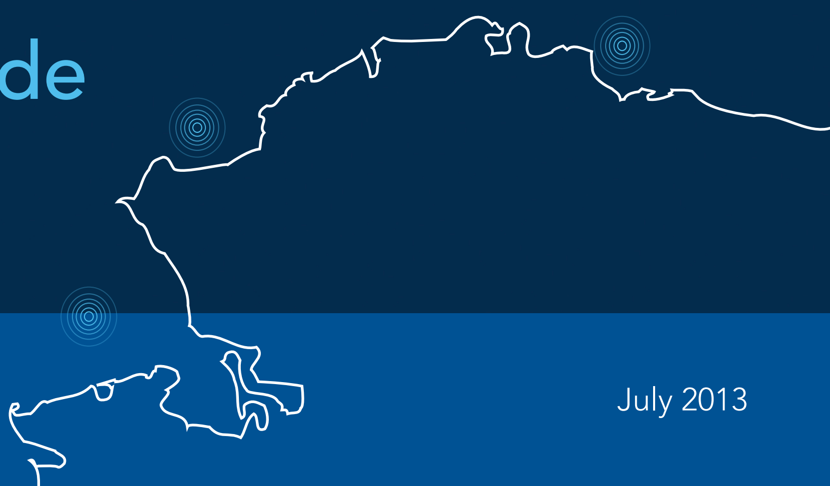
Anthropogenic Sound and Marine Mammals in the Arctic

Increases in Man-Made Noises Pose New Challenges



Prepared by Kate Stafford
for The Pew Charitable Trusts

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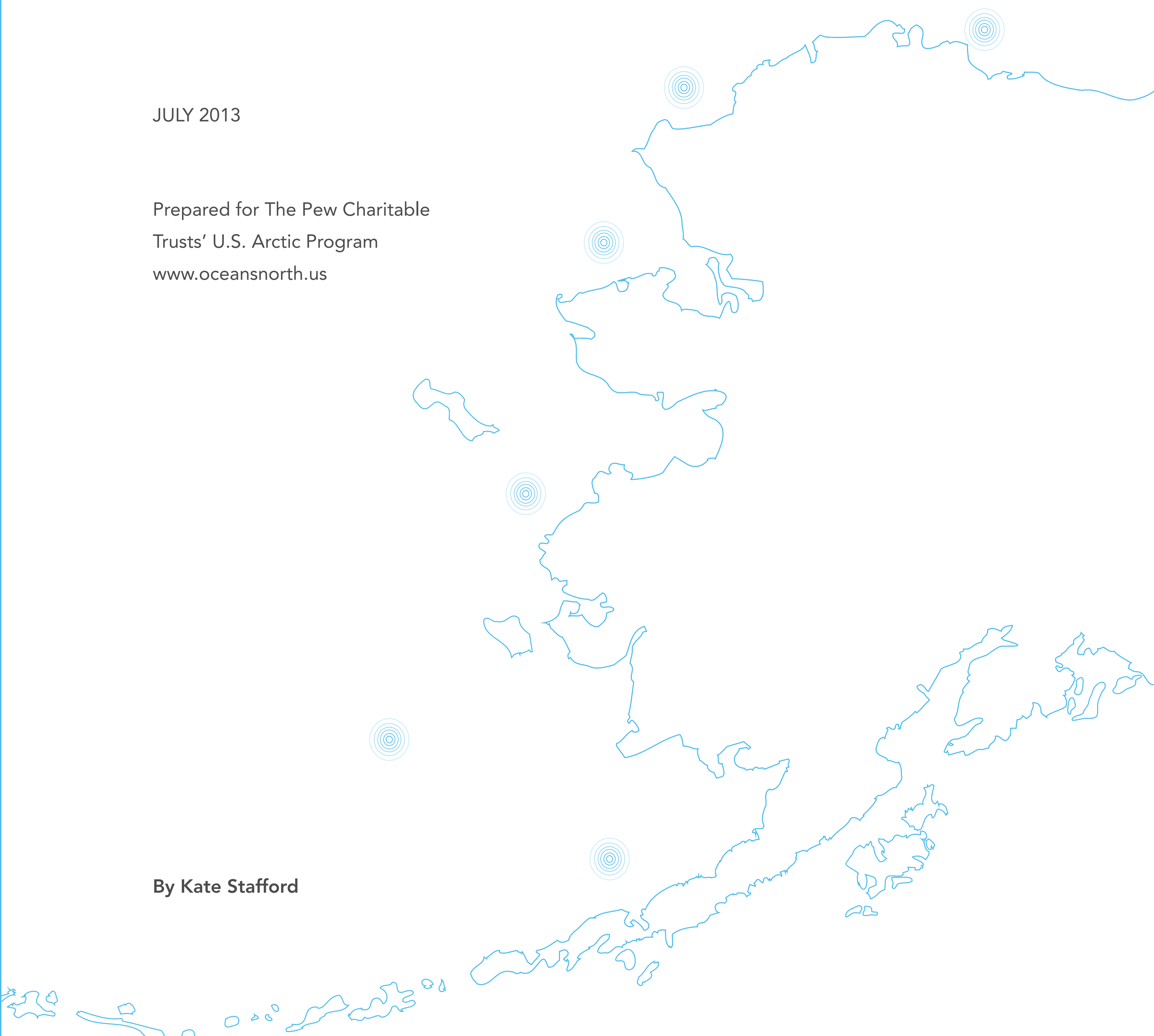

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Overview

Marine mammals, including those found in the Arctic, depend more on their hearing than other senses because sound travels well underwater. Bowhead whales; walrus; ringed, ribbon, and bearded seals; and other marine mammals rely on the sounds they make and hear to navigate, contact one another, court potential mates, find food, and avoid predators. The Arctic soundscape has long been shaped by their clicks and calls, as well as by wind, waves, and sea ice.

Today, the rapid loss of summer sea ice is opening this once largely inaccessible region to ship traffic, oil exploration, and other industrial activities. These changes mean the Arctic Ocean is becoming noisier—and that could have a profound impact on animals that rely on sound to survive.

This science brief looks at how anthropogenic, or man-made, sounds from ship engines, seismic surveys, and drilling machinery overlap with and may interfere with sounds produced and received by marine mammals. Studies show that whales, for example, respond to anthropogenic noise by leaving the area, reducing respiration or surface time, and decreasing calls to other whales. A study of northern right whales suggests they may be chronically stressed from high levels of sounds from ships. Additionally, collisions between animals and ships may result if the former are unable to locate and avoid the vessels because of masking, or interference, created by the sounds of the ships.

Commercial development is a relatively new phenomenon in the Arctic, so many questions about the impacts of noise, particularly anthropogenic, on its marine ecosystem are still unanswered. Future research should be conducted and monitoring should be designed to assess the sensitivity of marine mammals to noise and to determine what can be done to reduce or mitigate the potential impact of anthropogenic noise.

Why is sound important to Arctic marine mammals?

Hearing is the most important sense for marine mammals. Light and scents do not travel far in the ocean and are useful only over short distances. Sound, meanwhile, travels extremely well underwater and can be heard for many miles by marine mammals. Both producing and hearing sounds are important to their survival.

In the Arctic, beluga whales and narwhals use echolocation clicks as sonar systems (similar

Key terms*

Anthropogenic	Man-made.
Attenuation	The decrease in loudness or intensity of a sound.
Decibel (dB):	The unit used to measure how loud something is relative to a reference level of sound.
Echolocation	A means of locating something by listening for the echo of a sound off that item. Bats and dolphins use echolocation to detect and find prey and to navigate.
Frequency	The number of cycles of a sound wave per second measured in units of hertz, or Hz. A signal with few cycles per second is low frequency, and a signal with many cycles per second is higher frequency. Frequency might also be described as the pitch of a sound.
Masking	Interference from sound sources that reduces the ability to detect or locate sounds of interest.
Mitigation	The attempt to reduce or eliminate the effects of anthropogenic sound on marine mammals.

* An excellent resource for further information is the University of Rhode Island's website, Discovery of Sound in the Sea at www.dosits.org.

to bats) to find food and navigate through their environment. Bowhead whales produce simple sounds to maintain contact with one another as they migrate in ice-covered waters. Ice seals, walrus, and bowhead whales produce elaborate acoustic mating displays that are likely vital to reproductive success. Marine mammals also listen for acoustic cues within their environment, including those produced by predators. They do all of this amid ambient (background) sound levels that come from natural (environmental) and anthropogenic sources.

Sounds are classified by their frequency (or pitch). Humans can hear sounds from about 20 hertz, or Hz, to 20,000 Hz. Signals closer to 20 Hz, such as notes from an upright bass, are considered low frequency, while those closer to 20,000 Hz, such as notes from a piccolo, are high frequency. Human speaking voices produce sounds around 3,000 Hz, considered midfrequency.

As a group, marine mammals hear and produce sounds over a broader range of frequencies than do humans, with each species generally using quasi-specific frequency bands to communicate. For instance, bowhead whales produce sounds that are relatively low frequency (usually less than 1,000 Hz), bearded seals use midfrequencies (500 to 6,000 Hz), and beluga whales produce sounds in high frequencies (from a few thousand hertz to more than 100,000 Hz).

In the Arctic, the main sources of naturally occurring sounds include waves, winds, sea ice, and marine mammals.

Natural soundscape in the Arctic

In the Arctic, the main sources of naturally occurring sounds include waves, winds, sea ice, and marine mammals. There is a direct correlation between increasing wind speeds and increasing ambient sound levels over open water.[1] Sound levels tend to be higher for the same wind speed in shallow waters, such as those found in much of the nearshore Arctic, than in deep waters.[2] Although the ice-covered Arctic can experience very low ambient sound levels due to the lack of wind-driven waves, the dynamics of sea ice, including ice formation and deformation, pressure ridging, and cracking, can greatly increase ambient sound levels over a broad range of frequencies.[3]

Lastly, marine mammals, particularly during the spring when many species produce elaborate vocal displays as part of mating behavior, can create such a chorus of sounds that it can be difficult for human listeners to distinguish individual animals or even species. This is a time of year when it may be especially important for animals to communicate with each other and when they may be most sensitive to increases in background sound.

When does sound become noise?

Determining whether and how increases in ambient sound affect marine mammals and the severity of such impacts is extremely difficult.[4] This is due, in part, to an incomplete understanding of marine mammal behavior. Adding to this difficulty is the lack of means or standardized methodologies to measure the effects of sound on animals.[5]

When considering the potential for consequences of noise on marine species, both the frequency and amplitude (loudness)[6] of sound waves need to be considered. Sounds in the same range as those produced or heard by animals are considered more likely to affect them than sounds outside of their hearing range. This is because those sounds within the same range can interfere with signals that are important to animals, making it harder for them to hear each other or detect acoustic cues in the environment.

Loudness affects both how far away sound can be detected and whether it may cause temporary or longer-term hearing loss. Humans at a loud rock concert, for instance, may find standing next to a speaker to be almost painful or they may later experience ringing in their ears because the received level of sound is very high and within the frequency range at which human ears are most sensitive. The sound pressure levels exerted on the ear are directly proportional to the distance one is from the sound source. Sound travels much farther in water than in air, and low-frequency sounds travel farther than higher frequency sounds. Therefore, the area of possible impact for low sounds can be very large.

Determining just how far a sound can be heard underwater and cause a reaction in marine mammals is very difficult, in part because researchers have an incomplete understanding of the hearing response of many marine mammals, particularly large whales. Determining whether they can hear certain signals, and how loud they have to be to be heard, is often based on the frequency range of signals they produce, their cochlear structure, and equivalent information from land-based mammals. Because seals and small whales such as belugas have been kept in captivity, we have a better understanding of their hearing abilities.

Many marine mammal species spend more than 90 percent of their time underwater.

A second obstacle in documenting the impact of a sound on marine mammals stems from our inability to detect changes in behavior. Because sound travels much farther underwater than what we can measure in the air, visual observations from vessels may miss the potential effects on distant animals. Many marine mammal species spend more than 90 percent of their time underwater. That makes it difficult to document their responses to sounds that occur below the surface.

Finally, we still know very little about the ecology and behavior of most marine mammals. Unless an animal washes up on a beach with obvious signs of acoustic trauma, it is difficult to determine how exposure to underwater sounds affects marine mammals on an individual or population level.

What are the sources of anthropogenic sound in the Arctic?

Sources of man-made sounds include seismic exploration using air guns for oil and gas and seafloor mapping, resource extraction (drilling), and ships, including small boats and larger tourism and commercial vessels. Most of these man-made sources of noise are relatively low frequency.

In the Arctic, these sounds overlap with many of the sounds produced and received by bowhead whales, walrus, and ringed, ribbon, and bearded seals. Signals that overlap in frequency and amplitude with animal vocalizations are more likely to interfere with the animals' ability to hear sounds important to them. Low-frequency sounds are more likely to be problematic for bowhead whales, mid frequencies for bearded seals, and high frequencies for beluga whales.

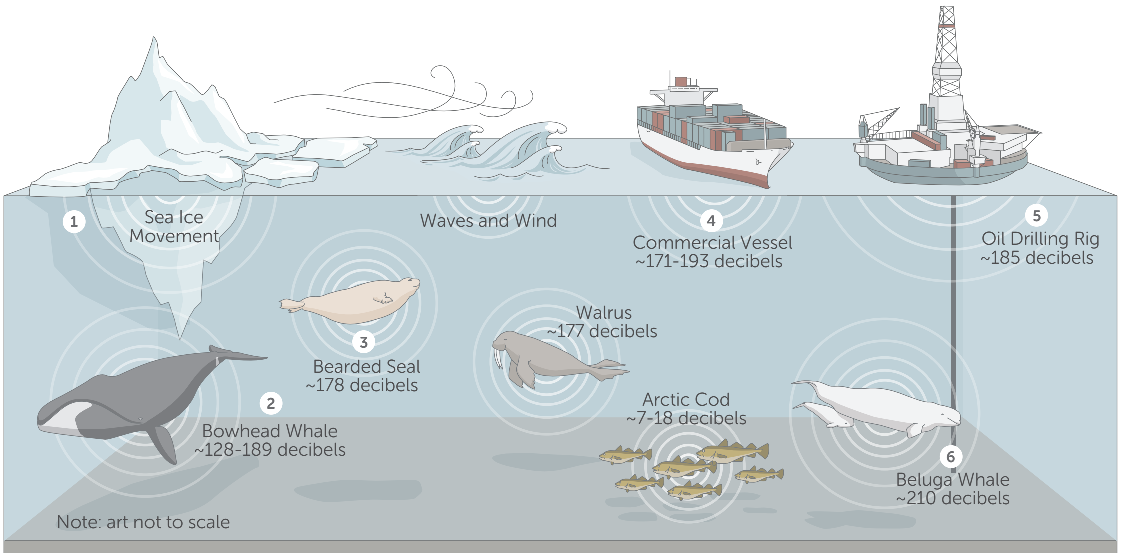
Sources of man–made sounds include seismic exploration using air guns for oil and gas and seafloor mapping, resource extraction (drilling), and ships, including small boats and larger tourism and commercial vessels.

Air gun signals are low-frequency, impulsive sounds created by using compressed air to form bubbles. The formation of these bubbles creates loud sounds that penetrate the seafloor. The information from the return (via reflection and refraction) of the pulses is used to map the seafloor and profile the seabed to depths that may exceed 10 kilometers (6.2 miles). Pulses are generally produced from 10 to 40 seconds apart during surveys that last from hours to days. These signals can be detected over 1,000 kilometers (621 miles) away from the source[7] and elevate noise levels even between pulses due to reverberation.[8] (See Figure 1.)

Drill ships are used by the oil and gas industry to explore areas that have been identified by air gun surveys as potentially rich in hydrocarbons. The signals from the rotating machinery used in drilling are generally low frequency (less than 1,000 Hz). These ships are seasonal, floating, oil-and-gas drilling structures deployed in the Arctic during the open water season (when northern oceans are largely free of sea ice). They return to port when sea ice begins to form in the fall. Because these ships operate around-the-clock, the sounds they produce are continuous and mostly stationary throughout the drilling season. Numerous supply and support vessels tend

Figure 1: The Changing Arctic Soundscape

Vessel traffic, drilling, and other industrial activities are producing new ambient sound in the Arctic.



1. The movement of sea ice—including ice formation and deformation, pressure ridging, and cracking—is one of the main sources of naturally occurring sounds in the Arctic.

2. Bowhead whales produce a variety of low-frequency sounds, including songs. The whales also produce simpler grunts to maintain contact with one another as they migrate in ice-covered waters.

3. Male bearded seals emit long, birdlike trills. These vocalizations are believed to advertise their breeding readiness to nearby females.

4. Icebreakers, research vessels, cargo ships, tankers, and tug and tow vessels produce continuous low-frequency noise, primarily through the movement of their propellers.

5. Oil drilling rigs operate around the clock, producing continuous low-frequency sounds. The numerous support vessels that tend to the rigs result in additional mobile noise sources and are often louder than the rigs themselves.

6. Beluga whales, like bats, use echolocation clicks to find food and to navigate.

In the Arctic, the main sources of naturally occurring sounds include waves, wind, sea ice, and marine mammals. As the rapid loss of summer sea ice opens the Arctic Ocean to industrial activities, this once largely inaccessible region is becoming noisier—and that could have profound impacts on animals that rely on sound to survive. *All decibels are re 1 μPa at 1 meter and are approximations.*

Illustration by The Pew Charitable Trusts

Sources:

Cummings, W.C., et al. *Technical Feasibility of Passive Acoustic Location of Bowhead Whales in Population Studies Off Point Barrow, Alaska: A Report to the North Slope Borough*. Also submitted as a paper to the Scientific Committee of the International Whaling Commission SC/35/Ps19 (1983): 9.

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the drill ships throughout the open water season, resulting in associated sound sources that are mobile and often louder than sounds from the drill ship.

Ship traffic from icebreakers, research vessels, cargo ships, tankers, and tug and tow vessels is increasing in the Arctic. Large vessels produce continuous low-frequency noise (less than 1,000 Hz) primarily from the rotation of their propellers.[9] In addition, local communities have long used small boats to hunt, fish, and move about in coastal and nearshore areas. These smaller vessels are usually equipped with outboard motors that produce higher-frequency noise than large ships.[10]

Ship traffic from icebreakers, research vessels, cargo ships, tankers, and tug and tow vessels is increasing in the Arctic.

All of these anthropogenic sources of sound are active primarily during summer and autumn when the Arctic is nearly free of sea ice. But exposure to these sounds is likely to increase over time as Arctic ice cover decreases. More vessels will be traveling in Arctic waters and will be operating for longer periods.[11] The exceptions to this are icebreakers and permanent drilling sites, such as the man-made Northstar Island that supports the Northstar drilling rig in the eastern Beaufort Sea, that operate even during heavy ice conditions.

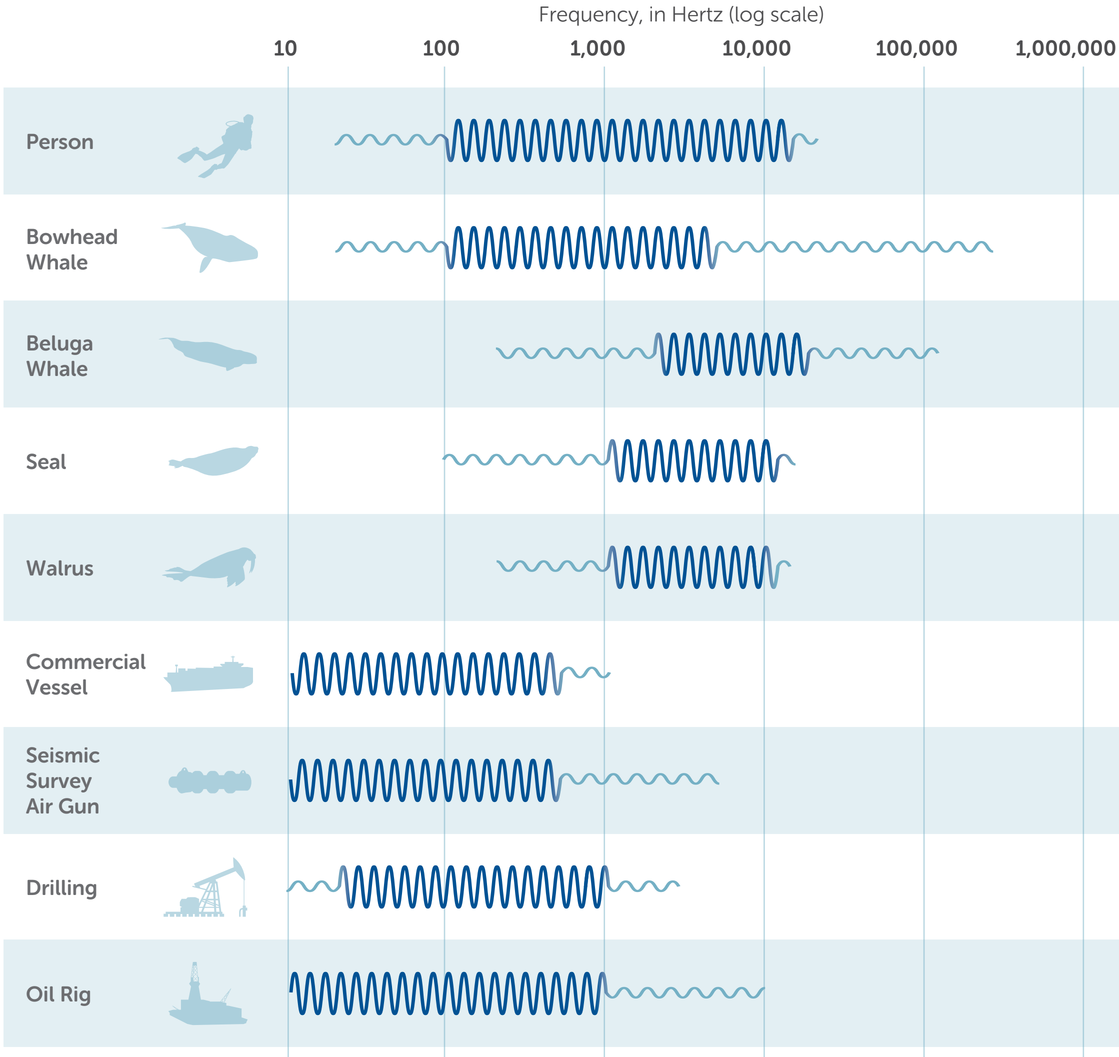
How does anthropogenic noise affect Arctic marine mammals?

Studies looking at changes in acoustic behavior of marine mammals and changes in environmental ambient sound levels typically rely on visual observations. But visual observations are limited to animals at the surface or within visual range, and to a limited number of behavioral cues, such as changes in swim speed or direction or changes in respiration rate.

The impact of seismic air gun pulses from oil exploration on bowhead whales has been the subject of numerous studies since the mid-1980s. Among the responses detected are the species leaving the area of seismic operations, reduced respiration or time at surface,[12] and a decrease in calling to other whales.[13] Studies of beluga whales have shown they are often deflected by icebreaker noise,[14] leaving an area with active icebreaking and remaining away for as long as two days.[15] For other Arctic marine mammals, such as ice seals, there are few studies on how underwater sound affects them.

Figure 2: Frequency Ranges of Marine Mammals and Industrial Activities

Man-made noise can overlap with and potentially mask the sounds animals use to communicate.



Rows represent the range of frequencies most commonly made and heard by animals and sounds made by human activities. The lines show the minimum and maximum range produced. For all species except bowhead whales, data on hearing come from audiograms. For bowhead whales, the hearing range is estimated from the shape of the inner ear.

Source:
D.K. Mellinger et al., "An Overview of Fixed Passive Acoustic Observation Methods for Cetaceans," *Oceanography* 20 (4) (2007): 37-45.

Though commercial shipping in the Arctic is a relatively new phenomenon, studies of marine mammals in other oceans have shown that during ship passages, the communication range of both baleen and some toothed whales is greatly reduced. And a recent study of northern right whales—a close relative of the bowhead whale—found that the sharp decrease in low-frequency underwater sound due to the near cessation of ship traffic immediately after 9/11 was significantly correlated with a reduction in stress hormones in the whales.[16] These data suggest that northern right whales, at least, may be chronically stressed from high levels of ship sound.

The response of an animal to sound is likely influenced by behavioral state, age, experience, individual hearing sensitivity, and sound tolerance,[17] as well as signal type.[18] For instance, resting and migrating whales are more likely to respond to sound than are those engaged in social or feeding activities.[19]

Animals also may respond more strongly to a sudden increase in sound versus a gradual increase. Because of these uncertainties, it is unknown if sound disturbances have long-lasting negative or population-scale consequences on marine mammals, and this will be difficult to determine definitively. The reverse of this is also true: It remains equally difficult to demonstrate that these kinds of negative effects are not occurring. What is certain is that the underwater soundscape of the Arctic will grow louder for longer periods of time as the open water season increases and more ships ply these waters.

Collisions may result from marine mammals, most likely whales, being unable to locate and avoid ships because ships emit sounds over a wide range of frequencies and in all directions.

Additionally, collisions may result from marine mammals, most likely whales, being unable to locate and avoid ships because ships emit sounds over a wide range of frequencies and in all directions.[20] At present only about 1 percent of bowhead whales show evidence of scarring from collisions with ships,[21] compared with about 7 percent of living North Atlantic right whales. Nearly 50 percent of recently documented mortalities for the latter species, whose habitat is exposed to higher levels of vessel traffic than that occurring in the Arctic Ocean, have been attributed to ship strikes.[22] As shipping and vessel traffic in the U.S. Arctic Ocean is projected to increase noticeably, scientists will watch to see if evidence of strikes also increases.

Finally, Arctic marine mammals are migratory and long-lived. They may, therefore, be exposed to multiple sources of sound in an area during a season, over a year, and over a lifetime. Each single ship passage or seismic survey may have an impact on an animal, but the impact of all of these sources together—their cumulative impact—may be of greater concern.

How can the impact of sound on Arctic marine mammals be reduced?

Given the inevitability of increasing anthropogenic sound in the Arctic, what can be done to reduce or mitigate the potential impact of man-made sound on marine mammals?

Mitigation measures for both offshore oil and gas activities and shipping could include closing areas at specific times as well as permanent closures in areas with the highest ecological value or where species are most vulnerable.

For the offshore oil and gas industry, reduction and mitigation efforts can include a cessation of seismic and development activities during known periods when high concentrations of marine mammals are likely to be present. Another option would be to impose a sound "budget" to limit the amount of sound from industrial activities that can be conducted at one time. Mitigation also could include modifying or shutting down a sound when marine mammals are detected within a specified "zone of influence" or slowly increasing the volume of the sound source to provide animals the opportunity to leave the area before the loudest noises begin.

With regard to seismic air gun surveys, new mapping technologies may be available soon but are still considered unproved or too costly to replace air gun surveys. These technologies include marine vibroseis,[23] which limits sound energy at frequencies above 100 Hz;[24] the use of ambient sound sources such as wind, waves, and microearthquakes to image the subseafloor;[25] or the use of bubble net curtains or other damping devices around air gun arrays to limit the horizontal transmission of sound. These technologies need to be investigated further, and exploration companies should be encouraged to continue developing means of reducing or quieting air guns in the Arctic. Reducing the number of simultaneous surveys or repeat surveys also will help to limit anthropogenic sound.

Mitigation efforts for the shipping industry and vessel traffic in general can include imposing speed limits, developing a standard for measuring radiated sound from vessels, and implementing quieting technologies on vessels to reduce sound in the environment. Although it would require considerable international cooperation, agreement on the location of shipping lanes and timing of transit could reduce ship strikes of marine mammals.

For instance, during their fall migration, the majority of western Arctic bowhead whales head south along the western side of Bering Strait in Russian territorial waters.[26] Moving southbound shipping lanes to the eastern side of the strait in U.S. waters may be one way to reduce ship strike mortality for this population. Reducing shipping or moving shipping lanes and improving tracking of ships in the Arctic through the Automatic Identification System should permit a better understanding and reduction of the total amount of sound[27] during important life history events, such as calving, mating, and feeding, or Alaska Native subsistence activities, such as coastal whaling.

Mitigation measures for both offshore oil and gas activities and shipping could include closing areas at specific times as well as permanently closing in areas with the highest ecological value or where species are most vulnerable. To minimize any impact from industry-related activities, it is essential to first identify areas and times of year when marine animals may be most affected by increases in anthropogenic sound.

More research needed to understand impacts of noise on Arctic marine mammals

Many questions about Arctic marine mammals and the impacts of sound, particularly anthropogenic sound, in their ecosystem remain unanswered. Future research should be conducted and monitoring should be designed to better understand the sensitivity of marine mammals to noise. Future research might seek answers to the following questions:

- What is the best way to document the response of Arctic marine mammals to sound?
- In what areas and during what times of year are marine mammals most affected by anthropogenic increases in sound?
- What are the cumulative effects of increases in ambient sound levels for Arctic marine mammals?
- What effect does the decrease in seasonal ice cover have on ambient noise levels?
- Are there differences in responses to sound or its impacts on marine mammals specific to species, age, sex, or season?

- What are the most effective mitigation strategies for reducing potential impacts?
- What evidence is there of marine mammals being struck by vessels?
- What cumulative effect has noise in the marine ecosystem had on the ability of Alaska Natives to successfully pursue subsistence practices?

About the author

Dr. Kate Stafford is a principal oceanographer at the Applied Physics Laboratory at the University of Washington in Seattle. Using passive acoustics and other techniques, Stafford has been studying the sounds of whales for more than a decade. Her focus has been primarily on baleen whales in the North Pacific, but she has worked in, or with data from, all the world's oceans.

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6. The loudness of a sound is measured in decibels, or dB. Decibel levels describe how loud a sound is relative to some reference (represented in units of amplitude called micro-pascals, or μPa). For instance, in air, measurements are referenced to 20 micro-pascals (μPa). In water, a different reference is used: 1 μPa. As such, dB levels are always reported as "dB re 1 μPa" for a sound in water or "dB re 20 μPa" for a sound in the air. The difference in reference levels used, combined with the difference between the density of air and water (the latter being more dense), means that the volume in dB of a sound transmitted through air cannot be directly compared to its volume in water. A signal that is reported as 100 dB re 1 μPa in water would be roughly equivalent to an in-air signal that is 37 dB re 20 μPa. Similarly, for an underwater signal to be as loud as a jet plane (140 dB re 20 μPa), it would have to be greater than 200 dB re 1 μPa in water. The simplest way to think of these differences is to consider an example potentially encountered every day. If the weatherman reports that the daily high temperature is going to be 40°, someone in California might bundle up for the day because their "reference" temperature is Fahrenheit (°F), while someone in Australia might head for the beach because their reference temperature is Celsius (°C, 40° C = 104° F).

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