Chapter 6

Disturbances Subsection

In *The Challenge of Arctic Shipping*, Smiley (1990) stated "Simply put, year-round vessel traffic in the Arctic will affect marine mammals in three ways: collisions, interference, and contamination." Nearly twenty years later, these pertinent issues still remain at the forefront of concern under the AMSA. With contamination (i.e., exposure to oil spill) being previously addressed in this chapter, the other two issues mentioned by Smiley (1990), along with additional potential disturbances, will be addressed in this section.

Noise Disturbances[1]

The underwater acoustic environment is inherently complex and sometimes relatively noisy as a result of a myriad of natural and anthropogenic sound sources. Some of the natural signals are biological (*e.g.*, fish, marine mammals, some invertebrates) whereas others are environmental (*e.g.*, waves, earthquakes). Among the anthropogenic sources, many produce noise either as a by-product of their normal operations (*e.g.*, shipping) or intentionally for particular purpose (*e.g.*, hydroacoustic devices and airguns). Substantial measurements have been made of many of these sound sources and their relative occurrence in the marine environment, although generally speaking this remains an area of considerable uncertainty, particularly regarding disturbance and other impacts.

For most marine vertebrates, making, hearing, and processing sounds of various types serve critical biological functions, including communication, foraging, navigation, and predator-avoidance (*e.g.*, Richardson *et al.*, 1995a; Tyack, 1998; Wartzok & Ketten, 1999; NRC 2003; 2005; Southall *et al.*, 2007). Specifically, the toothed whales have developed sophisticated biosonar capabilities to feed and navigate (see Au, 1993), the large baleen whales have developed long-range communication systems using sound in reproductive and social interaction (*e.g.*, Clark, 1990; Popper and Edds-Walton, 1997), the pinnipeds make and listen to sounds for critical communicative functions (Schusterman, 1981; Schusterman *et al*., 2000), and many fish utilize sounds in mating and other social interactions (Kaatz, 2002).

The introduction of noise into the environment can adversely affect the ability of marine life to use sound in various ways, inducing: alteration of behavior; reduction of communication ranges for social interactions, foraging, and predator avoidance; temporary or permanent compromise of the auditory or other systems; and/or, in extreme cases, habitat avoidance or even death (*e.g.*, Richardson *et al*., 1995a; NRC 2003, 2005; Clark and Ellison, 2004; Nowacek *et al.*, 2007; Southall *et al*., 2007). Noise may also affect behavior of animals and can also affect physiological functions and cause more generalized stress. Additionally, the impacts of noise may be additive or synergistic to

[1] Note all decibel (dB) levels associated with underwater sound sources, in this section, are presented as root-mean-square (rms) pressure levels referenced to 1 microPascal (μPa), unless otherwise indicated. Also note that when a sound level is presented as a source level, this indicates that this is the level measured 1 meter from the sound source (i.e., opposed to a received level, which is the level at the organism of interest).

those of other human stressors (*e.g.*, Evans, 2002). Determining when impacts of noise exposure, from any source, become biologically significant (*i.e.*, population- or ecosystem-level impacts) to a species is often difficult, especially in terms of behavioral responses (NRC, 2005). Nevertheless, this is an area where additional research is ongoing and needed in key areas (see: Southall *et al.*, 2007, Chapter 5).

Where there is an overlap between potential noise sources and the frequencies of sound used by marine life, there is particular concern as to how these sound sources can potentially interfere with important biological functions. For many of the kinds of potential impact, particularly relating to hearing and the process of "masking" (or noise interference), these effects depend critically on the relative "pitch" (or frequency) relationship between the sounds animals make and/or listen to and the noise source in question. As seen below (Figure 6-1), the predominately low sounds associated with large vessels is more similar to the general hearing sensitivity bandwidths of large whales and many fish species, whereas those of many hydroacoustic devices more closely overlap with the hearing of dolphins and porpoises.

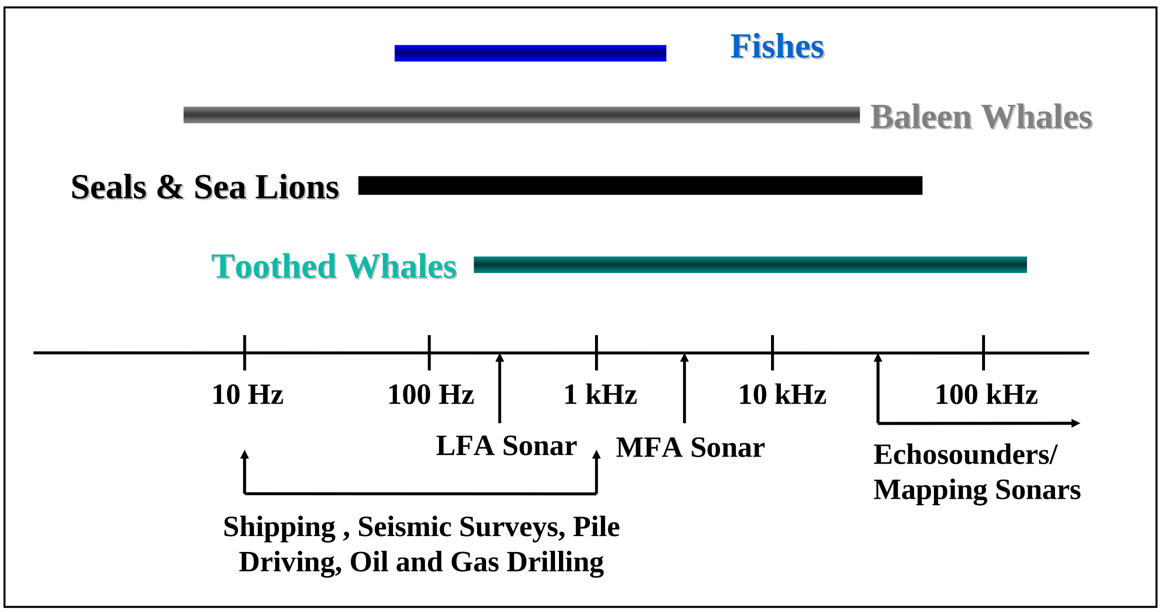

Figure 6-1: Frequency relationship between marine animal underwater hearing and human sources of noise (courtesy B. L. Southall, National Oceanic and Atmospheric Administration).

Arctic Ambient Acoustic Environment

The ambient (background) noise environment in the Arctic is more complex and variable than many other ocean areas due to the seasonal variability in ice cover. Most of the ambient noise levels in the Arctic can be attributed to the movement or cracking of ice, with higher frequency (~1 kHz) sounds being attributed to the cracking of ice (Milne and Ganton, 1964; Lewis and Denner, 1988). Ambient noise levels under ice covered areas are typically very low compared to those near the ice margins (*i.e.*, ice-water boundary), which are typically higher than open ocean levels due to wave and swell interactions (Diachok and Winokur, 1974). Typically, the size and spacing of the ice flows, as well as the sea state, near the ice margins, determine the amount of ambient noise (Uscinski and Wadhams, 1999). In addition to ambient sound associated with ice, many Arctic marine species also vocalize and contribute to background levels (*e.g.*, Stirling *et al.,* 1983; Moore *et al.*, 2006).

Recently, it has been determined that sound propagation loss (*i.e.*, a loss in amplitude) in the Arctic correlates with ice thickness (Gavrilov and Mikhalevskya, 2006). Since ice plays such a clearly critical role in controlling the ambient acoustic environment at some frequencies, it is expected that changes in ice cover from the current condition could impact background sound levels arising from natural processes. With less ice in the Arctic, it has also been predicted that this region will be more susceptible to wind, which will also increase ambient noise levels (*i.e.*, making them more similar to more temperate regions) as a function of natural abiotic processes (USARC, 2001).

Additionally, and perhaps more worrisome, with declines in the amount of sea ice in the Arctic (*i.e.*, more ice-free zones and longer ice-free seasons), there are expected huge increases in commercial traffic and other types of industrialization in the region. While the timing and magnitude of these changes are uncertain, the concomitant vessel traffic and associated activity (*e.g.*, seismic operation, hydroacoustic device usage) brings potential increases in noise in the marine environment and impacts to marine life, both acute from discrete, loud exposure and chronic from sustained presence of certain sound sources.

Vessel Operations

In addition to natural sources contributing to background levels, anthropogenic sources, like vessel traffic, can also have a profound impact on these levels. In most regions in the northern hemisphere, shipping noise is the dominant source of underwater noise below 300 hertz (Hz) (Ross, 1987; 1993). Additionally, small vessels and boats can contribute significant sound energy across a wider frequency band over small to moderate spatial scales (*e.g.*, Kipple and Gabriel, 2003). For some coastal regions that have been somewhat well-studied, low-frequency ambient noise levels have increased over time, very likely as a result of increased vessel operations in these areas (Curtis *et al.*, 1999; Andrew *et al.*, 2002; McDonald *et al.,* 2006).

All vessels produce sound as a by-product of their operation. Typically, vessels produce low frequency sound (i.e., below 1 kilohertz [kHz]) from the operation of machinery onboard, hydrodynamic flow noise around the hull, and from propeller cavitation, which is typically the dominant source of noise (Ross, 1987; 1993). Most sounds associated with vessels are broadband (*i.e.*, contain a broad range of frequencies), though, tones are also associated with the harmonics of the propeller blades (Ross, 1987; 1993). The sound a vessel produces typically relates to many factors, including size, speed, load, condition, age, and engine type (Richardson *et al*., 1995a; Arvenson and Vendittis 2000; NRC 2003). Usually, the larger the vessel or the faster it is moving results in more noise (Richardson *et al.*, 1995a). Depending on the vessel, source levels can range from less than 150 decibels (dB) to over 190 dB (Richardson et al. 1995a; Arvenson and Vendittis 2000).

Impacts from increased vessel operations can have a variety of impacts on the Arctic marine inhabitants. Behavioral reactions, such as avoidance, are some of the most common reactions to vessel noise (*e.g.*, Blane and Jaakson, 1994). Behavioral responses to noise can be complex to interpret and often depend on a variety of factors, including context, the age of the individuals involved, behavioral state, prior experience with the sound sources, distance from the sound source, and characteristics of the sound source, including movement (NRC 2003, 2005; Southall *et al.* 2007). For example, beluga whales (*Delphinapterus leucas*) can exhibit a variety of behaviors when exposed to vessel noise ranging from tolerance to fleeing an area (see Wartzok *et al.*, 2004). Often, behavioral responses, associated with this type of noise exposure, are considered transient. Nevertheless, how repeated short-term behavioral responses translate to cumulative or population-level impacts remains unknown (Bejder *et al.*, 2006; Stockin *et al.*, 2008).

In addition to inducing behavioral reactions, recent data for blue whales (*Balaenoptera musculus*), North Atlantic right whales (*Eubalaena glacialis*), killer whales (*Orcinus orca*), and beluga whales indicate that these species may be adjusting their vocalization (e.g., frequency, call rate, call duration, and loudness) to compensate for masking associated with vessel noise (Lesage *et al.*, 1999; Foote *et al.*, 2004; Schiefele *et al.*, 2005; McDonald *et al.*, 2006; Parks *et al.*, 2007). Additionally a recent studied demonstrated that a Cuvier's beaked whale (*Ziphius cavirostris*) reduced its vocal buzzes during foraging in response to a passing cargo ship (Soto, 2006).

Vessel noise, in addition to potentially impacting marine mammals, produce sounds in the hearing range of fishes (Amoser *et al.*, 2004). Continuous exposure (30 minutes) to boat noise has been shown to increase cortisol levels (stress response) in fishes (Wysocki *et al.*, 2006). Hearing impairment (*i.e.*, temporary threshold shifts [TTS]), associated with long-term, continuous exposure (2 hours), and masked hearing thresholds have also been recorded for fishes exposed to noise from small boats and ferries (Scholik and Yan, 2001; Vasconcelos *et al.*, 2007). Furthermore, vessels (i.e., trawlers, ferries, small boats) can also alter behavior in fishes (e.g., induce avoidance, alter swimming speed and direction, and alter schooling behavior), similar to marine mammals (Engås *et al.*, 1995; Engås *et al.*, 1998; Sarà *et al.*, 2007).

The Scientific Committee on Antarctic Research (SCAR) recently evaluated ship noise in Antarctica and concluded that due to the this being a continuous sound source (as opposed to an pulsed source, like airguns or hydroacoustic devices), it more likely to "interfere with communication" (SCAR, 2006a). Indeed, increased ambient noise levels can have the potential significantly decrease the range over which marine mammals, like baleen whales or fishes, communicate, attract mates, or defend territories (Payne and Webb, 1971; Vasconcelos *et al.*, 2007; Simard *et al.*, 2008; Tyack, 2008). Again, implications of these impacts are not completely understood but are an important consideration for the long-term health and sustainability of the Arctic ecosystem.

Icebreakers

Compared to other vessels, icebreakers produce louder and more variable sounds due to the episodic nature of their normal function (*i.e.*, ram forward into the ice and then move in reverse to begin the process again). The act of physically breaking ice does not produce the majority of noise underwater, instead, as with other vessels, propeller cavitation is the main source of noise (Malme *et al.*, 1989). Icebreakers are capable of producing sounds with higher frequency (> 5 kHz) components than other vessels and are typically much louder going in reverse compared to moving forward (due to cavitation) or when ramming fails (*i.e.*, little forward motion) and the propeller remains turning at full speed (Malme *et al.*, 1989; Cosens and Dueck, 1993; Richardson *et al.*, 1995a; Erbe and Farmer, 1998, 2000). Source levels for icebreakers can range from 174 dB to over 200 dB (Malme *et al.*, 1989; Richardson *et al.*, 1995; Erbe and Farmer, 1998).

Different species have been recorded to behave differently in the presence of icebreakers. For example, beluga whales data indicated (*e.g.*, alarm vocalizations) that they were aware of the icebreaker vessels presence at distances of over 80 kilometers (km) away and exhibited strong avoidance responses at distances 35 to 50 km away, while narwhal whales (*Monodon monoceros*) only displayed subtle response to the same icebreakers (Finley *et al.*, 1990). In another study, Richardson *et al*. (1995b) played bowhead (*Balaena mysticetes*) and beluga whales sounds from an icebreaker during their spring migration. Bowhead whales were tolerant of these sounds until levels were more than 20 dB higher than ambient levels. At that point, it was common for them to divert their migratory course to avoid higher exposure levels. It was predicted that bowhead whales could react in this manner from 10 to 50 km away from an actual icebreaker, which could have biologically significant implications, especially for mothers and calves. For beluga whales, the results were not as dramatic, with only six out of eleven groups altering their migratory path when exposed to these playbacks.

Some icebreakers are also equipped with bubbler systems to aid in clearing ice from the vessel's path that can create an additional noise source (Erbe and Farmer, 1998; 2000). Bubbler system noise is typically highest at frequencies below 5 kHz, with source levels as high as 194 dB (Erbe and Farmer, 1998; 2000). Bubbler systems and cavitation associated with icebreaker movement has the ability to mask auditory ability and potentially vocalization of Arctic inhabitants (Erbe and Farmer, 1998; 2000). Specifically, for belugas it was determined that zone of masking could extend from 14 to 71 km from the source (Erbe and Farmer, 2000). Erbe and Farmer (2000) estimated the zone of behavioral disturbance for icebreakers for beluga whales could be up to 32 km for bubblers and up 46 km for icebreakers. There is an increased possibility of TTS if animals are exposed to these types of sounds for an extended duration (i.e., animals do not or cannot alter behavior to avoid this type of exposure, which they are expected to do in most situations).

Seismic Operations

Pacific Environment Section

Hydroacoustic Devices

The majority of vessels and ships employ some type of hydroacoustic device (*e.g.*, commercial sonar, like bottom profilers, echosounders, side scan sonar, fish finders, etc.) for navigation, depth finding, seafloor mapping, or to detect biologics (e.g., fish, plankton) as a regular part of their operations. These types of devices produce short pulses (milliseconds in duration) and use frequencies ranging from low to high (few hundred Hz to hundreds of kHz), depending on their utility, with many capable at operating at multiple frequencies (Richardson *et al.*, 1995a; Kremser *et al.*, 2005). The majority of hydroacoustic devices operate at frequencies above 10 kHz, with sub-bottom profilers operating below 10 kHz most frequently (Richardson *et al.*, 1995a; ICES, 2005; SCAR, 2006a; 2006b). Most of the sound produced by these types of hydroacoustic devices is focused downward with a very narrow beam of acoustic energy (though some are forward looking). They are most often employed when a boat or vessel is in shallow waters (ICES, 2005). Though, some are capable of operating at full ocean depths (SCAR, 2006b). Some have rather high source levels exceeding 200 dB, with energy outside the main beam being typically at least 20 dB lower (Richardson *et al.*, 1995a; NRC, 2003; Kremser *et al.*, 2005; SCAR, 2006b).

The majority of commercial hydroacoustic devices produce frequencies too high to be audible by the majority of fish species (NRC 2003). Though, some clupeid species of fishes (specifically those in the subfamily Alosinae) have the ability to detect ultrasonic frequencies of sound (*i.e.*, above up to 180 kHz) and could potentially be impacted by these sources (Mann *et al.*, 2001). Due to the potential broad range of frequencies that can be associated with these types of devices, there are a broad range of species that could potentially be impacted.

A recent assessment evaluated the potential for hydroacoustic devices (*i.e.*, multibeam echosounder and sub-bottom profiler) to induce temporary hearing loss (i.e., TTS) (Kremser *et al.*, 2005). It was determined that this is very unlikely, unless the animal travels within close range of these devices while broadcasting. Mitigation measures (*e.g.*, shut down) that detect animals in close proximity are a possible way of minimizing this risk, although detection by some means (*i.e.*, visually or acoustically) can often be a challenge. SCAR also evaluated several hydroacoustic devices and concluded that the likelihood of auditory injury would be low and that minor displacement over short periods (days) may occur in exceptional situations (SCAR 2006b). Watkins *et al*. (1986)

reported sudden behavioral reactions from several large whale species only if echosounder was suddenly started near a whale. If the echosounder was already broadcasting as the vessel approached the whale, it was typically ignored (*i.e.*, whale did not exhibit a negative reaction), which seems to support SCAR's general conclusions. More information exists (see Southall *et al.*, 20007 for a review) on the potential impacts relating to use of military sonar and acoustic harassment or acoustic deterrent devices (AHDs/ADDs), which are similar but not identical to hydroacoustic devices (e.g., tactical sonar often is omnidirectional [that is the sound travels in all directions and is not just directed downward] or forward-looking and source levels are typically higher; AHDs/ADDs are also typically omnidirectional and are designed specifically to repel an animal from a location).

Conclusions

While there is clearly some degree of scientific uncertainty regarding the scope and nature of environmental disturbances arising from vessel operations, seismic surveys, hydroacoustic devices, and other anthropogenic sound sources, some simple conclusions that may be drawn.

- Sound is of vital biological importance to most, if not all, marine vertebrates and anthropogenic noise can have various adverse effects.
- Vessel activities and other industrial sound sources can increase marine ambient noise on both acute and chronic time scales; in some areas there appears to be an ever-louder low-frequency background din associated with increases in commercial shipping.
- The wide-scale introduction of commercial, military, and research activities into Arctic areas and concomitant increases in marine ambient noise are very likely to have impacts on both the acoustic environment and the sound-centric animals living there.
- Impacts from noise will vary by sound source (*e.g.*, vessel operation, icebreaker operations, seismic, and hydroacoustic devices), as well as by species (*i.e.*, different species hear and use sound differently).
- Very few of these effects are expected to include direct physical injuries to hearing or other systems from anthropogenic noise. Rather, there is more concern regarding behavioral disturbance and avoidance of key areas, as well as interference masking of acoustic communication. Cumulative and population- and ecosystem-level impacts of exposure to chronic sources of ambient noise from vessels remain poorly understood but are important considerations.
- Finally, there are existing and emerging technologies appropriate to minimizing the directed or incidental sound output of vessels, seismic survey operations, and active sonars which, as well as carefully-considered operational measures, could minimize radiated noise. However, the respective economic costs and environmental benefits of these measures remain somewhat uncertain.

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