location, increasing visual display). Birds have been shown to shift song frequencies in the presence of a tone at a similar frequency (Goodwin & Podos, 2013), and in continuously noisy urban habitats, populations have been shown to have altered song duration and shift to higher frequencies (Slabbekoorn & den Boer-Visser, 2006). Changes in vocalization may incur energetic costs and hinder communication with conspecifics, which, for example, could result in reduced mating opportunities. These effects are of long-term concern in constant noisy urban environments (Patricelli & Blickley, 2006) where masking conditions are prevalent.

D.8.3.2 Bats

Bats can experience masking during echolocation and communication from a variety of sources such as other bats and jamming of their echolocation signal by prey species (Bates et al., 2011; Chiu et al., 2008; Conner & Corcoran, 2012; Corcoran et al., 2009; Griffin et al., 1962; Simmons et al., 1988; Ulanovsky et al., 2004). They have many strategies to compensate for masking, such as dynamically changing the duration, spectrum, aim, and pattern of their echolocation (Bates et al., 2011; Moss et al., 2011; Petrites et al., 2009; Simmons et al., 2001; Wheeler et al., 2016).

Like other animals, bats increase the amplitude of their vocalizations in response to an increase in background noise level, which is known as the Lombard effect (Hage et al., 2013). It is estimated that a broadband signal of 65 dB re 20 μ Pa SPL would begin masking most bats' echolocation from targets beyond 1.5 m away (Arnett et al., 2013). Bats have been shown to shift the frequency of their calls when a stimulus was within 2 to 3 kHz of their preferred frequency (Bates et al., 2008).

Behavioral and psychophysical experiments show that the flexibility of bat vocalizations allows for perceptual rejection of masking due to clutter in the surroundings (Bates et al., 2011; Hiryu et al., 2010; Warnecke et al., 2015) or other sources of noise (Bates et al., 2008; Miller et al., 2004; Ulanovsky et al., 2004).

Overall, bats seem to avoid areas with high levels of noise—especially when the noise frequency spectrum overlaps with frequencies important for hunting (20 to 90 kHz). In a controlled laboratory experiment, Schaub et al. (2008) found that, when given a choice, bats spent 10 percent less time foraging in the compartment with noise (traffic, wind, and broadband white noise) as compared to the silent control chamber. Additionally, hunting in the noisy compartment yielded 10 percent fewer successful prey interceptions. Bats spent significantly less time and were significantly less successful as noise conditions increased in bandwidth and overall exposure levels. The greater the noise overlap with frequencies being attended to by the bat, the greater the disturbance to the bats' foraging behavior. However, this experiment was conducted on a small spatial scale, and with the absence of other sensory cues (light). Although laboratory research has shown that noise can decrease hunting success (Siemers & Schaub, 2011), and field and laboratory studies show that foraging bats avoid noise (Berthinus & Altringham, 2012; Schaub et al., 2008), no studies provide direct evidence from playback experiments in the field that commuting or migrating bats are disturbed by sound.

D.8.4 BEHAVIORAL REACTIONS

Hansen et al. (2020) exposed two common murrelets to broadband sound bursts and mid-frequency active sonar (3.5 to 4.1 kHz frequency range) playback during an underwater foraging task and found that both birds exhibited behavioral reactions to both stimuli as compared to no reactions in control trials. One subject exhibited stronger behavioral reactions to the noise bursts, and the other to the sonar. This effect was found for received levels between 110 and 137 dB re 1 μ Pa rms and the birds tended to turn or swim away from the sound source. This research suggests that anthropogenic noise within the birds' hearing range may cause behavioral disturbance while foraging underwater, and that they may exhibit avoidance responses. Sørensen et al. (2020) demonstrated that Gentoo penguins (*Pygoscelis papua*) react to noise bursts (0.2 to 6 kHz) by exposing seven individuals while underwater in a pool. Individual penguins received levels between 100 and 120 dB re 1 μ Pa, but a dose-response relationship between behavioral responses and SPL could not be established from the data. Variability both within and between individuals was observed. The data suggest that Gentoo penguins, a species adapted for pursuing prey underwater, are likely to react to received levels of 120 dB re 1 μ Pa and higher.

Numerous studies have documented that birds and other wild animals respond to human-made noise, including aircraft overflights, weapons firing, and explosions (Larkin et al., 1996; National Park Service, 1994; Plumpton, 2006). The way an animal responds to noise could depend on several factors, including life history characteristics of the species, characteristics of the noise source, sound source intensity, onset rate, distance from the noise source, presence or absence of associated visual stimuli, food and habitat availability, and previous exposure (see [Section 3.0.3.7.1](#), Conceptual Framework for Assessing Effects from Acoustic and Explosive Activities). Researchers have documented a range of bird behavioral responses to noise, including no response, head turn, alert behavior, startle response, flying or swimming away, diving into the water, and increased vocalizations (Brown et al., 1999; Larkin et al., 1996; National Park Service, 1994; Plumpton, 2006; Pytte et al., 2003; Stalmaster & Kaiser, 1997). Bat behavioral studies have shown reactions in response to acoustic interference such as reduced activity, area avoidance, and modifying the duration or frequency of calls (Arnett et al., 2013; Bates et al., 2008; Baxter et al., 2006). Some behavioral responses may be accompanied by physiological responses, such as increased heart rate or short-term changes in stress hormone levels (Partecke et al., 2006).

Behavioral responses may depend on the characteristics of the noise, and whether the noise is similar to biologically relevant sounds, such as alarm calls by other birds and predator sounds. For example, European starlings (*Sturnus vulgaris*) took significantly longer to habituate to repeated bird distress calls than white noise or pure tones (Johnson et al., 1985). Starlings may have been more likely to continue to respond to the distress because it is a more biologically meaningful sound. Starlings were also more likely to habituate in winter than summer, possibly meaning that food scarcity or seasonal physiological conditions may affect intensity of behavioral response (Johnson et al., 1985).

D.8.4.1 Behavioral Reactions to Impulsive Sound Sources

Studies regarding behavioral responses by non-nesting birds to impulsive sound sources are limited. Seismic surveys had no noticeable impacts on the movements or diving behavior of long-tailed ducks undergoing wing molt, a period in which flight is limited and food requirements are high (Lacroix et al., 2003). The birds may have tolerated the seismic survey noise to stay in preferred feeding areas.

Responses to aircraft sonic booms are informative of responses to single impulsive sounds. Responses to sonic booms are discussed below in Section D.8.4.3 (Behavioral Responses to Aircraft).

D.8.4.2 Behavioral Reactions to Sonar and Other Active Acoustic Sources

There are no studies of bird responses underwater to sonars, but the effect of pingers on fishing nets has been examined. Fewer common murre (*Uria aalge*) were entangled in gillnets when the gillnets were outfitted with 1.5 kHz pingers with a source level of 120 dB re 1 μ Pa; however, there was no significant reduction in rhinoceros auklet (*Cerorhinca monocerata*) bycatch in the same nets (Melvin et al., 2011; Melvin et al., 1999). It was unknown whether the pingers elicited a behavioral response by the birds or decreased prey availability.

D.8.4.3 Behavioral Responses to Aircraft

There are multiple possible factors involved in behavioral responses of birds and bats to aircraft overflights, including the noise stimulus as well as the visual stimulus.

Observations of tern colonies responses to balloon overflights suggest that visual stimulus is likely to be an important component of disturbance from overflights (Brown, 1990). Although it was assumed nesting colonial waterbirds may be more likely to flush or exhibit a mob response when disturbed, observations of nesting black skimmers and nesting least, gull-billed, and common terns showed they did not modify nesting behavior in response to military fixed-wing aircraft engaged in low-altitude tactical flights and rotary-wing overflights (Hillman et al., 2015). Maximum behavioral responses by crested tern (*Sterna bergii*) to aircraft noise were observed at SEL greater than 85 dBA re 20 μ Pa. However, herring gulls (*Larus argentatus*) significantly increased their aggressive interactions within the colony and their flights over the colony during overflights with received SPLs of 101 to 116 dBA re 20 μ Pa (Burger, 1981).

Raptors and wading birds have responded minimally to jet (110 dBA re 20 μ Pa) and propeller plane (92 dBA re 20 μ Pa) overflights, respectively (Ellis, 1981). Jet flights greater than 1,640 feet (ft.) distance from raptors were observed to elicit no response (Ellis, 1981). The impacts of low-altitude military training flights on wading bird colonies in Florida were estimated using colony distributions and turnover rates. There were no demonstrated impacts of military activity on wading bird colony establishment or size (Black et al., 1984). Fixed-winged jet aircraft disturbance did not seem to adversely affect waterfowl observed during a study in coastal North Carolina (Conomy et al., 1998); however, harlequin ducks were observed to show increased agonistic behavior and reduced courtship behavior up to one to two hours after low-altitude military jet overflights (Goudie & Jones, 2004).

It is possible that birds could habituate and no longer exhibit behavioral responses to aircraft noise, as has been documented for some impulsive noise sources (Ellis, 1981; Russel et al., 1996) and aircraft noise (Conomy et al., 1998). Ellis (1981) found that raptors would typically exhibit a minor short-term startle response to simulated sonic booms, and no long-term effect to productivity was noted.

Near-total failure of sooty tern nesting in the Dry Tortugas in the Key West Range Complex was reported in 1969 during a period when the birds were regularly exposed to sonic booms (Austin et al., 1970). In previous seasons, the birds were reported to react to the occasional sonic booms by rising immediately in a “panic flight,” circling over the island, and then usually settling down on their eggs again.

Researchers had no evidence that sonic booms caused physical damage to the sooty tern eggs but hypothesized that the strong booms occurred often enough to disturb the sooty terns’ incubating rhythm and cause nest desertion. The 1969 sooty tern nesting failure also prompted additional research to test the hypothesis that sonic booms could cause bird eggs to crack or otherwise affect bird eggs or embryos. However, the findings of the additional research determined that aircraft overflight and sonic booms were not a cause of the failure, and neither were panic flights, predators, weather, inadequate food supplies, or tick infestation (Bowles et al., 1991; Bowles et al., 1994a; Teer & Truett, 1973; Ting et al., 2002). That same year, the colony also contained approximately 2,500 brown noddies, whose young

hatched successfully. While it was impossible to conclusively determine the cause of the 1969 sooty tern nesting failure, actions were taken to curb planes breaking the sound barrier within range of the Tortugas, and much of the excess vegetation was cleared (another hypothesized contributing factor to the nesting failure). Similar nesting failures have not been reported since the 1969 failure.

D.8.5 PHYSIOLOGICAL RESPONSE

Chronic stress due to disturbance may compromise the general health and reproductive success of birds (Kight et al., 2012), but a physiological stress response is not necessarily indicative of negative consequences to individual birds or to populations (Larkin et al., 1996; National Park Service, 1994). The reported behavioral and physiological responses of birds to noise exposure can fall within the range of normal adaptive responses to external stimuli, such as predation, that birds face on a regular basis. These responses can include activation of the neural and endocrine systems, causing changes such as increased blood pressure, available glucose, and blood levels of corticosteroids (Manci et al., 1988). It is possible that individuals would return to normal almost immediately after short-term or transient exposure, and the individual's metabolism and energy budget would not be affected in the long-term. Studies have also shown that birds can habituate to noise following frequent exposure and cease to respond behaviorally to the noise (Larkin et al., 1996; National Park Service, 1994; Plumpton, 2006). However, the likelihood of habituation is dependent upon a number of factors, including species of bird (Bowles et al., 1991), and frequency of and proximity to exposure. Although Andersen et al. (1990) did not evaluate noise specifically, they found evidence that anthropogenic disturbance is related to changes in home ranges; for example, raptors have been shown to shift their terrestrial home range when concentrated military training activity was introduced to the area. On the other hand, cardinals nesting in areas with high levels of military training activity (including gunfire, artillery, and explosives) were observed to have similar reproductive success and stress hormone levels as cardinals in areas of low activity (Barron et al., 2012).

While physiological responses such as increased heart rate or startle response can be difficult to measure in the field, they often accompany more easily measured reactions like behavioral responses. A startle is a reflex characterized by rapid increase in heart rate, shutdown of nonessential functions, and mobilization of glucose reserves. Habituation keeps animals from expending energy and attention on harmless stimuli, but the physiological component might not habituate completely (Bowles, 1995).

A strong and consistent behavioral or physiological response is not necessarily indicative of negative consequences to individuals or to populations (Bowles, 1995; Larkin et al., 1996; National Park Service, 1994). For example, many of the reported behavioral and physiological responses to noise are within the range of normal adaptive responses to external stimuli, such as predation, that wild animals face on a regular basis. In many cases, individuals would return to homeostasis or a stable equilibrium almost immediately after exposure. The individual's overall metabolism and energy budgets would not be affected if it had time to recover before being exposed again. If the individual does not recover before being exposed again, physiological responses could be cumulative and lead to reduced fitness. However, it is also possible that an individual would have an avoidance reaction (i.e., move away from the noise source) to repeated exposure or habituate to the noise when repeatedly exposed.

Due to the limited information about acoustically induced stress responses, the Action Proponents conservatively assume in its effects analysis that any physiological response (e.g., hearing loss or injury) or significant behavioral response is also associated with a stress response.

D.8.6 DIRECT INJURY

Auditory structures are susceptible to injury from high levels of impulsive sound. This could include tympanic membrane rupture, disarticulation of the middle ear ossicles, and trauma to the inner ear

structures such as the hair cells within the organ of Corti. Auditory trauma differs from auditory fatigue in that the latter involves the overstimulation of the auditory system, rather than direct mechanical damage, which may result in hearing loss (see Section D.8.2, Hearing Loss and Auditory Injury). There are no data on damage to the middle ear structures of birds resulting from acoustic exposures. Because birds are known to regenerate auditory hair cells, studies have been conducted to purposely expose birds to very high SELs to induce hair cell damage in the inner ear. Because damage can co-occur with fatiguing exposures at high SELs, effects to hair cells are discussed above in Section D.8.2.

Because there are no data on non-auditory injury to birds from intense non-explosive sound sources, it may be useful to consider information for other similar-sized vertebrates. The rapid large pressure change near non-explosive impulsive sound sources, such as some large air guns and pile driving, are thought to be potentially injurious to other small animals (fishes and sea turtles). While long duration exposures (i.e., minutes to hours) to high sound levels of sonars are thought to be injurious to fishes, this has not been experimentally observed (Popper et al., 2014). The potential for injury is generally attributed to compression and expansion of body gas cavities, either due to rapid onset of pressure changes or resonance (enhanced oscillation of a cavity at its natural frequency). Because water is considered incompressible and animal tissue is generally of similar density as water, animals would be more susceptible to injury from a high-amplitude sound source in water than in air since waves would pass directly through the body rather than being reflected. Exposures to high-amplitude non-impulsive sounds underwater could be limited by a bird's surfacing response.

In air, the risk of barotrauma would be associated with high-amplitude impulses, such as from explosives (discussed in [Section 3.9.3.2](#), Explosive Stressors). Unlike in water, most acoustic energy reflects off the surface of an animal's body in air. Additionally, air is compressible whereas water is not, allowing energy to dissipate more rapidly. For these reasons, in-air non-explosive sound sources in this analysis are considered to pose little risk of non-auditory injury.

Limited data exist on instances of barotrauma to bats. Studies of the effects of rapid pressure changes from rotating wind turbine blades have demonstrated instances of ruptured tympana (Baerwald et al., 2008; Rollins et al., 2012). Although it is undetermined if these ruptures were the result of pressure changes or from a direct strike, the potential exists for auditory injury as a result of high-amplitude sound exposure.

D.8.7 LONG-TERM CONSEQUENCES

Long-term consequences to birds and bats due to acoustic exposures are considered following the Conceptual Framework for Assessing Effects from Proposed Action Activities ([Section 3.0.3.7.1](#)).

Long-term consequences due to individual behavioral reactions and short-term instances of physiological stress are especially difficult to predict because individual experience over time can create complex contingencies. It is more likely that any long-term consequences to an individual would be a result of costs accumulated over a season, year, or life stage due to multiple behavioral or stress responses resulting from exposures to multiple stressors over significant periods of time. Conversely, some birds and bats may habituate to or become tolerant of repeated acoustic exposures over time, learning to ignore a stimulus that in the past did not accompany any overt threat. Most research on long-term consequences to birds due to acoustic exposures has focused on breeding colonies or shore habitats and does not address the brief exposures that may be encountered during migration or foraging at sea. More research is needed to better understand the long-term consequences of human-made noise on birds and bats, although intermittent exposures are assumed to be less likely than prolonged exposures to have lasting consequences.

References

- Accomando, A. W., J. Mulsow, B. K. Branstetter, C. E. Schlundt, and J. F. Finneran. (2020). Directional hearing sensitivity for 2-30 kHz sounds in the bottlenose dolphin (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 14 (1): 388–398.
- Acevedo-Whitehouse, K., A. Rocha-Gosselin, and D. Gendron. (2010). A novel non-invasive tool for disease surveillance of freeranging whales and its relevance to conservation programs. *Animal Conservation* 13 217–225. DOI:10.1111/j.1469-1795.2009.00326
- Acevedo, A. (1991). Interactions between boats and bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. *Aquatic Mammals* 17 (3): 120–124.
- Acoustical Society of America. (2015). *Bioacoustical terminology*. Melville, NY: American National Standards Institute.
- Aguilar de Soto, N., M. Johnson, P. T. Madsen, P. L. Tyack, A. Bocconcelli, and J. F. Borsani. (2006). Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? *Marine Mammal Science* 22 (3): 690–789.
- Akamatsu, T., K. Nakamura, H. Nitto, and M. Watabe. (1996). Effects of underwater sounds on escape behavior of Steller sea lions. *Fisheries Science* 62 (4): 503–510.
- Akamatsu, T., T. Okumura, N. Novarini, and H. Y. Yan. (2002). Empirical refinements applicable to the recording of fish sounds in small tanks. *Journal of the Acoustical Society of America* 112 (6): 3073–3082. DOI:10.1121/1.1515799
- Akkaya Bas, A., F. Christiansen, A. Amaha Ozturk, B. Ozturk, and C. McIntosh. (2017). The effects of marine traffic on the behaviour of Black Sea harbour porpoises (*Phocoena phocoena relicta*) within the Istanbul Strait, Turkey. *PLoS ONE* 12 (3): e0172970. DOI:10.1371/journal.pone.0172970
- Allen, A. N., J. J. Schanze, A. R. Solow, and P. L. Tyack. (2014). Analysis of a Blainville's beaked whale's movement response to playback of killer whale vocalizations. *Marine Mammal Science* 30 (1): 154–168. DOI:10.1111/mms.12028
- Alves, A., R. Antunes, A. Bird, P. L. Tyack, P. J. O. Miller, F. P. A. Lam, and P. H. Kvadsheim. (2014). Vocal matching of naval sonar signals by long-finned pilot whales (*Globicephala melas*). *Marine Mammal Science* 30 (3): 1248–1257. DOI:10.1111/mms.12099
- Alves, D., M. C. P. Amorim, and P. J. Fonseca. (2016). Boat noise reduces acoustic active space in the lusitanian toadfish *Halobatrachus didactylus*. *Proceedings of Meetings on Acoustics* 27 010033. DOI:10.1121/2.0000325
- Amaral, J. (2020). The underwater sound from offshore wind farms. *Acoustics Today* 16 (2). DOI:10.1121/at.2020.16.2.13
- American National Standards Institute. (2013). *Acoustical Terminology*. Melville, NY: The Acoustical Society of America.
- Amorim, M. C. P., M. Vieira, G. Meireles, S. C. Novais, M. F. L. Lemos, T. Modesto, D. Alves, A. Zuazu, A. F. Lopes, A. B. Matos, and P. J. Fonseca. (2022). Boat noise impacts Lusitanian toadfish breeding males and reproductive outcome. *Science of the Total Environment* 830. DOI:10.1016/j.scitotenv.2022.154735

- Andersen, D. E., O. J. Rongstad, and W. R. Mytton. (1990). Home-range changes in raptor exposed to increased human activity levels in southeastern Colorado. *Wildlife Society Bulletin* 18 134–142.
- Anderson, E. R., J. Butler, and M. J. Butler. (2021). Response of fish and invertebrate larvae to backreef sounds at varying distances: Implications for habitat restoration. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.663887
- Anderwald, P., A. Brandecker, M. Coleman, C. Collins, H. Denniston, M. D. Haberlin, M. O'Donovan, R. Pinfield, F. Visser, and L. Walshe. (2013). Displacement responses of a mysticete, an odontocete, and a phocid seal to construction-related vessel traffic. *Endangered Species Research* 21 (3): 231–240. DOI:10.3354/esr00523
- Ando-Mizobata, N., K. Ichikawa, N. Arai, and H. Kato. (2014). Does boat noise affect dugong (*Dugong dugon*) vocalization? *Mammal Study* 39 (2): 121–127. DOI:dx.doi.org/10.3106/041.039.0208
- Antichi, S., A. M. Jaramillo-Legorreta, J. Urbán R, S. Martínez-Aguilar, and L. Vilorio-Gómora. (2022). Small vessel impact on the whistle parameters of two ecotypes of common bottlenose dolphin (*Tursiops truncatus*) in La Paz Bay, Mexico. *Diversity* 14 (9). DOI:10.3390/d14090712
- Antunes, R., P. H. Kvadsheim, F. P. Lam, P. L. Tyack, L. Thomas, P. J. Wensveen, and P. J. Miller. (2014). High thresholds for avoidance of sonar by free-ranging long-finned pilot whales (*Globicephala melas*). *Marine Pollution Bulletin* 83 (1): 165–180. DOI:10.1016/j.marpolbul.2014.03.056
- Arango, B. G., D. C. Ensminger, D. D. Moreno-Santillan, M. Harfush-Melendez, E. M. Lopez-Reyes, J. A. Marmolejo-Valencia, H. Merchant-Larios, D. E. Crocker, and J. P. Vazquez-Medina. (2022). Oxidative Stress Is a Potential Cost of Synchronous Nesting in Olive Ridley Sea Turtles. *Antioxidants* 11 (9). DOI:10.3390/antiox11091772
- Arcangeli, A. and R. Crosti. (2009). The short-term impact of dolphin-watching on the behaviour of bottlenose dolphins (*Tursiops truncatus*) in western Australia. *Journal of Marine Animals and Their Ecology* 2 (1): 3–9.
- Archer, F. I., S. L. Mesnick, and A. C. Allen. (2010). *Variation and Predictors of Vessel-Response Behavior in a Tropical Dolphin Community* (NOAA Technical Memorandum NMFS-SWFSC-457). La Jolla, CA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.
- Arnett, E. B., C. D. Hein, M. R. Schirmacher, M. M. Huso, and J. M. Szewczak. (2013). Evaluating the Effectiveness of an Ultrasonic Acoustic Deterrent for Reducing Bat Fatalities at Wind Turbines. *PLoS ONE* 8 (6): e65794. DOI:10.1371/journal.pone.0065794
- Arranz, P., M. Glarou, and K. Sprogis. (2021). Decreased resting and nursing in short-finned pilot whales when exposed to louder petrol engine noise of a hybrid whale-watch vessel. *Scientific Reports* 11 (1): 1-14.
- Astrup, J. (1999). Ultrasound detection in fish—A parallel to the sonar-mediated detection of bats by ultrasound-sensitive insects? *Comparative Biochemistry and Physiology, Part A* 124 19–27.
- Atkinson, S., D. Crocker, D. Houser, and K. Mashburn. (2015). Stress physiology in marine mammals: How well do they fit the terrestrial model? *Journal of Comparative Physiology B* 185 463–486.
- Au, W. and M. Hastings. (2008). *Principles of Marine Bioacoustics*. New York, NY: Springer-Verlag.
- Au, W. and P. Moore. (1984). Receiving beam patterns and directivity indices of the Atlantic bottlenose dolphin (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 75 255–262.

- Au, W. W. L. (1993). *The Sonar of Dolphins*. New York, NY: Springer-Verlag.
- Au, W. W. L. and K. Banks. (1998). The acoustics of the snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. *The Journal of the Acoustical Society of America* 103 (1): 41–47.
- Au, W. W. L., R. W. Floyd, R. H. Penner, and A. E. Murchison. (1974). Measurement of echolocation signals of the Atlantic bottlenose dolphin, *Tursiops truncatus* Montagu, in open waters. *The Journal of the Acoustical Society of America* 56 (4): 1280–1290.
- Au, W. W. L. and M. Green. (2000). Acoustic interaction of humpback whales and whale-watching boats. *Marine Environmental Research* 49 (5): 469–481.
- Au, W. W. L. and P. W. B. Moore. (1990). Critical ratio and critical bandwidth for the Atlantic bottlenose dolphin. *The Journal of the Acoustical Society of America* 88 (3): 1635–1638.
- Au, W. W. L., A. A. Pack, M. O. Lammers, L. M. Herman, M. H. Deakos, and K. Andrews. (2006). Acoustic properties of humpback whale songs. *The Journal of the Acoustical Society of America* 120 (2): 1103. DOI:10.1121/1.2211547
- Aubin, J. A., M. A. Mikus, R. Michaud, D. Mennill, and V. Vergara. (2023). Fly with care: belugas show evasive responses to low altitude drone flights. *Marine Mammal Science* 39 (3): 718-739. DOI:10.1111/mms.12997
- Austin, O. L., Jr., J. W. Robertson, and G. E. Woolfenden. (1970). *Mass hatchling failure in Dry Tortugas sooty terns*. Presented at the XVth International Ornithological Congress. The Hague, Netherlands.
- Avens, L. (2003). Use of multiple orientation cues by juvenile loggerhead sea turtles *Caretta caretta*. *The Journal of Experimental Biology* 206 (23): 4317–4325. DOI:10.1242/jeb.00657
- Ayres, K. L., R. K. Booth, J. A. Hempelmann, K. L. Koski, C. K. Emmons, R. W. Baird, K. Balcomb-Bartok, M. B. Hanson, M. J. Ford, and S. K. Wasser. (2012). Distinguishing the impacts of inadequate prey and vessel traffic on an endangered killer whale (*Orcinus orca*) population. *PLoS ONE* 7 (6): e36842. DOI:10.1371/journal.pone.0036842
- Azzara, A. J., W. M. von Zharen, and J. J. Newcomb. (2013). Mixed-methods analytic approach for determining potential impacts of vessel noise on sperm whale click behavior. *The Journal of the Acoustical Society of America* 134 (6): 4566–4574. DOI:10.1121/1.4828819
- Baerwald, E. F., G. H. D'Amours, B. J. Klug, and R. M. Barclay. (2008). Barotrauma is a significant cause of bat fatalities at wind turbines. *Current Biology* 18 (16): R695–R696. DOI:10.1016/j.cub.2008.06.029
- Bain, D. E. (2002). *A Model Linking Energetic Effects of Whale Watching to Killer Whale (Orcinus orca) Population Dynamics*. Friday Harbor, WA: Friday Harbor Laboratories, University of Washington.
- Baird, R. W., S. M. Jarvis, D. L. Webster, B. K. Rone, J. A. Shaffer, S. D. Mahaffy, A. M. Gorgone, and D. J. Moretti. (2014). *Odontocete Studies on the Pacific Missile Range Facility in July/August 2013: Satellite-Tagging, Photo Identification, and Passive Acoustic Monitoring*. Olympia, WA and Newport, RI: U.S. Navy Pacific Fleet.
- Baird, R. W., S. W. Martin, R. Manzano-Roth, D. L. Webster, and B. L. Southall. (2017). *Assessing Exposure and Response of Three Species of Odontocetes to Mid-frequency Active Sonar During Submarine Commanders Courses at the Pacific Missile Range Facility: August 2013 through February 2015. Draft Report*. Honolulu, HI: HDR, Inc.

- Baird, R. W., J. A. Shaffer, D. L. Webster, S. D. Fisher, J. M. Aschettino, A. M. Gorgone, B. K. Rone, S. D. Mahaffy, and D. J. Moretti. (2013). *Odontocete Studies Off the Pacific Missile Range Facility in February 2013: Satellite-Tagging, Photo Identification, and Passive Acoustic Monitoring for Species Verification*. Olympia, WA and Newport, RI: U.S. Navy Pacific Fleet.
- Baird, R. W., D. L. Webster, S. Watwood, R. Morrissey, B. K. Rone, S. D. Mahaffy, A. M. Gorgone, D. B. Anderson, and D. J. Moretti. (2016). *Odontocete Studies on the Pacific Missile Range Facility in February 2015: Satellite-Tagging, Photo-Identification, and Passive Acoustic Monitoring. Final Report*. Olympia, WA: HDR Environmental Inc.
- Baker, C. S., L. M. Herman, B. G. Bays, and G. B. Bauer. (1983). *The Impact of Vessel Traffic on the Behavior of Humpback Whales in Southeast Alaska: 1982 Season*. Honolulu, HI: Kewalo Basin Marine Mammal Laboratory, University of Hawaii.
- Bakhchina, A. V., L. M. Mukhametov, V. V. Rozhnov, and O. I. Lyamin. (2017). Spectral analysis of heart rate variability in the beluga (*Delphinapterus leucas*) during exposure to acoustic noise. *Journal of Evolutionary Biochemistry and Physiology* 53 (1): 60–65. DOI:10.1134/s0022093017010070
- Bakkeren, C., M. Ladegaard, K. A. Hansen, M. Wahlberg, P. T. Madsen, and L. Rojano-Donate. (2023). Visual deprivation induces a stronger dive response in a harbor porpoise. *iScience* 26 (3): 106204. DOI:10.1016/j.isci.2023.106204
- Barchi, J. R., J. M. Knowles, and J. A. Simmons. (2013). Spatial memory and stereotype of flight paths by big brown bats in cluttered surroundings. *The Journal of Experimental Biology* 216 (6): 1053–1063. DOI:10.1242/jeb.073197
- Barlow, J. (2016). *Cetacean Abundance in the California Current Estimated from Ship-based Line-transect Surveys in 1991–2014*. (NOAA Administrative Report NMFS-SWFSC-LJ-1601). La Jolla, CA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.
- Barlow, J., G. S. Schorr, E. A. Falcone, and D. Moretti. (2020). Variation in dive behavior of Cuvier’s beaked whales with seafloor depth, time-of-day, and lunar illumination. *Marine Ecological Progress Series* 644 199–214.
- Barrett, H. E. (2019). *Energetic Cost of Anthropogenic Disturbance on the Southern Sea otter*. (Master of Science Masters Thesis). San Jose State University, San Jose, CA.
- Barron, D. G., J. D. Brawn, L. K. Butler, L. M. Romero, and P. J. Weatherhead. (2012). Effects of military activity on breeding birds. *The Journal of Wildlife Management* 76 (5): 911–918.
- Bartol, S. M. and D. R. Ketten. (2006). *Turtle and Tuna Hearing*. NOAA Technical Memorandum NMFS-PIFSC-7. Honolulu, HI: National Marine Fisheries Service, Pacific Islands Fisheries Science Center.
- Bartol, S. M., J. A. Musick, and M. L. Lenhardt. (1999). Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). *Copeia* 1999 (3): 836–840.
- Bates, M. E., J. A. Simmons, and T. V. Zorikov. (2011). Bats Use Echo Harmonic Structure to Distinguish Their Targets from Background Clutter. *Science*, 333, 627–630.
- Bates, M. E., S. A. Stamper, and J. A. Simmons. (2008). Jamming avoidance response of big brown bats in target detection. *The Journal of Experimental Biology* 211 (1): 106–113. DOI:10.1242/jeb.009688
- Baumann-Pickering, S., M. A. McDonald, A. E. Simonis, A. Solsona Berga, K. P. B. Merkens, E. M. Oleson, M. A. Roch, S. M. Wiggins, S. Rankin, T. M. Yack, and J. A. Hildebrand. (2013). Species-specific

- beaked whale echolocation signals. *The Journal of the Acoustical Society of America* 134 (3): 2293–2301. DOI:10.1121/1.4817832
- Baxter, D. J. M., J. M. Psyllakis, M. P. Gillingham, and E. L. O'Brien. (2006). Behavioural response of bats to perceived predation risk while foraging. *Ethology* 112 997–983. DOI:10.1111/j.1439-0310.2006.01249
- Beason, R. (2004). *What Can Birds Hear?* Lincoln, NE: University of Nebraska.
- Bejder, L., A. Samuels, H. Whitehead, and N. Gales. (2006a). Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. *Animal Behaviour* 72 1149–1158. DOI:10.1016/j.anbehav.2006.04.003
- Bejder, L., A. Samuels, H. Whitehead, N. Gales, J. Mann, R. Connor, M. Heithaus, J. Waston-Capps, C. Flaherty, and M. Krützen. (2006b). Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. *Conservation Biology* 20 (6): 1791–1798.
- Benhemma-Le Gall, A., I. M. Graham, N. D. Merchant, and P. M. Thompson. (2021). Broad-Scale Responses of Harbor Porpoises to Pile-Driving and Vessel Activities During Offshore Windfarm Construction. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.664724
- Benoit-Bird, K. J., B. L. Southall, M. A. Moline, D. E. Claridge, C. A. Dunn, K. A. Dolan, and D. J. Moretti. (2020). Critical threshold identified in the functional relationship between beaked whales and their prey. *Marine Ecology Progress Series* 654 1–16.
- Bergström, L., L. Kautsky, T. Malm, R. Rosenberg, M. Wahlberg, N. Åstrand Capetillo, and D. Wilhelmsson. (2014). Effects of offshore wind farms on marine wildlife—A generalized impact assessment. *Environmental Research Letters* 9 (3): 12. DOI:10.1088/1748-9326/9/3/034012
- Bernaldo de Quirós, Y., A. Fernandez, R. W. Baird, R. L. Brownell, N. Aguilar de Soto, D. Allen, M. Arbelo, M. Arregui, A. Costidis, A. Fahlman, A. Frantzis, F. M. D. Gulland, M. Iñíguez, M. Johnson, A. Komnenou, H. Koopman, D. A. Pabst, W. D. Roe, E. Sierra, M. Tejedor, and G. Schorr. (2019). Advances in research on the impacts of anti-submarine sonar on beaked whales. *Proceedings of the Royal Society B: Biological Sciences* 286. DOI:10.1098/rspb.2018.2533
- Bernaldo de Quiros, Y., O. Gonzalez-Diaz, M. Arbelo, E. Sierra, S. Sacchini, and A. Fernandez. (2012). Decompression vs. decomposition: Distribution, amount, and gas composition of bubbles in stranded marine mammals. *Frontiers in Physiology* 3 Article 177 19. DOI:10.3389/fPhys.2012.0177
- Bernaldo de Quiros, Y., O. Gonzalez-Diaz, A. Mollerlokken, A. O. Brubakk, A. Hjelde, P. Saavedra, and A. Fernandez. (2013a). Differentiation at autopsy between in vivo gas embolism and putrefaction using gas composition analysis. *International Journal of Legal Medicine* 127 (2): 437–445. DOI:10.1007/s00414-012-0783-6
- Bernaldo de Quiros, Y., J. S. Seewald, S. P. Sylva, B. Greer, M. Niemeyer, A. L. Bogomolni, and M. J. Moore. (2013b). Compositional discrimination of decompression and decomposition gas bubbles in bycaught seals and dolphins. *PLoS ONE* 8 (12): e83994. DOI:10.1371/journal.pone.0083994
- Bernasconi, M., R. Patel, and L. Nøttestad. (2012). Behavioral observations of baleen whales in proximity of a modern fishing vessel. In A. N. Popper & A. Hawkins (Eds.), *The Effects of Noise on Aquatic Life*. New York, NY: Springer.

- Berrow, S. D. and B. Holmes. (1999). Tour boats and dolphins: A note on quantifying the activities of whalewatching boats in the Shannon Estuary, Ireland. *Journal of Cetacean Research and Management* 1 (2): 199–204.
- Berthinussen, A. and J. Altringham. (2012). The effect of a major road on bat activity and diversity. *Journal of Applied Ecology* 49 (1): 82–89. DOI:10.1111/j.1365-2664.2011.02068.x
- Bester, M. N., J. W. H. Ferguson, and F. C. Jonker. (2002). Population densities of pack ice seals in the Lazarev Sea, Antarctica. *Antarctic Science* 14 (2): 123–127.
- Beuter, K. J., R. Weiss, and B. Frankfurt. (1986). *Properties of the auditory system in birds and the effectiveness of acoustic scaring signals*. Presented at the Bird Strike Committee Europe, 18th Meeting Part I, 26–30 May 1986. Copenhagen, Denmark.
- Bierman, H. S., J. L. Thornton, H. G. Jones, K. Koka, B. A. Young, C. Brandt, J. Christensen-Dalsgaard, C. E. Carr, and D. J. Tollin. (2014). Biophysics of directional hearing in the American alligator (*Alligator mississippiensis*). *The Journal of Experimental Biology* 217 (Pt 7): 1094–1107. DOI:10.1242/jeb.092866
- Black, B. B., M. W. Collopy, H. F. Percival, A. A. Tiller, and P. G. Bohall. (1984). *Effects of Low Level Military Training Flights on Wading Bird Colonies in Florida*. Gainesville, FL: Florida Cooperative Fish and Wildlife Research Unit School of Forest Resources and Conservation University of Florida.
- Blackwell, S. B., J. W. Lawson, and M. T. Williams. (2004). Tolerance by ringed seals (*Phoca hispida*) to impact pipe-driving and construction sounds at an oil production island. *The Journal of the Acoustical Society of America* 115 (5 [Pt. 1]): 2346–2357.
- Blackwell, S. B., C. S. Nations, T. L. McDonald, C. R. Greene, A. M. Thode, M. Guerra, and A. M. Macrander. (2013). Effects of airgun sounds on bowhead whale calling rates in the Alaskan Beaufort Sea. *Marine Mammal Science* 29 E342–E365. DOI:10.1111/mms.12001
- Blackwell, S. B., C. S. Nations, T. L. McDonald, A. M. Thode, D. Mathias, K. H. Kim, C. R. Greene, Jr., and A. M. Macrander. (2015). Effects of airgun sounds on bowhead whale calling rates: Evidence for two behavioral thresholds. *PLoS ONE* 10 (6): e0125720. DOI:10.1371/journal.pone.0125720
- Blackwell, S. B., C. S. Nations, A. M. Thode, M. E. Kauffman, A. S. Conrad, R. G. Norman, and K. H. Kim. (2017). Effects of tones associated with drilling activities on bowhead whale calling rates. *PLoS ONE* 12 (11): e0188459. DOI:10.1371/journal.pone.0188459
- Blix, A. S., L. Walløe, and E. B. Messelt. (2013). On how whales avoid decompression sickness and why they sometimes strand. *Journal of Experimental Biology* 216 (18): 3385–3387.
- Blundell, G. M. and G. W. Pendleton. (2015). Factors affecting haul-out behavior of harbor seals (*Phoca vitulina*) in tidewater glacier inlets in Alaska: Can tourism vessels and seals coexist? *PLoS ONE* 10 (5): e0125486. DOI:10.1371/journal.pone.0125486
- Bohn, K. M., C. F. Moss, and G. S. Wilkinson. (2006). Correlated evolution between hearing sensitivity and social calls in bats. *Biology Letters* 2 (4): 561–564. DOI:10.1098/rsbl.2006.0501
- Bohnenstiehl, D. R., A. Lillis, and D. B. Eggleston. (2015). The curious acoustic behavior of estuarine snapping shrimp: temporal patterns of snapping shrimp sound in sub-tidal oyster reef habitat. *PLoS ONE* 11 (1). DOI:10.1371

- Boisseau, O., T. McGarry, S. Stephenson, R. Compton, A.-C. Cucknell, C. Ryan, R. McLanaghan, and A. Moscrop. (2021). Minke whales avoid a 15 kHz acoustic deterrent device. *Marine Ecology Progress Series*. DOI:10.3354/meps13690
- Booman, C., H. Dalen, H. Heivestad, A. Levesen, T. van der Meeren, and K. Toklum. (1996). (Seismic-fish) Effekter av luftkanonskyting pa egg, larver og ynell. *Havforskningsinstituttet* 3 1–88.
- Booth, C. G. (2019). Food for thought: Harbor porpoise foraging behavior and diet inform vulnerability to disturbance. *Marine Mammal Science* 1–14. DOI:10.1111/mms.12632
- Booth, C. G., N. Brannan, R. Dunlop, A. Friedlander, S. Isojunno, P. Miller, N. Quick, B. Southall, and E. Pirota. (2022). A sampling, exposure and receptor framework for identifying factors that modulate behavioural responses to disturbance in cetaceans. *Journal of Animal Ecology* 91 (10): 1948–1960. DOI:10.1111/1365-2656.13787
- Booth, C. G., R. R. Sinclair, and J. Harwood. (2020). Methods for Monitoring for the Population Consequences of Disturbance in Marine Mammals: A Review. *Frontiers in Marine Science* 7. DOI:10.3389/fmars.2020.00115
- Bostrom, B. L., A. Fahlman, and D. R. Jones. (2008). Tracheal compression delays alveolar collapse during deep diving in marine mammals. *Respiratory Physiology & Neurobiology* 161 (3): 298–305. DOI:10.1016/j.resp.2008.03.003
- Bowles, A. E. (1995). Chapter 8: Responses of Wildlife to Noise. In R. L. Knight & K. J. Gutzwiller (Eds.), *Wildlife and Recreationists: Coexistence Through Management and Research*. Washington, DC: Island Press.
- Bowles, A. E., C. Alves, and R. A. Anderson. (2001). Interactions of Florida manatees (*Trichechus manatus latirostris*) with simulated fishing gear and a pinger: Implications for preventing entanglements. *The Journal of the Acoustical Society of America* 110 (5): 2665. DOI:<http://dx.doi.org/10.1121/1.4777094>
- Bowles, A. E. and C. Anderson. (2012). Behavioral responses and habitation of pinnipeds and small cetaceans to novel objects and simulated fishing gear with and without a pinger. *Aquatic Mammals* 38 (2): 161–188.
- Bowles, A. E., F. T. Awbrey, and J. R. Jehl. (1991). *The Effects of High-Amplitude Impulsive Noise on Hatching Success: A Reanalysis of the Sooty Tern Incident*. Wright Patterson Airforce Base, OH: Noise and Sonic Boom Impact Technology Program.
- Bowles, A. E., M. Knobler, M. D. Seddon, and B. A. Kugler. (1994a). *Effects of Simulated Sonic Booms on the Hatchability of White Leghorn Chicken Eggs*. Brooks Air Force Base, TX: Systems Research Laboratories.
- Bowles, A. E., M. Smultea, B. Wursig, D. P. DeMaster, and D. Palka. (1994b). Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. *The Journal of the Acoustical Society of America* 96 2469–2484.
- Boyd, I. L., P. L. Tyack, D. Claridge, C. Clark, D. Moretti, and B. L. Southall. (2009, December 7–10, 2009). *Behavioural Response Study*. Presented at the 2009 ONR Marine Mammal Program Review. Alexandria, VA.
- Bracciali, C., D. Campobello, C. Giacomini, and G. Sara. (2012). Effects of nautical traffic and noise on foraging patterns of Mediterranean damselfish (*Chromis chromis*). *PLoS ONE* 7 (7): e40582. DOI:10.1371/journal.pone.0040582

- Brady, B., J. Moore, and K. Love. (2021). Behavior related vocalizations of the Florida manatee (*Trichechus manatus latirostris*). *Marine Mammal Science* 38 (3): 975-989. DOI:10.1111/mms.12904
- Brandt, M. J., A. Diederichs, K. Betke, and G. Nehls. (2011). Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. *Marine Ecology Progress Series* 421 205–216.
- Branstetter, B. K., K. Bakhtiari, A. Black, J. S. Trickey, J. J. Finneran, and H. Aihara. (2016). Energetic and informational masking of complex sounds by a bottlenose dolphin (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 140 (3): 1904–1917. DOI:10.1121/1.4962530]
- Branstetter, B. K., M. Felice, and T. Robeck. (2021). Auditory masking in killer whales (*Orcinus orca*): Critical ratios for tonal signals in Gaussian noise. *The Journal of the Acoustical Society of America* 149 2109–2115. DOI:10.1121/10.0003923
- Branstetter, B. K. and J. J. Finneran. (2008). Comodulation masking release in bottlenose dolphins (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 1 625–633.
- Branstetter, B. K. and E. Mercado. (2006). Sound localization by cetaceans. *International Journal of Comparative Psychology* 19 26–61.
- Branstetter, B. K. and J. M. Sills. (2022). Mechanisms of auditory masking in marine mammals. *Animal Cognition* 25 (5): 1029-1047. DOI:10.1007/s10071-022-01671-z
- Branstetter, B. K., J. S. Trickey, K. Bakhtiari, A. Black, H. Aihara, and J. J. Finneran. (2013). Auditory masking patterns in bottlenose dolphins (*Tursiops truncatus*) with natural, anthropogenic, and synthesized noise. *The Journal of the Acoustical Society of America* 133 (3): 1811–1818.
- Branstetter, B. K., K. R. Van Alstyne, T. A. Wu, R. A. Simmons, L. D. Curtis, and M. J. Xitco, Jr. (2017). Composite critical ratio functions for odontocete cetaceans. *The Journal of the Acoustical Society of America* 142 (4): 1897–1900.
- Breeze, H., S. Li, E. C. Marotte, J. A. Theriault, J. Wingfield, and J. Xu. (2021). Changes in underwater noise and vessel traffic in the approaches to Halifax Harbor, Nova Scotia, Canada. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.674788
- Breitzler, L., I. H. Lau, P. J. Fonseca, and R. O. Vasconcelos. (2020). Noise-induced hearing loss in zebrafish: Investigating structural and functional inner ear damage and recovery. *Hearing Research* 391. DOI:10.1016/j.heares.2020.107952
- Brewer, A. M., M. Castellote, A. M. Van Cise, T. Gage, and A. M. Berdahl. (2023). Communication in Cook Inlet beluga whales: Describing the vocal repertoire and masking of calls by commercial ship noise. *The Journal of the Acoustical Society of America* 154 (5): 3487-3505. DOI:10.1121/10.0022516
- Brown, A. L. (1990). Measuring the effect of aircraft noise on sea birds. *Environment International* 16 587–592.
- Brown, B. T., G. S. Mills, C. Powels, W. A. Russell, G. D. Therres, and J. J. Pottie. (1999). The influence of weapons-testing noise on bald eagle behavior. *Journal of Raptor Research* 33 (3): 227–232.
- Brown, N. A. W., W. D. Halliday, S. Balshine, and F. Juanes. (2021). Low-amplitude noise elicits the Lombard effect in plainfin midshipman mating vocalizations in the wild. *Animal Behaviour* 181 29–39. DOI:10.1016/j.anbehav.2021.08.025

- Bruintjes, R., J. Purser, K. A. Everley, S. Mangan, S. D. Simpson, and A. N. Radford. (2016). Rapid recovery following short-term acoustic disturbance in two fish species. *Royal Society - Open Science* 3 (1): 150686. DOI:10.1098/rsos.150686
- Brumm, H. and H. Slabbekoorn. (2005). Acoustic communication in noise. *Advances in the Study of Behavior* 35 151–209. DOI:10.1016/s0065-3454(05)35004-2
- Bryant, P. J., C. M. Lafferty, and S. K. Lafferty. (1984). Reoccupation of Laguna Guerrero Negro, Baja California, Mexico, by Gray Whales. In M. L. Jones, S. L. Swartz, & S. Leatherwood (Eds.), *The Gray Whale: Eschrichtius robustus* (pp. 375–387). Orlando, FL: Academic Press.
- Buckingham, C. A., L. W. Lefebvre, J. M. Schaefer, and H. I. Kochman. (1999). Manatee response to boating activity in a thermal refuge. *Wildlife Society Bulletin* 27 (2): 514–522.
- Buckstaff, K. C. (2004). Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science* 20 (4): 709-725. DOI:<https://doi.org/10.1111/j.1748-7692.2004.tb01189.x>
- Buerkle, U. (1968). Relation of pure tone thresholds to background noise level in the Atlantic cod (*Gadus morhua*). *Journal of the Fisheries Research Board of Canada* 25 1155–1160.
- Buerkle, U. (1969). Auditory masking and the critical band in Atlantic cod (*Gadus morhua*). *Journal of the Fisheries Research Board of Canada* 26 1113–1119.
- Buran, B. N., X. Deng, and A. N. Popper. (2005). Structural variation in the inner ears of four deep-sea elopomorph fishes. *Journal of Morphology* 265 215–225.
- Bureau of Ocean Energy Management. (2014). *Record of Decision for Final Programmatic Environmental Impact Statement for Atlantic OCS Proposed Geological and Geophysical Activities Mid-Atlantic and South Atlantic Planning Areas*. New Orleans, LA: U.S. Department of the Interior, Bureau of Ocean Energy Management.
- Burger, J. (1981). Behavioural responses of herring gulls, *Larus argentatus*, to aircraft noise. *Environmental Pollution Series A, Ecological and Biological* 24 (3): 177–184.
- Burnham, R. E., S. Vagle, P. Thupaki, and S. J. Thornton. (2023). Implications of wind and vessel noise on the sound fields experienced by southern resident killer whales *Orcinus orca* in the Salish Sea. *Endangered Species Research* 50 31-46. DOI:10.3354/esr01217
- Bussmann, K. (2020). Sound production in male and female corkwing wrasses and its relation to visual behaviour. *Bioacoustics*. DOI:10.1080/09524622.2020.1838324
- Butler, J. M. and K. P. Maruska. (2020). Underwater noise impairs social communication during aggressive and reproductive encounters. *Animal Behaviour* 164 9–23. DOI:10.1016/j.anbehav.2020.03.013
- Byl, J. A., L. Miersch, S. Wieskotten, and G. Dehnhardt. (2016). Underwater sound localization of pure tones in the median plane by harbor seals (*Phoca vitulina*). *The Journal of the Acoustical Society of America* 140 (6). DOI:10.1121/1.4972531
- Byl, J. A., L. Miersch, S. Wieskotten, and G. Dehnhardt. (2019). Underwater sound localization abilities of harbor seals (*Phoca vitulina*) for high-frequency noise band stimuli in the median plane. *The Journal of the Acoustical Society of America* 146 (1): 189–194.

- Caliani, I., L. Poggioni, A. D'Agostino, M. C. Fossi, and S. Casini. (2019). An immune response-based approach to evaluate physiological stress in rehabilitating loggerhead sea turtle. *Veterinary Immunology and Immunopathology* 207 18-24. DOI:10.1016/j.vetimm.2018.11.013
- Campbell, G. S., D. W. Weller, and J. A. Hildebrand. (2010). *SIO Small Boat Based Marine Mammal Surveys in Southern California: Report of Results for August 2009–July 2010: Annual Range Complex Monitoring Report for Hawaii and Southern California. Draft submission to the National Marine Fisheries Service September 15, 2010.* San Diego, CA: U.S. Department of the Navy.
- Carrera, M. L., E. G. P. Favaro, and A. Souto. (2008). The response of marine tucuxis (*Sotalia fluviatilis*) towards tourist boats involves avoidance behaviour and a reduction in foraging. *Animal Welfare* 17 117–123.
- Carretta, J. V. and J. Barlow. (2011). Long-term effectiveness, failure rates, and "dinner bell" properties of acoustic pingers in a gillnet fishery. *Marine Technology Society Journal* 45 (5): 7–19.
- Carretta, J. V., J. Barlow, and L. Enriquez. (2008). Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. *Marine Mammal Science* 24 (4): 2053–2073. DOI:10.1111/j.1748-7692.2008.00218
- Carretta, J. V., K. Danil, S. J. Chivers, D. W. Weller, D. S. Janiger, M. Berman-Kowalewski, K. M. Hernandez, J. T. Harvey, R. C. Dunkin, D. R. Casper, S. Stoudt, M. Flannery, K. Wilkinson, J. Huggins, and D. M. Lambourn. (2016a). Recovery rates of bottlenose dolphin (*Tursiops truncatus*) carcasses estimated from stranding and survival rate data. *Marine Mammal Science* 32 (1): 349–362. DOI:10.1111/mms.12264
- Carretta, J. V., M. M. Muto, S. Wilkin, J. Greenman, K. Wilkinson, M. DeAngelis, J. Viezbicke, D. Lawson, and J. Jannot. (2016b). *Sources of Human-Related Injury and Mortality for U.S. Pacific West Coast Marine Mammal Stock Assessments, 2010–2014.* La Jolla, CA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.
- Casey, C., S. Fregosi, J. N. Oswald, V. M. Janik, F. Visser, and B. Southall. (2024). Common dolphin whistle responses to experimental mid-frequency sonar. *PLoS One* 19 (4): e0302035. DOI:10.1371/journal.pone.0302035
- Casper, B. and D. Mann. (2006). Evoked potential audiograms of the nurse shark (*Ginglymostoma cirratum*) and the yellow stingray (*Urobatis haje*). *Environmental Biology of Fishes* 76 (1): 101–108. DOI:10.1007/s10641-006-9012-9
- Casper, B. M., M. B. Halvorsen, T. J. Carlson, and A. N. Popper. (2017). Onset of barotrauma injuries related to number of pile driving strike exposures in hybrid striped bass. *The Journal of the Acoustical Society of America* 141 (6): 4380. DOI:10.1121/1.4984976
- Casper, B. M., M. B. Halvorsen, F. Matthews, T. J. Carlson, and A. N. Popper. (2013a). Recovery of barotrauma injuries resulting from exposure to pile driving sound in two sizes of hybrid striped bass. *PLoS ONE* 8 (9): e73844. DOI:10.1371/journal.pone.0073844
- Casper, B. M., M. B. Halvorsen, and A. N. Popper. (2012a). Are Sharks Even Bothered by a Noisy Environment? In A. N. Popper & A. D. Hawkins (Eds.), *The Effects of Noise on Aquatic Life II* (Vol. 730). New York, NY: Springer.

- Casper, B. M. and D. A. Mann. (2009). Field hearing measurements of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*. *Journal of Fish Biology* 75 (10): 2768–2776. DOI:10.1111/j.1095-8649.2009.02477.x
- Casper, B. M., A. N. Popper, F. Matthews, T. J. Carlson, and M. B. Halvorsen. (2012b). Recovery of barotrauma injuries in Chinook salmon, *Oncorhynchus tshawytscha* from exposure to pile driving sound. *PLoS ONE* 7 (6): e39593. DOI:10.1371/journal.pone.0039593
- Casper, B. M., M. E. Smith, M. B. Halvorsen, H. Sun, T. J. Carlson, and A. N. Popper. (2013b). Effects of exposure to pile driving sounds on fish inner ear tissues. *Comparative Biochemistry and Physiology, Part A* 166 (2): 352–360. DOI:10.1016/j.cbpa.2013.07.008
- Castellini, M. A., D. S. Houser, and J. Mulsow. (2016). *Acoustics Marine Mammal Physiology: Requisites for Ocean Living* (pp. 245–268). Boca Raton, FL: CRC Press.
- Castellote, M., C. W. Clark, and M. O. Lammers. (2012). Acoustic and behavioral changes by fin whales (*Balaenoptera physalus*) in responses to shipping and airgun noise. *Biological Conservation* 147 115–122.
- Cates, K. and A. Acevedo-Gutiérrez. (2017). Harbor Seal (*Phoca vitulina*) tolerance to vessels under different levels of boat traffic. *Aquatic Mammals* 43 (2): 193–200. DOI:10.1578/AM.43.2.2017.193
- Cato, D. H. (1978). Marine biological choruses observed in tropical waters near Australia. *The Journal of the Acoustical Society of America* 64 (3): 736–743.
- Cavanaugh, W. J. and G. C. Tocci. (1998). Environmental Noise. *E.S.C., USC. Journal of Public Affairs* 1 (1): 11.
- Cecchetti, A., K. A. Stockin, J. Gordon, and J. M. N. Azevedo. (2017). Short-term effects of tourism on the behaviour of common dolphins (*Delphinus delphis*) in the Azores. *Journal of the Marine Biological Association of the United Kingdom* 98 (5): 1187–1196. DOI:10.1017/s0025315417000674
- Ceciarini, I., E. Franchi, F. Capanni, G. Consales, L. Minoia, S. Ancora, A. D'Agostino, A. Lucchetti, D. Li Veli, and L. Marsili. (2023). Assessment of interactive acoustic deterrent devices set on trammel nets to reduce dolphin-fishery interactions in the Northern Tyrrhenian Sea. *Scientific Reports* 13 (1): 20680. DOI:10.1038/s41598-023-46836-z
- Center for Naval Analysis. (2020). *Sonar Use and Beaked Whale: Strandings in the Mariana Islands* (Brief prepared for the Chief of Naval Operations Energy and Environmental Readiness Division). Washington, DC: U.S. Department of the Navy, Naval Operations Energy and Environmental Readiness Division.
- Cerchio, S., S. Strindberg, T. Collins, C. Bennett, and H. Rosenbaum. (2014). Seismic surveys negatively affect humpback whale singing activity off northern Angola. *PLoS ONE* 9 (3): e86464. DOI:10.1371/journal.pone.0086464
- Champagne, C. D., N. M. Kellar, M. L. Trego, B. Delehanty, R. Boonstra, S. K. Wasser, R. K. Booth, D. E. Crocker, and D. S. Houser. (2018). Comprehensive endocrine response to acute stress in the bottlenose dolphin from serum, blubber, and feces. *General and Comparative Endocrinology* 266 178–193. DOI:10.1016/j.ygcen.2018.05.015
- Chapman, C. J. and A. D. Hawkins. (1973). Field study of hearing in cod, *Gadus morhua* L. *Journal of Comparative Physiology* 85 (2): 147–167. DOI:10.1007/bf00696473

- Chapman, C. J. and O. Sand. (1974). Field studies of hearing in two species of flatfish *Pleuronectes platessa* (L.) and *Limanda limanda* (L.) (family Pleuronectidae). *Comparative Biochemistry and Physiology Part A* 47 371–385.
- Chapuis, L., S. P. Collin, K. E. Yopak, R. D. McCauley, R. M. Kempster, L. A. Ryan, C. Schmidt, C. C. Kerr, E. Gennari, C. A. Egeberg, and N. S. Hart. (2019). The effect of underwater sounds on shark behaviour. *Scientific Reports* 9 (1): 6924. DOI:10.1038/s41598-019-43078-w
- Charif, R. A., C. S. Oedekoven, A. Rahaman, B. J. Estabrook, L. Thomas, and A. N. Rice. (2015). *Development of Statistical Methods for Assessing Changes in Whale Vocal Behavior in Response to Mid-Frequency Active Sonar. Final Report*. Virginia Beach, VA: U.S. Fleet Forces Command.
- Charifi, M., A. Miserazzi, M. Sow, M. Perrigault, P. Gonzalez, P. Ciret, S. Benomar, and J.-C. Massabuau. (2018). Noise pollution limits metal bioaccumulation and growth rate in a filter feeder, the Pacific oyster *Magallana gigas*. *PLoS ONE* 13 (4): e0194174. DOI:10.1371/journal.pone.0194174
- Charrier, I., L. Jeantet, L. Maucourt, S. Régis, N. Lecerf, A. Benhalilou, and D. Chevallier. (2022). First evidence of underwater vocalizations in green sea turtles *Chelonia mydas*. *Endangered Species Research* 48 31–41.
- Chiu, C., W. Xian, and C. F. Moss. (2008). Flying in silence: echolocating bats cease vocalizing to avoid sonar jamming. *Proceedings of the National Academy of Sciences* 105 (35): 13116–13121. DOI:10.1073/pnas.0804408105
- Cholewiak, D., C. W. Clark, D. Ponirakis, A. Frankel, L. T. Hatch, D. Risch, J. E. Stanistreet, M. Thompson, E. Vu, and S. M. Van Parijs. (2018). Communicating amidst the noise: Modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. *Endangered Species Research* 36 59–75. DOI:10.3354/esr00875
- Cholewiak, D., A. I. DeAngelis, D. Palka, P. J. Corkeron, and S. M. Van Parijs. (2017). Beaked whales demonstrate a marked acoustic response to the use of shipboard echosounders. *Royal Society Open Science* 4 (12): 170940. DOI:10.1098/rsos.170940
- Christiansen, F., A. M. Dujon, K. R. Sprogis, J. P. Y. Arnould, and L. Bejder. (2016). Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales. *Ecosphere* 7 (10): e01468. DOI:10.1002/ecs2.1468
- Christiansen, F. and D. Lusseau. (2015). Linking behavior to vital rates to measure the effects of non-lethal disturbance on wildlife. *Conservation Letters* 8 (6): 424–431. DOI:10.1111/conl.12166
- Christiansen, F., M. L. Nielsen, C. Charlton, L. Bejder, and P. T. Madsen. (2020). Southern right whales show no behavioral response to low noise levels from a nearby unmanned aerial vehicle. *Marine Mammal Science*.
- Christiansen, F., M. Rasmussen, and D. Lusseau. (2013). Whale watching disrupts feeding activities of minke whales on a feeding ground. *Marine Ecology Progress Series* 478 239–251. DOI:10.3354/meps10163
- Christiansen, F., M. Rasmussen, and D. Lusseau. (2014). Inferring energy expenditure from respiration rates in minke whales to measure the effects of whale watching boat interactions. *Journal of Experimental Marine Biology and Ecology* 459 96–104. DOI:10.1016/j.jembe.2014.05.014
- Clark, C. (2015). *Potential Acoustic Impacts of Vessel Traffic from the Trans Mountain Expansion Project on Southern Resident Killer Whales*. Sidney, Canada: Prepared for Raincoast Conservation Foundation.

- Clark, C. W., W. T. Ellison, B. L. Southall, L. Hatch, S. M. Van Parijs, A. Frankel, and D. Ponirakis. (2009). Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. *Marine Ecology Progress Series* 395 201–222. DOI:10.3354/meps08402
- Clark, C. W. and K. M. Fristrup. (2001). Baleen whale responses to low-frequency human-made underwater sounds. *The Journal of the Acoustical Society of America* 110 (5): 2751. DOI:10.1121/1.4777574
- Clark, S. L. and J. W. Ward. (1943). The effects of rapid compression waves on animals submerged in water. *Surgery, Gynecology & Obstetrics* 77 403–412.
- Clarkson, C. J., F. Christiansen, T. Awbrey, L. Abbiss, N. Nikpaljevic, and A. Akkaya. (2020). Non-targeted tourism affects the behavioural budgets of bottlenose dolphins *Tursiops truncatus* in the South Adriatic (Montenegro). *Marine Ecology Progress Series* 638 165–176.
- Codarin, A., L. E. Wysocki, F. Ladich, and M. Picciulin. (2009). Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). *Marine Pollution Bulletin* 58 (12): 1880–1887. DOI:10.1016/j.marpolbul.2009.07.011
- Colleye, O., L. Kever, D. Lecchini, L. Berten, and E. Parmentier. (2016). Auditory evoked potential audiograms in post-settlement stage individuals of coral reef fishes. *Journal of Experimental Marine Biology and Ecology* 483 1–9. DOI:10.1016/j.jembe.2016.05.007
- Conner, W. E. and A. J. Corcoran. (2012). Sound strategies: the 65-million-year-old battle between bats and insects. *Annual Review of Entomology* 57 21–39. DOI:10.1146/annurev-ento-121510-133537
- Conomy, J. T., J. A. Dubovsky, J. A. Collazo, and W. J. Fleming. (1998). Do black ducks and wood ducks habituate to aircraft disturbance? *Journal of Wildlife Management* 62 (3): 1135–1142.
- Cook, S. L. and T. G. Forrest. (2005). Sounds produced by nesting leatherback sea turtles (*Dermochelys coriacea*). *Herpetological Review* 36 (4): 387–389.
- Coombs, S. and J. C. Montgomery. (1999). The Enigmatic Lateral Line System. In R. R. Fay & A. N. Popper (Eds.), *Comparative Hearing: Fish and Amphibians* (pp. 319–362). New York, NY: Springer-Verlag.
- Corcoran, A. J., J. R. Barber, and W. E. Conner. (2009). Tiger moth jams bat sonar. *Science*, 325, 325–327.
- Costa, D. P., D. E. Crocker, J. Gedamke, P. M. Webb, D. S. Houser, S. B. Blackwell, D. Waples, S. A. Hayes, and B. J. Le Boeuf. (2003). The effect of a low-frequency sound source (acoustic thermometry of the ocean climate) on the diving behavior of juvenile northern elephant seals, *Mirounga angustirostris*. *The Journal of the Acoustical Society of America* 113 (2): 1155–1165.
- Costa, D. P., L. A. Hückstädt, L. K. Schwarz, A. S. Friedlaender, B. R. Mate, A. N. Zerbini, A. Kennedy, and N. J. Gales. (2016a). *Assessing the exposure of animals to acoustic disturbance: Towards an understanding of the population consequences of disturbance*. Presented at the Fourth International Conference on the Effects of Noise on Aquatic Life. Dublin, Ireland. Retrieved from <http://acousticalsociety.org/>.
- Costa, D. P., L. Schwarz, P. Robinson, R. S. Schick, P. A. Morris, R. Condit, D. E. Crocker, and A. M. Kilpatrick. (2016b). A bioenergetics approach to understanding the population consequences of disturbance: Elephant seals as a model system. In *The Effects of Noise on Aquatic Life II* (pp. 116–169). New York, NY: Springer.

- Costidis, A. M. and S. A. Rommel. (2016). The extracranial venous system in the heads of beaked whales, with implications on diving physiology and pathogenesis. *Journal of Morphology* 277 (1): 34–64. DOI:10.1002/jmor.20437
- Cox, B. S., A. M. Dux, M. C. Quist, and C. S. Guy. (2012). Use of a seismic air gun to reduce survival of nonnative lake trout embryos: A tool for conservation? *North American Journal of Fisheries Management* 32 (2): 292–298. DOI:10.1080/02755947.2012.675960
- Cox, T. M., T. J. Ragen, A. J. Read, E. Vox, R. W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernandez, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, T. Hullar, P. D. Jepson, D. Ketten, C. D. MacLeod, P. Miller, S. Moore, D. C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Mead, and L. Benner. (2006). Understanding the impacts of anthropogenic sound on beaked whales. *Journal of Cetacean Research and Management* 7 (3): 177–187.
- Cranford, T. W. and P. Krysl. (2015). Fin whale sound reception mechanisms: Skull vibration enables low-frequency hearing. *PLoS ONE* 10 (1): e0116222. DOI:10.1371/journal.pone.0116222
- Crespo-Picazo, J. L., M. Parga, Y. B. de Quirós, D. Monteiro, V. Marco-Cabedo, C. Llopis-Belenguer, and D. García-Párraga. (2020). Novel insights into gas embolism in sea turtles: First description in three new species. *Frontiers in Marine Science* 7. DOI:10.3389/fmars.2020.00442
- Crocker, S. E. and F. D. Fratantonio. (2016). *Characteristics of Sounds Emitted During High-Resolution Marine Geophysical Surveys*. Herndon, VA: Bureau of Ocean Energy Management and United States Geological Survey.
- Croll, D. A., C. W. Clark, J. Calambokidis, W. T. Ellison, and B. R. Tershy. (2001). Effect of anthropogenic low-frequency noise on the foraging ecology of *Balaenoptera* whales. *Animal Conservation* 4 13–27.
- Crowell, S. C. (2016). Measuring in-air and underwater hearing in seabirds. *Advances in Experimental Medicine and Biology* 875 1155–1160. DOI:10.1007/978-1-4939-2981-8_144
- Crowell, S. E., A. M. Wells-Berlin, C. E. Carr, G. H. Olsen, R. E. Therrien, S. E. Ynnuzzi, and D. R. Ketten. (2015). A comparison of auditory brainstem responses across diving bird species. *Journal of Comparative Physiology A* 201 (8): 803–815. DOI:10.1007/s00359-015-1024-5
- Crum, L., M. Bailey, J. Guan, P. Hilmo, S. Kargl, and T. Matula. (2005). Monitoring bubble growth in supersaturated blood and tissue *ex vivo* and the relevance to marine mammal bioeffects. *Acoustics Research Letters Online* 6 (3): 214–220. DOI:10.1121/1.1930987
- Crum, L. and Y. Mao. (1996). Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *The Journal of the Acoustical Society of America* 99 (5): 2898–2907.
- Cummings, W. C. and P. O. Thompson. (1971). Gray whales, *Eschrichtius robustus*, avoid the underwater sounds of killer whales, *Orcinus orca*. *Fishery Bulletin* 69 (3): 525–530.
- Cunningham, K. A., B. L. Southall, and C. Reichmuth. (2014). Auditory sensitivity of seals and sea lions in complex listening scenarios. *The Journal of the Acoustical Society of America* 136 (6): 3410–3421. DOI:10.1121/1.4900568
- Curé, C., R. Antunes, F. Samarra, A. C. Alves, F. Visser, P. H. Kvadsheim, and P. J. Miller. (2012). Pilot whales attracted to killer whale sounds: Acoustically-mediated interspecific interactions in cetaceans. *PLoS ONE* 7 (12): e52201. DOI:10.1371/journal.pone.0052201

- Curé, C., S. Isojunno, M. L. Siemensma, P. J. Wensveen, C. Buisson, L. D. Sivle, B. Benti, R. Roland, P. H. Kvadsheim, F.-P. A. Lam, and P. J. O. Miller. (2021). Severity scoring of behavioral responses of Sperm Whales (*Physeter macrocephalus*) to novel continuous versus conventional pulsed active sonar. *Journal of Marine Science and Engineering* 9 (444). DOI:10.3390/jmse9040444
- Curé, C., S. Isojunno, F. Visser, P. J. Wensveen, L. D. Sivle, P. H. Kvadsheim, F. P. A. Lam, and P. J. O. Miller. (2016). Biological significance of sperm whale responses to sonar: Comparison with anti-predator responses. *Endangered Species Research* 31 89–102. DOI:10.3354/esr00748
- Curé, C., L. D. Sivle, F. Visser, P. J. Wensveen, S. Isojunno, C. M. Harris, P. H. Kvadsheim, F. P. A. Lam, and P. J. O. Miller. (2015). Predator sound playbacks reveal strong avoidance responses in a fight strategist baleen whale. *Marine Ecology Progress Series* 526 267–282. DOI:10.3354/meps11231
- Curland, J. M. (1997). *Effects of disturbance on sea otters (Enhydra lutris) near Monterey, California*. (Master's thesis). San Jose State University, San Jose, CA.
- Currie, H. A. L., P. R. White, T. G. Leighton, and P. S. Kemp. (2020). Group behavior and tolerance of Eurasian minnow (*Phoxinus phoxinus*) in response to tones of differing pulse repetition rate. *The Journal of the Acoustical Society of America* 147 (3). DOI:10.1121/10.0000910
- Curtis, K. R., B. M. Howe, and J. A. Mercer. (1999). Low-frequency ambient sound in the North Pacific: Long time series observations. *The Journal of the Acoustical Society of America* 106 (6): 3189–3200.
- Czapanskiy, M. F., M. S. Savoca, W. T. Gough, P. S. Segre, D. M. Wisniewska, D. E. Cade, and J. A. Goldbogen. (2021). Modelling short-term energetic costs of sonar disturbance to cetaceans using high-resolution foraging data. *Journal of Applied Ecology*. DOI:10.1111/1365-2664.13903
- D'Spain, G. L. and H. H. Batchelor. (2006). Observations of biological choruses in the Southern California Bight: A chorus at midfrequencies. *The Journal of the Acoustical Society of America* 120 (4): 1942. DOI:10.1121/1.2338802
- Dahl, P. H., D. R. Dall'Osto, and M. J. Harrington. (2021). Trends in low-frequency underwater noise off the Oregon coast and impacts of COVID-19 pandemic. *The Journal of the Acoustical Society of America* 149 (6): 4073. DOI:10.1121/10.0005192
- Dahl, P. H., A. Keith Jenkins, B. Casper, S. E. Kotecki, V. Bowman, C. Boerger, D. R. Dall'Osto, M. A. Babina, and A. N. Popper. (2020). Physical effects of sound exposure from underwater explosions on Pacific sardines (*Sardinops sagax*). *The Journal of the Acoustical Society of America* 147 (4). DOI:10.1121/10.0001064
- Dähne, M., V. Peschko, A. Gilles, K. Lucke, S. Adler, K. Ronnenberg, and U. Siebert. (2014). Marine mammals and windfarms: Effects of alpha ventus on harbour porpoises. In *Ecological Research at the Offshore Windfarm alpha ventus* (pp. 133–149). New York, NY: Springer Publishing.
- Dähne, M., J. Tougaard, J. Carstensen, A. Rose, and J. Nabe-Nielsen. (2017). Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. *Marine Ecology Progress Series* 580 221–237. DOI:10.3354/meps12257
- Danil, K., N. Beaulieu-McCoy, S. Dennison, D. Rotstein, T. Rowles, and S. Wilkin. (2021). *Uncommon Stranding Event of Bottlenose Dolphins (Tursiops truncatus) in San Diego, California (October 2015)*. La Jolla, CA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.

- Danil, K. and J. A. St Leger. (2011). Seabird and dolphin mortality associated with underwater detonation exercises. *Marine Technology Society Journal* 45 (6): 89–95.
- Davis, R. W., T. M. Williams, and F. Awbrey. (1988). *Sea Otter Oil Spill Avoidance Study*. New Orleans, LA: U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region.
- de Jong, K., T. N. Forland, M. C. P. Amorim, G. Rieucan, H. Slabbekoorn, and L. D. Siple. (2020). Predicting the effects of anthropogenic noise on fish reproduction. *Reviews in Fish Biology and Fisheries*. DOI:10.1007/s11160-020-09598-9
- De Robertis, A. and N. O. Handegard. (2013). Fish avoidance of research vessels and the efficacy of noise-reduced vessels: A review. *ICES Journal of Marine Science* 70 (1): 34–45. DOI:10.1093/icesjms/fss155
- De Silva, R., K. Grellier, G. Lye, N. McLean, and P. Thompson. (2014). *Use of population viability analysis to assess the potential for long term impacts from piling noise on marine mammal populations - a case study from the Scottish east coast*. Presented at the Proceedings of the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR2014). Stornoway. Isle of Lewis, Outer Hebrides, Scotland.
- De Soto, N. A., F. Visser, P. L. Tyack, J. Alcazar, G. Ruxton, P. Arranz, P. T. Madsen, and M. Johnson. (2020). Fear of killer whales drives extreme synchrony in deep diving beaked whales. *Scientific Reports* 10 (13).
- Debusschere, E., B. De Coensel, A. Bajek, D. Botteldooren, K. Hostens, J. Vanaverbeke, S. Vandendriessche, K. Van Ginderdeuren, M. Vincx, and S. Degraer. (2014). *In situ* mortality experiments with juvenile sea bass (*Dicentrarchus labrax*) in relation to impulsive sound levels caused by pile driving of windmill foundations. *PLoS ONE* 9 (10): e109280. DOI:10.1371/journal.pone.0109280
- Deecke, V. B., P. J. B. Slater, and J. K. B. Ford. (2002). Selective habituation shapes acoustic predator recognition in harbour seals. *Nature* 420 (November 14): 171–173.
- Demarchi, M. W., M. Holst, D. Robichaud, M. Waters, and A. O. MacGillivray. (2012). Responses of Steller sea lions (*Eumetopias jubatus*) to in-air blast noise from military explosions. *Aquatic Mammals* 38 (3): 279.
- Deng, X., H. J. Wagner, and A. N. Popper. (2011). The inner ear and its coupling to the swim bladder in the deep-sea fish *Antimora rostrata* (Teleostei: Moridae). *Deep Sea Research Part 1, Oceanographic Research Papers* 58 (1): 27–37. DOI:10.1016/j.dsr.2010.11.001
- Deng, X., H. J. Wagner, and A. N. Popper. (2013). Interspecific variations of inner ear structure in the deep-sea fish family Melamphidae. *The Anatomical Record* 296 (7): 1064–1082. DOI:10.1002/ar.22703
- Denk, M., A. Fahlman, S. Dennison-Gibby, Z. Song, and M. Moore. (2020). Hyperbaric tracheobronchial compression in cetaceans and pinnipeds. *Journal of Experimental Biology* 223 (Pt 5). DOI:10.1242/jeb.217885
- Dennison, S., M. J. Moore, A. Fahlman, K. Moore, S. Sharp, C. T. Harry, J. Hoppe, M. Niemeyer, B. Lentell, and R. S. Wells. (2012). Bubbles in live-stranded dolphins. *Proceedings of the Royal Society B: Biological Sciences* 279 (1732): 1396–1404. DOI:10.1098/rspb.2011.1754

- Denzinger, A. and H. U. Schnitzler. (2013). Bat guilds, a concept to classify the highly diverse foraging and echolocation behaviors of microchiropteran bats. *Frontiers in Physiology* 4 164. DOI:10.3389/fphys.2013.00164
- Deros, D., M. Doeschate, A. C. Brownlow, N. J. Davison, and D. Lusseau. (2020). Toward New Ecologically Relevant Markers of Health for Cetaceans. *Frontiers in Marine Science* 7.
- DeRuiter, S. L., I. L. Boyd, D. E. Claridge, C. W. Clark, C. Gagon, B. L. Southall, and P. L. Tyack. (2013a). Delphinid whistle production and call matching during playback of simulated military sonar. *Marine Mammal Science* 29 (2): E46–59. DOI:10.1111/j.1748-7692.2012.00587
- DeRuiter, S. L. and K. L. Doukara. (2012). Loggerhead turtles dive in response to airgun sound exposure. *Endangered Species Research* 16 (1): 55–63. DOI:10.3354/esr00396
- DeRuiter, S. L., R. Langrock, T. Skirbutas, J. A. Goldbogen, J. Calambokidis, A. S. Friedlaender, and B. L. Southall. (2017). A multivariate mixed hidden Markov model for blue whale behaviour and responses to sound exposure. *The Annals of Applied Statistics* 11 (1): 362–392. DOI:10.1214/16-aos1008
- DeRuiter, S. L., B. L. Southall, J. Calambokidis, W. M. Zimmer, D. Sadykova, E. A. Falcone, A. S. Friedlaender, J. E. Joseph, D. Moretti, G. S. Schorr, L. Thomas, and P. L. Tyack. (2013b). First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar. *Biology Letters* 9 (4): 20130223. DOI:10.1098/rsbl.2013.0223
- Di Clemente, J., F. Christiansen, E. Pirotta, D. Steckler, M. Wahlberg, and H. C. Pearson. (2018). Effects of whale watching on the activity budgets of humpback whales, *Megaptera novaeangliae* (Borowski, 1781), on a feeding ground. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28 (4): 810–820. DOI:10.1002/aqc.2909
- Di Lorio, L. and C. W. Clark. (2010). Exposure to seismic survey alters blue whale acoustic communication. *Biology Letters* 6 51–54.
- Diaz, M. P., H. P. Kunc, and J. D. R. Houghton. (2023). Anthropogenic noise predicts sea turtle behavioural responses. *Marine Pollution Bulletin* 198 115907. DOI:10.1016/j.marpolbul.2023.115907
- DiMarzio, N., S. Watwood, T. Fetherston, and D. Moretti. (2019). *Marine Mammal Monitoring on Navy Ranges (M3R) on the Southern California Anti-Submarine Warfare Range (SOAR) and the Pacific Missile Range Facility (PMRF)* (Prepared for: U.S. Navy, U.S. Pacific Fleet, Pearl Harbor, HI). Newport, RI: Naval Undersea Warfare Center.
- Doksaeter, L., O. R. Godo, N. O. Handegard, P. H. Kvadsheim, F. P. A. Lam, C. Donovan, and P. J. O. Miller. (2009). Behavioral responses of herring (*Clupea harengus*) to 1–2 and 6–7 kHz sonar signals and killer whale feeding sounds. *The Journal of the Acoustical Society of America* 125 (1): 554–564.
- Doksaeter, L., N. O. Handegard, O. R. Godo, P. H. Kvadsheim, and N. Nordlund. (2012). Behavior of captive herring exposed to naval sonar transmissions (1.0–1.6 kHz) throughout a yearly cycle. *The Journal of the Acoustical Society of America* 131 (2): 1632–1642. DOI:10.1121/1.3675944
- Dooling, R. (2002). *Avian Hearing and the Avoidance of Wind Turbines*. College Park, MD: University of Maryland.
- Dooling, R. J. (1980). Behavior and Psychophysics of Hearing in Birds. In A. N. Popper & R. R. Fay (Eds.), *Comparative Studies of Hearing in Vertebrates* (pp. 261–288). New York, NY: Springer-Verlag.

- Dooling, R. J. and A. N. Popper. (2000). Hearing in birds and reptiles. In R. J. Dooling, R. R. Fay, & A. N. Popper (Eds.), *Comparative Hearing in Birds and Reptiles* (Vol. 13, pp. 308–359). New York, NY: Springer-Verlag.
- Dooling, R. J. and S. C. Therrien. (2012). Hearing in birds: What changes from air to water. *Advances in Experimental Medicine and Biology* 730 77–82. DOI:10.1007/978-1-4419-7311-5_17
- Dossot, G. A., J. S. Krumholz, D. M. Hudson, D. L. Pochtar, N. C. Dickenson, E. B. Baker, and T. E. Moll. (2017). *Simulated anthropogenic noise exposure to marine invertebrates using a standing wave tube*. Presented at the Acoustical Society of America Meeting. New Orleans, LA.
- Doyle, L. R., B. McCowan, S. F. Hanser, C. Chyba, T. Bucci, and E. J. Blue. (2008). Applicability of information theory to the quantification of responses to anthropogenic noise by southeast Alaskan humpback whales. *Entropy* 10 33–46. DOI:10.3390/entropy-e10020033
- Duarte, C. M., L. Chapuis, S. P. Collin, D. P. Costa, R. P. Devassy, V. M. Eguiluz, C. Erbe, T. A. C. Gordon, B. S. Halpern, H. R. Harding, M. N. Havlik, M. Meekan, N. D. Merchant, J. L. Miksis-Olds, M. Parsons, M. Predragovic, A. N. Radford, C. A. Radford, S. D. Simpson, H. Slabbekoorn, E. Staaterman, I. C. V. Opzeeland, J. Winderen, X. Zhang, and F. Juanes. (2021). The soundscape of the Anthropocene ocean. *Science* 5 (371). DOI:10.1126/science.aba4658
- Dunlop, R. A. (2016). The effect of vessel noise on humpback whale, *Megaptera novaeangliae*, communication behaviour. *Animal Behaviour* 111 13–21. DOI:10.1016/j.anbehav.2015.10.002
- Dunlop, R. A. (2018). The communication space of humpback whale social sounds in wind-dominated noise. *The Journal of the Acoustical Society of America* 144 (2): 540–551.
- Dunlop, R. A. (2019). The effects of vessel noise on the communication network of humpback whales. *Royal Society of Open Science* 6 (11). DOI:10.1098/rsos.190967
- Dunlop, R. A., J. Braithwaite, L. O. Mortensen, and C. M. Harris. (2021). Assessing population-level effects of anthropogenic disturbance on a marine mammal population. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.624981
- Dunlop, R. A., D. H. Cato, and M. J. Noad. (2010). Your attention please: Increasing ambient noise levels elicits a change in communication behaviour in humpback whales (*Megaptera novaeangliae*). *Proceedings of the Royal Society B: Biological Sciences* 277 2521–2529.
- Dunlop, R. A., D. H. Cato, and M. J. Noad. (2014). Evidence of a Lombard response in migrating humpback whales (*Megaptera novaeangliae*). *The Journal of the Acoustical Society of America* 136 (1): 430–437. DOI:10.1121/1.4883598
- Dunlop, R. A., R. D. McCauley, and M. J. Noad. (2020). Ships and air guns reduce social interactions in humpback whales at greater ranges than other behavioral impacts. *Marine Pollution Bulletin* 154.
- Dunlop, R. A., M. J. Noad, D. H. Cato, E. Kniest, P. J. Miller, J. N. Smith, and M. D. Stokes. (2013). Multivariate analysis of behavioural response experiments in humpback whales (*Megaptera novaeangliae*). *The Journal of Experimental Biology* 216 (5): 759–770.
- Dunlop, R. A., M. J. Noad, R. D. McCauley, E. Kniest, D. Paton, and D. H. Cato. (2015). The behavioural response of humpback whales (*Megaptera novaeangliae*) to a 20 cubic inch air gun. *Aquatic Mammals* 41 (4): 412.

- Dunlop, R. A., M. J. Noad, R. D. McCauley, E. Kniest, R. Slade, D. Paton, and D. H. Cato. (2016). Response of humpback whales (*Megaptera novaeangliae*) to ramp-up of a small experimental air gun array. *Marine Pollution Bulletin* 103 (1–2): 72–83. DOI:10.1016/j.marpolbul.2015.12.044
- Dunlop, R. A., M. J. Noad, R. D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D. H. Cato. (2017). Determining the behavioural dose-response relationship of marine mammals to air gun noise and source proximity. *The Journal of Experimental Biology* 220 (16): 2878–2886. DOI:10.1242/jeb.160192
- Durbach, I. N., C. M. Harris, C. Martin, T. A. Helble, E. E. Henderson, G. Lerley, L. Thomas, and S. W. Martin. (2021). Changes in the Movement and Calling Behavior of Minke Whales (*Balaenoptera acutorostrata*) in Response to Navy Training. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.660122
- Durban, J. W., H. Fearnbach, L. G. Barrett-Lennard, W. L. Perryman, and D. J. Leroi. (2015). Photogrammetry of killer whales using a small hexacopter launched at sea. *Journal of Unmanned Vehicle Systems* 3 (3): 131–135.
- Durban, J. W., B. L. Southall, J. Calambokidis, C. Casey, H. Fearnbach, T. W. Joyce, J. A. Fahlbusch, M. G. Oudejans, S. Fregosi, A. S. Friedlaender, N. M. Kellar, and F. Visser. (2022). Integrating remote sensing methods during controlled exposure experiments to quantify group responses of dolphins to navy sonar. *Marine Pollution Bulletin* 174 113–194. DOI:10.1016/j.marpolbul.2021.113194
- Dyndo, M., D. M. Wisniewska, L. Rojano-Donate, and P. T. Madsen. (2015). Harbour porpoises react to low levels of high frequency vessel noise. *Scientific Reports* 5 11083. DOI:10.1038/srep11083
- Edds-Walton, P. L. (1997). Acoustic communication signals of mysticete whales. *Bioacoustics* 8 47–60.
- Eisenhardt, E. (2014). *Recent Trends of Vessel Activities in Proximity to Cetaceans in the Central Salish Sea*. Presented at the Salish Sea Ecosystem Conference. Seattle, WA. Retrieved from <http://cedar.wvu.edu/ssec/2014ssec/Day2/130/>.
- Elkhorn Slough National Estuarine Research Reserve. (2011). *Parsons Slough Project 30 Day Post Construction Report* (Parsons Slough Project). Watsonville, CA: Elkhorn Slough National Estuarine Research Reserve.
- Eller, A. I. and R. C. Cavanagh. (2000). *Subsonic Aircraft Noise at and Beneath the Ocean Surface: Estimation of Risk for Effects on Marine Mammals*. McLean, VA: United States Air Force Research Laboratory.
- Ellis, D. H. (1981). *Responses of Raptorial Birds to Low Level Military Jets and Sonic Booms* (Results of the 1980-1981 joint U.S. Air Force-U.S. Fish and Wildlife Service Study). Oracle, AZ: Institute for Raptor Studies.
- Ellison, W. T., B. L. Southall, C. W. Clark, and A. S. Frankel. (2011). A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. *Conservation Biology* 26 (1): 21–28.
- Elmegaard, S. L., B. I. McDonald, J. Teilmann, and P. T. Madsen. (2021). Heart rate and startle responses in diving, captive harbour porpoises (*Phocoena phocoena*) exposed to transient noise and sonar. *The Company of Biologists* 10. DOI:10.1242/bio.058679
- Elmegaard, S. L., J. Teilmann, L. Rojano-Donate, D. Brennecke, L. Mikkelsen, J. D. Balle, U. Gosewinkel, L. A. Kyhn, P. Tonnesen, M. Wahlberg, A. Ruser, U. Siebert, and P. T. Madsen. (2023). Wild harbour

- porpoises startle and flee at low received levels from acoustic harassment device. *Scientific Reports* 13 (1): 16691. DOI:10.1038/s41598-023-43453-8
- Engås, A., O. A. Misund, A. V. Soldal, B. Horvei, and A. Solstad. (1995). Reactions of penned herring and cod to playback of original, frequency-filtered and time-smoothed vessel sound. *Fisheries Research* 22 (3): 243–254.
- Enger, P. S. (1981). *Frequency Discrimination in Teleosts—Central or Peripheral?* New York, NY: Springer-Verlag.
- Erbe, C. (2002). Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science* 18 (2): 394–418.
- Erbe, C., S. A. Marley, R. P. Schoeman, J. N. Smith, L. E. Trigg, and C. B. Embling. (2019). The effects of ship noise on marine mammals—A review. *Frontiers in Marine Science* 6. DOI:10.3389/fmars.2019.00606
- Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, and R. Dooling. (2016). Communication masking in marine mammals: A review and research strategy. *Marine Pollution Bulletin* 103 (1–2): 15–38. DOI:10.1016/j.marpolbul.2015.12.007
- Erbe, C. and J. A. Thomas. (2022). *Exploring Animal Behavior Through Sound: Volume 1*. Cham, Switzerland: Springer.
- Erbe, C., R. Williams, D. Sandilands, and E. Ashe. (2014). Identifying modeled ship noise hotspots for marine mammals of Canada's Pacific region. *PLoS ONE* 9 (3): e89820. DOI:10.1371/journal.pone.0089820
- Erisman, B. E. and T. J. Rowell. (2017). A sound worth saving: acoustic characteristics of a massive fish spawning aggregation. *Biology Letters* 13 (12): 1–5. DOI:10.1098/rsbl.2017.0656
- Evans, P. G. H. and L. A. Miller. (2003). *Proceedings of the workshop on active sonar and cetaceans* (European Cetacean Society newsletter, No. 42—Special Issue). Las Palmas, Gran Canaria: European Cetacean Society.
- Fahlman, A., S. K. Hooker, A. Olszowka, B. L. Bostrom, and D. R. Jones. (2009). Estimating the effect of lung collapse and pulmonary shunt on gas exchange during breath-hold diving: The Scholander and Kooyman legacy. *Respiratory Physiology & Neurobiology* 165 (1): 28–39. DOI:10.1016/j.resp.2008.09.013
- Fahlman, A., M. J. Moore, and R. S. Wells. (2021). How do marine mammals manage and usually avoid gas emboli formation and gas embolic pathology? Critical clues from studies of wild dolphins. *Frontiers in Marine Science*, 8. Retrieved April 13, 2021, from <https://doi.org/10.3389/fmars.2021.598633>.
- Fahlman, A., A. Olszowka, B. Bostrom, and D. R. Jones. (2006). Deep diving mammals: Dive behavior and circulatory adjustments contribute to bends avoidance. *Respiratory Physiology and Neurobiology* 153 66–77.
- Fahlman, A., P. L. Tyack, P. J. O. Miller, and P. H. Kvadsheim. (2014). How man-made interference might cause gas bubble emboli in deep diving whales. *Frontiers in Physiology* 5 (13): 1–6. DOI:10.3389/fphys.2014.00013
- Fair, P. A., A. M. Schaefer, T. A. Romano, G. D. Bossart, S. V. Lamb, and J. S. Reif. (2014). Stress response of wild bottlenose dolphins (*Tursiops truncatus*) during capture-release health assessment

- studies. *General and Comparative Endocrinology* 206 203–212.
DOI:<http://dx.doi.org/10.1016/j.ygcen.2014.07.002>
- Fakan, E. P. and M. I. McCormick. (2019). Boat noise affects the early life history of two damselfishes. *Marine Pollution Bulletin* 141 493–500. DOI:10.1016/j.marpolbul.2019.02.054
- Falcone, E. A. and G. S. Schorr. (2012). *Distribution and Demographics of Marine Mammals in SOCAL Through Photo-Identification, Genetics, and Satellite Telemetry: A Summary of Surveys Conducted 1 July 2011 – 15 June 2012*. Monterey, CA: Naval Postgraduate School.
- Falcone, E. A. and G. S. Schorr. (2014). *Distribution and Demographics of Marine Mammals in SOCAL through Photo-Identification, Genetics, and Satellite Telemetry* (Prepared for Chief of Naval Operations Energy and Environmental Readiness Division: NPS-OC-14-005CR). Monterey, CA: Naval Postgraduate School.
- Falcone, E. A., G. S. Schorr, A. B. Douglas, J. Calambokidis, E. Henderson, M. F. McKenna, J. Hildebrand, and D. Moretti. (2009). Sighting characteristics and photo-identification of Cuvier's beaked whales (*Ziphius cavirostris*) near San Clemente Island, California: A key area for beaked whales and the military? *Marine Biology* 156 2631–2640.
- Falcone, E. A., G. S. Schorr, S. L. Watwood, S. L. DeRuiter, A. N. Zerbini, R. D. Andrews, R. P. Morrissey, and D. J. Moretti. (2017). Diving behaviour of Cuvier's beaked whales exposed to two types of military sonar. *Royal Society Open Science* 4 (170629): 1–21. DOI:10.1098/rsos.170629
- Falke, K. J., R. D. Hill, J. Qvist, R. C. Schneider, M. Guppy, G. C. Liggins, P. W. Hochachka, R. E. Elliott, and W. M. Zapol. (1985). Seal lungs collapse during free diving: Evidence from arterial nitrogen tensions. *Science* 229 556–558.
- Faria, A., P. J. Fonseca, M. Vieira, L. M. F. Alves, M. F. L. Lemos, S. C. Novais, A. B. Matos, D. Vieira, and M. C. P. Amorim. (2022). Boat noise impacts early life stages in the Lusitanian toadfish: A field experiment. *Science of the Total Environment* 811. DOI:10.1016/j.scitotenv.2021.151367
- Farmer, N. A., K. Baker, D. G. Zeddies, S. L. Denes, D. P. Noren, L. P. Garrison, A. Machernis, E. M. Fougères, and M. Zykov. (2018a). Population consequences of disturbance by offshore oil and gas activity for endangered sperm whales (*Physeter macrocephalus*). *Biological Conservation* 227 189–204. DOI:10.1016/j.biocon.2018.09.006
- Farmer, N. A., D. P. Noren, E. M. Fougères, A. Machernis, and K. Baker. (2018b). Resilience of the endangered sperm whale *Physeter macrocephalus* to foraging disturbance in the Gulf of Mexico, USA: A bioenergetic approach. *Marine Ecology Progress Series* 589 241–261. DOI:10.3354/meps12457
- Faulkner, S. G., W. M. Tonn, M. Welz, and D. R. Schmitt. (2006). Effects of explosives on incubating lake trout eggs in the Canadian Arctic. *North American Journal of Fisheries Management* 26 (4): 833–842. DOI:10.1577/m05-132.1
- Faulkner, S. G., M. Welz, W. M. Tonn, and D. R. Schmitt. (2008). Effects of simulated blasting on mortality of rainbow trout eggs. *Transactions of the American Fisheries Society* 137 (1): 1–12. DOI:10.1577/t07-035.1
- Fay, R. R. and A. N. Popper. (1994). *Comparative Hearing: Mammals*. New York, NY: Springer-Verlag.
- Ferguson, M. C., J. Barlow, P. Feidler, S. B. Reilly, and T. Gerrodette. (2006). Spatial models of delphinid (family Delphinidae) encounter rate and group size in the eastern tropical Pacific Ocean. *Ecological Modelling* 193 645–662.

- Fernandes, P. G., A. S. Brierley, E. J. Simmonds, N. W. Millard, S. D. McPhail, F. Armstrong, P. Stevenson, and M. Squires. (2000). Fish do not avoid survey vessels (plus addendum). *Nature* 404 35-36. DOI:<https://doi.org/10.1038/35003648>
- Fernandez, A. (2006). *Beaked Whale (Ziphius cavirostris) Mass Stranding on Almeria's Coasts in Southern Spain*. Las Palmas, Canary Islands: University of Las Palmas de Gran Canaria.
- Fernandez, A., J. Edwards, F. Rodriguez, A. Espinosa De Los Monteros, P. Herraiez, P. Castro, J. Jaber, V. Martin, and M. Arbelo. (2005). "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family *Ziphiidae*) exposed to anthropogenic sonar signals. *Veterinary Pathology* 42 (4): 446–457.
- Fernandez, A., E. Sierra, J. Diaz-Delgado, S. Sacchini, Y. Sanchez-Paz, C. Suarez-Santana, M. Arregui, M. Arbelo, and Y. Bernaldo de Quiros. (2017). Deadly acute decompression sickness in Risso's dolphins. *Scientific Reports* 7 (1): 13621. DOI:10.1038/s41598-017-14038-z
- Ferrara, C. R., R. C. Vogt, M. R. Harfush, R. S. Sousa-Lima, E. Albavera, and A. Tavera. (2014). First evidence of leatherback turtle (*Dermochelys coriacea*) embryos and hatchlings emitting sounds. *Chelonian Conservation and Biology* 13 (1): 110–114.
- Ferrara, C. R., R. C. Vogt, R. S. Sousa-Lima, A. Lenz, and J. E. Morales-Mávil. (2019). Sound communication in embryos and hatchlings of *Lepidochelys kempii*. *Chelonian Conservation and Biology* 18 (2). DOI:10.2744/ccb-1386.1
- Ferrari, M. C. O., M. I. McCormick, M. G. Meekan, S. D. Simpson, S. L. Nedelec, and D. P. Chivers. (2018). School is out on noisy reefs: The effect of boat noise on predator learning and survival of juvenile coral reef fishes. *Proceedings B: Biological Sciences* 285 (1871). DOI:10.1098/rspb.2018.0033
- Ferrier-Pages, C., M. C. Leal, R. Calado, D. W. Schmid, F. Bertucci, D. Lecchini, and D. Allemand. (2021). Noise pollution on coral reefs? - A yet underestimated threat to coral reef communities. *Marine Pollution Bulletin* 165 112–129. DOI:10.1016/j.marpolbul.2021.112129
- Fetherston, T., S. Turner, G. Mitchell, and E. Guzas. (2019). Marine mammal lung dynamics when exposed to underwater explosion impulse. *The Anatomical Record* 302 (5): 718-734. DOI:10.1002/ar.24033
- Fewtrell, J. L. and R. D. McCauley. (2012). Impact of air gun noise on the behaviour of marine fish and squid. *Marine Pollution Bulletin* 64 (5): 984–993. DOI:10.1016/j.marpolbul.2012.02.009
- Filadelfo, R., J. Mintz, E. Michlovich, A. D'Amico, and D. R. Ketten. (2009a). Correlating military sonar use with beaked whale mass strandings: What do the historical data show? *Aquatic Mammals* 35 (4): 435–444.
- Filadelfo, R., Y. K. Pinelis, S. Davis, R. Chase, J. Mintz, J. Wolfanger, P. L. Tyack, D. R. Ketten, and A. D'Amico. (2009b). Correlating whale strandings with Navy exercises off Southern California. *Aquatic Mammals* 35 (4): 445–451. DOI:10.1578/am.35.4.2009.445
- Findlay, C. R., F. G. Coomber, R. Dudley, L. Bland, S. V. Calderan, L. Hartny-Mills, R. Leaper, J. Tougaard, N. D. Merchant, D. Risch, and B. Wilson. (2024). Harbour porpoises respond to chronic acoustic deterrent device noise from aquaculture. *Biological Conservation* 293. DOI:10.1016/j.biocon.2024.110569

- Finneran, J. J. (2003). Whole-lung resonance in a bottlenose dolphin (*Tursiops truncatus*) and white whale (*Delphinapterus leucas*). *The Journal of the Acoustical Society of America* 114 (1): 529–535.
- Finneran, J. J. (2015). Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. *The Journal of the Acoustical Society of America* 138 (3): 1702–1726. DOI:10.1121/1.4927418
- Finneran, J. J. (2018). Conditioned attenuation of auditory brainstem responses in dolphins warned of an intense noise exposure: Temporal and spectral patterns. *The Journal of the Acoustical Society of America* 143 (2): 795. DOI:10.1121/1.5022784
- Finneran, J. J. and B. K. Branstetter. (2013). Effects of Noise on Sound Perception in Marine Mammals *Animal Communication and Noise* (Vol. 2, pp. 273–308). Berlin, Germany: Springer Berlin Heidelberg.
- Finneran, J. J., D. A. Carder, R. Dear, T. Belting, and S. H. Ridgway. (2003a). Pure-tone audiograms and hearing loss in the white whale (*Delphinapterus leucas*). *The Journal of the Acoustical Society of America* 114 2434(A).
- Finneran, J. J., D. A. Carder, and S. H. Ridgway. (2001). Temporary threshold shift (TTS) in bottlenose dolphins (*Tursiops truncatus*) exposed to tonal signals. *The Journal of the Acoustical Society of America* 110 (5): 2749(A).
- Finneran, J. J., D. A. Carder, C. E. Schlundt, and R. L. Dear. (2010a). Growth and recovery of temporary threshold shift at 3 kHz in bottlenose dolphins: Experimental data and mathematical models. *The Journal of the Acoustical Society of America* 127 (5): 3256–3266.
- Finneran, J. J., D. A. Carder, C. E. Schlundt, and R. L. Dear. (2010b). Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. *The Journal of the Acoustical Society of America* 127 (5): 3267–3272. DOI:10.1121/1.3377052
- Finneran, J. J., D. A. Carder, C. E. Schlundt, and S. H. Ridgway. (2005). Temporary threshold shift (TTS) in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. *The Journal of the Acoustical Society of America* 118 (4): 2696–2705.
- Finneran, J. J., R. Dear, D. A. Carder, and S. H. Ridgway. (2003b). Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. *The Journal of the Acoustical Society of America* 114 (3): 1667–1677.
- Finneran, J. J., K. Lally, J. Mulsow, and D. S. Houser. (2024). Dolphin short-term auditory fatigue and self-mitigation. *The Journal of the Acoustical Society of America* 155 (3): 2241–2246. DOI:10.1121/10.0025387
- Finneran, J. J., K. Lally, M. G. Strahan, K. Donohoe, J. Mulsow, and D. S. Houser. (2023). Dolphin conditioned hearing attenuation in response to repetitive tones with increasing level. *The Journal of the Acoustical Society of America* 153 (1): 496–504. DOI:10.1121/10.0016868
- Finneran, J. J. and C. E. Schlundt. (2004). *Effects of Intense Pure Tones on the Behavior of Trained Odontocetes*. San Diego, CA: Space and Naval Warfare Systems Center Pacific.
- Finneran, J. J. and C. E. Schlundt. (2013). Effects of fatiguing tone frequency on temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 133 (3): 1819–1826. DOI:<http://dx.doi.org/10.1121/1.4776211>

- Finneran, J. J., C. E. Schlundt, B. Branstetter, and R. L. Dear. (2007). Assessing temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) using multiple simultaneous auditory evoked potentials. *The Journal of the Acoustical Society of America* 122 (2): 1249–1264. DOI:10.1121/1.2749447
- Finneran, J. J., C. E. Schlundt, B. K. Branstetter, J. S. Trickey, V. Bowman, and K. Jenkins. (2015). Effects of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior. *The Journal of the Acoustical Society of America* 137 (4): 1634–1646. DOI:10.1121/1.4916591
- Finneran, J. J., C. E. Schlundt, D. A. Carder, J. A. Clark, J. A. Young, J. B. Gaspin, and S. H. Ridgway. (2000). Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. *The Journal of the Acoustical Society of America* 108 (1): 417–431.
- Finneran, J. J., C. E. Schlundt, R. Dear, D. A. Carder, and S. H. Ridgway. (2002). Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *The Journal of the Acoustical Society of America* 111 (6): 2929–2940. DOI:10.1121/1.1479150
- Fiori, L., E. Martinez, M. B. Orams, and B. Bollard. (2019). Effects of whale-based tourism in Vava'u, Kingdom of Tonga: Behavioural responses of humpback whales to vessel and swimming tourism activities. *PLoS ONE* 14 (7). DOI:10.1371/journal.pone.0219364
- Fish, J. F. and J. S. Vania. (1971). Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. *Fishery Bulletin* 69 (3): 531–535.
- Fitch, J. E. and P. H. Young. (1948). *Use and Effect of Explosives in California Coastal Waters*. Sacramento, CA: California Division Fish and Game.
- Fitch, R., J. Harrison, and J. Lewandowski. (2011). *Marine Mammal and Sound Workshop July 13th and 14th, 2010: Report to the National Ocean Council Ocean Science and Technology Interagency Policy Committee*. Washington, DC: Bureau of Ocean Energy Management; U.S. Department of the Navy; National Oceanic and Atmospheric Administration.
- Flower, J. E., T. M. Norton, K. M. Andrews, S. E. Nelson, Jr., C. E. Parker, L. M. Romero, and M. A. Mitchell. (2015). Baseline plasma corticosterone, haematological and biochemical results in nesting and rehabilitating loggerhead sea turtles (*Caretta caretta*). *Conservation Physiology* 3 (1): cov003. DOI:10.1093/conphys/cov003
- Foote, A. D., R. W. Osborne, and A. R. Hoelzel. (2004). Whale-call response to masking boat noise. *Nature* 428 910.
- Forney, K. A., B. L. Southall, E. Slooten, S. Dawson, A. J. Read, R. W. Baird, and R. L. Brownell, Jr. (2017). Nowhere to go: Noise impact assessments for marine mammal populations with high site fidelity. *Endangered Species Research* 32 391–413.
- Fournet, M. E. H., L. P. Matthews, C. M. Bagriale, S. Haver, D. K. Mellinger, and H. Klinck. (2018). Humpback whales *Megaptera novaeangliae* alter calling behavior in response to natural sounds and vessel noise. *Marine Ecology Progress Series* 607 251–268.
- Fournet, M. E. H., M. Silvestri, C. W. Clark, H. Klinck, and A. N. Rice. (2021). Limited vocal compensation for elevated ambient noise in bearded seals: Implications for an industrializing Arctic Ocean. *Proceedings of the Royal Society B*, 288. Retrieved April 16, 2021, from <https://doi.org/10.1098/rspb.2020.2712>.

- Frankel, A. S. and C. W. Clark. (2000). Behavioral responses of humpback whales (*Megaptera novaeangliae*) to full-scale ATOC signals. *The Journal of the Acoustical Society of America* 108 (4): 1930–1937.
- Frankel, A. S. and P. J. Stein. (2020). Gray whales hear and respond to signals from a 21–25 kHz active sonar. *Marine Mammal Science*. DOI:10.1111/mms.12700
- Frankish, C. K., A. M. von Benda-Beckmann, J. Teilmann, J. Tougaard, R. Dietz, S. Sveegaard, B. Binnerts, C. A. F. de Jong, and J. Nabe-Nielsen. (2023). Ship noise causes tagged harbour porpoises to change direction or dive deeper. *Marine Pollution Bulletin* 197 115755. DOI:10.1016/j.marpolbul.2023.115755
- Frazer, L. N. and E. Mercado, III. (2000). A Sonar Model for Humpback Whale Song. *IEEE Journal of Oceanic Engineering* 25 (1): 160–182.
- Fricke, R., W. Eschmeyer, and J. D. Fong. (2020). *Eschmeyer's Catalog of Fishes*. San Francisco, CA: California Academy of Sciences.
- Friedlaender, A. S., E. L. Hazen, J. A. Goldbogen, A. K. Stimpert, J. Calambokidis, and B. L. Southall. (2016). Prey-mediated behavioral responses of feeding blue whales in controlled sound exposure experiments. *Ecological Applications* 26 (4): 1075–1085.
- Frisk, G. V. (2012). Noiseconomics: The relationship between ambient noise levels in the sea and global economic trends. *Scientific Reports* 2 (437): 1–4. DOI:10.1038/srep00437
- Fristrup, K. M., L. T. Hatch, and C. W. Clark. (2003). Variation in humpback whale (*Megaptera novaeangliae*) song length in relation to low-frequency sound broadcasts. *The Journal of the Acoustical Society of America* 113 (6): 3411–3424. DOI:10.1121/1.1573637
- Fromm, D. M. (2009). *Reconstruction of Acoustic Exposure on Orcas in Haro Strait* (Acoustics). Washington, DC: U.S. Naval Research Laboratory.
- Fumagalli, M., A. Cesario, M. Costa, J. Harraway, G. Notarbartolo di Sciara, and E. Slooten. (2018). Behavioural responses of spinner dolphins to human interactions. *Royal Society Open Science* 5 (4): 172044. DOI:10.1098/rsos.172044
- Gabriele, C. M., D. W. Ponirakis, C. W. Clark, J. N. Womble, and P. B. S. Vanselow. (2018). Underwater Acoustic Ecology Metrics in an Alaska Marine Protected Area Reveal Marine Mammal Communication Masking and Management Alternatives. *Frontiers in Marine Science* 5 (270): 1–17.
- Gailey, G., O. Sychenko, T. McDonald, R. Racca, A. Rutenko, and K. Bröker. (2016). Behavioural responses of western gray whales to a 4-D seismic survey off northeastern Sakhalin Island, Russia. *Endangered Species Research* 30 53–71. DOI:10.3354/esr00713
- Gailey, G., O. Sychenko, M. Zykov, A. Rutenko, A. Blanchard, and R. H. Melton. (2022). Western gray whale behavioral response to seismic surveys during their foraging season. *Environmental Monitoring and Assessment* 194 (Suppl 1): 740. DOI:10.1007/s10661-022-10023-w
- Gailey, G., B. Wursig, and T. L. McDonald. (2007). Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, Northeast Sakhalin Island, Russia. *Environmental Monitoring and Assessment* 134 75–91.
- Gallagher, C. A., V. Grimm, L. A. Kyhn, C. C. Kinze, and J. Nabe-Nielsen. (2021). Movement and seasonal energetics mediate vulnerability to disturbance in marine mammal populations. *The American Naturalist* 197 (3): 296–311.

- Garcia-Parraga, D., J. L. Crespo-Picazo, Y. B. de Quiros, V. Cervera, L. Marti-Bonmati, J. Diaz-Delgado, M. Arbelo, M. J. Moore, P. D. Jepson, and A. Fernandez. (2014). Decompression sickness ('the bends') in sea turtles. *Diseases of Aquatic Organisms* 111 (3): 191–205. DOI:10.3354/dao02790
- Garcia Parraga, D., M. Moore, and A. Fahlman. (2018). Pulmonary ventilation-perfusion mismatch: A novel hypothesis for how diving vertebrates may avoid the bends. *Proceedings of the Royal Society B: Biological Sciences* 285 (1877). DOI:10.1098/rspb.2018.0482
- Garrick, L. D., J. W. Lang, and H. A. Herzog. (1978). Social signals of adult American alligators. *Bulletin of the American Museum of Natural History* 160 (3): 163–192.
- Gaspard, J. C., G. B. Bauer, R. L. Reep, K. Dziuk, A. Cardwell, L. Read, and D. A. Mann. (2012). Audiogram and auditory critical ratios of two Florida manatees (*Trichechus manatus latirostris*). *The Journal of Experimental Biology* 215 (Pt 9): 1442–1447. DOI:10.1242/jeb.065649
- Gaspin, J. B. (1975). *Experimental Investigations of the Effects of Underwater Explosions on Swimbladder Fish, I: 1973 Chesapeake Bay Tests*. Silver Spring, MD: Naval Surface Weapons Center, White Oak Laboratory.
- Gaspin, J. B., G. B. Peters, and M. L. Wisely. (1976). *Experimental Investigations of the Effects of Underwater Explosions on Swimbladder Fish*. Silver Spring, MD: Naval Ordnance Lab.
- Gende, S. M., A. N. Hendrix, K. R. Harris, B. Eichenlaub, J. Nielsen, and S. Pyare. (2011). A Bayesian approach for understanding the role of ship speed in whale-ship encounters. *Ecological Applications* 21 (6): 2232–2240.
- Gendron, G., R. Tremblay, A. Jolivet, F. Olivier, L. Chauvaud, G. Winkler, and C. Audet. (2020). Anthropogenic boat noise reduces feeding success in winter flounder larvae (*Pseudopleuronectes americanus*). *Environmental Biology of Fishes* 103 1079–1090. DOI:10.1007/s10641-020-01005-3
- Gervaise, C., Y. Simard, N. Roy, B. Kinda, and N. Menard. (2012). Shipping noise in whale habitat: Characteristics, sources, budget, and impact on belugas in Saguenay–St. Lawrence Marine Park hub. *The Journal of the Acoustical Society of America* 132 (1): 76–89.
- Ghoul, A. and C. Reichmuth. (2014a). Hearing in sea otters (*Enhydra lutris*): Audible frequencies determined from a controlled exposure approach. *Aquatic Mammals* 40 (3): 243–251. DOI:10.1578/am.40.3.2014.243
- Ghoul, A. and C. Reichmuth. (2014b). Hearing in the sea otter (*Enhydra lutris*): Auditory profiles for an amphibious marine carnivore. *Journal of Comparative Physiology A: Neuroethology, Sensory Neural, and Behavioral Physiology* 200 (11): 967–981. DOI:10.1007/s00359-014-0943-x
- Giles, J. C., J. A. Davis, R. D. McCauley, and G. Kuchling. (2009). Voice of the turtle: the underwater acoustic repertoire of the long-necked freshwater turtle, *Chelodina oblonga*. *The Journal of the Acoustical Society of America* 126 (1): 434–443. DOI:10.1121/1.3148209
- Girola, E., R. A. Dunlop, and M. J. Noad. (2023). Singing humpback whales respond to wind noise, but not to vessel noise. *Proceeding of the Royal Society B* 290 (1998). DOI:10.1098/rspb.2023.0204
- Gitschlag, G. R., M. J. Schirripa, and J. E. Powers. (2000). *Estimation of Fisheries Impacts Due to Underwater Explosives Used to Sever and Salvage Oil and Gas Platforms in the U.S. Gulf of Mexico: Final Report*. Washington, DC: U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region.

- Gjertz, I. and A. Børset. (1992). Pupping in the most northerly harbor seal (*Phoca vitulina*). *Marine Mammal Science* 8 (2): 103–109.
- Gleich, O. and G. A. Manley. (2000). The hearing organ of birds and crocodilia. In R. Dooling, A. N. Popper, & R. R. Fay Springer-Verlag (Eds.), *Comparative Hearing: Birds and Reptiles* (pp. 70–138). New York, NY: Springer Handbook of Auditory Research.
- Goertner, J. F. (1978). *Dynamical Model for Explosion Injury to Fish*. Dalgren, VA: U.S. Department of the Navy, Naval Surface Weapons Center.
- Goertner, J. F. (1982). *Prediction of Underwater Explosion Safe Ranges for Sea Mammals*. Dahlgren, VA: Naval Surface Weapons Center.
- Goertner, J. F., M. L. Wiley, G. A. Young, and W. W. McDonald. (1994). *Effects of Underwater Explosions on Fish Without Swimbladders*. Silver Spring, MD: Naval Surface Warfare Center.
- Goetz, S., M. B. Santos, J. Vingada, D. C. Costas, A. G. Villanueva, and G. J. Pierce. (2015). Do pingers cause stress in fish? An experimental tank study with European sardine, *Sardina pilchardus* (Walbaum, 1792) (Actinopterygii, Clupeidae), exposed to a 70 kHz dolphin pinger. *Hydrobiologia* 749 (1): 83–96. DOI:10.1007/s10750-014-2147-3
- Goldbogen, J. A., B. L. Southall, S. L. DeRuiter, J. Calambokidis, A. S. Friedlaender, E. L. Hazen, E. A. Falcone, G. S. Schorr, A. Douglas, D. J. Moretti, C. Kyburg, M. F. McKenna, and P. L. Tyack. (2013). Blue whales respond to simulated mid-frequency military sonar. *Proceedings of the Royal Society B: Biological Sciences* 280 (1765): 20130657. DOI:10.1098/rspb.2013.0657
- Gong, Z., A. D. Jain, D. Tran, D. H. Yi, F. Wu, A. Zorn, P. Ratilal, and N. C. Makris. (2014). Ecosystem scale acoustic sensing reveals humpback whale behavior synchronous with herring spawning processes and re-evaluation finds no effect of sonar on humpback song occurrence in the Gulf of Maine in fall 2006. *PLoS ONE* 9 (10): e104733. DOI:10.1371/journal.pone.0104733
- Gonzalez-Socoloske, D. and L. D. Olivera-Gomez. (2012). Gentle giants in dark waters: using side-scan sonar for manatee research. *The Open Remote Sensing Journal* 5 (1): 1–14. DOI:10.2174/1875413901205010001
- Gonzalez-Socoloske, D., L. D. Olivera-Gomez, and R. E. Ford. (2009). Detection of free-ranging West Indian manatees *Trichechus manatus* using side-scan sonar. *Endangered Species Research* 8 249–257.
- Gonzalez-Terrazas, T. P., J. C. Koblitz, T. H. Fleming, R. A. Medellín, E. K. Kalko, H. U. Schnitzler, and M. Tschapka. (2016). How nectar-feeding bats localize their food: Echolocation behavior of *leptonycteris yerbabuenae* approaching cactus flowers. *PLoS ONE* 11 (9): e0163492. DOI:10.1371/journal.pone.0163492
- Goodwin, S. E. and J. Podos. (2013). Shift of song frequencies in response to masking tones. *Animal Behaviour* 85 435–440. DOI:10.1016/j.anbehav.2012.12.003
- Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M. P. Simmonds, R. Swift, and D. Thompson. (2003). A review of the effects of seismic surveys on marine mammals. *Marine Technology Society Journal* 37 (4): 16–34.
- Gospić, N. R. and M. Picciulin. (2016). Changes in whistle structure of resident bottlenose dolphins in relation to underwater noise and boat traffic. *Marine Pollution Bulletin* 105 193–198.
- Götz, T. and V. M. Janik. (2010). Aversiveness of sounds in phocid seals: Psycho-physiological factors, learning processes and motivation. *The Journal of Experimental Biology* 213 1536–1548.

- Götz, T. and V. M. Janik. (2011). Repeated elicitation of the acoustic startle reflex leads to sensation in subsequent avoidance behaviour and induces fear conditioning. *BMC Neuroscience* 12 (30): 13.
- Gotz, T., A. F. Pacini, P. E. Nachtigall, and V. M. Janik. (2020). The startle reflex in ecological odontocetes: Basic physiology and practical implications. *Journal of Experimental Biology* 223.
- Goudie, R. I. and I. L. Jones. (2004). Dose-response relationships of harlequin duck behavior to noise from low-level military jet over-flights in central Labrador. *Environmental Conservation* 31 (4): 289–298.
- Govoni, J. J., L. R. Settle, and M. A. West. (2003). Trauma to juvenile pinfish and spot inflicted by submarine detonations. *Journal of Aquatic Animal Health* 15 111–119.
- Govoni, J. J., M. A. West, L. R. Settle, R. T. Lynch, and M. D. Greene. (2008). Effects of Underwater Explosions on Larval Fish: Implications for a Coastal Engineering Project. *Journal of Coastal Research* 2 228–233. DOI:10.2112/05-0518.1
- Graham, I. M., N. D. Merchant, A. Farcas, T. R. Barton, B. Cheney, S. Bono, and P. M. Thompson. (2019). Harbour porpoise responses to pile-driving diminish over time. *Royal Society Open Science* 6 (6). DOI:10.1098/rsos.190335
- Gransier, R. and R. A. Kastelein. (2024). Similar susceptibility to temporary hearing threshold shifts despite different audiograms in harbor porpoises and harbor seals. *The Journal of the Acoustical Society of America* 155 (1): 396–404. DOI:10.1121/10.0024343
- Greaves, F. C., R. H. Draeger, O. A. Brines, J. S. Shaver, and E. L. Corey. (1943). An experimental study of concussion. *United States Naval Medical Bulletin* 41 (1): 339–352.
- Green, D. M. (1994). Sound's effects on marine mammals need investigation. *Eos* 75(27) 305–306.
- Green, D. M., H. DeFerrari, D. McFadden, J. Pearse, A. Popper, W. J. Richardson, S. H. Ridgway, and P. Tyack. (1994). *Low-Frequency Sound and Marine Mammals: Current Knowledge and Research Needs*. Washington, DC: Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council.
- Green, G. A., J. J. Brueggeman, R. A. Grotefendt, C. E. Bowlby, M. L. Bonnell, and K. C. Balcomb, III. (1992). *Cetacean Distribution and Abundance off Oregon and Washington, 1989–1990*. Los Angeles, CA: U.S. Department of the Interior, Minerals Management Service.
- Greene, C. R. and W. J. Richardson. (1988). Characteristics of marine seismic survey sounds in the Beaufort Sea. *The Journal of the Acoustical Society of America* 83 (6): 2246–2254. DOI:10.1121/1.396354
- Gregory, L. F. and J. R. Schmid. (2001). Stress response and sexing of wild Kemp's ridley sea turtles (*Lepidochelys kempii*) in the Northeastern Gulf of Mexico. *General and Comparative Endocrinology* 124 66–74. DOI:10.1006/gcen.2001.7683
- Gregory, P. R. and A. A. Rowden. (2001). Behaviour patterns of bottlenose dolphins (*Tursiops truncatus*) relative to tidal state, time-of-day, and boat traffic in Cardigan Bay, West Wales. *Aquatic Mammals* 27.2 105–114.
- Griffin, D. R., J. J. G. McCue, and A. D. Grinnell. (1962). The resistance of bats to jamming. *Journal of Experimental Zoology* (285): 1–34. DOI:10.1002/jez.1401520303

- Grigg, G. and C. Gans. (1993). Morphology and physiology of the Crocodylia *Fauna of Australia Vol 2A Amphibia and Reptilia* (pp. 326–336). Canberra, Australia: Australian Government Publishing Service.
- Guerra, M., S. M. Dawson, T. E. Brough, and W. J. Rayment. (2014). Effects of boats on the surface and acoustic behaviour of an endangered population of bottlenose dolphins. *Endangered Species Research* 24 (3): 221–236. DOI:10.3354/esr00598
- Guh, Y. J., Y. C. Tseng, and Y. T. Shao. (2021). To cope with a changing aquatic soundscape: Neuroendocrine and antioxidant responses to chronic noise stress in fish. *General and Comparative Endocrinology* 314 113918. DOI:10.1016/j.ygcen.2021.113918
- Haelters, J., V. Dulière, L. Vigin, and S. Degraer. (2014). Towards a numerical model to simulate the observed displacement of harbour porpoises *Phocoena phocoena* due to pile driving in Belgian waters. *Hydrobiologia* 756 (1): 105–116. DOI:10.1007/s10750-014-2138-4
- Hage, S. R., T. Jiang, S. W. Berquist, J. Feng, and W. Metzner. (2013). Ambient noise induces independent shifts in call frequency and amplitude within the Lombard effect in echolocating bats. *Proceedings of the National Academy of Sciences* 110 (10): 4063–4068. DOI:10.1073/pnas.1211533110
- Halvorsen, M. B., B. M. Casper, F. Matthews, T. J. Carlson, and A. N. Popper. (2012a). Effects of exposure to pile-driving sounds on the lake sturgeon, Nile tilapia and hogchoker. *Proceedings of the Royal Society B: Biological Sciences* 279 (1748): 4705–4714. DOI:10.1098/rspb.2012.1544
- Halvorsen, M. B., B. M. Casper, C. M. Woodley, T. J. Carlson, and A. N. Popper. (2011). *Hydroacoustic Impacts on Fish from Pile Installation* (Research Results Digest). Washington, DC: National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences.
- Halvorsen, M. B., B. M. Casper, C. M. Woodley, T. J. Carlson, and A. N. Popper. (2012b). Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. *PLoS ONE* 7 (6): e38968. DOI:10.1371/journal.pone.0038968
- Halvorsen, M. B., D. G. Zeddies, D. Chicoine, and A. N. Popper. (2013). Effects of low-frequency naval sonar exposure on three species of fish. *The Journal of the Acoustical Society of America* 134 (2): EL205–210. DOI:10.1121/1.4812818
- Halvorsen, M. B., D. G. Zeddies, W. T. Ellison, D. R. Chicoine, and A. N. Popper. (2012c). Effects of mid-frequency active sonar on hearing in fish. *The Journal of the Acoustical Society of America* 131 (1): 599–607.
- Hamernik, R. P. and K. D. Hsueh. (1991). Impulse noise: Some definitions, physical acoustics and other considerations. *The Journal of the Acoustical Society of America* 90 (1): 189–196.
- Hance, A. J., E. D. Robin, J. B. Halter, N. Lewiston, D. A. Robin, L. Cornell, M. Caligiuri, and J. Theodore. (1982). Hormonal changes and enforced diving in the harbor seal *Phoca vitulina* II. Plasma catecholamines. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology* 242 (5): R528–R532.
- Handegard, N. O., K. Michalsen, and D. Tjøstheim. (2003). Avoidance behaviour in cod (*Gadus morhua*) to a bottom-trawling vessel. *Aquatic Living Resources* 16 (3): 265–270.
- Handegard, N. O., A. D. Robertis, G. Rieucou, K. Boswell, G. J. Macaulay, and J. M. Jech. (2015). The reaction of a captive herring school to playbacks of a noise-reduced and a conventional research

- vessel. *Canadian Journal of Fisheries and Aquatic Sciences* 72 (4): 491–499. DOI:10.1139/cjfas-2014-0257
- Hansen, K. A., A. Hernandez, T. A. Mooney, M. H. Rasmussen, K. Sorensen, and M. Whalberg. (2020). The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound. *The Journal of the Acoustical Society of America* 147 (6): 4069–4074.
- Hansen, K. A., A. Maxwell, U. Siebert, O. N. Larsen, and M. Wahlberg. (2017). Great cormorants (*Phalacrocorax carbo*) can detect auditory cues while diving. *The Science of Nature* 104 (5–6): 45. DOI:10.1007/s00114-017-1467-3
- Harcourt, R., V. Pirotta, G. Heller, V. Peddemors, and D. Slip. (2014). A whale alarm fails to deter migrating humpback whales: An empirical test. *Endangered Species Research* 25 (1): 35–42. DOI:10.3354/esr00614
- Harris, C. M., M. L. Burt, A. N. Allen, P. J. Wensveen, P. J. O. Miller, and L. D. Sivle. (2019a). Foraging behavior and disruption in Blue, Fin, and Humpback Whales in relation to sonar exposure: The challenges of generalizing responsiveness in species with high individual variability. *Aquatic Mammals* 45 (6): 646–660. DOI:10.1578/am.45.6.2019.646
- Harris, C. M., S. W. Martin, C. Martin, T. A. Helble, E. E. Henderson, C. G. M. Paxton, and L. Thomas. (2019b). Changes in the spatial distribution of acoustically derived minke whale (*Balaenoptera acutorostrata*) tracks in response to Navy training. *Aquatic Mammals* 45 (6): 661–674. DOI:10.1578/am.45.6.2019.661
- Harris, C. M., D. Sadykova, S. L. DeRuiter, P. L. Tyack, P. J. O. Miller, P. H. Kvadsheim, F. P. A. Lam, and L. Thomas. (2015). Dose response severity functions for acoustic disturbance in cetaceans using recurrent event survival analysis. *Ecosphere* 6 (11): art236. DOI:10.1890/es15-00242.1
- Harris, C. M., L. Thomas, E. A. Falcone, J. Hildebrand, D. Houser, P. H. Kvadsheim, F.-P. A. Lam, P. J. O. Miller, D. J. Moretti, A. J. Read, H. Slabbekoorn, B. L. Southall, P. L. Tyack, D. Wartzkow, V. M. Janik, and J. Blanchard. (2018). Marine mammals and sonar: Dose-response studies, the risk-disturbance hypothesis and the role of exposure context. *Journal of Applied Ecology* 55 (1): 396–404. DOI:10.1111/1365-2664.12955
- Harris, G. G. and W. A. van Bergeijk. (1962). Evidence that the lateral-line organ responds to near-field displacements of sound sources in water. *The Journal of The Acoustical Society of America* 34 (12): 1831–1841. DOI:<https://doi.org/10.1121/1.1909138>
- Hashino, E., M. Sokabe, and K. Miyamoto. (1988). Frequency specific susceptibility to acoustic trauma in the budgerigar (*Melopsittacus undulatus*). *The Journal of the Acoustical Society of America* 83 (6): 2450–2453.
- Hastie, G., N. Merchant, T. Gotz, D. J. Russell, P. Thompson, and V. M. Janik. (2019). Effects of impulsive noise on marine mammals: Investigating range-dependent risk. *Ecological Applications* 25 (5): 1–10. DOI:10.5061/dryad.qg41t6k
- Hastie, G. D., C. Donovan, T. Gotz, and V. M. Janik. (2014). Behavioral responses by grey seals (*Halichoerus grypus*) to high frequency sonar. *Marine Pollution Bulletin* 79 (1-2): 205–210. DOI:10.1016/j.marpolbul.2013.12.013
- Hastie, G. D., P. Lepper, C. McKnight, R. Milne, D. J. F. Russell, and D. Thompson. (2021). Acoustic risk balancing by marine mammals: anthropogenic noise can influence the foraging decisions by seals. *British Ecological Society*. DOI:10.1111/1365-2664.13931

- Hastings, M., A. Popper, J. Finneran, and P. Lanford. (1996). Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. *The Journal of the Acoustical Society of America* 99 (3): 1759–1766.
- Hastings, M. C. (1991, November 7, 1991). *Effects of underwater sound on bony fishes*. Presented at the 122nd Meeting of the Acoustical Society of America. Houston, TX.
- Hastings, M. C. (1995). *Physical effects of noise on fishes*. Presented at the 1995 International Congress on Noise Control Engineering. Newport Beach, CA.
- Hastings, M. C. and A. N. Popper. (2005). *Effects of Sound on Fish* (Final Report #CA05-0537). Sacramento, CA: California Department of Transportation.
- Hastings, M. C., C. A. Reid, C. C. Grebe, R. L. Hearn, and J. G. Colman. (2008). The effects of seismic airgun noise on the hearing sensitivity of tropical reef fishes at Scott Reef, Western Australia. *Proceedings of the Institute of Acoustics* 30 (5): 8.
- Hatch, L. T., C. W. Clark, S. M. Van Parijs, A. S. Frankel, and D. W. Ponirakis. (2012). Quantifying loss of acoustic communication space for right whales in and around a U.S. National Marine Sanctuary. *Conservation Biology* 26 (6): 983–994. DOI:10.1111/j.1523-1739.2012.01908
- Haubold, E. M., C. Deutsch, and C. Fonnesbeck. (2006). *Final Biological Status Review of the Florida Manatee (Trichechus manatus latirostris)*. St. Petersburg, FL: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute.
- Haver, S. M., J. D. Adams, L. T. Hatch, S. M. Van Parijs, R. P. Dziak, J. Haxel, S. A. Heppell, M. F. McKenna, D. K. Mellinger, and J. Gedamke. (2021). Large vessel activity and low-frequency underwater sound benchmarks in United States waters. *Marine Science* 8. DOI:10.3389/fmars.2021.669528
- Haviland-Howell, G., A. S. Frankel, C. M. Powell, A. Bocconcelli, R. L. Herman, and L. S. Sayigh. (2007). Recreational boating traffic: A chronic source of anthropogenic noise in the Wilmington, North Carolina Intracoastal Waterway. *The Journal of the Acoustical Society of America* 122 (1): 151–160. DOI:10.1121/1.2717766
- Hawkins, A. D. and A. D. F. Johnstone. (1978). The hearing of the Atlantic salmon, *Salmo salar*. *Journal of Fish Biology* 13 655–673.
- Hawkins, A. D., A. E. Pembroke, and A. N. Popper. (2015). Information gaps in understanding the effects of noise on fishes and invertebrates. *Reviews in Fish Biology and Fisheries* 25 39–64. DOI:10.1007/s11160-014-9369-3
- Hawkins, A. D., L. Roberts, and S. Cheesman. (2014). Responses of free-living coastal pelagic fish to impulsive sounds. *The Journal of the Acoustical Society of America* 135 (5): 3101–3116. DOI:10.1121/1.4870697
- Hazel, J., I. R. Lawler, H. Marsh, and S. Robson. (2007). Vessel speed increases collision risk for the green turtle *Chelonia mydas*. *Endangered Species Research* 3 105–113.
- HDR. (2011). *Virginia Capes (VACAPES) FIREX with IMPASS Marine Species Monitoring Aerial Monitoring Surveys Trip Report, 13–15 July 2011* (Contract # N62470-10-D-3011). Virginia Beach, VA: U.S. Navy Marine Species Monitoring Program.
- HDR EOC. (2012). *Guam and Saipan Marine Species Monitoring Winter-Spring Survey, March 2012*. Pearl Harbor, HI: Naval Facilities Engineering Command.

- Heffner, R. S. and H. E. Heffner. (1982). Hearing in the elephant (*Elephas maximus*): Absolute sensitivity, frequency discrimination, and sound localization. *Journal of Comparative and Physiological Psychology* 96 (6): 926–944.
- Heide-Jorgensen, M. P., S. B. Blackwell, O. M. Tervo, A. L. Samson, E. Garde, R. G. Hansen, M. C. ò. n. Ngô, A. S. Conrad, P. Trinhhammer, H. C. Schmidt, M.-H. S. Sinding, T. M. Williams, and S. Ditlevsen. (2021). Behavioral response study on seismic airgun and vessel exposures in narwhals. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.658173
- Heinis, F., C. A. F. De Jong, and Rijkswaterstaat Underwater Sound Working Group. (2015). *Framework for Assessing Ecological and Cumulative Effects of Offshore Wind Farms: Cumulative Effects of Impulsive Underwater Sound on Marine Mammals* (TNO Report R10335-A). The Hague, Netherlands: Rijkswaterstaat Zee en Delta.
- Henderson, E. E., J. Aschettino, M. Deakos, G. Alongi, and T. Leota. (2019). Quantifying the behavior of humpback whales (*Megaptera novaeangliae*) and potential responses to sonar. *Aquatic Mammals* 45 (6): 612–631. DOI:10.1578/am.45.6.2019.612
- Henderson, E. E., R. A. Manzano-Roth, S. W. Martin, and B. Matsuyama. (2015). *Impacts of U.S. Navy Training Events on Beaked Whale Foraging Dives in Hawaiian Waters: Update*. San Diego, CA: Space and Naval Warfare Systems Command Systems Center Pacific.
- Henderson, E. E., S. W. Martin, R. Manzano-Roth, and B. M. Matsuyama. (2016). Occurrence and habitat use of foraging Blainville's beaked whales (*Mesoplodon densirostris*) on a U.S. Navy range in Hawai'i. *Aquatic Mammals* 42 (4): 549–562.
- Henderson, E. E., M. H. Smith, M. Gassmann, S. M. Wiggins, A. B. Douglas, and J. A. Hildebrand. (2014). Delphinid behavioral responses to incidental mid-frequency active sonar. *The Journal of the Acoustical Society of America* 136 (4): 2003–2014. DOI:10.1121/1.4895681
- Hermannsen, L., K. Beedholm, J. Tougaard, and P. T. Madsen. (2014). High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (*Phocoena phocoena*). *The Journal of the Acoustical Society of America* 136 (4): 1640–1653. DOI:10.1121/1.4893908
- Hermannsen, L., L. Mikkelsen, J. Tougaard, K. Beedholm, M. Johnson, and P. T. Madsen. (2019). Recreational vessels without Automatic Identification System (AIS) dominate anthropogenic noise contributions to a shallow water soundscape. *Scientific Reports* 9 (1): 15477. DOI:10.1038/s41598-019-51222-9
- Hetherington, T. (2008). Comparative anatomy and function of hearing in aquatic amphibians, reptiles, and birds. In J. G. M. Thewissen & S. Nummela (Eds.), *Sensory Evolution on the Threshold* (pp. 182–209). Berkeley, CA: University of California Press.
- Hewitt, J., A. E. Gelfand, N. J. Quick, W. R. Cioffi, B. L. Southall, S. L. DeRuiter, and R. S. Schick. (2022). Kernel density estimation of conditional distributions to detect responses in satellite tag data. *Animal Biotelemetry* 10 (1). DOI:10.1186/s40317-022-00299-7
- Hewitt, R. P. (1985). Reaction of dolphins to a survey vessel: Effects on census data. *Fishery Bulletin* 83 (2): 187–193.
- Higgs, D. M. (2005). Auditory cues as ecological signals for marine fishes. *Marine Ecology Progress Series* 287 278–281.

- Higgs, D. M., E. F. Brittan-Powell, D. Soares, M. J. Souza, C. E. Carr, R. J. Dooling, and A. N. Popper. (2002). Amphibious auditory responses of the American alligator (*Alligator mississippiensis*). *Journal of Comparative Physiology A* 188 217–223. DOI:10.1007/s00359-002-0296-8
- Higgs, D. M. and S. R. Humphrey. (2019). Passive acoustic monitoring shows no effect of anthropogenic noise on acoustic communication in the invasive round goby (*Neogobius melanostomus*). *Freshwater Biology* 65 (1): 66–74. DOI:10.1111/fwb.13392
- Higgs, D. M. and C. A. Radford. (2013). The contribution of the lateral line to 'hearing' in fish. *The Journal of Experimental Biology* 216 (Pt 8): 1484–1490. DOI:10.1242/jeb.078816
- Hildebrand, J. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series* 395 5–20. DOI:10.3354/meps08353.
- Hiley, H. M., V. M. Janik, and T. Götz. (2021). Behavioural reactions of harbour porpoises *Phocoena phocoena* to startle-eliciting stimuli: movement responses and practical applications. *Marine Ecology Progress Series* 672 223–241. DOI:10.3354/meps13757
- Hillman, M. D., S. M. Karpany, J. D. Fraser, and A. Deroose-Wilson. (2015). Effects of aircraft and recreation on colonial waterbird nesting behavior. *Journal of Wildlife Management* 79 (7): 1192–1198. DOI:10.1002/jwmg.925
- Hin, V., A. M. De Roos, K. J. Benoit-Bird, D. E. Claridge, N. DiMarzio, J. W. Durban, E. A. Falcone, E. K. Jacobson, C. M. Jones-Todd, and E. Pirotta. (2023). Using individual-based bioenergetic models to predict the aggregate effects of disturbance on populations: A case study with beaked whales and Navy sonar. *PLoS ONE* 18 (8): e0290819.
- Hin, V., J. Harwood, and A. M. de Roos. (2021). Density dependence can obscure nonlethal effects of disturbance on life history of medium-sized cetaceans. *PLoS ONE* 16 (6). DOI:10.1371/journal.pone.0252677
- Hin, V., J. Harwood, and A. Roos. (2019). Bio-energetic modeling of medium-sized cetaceans shows high sensitivity to disturbance in seasons of low resource supply. *Ecological Applications* 25 (5): 1–19.
- Hiryu, S., M. E. Bates, J. A. Simmons, and H. Riquimaroux. (2010). FM echolocating bats shift frequencies to avoid broadcast-echo ambiguity in clutter. *Proceedings of the National Academy of Sciences* 107 (15): 7048–7053. DOI:10.1073/pnas.1000429107
- Hochachka, P. W., G. C. Liggins, G. P. Guyton, R. C. Schneider, K. S. Stanek, W. E. Hurford, R. K. Creasy, D. G. Zapol, and W. M. Zapol. (1995). Hormonal regulatory adjustments during voluntary diving in Weddell seals. *Comparative Biochemistry and Physiology B* 112 361–375.
- Hodgson, A., N. Kelly, and D. Peel. (2013). Unmanned aerial vehicles (UAVs) for surveying marine fauna: A dugong case study. *PLoS ONE* 8 (11): e79556. DOI:10.1371/journal.pone.0079556
- Hodgson, A. J. and H. Marsh. (2007). Response of dugongs to boat traffic: The risk of disturbance and displacement. *Journal of Experimental Marine Biology and Ecology* 340 (1): 50–61. DOI:<http://dx.doi.org/10.1016/j.jembe.2006.08.006>
- Holland, R. A., J. L. Kirschvink, T. G. Doak, and M. Wikelski. (2008). Bats use magnetite to detect the earth's magnetic field. *PLoS ONE* 3 (2): e1676. DOI:10.1371/journal.pone.0001676
- Holland, R. A., K. Thorup, M. J. Vonhof, W. W. Cochran, and M. Wikelski. (2006). Navigation: Bat orientation using Earth's magnetic field. *Nature* 444 (7120): 702. DOI:10.1038/444702a

- Holt, D. E. and C. E. Johnston. (2014). Evidence of the Lombard effect in fishes. *Behavioral Ecology* 25 (4): 819–826. DOI:10.1093/beheco/aru028
- Holt, M. M., M. B. Hanson, D. A. Giles, C. K. Emmons, and J. T. Hogan. (2017). Noise levels received by endangered killer whales *Orcinus orca* before and after implementation of vessel regulations. *Endangered Species Research* 34 15–26. DOI:10.3354/esr00841
- Holt, M. M., D. P. Noren, R. C. Dunkin, and T. M. Williams. (2015). Vocal performance affects metabolic rate in dolphins: Implications for animals communicating in noisy environments. *The Journal of Experimental Biology* 218 (Pt 11): 1647–1654. DOI:10.1242/jeb.122424
- Holt, M. M., D. P. Noren, and C. K. Emmons. (2011). Effects of noise levels and call types on the source levels of killer whale calls. *The Journal of the Acoustical Society of America* 130 (5): 3100–3106. DOI:10.1121/1.3641446
- Holt, M. M., D. P. Noren, V. Veirs, C. K. Emmons, and S. Veirs. (2008). Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. *The Journal of the Acoustical Society of America* 125 (1): EL27–EL32. DOI:10.1121/1.3040028
- Holt, M. M. and R. J. Schusterman. (2007). Spatial release from masking of aerial tones in pinnipeds. *The Journal of the Acoustical Society of America* 121 1219–1225.
- Holt, M. M., J. B. Tennessen, E. J. Ward, M. B. Hanson, C. K. Emmons, D. A. Giles, and J. T. Hogan. (2021). Effects of vessel distance and sex on the behavior of endangered killer whales. *Frontiers in Marine Science* 7. DOI:10.3389/fmars.2020.582182
- Hom, K. N., M. Linnenschmidt, J. A. Simmons, and A. M. Simmons. (2016). Echolocation behavior in big brown bats is not impaired after intense broadband noise exposures. *The Journal of Experimental Biology* 219 (20): 3253–3260. DOI:10.1242/jeb.143578
- Hooker, S. K., R. W. Baird, and A. Fahlman. (2009). Could beaked whales get the bends? Effect of diving behaviour and physiology on modelled gas exchange for three species: *Ziphius cavirostris*, *Mesoplodon densirostris* and *Hyperoodon ampullatus*. *Respiratory Physiology & Neurobiology* 167 (3): 235–246. DOI:10.1016/j.resp.2009.04.023
- Hooker, S. K., A. Fahlman, M. J. Moore, N. A. de Soto, Y. B. de Quiros, A. O. Brubakk, D. P. Costa, A. M. Costidis, S. Dennison, K. J. Falke, A. Fernandez, M. Ferrigno, J. R. Fitz-Clarke, M. M. Garner, D. S. Houser, P. D. Jepson, D. R. Ketten, P. H. Kvaldheim, P. T. Madsen, N. W. Pollock, D. S. Rotstein, T. K. Rowles, S. E. Simmons, W. Van Bonn, P. K. Weathersby, M. J. Weise, T. M. Williams, and P. L. Tyack. (2012). Deadly diving? Physiological and behavioural management of decompression stress in diving mammals. *Proceedings of the Royal Society B: Biological Sciences* 279 (1731): 1041–1050. DOI:10.1098/rspb.2011.2088
- Hoopes, L. A., A. M. Landry Jr., and E. K. Stabenau. (2000). Physiological effects of capturing Kemp's ridley sea turtles, *Lepidochelys kempii*, in entanglement nets. *Canadian Journal of Zoology* 78 (11): 1941–1947.
- Hoover, A. A. (1988). Harbor Seal (*Phoca vitulina*). In J. W. Lentfer (Ed.), *Selected Marine Mammals of Alaska: Species Accounts with Research and Management Recommendations* (pp. 125–157). Washington, DC: Marine Mammal Commission.
- Horton, T. (2016, September 8). *Stealth reefs and the Navy's big guns*. *Suffolk News-Herald*. Retrieved March 10, 2017, from <http://www.suffolknewsherald.com/2016/09/08/stealth-reefs-and-the-navys-big-guns/>.

- Hotchkin, C. and S. Parks. (2013). The Lombard effect and other noise-induced vocal modifications: Insight from mammalian communication systems. *Biological Reviews of the Cambridge Philosophical Society* 88 (4): 809–824. DOI:10.1111/brv.12026
- Houser, D. S., C. D. Champagne, S. K. Wasser, R. K. Booth, T. Romano, and D. E. Crocker. (2021). Influence of season, age, sex, and time of day on the endocrine profile of the common bottlenose dolphin (*Tursiops truncatus*). *General and Comparative Endocrinology* 313 113889. DOI:<https://doi.org/10.1016/j.ygcen.2021.113889>
- Houser, D. S., L. A. Dankiewicz-Talmadge, T. K. Stockard, and P. J. Ponganis. (2009). Investigation of the potential for vascular bubble formation in a repetitively diving dolphin. *The Journal of Experimental Biology* 213 52–62. DOI:10.1242/jeb.028365
- Houser, D. S., D. A. Helweg, and P. W. B. Moore. (2001a). A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals* 27 (2): 82–91.
- Houser, D. S., R. Howard, and S. Ridgway. (2001b). Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? *Journal of Theoretical Biology* 213 183–195. DOI:10.1006/jtbi.2001.2415
- Houser, D. S., P. Kvadsheim, L. Kleivane, J. Mulsow, R. Ølberg, C. Harms, J. Teilmann, and J. J. Finneran. (2024). First direct hearing measurements in a baleen whale suggest unexpected high-frequency sensitivity. *Science (in prep)*.
- Houser, D. S., S. Martin, D. E. Crocker, and J. J. Finneran. (2020). Endocrine response to simulated U.S. Navy mid-frequency sonar exposures in the bottlenose dolphin (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 147 (3): 1681–1687.
- Houser, D. S., S. W. Martin, and J. J. Finneran. (2013a). Behavioral responses of California sea lions to mid-frequency (3250–3450 Hz) sonar signals. *Marine Environmental Research* 92 268–278. DOI:10.1016/j.marenvres.2013.10.007
- Houser, D. S., S. W. Martin, and J. J. Finneran. (2013b). Exposure amplitude and repetition affect bottlenose dolphin behavioral responses to simulated mid-frequency sonar signals. *Journal of Experimental Marine Biology and Ecology* 443 123–133. DOI:10.1016/j.jembe.2013.02.043
- Houser, D. S., L. Noble, E. Fougères, J. Mulsow, and J. J. Finneran. (2022). Audiograms and click spectra of seven novel and seldom-tested odontocetes. *Frontiers in Marine Science* 9. DOI:10.3389/fmars.2022.984333
- Houser, D. S., L. C. Yeates, and D. E. Crocker. (2011). Cold stress induces an adrenocortical response in bottlenose dolphins (*Tursiops truncatus*). *Journal of Zoo and Wildlife Medicine* 42 (4): 565–571. DOI:10.1638/2010-0121.1
- Hubbs, C. and A. Rehnitz. (1952). Report on experiments designed to determine effects of underwater explosions on fish life. *California Fish and Game* 38 333–366.
- Hubert, J., E. Booms, R. Witbaard, and H. Slabbekoorn. (2022). Responsiveness and habituation to repeated sound exposures and pulse trains in blue mussels. *Journal of Experimental Marine Biology and Ecology* 547 151668. DOI:<https://doi.org/10.1016/j.jembe.2021.151668>
- Hubert, J., J. A. Campbell, and H. Slabbekoorn. (2020a). Effects of seismic airgun playbacks on swimming patterns and behavioural states of Atlantic cod in a net pen. *Marine Pollution Bulletin* 160. DOI:10.1016/j.marpolbul.2020.111680

- Hubert, J., Y. Y. Neo, H. V. Winter, and H. Slabbekoorn. (2020b). The role of ambient sound levels, signal-to-noise ratio, and stimulus pulse rate on behavioural disturbance of seabass in a net pen. *Behavioural Processes* 170. DOI:10.1016/j.beproc.2019.103992
- Hudson, D. M., J. S. Krumholz, D. L. Pochtar, N. C. Dickenson, G. Dossot, G. Phillips, E. P. Baker, and T. E. Moll. (2022). Potential impacts from simulated vessel noise and sonar on commercially important invertebrates. *PeerJ* 10. DOI:10.7717/peerj.12841
- Hunt, K. E., C. Innis, C. Merigo, E. A. Burgess, T. Norton, D. Davis, A. E. Kennedy, and C. L. Buck. (2019). Ameliorating transport-related stress in endangered Kemp's ridley sea turtles (*Lepidochelys kempii*) with a recovery period in saltwater pools. *Conservation Physiology* 7 (1): coy065. DOI:10.1093/conphys/coy065
- Hunt, K. E., C. Merigo, E. A. Burgess, C. L. Buck, D. Davis, A. Kennedy, L. Lory, J. Wocial, K. McNally, and C. Innis. (2020). Effects of Ground Transport in Kemp's Ridley (*Lepidochelys kempii*) and Loggerhead (*Caretta caretta*) Turtles. *Integrative Organismal Biology* 2 (1): 1-16. DOI:10.1093/iob/obaa012
- Hurford, W. E., P. W. Hochachka, R. C. Schneider, G. P. Guyton, K. S. Stanek, D. G. Zapol, G. C. Liggins, and W. M. Zapol. (1996). Splenic contraction, catecholamine release, and blood volume redistribution during diving in the Weddell seal. *Journal of Applied Physiology* 80 (1): 298–306.
- Hütt, J. C., P. Corkeron, J. M. van der Hoop, and M. J. Moore. (2023). Uncertain bioenergetics of North Atlantic right whales. *Marine Ecology Progress Series* 725 167–184. DOI:10.3354/meps14461
- Iafrate, J. D., S. L. Watwood, E. A. Reyier, D. M. Scheidt, G. A. Dossot, and S. E. Crocker. (2016). Effects of pile driving on the residency and movement of tagged reef fish. *PLoS ONE* 11 (11): e0163638. DOI:10.14286/2016_IAFRATE_PLOSONE
- Ichikawa, K., T. Akamatsu, T. Shinke, K. Sasamori, Y. Miyauchi, Y. Abe, K. Adulyanukosol, and N. Arai. (2009). Detection probability of vocalizing dugongs during playback of conspecific calls. *The Journal of the Acoustical Society of America* 126 (4): 1954–1959. DOI:10.1121/1.3203805
- International Organization for Standardization. (2017). *Underwater acoustics - terminology*. Geneva, Switzerland: International Organization for Standardization.
- Isojunno, S., K. Aoki, C. Cure, P. H. Kvadsheim, and P. J. O. Miller. (2018). Breathing patterns indicate cost of exercise during diving and response to experimental sound exposures in Long-Finned Pilot Whales. *Frontiers in Physiology* 9 1462. DOI:10.3389/fphys.2018.01462
- Isojunno, S., C. Curé, P. H. Kvadsheim, F. A. Lam, P. L. Tyack, P. Jacobus, P. J. Wensveen, and P. J. O. Miller. (2016). Sperm whales reduce foraging effort during exposure to 1–2 kHz sonar and killer whale sounds. *Ecological Applications* 26 (1): 77–93.
- Isojunno, S. and P. J. O. Miller. (2015). Sperm whale response to tag boat presence: Biologically informed hidden state models quantify lost feeding opportunities. *Ecosphere* 6 (1): 1–6. DOI:10.1890/es14-00130.1
- Isojunno, S., D. Sadykova, S. DeRuiter, C. Cure, F. Visser, L. Thomas, P. J. O. Miller, and C. M. Harris. (2017). Individual, ecological, and anthropogenic influences on activity budgets of long-finned pilot whales. *Ecosphere* 8 (12): 1–26.
- Isojunno, S., A. M. von Benda-Beckmann, P. J. Wensveen, P. H. Kvadsheim, F. P. A. Lam, K. C. Gkikopoulou, V. Pöyhönen, P. L. Tyack, B. Benti, I. Foskolos, J. Bort, M. Neves, N. Biassoni, and P.

- J. O. Miller. (2021). Sperm whales exhibit variation in echolocation tactics with depth and sea state but not naval sonar exposures. *Marine Mammal Science*. DOI:10.1111/mms.12890
- Isojunno, S., P. J. Wensveen, F. P. A. Lam, P. H. Kvadsheim, A. M. Von Benda-Beckmann, L. M. M. Lopez, L. Kleivane, E. M. Siegal, and P. J. O. Miller. (2020). When the noise goes on: Received sound energy predicts sperm whale responses to both intermittent and continuous navy sonar. *Journal of Experimental Biology* 223 (7).
- Ivanova, S. V., S. T. Kessel, M. Espinoza, M. F. McLean, C. O'Neill, J. Landry, N. E. Hussey, R. Williams, S. Vagle, and A. T. Fisk. (2020). Shipping alters the movement and behavior of Arctic cod (*Boreogadus saida*), a keystone fish in Arctic marine ecosystems. *Ecological Applications* 30 (3). DOI:10.1002/eap.2050
- Jacobs, E. R., S. Gero, C. E. Malinka, P. H. Tonnesen, K. Beedholm, S. L. DeRuiter, and P. T. Madsen. (2024). The active space of sperm whale codas: inter-click information for intra-unit communication. *The Journal of Experimental Biology* 227 (4). DOI:10.1242/jeb.246442
- Jacobson, E. K., E. E. Henderson, D. L. Miller, C. S. Oedekoven, D. J. Moretti, and L. Thomas. (2022). Quantifying the response of Blainville's beaked whales to U.S. naval sonar exercises in Hawaii. *Marine Mammal Science*. DOI:<https://doi.org/10.1111/mms.12944>
- Jahoda, M., C. L. Lafortuna, N. Biassoni, C. Almirante, A. Azzellino, S. Panigada, M. Zanardelli, and G. N. Di Sciara. (2003). Mediterranean fin whale's (*Balaenoptera physalus*) response to small vessels and biopsy sampling assessed through passive tracking and timing of respiration. *Marine Mammal Science* 19 (1): 96–110. DOI:10.1111/j.1748-7692.2003.tb01095
- Jain-Schlaepfer, S., E. Fakan, J. L. Rummer, S. D. Simpson, and M. I. McCormick. (2018). Impact of motorboats on fish embryos depends on engine type. *Conservation Physiology* 6 (1): coy014. DOI:10.1093/conphys/coy014
- Jakobsen, L., S. Brinkløv, and A. Surlykke. (2013). Intensity and directionality of bat echolocation signals. *Frontiers in Physiology* 4 1–9. DOI:10.3389/fphys.2013.00089
- Janik, V. M. and P. M. Thompson. (1996). Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. *Marine Mammal Science* 12 (4): 597–602.
- Jansen, J. K., P. L. Boveng, S. P. Dahle, and J. L. Bengtson. (2010). Reaction of harbor seals to cruise ships. *Journal of Wildlife Management* 74 (6): 1186–1194. DOI:10.2193/2008-192
- Jefferson, T. A. and B. E. Curry. (1996). Acoustic methods of reducing or eliminating marine mammal-fishery interactions: Do they work? *Ocean & Coastal Management* 31 (1): 41–70.
- Jenkins, A. K., P. H. Dahl, S. E. Kotecki, V. Bowman, B. Casper, C. Boerger, and A. N. Popper. (2022). Physical effects of sound exposure from underwater explosions on Pacific mackerel (*Scomber japonicus*): Effects on non-auditory tissues. *The Journal of the Acoustical Society of America* 151 (6): 3947. DOI:10.1121/10.0011587
- Jensen, F. H., L. Bejder, M. Wahlberg, N. Aguilar Soto, M. Johnson, and P. T. Madsen. (2009). Vessel noise effects on delphinid communication. *Marine Ecology Progress Series* 395 161-175.
- Jensen, J. O. T. (2003). *New Mechanical Shock Sensitivity Units in Support of Criteria for Protection of Salmonid Eggs from Blasting or Seismic Disturbance*. Nanaimo, Canada: Fisheries and Oceans Canada Science Branch Pacific Region, Pacific Biological Station.

- Jensen, M. E., C. F. Moss, and A. Surlykke. (2005). Echolocating bats can use acoustic landmarks for spatial orientation. *The Journal of Experimental Biology* 208 (23): 4399–4410. DOI:10.1242/jeb.01901
- Jepson, P. D., M. Arbelo, R. Deaville, I. A. R. Patterson, P. Castro, J. R. Baker, E. Degollada, H. M. Ross, P. Herráez, A. M. Pocknell, F. Rodriguez, F. E. Howie, A. Espinosa, R. J. Reid, J. R. Jaber, V. Martin, A. A. Cunningham, and A. Fernandez. (2003). Gas-bubble lesions in stranded cetaceans: Was sonar responsible for a spate of whale deaths after an Atlantic military exercise? *Nature* 425 575–576.
- Jepson, P. D., P. M. Bennett, R. Deaville, C. R. Allchin, J. R. Baker, and R. J. Law. (2005). Relationships between polychlorinated biphenyls and health status in harbor porpoises (*Phocoena phocoena*) stranded in the United Kingdom. *Environmental Toxicology and Chemistry* 24 (1): 238–248.
- Jézéquel, Y., J. Bonnel, and L. Chauvaud. (2021). Potential for acoustic masking due to shipping noise in the European lobster (*Homarus gammarus*). *Marine Pollution Bulletin* 173 112934. DOI:<https://doi.org/10.1016/j.marpolbul.2021.112934>
- Jezequel, Y., J. Bonnel, P. Elies, and L. Chauvaud. (2022). Acoustic scaling in the European spiny lobster (*Palinurus elephas*). *The Journal of the Acoustical Society of America* 152 (6): 3235. DOI:10.1121/10.0016363
- Jézéquel, Y., S. Cones, F. H. Jensen, H. Brewer, J. Collins, and T. A. Mooney. (2022). Pile driving repeatedly impacts the giant scallop (*Placopecten magellanicus*). *Scientific Reports* 12 (1): 15380. DOI:10.1038/s41598-022-19838-6
- Jézéquel, Y., P. Jandial, S. F. Cones, S. Ferguson, N. Aoki, Y. Girdhar, and T. A. Mooney. (2023). Short-term habituation of the longfin squid (*Doryteuthis pealeii*) to pile driving sound. *ICES Journal of Marine Science*. DOI:10.1093/icesjms/fsad157
- Jimenez, L. V., E. P. Fakan, and M. I. McCormick. (2020). Vessel noise affects routine swimming and escape response of a coral reef fish. *PLoS ONE* 15 (7). DOI:10.1371/journal.pone.0235742
- Johansen, S., O. N. Larsen, J. Christensen-Dalsgaard, L. Seidelin, T. Huulvej, K. Jensen, S. G. Lunneryd, M. Bostrom, and M. Wahlberg. (2016). In-air and underwater hearing in the great cormorant (*Phalacrocorax carbo sinensis*). *Advances in Experimental Medicine and Biology* 875 505–512. DOI:10.1007/978-1-4939-2981-8_61
- Johnson, C. S., M. W. McManus, and D. Skaar. (1989). Masked tonal hearing thresholds in the beluga whale. *The Journal of the Acoustical Society of America* 85 (6): 2651–2654.
- Johnson, R. J., P. H. Cole, and W. W. Stroup. (1985). Starling response to three auditory stimuli. *Journal of Wildlife Management* 49 (3): 620–625.
- Jones-Todd, C. M., E. Pirotta, J. W. Durban, D. E. Claridge, R. W. Baird, E. A. Falcone, G. S. Schorr, S. Watwood, and L. Thomas. (2021). Discrete-space continuous-time models of marine mammal exposure to Navy sonar. *Ecological Applications*. DOI:10.1002/EAP.2475
- Jones, E. L., G. D. Hastie, S. Smout, J. Onoufriou, N. D. Merchant, K. L. Brookes, D. Thompson, and M. González-Suárez. (2017). Seals and shipping: Quantifying population risk and individual exposure to vessel noise. *Journal of Applied Ecology* 54 (6): 1930–1940. DOI:10.1111/1365-2664.12911
- Jones IV, G. P., L. G. Pearlstine, and H. F. Percival. (2006). An assessment of small unmanned aerial vehicles for wildlife research. *Wildlife Society Bulletin* 34 (3): 750–758.

- Jorgensen, R., K. K. Olsen, I. B. Falk-Petersen, and P. Kanapthippilai. (2005). *Investigations of Potential Effects of Low Frequency Sonar Signals on Survival, Development and Behaviour of Fish Larvae and Juveniles*. Tromsø, Norway: University of Tromsø, The Norwegian College of Fishery Science.
- Joyce, T. W., J. W. Durban, D. E. Claridge, C. A. Dunn, L. S. Hickmott, H. Fearnbach, K. Dolan, and D. Moretti. (2019). Behavioral responses of satellite tracked Blainville's beaked whales (*Mesoplodon densirostris*) to mid-frequency active sonar. *Marine Mammal Science* 1–18. DOI:10.1111/mms.12624
- Kane, A. S., J. Song, M. B. Halvorsen, D. L. Miller, J. D. Salierno, L. E. Wysocki, D. Zeddies, and A. N. Popper. (2010). Exposure of fish to high intensity sonar does not induce acute pathology. *Journal of Fish Biology* 76 (7): 1825–1840. DOI:10.1111/j.1095-8649.2010.02626
- Karpovich, S. A., J. P. Skinner, J. E. Mondragon, and G. M. Blundell. (2015). Combined physiological and behavioral observations to assess the influence of vessel encounters on harbor seals in glacial fjords of southeast Alaska. *Journal of Experimental Marine Biology and Ecology* 473 110–120. DOI:10.1016/j.jembe.2015.07.016
- Kassamali-Fox, A., F. Christiansen, L. J. May-Collado, E. A. Ramos, and B. A. Kaplin. (2020). Tour boats affect the activity patterns of bottlenose dolphins (*Tursiops truncatus*) in Bocas del Toro, Panama. *PeerJ* 8.
- Kastak, D., C. Reichmuth, M. M. Holt, J. Mulsow, B. L. Southall, and R. J. Schusterman. (2007). Onset, growth, and recovery of in-air temporary threshold shift in a California sea lion (*Zalophus californianus*). *The Journal of the Acoustical Society of America* 122 (5): 2916–2924. DOI:10.1121/1.2783111
- Kastak, D., B. L. Southall, R. J. Schusterman, and C. R. Kastak. (2005). Underwater temporary threshold shift in pinnipeds: Effects of noise level and duration. *The Journal of the Acoustical Society of America* 118 (5): 3154–3163. DOI:10.1121/1.2047128
- Kastelein, R., N. Jennings, W. Verboom, D. de Haan, and N. M. Schooneman. (2006). Differences in the response of a striped dolphin (*Stenella coeruleoalba*) and a harbor porpoise (*Phocoena phocoena*) to an acoustic alarm. *Marine Environmental Research* 61 363–378.
- Kastelein, R. A., M. A. Ainslie, and R. van Kester. (2019a). Behavioral Responses of Harbor Porpoises (*Phocoena phocoena*) to U.S. Navy 53C Sonar Signals in Noise. *Aquatic Mammals* 45 (4): 359–366. DOI:10.1578/am.45.4.2019.359
- Kastelein, R. A., M. Brouwers, L. Helder-Hoek, and R. Gransier. (2019b). Hearing thresholds of two harbor seals (*Phoca vitulina*) for helicopter dipping sonar signals (1.3-1.4 kHz). *Aquatic Mammals* 45 (3).
- Kastelein, R. A., S. A. Cornelisse, L. A. Huijser, and L. Helder-Hoek. (2020a). Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth-octave noise bands at 63 kHz. *Aquatic Mammals* 46 (2): 167–182.
- Kastelein, R. A., D. de Haan, N. Vaughan, C. Staal, and N. M. Schooneman. (2001). The influence of three acoustic alarms on the behaviour of harbour porpoises (*Phocoena phocoena*) in a floating pen. *Marine Environmental Research* 52 351–371.
- Kastelein, R. A., C. A. F. de Jong, J. Tougaard, A. University, and L. Hoek. (2022). Behavioral responses of a harbor porpoise (*Phocoena phocoena*) depend on the frequency content of pile-driving sounds. *Aquatic Mammals* 48 (2). DOI:10.1578/AM.48.2.2022.97

- Kastelein, R. A., R. Gransier, L. Hoek, A. Macleod, and J. M. Terhune. (2012a). Hearing threshold shifts and recovery in harbor seals (*Phoca vitulina*) after octave-band noise exposure at 4 kHz. *The Journal of the Acoustical Society of America* 132 (4): 2745–2761. DOI:10.1121/1.4747013
- Kastelein, R. A., R. Gransier, L. Hoek, and J. Olthuis. (2012b). Temporary threshold shifts and recovery in a harbor porpoise (*Phocoena phocoena*) after octave-band noise at 4 kHz. *The Journal of the Acoustical Society of America* 132 (5): 3525–3537. DOI:10.1121/1.4757641
- Kastelein, R. A., R. Gransier, L. Hoek, and M. Rambags. (2013a). Hearing frequency thresholds of a harbor porpoise (*Phocoena phocoena*) temporarily affected by a continuous 1.5 kHz tone. *The Journal of the Acoustical Society of America* 134 (3): 2286–2292. DOI:10.1121/1.4816405
- Kastelein, R. A., R. Gransier, J. Schop, and L. Hoek. (2015a). Effects of exposure to intermittent and continuous 6–7 kHz sonar sweeps on harbor porpoise (*Phocoena phocoena*) hearing. *The Journal of the Acoustical Society of America* 137 (4): 1623–1633.
- Kastelein, R. A., L. Helder-Hoek, C. Booth, N. Jennings, and M. Leopold. (2019c). High levels of food intake in harbor porpoises (*Phocoena phocoena*): Insight into recovery from disturbance. *Aquatic Mammals* 45 (4): 380–388. DOI:10.1578/am.45.4.2019.380
- Kastelein, R. A., L. Helder-Hoek, S. Cornelisse, L. A. E. Huijser, and R. Gransier. (2019d). Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth octave noise band at 32 kHz. *Aquatic Mammals* 45 (5): 549–562. DOI:10.1578/am.45.5.2019.549
- Kastelein, R. A., L. Helder-Hoek, S. A. Cornelisse, L. A. E. Huijser, and J. M. Terhune. (2020b). Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 32 kHz. *The Journal of the Acoustical Society of America* 147 (3). DOI:10.1121/10.0000889
- Kastelein, R. A., L. Helder-Hoek, J. Covi, J. M. Terhune, and G. Klump. (2021). Masking release at 4 kHz in harbor porpoises (*Phocoena phocoena*) associated with sinusoidal amplitude-modulated masking noise. *The Journal of the Acoustical Society of America* 150 (3): 1721. DOI:10.1121/10.0006103
- Kastelein, R. A., L. Helder-Hoek, and R. Gransier. (2019e). Frequency of greatest temporary hearing threshold shift in harbor seals (*Phoca vitulina*) depends on fatiguing sound level. *The Journal of the Acoustical Society of America* 145 (3): 1353–1362. DOI:10.1121/1.5092608
- Kastelein, R. A., L. Helder-Hoek, R. Gransier, J. M. Terhune, N. Jennings, and C. A. F. de Jong. (2015b). Hearing thresholds of harbor seals (*Phoca vitulina*) for playbacks of seal scarer signals, and effects of the signals on behavior. *Hydrobiologia* 756 (1): 75–88. DOI:10.1007/s10750-014-2152-6
- Kastelein, R. A., L. Helder-Hoek, G. Janssens, R. Gransier, and T. Johansson. (2015c). Behavioral responses of harbor seals (*Phoca vitulina*) to sonar signals in the 25-kHz range. *Aquatic Mammals* 41 (4): 388–399. DOI:10.1578/am.41.4.2015.388
- Kastelein, R. A., L. Helder-Hoek, A. Kommeren, J. Covi, and R. Gransier. (2018a). Effect of pile-driving sounds on harbor seal (*Phoca vitulina*) hearing. *The Journal of the Acoustical Society of America* 143 (6): 3583–3594.
- Kastelein, R. A., L. Helder-Hoek, S. Van de Voorde, S. de Winter, S. Janssen, and M. A. Ainslie. (2018b). Behavioral responses of harbor porpoises (*Phocoena phocoena*) to sonar playback sequences of

- sweeps and tones (3.5–4.1 kHz). *Aquatic Mammals* 44 (4): 389–404.
DOI:10.1578/am.44.4.2018.389
- Kastelein, R. A., L. Helder-Hoek, R. van Kester, R. Huisman, and R. Gransier. (2019f). Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth octave noise band at 16 kHz. *Aquatic Mammals* 45 (3): 280–292. DOI:10.1578/am.45.3.2019.280
- Kastelein, R. A., L. Hoek, R. Gransier, C. A. F. de Jong, J. M. Terhune, and N. Jennings. (2015d). Hearing thresholds of a harbor porpoise (*Phocoena phocoena*) for playbacks of seal scarer signals, and effects of the signals on behavior. *Hydrobiologia* 756 (1): 89–103. DOI:10.1007/s10750-014-p2035-x
- Kastelein, R. A., L. Hoek, R. Gransier, M. Rambags, and N. Claeys. (2014a). Effect of level, duration, and inter-pulse interval of 1–2 kHz sonar signal exposures on harbor porpoise hearing. *The Journal of the Acoustical Society of America* 136 (1): 412–422.
- Kastelein, R. A., J. Huybrechts, J. Covi, and L. Helder-Hoek. (2017). Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to sounds from an acoustic porpoise deterrent. *Aquatic Mammals* 43 (3): 233–244. DOI:10.1578/AM.43.3.2017.233
- Kastelein, R. A., M. Janssen, W. C. Verboom, and D. de Haan. (2005a). Receiving beam patterns in the horizontal plane of a harbor porpoise (*Phocoena phocoena*). *The Journal of the Acoustical Society of America* 118 (2): 1172–1179. DOI:10.1121/1.1945565
- Kastelein, R. A., J. Schop, R. Gransier, and L. Hoek. (2014b). Frequency of greatest temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) depends on the noise level. *The Journal of the Acoustical Society of America* 136 (3): 1410–1418. DOI:10.1121/1.4892794
- Kastelein, R. A., J. Schop, R. Gransier, N. Steen, and N. Jennings. (2014c). Effect of series of 1 to 2 kHz and 6 to 7 kHz up-sweeps and down-sweeps on the behavior of a harbor porpoise (*Phocoena phocoena*). *Aquatic Mammals* 40 (3): 232–242. DOI:10.1578/am.40.3.2014.232
- Kastelein, R. A., A. Smink, and N. Jennings. (2023). Atlantic Green Turtles and Hawksbill Turtles: Behavioral Responses to Sound. In A. N. Popper, Sisneros, J., Hawkins, A.D., Thomsen, F. (Ed.), *The Effects of Noise on Aquatic Life*. Cham, Switzerland: Springer, Cham.
- Kastelein, R. A., I. van den Belt, R. Gransier, and T. Johansson. (2015e). Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to 25.5- to 24.5-kHz sonar down-sweeps with and without side bands. *Aquatic Mammals* 41 (4): 400–411. DOI:10.1578/am.41.4.2015.400
- Kastelein, R. A., I. van den Belt, L. Helder-Hoek, R. Gransier, and T. Johansson. (2015f). Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to 25-kHz FM sonar signals. *Aquatic Mammals* 41 (3): 311–326. DOI:10.1578/am.41.3.2015.311
- Kastelein, R. A., D. van Heerden, R. Gransier, and L. Hoek. (2013b). Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to playbacks of broadband pile driving sounds. *Marine Environmental Research* 92 206–214.
- Kastelein, R. A., W. C. Verboom, M. Muijsers, N. V. Jennings, and S. van der Heul. (2005b). The influence of acoustic emissions for underwater data transmission on the behaviour of harbour porpoises (*Phocoena phocoena*) in a floating pen. *Marine Environmental Research* 59 287–307.
DOI:10.1016/j.marenvres.2004.05.005

- Kastelein, R. A. and P. J. Wensveen. (2008). Effect of two levels of masking noise on the hearing threshold of a harbor porpoise (*Phocoena phocoena*) for a 4.0 kHz signal. *Aquatic Mammals* 34 (4): 420–425. DOI:10.1578/am.34.4.2008.420
- Kasumyan, A. O. (2008). Sounds and sound production in fishes. *Journal of Ichthyology* 48 (11): 981–1030. DOI:10.1134/s0032945208110039
- Kasumyan, A. O. (2009). Acoustic signaling in fish. *Journal of Ichthyology* 49 (11): 963–1020. DOI:10.1134/s0032945209110010
- Kavanagh, A. S., M. Nykanen, W. Hunt, N. Richardson, and M. J. Jessopp. (2019). Seismic surveys reduce cetacean sightings across a large marine ecosystem. *Scientific Reports* 9 (1). DOI:10.1038/s41598-019-55500-4
- Keen, K. A., R. S. Beltran, E. Pirotta, and D. P. Costa. (2021). Emerging themes in Population Consequences of Disturbance models. *Proceedings of the Royal Society B* 288 (1957): 20210325.
- Keevin, T. M. and G. L. Hempen. (1997). *The Environmental Effects of Underwater Explosions with Methods to Mitigate Impacts*. St. Louis, MO: U.S. Army Corps of Engineers.
- Ketten, D. R. (1998). *Marine Mammal Auditory Systems: A Summary of Audiometric and Anatomical Data and Its Implications for Underwater Acoustic Impacts*. La Jolla, CA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.
- Ketten, D. R., J. Lien, and S. Todd. (1993). Blast injury in humpback whale ears: Evidence and implications. *The Journal of the Acoustical Society of America* 94 (3): 1849–1850.
- Ketten, D. R. and S. Moein-Bartol. (2006). *Functional Measures of Sea Turtle Hearing*. Woods Hole, MA: Woods Hole Oceanographic Institution.
- Kéver, L., O. Colleye, A. Herrel, P. Romans, and E. Parmentier. (2014). Hearing capacities and otolith size in two ophidiiform species (*Ophidion rochei* and *Carapus acus*). *The Journal of Experimental Biology* 217 (Pt 14): 2517–2525. DOI:10.1242/jeb.105254
- Kight, C. R., S. S. Saha, and J. P. Swaddle. (2012). Anthropogenic noise is associated with reductions in the productivity of breeding Eastern Bluebirds (*Sialia sialis*). *Ecological Applications* 22 (7): 1989–1996.
- Kindt-Larsen, L., C. W. Berg, S. Northridge, and F. Larsen. (2019). Harbor porpoise (*Phocoena phocoena*) reactions to pingers. *Marine Mammal Science* 35 (2): 552–573. DOI:10.1111/mms.12552
- King, S. L., R. S. Schick, C. Donovan, C. G. Booth, M. Burgman, L. Thomas, and J. Harwood. (2015). An interim framework for assessing the population consequences of disturbance. *Methods in Ecology and Evolution* 6 (10): 1150–1158. DOI:10.1111/2041-210x.12411
- Kinney, G. F. and K. J. Graham. (1985). *Explosive Shocks in Air* (2nd ed.). New York, NY: Springer-Verlag.
- Kinsler, L. E., A. R. Frey, A. B. Coppens, and J. V. Sanders. (1982). *Fundamentals of Acoustics* (3rd ed.). New York, NY: John Wiley & Sons.
- Klima, E. F., G. R. Gitschlag, and M. L. Renaud. (1988). Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. *Marine Fisheries Review* 50 (3): 33–42.
- Knudsen, V. O., R. S. Alford, and J. W. Emling. (1948). Underwater ambient noise. *Journal of Marine Research* VII (3): 410–429.

- Koay, G., H. E. Heffner, and R. S. Heffner. (1997). Audiogram of the big brown bat (*Eptesicus fuscus*). *Hearing Research* 105 202–210.
- Kok, A. C. M., L. Bruil, B. Berges, S. Sakinan, E. Debusschere, J. Reubens, D. de Haan, A. Norro, and H. Slabbekoorn. (2021). An echosounder view on the potential effects of impulsive noise pollution on pelagic fish around windfarms in the North Sea. *Environmental Pollution* 290 118063. DOI:10.1016/j.envpol.2021.118063
- Königson, S., R. Naddafi, M. Hedgårde, A. Pettersson, Ö. Östman, E. Benavente Norrman, and M. Amundin. (2021). Will harbor porpoises (*Phocoena phocoena*) be deterred by a pinger that cannot be used as a “dinner bell” by seals? *Marine Mammal Science* 38 (2): 469–485. DOI:10.1111/mms.12880
- Kooyman, G. L., D. H. Kerem, W. B. Campbell, and J. J. Wright. (1973). Pulmonary gas exchange in freely diving Weddell seals, *Leptonychotes weddelli*. *Respiration Physiology* 17 283–290.
- Kooyman, G. L., J. P. Schroeder, D. M. Denison, D. D. Hammond, J. J. Wright, and W. P. Bergman. (1972). Blood nitrogen tensions of seals during simulated deep dives. *American Journal of Physiology* 223 (5): 1016–1020.
- Kooyman, G. L. and E. E. Sinnett. (1982). Pulmonary shunts in harbor seals and sea lions during simulated dives to depth. *Physiological Zoology* 55 (1): 105–111.
- Koski, W. R., G. Gamage, A. R. Davis, T. Mathews, B. LeBlanc, and S. H. Ferguson. (2015). Evaluation of UAS for photographic re-identification of bowhead whales, *Balaena mysticetus*. *Journal of Unmanned Vehicle Systems* 3 (1): 22–29.
- Koski, W. R., J. W. Lawson, D. H. Thomson, and W. J. Richardson. (1998). *Point Mugu Sea Range Marine Mammal Technical Report*. San Diego, CA: Naval Air Warfare Center, Weapons Division and Southwest Division, Naval Facilities Engineering Command.
- Krahforst, C. S., M. W. Sprague, and J. J. Luczkovich. (2016). The impact of vessel noise on oyster toadfish (*Opsanus tau*) communication. *Proceedings of Meetings on Acoustics* 27. DOI:10.1121/2.0000313
- Kritzler, H. and L. Wood. (1961). Provisional audiogram for the shark, *Carcharhinus leucas*. *Science* 133 (3463): 1480–1482.
- Krumpel, A., A. Rice, K. E. Frasier, F. Reese, J. S. Trickey, A. E. Simonis, J. P. Ryan, S. M. Wiggins, A. Denzinger, H.-U. Schnitzler, and S. Baumann-Pickering. (2021). Long-Term Patterns of Noise From Underwater Explosions and Their Relation to Fisheries in Southern California. *Frontiers in Marine Science* 8 (1925). DOI:10.3389/fmars.2021.796849
- Kruse, S. (1991). The interactions between killer whales and boats in Johnstone Strait, B.C. In K. Pryor & K. S. Norris (Eds.), *Dolphin Societies: Discoveries and Puzzles* (pp. 149–159). Berkeley and Los Angeles, CA: University of California Press.
- Kujawa, S. G. and M. C. Liberman. (2009). Adding insult to injury: Cochlear nerve degeneration after “temporary” noise-induced hearing loss. *The Journal of Neuroscience* 29 (45): 14077–14085. DOI:10.1523/JNEUROSCI.2845-09.2009
- Kuningas, S., P. H. Kvadsheim, F. P. A. Lam, and P. J. O. Miller. (2013). Killer whale presence in relation to naval sonar activity and prey abundance in northern Norway. *ICES Journal of Marine Science* 70 (7): 1287–1293. DOI:10.1093/icesjms/fst127

- Kusku, H. (2020). Acoustic sound-induced stress response of Nile tilapia (*Oreochromis niloticus*) to long-term underwater sound transmissions of urban and shipping noises. *Environmental Science and Pollution Research* 27 36857–36864. DOI:10.1007/s11356-020-09699-9
- Kvadsheim, P. H., S. DeRuiter, L. D. Sivle, J. Goldbogen, R. Roland-Hansen, P. J. O. Miller, F. A. Lam, J. Calambokidis, A. Friedlaender, F. Visser, P. L. Tyack, L. Kleivane, and B. Southall. (2017). Avoidance responses of minke whales to 1-4 kHz naval sonar. *Marine Pollution Bulletin* 121 (1–2): 60–68. DOI:10.1016/j.marpolbul.2017.05.037
- Kvadsheim, P. H., P. J. Miller, P. L. Tyack, L. D. Sivle, F. P. Lam, and A. Fahlman. (2012). Estimated Tissue and Blood N₂ Levels and Risk of Decompression Sickness in Deep-, Intermediate-, and Shallow-Diving Toothed Whales during Exposure to Naval Sonar. *Frontiers in Physiology* 3 (Article 125): 125. DOI:10.3389/fphys.2012.00125
- Kvadsheim, P. H. and E. M. Sevaldsen. (2005). *The Potential Impact of 1-8 kHz Active Sonar on Stocks of Juvenile Fish During Sonar Exercises*. Kjeller, Norway: Norwegian Defence Research Establishment.
- Kvadsheim, P. H., E. M. Sevaldsen, L. P. Folkow, and A. S. Blix. (2010a). Behavioural and physiological responses of hooded seals (*Cytophoca cristata*) to 1 to 7 kHz sonar signals. *Aquatic Mammals* 36 (3): 239–247.
- Kvadsheim, P. H., E. M. Sevaldsen, D. Scheie, L. P. Folkow, and A. S. Blix. (2010b). *Effects of Naval Sonar on Seals*. Kjeller, Norway: Norwegian Defense Research Establishment.
- Kyhn, L. A., P. B. Jorgensen, J. Carstensen, N. I. Bech, J. Tougaard, T. Dabelsteen, and J. Teilmann. (2015). Pingers cause temporary habitat displacement in the harbour porpoise *Phocoena phocoena*. *Marine Ecology Progress Series* 526 253–265. DOI:10.3354/meps11181
- Laborie, J., F. Christiansen, K. Beedholm, P. T. Madsen, and K. Heerah. (2021). Behavioural impact assessment of unmanned aerial vehicles on Weddell seals (*Leptonychotes weddellii*). *Journal of Experimental Marine Biology and Ecology*, 536. Retrieved April 13, 2021, from <https://doi.org/10.1016/j.jembe.2020.151509>.
- Lacroix, D. L., R. B. Lanctot, J. A. Reed, and T. L. McDonald. (2003). Effect of underwater seismic surveys on molting male long-tailed ducks in the Beaufort Sea, Alaska. *Canadian Journal of Zoology* 81 1862–1875. DOI:10.1139/Z09-185
- Ladich, F. (2000). Acoustic communication and the evolution of hearing in fishes. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 355 (1401): 1285–1288. DOI:10.1098/rstb.2000.0685
- Ladich, F. (2008). Sound communication in fishes and the influence of ambient and anthropogenic noise. *Bioacoustics* 17 35–37.
- Ladich, F. (2014). Fish bioacoustics. *Current Opinion in Neurobiology* 28 121–127. DOI:10.1016/j.conb.2014.06.013
- Ladich, F. and R. R. Fay. (2013). Auditory evoked potential audiometry in fish. *Reviews in Fish Biology and Fisheries* 23 (3): 317–364. DOI:10.1007/s11160-012-9297-z
- Lalas, C. and H. McConnell. (2016). Effects of seismic surveys on New Zealand fur seals during daylight hours: Do fur seals respond to obstacles rather than airgun noise? *Marine Mammal Science* 32 (2): 643–663. DOI:10.1111/mms.12293

- Lammers, M. O., M. Howe, E. Zang, M. McElligott, A. Engelhaupt, and L. Munger. (2017). Acoustic monitoring of coastal dolphins and their response to naval mine neutralization exercises. *Royal Society Open Science* 4 (12): e170558. DOI:10.1098/rsos.170558
- Lance, R. M., B. Capehart, O. Kadro, and C. R. Bass. (2015). Human injury criteria for underwater blasts. *PLoS One* 10 (11): e0143485. DOI:10.1371/journal.pone.0143485
- Lara, R. A., L. Breitzler, I. H. Lau, F. Gordillo-Martinez, F. Chen, P. J. Fonseca, A. H. Bass, and R. O. Vasconcelos. (2022). Noise-induced hearing loss correlates with inner ear hair cell decrease in larval zebrafish. *Journal of Experimental Biology* 225 (7). DOI:10.1242/jeb.243743
- Lara, R. A. and R. O. Vasconcelos. (2021). Impact of noise exposure on development, physiological stress and behavioural patterns in larval zebrafish. *Scientific Reports*. DOI:10.21203/rs.3.rs-126894/v1
- Larkin, R. P., L. L. Pater, and D. J. Tazlk. (1996). *Effects of Military Noise on Wildlife: A Literature Review* (USACERL Technical Report 96/21). Champaign, IL: U.S. Army Construction Engineering Research Laboratories.
- Larsen, O. N., M. Wahlberg, and J. Christensen-Dalsgaard. (2020). Amphibious hearing in a diving bird, the great cormorant (*Phalacrocorax carbo sinensis*). *Journal of Experimental Biology* 223 (6). DOI:10.1242/jeb.217265
- Laute, A., T. J. Grove, M. H. Rasmussen, A. Smith, O. Loisa, and M. E. H. Fournet. (2022). Impact of whale-watching vessels on humpback whale calling behavior on an Icelandic foraging ground during the Covid-19 pandemic. *Marine Ecology Progress Series* 701 159-173. DOI:10.3354/meps14202
- Lavender, A. L., S. M. Bartol, and I. K. Bartol. (2014). Ontogenetic investigation of underwater hearing capabilities in loggerhead sea turtles (*Caretta caretta*) using a dual testing approach. *The Journal of Experimental Biology* 217 (Pt 14): 2580–2589. DOI:10.1242/jeb.096651
- Leatherwood, S., F. T. Awbrey, and J. A. Thomas. (1982). Minke whale response to a transiting survey vessel. *Reports of the International Whaling Commission* 32 795–802.
- Lemons, D. W., L. N. Kloepper, P. E. Nachtigall, W. W. Au, S. A. Vlachos, and B. K. Branstetter. (2011). A re-evaluation of auditory filter shape in delphinid odontocetes: Evidence of constant-bandwidth filters. *The Journal of the Acoustical Society of America* 130 (5): 3107–3114. DOI:10.1121/1.3644912
- Lemos, L. S., J. H. Haxel, A. Olsen, J. D. Burnett, A. Smith, T. E. Chandler, S. L. Nieukirk, S. E. Larson, K. E. Hunt, and L. G. Torres. (2022). Effects of vessel traffic and ocean noise on gray whale stress hormones. *Scientific Reports* 12 18580. DOI:<https://doi.org/10.1038/s41598-022-14510-5>
- Lenhardt, M. L. (1994). *Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (Caretta caretta)*. Presented at the Proceedings of the Fourteenth Annual Symposium on Sea Turtle Biology and Conservation. Hilton Head, SC.
- Lenhardt, M. L., S. Bellmund, R. A. Byles, S. W. Harkins, and J. A. Musick. (1983). Marine turtle reception of bone-conducted sound. *The Journal of Auditory Research* 23 119–125.
- Lenhardt, M. L., R. C. Klinger, and J. A. Musick. (1985). Marine turtle middle-ear anatomy. *The Journal of Auditory Research* 25 66–72.
- Lesage, V., C. Barrette, M. C. S. Kingsley, and B. Sjare. (1999). The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. *Marine Mammal Science* 15 (1): 65–84.

- Lesage, V., A. Omrane, T. Daniol-Valcroze, and A. Mosnier. (2017). Increased proximity of vessels reduces feeding opportunities of blue whales in the St. Lawrence Estuary, Canada. *Endangered Species Research* 32 351–361. DOI:doi.org/10.3354/esr00825
- Lester, L. A. (2012). *Direct and Indirect Effects of Recreational Boats on Diamondback Terrapins (Malaclemys terrapin)*. (Unpublished doctoral dissertation). Drexel University, Philadelphia, PA. Retrieved from <http://hdl.handle.net/1860/3982>.
- Lester, L. A., E. A. Standora, W. F. Bien, and H. W. Avery. (2012). Behavioral Responses of Diamondback Terrapins (*Malaclemys terrapin terrapin*) to Recreational Boat Sounds. In A. N. Popper & A. Hawkins (Eds.), *The Effects of Noise on Aquatic Life*. New York, NY: Springer Science + Business Media.
- LGL Ltd Environmental Research Associates, Lamont Doherty Earth Observatory, and National Science Foundation. (2008). *Environmental Assessment of a Marine Geophysical Survey by the R/V Melville in the Santa Barbara Channel*. King City, Ontario: La Jolla, CA, Scripps Institution of Oceanography and Arlington, VA, National Science Foundation: Division of Ocean Sciences.
- Li, S., T. Akamatsu, D. Wang, K. Wang, S. Dong, X. Zhao, Z. Wei, X. Zhang, B. Taylor, L. A. Barrett, S. T. Turvey, R. R. Reeves, B. S. Stewart, M. Richlen, and J. R. Brandon. (2008). Indirect evidence of boat avoidance behavior of Yangtze finless porpoises. *Bioacoustics* 17 174–176.
- Li, S., H. Wu, Y. Xu, C. Peng, L. Fang, M. Lin, L. Xing, and P. Zhang. (2015). Mid- to high-frequency noise from high-speed boats and its potential impacts on humpback dolphins. *The Journal of the Acoustical Society of America* 138 (2): 942–952. DOI:10.1121/1.4927416
- Lin, H. W., A. C. Furman, S. G. Kujawa, and M. C. Liberman. (2011). Primary neural degeneration in the guinea pig cochlea after reversible noise-induced threshold shift. *Journal of the Association for Research in Otolaryngology* 12 (5): 605–616. DOI:10.1007/s10162-011-0277-0
- Liu, M., L. Dong, M. Lin, and S. Li. (2017). Broadband ship noise and its potential impacts on Indo-Pacific humpback dolphins: Implications for conservation and management. *The Journal of the Acoustical Society of America* 142 (5): 2766. DOI:10.1121/1.5009444
- Lohmann, K. J. and C. M. F. Lohmann. (2019). There and back again: natal homing by magnetic navigation in sea turtles and salmon. *Journal of Experimental Biology* 222 (Pt Suppl 1). DOI:10.1242/jeb.184077
- Løkkeborg, S., E. Ona, A. Vold, and A. Salthaug. (2012). Effects of sounds from seismic air guns on fish behavior and catch rates. In A. N. Popper & A. Hawkins (Eds.), *The Effects of Noise on Aquatic Life* (Vol. 730, pp. 415–419). New York, NY: Springer.
- Lombarte, A. and A. N. Popper. (1994). Quantitative analyses of postembryonic hair cell addition in the otolithic endorgans of the inner ear of the European hake, *Merluccius merluccius* (Gadiformes, Teleostei). *The Journal of Comparative Neurology* 345 419–428.
- Lombarte, A., H. Y. Yan, A. N. Popper, J. C. Chang, and C. Platt. (1993). Damage and regeneration of hair cell ciliary bundles in a fish ear following treatment with gentamicin. *Hearing Research* 66 166–174.
- Løvik, A. and J. M. Hovem. (1979). An experimental investigation of swimbladder resonance in fishes. *The Journal of the Acoustical Society of America* 66 (3): 850–854.

- Luczkovich, J. J., C. S. Krahforst, H. Hoppe, and M. W. Sprague. (2016a). Does vessel noise affect oyster toadfish calling rates? *Advances in Experimental Medicine and Biology* 875: 647–653. DOI:10.1007/978-1-4939-2981-8_78
- Luczkovich, J. J., C. S. Krahforst, K. E. Kelly, and M. W. Sprague. (2016b). *The Lombard effect in fishes: How boat noise impacts oyster toadfish vocalization amplitudes in natural experiments* [Extended Abstract]. Presented at the Fourth International Conference on the Effects of Noise on Aquatic Life. Dublin, Ireland.
- Luís, A. R., M. N. Couchinho, and M. E. dos Santos. (2014). Changes in the acoustic behavior of resident bottlenose dolphins near operating vessels. *Marine Mammal Science* 30 (4): 1417–1426. DOI:10.1111/mms.12125
- Luo, J. and L. Wiegerebe. (2016). Biomechanical control of vocal plasticity in an echolocating bat. *The Journal of Experimental Biology* 219 (6): 878–886. DOI:10.1242/jeb.134957
- Lusseau, D. (2004). The hidden cost of tourism: Detecting long-term effects of tourism using behavioral information. *Ecology and Society* 9 (1): 2.
- Lusseau, D. (2006). The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. *Marine Mammal Science* 22 (4): 802–818. DOI:10.1111/j.1748-7692.2006.00052
- Lusseau, D., D. E. Bain, R. Williams, and J. C. Smith. (2009). Vessel traffic disrupts the foraging behavior of southern resident killer whales, *Orcinus orca*. *Endangered Species Research* 6: 211–221. DOI:10.3354/esr00154
- Lusseau, D. and L. Bejder. (2007). The long-term consequences of short-term responses to disturbance experiences from whalewatching impact assessment. *International Journal of Comparative Psychology* 20: 228–236.
- Lutcavage, M. E. and P. L. Lutz. (1997). Diving Physiology. In P. L. Lutz & J. A. Musick (Eds.), *The Biology of Sea Turtles* (pp. 277–296). Boca Raton, FL: CRC Press.
- Lyamin, O. I., S. M. Korneva, V. V. Rozhnov, and L. M. Mukhametov. (2011). Cardiorespiratory changes in beluga in response to acoustic noise. *Doklady Biological Sciences* 440 (5): 704–707.
- Machernis, A., J. R. Powell, L. K. Engleby, and T. R. Spradlin. (2018). *An Updated Literature Review Examining the Impacts of Tourism on Marine Mammals over the Last Fifteen Years (2000-2015) to Inform Research and Management Programs*. St. Petersburg, FL: National Marine Fisheries Service, Southeast Regional Office.
- Madaro, A., R. E. Olsen, T. S. Kristiansen, L. O. Ebbesson, T. O. Nilsen, G. Flik, and M. Gorissen. (2015). Stress in Atlantic salmon: Response to unpredictable chronic stress. *The Journal of Experimental Biology* 218 (16): 2538–2550. DOI:10.1242/jeb.120535
- Madsen, P., M. Johnson, P. Miller, N. Soto, J. Lynch, and P. Tyack. (2006). Quantitative measures of air-gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. *The Journal of the Acoustical Society of America* 120 (4): 2366–2379.
- Madsen, P. T., D. A. Carder, K. Bedholm, and S. H. Ridgway. (2005). Porpoise clicks from a sperm whale nose—Convergent evolution of 130 kHz pulses in toothed whale sonars? *Bioacoustics* 15: 195–206.

- Magalhães, S., R. Prieto, M. A. Silva, J. Gonçalves, M. Afonso-Dias, and R. S. Santos. (2002). Short-term reactions of sperm whales (*Physeter macrocephalus*) to whale-watching vessels in the Azores. *Aquatic Mammals* 28 (3): 267–274.
- Magnhagen, C., K. Johansson, and P. Sigray. (2017). Effects of motorboat noise on foraging behaviour in Eurasian perch and roach: a field experiment. *Marine Ecology Progress Series* 564 115–125. DOI:10.3354/meps11997
- Maiditsch, I. P. and F. Ladich. (2022). Noise-induced masking of hearing in a labyrinth fish: effects on sound detection in croaking gouramis. *PeerJ* 10 e14230. DOI:10.7717/peerj.14230
- Malme, C. I., B. Würsig, J. E. Bird, and P. Tyack. (1986). *Behavioral responses of gray whales to industrial noise: Feeding observations and predictive modelling* (Outer Continental Shelf Environmental Assessment Program, Final Report of Principal Investigators MMS 88-0048). Anchorage, AK: Bolt Beranek, & Newman, Inc.
- Malme, C. I., B. Würsig, J. E. Bird, and P. Tyack. (1988). Observations of feeding gray whale responses to controlled industrial noise exposure. In W. M. Sackinger, M. O. Jeffries, J. L. Imm, & S. D. Tracey (Eds.), *Port and Ocean Engineering Under Arctic Conditions* (Vol. 2, pp. 55–73). Fairbanks, AK: Geophysical Institute, University of Alaska.
- Manci, K. M., D. N. Gladwin, R. Villella, and M. G. Cavendish. (1988). *Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife: A Literature Synthesis* (NERC-88/29). Fort Collins, CO: U.S. Fish and Wildlife Service, National Ecology Research Center.
- Mann, D., D. Higgs, W. Tavalga, M. Souza, and A. Popper. (2001). Ultrasound detection by clupeiform fishes. *The Journal of the Acoustical Society of America* 3048–3054.
- Mann, D. A., Z. Lu, M. C. Hastings, and A. N. Popper. (1998). Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (*Alosa sapidissima*). *The Journal of the Acoustical Society of America* 104 (1): 562–568.
- Mann, D. A., Z. Lu, and A. N. Popper. (1997). A clupeid fish can detect ultrasound. *Nature* 389 341.
- Mann, D. A., A. N. Popper, and B. Wilson. (2005). Pacific herring hearing does not include ultrasound. *Biology Letters* 1 (2): 158–161. DOI:10.1098/rsbl.2004.0241
- Manzano-Roth, R., E. E. Henderson, G. C. Alongi, C. R. Martin, S. W. Martin, and B. Matsuyama. (2022). Dive characteristics of Cross Seamount beaked whales from long-term passive acoustic monitoring at the Pacific Missile Range Facility, Kaua‘i. *Marine Mammal Science*. DOI:<https://doi.org/10.1111/mms.12959>
- Manzano-Roth, R., E. E. Henderson, S. W. Martin, C. Martin, and B. M. Matsuyama. (2016). Impacts of U.S. Navy training events on Blainville's beaked whale (*Mesoplodon densirostris*) foraging dives in Hawaiian waters. *Aquatic Mammals* 42 (4): 507–518. DOI:10.1578/AM.42.4.2016.507
- Marega, M., G. Henrique, Y. Le Pendu, P. da Silva, and A. Schiavetti. (2018). Behavioral responses of *Sotalia guianensis* (Cetartiodactyla, Delphinidae) to boat approaches in northeast Brazil. *Latin American Journal of Aquatic Research* 46 (2): 268–279. DOI:10.3856/vol46-issue2-fulltext-3
- Martin, B., D. G. Zeddies, B. Gaudet, and J. Richard. (2016). Evaluation of three sensor types for particle motion measurement. *Advances in Experimental Medicine and Biology* 875 679–686. DOI:10.1007/978-1-4939-2981-8_82
- Martin, C. R., S. W. Martin, E. E. Henderson, T. A. Helble, R. A. Manzano-Roth, B. M. Matsuyama, and G. C. Alongi. (2017). *SSC Pacific FY16 annual report on PMRF Marine Mammal Monitoring. Final*

- Report*. San Diego, CA: National Marine Mammal Foundation; and Space and Naval Warfare Systems Center Pacific.
- Martin, K. J., S. C. Alessi, J. C. Gaspard, A. D. Tucker, G. B. Bauer, and D. A. Mann. (2012). Underwater hearing in the loggerhead turtle (*Caretta caretta*): A comparison of behavioral and auditory evoked potential audiograms. *The Journal of Experimental Biology* 215 (17): 3001–3009. DOI:10.1242/jeb.066324
- Martin, M., T. Gridley, S. Elwen, and I. Charrier. (2023a). Inter-site variability in the Cape fur seal's behavioural response to boat noise exposure. *Marine Pollution Bulletin* 196 115589. DOI:10.1016/j.marpolbul.2023.115589
- Martin, M., T. Gridley, S. H. Elwen, and I. Charrier. (2022). Assessment of the impact of anthropogenic airborne noise on the behaviour of Cape fur seals during the breeding season in Namibia. *Journal of Experimental Marine Biology and Ecology* 550 151721.
- Martin, M. J., W. D. Halliday, J. J. Citta, L. Quakenbush, L. Harwood, E. V. Lea, F. Juanes, J. Dawson, A. Nicoll, and S. J. Insley. (2023b). Exposure and behavioural responses of tagged bowhead whales (*Balaena mysticetus*) to vessels in the Pacific Arctic. *Arctic Science*. DOI:10.1139/as-2022-0052
- Martin, S. B., K. Lucke, and D. R. Barclay. (2020). Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. *The Journal of the Acoustical Society of America* 147 (4).
- Martin, S. W., C. R. Martin, B. M. Matsuyama, and E. E. Henderson. (2015). Minke whales (*Balaenoptera acutorostrata*) respond to navy training. *The Journal of the Acoustical Society of America* 137 (5): 2533–2541. DOI:10.1121/1.4919319
- Masud, N., L. Hayes, D. Crivelli, S. Grigg, and J. Cable. (2020). Noise pollution: Acute noise exposure increases susceptibility to disease and chronic exposure reduces host survival. *Royal Society Open Science* 7 (9): 200172. DOI:10.1098/rsos.200172
- Mattson, M. C., J. A. Thomas, and D. St. Aubin. (2005). Effects of boat activity on the behavior of bottlenose dolphins (*Tursiops truncatus*) in waters surrounding Hilton Head Island, South Carolina. *Aquatic Mammals* 31 (1): 133–140. DOI:10.1578/AM.31.1.2005.133
- Mauro, M., I. Perez-Arjona, E. J. B. Perez, M. Ceraulo, M. Bou-Cabo, T. Benson, V. Espinosa, F. Beltrame, S. Mazzola, M. Vazzana, and G. Buscaino. (2020). The effect of low frequency noise on the behaviour of juvenile *Sparus aurata*. *The Journal of the Acoustical Society of America* 147 (6): 3795–3807. DOI:10.1121/10.0001255
- McCarthy, E., D. Moretti, L. Thomas, N. DiMarzio, R. Morrissey, S. Jarvis, J. Ward, A. Izzi, and A. Dilley. (2011). Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multiship exercises with mid-frequency sonar. *Marine Mammal Science* 27 (3): E206–E226. DOI:10.1111/j.1748-7692.2010.00457
- McCartney, B. S. and A. R. Stubbs. (1971). Measurements of the acoustic target strengths of fish in dorsal aspect, including swimbladder resonance. *Journal of Sound and Vibration* 15 (3): 397–420.
- McCauley, R. D. and D. H. Cato. (2000). Patterns of fish calling in a nearshore environment in the Great Barrier Reef. *Philosophical Transactions: Biological Sciences* 355 (1401): 1289–1293.

- McCauley, R. D., J. Fewtrell, A. J. Duncan, C. Jenner, M.-N. Jenner, J. D. Penrose, R. I. T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. (2000a). Marine seismic surveys: A study of environmental implications. *Australian Petroleum Production Exploration Association Journal* 2000 692–708.
- McCauley, R. D., J. Fewtrell, A. J. Duncan, C. Jenner, M.-N. Jenner, J. D. Penrose, R. I. T. Prince, A. Adhitya, J. Murdoch, and K. A. McCabe. (2000b). *Marine Seismic Surveys: Analysis and Propagation of Air-gun Signals; and Effects of Air-gun Exposure on Humpback Whales, Sea Turtles, Fishes and Squid*. Bentley, Australia: Centre for Marine Science and Technology.
- McCauley, R. D., J. Fewtrell, and A. N. Popper. (2003). High intensity anthropogenic sound damages fish ears. *The Journal of the Acoustical Society of America* 113 (1): 638–642. DOI:10.1121/1.1527962
- McCauley, R. D., M. N. Jenner, C. Jenner, K. A. McCabe, and J. Murdoch. (1998). The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: Preliminary results of observations about a working seismic vessel and experimental exposures. *Australian Petroleum Production and Exploration Association Journal* 38 692–706.
- McCauley, R. D. and C. S. Kent. (2012). A lack of correlation between air gun signal pressure waveforms and fish hearing damage. *Advances in Experimental Medicine and Biology* 730 245–250. DOI:10.1007/978-1-4419-7311-5_54
- McCloskey, K. P., K. E. Chapman, L. Chapuis, M. I. McCormick, A. N. Radford, and S. D. Simpson. (2020). Assessing and mitigating impacts of motorboat noise on nesting damselfish. *Environmental Pollution* 266 (Pt 2). DOI:10.1016/j.envpol.2020.115376
- McCormick, M. I., E. P. Fakan, S. L. Nedelec, and B. J. M. Allan. (2019). Effects of boat noise on fish fast-start escape response depend on engine type. *Scientific Reports* 9 (1). DOI:10.1038/s41598-019-43099-5
- McCormick, M. I., S. A. Watson, S. D. Simpson, and B. J. M. Allan. (2018). Effect of elevated CO₂ and small boat noise on the kinematics of predator-prey interactions. *Proceedings B: Biological Sciences* 285 (1875). DOI:10.1098/rspb.2017.2650
- McDonald, B. I. and P. J. Ponganis. (2012). Lung collapse in the diving sea lion: Hold the nitrogen and save the oxygen. *Biology Letters* 8 1047–1049. DOI:doi: 10.1098/rsbl.2012.0743
- McDonald, M., J. Hildebrand, S. Wiggins, and D. Ross. (2008). A 50 year comparison of ambient ocean noise near San Clemente Island: A bathymetrically complex coastal region off Southern California. *The Journal of the Acoustical Society of America* 124 (4): 1985–1992. DOI:10.1121/1.2967889.
- McDonald, M. A., J. A. Hildebrand, and S. C. Webb. (1995). Blue and fin whales observed on a seafloor array in the Northeast Pacific. *The Journal of the Acoustical Society of America* 98 (2): 712–721.
- McDonald, M. A., J. A. Hildebrand, S. M. Wiggins, D. W. Johnston, and J. J. Polovina. (2009). An acoustic survey of beaked whales at Cross Seamount near Hawaii. *The Journal of the Acoustical Society of America* 125 (2): 624–627. DOI:10.1121/1.3050317
- McGrath, J. R. (1976). Infrasonic sea noise at the Mid-Atlantic Ridge near 37°N. *The Journal of the Acoustical Society of America* 60 (6): 1290-1299. DOI:10.1121/1.381243
- McGrew, K. A., S. E. Crowell, J. L. Fiely, A. M. Berlin, G. H. Olsen, J. James, H. Hopkins, and C. K. Williams. (2022). Underwater hearing in sea ducks with applications for reducing gillnet bycatch through acoustic deterrence. *The Journal of Experimental Biology* 225 (20). DOI:10.1242/jeb.243953

- McHuron, E. A., L. Aerts, G. Gailey, O. Sychenko, D. P. Costa, M. Mangel, and L. K. Schwarz. (2021). Predicting the population consequences of acoustic disturbance, with application to an endangered gray whale population. *Ecological Applications* e02440. DOI:10.1002/eap.2440
- McHuron, E. A., B. A. Block, and D. P. Costa. (2018a). Movements and dive behavior of juvenile California sea lions from Año Nuevo Island. *Marine Mammal Science* 34 (1): 238-249.
- McHuron, E. A., M. Castellote, G. K. Himes Boor, K. E. W. Shelden, A. J. Warlick, T. L. McGuire, P. R. Wade, and K. T. Goetz. (2023a). Modeling the impacts of a changing and disturbed environment on an endangered beluga whale population. *Ecological Modelling* 483. DOI:10.1016/j.ecolmodel.2023.110417
- McHuron, E. A., L. K. Schwarz, D. P. Costa, and M. Mangel. (2018b). A state-dependent model for assessing the population consequences of disturbance on income-breeding mammals. *Ecological Modelling* 385 133–144. DOI:10.1016/j.ecolmodel.2018.07.016
- McHuron, E. A., J. T. Sterling, and M. Mangel. (2023b). The influence of prey availability on behavioral decisions and reproductive success of a central-place forager during lactation. *Journal of Theoretical Biology* 560 111392. DOI:10.1016/j.jtbi.2022.111392
- McIver, E. L., M. A. Marchaterre, A. N. Rice, and A. H. Bass. (2014). Novel underwater soundscape: Acoustic repertoire of plainfin midshipman fish. *The Journal of Experimental Biology* 217 (Pt 13): 2377–2389. DOI:10.1242/jeb.102772
- McKenna, L. N., F. V. Paladino, P. S. Tomillo, and N. J. Robinson. (2019). Do sea turtles vocalize to synchronize hatching or nest emergence? *Copeia* 107 (1): 120–123. DOI:10.1643/ce-18-069
- McKenna, M. F., D. Ross, S. M. Wiggins, and J. A. Hildebrand. (2012). Underwater radiated noise from modern commercial ships. *The Journal of the Acoustical Society of America* 131 (1): 92–103. DOI:10.1121/1.3664100
- McQueen, K., J. J. Meager, D. Nyqvist, J. E. Skjæraasen, E. M. Olsen, Ø. Karlsen, P. H. Kvadsheim, N. O. Handegard, T. N. Forland, L. D. Sivle, and F. Juanes. (2022). Spawning Atlantic cod (*Gadus morhua* L.) exposed to noise from seismic airguns do not abandon their spawning site. *ICES Journal of Marine Science* 79 (10): 2697-2708. DOI:10.1093/icesjms/fsac203
- Medwin, H. and C. Clay. (1998). *Fundamentals of Acoustical Oceanography*. San Diego, CA: Academic Press.
- Meekan, M. G., C. W. Speed, R. D. McCauley, R. Fisher, M. J. Birt, L. M. Currey-Randall, J. M. Semmens, S. J. Newman, K. Cure, M. Stowar, B. Vaughan, and M. J. G. Parsons. (2021). A large-scale experiment finds no evidence that a seismic survey impacts a demersal fish fauna. *Proceedings of the National Academy of Sciences of the United States of America* 118 (30). DOI:10.1073/pnas.2100869118
- Meissner, A. M., F. Christiansen, E. Martinez, M. D. Pawley, M. B. Orams, and K. A. Stockin. (2015). Behavioural effects of tourism on oceanic common dolphins, *Delphinus* sp., in New Zealand: The effects of Markov analysis variations and current tour operator compliance with regulations. *PLoS ONE* 10 (1): e0116962. DOI:10.1371/journal.pone.0116962
- Melcón, M. L., A. J. Cummins, S. M. Kerosky, L. K. Roche, S. M. Wiggins, and J. A. Hildebrand. (2012). Blue whales respond to anthropogenic noise. *PLoS ONE* 7 (2). DOI:10.1371/journal.pone.0032681

- Melvin, E. F., K. S. Dietrich, S. Fitzgerald, and T. Cardoso. (2011). Reducing seabird strikes with trawl cables in the pollock catcher-processor fleet in the eastern Bering Sea. *Polar Biology* 34 (2): 215–226.
- Melvin, E. F., J. K. Parrish, and L. L. Conquest. (1999). Novel tools to reduce seabird bycatch in coastal gillnet fisheries; Nuevas herramientas para reducir la captura accidental de aves marinas con redes agalleras de pesquerías costeras. *Conservation Biology* 13 (6): 1386–1397. DOI:10.1046/j.1523-1739.1999.98426
- Mensing, A. F., R. L. Putland, and C. A. Radford. (2018). The effect of motorboat sound on Australian snapper *Pagrus auratus* inside and outside a marine reserve. *Ecology and Evolution* 8 (13): 6438–6448.
- Mercado, E., III. (2021). Spectral interleaving by singing humpback whales: Signs of sonar. *The Journal of the Acoustical Society of America* 149 (2). DOI:10.1121/10.0003443
- Mickle, M. F. and D. M. Higgs. (2021). Towards a new understanding of elasmobranch hearing. *Marine Biology* 169 (1). DOI:10.1007/s00227-021-03996-8
- Miguel, C., J. H. Becker, B. S. de Freitas, L. B. A. Touguinha, M. Salvador, and G. T. Oliveira. (2020). Physiological effects of incidental capture and seasonality on juvenile green sea turtles (*Chelonia mydas*). *Journal of Experimental Marine Biology and Ecology* 533. DOI:10.1016/j.jembe.2020.151460
- Mikkelsen, L., L. Hermannsen, K. Beedholm, P. T. Madsen, and J. Tougaard. (2017). Simulated seal scarer sounds scare porpoises, but not seals: Species-specific responses to 12 kHz deterrence sounds. *Royal Society Open Science* 4 (7): 170286. DOI:10.1098/rsos.170286
- Mikkelsen, L., M. Johnson, D. M. Wisniewska, A. van Neer, U. Siebert, P. T. Madsen, and J. Teilmann. (2019). Long-term sound and movement recording tags to study natural behavior and reaction to ship noise of seals. *Ecology and Evolution*. DOI:10.1002/ece3.4923
- Miksis-Olds, J. L., P. L. Donaghay, J. H. Miller, P. L. Tyack, and J. E. Reynolds, III. (2007). Simulated vessel approaches elicit differential responses from manatees. *Marine Mammal Science* 23 (3): 629–649. DOI:10.1111/j.1748-7692.2007.00133
- Miksis-Olds, J. L. and P. L. Tyack. (2009). Manatee (*Trichechus manatus*) vocalization usage in relation to environmental noise levels. *The Journal of the Acoustical Society of America* 125 (3): 1806–1815.
- Miksis, J. L., R. C. Connor, M. D. Grund, D. P. Nowacek, A. R. Solow, and P. L. Tyack. (2001). Cardiac responses to acoustic playback experiments in the captive bottlenose dolphin (*Tursiops truncatus*). *Journal of Comparative Psychology* 115 (3): 227–232.
- Miller, L. A., V. Futtrup, and D. C. Dunning. (2004). How Extrinsic Sounds Interfere with Bat Biosonar. In J. A. Thomas, C. F. Moss, & M. Vater (Eds.), *Echolocation in Bats and Dolphins* (pp. 380–385). Chicago, IL: University of Chicago Press.
- Miller, P. (2012). The severity of behavioral changes observed during experimental exposures of killer (*Orcinus orca*), long-finned pilot (*Globicephala melas*), and sperm (*Physeter macrocephalus*) whales to naval sonar. *Aquatic Mammals* 38 (4): 362–401. DOI:10.1578/am.38.4.2012.362
- Miller, P., R. Antunes, A. C. Alves, P. Wensveen, P. Kvadsheim, L. Kleivane, N. Nordlund, F.-P. Lam, S. van IJsselmuide, F. Visser, and P. Tyack. (2011). *The 3S experiments: Studying the behavioural effects of naval sonar on killer whales (Orcinus orca), sperm whales (Physeter macrocephalus), and long-*

- finned pilot whales (Globicephala melas) in Norwegian waters* (Technical Report SOI-2011-001). St. Andrews, United Kingdom: Scottish Oceans Institute.
- Miller, P., M. Johnson, P. Madsen, N. Biassoni, M. Quero, and P. Tyack. (2009). Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. *Deep Sea Research I* 56 (7): 1168–1181. DOI:10.1016/j.dsr.2009.02.008.
- Miller, P. J., R. N. Antunes, P. J. Wensveen, F. I. Samarra, A. C. Alves, P. L. Tyack, P. H. Kvadsheim, L. Kleivane, F. P. Lam, M. A. Ainslie, and L. Thomas. (2014). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. *The Journal of the Acoustical Society of America* 135 (2): 975–993. DOI:10.1121/1.4861346
- Miller, P. J., S. Isojunno, E. Siegal, F.-P. A. Lam, P. H. Kvadsheim, and C. Curé. (2022). Behavioral responses to predatory sounds predict sensitivity of cetaceans to anthropogenic noise within a soundscape of fear. *Proceedings of the National Academy of Sciences* 119 (13): e2114932119.
- Miller, P. J., P. H. Kvadsheim, F. P. Lam, P. L. Tyack, C. Cure, S. L. DeRuiter, L. Kleivane, L. D. Sivle, I. S. P. van, F. Visser, P. J. Wensveen, A. M. von Benda-Beckmann, L. M. Martin Lopez, T. Narazaki, and S. K. Hooker. (2015). First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise. *Royal Society Open Science* 2 (6): 140484. DOI:10.1098/rsos.140484
- Miller, P. J. O., N. Biassoni, A. Samuels, and P. L. Tyack. (2000). Whale songs lengthen in response to sonar. *Nature* 405 (6789): 903.
- Mills, E. M. M., S. Piwetz, and D. N. Orbach. (2023). Vessels Disturb Bottlenose Dolphin Behavior and Movement in an Active Ship Channel. *Animals (Basel)* 13 (22). DOI:10.3390/ani13223441
- Mills, S. C., R. Beldade, L. Henry, D. Lavery, S. L. Nedelec, S. D. Simpson, and A. N. Radford. (2020). Hormonal and behavioural effects of motorboat noise on wild coral reef fish. *Environmental Pollution* 262. DOI:10.1016/j.envpol.2020.114250
- Mintz, J. D. (2012). *Vessel Traffic in the Hawaii-Southern California and Atlantic Fleet Testing and Training Study Areas*. Alexandria, VA: Center for Naval Analyses.
- Mintz, J. D. (2016). *Characterization of Vessel Traffic in the Vicinities of HRC, SOCAL, and the Navy Operating Areas off the U.S. East Coast*. Alexandria, VA: Center for Naval Analyses.
- Mintz, J. D. and R. J. Filadelfo. (2011). *Exposure of Marine Mammals to Broadband Radiated Noise* (Specific Authority N0001-4-05-D-0500). Washington, DC: Center for Naval Analyses.
- Misund, O. A. (1997). Underwater acoustics in marine fisheries and fisheries research. *Reviews in Fish Biology and Fisheries* 7 1–34.
- Mobley, J. R. (2011). *Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaii Range Complex in Conjunction with Two Navy Training Events. SCC and USWEX February 16–March 5, 2011. Final Field Report*. San Diego, CA: HDR Inc.
- Mobley, J. R. and A. Milette. (2010). *Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaiian Range Complex in Conjunction with a Navy Training Event, SCC February 16–21, 2010, Final Field Report*. Pearl Harbor, HI: Commander, U.S. Pacific Fleet.
- Mobley, J. R. and A. F. Pacini. (2012). *Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaii Range Complex in Conjunction with a Navy Training Event, SCC February 15–25, 2012, Final Field Report*. Pearl Harbor, HI: Commander, U.S. Pacific Fleet.

- Mobley, J. R., M. A. Smultea, C. E. Bacon, and A. S. Frankel. (2012). *Preliminary Report: Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaii Range Complex—Summary of Focal Follow Analysis for 2008–2012 SCC Events: Preliminary Report*. Pearl Harbor, HI: Commander, U.S. Pacific Fleet.
- Moein Bartol, S. E., J. A. Musick, J. A. Keinath, D. E. Barnard, M. L. Lenhardt, and R. George. (1995). Evaluation of Seismic Sources for Repelling Sea Turtles from Hopper Dredges. In L. Z. Hales (Ed.), *Sea Turtle Research Program: Summary Report* (Vol. Technical Report CERC-95, pp. 90–93). Kings Bay, GA: U.S. Army Engineer Division, South Atlantic, Atlanta, GA and U.S. Naval Submarine Base.
- Møller, A. R. (2013). *Hearing: Anatomy, Physiology, and Disorders of the Auditory System*. San Diego, CA: Plural Publishing.
- Mooney, T. A., P. E. Nachtigall, M. Breese, S. Vlachos, W. Whitlow, and L. Au. (2009a). Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): The effects of noise level and duration. *The Journal of the Acoustical Society of America* 125 (3): 1816–1826.
- Mooney, T. A., P. E. Nachtigall, M. Castellote, K. A. Taylor, A. F. Pacini, and J.-A. Esteban. (2008). Hearing pathways and directional sensitivity of the beluga whale, *Delphinapterus leucas*. *Journal of Experimental Marine Biology and Ecology* 362 (2): 108–116. DOI:10.1016/j.jembe.2008.06.004
- Mooney, T. A., P. E. Nachtigall, and S. Vlachos. (2009b). Sonar-induced temporary hearing loss in dolphins. *Biology Letters* 5 (4): 565–567. DOI:10.1098/rsbl.2009.0099
- Mooney, T. A., A. Smith, O. N. Larsen, K. A. Hansen, and M. Rasmussen. (2020). A field study of auditory sensitivity of the Atlantic puffin, *Fratercula arctica*. *Journal of Experimental Biology* 223. DOI:10.1242/jeb.228270
- Mooney, T. A., A. Smith, O. N. Larsen, K. A. Hansen, M. Wahlberg, and M. H. Rasmussen. (2019). Field-based hearing measurements of two seabird species. *Journal of Experimental Biology* 222 1–7. DOI:DOI:10.1242/jeb.190710
- Moore, J. and J. Barlow. (2017). *Population Abundance and Trend Estimates for Beaked Whales and Sperm Whales in the California Current from Ship-Based Visual Line-Transect Survey Data, 1991–2014* (National Oceanic and Atmospheric Administration Technical Memorandum NMFS-SWFSC-585). La Jolla, CA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.
- Moore, J. E. and J. P. Barlow. (2013). Declining abundance of beaked whales (Family Ziphiidae) in the California Current Large Marine Ecosystem. *PLoS ONE* 8 (1): e52770. DOI:10.1371/journal.pone.0052770
- Moore, M. J., A. L. Bogomolni, S. E. Dennison, G. Early, M. M. Garner, B. A. Hayward, B. J. Lentell, and D. S. Rotstein. (2009). Gas bubbles in seals, dolphins, and porpoises entangled and drowned at depth in gillnets. *Veterinary Pathology* 46 536–547. DOI:10.1354/vp.08-VP-0065-M-FL
- Moore, M. J. and G. A. Early. (2004). Cumulative sperm whale bone damage and the bends. *Science* 306 2215.
- Moore, M. J., G. H. Mitchell, T. K. Rowles, and G. Early. (2020). Dead cetacean? Beach, bloat, float, sink. *Frontiers in Marine Science* 7.
- Moore, M. J., J. van der Hoop, S. G. Barco, A. M. Costidis, F. M. Gulland, P. D. Jepson, K. T. Moore, S. Raverty, and W. A. McLellan. (2013). Criteria and case definitions for serious injury and death of

- pinnipeds and cetaceans caused by anthropogenic trauma. *Diseases of Aquatic Organisms* 103 (3): 229–264. DOI:10.3354/dao02566
- Moreland, E. E., M. F. Cameron, R. P. Angliss, and P. L. Boveng. (2015). Evaluation of a ship-based unoccupied aircraft system (UAS) for surveys of spotted and ribbon seals in the Bering Sea pack ice. *Journal of Unmanned Vehicle Systems* 3 (3): 114–122. DOI:10.1139/juvs-2015-0012
- Moretti, D., L. Thomas, T. Marques, J. Harwood, A. Dilley, B. Neales, J. Shaffer, E. McCarthy, L. New, S. Jarvis, and R. Morrissey. (2014). A risk function for behavioral disruption of Blainville's beaked whales (*Mesoplodon densirostris*) from mid-frequency active sonar. *PLoS ONE* 9 (1): e85064. DOI:10.1371/journal.pone.0085064
- Morton, A. B. and H. K. Symonds. (2002). Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *ICES Journal of Marine Science* 59 (1): 71–80. DOI:10.1006/jmsc.2001.1136
- Moss, C. F., C. Chiu, and A. Surlykke. (2011). Adaptive vocal behavior drives perception by echolocation in bats. *Current Opinion in Neurobiology* 21 (4): 645–652. DOI:10.1016/j.conb.2011.05.028
- Mrosovsky, N. (1972). Spectrographs of the sounds of leatherback turtles. *Herpetologica* 28 (3): 256–258.
- Mueller-Blenkle, C., P. K. McGregor, A. B. Gill, M. H. Andersson, J. Metcalfe, V. Bendall, P. Sigray, D. Wood, and F. Thomsen. (2010). *Effects of Pile-Driving Noise on the Behaviour of Marine Fish*. London, United Kingdom: COWRIE Ltd.
- Mulsow, J. and C. Reichmuth. (2010). Psychophysical and electrophysiological aerial audiograms of a Steller sea lion (*Eumetopias jubatus*). *The Journal of the Acoustical Society of America* 127 (4): 2692–2701.
- Munger, L. M., M. O. Lammers, and W. W. L. Au. (2014). *Passive Acoustic Monitoring for Cetaceans within the Marianas Islands Range Complex. Preliminary Report*. Pearl Harbor, HI: Naval Facilities Engineering Command Pacific.
- Munger, L. M., M. O. Lammers, J. N. Oswald, T. M. Yack, and W. W. L. Au. (2015). *Passive Acoustic Monitoring of Cetaceans within the Mariana Islands Range Complex Using Ecological Acoustic Recorders. Final Report*. Pearl Harbor, HI: Naval Facilities Engineering Command Pacific.
- Murphy, K. A., H. Davies, H. Shafer, K. Cox, K. Nikolich, and F. Juanes. (2019). Impacts of noise on the behavior and physiology of marine invertebrates: A meta-analysis. *Proceedings of Meetings on Acoustics* 37 (1). DOI:10.1121/2.0001217
- Murray, C. C., L. C. Hannah, T. Doniol-Valcroze, B. M. Wright, E. H. Stredulinsky, J. C. Nelson, A. Locke, and R. C. Lacy. (2021). A cumulative effects model for population trajectories of resident killer whales in the Northeast Pacific. *Biological Conservation* 257. DOI:10.1016/j.biocon.2021.109124
- Myrberg, A. A., C. R. Gordon, and A. P. Klimley. (1976). Attraction of free ranging sharks by low frequency sound, with comments on its biological significance. In A. Schuiff & A. D. Hawkins (Eds.), *Sound Reception in Fish*. Amsterdam, Netherlands: Elsevier.
- Myrberg, A. A., Jr. (2001). The acoustical biology of elasmobranchs. *Environmental Biology of Fishes* 60 31–45.
- Myrberg, A. A., Jr., A. Banner, and J. D. Richard. (1969). Shark attraction using a video-acoustic system. *Marine Biology* 2 (3): 264–276.

- Myrberg, A. A., Jr., S. J. Ha, S. Walewski, and J. C. Banbury. (1972). Effectiveness of acoustic signals in attracting epipelagic sharks to an underwater sound source. *Bulletin of Marine Science* 22: 926–949.
- Nabe-Nielsen, J., R. M. Sibly, J. Tougaard, J. Teilmann, and S. Sveegaard. (2014). Effects of noise and by-catch on a Danish harbour porpoise population. *Ecological Modelling* 272: 242–251.
- Nachtigall, P. E. and A. Y. Supin. (2013). A false killer whale reduces its hearing sensitivity when a loud sound is preceded by a warning. *Journal of Experimental Biology* 216 (16): 3062–3070.
- Nachtigall, P. E. and A. Y. Supin. (2014). Conditioned hearing sensitivity reduction in a bottlenose dolphin (*Tursiops truncatus*). *The Journal of Experimental Biology* 217 (Pt 15): 2806–2813.
DOI:10.1242/jeb.104091
- Nachtigall, P. E. and A. Y. Supin. (2015). Conditioned frequency-dependent hearing sensitivity reduction in the bottlenose dolphin (*Tursiops truncatus*). *The Journal of Experimental Biology* 218 (7): 999–1005.
- Nachtigall, P. E., A. Y. Supin, J. A. Estaban, and A. F. Pacini. (2015). Learning and extinction of conditioned hearing sensation change in the beluga whale (*Delphinapterus leucas*). *Journal of Comparative Physiology A* 202 (2): 105–113. DOI:10.1007/s00359-015-1056-x
- Nachtigall, P. E., A. Y. Supin, A. F. Pacini, and R. A. Kastelein. (2016a). Conditioned hearing sensitivity change in the harbor porpoise (*Phocoena phocoena*). *The Journal of the Acoustical Society of America* 140 (2): 960–967.
- Nachtigall, P. E., A. Y. Supin, A. F. Pacini, and R. A. Kastelein. (2018). Four odontocete species change hearing levels when warned of impending loud sound. *Integrative Zoology* 13: 2–20.
DOI:10.1111/1749-4877.12286
- Nachtigall, P. E., A. Y. Supin, J. Pawloski, and W. W. L. Au. (2004). Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. *Marine Mammal Science* 20 (4): 673–687.
- Nachtigall, P. E., A. Y. Supin, A. B. Smith, and A. F. Pacini. (2016b). Expectancy and conditioned hearing levels in the bottlenose dolphin (*Tursiops truncatus*). *Journal of Experimental Biology* 219 (6): 844–850.
- Narazaki, T., K. Sato, K. J. Abernathy, G. J. Marshall, and N. Miyazaki. (2013). Loggerhead turtles (*Caretta caretta*) use vision to forage on gelatinous prey in mid-water. *PLoS ONE* 8 (6): e66043.
DOI:10.1371/journal.pone.0066043
- National Academies of Sciences Engineering and Medicine. (2017). *Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals*. Washington, DC: The National Academies Press.
- National Marine Fisheries Service. (2005). *Assessment of Acoustic Exposures on Marine Mammals in Conjunction with USS Shoup Active Sonar Transmissions in the Eastern Strait of Juan de Fuca and Haro Strait, Washington (5 May 2003)*. Seattle, WA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
- National Marine Fisheries Service. (2007). *Biological Opinion on the U.S. Navy's Proposed Undersea Warfare Training Exercises in the Hawaii Range Complex from January 2007 Through January 2009*. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

- National Marine Fisheries Service. (2019). *2019 Report of Marine Mammal Strandings in the United States: National Overview*. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources.
- National Oceanic and Atmospheric Administration. (2002). *Report of the Workshop on acoustic resonance as a source of tissue trauma in cetaceans*. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
- National Oceanic and Atmospheric Administration. (2010). *National Marine Fisheries Service's Final Biological Opinion for the Proposed Issuance of a United States Coast Guard Permit to the St. George Reef Lighthouse Preservation Society to Maintain the St. George Reef Lighthouse as a Private Aid to Navigation and Its Effect on the Federally Threatened Eastern Distinct Population Segment of Steller Sea Lion and Designated Critical Habitat*. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
- National Oceanic and Atmospheric Administration. (2014). *Southern Resident Killer Whales: 10 Years of Research & Conservation*. Seattle, WA: National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
- National Park Service. (1994). *Report on Effects of Aircraft Overflights on the National Park System* (Report to Congress prepared pursuant to Public Law 100-191, the National Parks Overflights Act of 1987). Washington, DC: National Park Service.
- National Research Council. (2003). *Ocean Noise and Marine Mammals*. Washington, DC: The National Academies Press.
- National Research Council. (2005). *Marine Mammal Populations and Ocean Noise*. Washington, DC: The National Academies Press.
- Nedelec, S. L., J. Campbell, A. N. Radford, S. D. Simpson, and N. D. Merchant. (2016a). Particle motion: The missing link in underwater acoustic ecology. *Methods in Ecology and Evolution* 7 (7): 836–842. DOI:10.1111/2041-210X.12544
- Nedelec, S. L., S. C. Mills, D. Lecchini, B. Nedelec, S. D. Simpson, and A. N. Radford. (2016b). Repeated exposure to noise increases tolerance in a coral reef fish. *Environmental Pollution* 216 428–236. DOI:10.1016/j.envpol.2016.05.058
- Nedelec, S. L., S. C. Mills, A. N. Radford, R. Beldade, S. D. Simpson, B. Nedelec, and I. M. Cote. (2017a). Motorboat noise disrupts co-operative interspecific interactions. *Scientific Reports* 7 (1). DOI:10.1038/s41598-017-06515-2
- Nedelec, S. L., A. N. Radford, L. Pearl, B. Nedelec, M. I. McCormick, M. G. Meekan, and S. D. Simpson. (2017b). Motorboat noise impacts parental behaviour and offspring survival in a reef fish. *Proceedings of the Royal Society of London B: Biological Sciences* 284 (1856). DOI:10.1098/rspb.2017.0143
- Nedelec, S. L., S. D. Simpson, E. L. Morley, B. Nedelec, and A. N. Radford. (2015). Impacts of regular and random noise on the behaviour, growth and development of larval Atlantic cod (*Gadus morhua*). *Proceedings of the Royal Society B: Biological Sciences* 282 (1817): 1–7. DOI:10.1098/rspb.2015.1943

- Neenan, S. T. V., R. Piper, P. R. White, P. Kemp, T. G. Leighton, and P. J. Shaw. (2016). Does Masking Matter? Shipping Noise and Fish Vocalizations. In A. N. Popper & A. D. Hawkins (Eds.), *The Effects of Noise on Aquatic Life II* (pp. 747–754). New York, NY: Springer.
- Nelson, D. R. and R. H. Johnson. (1972). Acoustic attraction of Pacific reef sharks: Effect of pulse intermittency and variability. *Comparative Biochemistry and Physiology Part A* 42 85–95.
- Neo, Y. Y., J. Seitz, R. A. Kastelein, H. V. Winter, C. Ten Cate, and H. Slabbekoorn. (2014). Temporal structure of sound affects behavioural recovery from noise impact in European seabass. *Biological Conservation* 178 65–73. DOI:10.1016/j.biocon.2014.07.012
- Neo, Y. Y., E. Ufkes, R. A. Kastelein, H. V. Winter, C. Ten Cate, and H. Slabbekoorn. (2015). Impulsive sounds change European seabass swimming patterns: Influence of pulse repetition interval. *Marine Pollution Bulletin* 97 (1–2): 111–117. DOI:10.1016/j.marpolbul.2015.06.027
- New, L., D. Lusseau, and R. Harcourt. (2020). Dolphins and Boats: When Is a Disturbance, Disturbing? *Frontiers in Marine Science* 7.
- New, L. F., J. S. Clark, D. P. Costa, E. Fleishman, M. A. Hindell, T. Klanjšček, D. Lusseau, S. Kraus, C. R. McMahon, P. W. Robinson, R. S. Schick, L. K. Schwarz, S. E. Simmons, L. Thomas, P. Tyack, and J. Harwood. (2014). Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. *Marine Ecology Progress Series* 496 99–108. DOI:10.3354/meps10547
- New, L. F., J. Harwood, L. Thomas, C. Donovan, J. S. Clark, G. Hastie, P. M. Thompson, B. Cheney, L. Scott-Hayward, D. Lusseau, and D. Costa. (2013a). Modelling the biological significance of behavioural change in coastal bottlenose dolphins in response to disturbance. *Functional Ecology* 27 (2): 314–322. DOI:10.1111/1365-2435.12052
- New, L. F., D. J. Moretti, S. K. Hooker, D. P. Costa, and S. E. Simmons. (2013b). Using energetic models to investigate the survival and reproduction of beaked whales (family Ziphiidae). *PLoS ONE* 8 (7): e68725. DOI:10.1371/journal.pone.0068725
- Ng, S. L. and S. Leung. (2003). Behavioral response of Indo-Pacific humpback dolphin (*Sousa chinensis*) to vessel traffic. *Marine Environmental Research* 56 (5): 555–567.
- Nichols, T. A., T. W. Anderson, and A. Širović. (2015). Intermittent noise induces physiological stress in a coastal marine fish. *PLoS ONE* 10 (9): e0139157. DOI:10.1371/journal.pone.0139157
- Niemiec, A. J., Y. Raphael, and D. B. Moody. (1994). Return of auditory function following structural regeneration after acoustic trauma: Behavioral measures from quail. *Hearing Research* 75 209–224.
- Nieukirk, S. L., D. K. Mellinger, S. E. Moore, K. Klinck, R. P. Dziak, and J. Goslin. (2012). Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999–2009. *The Journal of the Acoustical Society of America* 131 (2): 1102–1112.
- Niezrecki, C. (2010). Identifying manatee location using dual-frequency sonar DIDSON. *The Journal of the Acoustical Society of America* 127 (3): 1862. DOI:10.1121/1.3384452
- Niu, F. Q., Z. W. Liu, H. T. Wen, D. W. Xu, and Y. M. Yang. (2012). Behavioral responses of two captive bottlenose dolphins (*Tursiops truncatus*) to a continuous 50 kHz tone. *The Journal of the Acoustical Society of America* 131 (2): 1643–1649. DOI:10.1121/1.3675945
- Nix, P. and P. Chapman. (1985). *Monitoring of underwater blasting operations in False Creek, British Columbia*. Presented at the Proceedings of the Workshop on Effects of Explosive Use in the Marine Environment. Ottawa, Canada.

- Noirot, I. C., E. F. Brittan-Powell, and R. J. Dooling. (2011). Masked auditory thresholds in three species of birds, as measured by the auditory brainstem response. *The Journal of the Acoustical Society of America* 129 (6): 3445–3448. DOI:10.1121
- Noren, D. P., A. H. Johnson, D. Rehder, and A. Larson. (2009). Close approaches by vessels elicit surface active behaviors by southern resident killer whales. *Endangered Species Research* 8 (3): 179–192.
- Norris, K. S. and J. H. Prescott. (1961). Observations on Pacific cetaceans of Californian and Mexican waters. *University of California Publications in Zoology* 63 (4): 291–402.
- Norris, T. F., J. O. Oswald, T. M. Yack, and E. L. Ferguson. (2012). *An Analysis of Marine Acoustic Recording Unit (MARU) Data Collected off Jacksonville, Florida in Fall 2009 and Winter 2009–2010*. Norfolk, VA: Naval Facilities Engineering Command Atlantic.
- Northrop, J. (1974). Detection of low-frequency underwater sounds from a submarine volcano in the Western Pacific. *The Journal of the Acoustical Society of America* 56 (3): 837–841.
- Nowacek, D., M. Johnson, and P. Tyack. (2004a). North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. *Proceedings of the Royal Society of London* 271 (B): 227–231. DOI:10.1098/rspb.2003.2570
- Nowacek, D., L. H. Thorne, D. Johnston, and P. Tyack. (2007). Responses of cetaceans to anthropogenic noise. *Mammal Review* 37 (2): 81–115.
- Nowacek, D. P., F. Christiansen, L. Bejder, J. A. Goldbogen, and A. S. Friedlaender. (2016). Studying cetacean behaviour: New technological approaches and conservation applications. *Animal Behaviour* 120 235–244. DOI:10.1016/j.anbehav.2016.07.019
- Nowacek, S. M., R. S. Wells, E. C. G. Owen, T. R. Speakman, R. O. Flamm, and D. P. Nowacek. (2004b). Florida manatees, *Trichechus manatus latirostris*, respond to approaching vessels. *Biological Conservation* 119 517–523. DOI:10.1016/j.biocon.2003.11.020
- Nystuen, J. A. (2001). Listening to raindrops from underwater: An acoustic disdrometer. *Journal of Atmospheric and Oceanic Technology* 18 1640–1657.
- Nystuen, J. A. and D. M. Farmer. (1987). The influence of wind on the underwater sound generated by light rain. *The Journal of the Acoustical Society of America* 82 (1): 270–274. DOI:10.1121/1.395563
- O'Hara, J. and J. R. Wilcox. (1990). Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. *Copeia* 1990 (2): 564–567.
- O'Keefe, D. J. (1984). *Guidelines for Predicting the Effects of Underwater Explosions on Swimbladder Fish*. Dahlgren, VA: Naval Surface Weapons Center.
- O'Keefe, D. J. and G. A. Young. (1984). *Handbook on the Environmental Effects of Underwater Explosions*. Silver Spring, MD: U.S. Navy, Naval Surface Weapons Center (Code R14).
- Oakley, J. A., A. T. Williams, and T. Thomas. (2017). Reactions of harbour porpoise (*Phocoena phocoena*) to vessel traffic in the coastal waters of South West Wales, UK. *Ocean & Coastal Management* 138 158–169. DOI:10.1016/j.ocecoaman.2017.01.003
- Office of the Surgeon General. (1991). Conventional warfare ballistic, blast, and burn injuries. In R. Zajitchuk, Col. (Ed.), *U.S.A. Textbook of Military Medicine*. Washington, DC: Office of the Surgeon General.

- Okumura, T., T. Akamatsu, and H. Y. Yan. (2002). Analyses of small tank acoustics: Empirical and theoretical approaches. *Bioacoustics* 12 (2–3): 330–332. DOI:10.1080/09524622.2002.9753738
- Oliveira, C., S. Pérez-Jorge, R. Prieto, I. Cascão, P. J. Wensveen, and M. A. Silva. (2022). Exposure to whale watching vessels affects dive ascents and resting behavior in sperm whales. *Frontiers in Marine Science* 9. DOI:10.3389/fmars.2022.914397
- Olivier, F., M. Gigot, D. Mathias, Y. Jezequel, T. Meziane, C. L'Her, L. Chauvaud, and J. Bonnel. (2023). Assessing the impacts of anthropogenic sounds on early stages of benthic invertebrates: The “Larvosonic system”. *Limnology and Oceanography: Methods* 21 (2): 53–68. DOI:<https://doi.org/10.1002/lom3.10527>
- Olson, J. K. (2013). *The effect of human exposure on the anti-predatory response of harbor seals (Phoca vitulina)*. (Unpublished master's thesis). Western Washington University, Bellingham, WA. Retrieved from <http://cedar.wvu.edu/wwuet/291>.
- Omeyer, L. C., P. D. Doherty, S. Dolman, R. Enever, A. Reese, N. Tregenza, R. Williams, and B. J. Godley. (2020). Assessing the Effects of Banana Pingers as a Bycatch Mitigation Device for Harbour Porpoises (*Phocoena phocoena*). *Frontiers in Marine Science* 7. DOI:10.3389/fmars.2020.00285
- Owen, M. A. and A. E. Bowles. (2011). In-air auditory psychophysics and the management of a threatened carnivore, the polar bear (*Ursus maritimus*). *International Journal of Comparative Psychology* 24 244–254.
- Paitach, R. L., M. Amundin, S. Königson, and M. J. Cremer. (2022). Assessing effectiveness and side effects of likely “seal safe” pinger sounds to ward off endangered franciscana dolphins (*Pontoporia blainvillei*). *Marine Mammal Science*. DOI:10.1111/mms.12907
- Pangerc, T., P. D. Theobald, L. S. Wang, S. P. Robinson, and P. A. Lepper. (2016). Measurement and characterisation of radiated underwater sound from a 3.6 MW monopile wind turbine. *The Journal of the Acoustical Society of America* 140 (4): 2913. DOI:10.1121/1.4964824
- Papale, E., M. Gamba, M. Perez-Gil, V. M. Martin, and C. Giacomini. (2015). Dolphins adjust species-specific frequency parameters to compensate for increasing background noise. *PLoS ONE* 10 (4): e0121711. DOI:10.1371/journal.pone.0121711
- Parks, S. E., C. W. Clark, and P. L. Tyack. (2007). Short- and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. *The Journal of the Acoustical Society of America* 122 (6): 3725–3731. DOI:10.1121/1.2799904
- Parks, S. E., M. Johnson, D. Nowacek, and P. L. Tyack. (2011). Individual right whales call louder in increased environmental noise. *Biology Letters* 7 33–35. DOI:10.1098
- Parks, S. E., I. Urazghildiiev, and C. W. Clark. (2009). Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. *The Journal of the Acoustical Society of America* 125 (2): 1230–1239. DOI:10.1121/1.3050282
- Parmentier, E., F. Bertucci, M. Bolgan, and D. Lecchini. (2021). How many fish could be vocal? An estimation from a coral reef (Moorea Island). *Belgian Journal of Zoology* 151. DOI:10.26496/bjz.2021.82
- Partecke, J., I. Schwabl, and E. Gwinner. (2006). Stress and the city: Urbanization and its effects on the stress physiology in European blackbirds. *Ecology* 87 (8): 1945–1952.

- Patenaude, N. J., W. J. Richardson, M. A. Smultea, W. R. Koski, G. W. Miller, B. Würsig, and C. R. Greene, Jr. (2002). Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. *Marine Mammal Science* 18 (2): 309–335.
- Patricelli, G. L. and J. L. Blickley. (2006). Avian communication in urban noise: Causes and consequences of vocal adjustment. *The Auk* 123 (3): 639–649.
- Pearson, W. H., J. R. Skalski, and C. I. Malme. (1992). Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Sciences* 49 1343–1356.
- Pena, H., N. O. Handegard, and E. Ona. (2013). Feeding herring schools do not react to seismic air gun surveys. *ICES Journal of Marine Science* 70 (6): 1174–1180. DOI:10.1093/icesjms/fst079
- Perez-Ortega, B., R. Daw, B. Paradee, E. Gimbrere, and L. J. May-Collado. (2021). Dolphin-watching boats affect whistle frequency modulation in bottlenose dolphins. *Frontiers in Marine Science* 8 102–114.
- Petrites, A. E., O. S. Eng, D. S. Mowlds, J. A. Simmons, and C. M. DeLong. (2009). Interpulse interval modulation by echolocating big brown bats (*Eptesicus fuscus*) in different densities of obstacle clutter. *Journal of Comparative Physiology A* 195 (6): 603–617. DOI:10.1007/s00359-009-0435-6
- Piantadosi, C. A. and E. D. Thalmann. (2004). Whales, sonar and decompression sickness. *Nature* 425 575–576. DOI:10.1038/nature02527
- Pickering, A. D. (1981). *Stress and Fish*. New York, NY: Academic Press.
- Pierce, A. D. (1989). *Acoustics: An Introduction to Its Physical Principles and Applications*. Woodbury, NY: The Journal of the Acoustical Society of America.
- Piniak, W. E. D., S. A. Eckert, C. A. Harms, and E. M. Stringer. (2012a). *Underwater Hearing Sensitivity of the Leatherback Sea Turtle (Dermochelys coriacea): Assessing the Potential Effect of Anthropogenic Noise* (OCS Study BOEM 2012-01156). Herndon, VA: U.S. Department of the Interior, Bureau of Ocean Energy Management.
- Piniak, W. E. D., C. A. Harms, E. M. Stringer, and S. A. Eckert. (2012b). *Hearing sensitivity of hatchling leatherback sea turtles (Dermochelys coriacea)* (32nd Annual Symposium on Sea Turtle Biology and Conservation). Washington, DC: U.S. Department of the Interior, Bureau of Ocean Energy Management.
- Piniak, W. E. D., D. A. Mann, C. A. Harms, T. T. Jones, and S. A. Eckert. (2016). Hearing in the juvenile green sea turtle (*Chelonia mydas*): A comparison of underwater and aerial hearing using auditory evoked potentials. *PLoS ONE* 11 (10): e0159711.
- Pirotta, E. (2022). A review of bioenergetic modelling for marine mammal populations. *Conservation Physiology* 10 (1): coac036. DOI:10.1093/conphys/coac036
- Pirotta, E., C. G. Booth, D. E. Cade, J. Calambokidis, D. P. Costa, J. A. Fahlbusch, A. S. Friedlaender, J. A. Goldbogen, J. Harwood, E. L. Hazen, L. New, and B. L. Southall. (2021). Context-dependent variability in the predicted daily energetic costs of disturbance for blue whales. *Conservation Physiology* 9 (1). DOI:10.1093/conphys/coaa137
- Pirotta, E., C. G. Booth, J. Calambokidis, D. P. Costa, J. A. Fahlbusch, A. S. Friedlaender, J. A. Goldbogen, J. Harwood, E. L. Hazen, L. New, J. A. Santora, S. L. Watwood, C. Wertman, and B. L. Southall. (2022a). From individual responses to population effects: Integrating a decade of

- multidisciplinary research on blue whales and sonar. *Animal Conservation*. DOI:10.1111/acv.12785
- Pirotta, E., C. G. Booth, D. P. Costa, E. Fleishman, S. D. Kraus, D. Lusseau, D. Moretti, L. F. New, R. S. Schick, L. K. Schwarz, S. E. Simmons, L. Thomas, P. L. Tyack, M. J. Weise, R. S. Wells, and J. Harwood. (2018a). Understanding the population consequences of disturbance. *Ecology and Evolution* 8 (19): 9934–9946. DOI:10.1002/ece3.4458
- Pirotta, E., K. L. Brookes, I. M. Graham, and P. M. Thompson. (2014). Variation in harbour porpoise activity in response to seismic survey noise. *Biology Letters* 10 (5): 20131090. DOI:10.1098/rsbl.2013.1090
- Pirotta, E., J. Harwood, P. M. Thompson, L. New, B. Cheney, M. Arso, P. S. Hammond, C. Donovan, and D. Lusseau. (2015a). Predicting the effects of human developments on individual dolphins to understand potential long-term population consequences. *Proceedings of the Royal Society B: Biological Sciences* 282 (1818): 20152109. DOI:10.1098/rspb.2015.2109
- Pirotta, E., V. Hin, M. Mangel, L. New, D. P. Costa, A. M. de Roos, and J. Harwood. (2020). Propensity for risk in reproductive strategy affects susceptibility to anthropogenic disturbance. *The American Naturalist* 196 (4): E71–E87. DOI:10.1086/710150
- Pirotta, E., M. Mangel, D. P. Costa, J. Goldbogen, J. Harwood, V. Hin, L. M. Irvine, B. R. Mate, E. A. McHuron, D. M. Palacios, L. K. Schwarz, and L. New. (2019). Anthropogenic disturbance in a changing environment: Modelling lifetime reproductive success to predict the consequences of multiple stressors on a migratory population. *Oikos* 128 (9): 1340–1357. DOI:10.1111/oik.06146
- Pirotta, E., M. Mangel, D. P. Costa, B. Mate, J. A. Goldbogen, D. M. Palacios, L. A. Hückstädt, E. A. McHuron, L. Schwarz, and L. New. (2018b). A Dynamic State Model of Migratory Behavior and Physiology to Assess the Consequences of Environmental Variation and Anthropogenic Disturbance on Marine Vertebrates. *The American Naturalist* 191 (2): 17. DOI:10.5061/dryad.md416
- Pirotta, E., N. D. Merchant, P. M. Thompson, T. R. Barton, and D. Lusseau. (2015b). Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. *Biological Conservation* 181 82–89. DOI:10.1016/j.biocon.2014.11.003
- Pirotta, E., R. Milor, N. Quick, D. Moretti, N. Di Marzio, P. Tyack, I. Boyd, and G. Hastie. (2012). Vessel noise affects beaked whale behavior: Results of a dedicated acoustic response study. *PLoS ONE* 7 (8): e42535. DOI:10.1371/journal.pone.0042535
- Pirotta, E., L. Thomas, D. P. Costa, A. J. Hall, C. M. Harris, J. Harwood, S. D. Kraus, P. J. O. Miller, M. J. Moore, T. Photopoulou, R. M. Rolland, L. Schwacke, S. E. Simmons, B. L. Southall, and P. L. Tyack. (2022b). Understanding the combined effects of multiple stressors: A new perspective on a longstanding challenge. *Science of the Total Environment* 821 153322. DOI:10.1016/j.scitotenv.2022.153322
- Pirotta, V., D. Slip, I. D. Jonsen, V. M. Peddemors, D. H. Cato, G. Ross, and R. Harcourt. (2016). Migrating humpback whales show no detectable response to whale alarms off Sydney, Australia. *Endangered Species Research* 29 (3): 201–209. DOI:10.3354/esr00712
- Plumpton, D. (2006). *Review of Studies Related to Aircraft Noise Disturbance of Waterfowl: A Technical Report in Support of the Supplemental Environmental Impact Statement for Introduction of F/A-18 E/F (Super Hornet) Aircraft to the East Coast of the United States*. Norfolk, VA: U.S. Department of the Navy.

- Polacheck, T. and L. Thorpe. (1990). The swimming direction of harbor porpoise in relationship to a survey vessel. *Reports of the International Whaling Commission* 40: 463–470.
- Pomeroy, P., L. O'Connor, and P. Davies. (2015). Assessing use of and reaction to unmanned aerial systems in gray and harbor seals during breeding and molt in the UK. *Journal of Unmanned Vehicle Systems* 3 (3): 102–113. DOI:10.1139/juvs-2015-0013
- Popov, V. V. and A. Y. Supin. (2009). Comparison of directional selectivity of hearing in a beluga whale and a bottlenose dolphin. *The Journal of the Acoustical Society of America* 126 (3): 1581–1587. DOI:10.1121/1.3177273
- Popov, V. V., A. Y. Supin, A. P. Gvozdeva, D. I. Nechaev, and M. B. Tarakanov. (2020). Spatial release from masking in a bottlenose dolphin (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 147 (3): 1719–1726.
- Popov, V. V., A. Y. Supin, V. V. Rozhnov, D. I. Nechaev, and E. V. Sysueva. (2014). The limits of applicability of the sound exposure level (SEL) metric to temporal threshold shifts (TTS) in beluga whales, *Delphinapterus leucas*. *The Journal of Experimental Biology* 217 (Pt 10): 1804–1810. DOI:10.1242/jeb.098814
- Popov, V. V., A. Y. Supin, V. V. Rozhnov, D. I. Nechaev, E. V. Sysuyeva, V. O. Klishin, M. G. Pletenko, and M. B. Tarakanov. (2013). Hearing threshold shifts and recovery after noise exposure in beluga whales, *Delphinapterus leucas*. *The Journal of Experimental Biology* 216 (9): 1587–1596. DOI:10.1242/jeb.078345
- Popov, V. V., A. Y. Supin, D. Wang, K. Wang, L. Dong, and S. Wang. (2011). Noise-induced temporary threshold shift and recovery in Yangtze finless porpoises, *Neophocaena phocaenoides asiaeorientalis*. *The Journal of the Acoustical Society of America* 130 (1): 574–584. DOI:10.1121/1.3596470
- Popper, A. N. (2008). *Effects of Mid- and High-Frequency Sonars on Fish*. Newport, RI: Naval Undersea Warfare Center Division.
- Popper, A. N. and R. R. Fay. (2010). Rethinking sound detection by fishes. *Hearing Research* 273 (1–2): 25–36. DOI:10.1016/j.heares.2009.12.023
- Popper, A. N., R. R. Fay, C. Platt, and O. Sand. (2003). Sound detection mechanisms and capabilities of teleost fishes. In S. P. Collin & N. J. Marshall (Eds.), *Sensory Processing in Aquatic Environment*. New York, NY: Springer-Verlag.
- Popper, A. N., J. A. Gross, T. J. Carlson, J. Skalski, J. V. Young, A. D. Hawkins, and D. G. Zeddies. (2016). Effects of exposure to the sound from seismic airguns on pallid sturgeon and paddlefish. *PLoS ONE* 11 (8): e0159486. DOI:10.1371/journal.pone.0159486
- Popper, A. N., M. B. Halvorsen, A. Kane, D. L. Miller, M. E. Smith, J. Song, P. Stein, and L. E. Wysocki. (2007). The effects of high-intensity, low-frequency active sonar on rainbow trout. *The Journal of the Acoustical Society of America* 122 (1): 623–635.
- Popper, A. N. and M. C. Hastings. (2009a). The effects of anthropogenic sources of sound on fishes. *Journal of Fish Biology* 75 (3): 455–489. DOI:10.1111/j.1095-8649.2009.02319
- Popper, A. N. and M. C. Hastings. (2009b). The effects of human-generated sound on fish. *Integrative Zoology* 4: 43–52. DOI:10.1111/j.1749-4877.2008.00134.x
- Popper, A. N., A. D. Hawkins, R. R. Fay, D. A. Mann, S. M. Bartol, T. J. Carlson, S. Coombs, W. T. Ellison, R. L. Gentry, M. B. Halvorsen, S. Løkkeborg, P. H. Rogers, B. L. Southall, D. G. Zeddies, and W. N.

- Tavolga. (2014). *ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. Acoustical Society of America Press, New York, NY.
- Popper, A. N., A. D. Hawkins, O. Sand, and J. A. Sisneros. (2019). Examining the hearing abilities of fishes. *The Journal of the Acoustical Society of America* 146 (2). DOI:10.1121/1.5120185
- Popper, A. N. and B. Hoxter. (1984). Growth of a fish ear: 1. Quantitative analysis of sensory hair cell and ganglion cell proliferation. *Hearing Research* 15 133–142.
- Popper, A. N. and C. R. Schilt. (2008). Hearing and acoustic behavior (basic and applied considerations). In J. F. Webb, R. R. Fay, & A. N. Popper (Eds.), *Fish Bioacoustics*. New York, NY: Springer Science + Business Media, LLC.
- Popper, A. N., M. E. Smith, P. A. Cott, B. W. Hanna, A. O. MacGillivray, M. E. Austin, and D. A. Mann. (2005). Effects of exposure to seismic airgun use on hearing of three fish species. *The Journal of the Acoustical Society of America* 117 (6): 3958–3971.
- Puszkas, H., J. Shimeta, and K. Robb. (2021). Assessment on the effectiveness of vessel-approach regulations to protect cetaceans in Australia: A review on behavioral impacts with case study on the threatened Burrnun dolphin (*Tursiops australis*). *PLoS ONE* 16 (1).
- Putland, R. L., N. D. Merchant, A. Farcas, and C. A. Radford. (2018). Vessel noise cuts down communication space for vocalizing fish and marine mammals. *Global Change Biology* 24 1708–1721.
- Putman, N. F., P. Verley, C. S. Endres, and K. J. Lohmann. (2015). Magnetic navigation behavior and the oceanic ecology of young loggerhead sea turtles. *The Journal of Experimental Biology* 218 (7): 1044–1050.
- Pytte, C. L., K. M. Rusch, and M. S. Ficken. (2003). Regulation of vocal amplitude by the blue-throated hummingbird, *Lampornis clemenciae*. *Animal Behaviour* 66 703–710. DOI:10.1006/anbe.2003.2257
- Quick, N., L. Scott-Hayward, D. Sadykova, D. Nowacek, and A. Read. (2017). Effects of a scientific echo sounder on the behavior of short-finned pilot whales (*Globicephala macrorhynchus*). *Canadian Journal of Fisheries and Aquatic Sciences* 74 (5): 716–726. DOI:10.1139/cjfas-2016-0293
- Radford, A. N., E. Kerridge, and S. D. Simpson. (2014). Acoustic communication in a noisy world: Can fish compete with anthropogenic noise? *Behavioral Ecology* 25 (5): 1022–1030. DOI:10.1093/beheco/aru029
- Radford, A. N., L. Lebre, G. Lecaillon, S. L. Nedelec, and S. D. Simpson. (2016). Repeated exposure reduces the response to impulsive noise in European seabass. *Global Change Biology* 22 (10): 3349–3360. DOI:10.1111/gcb.13352
- Radford, C., A. Jeffs, C. Tindle, and J. C. Montgomery. (2008). Resonating sea urchin skeletons create coastal choruses. *Marine Ecology Progress Series* 362 37–43. DOI:10.3354/meps07444
- Radford, C. A., J. C. Montgomery, P. Caiger, and D. M. Higgs. (2012). Pressure and particle motion detection thresholds in fish: A re-examination of salient auditory cues in teleosts. *The Journal of Experimental Biology* 215 (Pt 19): 3429–3435. DOI:10.1242/jeb.073320
- Radford, C. A., R. L. Putland, and A. F. Mensinger. (2018). Barking mad: The vocalisation of the John Dory, *Zeus faber*. *PLoS ONE* 13 (10): e0204647. DOI:10.1371/journal.pone.0204647

- Ramcharitar, J., D. Higgs, and A. Popper. (2006). Audition in sciaenid fishes with different swim bladder-inner ear configurations. *The Journal of the Acoustical Society of America* 119 (1): 439–443.
- Ramcharitar, J., D. M. Higgs, and A. N. Popper. (2001). Sciaenid inner ears: A study in diversity. *Brain, Behavior and Evolution* 58 152–162.
- Ramcharitar, J. and A. N. Popper. (2004). Masked auditory thresholds in sciaenid fishes: A comparative study. *The Journal of the Acoustical Society of America* 116 (3): 1687–1691.
DOI:10.1121/1.1771614
- Ramesh, K., S. Berrow, R. Meade, and J. O'Brien. (2021). Habitat Modelling on the Potential Impacts of Shipping Noise on Fin Whales (*Balaenoptera physalus*) in Offshore Irish Waters off the Porcupine Ridge. *Journal of Marine Science and Engineering* 9 (11). DOI:10.3390/jmse9111207
- Ramos, E. A., B. Maloney, M. O. Magnasco, and D. Reiss. (2018). Bottlenose dolphins and Antillean manatees respond to small multi-rotor unmanned aerial systems. *Frontiers in Marine Science* 5 316. DOI:10.3389/fmars.2018.00316
- Rathbun, G. B. (1988). Fixed-wing airplane versus helicopter surveys of manatees (*Trichechus manatus*). *Marine Mammal Science* 4 (1): 71–75.
- Read, A. J., S. Barco, J. Bell, D. L. Borchers, M. L. Burt, E. W. Cummings, J. Dunn, E. M. Fougères, L. Hazen, L. E. W. Hodge, A.-M. Laura, R. J. McAlarney, P. Nilsson, D. A. Pabst, C. G. M. Paxton, S. Z. Schneider, K. W. Urian, D. M. Waples, and W. A. McLellan. (2014). Occurrence, distribution, and abundance of cetaceans in Onslow Bay, North Carolina, USA. *Journal of Cetacean Research and Management* 14 23–35.
- Read, A. J., D. M. Waples, H. J. Foley, Z. T. Swaim, J. Calambokidis, A. Vanderzee, D. P. Nowacek, and B. L. Southall. (2022). A stampede of Risso's Dolphins (*Grampus griseus*) following playbacks of the calls of mammal-eating killer whales. *Aquatic Mammals* 48 (6): 674–677.
DOI:10.1578/am.48.6.2022.674
- Reed, J., R. Harcourt, L. New, and K. Bilgmann. (2020). Extreme effects of extreme disturbances: A simulation approach to assess population specific responses. *Frontiers in Marine Science* 7 829–846.
- Reeves, R. R., G. K. Silber, and P. M. Payne. (1998). *Draft recovery plan for the fin whale Balaenoptera physalus and sei whale Balaenoptera borealis*. Silver Spring, MD: Office of Protected Resources, National Marine Fisheries Service, National Oceanic and Atmospheric Administration.
- Reichmuth, C., A. Ghoul, J. M. Sills, A. Rouse, and B. L. Southall. (2016). Low-frequency temporary threshold shift not observed in spotted or ringed seals exposed to single air gun impulses. *The Journal of the Acoustical Society of America* 140 (4): 2646–2658.
DOI:<http://dx.doi.org/10.1121/1.4964470>
- Reichmuth, C., M. M. Holt, J. Mulsow, J. M. Sills, and B. L. Southall. (2013). Comparative assessment of amphibious hearing in pinnipeds. *Journal of Comparative Physiology A: Neuroethology, Sensory Neural, and Behavioral Physiology* 199 (6): 491–507. DOI:10.1007/s00359-013-0813-y
- Reichmuth, C., J. M. Sills, J. Mulsow, and A. Ghoul. (2019). Long-term evidence of noise-induced permanent threshold shift in a harbor seal (*Phoca vitulina*). *The Journal of the Acoustical Society of America* 146 (4): 2552–2561.
- Reidman, M. L. (1983). *Studies of the Effects of Experimentally Produced Noise Associated with Oil and Gas Exploration and Development on Sea Otters in California*. Santa Cruz, CA: California

- University, Santa Cruz. Center for Coastal Marine Studies; Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.
- Reinhall, P. G. and P. H. Dahl. (2011). Underwater Mach wave radiation from impact pile driving: Theory and observation. *The Journal of the Acoustical Society of America* 130 (3): 1209–1216. DOI:10.1121/1.3614540
- Remage-Healey, L., D. P. Nowacek, and A. H. Bass. (2006). Dolphin foraging sounds suppress calling and elevate stress hormone levels in a prey species, the Gulf toadfish. *The Journal of Experimental Biology* 209 (Pt 22): 4444–4451. DOI:10.1242/jeb.02525
- Renaud, D. L. and A. N. Popper. (1975). Sound localization by the bottlenose porpoise *Tursiops truncatus*. *Journal of Experimental Biology* 63 (3): 569–585.
- Rey-Baquero, M. P., L. V. Huertas-Amaya, K. D. Seger, N. Botero-Acosta, A. Luna-Acosta, C. E. Perazio, J. K. Boyle, S. Rosenthal, and A. C. Vallejo. (2021). Understanding effects of whale-watching vessel noise on humpback whale song in the North Pacific Coast of Colombia with propagation models of masking and acoustic data observations. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.623724
- Richardson, W. J., M. A. Fraker, B. Würsig, and R. S. Wells. (1985). Behaviour of bowhead whales (*Balaena mysticetus*) summering in the Beaufort Sea: Reactions to industrial activities. *Biological Conservation* 32 195–230.
- Richardson, W. J., C. R. Greene, Jr., J. S. Hanna, W. R. Koski, G. W. Miller, N. J. Patenaude, and M. A. Smultea. (1995a). *Acoustic Effects of Oil Production Activities on Bowhead and White Whales Visible during Spring Migration near Pt. Barrow, Alaska – 1991 and 1994 Phases: Sound Propagation and Whale Responses to Playbacks of Icebreaker Noise*. Anchorage, AK: U.S. Minerals Management Service, Procurement Operations.
- Richardson, W. J., C. R. Greene, Jr., C. I. Malme, and D. H. Thomson. (1995b). *Marine Mammals and Noise*. San Diego, CA: Academic Press.
- Richardson, W. J., G. W. Miller, and C. R. Greene. (1999). Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. *The Journal of the Acoustical Society of America* 106 (4): 2281. DOI:10.1121/1.427801
- Richmond, D. R., J. T. Yelverton, and E. R. Fletcher. (1973). *Far-Field Underwater-Blast Injuries Produced by Small Charges*. Washington, DC: Lovelace Foundation for Medical Education and Research, Defense Nuclear Agency.
- Richter, C., S. Dawson, and E. Slooten. (2006). Impacts of commercial whale watching on male sperm whales at Kaikoura, New Zealand. *Marine Mammal Science* 22 (1): 46–63. DOI:10.1111/j.1748-7692.2006.00005
- Richter, C., S. M. Dawson, and E. Slooten. (2003). Sperm whale watching off Kaikoura, New Zealand: Effects of current activities on surfacing and vocalisation patterns. *Science for Conservation* 219 78.
- Ridgway, S. H. (1972). Homeostasis in the Aquatic Environment. In S. H. Ridgway (Ed.), *Mammals of the Sea: Biology and Medicine* (pp. 590–747). Springfield, IL: Charles C. Thomas.
- Ridgway, S. H., D. A. Carder, R. R. Smith, T. Kamolnick, C. E. Schlundt, and W. R. Elsberry. (1997). *Behavioral Responses and Temporary Shift in Masked Hearing Threshold of Bottlenose Dolphins, Tursiops truncatus, to 1-second Tones of 141 to 201 dB re 1 μ Pa*. San Diego, CA: U.S. Department

- of Navy, Naval Command, Control and Ocean Surveillance Center, Research, Development, Test, and Evaluation Division.
- Ridgway, S. H. and R. Howard. (1979). Dolphin lung collapse and intramuscular circulation during free diving: Evidence from nitrogen washout. *Science* 206 1182–1183.
- Ridgway, S. H., E. G. Wever, J. G. McCormick, J. Palin, and J. H. Anderson. (1969). Hearing in the giant sea turtle, *Chelonia mydas*. *Proceedings of the National Academy of Sciences U.S.A.* 64 (3): 884–890.
- Riedman, M. L. (1984). *Appendix D: Effects of Sounds Associated with Petroleum Industry Activities on the Behavior of Sea Otters in California*. Cambridge, MA: Bolt Beranek and Newman Inc.
- Rijke, A. M. (1970). Wettability and phylogenetic development of feather structure in water birds. *The Journal of Experimental Biology* 52 (2): 469–479.
- Risch, D., P. J. Corkeron, W. T. Ellison, and S. M. Van Parijs. (2012). Changes in humpback whale song occurrence in response to an acoustic source 200 km away. *PLoS ONE* 7 (1): e29741.
- Risch, D., P. J. Corkeron, W. T. Ellison, and S. M. Van Parijs. (2014). Formal comment to Gong et al.: Ecosystem scale acoustic sensing reveals humpback whale behavior synchronous with herring spawning processes and re-evaluation finds no effect of sonar on humpback song occurrence in the Gulf of Maine in fall 2006. *PLoS ONE* 9 (10): e109225. DOI:10.1371/journal.pone.0109225
- Ritter, F. (2002). Behavioural observations of rough-toothed dolphins (*Steno bredanensis*) off La Gomera, Canary Islands (1995–2000), with special reference to their interactions with humans. *Aquatic Mammals* 28 (1): 46–59.
- Roberts, L., S. Cheesman, and A. D. Hawkins. (2016a). Effects of Sounds on the Behavior of Wild, Unrestrained Fish Schools. In A. N. Popper & A. D. Hawkins (Eds.), *The Effects of Noise on Aquatic Life II* (pp. 917–924). New York, NY: Springer.
- Roberts, L., R. Perez-Dominguez, and M. Elliott. (2016b). Use of baited remote underwater video (BRUV) and motion analysis for studying the impacts of underwater noise upon free ranging fish and implications for marine energy management. *Marine Pollution Bulletin* 112 (1–2): 75–85. DOI:10.1016/j.marpolbul.2016.08.039
- Robertson, F. C., W. R. Koski, T. A. Thomas, W. J. Richardson, B. Würsig, and A. W. Trites. (2013). Seismic operations have variable effects on dive-cycle behavior of bowhead whales in the Beaufort Sea. *Endangered Species Research* 21 (2): 143–160. DOI:10.3354/esr00515
- Rogers, L. S., A. B. Coffin, and J. A. Sisneros. (2022). Reproductive state modulates utricular auditory sensitivity in a vocal fish. *Journal of Neurophysiology* 128 (5): 1344–1354. DOI:10.1152/jn.00315.2022
- Rogers, L. S., R. L. Putland, and A. F. Mensinger. (2020). The effect of biological and anthropogenic sound on the auditory sensitivity of oyster toadfish, *Opsanus tau*. *Journal of Comparative Physiology A* 206 (1). DOI:10.1007/s00359-019-01381-x
- Rogers, P. H., A. D. Hawkins, A. N. Popper, R. R. Fay, and M. D. Gray. (2016). Parvulescu Revisited: Small Tank Acoustics for Bioacousticians. In A. N. Popper & A. D. Hawkins (Eds.), *The Effects of Noise on Aquatic Life II*. New York, NY: Springer.
- Rolland, R. M., W. A. McLellan, M. J. Moore, C. A. Harms, E. A. Burgess, and K. E. Hunt. (2017). Fecal glucocorticoids and anthropogenic injury and mortality in North Atlantic right whales *Eubalaena glacialis*. *Endangered Species Research* 34 417–429. DOI:10.3354/esr00866

- Rolland, R. M., S. E. Parks, K. E. Hunt, M. Castellote, P. J. Corkeron, D. P. Nowacek, S. K. Wasser, and S. D. Kraus. (2012). Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B: Biological Sciences* 279 (1737): 2363–2368. DOI:10.1098/rspb.2011.2429
- Rollins, K. E., D. K. Meyerholz, G. D. Johnson, A. P. Capparella, and S. S. Loew. (2012). A forensic investigation into the etiology of bat mortality at a wind farm: Barotrauma or traumatic injury? *Veterinary Pathology* 49 (2): 362–371. DOI:10.1177/0300985812436745
- Romano, T. A., M. J. Keogh, C. Kelly, P. Feng, L. Berk, C. E. Schlundt, D. A. Carder, and J. J. Finneran. (2004). Anthropogenic sound and marine mammal health: Measures of the nervous and immune systems before and after intense sound exposures. *Canadian Journal of Fisheries and Aquatic Sciences* 61 1124–1134. DOI:10.1139/F04-055
- Rosowski, J. J. (1994). Outer and Middle Ears. In R. R. Fay & A. N. Popper (Eds.), *Comparative Hearing: Mammals* (pp. 172–247). Berlin, Germany: Springer-Verlag.
- Rostad, A., S. Kaartvedt, T. A. Klevjer, and W. Melle. (2006). Fish are attracted to vessels. *ICES Journal of Marine Science* 63 (8): 1431–1437. DOI:10.1016/j.icesjms.2006.03.026
- Rountree, R. A., F. Juanes, and M. Bolgan. (2018). Air movement sound production by alewife, white sucker, and four salmonid fishes suggests the phenomenon is widespread among freshwater fishes. *PLoS ONE* 13 (9): e0204247.
- Rowell, T. J., G. L. D'Spain, O. Aburto-Oropeza, and B. E. Erisman. (2020). Drivers of male sound production and effective communication distances at fish spawning aggregation sites. *ICES Journal of Marine Science* 77 (2): 730–745. DOI:10.1093/icesjms/fsz236
- Rowell, T. J., M. T. Schärer, and R. S. Appeldoorn. (2018). Description of a new sound produced by Nassau grouper at spawning aggregation sites. *Gulf and Caribbean Research* 29 GCFI22-GCFI26. DOI:10.18785/gcr.2901.12
- Rubel, E. W., S. A. Furrer, and J. S. Stone. (2013). A brief history of hair cell regeneration research and speculations on the future. *Hearing Research* 297 42–51. DOI:10.1016/j.heares.2012.12.014
- Ruppel, C. D., T. C. Weber, E. R. Staatterman, S. J. Labak, and P. E. Hart. (2022). Categorizing Active Marine Acoustic Sources Based on Their Potential to Affect Marine Animals. *Journal of Marine Science and Engineering* 10 (9): 1278.
- Russel, W. A., Jr., N. D. Lewis, and B. T. Brown. (1996). The impact of impulsive noise on bald eagles at Aberdeen Proving Ground, Maryland. *The Journal of the Acoustical Society of America* 99 (4): 2576–2603.
- Russell, D. J. F., G. D. Hastie, D. Thompson, V. M. Janik, P. S. Hammond, L. A. S. Scott-Hayward, J. Matthiopoulos, E. L. Jones, B. J. McConnell, and S. Votier. (2016). Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology* 53 1642–1652. DOI:10.1111/1365-2664.12678
- Ryals, B. M., R. J. Dooling, E. Westbrook, M. L. Dent, A. MacKenzie, and O. N. Larsen. (1999). Avian species differences in susceptibility to noise exposure. *Hearing Research* 131 71–88.
- Rycyk, A. M., C. J. Deutsch, M. E. Barlas, S. K. Hardy, K. Frisch, E. H. Leone, and D. P. Nowacek. (2018). Manatee behavioral response to boats. *Marine Mammal Science* 34 (4): 924–962. DOI:10.1111/mms.12491
- Sade, J., Y. Handrich, J. Bernheim, and D. Cohen. (2008). Pressure equilibration in the penguin middle ear. *Acta Oto-Laryngologica* 128 (1): 18–21. DOI:10.1080/00016480701299667

- Sairanen, E. E. (2014). *Weather and Ship Induced Sounds and the Effect of Shipping on Harbor Porpoise (Phocoena phocoena) Activity*. (Unpublished master's thesis). University of Helsinki, Helsinki, Finland. Retrieved from helda.helsinki.fi.
- Salas, A. K., A. M. Capuano, C. A. Harms, W. E. D. Piniak, and T. A. Mooney. (2023). Temporary noise-induced underwater hearing loss in an aquatic turtle (*Trachemys scripta elegans*). *The Journal of the Acoustical Society of America* 154 (2): 1003-1017. DOI:10.1121/10.0020588
- Salas, A. K., A. M. Capuano, C. A. Harms, W. E. D. Piniak, and T. A. Mooney. (2024). Frequency-dependent temporary threshold shifts in the Eastern painted turtle (*Chrysemys picta picta*). *J Acoust Soc Am* 155 (5): 3254-3266. DOI:10.1121/10.0026021
- Santos-Carvalho, M., F. Barilari, M. J. Pérez-Alvarez, L. Gutiérrez, G. Pavez, H. Araya, C. Anguita, C. Cerda, and M. Sepúlveda. (2021). Impacts of whale-watching on the short-term behavior of fin whales (*Balaenoptera physalus*) in a marine protected area in the Southeastern Pacific. *Frontiers in Marine Science*, 8. Retrieved April 13, 2021, from <https://doi.org/10.3389/fmars.2021.623954>.
- Sapozhnikova, Y. P., A. G. Koroleva, V. M. Yakhnenko, M. L. Tyagun, O. Y. Glyzina, A. B. Coffin, M. M. Makarov, A. N. Shagun, V. A. Kulikov, P. V. Gasarov, S. V. Kirilchik, I. V. Klimenkov, N. P. Sudakov, P. N. Anoshko, N. A. Kurashova, and L. V. Sukhanova. (2020). Molecular and cellular responses to long-term sound exposure in peled (*Coregonus peled*). *The Journal of the Acoustical Society of America* 148 (2): 895. DOI:10.1121/10.0001674
- Sarnocińska, J., J. Teilmann, J. D. Balle, F. M. van Beest, M. Delefosse, and J. Tougaard. (2020). Harbor porpoise (*Phocoena phocoena*) reaction to a 3D seismic airgun survey in the North Sea. *Frontiers in Marine Science* 6. DOI:10.3389/fmars.2019.00824
- Saunders, J. C. and R. Dooling. (1974). Noise-induced threshold shift in the parakeet (*Melopsittacus undulatus*). *Proceedings of the National Academy of Sciences* 71 (5): 1962–1965.
- Saunders, J. C., R. K. Duncan, D. E. Doan, and Y. L. Werner. (2000). The Middle Ear of Reptiles and Birds. In Dooling R.J., Fay R.R., & Popper A.N. (Eds.), *Comparative Hearing: Birds and Reptiles* (Vol. 13, pp. 13–69). New York, NY: Springer.
- Saunders, K. J., P. R. White, and T. G. Leighton. (2008). Models for Predicting Nitrogen Tensions and Decompression Sickness Risk in Diving Beaked Whales. *Proceedings of the Institute of Acoustics* 30 (5): 1–8.
- Savage, K. N., K. Burek-Huntington, S. K. Wright, A. L. Bryan, G. Sheffield, M. Webber, R. Stimmelmayer, P. Tuomi, M. A. Delaney, and W. Walker. (2021). Stejneger's beaked whale strandings in Alaska, 1995–2020. *Marine Mammal Science* 1–27. DOI:10.1111/mms.12780
- Scarpaci, C., S. W. Bigger, P. J. Corkeron, and D. Nugegoda. (2000). Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence of 'swim-with-dolphin' tour operations. *Journal of Cetacean Research and Management* 2 (3): 183–185.
- Schakner, Z. A. and D. T. Blumstein. (2013). Behavioral biology of marine mammal deterrents: A review and prospectus. *Biological Conservation* 167 380–389. DOI:10.1016/j.biocon.2013.08.024
- Schaub, A., J. Ostwald, and B. M. Siemers. (2008). Foraging bats avoid noise. *The Journal of Experimental Biology* 211 (19): 3174–3180. DOI:10.1242/jeb.022863
- Scheifele, P. M., S. Andrew, R. A. Cooper, M. Darre, R. E. Musiek, and L. Max. (2005). Indication of a Lombard vocal response in the St. Lawrence River beluga. *The Journal of the Acoustical Society of America* 117 (3): 1486–1492. DOI:10.1121/1.1835508

- Schlundt, C. E., J. J. Finneran, D. A. Carder, and S. H. Ridgway. (2000). Temporary shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. *The Journal of the Acoustical Society of America* 107 (6): 3496–3508.
- Schnitzler, H. U., C. F. Moss, and A. Denzinger. (2003). From spatial orientation to food acquisition in echolocating bats. *Trends in Ecology and Evolution* 18 (8): 386–394. DOI:10.1016/S0169-5347(03)00185-X
- Scholik, A. R. and H. Y. Yan. (2001). Effects of underwater noise on auditory sensitivity of a cyprinid fish. *Hearing Research* 152 (1–2): 17–24.
- Scholik, A. R. and H. Y. Yan. (2002a). Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. *Environmental Biology of Fishes* 63 203–209.
- Scholik, A. R. and H. Y. Yan. (2002b). The effects of noise on the auditory sensitivity of the bluegill sunfish, *Lepomis macrochirus*. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 133 (1): 43–52. DOI:10.1016/S1095-6433(02)00108-3
- Schorr, G. S., E. A. Falcone, D. J. Moretti, and R. D. Andrews. (2014). First long-term behavioral records from Cuvier's beaked whales (*Ziphius cavirostris*) reveal record-breaking dives. *PLoS ONE* 9 (3): e92633. DOI:10.1371/journal.pone.0092633
- Schorr, G. S., E. A. Falcone, and B. K. Rone. (2017). *Distribution and Demographics of Cuvier's Beaked Whales and Fin Whales in the Southern California Bight* (Annual report for on-water surveys conducted in conjunction with Marine Mammal Monitoring on Navy Ranges). Seabeck, WA: Marine Ecology and Telemetry Research.
- Schuler, A. R., S. Piwetz, J. Di Clemente, D. Steckler, F. Mueter, and H. C. Pearson. (2019). Humpback whale movements and behavior in response to whale-watching vessels in Juneau, AK. *Frontiers in Marine Science* 6. DOI:10.3389/fmars.2019.00710
- Schulz-Mirbach, T., F. Ladich, A. Mittone, M. Olbinado, A. Bravin, I. P. Maiditsch, R. R. Melzer, P. Krysl, and M. Hess. (2020). Auditory chain reaction: Effects of sound pressure and particle motion on auditory structures in fishes. *PLoS ONE* 15 (3). DOI:10.1371/journal.pone.0230578
- Schwarz, A. B. and G. L. Greer. (1984). Responses of Pacific herring, *Clupea harengus pallasi*, to some underwater sounds. *Canadian Journal of Fisheries and Aquatic Science* 41 1183–1192.
- Schwarz, L., E. McHuron, M. Mangel, G. Gailey, and O. Sychenko. (2022). Gray whale habitat use and reproductive success during seismic surveys near their feeding grounds: comparing state-dependent life history models and field data. *Environmental Monitoring and Assessment* 194 (Suppl 1): 733. DOI:10.1007/s10661-022-10024-9
- Settle, L. R., J. J. Govoni, M. D. Greene, M. A. West, R. T. Lynch, and G. Revy. (2002). *Investigation of Impacts of Underwater Explosions on Larval and Early Juvenile Fishes*. Beaufort, NC: Center for Coastal Fisheries and Habitat Research.
- Shabangu, F. W., D. Yemane, G. Best, and B. J. Estabrook. (2022). Acoustic detectability of whales amidst underwater noise off the west coast of South Africa. *Marine Pollution Bulletin* 184 114122. DOI:10.1016/j.marpolbul.2022.114122
- Shane, S. H., R. S. Wells, and B. Wursig. (1986). Ecology, behavior and social organization of the bottlenose dolphin: A review. *Marine Mammal Science* 2 (1): 34–63.

- Short, M., P. R. White, T. G. Leighton, and P. S. Kemp. (2020). Influence of acoustics on the collective behaviour of a shoaling freshwater fish. *Freshwater Biology*. DOI:DOI: 10.1111/fwb.13612
- Shute, C. C. D. and A. d. A. Bellairs. (1955). The external ear in Crocodilia. *Journal of Zoology* 124 (4): 741–749.
- Siddagangaiah, S., C. F. Chen, W. C. Hu, N. Pieretti, V. Lecours, and D. Risch. (2021). Impact of pile-driving and offshore windfarm operational noise on fish chorusing. *Remote Sensing in Ecology and Conservation* 8 (1): 119–134. DOI:10.1002/rse2.231
- Siebert, U., J. Sturznickel, T. Schaffeld, R. Oheim, T. Rolvien, E. Prenger-Berninghoff, P. Wohlsein, J. Lakemeyer, S. Rohner, L. Aroha Schick, S. Gross, D. Nachtsheim, C. Ewers, P. Becher, M. Amling, and M. Morell. (2022). Blast injury on harbour porpoises (*Phocoena phocoena*) from the Baltic Sea after explosions of deposits of World War II ammunition. *Environment International* 159 107014. DOI:10.1016/j.envint.2021.107014
- Siegal, E., S. K. Hooker, S. Isojunno, and P. J. O. Miller. (2022). Beaked whales and state-dependent decision-making: How does body condition affect the trade-off between foraging and predator avoidance? *Proceedings of the Royal Society B: Biological Sciences* 289 (1967). DOI:10.1098/rspb.2021.2539
- Siemers, B. M. and A. Schaub. (2011). Hunting at the highway: Traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of the Royal Society of London B: Biological Sciences* 278 (1712): 1646–1652. DOI:10.1098/rspb.2010.2262
- Sierra-Flores, R., T. Attack, H. Migaud, and A. Davie. (2015). Stress response to anthropogenic noise in Atlantic cod *Gadus morhua* L. *Aquacultural Engineering* 67 67–76. DOI:10.1016/j.aquaeng.2015.06.003
- Sills, J. M., B. L. Southall, and C. Reichmuth. (2014). Amphibious hearing in spotted seals (*Phoca largha*): Underwater audiograms, aerial audiograms and critical ratio measurements. *The Journal of Experimental Biology* 217 (Pt 5): 726–734. DOI:10.1242/jeb.097469
- Sills, J. M., B. L. Southall, and C. Reichmuth. (2015). Amphibious hearing in ringed seals (*Pusa hispida*): Underwater audiograms, aerial audiograms and critical ratio measurements. *The Journal of Experimental Biology* 218 (Pt 14): 2250–2259. DOI:10.1242/jeb.120972
- Sills, J. M., B. L. Southall, and C. Reichmuth. (2017). The influence of temporally varying noise from seismic air guns on the detection of underwater sounds by seals. *The Journal of the Acoustical Society of America* 141 (2): 996–1008. DOI:10.1121/1.4976079]
- Simmons, A. M., S. Boku, H. Riquimaroux, and J. A. Simmons. (2015). Auditory brainstem responses of Japanese house bats (*Pipistrellus abramus*) after exposure to broadband ultrasonic noise. *The Journal of the Acoustical Society of America* 138 (4): 2430–2437. DOI:10.1121/1.4931901
- Simmons, A. M., K. N. Hom, M. Warnecke, and J. A. Simmons. (2016). Broadband noise exposure does not affect hearing sensitivity in big brown bats (*Eptesicus fuscus*). *The Journal of Experimental Biology* 219 (7): 1031–1040. DOI:10.1242/jeb.135319
- Simmons, J. A., K. M. Eastman, S. S. Horowitz, M. J. O'Farrell, and D. N. Lee. (2001). Versatility of biosonar in the big brown bat, *Eptesicus fuscus*. *Acoustics Research Letters Online* 2 (1): 43–48. DOI:10.1121/1.1352717

- Simmons, J. A., S. A. Kick, A. J. M. Moffat, M. W. Masters, and D. Kon. (1988). Clutter interference along the target range axis in the echolocating bat, *Eptesicus fuscus*. *The Journal of the Acoustical Society of America* 84 (2): 551–559. DOI:10.1121/1.396832
- Simonis, A. E., R. L. Brownell, B. J. Thayre, J. S. Trickey, E. M. Oleson, R. Huntington, and S. Baumann-Pickering. (2020). Co-occurrence of beaked whale strandings and naval sonar in the Mariana Islands, Western Pacific. *Proceedings of the Royal Society* 287. DOI:10.1098/rspb.2020.0070
- Simpson, S. D., J. Purser, and A. N. Radford. (2015). Anthropogenic noise compromises antipredator behaviour in European eels. *Global Change Biology* 21 (2): 586–593. DOI:10.1111/gcb.12685
- Simpson, S. D., A. N. Radford, S. L. Nedelec, M. C. Ferrari, D. P. Chivers, M. I. McCormick, and M. G. Meekan. (2016). Anthropogenic noise increases fish mortality by predation. *Nature Communications* 7 10544. DOI:10.1038/ncomms10544
- Širović, A., K. Evans, C. Garcia-Soto, J. H. Hildebrand, S. M. Jesus, and J. H. Miller. (2020). *Chapter 20: Trends in inputs of anthropogenic noise into the marine environment*. New York, NY: United Nations.
- Širović, A., J. A. Hildebrand, and S. M. Wiggins. (2007). Blue and fin whale call source levels and propagation range in the Southern Ocean. *The Journal of the Acoustical Society of America* 122 (2): 1208–1215. DOI:10.1121/1.2749452
- Sisneros, J. A. and A. H. Bass. (2003). Seasonal plasticity of peripheral auditory frequency sensitivity. *The Journal of Neuroscience* 23 (3): 1049–1058.
- Sivle, L. D., P. H. Kvadsheim, and M. Ainslie. (2016a). Potential population consequences of active sonar disturbance in Atlantic herring: Estimating the maximum risk. *Advances in Experimental Medicine and Biology* 875 217–222. DOI:10.1007/978-1-4939-2981-8_25
- Sivle, L. D., P. H. Kvadsheim, and M. A. Ainslie. (2015a). Potential for population-level disturbance by active sonar in herring. *ICES Journal of Marine Science* 72 (2): 558–567. DOI:10.1093/icesjms/fsu154
- Sivle, L. D., P. H. Kvadsheim, M. A. Ainslie, A. Solow, N. O. Handegard, N. Nordlund, and F. P. A. Lam. (2012a). Impact of naval sonar signals on Atlantic herring (*Clupea harengus*) during summer feeding. *ICES Journal of Marine Science* 69 (6): 1078–1085. DOI:10.1093/icesjms/fss080
- Sivle, L. D., P. H. Kvadsheim, C. Curé, S. Isojunno, P. J. Wensveen, F. A. Lam, F. Visser, L. Kleivane, P. L. Tyack, C. M. Harris, and P. J. O. Miller. (2015b). Severity of expert-identified behavioural responses of humpback whale, minke whale, and northern bottlenose whale to naval sonar. *Aquatic Mammals* 41 (4): 469–502. DOI:10.1578/am.41.4.2015.469
- Sivle, L. D., P. H. Kvadsheim, A. Fahlman, F. P. A. Lam, P. L. Tyack, and P. J. Miller. (2012b). Changes in dive behavior during naval sonar exposure in killer whales, long-finned pilot whales, and sperm whales. *Frontiers in Physiology* 3 400. DOI:10.3389/fphys.2012.00400
- Sivle, L. D., P. J. Wensveen, P. H. Kvadsheim, F. P. A. Lam, F. Visser, C. Curé, C. M. Harris, P. L. Tyack, and P. J. O. Miller. (2016b). Naval sonar disrupts foraging in humpback whales. *Marine Ecology Progress Series* 562 211–220. DOI:10.3354/meps11969
- Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A. N. Popper. (2010). A noisy spring: The impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution* 25 (7): 419–427. DOI:10.1016/j.tree.2010.04.005

- Slabbekoorn, H. and A. den Boer-Visser. (2006). Cities change the songs of birds. *Current Biology* 16 (23): 2326–2331.
- Slotte, A., K. Hansen, J. Dalen, and E. Ona. (2004). Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. *Fisheries Research* 67 143–150. DOI:10.1016/j.fishres.2003.09.046
- Smith, A. B., M. Kissling, A. M. Capuano, S. B. Lewis, and T. A. Mooney. (2023). Aerial hearing thresholds and ecoacoustics of a threatened pursuit-diving seabird, the marbled murrelet *Brachyramphus marmoratus*. *Endangered Species Research* 50 167–179. DOI:10.3354/esr01234
- Smith, C. E., S. T. Sykora–Bodie, B. Bloodworth, S. M. Pack, T. R. Spradlin, and N. R. LeBoeuf. (2016). Assessment of known impacts of unmanned aerial systems (UAS) on marine mammals: Data gaps and recommendations for researchers in the United States. *Journal of Unmanned Vehicle Systems* 4 (1): 31–44.
- Smith, M. E., A. W. Accomando, V. Bowman, B. M. Casper, P. H. Dahl, A. K. Jenkins, S. Kotecki, and A. N. Popper. (2022). Physical effects of sound exposure from underwater explosions on Pacific mackerel (*Scomber japonicus*): Effects on the inner ear. *The Journal of the Acoustical Society of America* 152 (2): 733. DOI:10.1121/10.0012991
- Smith, M. E., A. B. Coffin, D. L. Miller, and A. N. Popper. (2006). Anatomical and functional recovery of the goldfish (*Carassius auratus*) ear following noise exposure. *The Journal of Experimental Biology* 209 (21): 4193–4202. DOI:10.1242/jeb.02490
- Smith, M. E. and R. R. Gilley. (2008). Testing the equal energy hypothesis in noise-exposed fishes. *Bioacoustics* 17 (1–3): 343–345. DOI:10.1080/09524622.2008.9753871
- Smith, M. E., A. S. Kane, and A. N. Popper. (2004a). Acoustical stress and hearing sensitivity in fishes: Does the linear threshold shift hypothesis hold water? *The Journal of Experimental Biology* 207 3591–3602. DOI:10.1242/jeb.01188
- Smith, M. E., A. S. Kane, and A. N. Popper. (2004b). Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). *The Journal of Experimental Biology* 207 (3): 427–435. DOI:10.1242/jeb.00755
- Smultea, M. A., C. E. Bacon, T. F. Norris, and D. Steckler. (2012). *Aerial Surveys Conducted in the SOCAL OPAREA From 1 August 2011–31 July 2012*. San Diego, CA: HDR, Inc.
- Smultea, M. A. and K. Lomac-MacNair. (2016). Assessing 'Observer Effects' from a Research Aircraft on Behavior of Three Delphinidae Species (*Grampus griseus*, *Delphinus delphis*, and *Orcinus orca*). *Wildlife Biology in Practice* 12 (2): 75–90.
- Smultea, M. A., J. R. Mobley, Jr., D. Fertl, and G. L. Fulling. (2008). An unusual reaction and other observations of sperm whales near fixed-wing aircraft. *Gulf and Caribbean Research* 20 75–80.
- Smultea, M. A., J. R. Mobley, Jr., and K. Lomac-MacNair. (2009). *Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaii Range Complex in Conjunction with a Navy Training Event, SSC OPS February 15–19, 2009, Final Field Report*. Honolulu, HI: Marine Mammal Research Consultants and Issaquah, WA: Smultea Environmental Sciences, LLC.
- Snoddy, J. E., M. Landon, G. Blanvillain, and A. Southwood. (2009). Blood biochemistry of sea turtles captured in gillnets in the lower Cape Fear River, North Carolina, USA. *Journal of Wildlife Management* 73 (8): 1394–1401.

- Solé, M., S. De Vreese, J.-M. Fortuño, and M. van der Schaar. (2023a). Artificial sound impact could put at risk hermit crabs and their symbiont anemones. *Science of The Total Environment* 900 165756. DOI:<https://doi.org/10.1016/j.scitotenv.2023.165756>
- Solé, M., S. De Vreese, A. M. Sánchez, J.-M. Fortuño, M. van der Schaar, N. Sancho, and M. André. (2023b). Cross-sensory interference assessment after exposure to noise shows different effects in the blue crab olfactory and sound sensing capabilities. *Science of The Total Environment* 873 162260. DOI:<https://doi.org/10.1016/j.scitotenv.2023.162260>
- Solé, M., K. Kaifu, T. A. Mooney, S. L. Nedelec, F. Olivier, A. N. Radford, M. Vazzana, M. A. Wale, J. M. Semmens, S. D. Simpson, G. Buscaino, A. Hawkins, N. Aguilar de Soto, T. Akamatsu, L. Chauvaud, R. D. Day, Q. Fitzgibbon, R. D. McCauley, and M. André. (2023c). Marine invertebrates and noise. *Frontiers in Marine Science* 10. DOI:10.3389/fmars.2023.1129057
- Solé, M., M. Lenoir, M. Durfort, J. M. Fortuno, M. van der Schaar, S. De Vreese, and M. Andre. (2021). Seagrass *Posidonia* is impaired by human-generated noise. *Communications Biology* 4 (1). DOI:10.1038/s42003-021-02165-3
- Somogyi, N. A. and R. A. Rountree. (2023). The sound production of *Aplodinotus grunniens* in the presence of boat sounds. *Journal of the Acoustic Society of America* 154 (2): 831–840. DOI:10.1121/10.0020542
- Song, J., D. A. Mann, P. A. Cott, B. W. Hanna, and A. N. Popper. (2008). The inner ears of northern Canadian freshwater fishes following exposure to seismic air gun sounds. *The Journal of the Acoustical Society of America* 124 (2): 1360–1366. DOI:10.1121/1.2946702
- Sørensen, K., C. Neumann, M. Dahne, K. A. Hansen, and M. Wahlberg. (2020). Gentoo penguins (*Pygoscelis papua*) react to underwater sounds. *Royal Society Open Science* 7 (2).
- Sørensen, P. M., A. Haddock, E. Guarino, K. Jaakkola, C. McMullen, F. H. Jensen, P. L. Tyack, and S. L. King. (2023). Anthropogenic noise impairs cooperation in bottlenose dolphins. *Current Biology* 33 1-6. DOI:10.1016/j.cub.2022.12.063
- Soudijn, F. H., T. v. Kooten, H. Slabbekoorn, and A. M. d. Roos. (2020). Population-level effects of acoustic disturbance in Atlantic cod: A size-structured analysis based on energy budgets. *Proceedings of the Royal Society B: Biological Sciences* 287. DOI:10.1098/rspb.2020.0490
- Sousa-Lima, R. S. and C. W. Clark. (2008). Modeling the effect of boat traffic on the fluctuation of humpback whale singing activity in the Abrolhos National Marine Park, Brazil. *Canadian Acoustics* 36 (1): 174–181.
- Southall, B., A. Bowles, W. Ellison, J. Finneran, R. Gentry, C. Greene, D. Kastak, D. Ketten, J. Miller, P. Nachtigall, W. Richardson, J. Thomas, and P. Tyack. (2007). Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals* 33 (4): 122.
- Southall, B., J. Calambokidis, P. Tyack, D. Moretti, J. Hildebrand, C. Kyburg, R. Carlson, A. Friedlaender, E. Falcone, G. Schorr, A. Douglas, S. DeRuiter, J. Goldbogen, and J. Barlow. (2011). *Biological and Behavioral Response Studies of Marine Mammals in Southern California, 2010 ("SOCAL-10") Project Report*. Pearl Harbor, HI: U.S. Navy Pacific Fleet.
- Southall, B. L., A. N. Allen, J. Calambokidis, C. Casey, S. L. DeRuiter, S. Fregosi, A. S. Friedlaender, J. A. Goldbogen, C. M. Harris, E. L. Hazen, V. Popov, and A. K. Stimpert. (2023). Behavioural responses of fin whales to military mid-frequency active sonar. *Royal Society Open Science* 10 (12): 231775. DOI:<https://doi.org/10.1098/rsos.231775>

- Southall, B. L., K. J. Benoit-Bird, M. A. Moline, and D. Moretti. (2019a). Quantifying deep-sea predator-prey dynamics: Implications of biological heterogeneity for beaked whale conservation. *Journal of Applied Ecology* 2019 1–10. DOI:10.1111/1365-2664.13334
- Southall, B. L., A. E. Bowles, W. T. Ellison, J. J. Finneran, R. L. Gentry, C. R. Greene, D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas, and P. L. Tyack. (2009). Marine mammal noise and exposure criteria: Initial scientific recommendations. *The Journal of the Acoustical Society of America* 125 (4): 2517.
- Southall, B. L., R. Braun, F. M. D. Gulland, A. D. Heard, R. W. Baird, S. M. Wilkin, and T. K. Rowles. (2006). *Hawaiian Melon-headed Whales (Peponacephala electra) Mass Stranding Event of July 3–4, 2004* (National Oceanic and Atmospheric Administration Technical Memorandum NMFS-OPR-31). Silver Spring, MD: National Oceanic and Atmospheric Administration, National Marine Fisheries Service.
- Southall, B. L., S. L. DeRuiter, A. Friedlaender, A. K. Stimpert, J. A. Goldbogen, E. Hazen, C. Casey, S. Fregosi, D. E. Cade, A. N. Allen, C. M. Harris, G. Schorr, D. Moretti, S. Guan, and J. Calambokidis. (2019b). Behavioral responses of individual blue whales (*Balaenoptera musculus*) to mid-frequency military sonar. *Journal of Experimental Biology* 222 (Pt 5). DOI:10.1242/jeb.190637
- Southall, B. L., J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. P. Nowacek, and P. L. Tyack. (2019c). Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. *Aquatic Mammals* 45 (2): 125–232. DOI:10.1578/am.45.2.2019.125
- Southall, B. L., D. P. Nowacek, A. E. Bowles, V. Senigaglia, L. Bejder, and P. L. Tyack. (2021). Marine mammal noise exposure criteria: Assessing the severity of marine mammal behavioral responses to human noise. *Aquatic Mammals* 47 (5): 421–464. DOI:10.1578/am.47.5.2021.421
- Southall, B. L., D. P. Nowacek, P. J. O. Miller, and P. L. Tyack. (2016). Experimental field studies to measure behavioral responses of cetaceans to sonar. *Endangered Species Research* 31 293–315. DOI:10.3354/esr00764
- Southall, B. L., R. J. Schusterman, and D. Kastak. (2000). Masking in three pinnipeds: Underwater, low-frequency critical ratios. *The Journal of the Acoustical Society of America* 108 (3): 1322–1326.
- Southall, B. L., R. J. Schusterman, and D. Kastak. (2003). Auditory masking in three pinnipeds: Aerial critical ratios and direct critical bandwidth measurements. *The Journal of the Acoustical Society of America* 114 (3): 1660–1666. DOI:10.1121/1.1587733
- Spiga, I., N. Aldred, and G. S. Caldwell. (2017). Anthropogenic noise compromises the anti-predator behaviour of the European seabass, *Dicentrarchus labrax* (L.). *Marine Pollution Bulletin* 122 (1–2): 297–305. DOI:10.1016/j.marpolbul.2017.06.067
- Sprague, M. W. and J. J. Luczkovich. (2004). Measurement of an individual silver perch, *Bairdiella chrysoura*, sound pressure level in a field recording. *The Journal of the Acoustical Society of America* 116 (5): 3186–3191. DOI:10.1121/1.1802651
- Sprogis, K. R., D. Holman, P. Arranz, and F. Christiansen. (2023). Effects of whale-watching activities on southern right whales in Encounter Bay, South Australia. *Marine Policy* 150. DOI:10.1016/j.marpol.2023.105525
- Sprogis, K. R., S. Videsen, and P. T. Madsen. (2020). Vessel noise levels drive behavioural responses of humpback whales with implications for whale-watching. *eLife* 9.

- St. Aubin, D. and L. A. Dierauf. (2001). Stress and Marine Mammals. In L. A. Dierauf & F. M. D. Gulland (Eds.), *Marine Mammal Medicine* (2nd ed., pp. 253–269). Boca Raton, FL: CRC Press.
- St. Aubin, D. J. and J. R. Geraci. (1989). Adaptive changes in hematologic and plasma chemical constituents in captive beluga whales, *Delphinapterus leucas*. *Canadian Journal of Fisheries and Aquatic Sciences* 46 796–803.
- St. Aubin, D. J., S. H. Ridgway, R. S. Wells, and H. Rhinehart. (1996). Dolphin thyroid and adrenal hormones: Circulating levels in wild and semidomesticated *Tursiops truncatus*, and influence of sex, age, and season. *Marine Mammal Science* 12 (1): 1–13.
- Staaterman, E., A. J. Gallagher, P. E. Holder, C. H. Reid, A. H. Altieri, M. B. Ogburn, J. L. Rummer, and S. J. Cooke. (2020). Exposure to boat noise in the field yields minimal stress response in wild reef fish. *Aquatic Biology* 29 93–103. DOI:10.3354/ab00728
- Stabenau, E. K., T. A. Heming, and J. F. Mitchell. (1991). Respiratory, acid-base and ionic status of Kemp's ridley sea turtles (*Lepidochelys kempii*) subjected to trawling. *Comparative Biochemistry and Physiology Part A: Physiology* 99 (1): 107–111.
- Stalmaster, M. V. and J. L. Kaiser. (1997). Flushing responses of wintering bald eagles to military activity. *The Journal of Wildlife Management* 61 (4): 1307–1313.
- Stamaton, K. A., D. B. Croft, P. D. Shaughnessy, K. A. Waples, and S. V. Briggs. (2010). Behavioral responses of humpback whales (*Megaptera novaeangliae*) to whale-watching vessels on the southeastern coast of Australia. *Marine Mammal Science* 26 (1): 98–122. DOI:10.1111/j.1748-7692.2009.00320.x
- Stanistreet, J. E., W. A. Beslin, K. Kowarski, S. B. Martin, A. Westell, and H. B. Moors-Murphy. (2022). Changes in the acoustic activity of beaked whales and sperm whales recorded during a naval training exercise off eastern Canada. *Scientific Reports* 12 (1). DOI:10.1038/s41598-022-05930-4
- Stanley, J. A., P. E. Caiger, B. Phelan, K. Shelledy, T. A. Mooney, and S. M. Van Parijs. (2020). Ontogenetic variation in the auditory sensitivity of black sea bass (*Centropristis striata*) and the implications of anthropogenic sound on behavior and communication. *Journal of Experimental Biology* 223 (Pt 13). DOI:10.1242/jeb.219683
- Stanley, J. A., S. M. Van Parijs, and L. T. Hatch. (2017). Underwater sound from vessel traffic reduces the effective communication range in Atlantic cod and haddock. *Scientific Reports* 7 (1): 14633. DOI:10.1038/s41598-017-14743-9
- Stasso, J. J., R. H. Pieniazek, and D. M. Higgs. (2022). Interspecific variation in the response of fish to anthropogenic noise. *Freshwater Biology* 68 (1): 25–32. DOI:10.1111/fwb.14006
- Steckenreuter, A., R. Harcourt, and L. Moller. (2011). Distance does matter: Close approaches by boats impede feeding and resting behaviour of Indo-Pacific bottlenose dolphins. *Wildlife Research* 38 (6): 455–463.
- Stimpert, A. K., S. L. DeRuiter, B. L. Southall, D. J. Moretti, E. A. Falcone, J. A. Goldbogen, A. Friedlaender, G. S. Schorr, and J. Calambokidis. (2014). Acoustic and foraging behavior of a Baird's beaked whale, *Berardius bairdii*, exposed to simulated sonar. *Scientific Reports* 4 7031. DOI:10.1038/srep07031
- Stimpert, A. K., D. N. Wiley, W. W. Au, M. P. Johnson, and R. Arsenault. (2007). 'Megapclicks': Acoustic click trains and buzzes produced during night-time foraging of humpback whales (*Megaptera novaeangliae*). *Biology Letters* 3 (5): 467–470. DOI:10.1098/rsbl.2007.0281

- Stockin, K. A., D. Lusseau, V. Binedell, N. Wiseman, and M. B. Orams. (2008). Tourism affects the behavioural budget of the common dolphin *Delphinus* sp. in the Hauraki Gulf, New Zealand. *Marine Ecology Progress Series* 355: 287–295. DOI:10.3354/meps07386.
- Sullivan, F. A. and L. G. Torres. (2018). Assessment of vessel disturbance to gray whales to inform sustainable ecotourism. *The Journal of Wildlife Management* 82 (5): 896–905.
- Sverdrup, A., E. Kjellsby, P. G. Krüger, R. Fløysand, F. R. Knudsen, P. S. Enger, G. Serck-Hanssen, and K. B. Helle. (1994). Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. *Journal of Fish Biology* 45 (6): 973–995.
- Sweeney, K. L., V. T. Helker, W. L. Perryman, D. J. LeRoi, L. W. Fritz, T. S. Gelatt, and R. P. Angliss. (2015). Flying beneath the clouds at the edge of the world: Using a hexacopter to supplement abundance surveys of Steller sea lions (*Eumetopias jubatus*) in Alaska. *Journal of Unmanned Vehicle Systems* 4 (1): 70–81.
- Szesciorka, A. R., A. N. Allen, J. Calambokidis, J. Fahlbusch, M. F. McKenna, and B. Southall. (2019). A case study of a near vessel strike of a Blue Whale: Perceptual cues and fine-scale aspects of behavioral avoidance. *Frontiers in Marine Science* 6.
- Takahashi, R. and T. Akamatsu. (2018). Measurement of the stable sound field in the small tank for simple calibration. *The Journal of the Marine Acoustics Society of Japan* 45: 11.
- Tavolga, W. N. (1974). Signal/noise ratio and the critical band in fishes. *The Journal of the Acoustical Society of America* 55 (6): 1323–1333. DOI:10.1121/1.1914704
- Tavolga, W. N. and J. Wodinsky. (1963). Auditory capacities in fishes: Pure tone thresholds in nine species of marine teleosts. *Bulletin of the American Museum of Natural History* 126 (2): 179–239.
- Taylor, R. L., C. V. Jay, W. S. Beatty, A. S. Fischbach, L. T. Quakenbush, and J. A. Crawford. (2023). Exploring effects of vessels on walrus behaviors using telemetry, automatic identification system data and matching. *Ecosphere* 14 (3). DOI:10.1002/ecs2.4433
- Teer, J. G. and J. C. Truett. (1973). *Studies of the Effects of Sonic Boom on Birds*. Springfield, VA: U.S. Department of Transportation, Federal Aviation Administration.
- Teilmann, J., J. Tougaard, L. A. Miller, T. Kirketerp, K. Hansen, and S. Brando. (2006). Reactions of captive harbor porpoises (*Phocoena phocoena*) to pinger-like sounds. *Marine Mammal Science* 22 (2): 240–260.
- Terhune, J. M. and W. C. Verboom. (1999). Right whales and ship noises. *Marine Mammal Science* 15 (1): 256–258.
- Thiessen, G. J. (1958). Threshold of hearing of a ring-billed gull. *The Journal of the Acoustical Society of America* 30 (11): 1047.
- Thomas, J., P. Moore, R. Withrow, and M. Stoermer. (1990a). Underwater audiogram of a Hawaiian monk seal (*Monachus schauinslandi*). *The Journal of the Acoustical Society of America* 87 (1): 417–420.
- Thomas, J. A., R. A. Kastelein, and F. T. Awbrey. (1990b). Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. *Zoo Biology* 9 (5): 393–402.

- Thompson, D., M. Sjoberg, M. E. Bryant, P. Lovell, and A. Bjorge. (1998). *Behavioral and physiological responses of harbour (Phoca vitulina) and grey (Halichoerus grypus) seals to seismic surveys*(Halichoerus grypus) seals to seismic surveys (Report to European Commission of BROMMAD Project. MAS2 C7940098). Brussels, Belgium: European Commission.
- Thompson, P. M., K. L. Brookes, I. M. Graham, T. R. Barton, K. Needham, G. Bradbury, and N. D. Merchant. (2013a). Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. *Proceedings of the Royal Society B: Biological Sciences* 280 (1771): 20132001. DOI:10.1098/rspb.2013.2001
- Thompson, P. M., G. D. Hastie, J. Nedwell, R. Barham, K. L. Brookes, L. S. Cordes, H. Bailey, and N. McLean. (2013b). Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. *Environmental Impact Assessment Review* 43 73-85. DOI:10.1016/j.eiar.2013.06.005
- Thompson, P. M., D. Lusseau, T. Barton, D. Simmons, J. Rusin, and H. Bailey. (2010). Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. *Marine Pollution Bulletin* 60 (8): 1200–1208.
- Thomson, D. J. M., D. R. (2020). Real-time observations of the impact of COVID-19 on underwater noise. *The Journal of the Acoustical Society of America* 147 (5): 3390–3396. DOI:10.1121/10.0001271
- Ting, C., J. Garrelick, and A. Bowles. (2002). An analysis of the response of Sooty Tern eggs to sonic boom overpressures. *The Journal of the Acoustical Society of America* 111 (1): 562–568. DOI:10.1121/1.1371766
- Tixier, P., N. Gasco, G. Duhamel, and C. Guinet. (2014). Habituation to an acoustic harassment device by killer whales depredating demersal longlines. *ICES Journal of Marine Science* 72 (5): 1673–1681. DOI:10.1093/icesjms/fsu166
- Todd, N. R. E., M. Jessopp, E. Rogan, and A. S. Kavanagh. (2022). Extracting foraging behavior from passive acoustic monitoring data to better understand harbor porpoise (Phocoena phocoena) foraging habitat use. *Marine Mammal Science* 38 (4): 1623-1642. DOI:<https://doi.org/10.1111/mms.12951>
- Todd, S., P. Stevick, J. Lien, F. Marques, and D. Ketten. (1996). Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). *Canadian Journal of Zoology* 74 1661–1672.
- Toro, F., J. Alarcón, B. Toro-Barros, G. Mallea, J. Capella, C. Umaran-Young, P. Abarca, N. Lakestani, C. Peña, M. Alvarado-Rybak, C. Cruz, V. Vilina, and G. Gibbons. (2021). Spatial and temporal effects of whale watching on a tourism-naïve resident population of bottlenose dolphins (*Tursiops truncatus*) in the Humboldt Penguin National Reserve, Chile. *Frontiers in Marine Science* 8 (298). DOI:10.3389/fmars.2021.624974
- Torres Borda, L., Y. Jadoul, H. Rasilo, A. Salazar Casals, and A. Ravignani. (2021). Vocal plasticity in harbour seal pups. *Philosophical Transactions of the Royal Society B* 376 (1840). DOI:10.1098/rstb.2020.0456
- Tougaard, J., J. Carstensen, J. Teilmann, N. I. Bech, H. Skov, and O. D. Henriksen. (2005). *Effects of the Nysted Offshore Wind Farm on Harbour Porpoises* (Annual Status Report for the T-POD Monitoring Program). Roskilde, Denmark: National Environmental Research Institute.

- Tougaard, J., J. Carstensen, J. Teilmann, H. Skov, and P. Rasmussen. (2009). Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* [L.]). *The Journal of the Acoustical Society of America* 126 (1): 11. DOI:10.1121/1.3132523
- Trabulo, R., M. C. P. Amorim, P. J. Fonseca, M. Vieira, A. B. Matos, T. Marin-Cudraz, M. F. L. Lemos, A. B. Moutinho, S. C. Novais, P. Pousao-Ferreira, A. Candeias-Mendes, and A. M. Faria. (2023). Impact of anthropogenic noise on the survival and development of meagre (*Argyrosomus regius*) early life stages. *Marine Environmental Research* 185 105894. DOI:10.1016/j.marenvres.2023.105894
- Trickey, J. S., B. K. Branstetter, and J. J. Finneran. (2010). Auditory masking of a 10 kHz tone with environmental, comodulated, and Gaussian noise in bottlenose dolphins (*Tursiops truncatus*). *The Journal of the Acoustical Society of America* 128 (6): 3799–3804. DOI:10.1121/1.3506367
- Trickey, J. S., G. Cardenas-Hinojosa, L. Rojas-Bracho, G. S. Schorr, B. K. Rone, E. Hidalgo-Pla, A. Rice, and S. Baumann-Pickering. (2022). Ultrasonic antifouling devices negatively impact Cuvier's beaked whales near Guadalupe Island, Mexico. *Communications Biology* 5 (1): 1005. DOI:10.1038/s42003-022-03959-9
- Trites, A. W. and D. E. Bain. (2000). *Short- and long-term effects of whale watching on killer whales (Orcinus orca) in British Columbia*. Adelaide, Australia: International Whaling Commission.
- Tyack, P., W. Zimmer, D. Moretti, B. Southall, D. Claridge, J. Durban, C. Clark, A. D'Amico, N. DiMarzio, S. Jarvis, E. McCarthy, R. Morrissey, J. Ward, and I. Boyd. (2011). Beaked Whales Respond to Simulated and Actual Navy Sonar. *PLoS ONE* 6 (3): 15. DOI:10.1371/journal.pone.0017009.
- Tyack, P. L. (2009). Human-generated sound and marine mammals. *Physics Today* 39–44.
- Tyack, P. L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P. T. Madsen. (2006). Extreme deep diving of beaked whales. *The Journal of Experimental Biology* 209 4238–4253. DOI:10.1242/jeb.02505
- U.S. Department of Commerce and U.S. Department of the Navy. (2001). *Joint Interim Report Bahamas Marine Mammal Stranding Event of 15–16 March 2000*. Washington, DC: Department of Commerce.
- U.S. Department of the Air Force. (2000). *Supersonic Aircraft Noise At and Beneath the Ocean Surface: Estimation of Risk for Effects on Marine Mammals* (AFRL-HE-WP-TR-2000-0167). McLean, VA: United States Air Force Research Laboratory.
- U.S. Department of the Navy. (2004). *Report on the Results of the Inquiry into Allegations of Marine Mammal Impacts Surrounding the Use of Active Sonar by USS SHOUP (DDG 86) in the Haro Strait on or about 5 May 2003*. Pearl Harbor, HI: Commander, U.S. Pacific Fleet.
- U.S. Department of the Navy. (2011a). *Marine Species Monitoring for the U.S. Navy's Hawaii Range Complex and the Southern California Range Complex, 2011 Annual Report*. Pearl Harbor, HI: U.S. Navy Pacific Fleet.
- U.S. Department of the Navy. (2011b). *Marine Species Monitoring, Information on Sightings Recorded by U.S. Navy MMOs on Vessels during Sonar Test Events in the Naval Surface Warfare Center Panama City Division (NSWC PCD)*. Norfolk, VA: United States Fleet Forces Command.
- U.S. Department of the Navy. (2013). *Comprehensive Exercise and Marine Species Monitoring Report for the U.S. Navy's Atlantic Fleet Active Sonar Training (AFAST) and Virginia Capes, Cherry Point, Jacksonville, and Gulf of Mexico Range Complexes 2009–2012*. Norfolk, VA: United States Fleet Forces Command.

- U.S. Department of the Navy. (2014). *Marine Species Monitoring Report for the U.S. Navy's Atlantic Fleet Active Sonar Training (AFAST) and Virginia Capes, Cherry Point, Jacksonville, and Gulf of Mexico Range Complexes - Annual Report 2013*. Norfolk, VA: United States Fleet Forces Command.
- U.S. Department of the Navy. (2017a). *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III)*. San Diego, CA: Space and Naval Warfare Systems Command, Pacific.
- U.S. Department of the Navy. (2017b). *Marine Mammal Strandings Associated with U.S. Navy Sonar Activities*. San Diego, CA: U.S. Navy Marine Mammal Program and SPAWAR Naval Facilities Engineering Command.
- U.S. Department of the Navy. (2017c). *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing* (Technical Report prepared by Space and Naval Warfare Systems Center Pacific). San Diego, CA: Naval Undersea Warfare Center.
- U.S. Department of the Navy. (2024a). *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase IV)*. San Diego, CA: Naval Information Warfare Center, Pacific.
- U.S. Department of the Navy. (2024b). *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase IV Training and Testing* (Technical Report prepared by Naval Information Warfare Center Pacific). San Diego, CA: Naval Undersea Warfare Center.
- U.S. Fish and Wildlife Service. (2012). Endangered and Threatened Wildlife and Plants; Termination of the Southern Sea Otter Translocation Program; Final Rule. *Federal Register* 77 (244): 75266–75297.
- U.S. Fish and Wildlife Service. (2015). *Southern Sea Otter (Enhydra lutris nereis) 5-Year Review: Summary and Evaluation*. Ventura, CA: Ventura Fish and Wildlife Office.
- Ulanovsky, N., M. B. Fenton, A. Tsoar, and C. Korine. (2004). Dynamics of jamming avoidance in echolocating bats. *Proceedings of the Royal Society of London B: Biological Sciences* 271 (1547): 1467–1475. DOI:10.1098/rspb.2004.2750
- Ulanovsky, N. and C. F. Moss. (2008). What the bat's voice tells the bat's brain. *Proceedings of the National Academy of Sciences* 105 (25): 8491–8498. DOI:10.1073/pnas.0703550105
- Ulanovsky, N. and C. F. Moss. (2011). Dynamics of hippocampal spatial representation in echolocating bats. *Hippocampus* 21 (2): 150–161. DOI:10.1002/hipo.20731
- Urick, R. J. (1983). *Principles of Underwater Sound* (3rd ed.). Los Altos, CA: Peninsula Publishing.
- Usategui-Martin, A., A. Liria-Loza, R. A. Valverde, J. Pinos-Crosas, F. Tuya, A. Carbajal, M. Lopez-Bejar, and D. Montero. (2021). Assessment of captive rearing conditions on loggerhead hatchlings: Effect of handling frequency and stocking density. *JEZ-A Ecological and Integrative Physiology* 335 (5): 489–498. DOI:10.1002/jez.2469
- Valverde, R. A., D. W. Owens, D. S. MacKenzie, and M. S. Amoss. (1999). Basal and stress-induced corticosterone levels in olive ridley sea turtles (*Lepidochelys olivacea*) in relation to their mass nesting behavior. *Journal of Experimental Zoology* 284 (6): 652–662.
- van Beest, F. M., L. Kindt-Larsen, F. Bastardie, V. Bartolino, and J. Nabe-Nielsen. (2017). Predicting the population-level impact of mitigating harbor porpoise bycatch with pingers and time-area fishing closures. *Ecosphere* 8 (4): e01785. DOI:10.1002/ecs2.1785

- van der Knaap, I., J. Reubens, L. Thomas, M. A. Ainslie, H. V. Winter, J. Hubert, B. Martin, and H. Slabbekoorn. (2021). Effects of a seismic survey on movement of free-ranging Atlantic cod. *Current Biology* 31 (7): 1555-1562. DOI:10.1016/j.cub.2021.01.050
- van der Knaap, I., H. Slabbekoorn, T. Moens, D. Van den Eynde, and J. Reubens. (2022). Effects of pile driving sound on local movement of free-ranging Atlantic cod in the Belgian North Sea. *Environmental Pollution* 300 118913. DOI:10.1016/j.envpol.2022.118913
- Varghese, H. K., K. Lowell, J. Miksis-Olds, N. DiMarzio, D. Moretti, and L. Mayer. (2021). Spatial analysis of beaked whale foraging during two 12 kHz multibeam echosounder surveys. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.654184
- Varghese, H. K., J. Miksis-Olds, N. DiMarzio, K. Lowel, E. Linder, L. Mayer, and D. Moretti. (2020). The effect of two 12 kHz multibeam mapping surveys on the foraging behavior of Cuvier's beaked whales off of southern California. *The Journal of the Acoustical Society of America* 147 3849–3858.
- Vasquez-Bultron, O. S., D. E. Moreno-Espinoza, L. T. Hernandez-Salazar, and J. E. Morales-Mávil. (2021). Rapid stress response in post-nesting Kemp's ridley turtle (*Lepidochelys kempii*). *Salamandra* 57 (1): 146-150.
- Vazzana, M., M. Ceraulo, M. Mauro, E. Papale, M. Dioguardi, S. Mazzola, V. Arizza, M. Chiaramonte, and G. Buscaino. (2020a). Effects of acoustic stimulation on biochemical parameters in the digestive gland of Mediterranean mussel *Mytilus galloprovincialis* (Lamarck, 1819)a). *The Journal of the Acoustical Society of America* 147 (4): 2414–2422. DOI:10.1121/10.0001034
- Vazzana, M., M. Mauro, M. Ceraulo, M. Dioguardi, E. Papale, S. Mazzola, V. Arizza, F. Beltrame, L. Inguglia, and G. Buscaino. (2020b). Underwater high frequency noise: Biological responses in sea urchin *Arbacia lixula* (Linnaeus, 1758). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* 242 110650. DOI:<https://doi.org/10.1016/j.cbpa.2020.110650>
- Veirs, S., V. Veirs, and J. Wood. (2015). Ship noise in an urban estuary extends to frequencies used for echolocation by endangered killer whales. *PeerJ* 4 e1657. DOI:10.7287/peerj.preprints.955v2
- Velazquez-Wallraf, A., A. Fernandez, M. J. Caballero, A. Mollerlokken, P. D. Jepson, M. Andrada, and Y. Bernaldo de Quiros. (2021). Decompressive pathology in cetaceans based on an experimental pathological model. *Frontiers in Veterinary Science* 8. DOI:10.3389/fvets.2021.676499
- Vergara, V., J. Wood, V. Lesage, A. Ames, M.-A. Mikus, and R. Michaud. (2021). Can you hear me? Impacts of underwater noise on communication space of adult, sub-adult and calf contact calls of endangered St. Lawrence belugas (*Delphinapterus leucas*). *Polar Research* 40. DOI:10.33265/polar.v40.5521
- Vergne, A. L., M. B. Pritz, and N. Mathevon. (2009). Acoustic communication in crocodilians: From behaviour to brain. *Biological Reviews* 84 391–411.
- Vetter, B. J. and J. A. Sisneros. (2020). Swim bladder enhances lagenar sensitivity to sound pressure and higher frequencies in female plainfin midshipman (*Porichthys notatus*). *Journal of Experimental Biology* 223 (Pt 14). DOI:10.1242/jeb.225177
- Viada, S. T., R. M. Hammer, R. Racca, D. Hannay, M. J. Thompson, B. J. Balcom, and N. W. Phillips. (2008). Review of potential impacts to sea turtles from underwater explosive removal of offshore

- structures. *Environmental Impact Assessment Review* 28 267–285.
DOI:10.1016/j.eiar.2007.05.010
- Vieira, M., M. Beauchaud, M. C. P. Amorim, and P. J. Fonseca. (2021). Boat noise affects meagre (*Argyrosomus regius*) hearing and vocal behaviour. *Marine Pollution Bulletin* 172.
DOI:10.1016/j.marpolbul.2021.112824
- Vilela, R., U. Pena, R. Esteban, and R. Koemans. (2016). Bayesian spatial modeling of cetacean sightings during a seismic acquisition survey. *Marine Pollution Bulletin* 109 (1): 512–520.
- Villadsgaard, A., M. Wahlberg, and J. Tougaard. (2007). Echolocation signals of wild harbour porpoises, *Phocoena phocoena*. *The Journal of Experimental Biology* 210 56–64. DOI:10.1242/jeb.02618
- Villegas-Amtmann, S., L. K. Schwarz, G. Gailey, O. Sychenko, and D. P. Costa. (2017). East or west: The energetic cost of being a gray whale and the consequence of losing energy to disturbance. *Endangered Species Research* 34 167–183. DOI:10.3354/esr00843
- Visser, F., C. Cure, P. H. Kvadsheim, F. P. Lam, P. L. Tyack, and P. J. Miller. (2016). Disturbance-specific social responses in long-finned pilot whales, *Globicephala melas*. *Scientific Reports* 6 28641. DOI:10.1038/srep28641
- Vliet, K. A. (1989). Social displays of the American alligator (*Alligator mississippiensis*). *American Zoologist* 29 1019–1031.
- Voellmy, I. K., J. Purser, D. Flynn, P. Kennedy, S. D. Simpson, and A. N. Radford. (2014). Acoustic noise reduces foraging success in two sympatric fish species via different mechanisms. *Animal Behaviour* 89 191–198. DOI:10.1016/j.anbehav.2013.12.029
- von Benda-Beckmann, A. M., S. Isojunno, M. Zandvliet, A. Ainslie, P. J. Wensveen, P. L. Tyack, P. H. Kvadsheim, P. A. Lam, and P. J. O. Miller. (2021). Modeling potential masking of echolocating sperm whales exposed to continuous 1–2 kHz naval sonar. *The Journal of the Acoustical Society of America* 149 2908–2925. DOI:10.1121/10.0004769
- von Benda-Beckmann, A. M., P. J. Wensveen, M. Prior, M. A. Ainslie, R. R. Hansen, S. Isojunno, F. P. A. Lam, P. H. Kvadsheim, and P. J. O. Miller. (2019). Predicting acoustic dose associated with marine mammal behavioural responses to sound as detected with fixed acoustic recorders and satellite tags. *The Journal of the Acoustical Society of America* 145 (3): 1401–1416. DOI:10.1121/1.5093543
- Voß, J., A. Rose, V. Kosarev, R. Vilela, I. C. van Opzeeland, and A. Diederichs. (2023). Response of harbor porpoises (*Phocoena phocoena*) to different types of acoustic harassment devices and subsequent piling during the construction of offshore wind farms. *Frontiers in Marine Science* 10. DOI:10.3389/fmars.2023.1128322
- Waddell, E. E. and A. Sirovic. (2023). Effects of anthropogenic noise and natural soundscape on larval fish behavior in four estuarine species. *The Journal of the Acoustical Society of America* 154 (2): 863–873. DOI:10.1121/10.0020581
- Wale, M. A., R. A. Briers, and K. Diele. (2021). Marine invertebrate anthropogenic noise research – Trends in methods and future directions. *Marine Pollution Bulletin* 173 112958.
DOI:<https://doi.org/10.1016/j.marpolbul.2021.112958>
- Wale, M. A., R. A. Briers, M. G. J. Hartl, D. Bryson, and K. Diele. (2019). From DNA to ecological performance: Effects of anthropogenic noise on a reef-building mussel. *Science of The Total Environment* 689 126–132. DOI:<https://doi.org/10.1016/j.scitotenv.2019.06.380>

- Wang, Y., Y. Pan, S. Parsons, M. Walker, and S. Zhang. (2007). Bats respond to polarity of a magnetic field. *Proceedings of the Royal Society of London B: Biological Sciences* 274 (1627): 2901–2905. DOI:10.1098/rspb.2007.0904
- Wardle, C. S., T. J. Carter, G. G. Urquhart, A. D. F. Johnstone, A. M. Ziolkowski, G. Hampson, and D. Mackie. (2001). Effects of seismic air guns on marine fish. *Continental Shelf Research* 21 1005–1027.
- Warnecke, M., C. Chiu, J. Engelberg, and C. F. Moss. (2015). Active listening in a bat cocktail party: Adaptive echolocation and flight behaviors of big brown bats, *Eptesicus fuscus*, foraging in a cluttered acoustic environment. *Brain, Behavior and Evolution* 86 (1): 6–16. DOI:10.1159/000437346
- Wartzok, D. and D. R. Ketten. (1999). Marine Mammal Sensory Systems. In J. E. Reynolds, III & S. A. Rommel (Eds.), *Biology of Marine Mammals* (pp. 117–175). Washington, DC: Smithsonian Institution Press.
- Wartzok, D., A. N. Popper, J. Gordon, and J. Merrill. (2003). Factors affecting the responses of marine mammals to acoustic disturbance. *Marine Technology Society Journal* 37 (4): 6–15.
- Watkins, W. A. (1981). Reaction of three species of whales *Balaenoptera physalus*, *Megaptera novaeangliae*, and *Balaenoptera edeni* to implanted radio tags. *Deep-Sea Research* 28A (6): 589–599.
- Watkins, W. A. (1986). Whale reactions to human activities in Cape Cod waters. *Marine Mammal Science* 2 (4): 251–262.
- Watkins, W. A., K. E. Moore, and P. Tyack. (1985). Sperm whale acoustic behavior in the southeast Caribbean. *Cetology* 49 1–15.
- Watkins, W. A. and W. E. Schevill. (1975). Sperm whales (*Physeter catodon*) react to pingers. *Deep-Sea Research* 22 123–129.
- Watkins, W. A. and W. E. Schevill. (1977). Sperm whale codas. *The Journal of the Acoustical Society of America* 62 (6): 1485–1490. DOI:10.1121/1.381678
- Watwood, S., M. Fagan, A. D'Amico, and T. Jefferson. (2012). *Cruise Report, Marine Species Monitoring and Lookout Effectiveness Study, Koa Kai, November 2011, Hawaii Range Complex*. Pearl Harbor, HI: Commander, U.S. Pacific Fleet.
- Watwood, S., E. McCarthy, N. DiMarzio, R. Morrissey, S. Jarvis, and D. Moretti. (2017). *Beaked whale foraging behavior before, during, and after sonar exposure on a Navy test range*. Presented at the 22nd Biennial Conference on the Biology of Marine Mammals. Halifax, Canada.
- Watwood, S. L., J. D. Iafate, E. A. Reyier, and W. E. Redfoot. (2016). Behavioral Response of Reef Fish and Green Sea Turtles to Mid-Frequency Sonar. In A. N. Popper & A. Hawkins (Eds.), *The Effects of Noise on Aquatic Life II* (pp. 1213–1221). New York, NY: Springer.
- Weaver, A. (2015). Sex difference in bottlenose dolphin sightings during a long-term bridge construction project. *Animal Behavior and Cognition* 2 (1): 1–13. DOI:10.12966/abc.02.01.2015
- Webb, J. F., J. C. Montgomery, and J. Mogdans. (2008). Bioacoustics and the Lateral Line of Fishes. In J. F. Webb, R. R. Fay, & A. N. Popper (Eds.), *Fish Bioacoustics* (pp. 145–182). New York, NY: Springer.
- Weir, C. R. (2007). Observations of marine turtles in relation to seismic airgun sound off Angola. *Marine Turtle Newsletter* 116 17–20.

- Weir, C. R. (2008). Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. *Aquatic Mammals* 34 (1): 71–83. DOI:10.1578/am.34.1.2008.71
- Wensveen, P. J., S. Isojunno, R. R. Hansen, A. M. von Benda-Beckmann, L. Kleivane, v. I. S., F. A. Lam, P. H. Kvadsheim, S. L. DeRuiter, C. Cure, T. Narazaki, P. L. Tyack, and P. J. O. Miller. (2019). Northern bottlenose whales in a pristine environment respond strongly to close and distant navy sonar signals. *Proceedings of the Royal Society B: Biological Sciences* 286 (1899): 20182592. DOI:10.1098/rspb.2018.2592
- Wensveen, P. J., P. H. Kvadsheim, F.-P. A. Lam, A. M. Von Benda-Beckmann, L. D. Sivle, F. Visser, C. Curé, P. Tyack, and P. J. O. Miller. (2017). Lack of behavioural responses of humpback whales (*Megaptera novaeangliae*) indicate limited effectiveness of sonar mitigation. *The Journal of Experimental Biology* 220 1–12.
- Wensveen, P. J., A. M. von Benda-Beckmann, M. A. Ainslie, F. P. Lam, P. H. Kvadsheim, P. L. Tyack, and P. J. Miller. (2015). How effectively do horizontal and vertical response strategies of long-finned pilot whales reduce sound exposure from naval sonar? *Marine Environmental Research* 106 68–81. DOI:10.1016/j.marenvres.2015.02.005
- Wenz, G. M. (1962). Acoustic ambient noise in the ocean: Spectra and sources. *The Journal of the Acoustical Society of America* 34 (12): 1936–1956.
- Westdal, K. H., P. R. Richard, J. Sportelli, E. Gillis, and S. H. Ferguson. (2023). Beluga whale (*Delphinapterus leucas*) behaviour in the presence of whale-watching vessels. *Frontiers in Marine Science* 9. DOI:10.3389/fmars.2022.891003
- Wever, E. G. (1971). Hearing in the Crocodilia. *Proceedings of the National Academy of Sciences U.S.A.* 68 1498–1500.
- Wever, E. G., P. N. Herman, J. A. Simmons, and D. R. Hertzler. (1969). Hearing in the blackfooted penguin (*Spheniscus demersus*), as represented by the cochlear potentials. *Proceedings of the National Academy of Sciences* 63 676–680.
- Wheeler, A. R., K. A. Fulton, J. E. Gaudette, R. A. Simmons, I. Matsuo, and J. A. Simmons. (2016). Echolocating big brown bats, *Eptesicus fuscus*, modulate pulse intervals to overcome range ambiguity in cluttered surroundings. *Frontiers in Behavioral Neuroscience* 10 125. DOI:10.3389/fnbeh.2016.00125
- Wieland, M., A. Jones, and S. Renn. (2010). Changing duration of Southern resident killer whale (*Orcinus orca*) discrete calls between two periods spanning 28 years. *Marine Mammal Science* 26 (1): 195–201. DOI:10.1111/j.1748-7692.2009.00351.x
- Wiernicki, C. J., D. Liang, H. Bailey, and D. H. Secor. (2020). The effect of swim bladder presence and morphology on sound frequency detection for fishes. *Reviews in Fisheries Science & Aquaculture*. DOI:10.1080/23308249.2020.1762536
- Wiley, M. L., J. B. Gaspin, and J. F. Goertner. (1981). Effects of underwater explosions on fish with a dynamical model to predict fishkill. *Ocean Science and Engineering* 6 (2): 223–284.
- William, T. C. and J. M. Williams. (1970). Radio tracking of homing and feeding flights of a neotropical bat, *Phyllostomus hastatus*. *Animal Behaviour* 18 302–309.

- Williams, C. M., R. A. Stephen, and D. K. Smith. (2006a). Hydroacoustic events located at the intersection of the Atlantis (30°N) and Kane (23°40'N) Transform Faults with the Mid-Atlantic Ridge. *Geochemistry, Geophysics, Geosystems* 7 (6). DOI:10.1029/2005gc001127
- Williams, R., D. E. Bain, J. K. B. Ford, and A. W. Trites. (2002a). Behavioural responses of male killer whales to a 'leapfrogging' vessel. *Journal of Cetacean Research and Management* 4 (3): 305–310.
- Williams, R., D. E. Bain, J. C. Smith, and D. Lusseau. (2009). Effects of vessels on behaviour patterns of individual southern resident killer whales, *Orcinus orca*. *Endangered Species Research* 6 199–209. DOI:10.3354/esr00150
- Williams, R., C. W. Clark, D. Ponirakis, and E. Ashe. (2014a). Acoustic quality of critical habitats for three threatened whale populations. *Animal Conservation* 17 (2): 174–185. DOI:10.1111/acv.12076
- Williams, R., C. Erbe, E. Ashe, A. Beerman, and J. Smith. (2014b). Severity of killer whale behavioral responses to ship noise: A dose-response study. *Marine Pollution Bulletin* 79 (1–2): 254–260. DOI:10.1016/j.marpolbul.2013.12.004
- Williams, R., D. Lusseau, and P. S. Hammond. (2006b). Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). *Biological Conservation* 133 301–311. DOI:10.1016/j.biocon.2006.06.010.
- Williams, R., A. W. Trites, and D. E. Bain. (2002b). Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: Opportunistic observations and experimental approaches. *Journal of Zoology, London* 256 255–270. DOI:10.1017/S0952836902000298
- Williams, T. C., J. M. Williams, and D. R. Griffin. (1966). The homing ability of the neotropical bat *Phyllostomus Hastatus*, with evidence for visual orientation. *Animal Behaviour* 14 (4): 468–473.
- Williams, T. M., S. B. Blackwell, O. Tervo, E. Garde, M. H. S. Sinding, B. Richter, and M. P. Heide-Jørgensen. (2022). Physiological responses of narwhals to anthropogenic noise: A case study with seismic airguns and vessel traffic in the Arctic. *Functional Ecology* 36 (9): 2251–2266. DOI:10.1111/1365-2435.14119
- Williams, T. M., T. L. Kendall, B. P. Richter, C. R. Ribeiro-French, J. S. John, K. L. Odell, B. A. Losch, D. A. Feuerbach, and M. A. Stamper. (2017). Swimming and diving energetics in dolphins: A stroke-by-stroke analysis for predicting the cost of flight responses in wild odontocetes. *The Journal of Experimental Biology* 220 (6): 1135–1145. DOI:10.1242/jeb.154245
- Willis, K. L., J. Christensen-Dalsgaard, D. R. Ketten, and C. E. Carr. (2013). Middle ear cavity morphology is consistent with an aquatic origin for testudines. *PLoS ONE* 8 (1): e54086.
- Wisniewska, D. M., M. Johnson, J. Teilmann, U. Siebert, A. Galatius, R. Dietz, and P. T. Madsen. (2018). High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*). *Proceedings of the Royal Society B: Biological Sciences* 285 (1872): 10. DOI:10.1098/rspb.2017.2314
- Wong, M. I., I. H. Lau, F. Gordillo-Martinez, and R. O. Vasconcelos. (2022). The effect of time regime in noise exposure on the auditory system and behavioural stress in the zebrafish. *Scientific Report* 12. DOI:10.21203/rs.3.rs-1474602/v1
- Wright, D. G. (1982). *A Discussion Paper on the Effects of Explosives on Fish and Marine Mammals in the Waters of the Northwest Territories* (Canadian Technical Report of Fisheries and Aquatic Sciences). Winnipeg, Canada: Western Region Department of Fisheries and Oceans.

- Würsig, B., S. K. Lynn, T. A. Jefferson, and K. D. Mullin. (1998). Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. *Aquatic Mammals* 24 (1): 41–50.
- Wysocki, L. E., J. W. Davidson, III, M. E. Smith, A. S. Frankel, W. T. Ellison, P. M. Mazik, A. N. Popper, and J. Bebak. (2007). Effects of aquaculture production noise on hearing, growth, and disease resistance of rainbow trout, *Oncorhynchus mykiss*. *Aquaculture* 272 687–697. DOI:10.1016/j.aquaculture.2007.07.225
- Wysocki, L. E., J. P. Dittami, and F. Ladich. (2006). Ship noise and cortisol secretion in European freshwater fishes. *Biological Conservation* 128 501–508. DOI:10.1016/j.biocon.2005.10.020
- Wysocki, L. E. and F. Ladich. (2005). Hearing in fishes under noise conditions. *Journal of the Association for Research in Otolaryngology* 6 (1): 28–36. DOI:10.1007/s10162-004-2427-0
- Yang, W. C., C.-F. Chen, Y.-C. Chuah, C.-R. Zhuang, I.-H. Chen, T. A. Mooney, J. Stott, M. Blanchard, I.-F. Jen, and L.-S. Chou. (2021). Anthropogenic sound exposure-induced stress in captive dolphins and implications for cetacean health. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.606736
- Yazvenko, S. B., T. L. McDonald, S. A. Blokhin, S. R. Johnson, H. R. Melton, M. W. Newcomer, R. Nielson, and P. W. Wainwright. (2007). Feeding of western gray whales during a seismic survey near Sakhalin Island, Russia. *Environmental Monitoring and Assessment* 134 (1–3): 93–106. DOI:10.1007/s10661-007-9810-3
- Yeates, L. C., T. M. Williams, and T. L. Fink. (2007). Diving and foraging energetics of the smallest marine mammal, the sea otter (*Enhydra lutris*). *The Journal of Experimental Biology* 210 (Pt 11): 1960–1970. DOI:10.1242/jeb.02767
- Yelverton, J. T. and D. R. Richmond. (1981). *Underwater Explosion Damage Risk Criteria for Fish, Birds, and Mammals*. Presented at the 102nd Meeting of the Acoustical Society of America. Miami Beach, FL.
- Yelverton, J. T., D. R. Richmond, E. R. Fletcher, and R. K. Jones. (1973). *Safe Distances From Underwater Explosions for Mammals and Birds*. Albuquerque, NM: Lovelace Foundation for Medical Education and Research.
- Yelverton, J. T., D. R. Richmond, W. Hicks, K. Saunders, and E. R. Fletcher. (1975). *The Relationship between Fish Size and Their Response to Underwater Blast*. Albuquerque, NM: Defense Nuclear Agency.
- Young, G. A. (1991). *Concise Methods for Predicting the Effects of Underwater Explosions on Marine Life*. Silver Spring, MD: Naval Surface Warfare Center.
- Young, R. W. (1973). Sound pressure in water from a source in air and vice versa. *The Journal of the Acoustical Society of America* 53 (6): 1708–1716.
- Yudhana, A., J. Din, Sundari, S. Abdullah, and R. B. R. Hassan. (2010). Green turtle hearing identification based on frequency spectral analysis. *Applied Physics Research* 2 (1): 125–134.
- Zelick, R., D. A. Mann, and A. N. Popper. (1999). Acoustic communication in fishes and frogs. In R. R. Fay & A. N. Popper (Eds.), *Comparative Hearing: Fish and Amphibians* (pp. 363–411). New York, NY: Springer-Verlag.
- Zeyl, J. N., E. P. Snelling, M. Connan, M. Basille, T. A. Clay, R. Joo, S. C. Patrick, R. A. Phillips, P. A. Pistorius, P. G. Ryan, A. Snyman, and S. Clusella-Trullas. (2022). Aquatic birds have middle ears

- adapted to amphibious lifestyles. *Scientific Reports* 12 (1): 5251. DOI:10.1038/s41598-022-09090-3
- Zhang, Y., C. Liu, J. Liu, X. Liu, Z. Tu, Y. Zheng, J. Xu, H. Fan, Y. Wang, and M. Hu. (2022). Multi-omics reveals response mechanism of liver metabolism of hybrid sturgeon under ship noise stress. *Science of the Total Environment* 851 (Pt 2): 158348. DOI:10.1016/j.scitotenv.2022.158348
- Zhao, X., S. Sun, W. Shi, X. Sun, Y. Zhang, L. Zhu, Q. Sui, B. Xia, K. Qu, B. Chen, and G. Liu. (2021). Mussel byssal attachment weakened by anthropogenic noise. *Frontiers in Marine Science* 8. DOI:10.3389/fmars.2021.821019
- Zimmer, W. M. X. and P. L. Tyack. (2007). Repetitive shallow dives pose decompression risk in deep-diving beaked whales. *Marine Mammal Science* 23 (4): 888–925. DOI:10.1111/j.1748-7692.2007.00152
- Zoidis, A. M., M. A. Smultea, A. S. Frankel, J. L. Hopkins, A. Day, and A. S. McFarland. (2008). Vocalizations produced by humpback whale (*Megaptera novaeangliae*) calves recorded in Hawaii. *The Journal of the Acoustical Society of America* 123 (3): 1737–1746. DOI:10.1121/1.2836750

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