# Shipping Noise and Marine Mammals

A Background Paper Produced by Participants of the
International Workshop on Shipping Noise and Marine Mammals
Held By Okeanos: Foundation for the Sea
Hamburg, Germany, 21st-24th April 2008

*Purpose*

In 2004, the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and a number of other government, industry, and academic partners convened the first formal meeting ("Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology") to consider the effects of sounds from large vessels on marine life (see: www.nmfs.noaa.gov/pr/acoustics/). This meeting was followed by a second NOAA-sponsored and internationally attended symposium held in May 2007, which discussed potential applications of vessel-quieting technologies on large commercial vessels. In April, 2008, Okeanos - Stiftung für das Meer (Foundation for the Sea), a non-profit organization created to protect the ocean and marine life, convened a workshop in Hamburg, Germany, focused on shipping noise and marine mammals. This workshop concentrated on engaging members of the international maritime transport industry, particularly ship builders and architects. Attendees of this workshop created this reference paper to assist in educating stakeholders as to the status of current scientific knowledge on the effects of shipping noise and marine mammals.

## 1. Introduction

It is clear from scientific investigations of marine mammals that the perception and production of sound is critical to various aspects of their life history. Marine mammals use sound as a primary means for underwater communication and sensing (Wartzok & Ketten 1999). Toothed whales have developed sophisticated echolocation systems to sense and track the presence of prey (Au 1993). Baleen whales have developed long-range acoustic (sound-based) communication systems to facilitate mating and social interaction (Clark 1990, Edds-Walton 1997).

It is also evident that human-induced underwater noise can interfere with these functions (U.S. National Research Council – NRC 2003, 2005).[1] Noise may affect marine mammals' ability to detect sounds such as calls of conspecifics (i.e., other animals of the same species), echoes from prey, and natural sounds that aid in navigation or foraging (Clark & Ellison 2004). Noise may also affect physiological functions and cause more generalized stress. The impacts of other human activities may be additive or synergistic with those of noise (e.g., Evans & English 2002).

Commercial ships are a ubiquitous feature of the world's oceans. Analysis of radiated sound from ships (Ross 1976) has revealed that they are the dominant source of underwater noise at frequencies below 300 Hz in many areas (Figure 1). Commercial ships have been increasing in both number and size, and are producing ever-greater amounts of underwater noise as an incidental by-product of their operation.[2] Based on deep-water studies in the Northeastern Pacific (Figure 2), low-frequency background noise has approximately doubled (i.e., an increase in power of 3 dB) in each of the past four decades (i.e., within the lifetimes for many baleen whales) primarily as a result of increased commercial shipping

[1] The NRC reports use the terms noise and sound. Sound is an all-encompassing term referring to any acoustic energy. Noise is a subset of sound, referring to sound unwanted to a particular receiver (i.e., someone who hears it). The opposite of noise is a signal: a sound containing useful or desired information. For this reason, the sound may be a signal to some and noise to others. Use of the term noise presumes nothing about a sound's potential effect (neutral or negative) other than that the sound is not a meaningful signal for a particular receiver. Additionally, "ambient noise" is a standard, scientifically accepted term used to describe "the noise associated with the background din emanating from a myriad of unidentified sources" (NRC 2003).

[2] Incidental refers to the unintended production of sound energy from vessel propulsion systems and internal machinery.

(Andrew *et al*. 2002, McDonald *et al*. 2006). This has resulted in at least a 15-20 dB increase in ambient noise conditions compared to pre-industrial levels. Other studies have characterized the contributions of shipping to low-frequency noise elsewhere in the world with similar results (e.g., Zakarauskas *et al*. 1990, Cato & McCauley 2002). These studies also indicate that ships are the dominant source of noise in most coastal zones in the Northern Hemisphere, areas that are important habitat for many marine mammals (Worley & Walker 1982, Bachman *et al*. 1996, Zakarauskas *et al*. 1990, Heitmeyer *et al*. 2004, Hatch *et al*. in press).

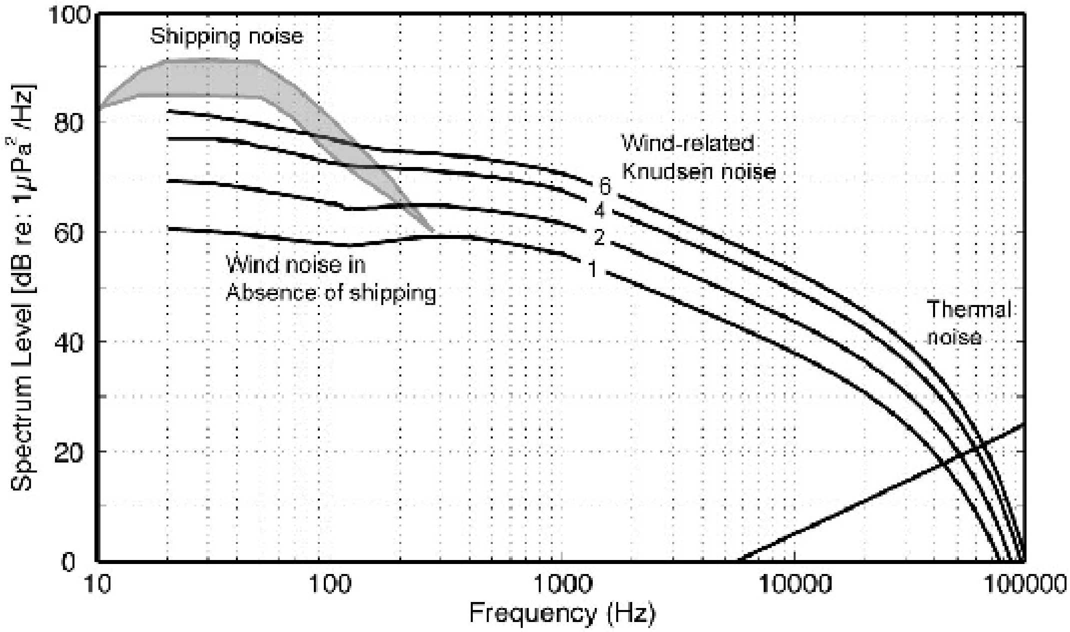



**Figure 1. Ocean ambient noise for frequencies between 10 Hz and 100 kHz. This plot has the same form as the underwater noise curves developed by the U S Navy in the 1960's (Wenz 1962), but it has been modified to reflect modern levels of shipping noise (shaded area), which exceed natural wind-noise, even for high sea-states (numbered curves). Figure courtesy of J. Hildebrand, Scripps Institution of Oceanography/UCSD.**

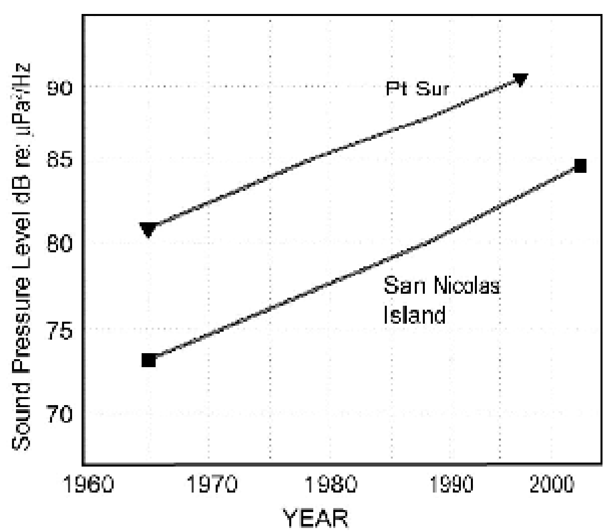



**Figure 2. Ocean ambient noise has been increasing by about 3 dB per decade, docu-mented at two sites off California by comparing U S Navy data from the 1960's (Wenz, 1969) with recent measurements (Andrews** *et al*. **2002, McDonald** *et al*. **2006).**

## 2. Effects of vessel noise on marine mammals

Human-produced sound has the potential to interfere with various important biological functions in marine mammals (Payne & Webb 1971, NRC 2003, 2005). The types and ranges of such impacts are highly dependent on the characteristics of the sound source, the environment in which the sound occurs, and the animal(s) receiving the sounds. Many marine mammals (such as baleen whales, and some seals and sea lions), as well as other marine animals (e.g., many fishes), are particularly vulnerable to impacts from incidental shipping noise because they produce and perceive low-frequency sounds.

Hearing capabilities have been studied for 22 of the approximately 125 species of living marine mammals (reviewed in Southall et al. 2007). Baleen whales are thought to be most sensitive to a range of low-frequency sounds (~ 10 Hz to 1000 Hz). Toothed cetaceans have good hearing sensitivity across a broader range of mid to high frequencies (~ 4 kHz to 100 kHz), but generally have poor hearing at lower frequencies. Seals and sea lions have sensitive hearing across fairly wide frequency bands both in air and water. Manatees and dugongs have a relatively narrower range of hearing sensitivity (~ 5 kHz to 30 kHz).

### *2.1 Effect of Masking by Vessel Noise*

An important effect of increased ambient noise on marine mammals is the potential for that noise to mask biologically significant sounds (i.e., interfere with clear reception of signals of interest). For example, masking can result in disruption of breeding in animals that use sound during mating and reproduction, and disruption of foraging in animals that use sound to detect prey. In addition, noise can mask important acoustic environmental cues that animals use to navigate and/or sense their surroundings, including sounds that are used to detect predators. Most of the acoustic energy radiated from commercial vessels is below 1 kHz; however other sources of sound often dominate ambient noise at frequencies over 300 Hz (Figure 1). The greatest potential for masking exists for groups of marine mammals that produce and perceive sounds at these lower frequencies (Figure 3), such as baleen whales, seals, and sea lions. The potential for masking at higher frequencies (1 – 25 kHz) exists when the vessel is in close proximity to the animal. In these close proximity circumstances other marine mammals, including many toothed cetaceans (beaked whales, sperm whales, dolphins and porpoises) may also experience masking from vessel noise.

There is extensive documentation of how sound can mask marine animal communication systems, including specific examples relating to commercial shipping noise and its impact on marine animals. The ability of noise to mask hearing is a general phenomenon across many mammalian species (see Fay 1988, Ward, 1997). Numerous studies have examined the impacts of masking, and related their findings to concerns regarding low-frequency noise from shipping (e.g., Payne & Webb 1971, Erbe & Farmer 1998, 2000, Southall *et al*. 2000, in press, Erbe 2002, Morisaka *et al*. 2005, Nowacek *et al*. 2007). Recent data on North Pacific blue whales (*Balaenoptera musculus*) and North Atlantic right whales (*Eubalaena glacialis*) indicate that these species adjust their vocalization (frequency and loudness) in the presence of vessel noise (McDonald *et al*. 2006, Parks 2003). A Cuvier's beaked whale (*Ziphius carvirostris*) was found to reduce its production of sounds associated with foraging in response to a passing cargo ship (Aguilar Soto *et al*. 2006).

Although some species may be able to alter their communication signals to avoid being masked by vessel noise, the extent of such alterations is constrained behaviorally, physiologically and environmentally. These alternations also represent sub-optimal behaviors since marine mammal communication systems evolved to maximize the ability for species to recognize biologically meaningful sounds relative to background noise. Therefore, the alterations can be presumed to be costly to survival and/or reproductive success. Marine mammals, which are adapted to perceive and communicate with sounds under preshipping ambient noise conditions, have certainly not had time to adapt to a noisier ocean resulting from the rapid rise in shipping noise (Payne & Webb 1971). Figure 4 shows an example of predicted decreased communication ranges for baleen whales, owing to increases in ambient noise due to shipping.

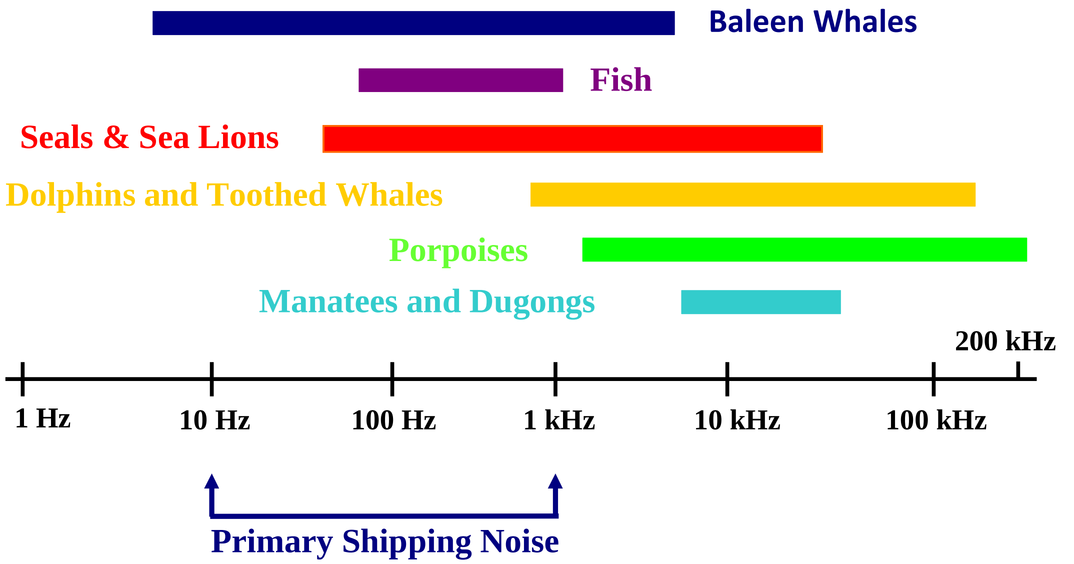



**Figure 3. Frequency Relationships Between Marine Animal Sounds and Sounds from Shipping. Figure courtesy of B. Southall, NMFS/NOAA**

**Figure 4. Estimated reduction in baleen whale communication range from (left) prior to the advent of commercial shipping to (right) the expected ranges of today. Figure courtesy of C. W. Clark, Cornell University.**

### *2.2 Behavioral Effects of Vessel Noise*

Noise has been observed to affect the behavior of marine mammals in ways ranging from subtle to severe (Richardson *et al*. 1995). For example, reactions to noise may range from a shift in orientation toward a sound source, to an escape or flight response. These changes in behavior have direct energetic costs and potential long-term effects on foraging, navigation, and reproductive activities.

Several studies have shown that dolphins and whales exposed to noise from vessel approach may alter their behaviors (Janik & Thompson 1996, Nowacek *et al*. 2001, Williams *et al*. 2002, Hastie *et al*. 2003). Manatees (*Trichechus manatus*) have been shown to respond to approaching vessels by changing their fluke rate, heading, and dive depth, as well as by swimming toward deeper water in an apparent flight response (Nowacek *et al*. 2004). Beluga whales (*Delphinapterus leucas*) are known to take evasive action when exposed to icebreaker noise at distances of 35-50 km (Finley *et al*. 1990, Cosens & Dueck 1993).

In response to vessels, marine mammals may modify or cease producing sounds that they use to communicate, forage, avoid predators, or gain awareness of their environment (Au & Green 2000, Van Parijs & Corkeron 2001). For instance, beluga whales have been observed to reduce their calling rates when vessels are approaching (Lesage *et al*. 1999), and shift the frequency band of their calls (Lesage *et al*. 1999) or increase call source level (Scheifele *et al*. 2005) when vessels are in close proximity. Killer whales (*Orcinus orca*) have been observed to increase the length of their calls in the presence of increased whale-watch boat noise (Foote *et al*. 2004), and bottlenose dolphins (*Tursiops truncatus*) have been reported changing their vocalization rates when exposed to boat noise (Buckstaff 2004).

### *2.3 Physiological Effects of Vessel Noise*

Noise can also result in a range of physiological effects on marine mammals. There are physiological constraints on how well marine mammals can cope with higher noise levels. Reduced overt behavioral response to long-term noise exposure may not be associated with an improvement in physiological (or psychological) state. For example, an animal that has learned to tolerate exposure to a sound in order to feed or reproduce may still incur physiological impacts.

Long-term noise exposure also may cause stress responses in marine mammals, as these responses are thought to be highly consistent across species (Wright et al. in press). It is possible that marine mammals exposed to omnipresent shipping noise suffer from chronic stress responses in a manner similar to humans who live near busy highways or airports (Evans 2001, see references in Wright et al. in press).

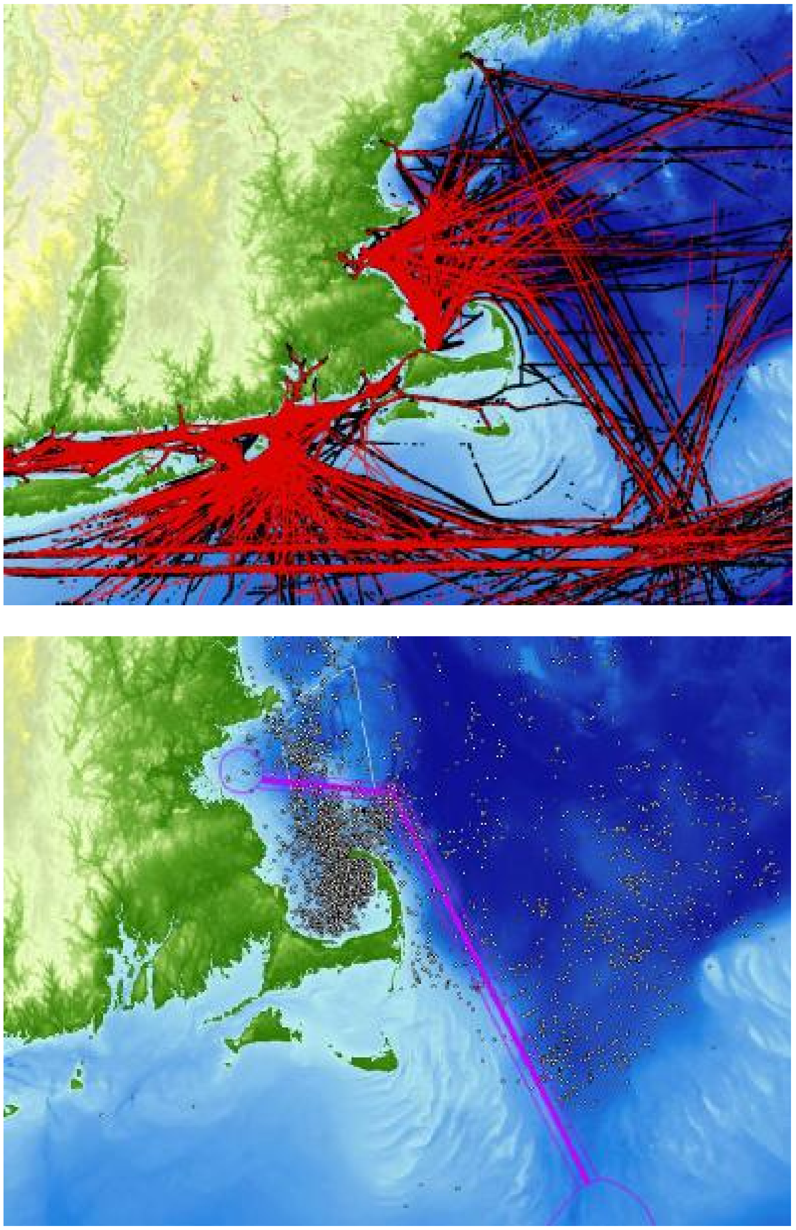
## 3. Spatial and temporal considerations

Commercial vessels are a ubiquitous source of low-frequency (predominately <300 Hz) noise, with potential impacts over ocean-basin spatial scales. In the absence of nearby ships, low-frequency ambient noise is dominated by noise from distant ships. The contribution of shipping to ambient noise is especially high near major ports and heavily travelled shipping lanes. Models for shipping density (Heitmeyer *et al*. 2004) suggest that up to ten ships per degree-square are found at key coastal locations, such as along the US Eastern Seaboard. In contrast, one ship or less per degree-square is typical for most deep-water North Pacific and North Atlantic regions. There is an asymmetry in shipping densities between the Northern Hemisphere and Southern Hemisphere, with greater levels of ship traffic occurring in the north. Greater Northern Hemisphere shipping explains why ambient noise at some sites in the Southern Hemisphere may be 20 dB less than the northern hemisphere average (Cato 1976). High shipping densities in the Mediterranean result in high levels of ambient noise (Ross 2005). Therefore, areas for which marine mammal distributions overlap with high-density shipping are of particular concern. Specifically, shipping lanes and port areas through which marine mammals migrate or in which they congregate to breed, nurse and/or feed are the focus of active research efforts (Hatch *et al*. in press).

Future trends in shipping industry (e.g., the rising use of short-sea shipping and a predicted increase in trans-Arctic traffic with the opening of the Arctic Ocean) are expected to change the distribution of near-field and far-field shipping noise across and between ocean basins (Southall 2005).

## 4. Conclusions

Increasing noise from commercial shipping now dominates underwater ambient noise at frequencies below 300 Hz in many if not most ocean environments, particularly coastal areas with relatively high abundance of marine life. Baleen whales and many other marine mammals perceive and produce sound in the 10-300 Hz frequency range, relying heavily on their hearing and their vocal communication capabilities to survive and to reproduce. Reducing low frequency ambient noise levels would thus benefit many marine mammals, as well as some fish and invertebrate species. A reduction in ambient noise below 300 Hz could be achieved by limiting the amount of sound produced by individual ships in the 10-300 Hz frequency range.



(a)

(b)

**Figure 5. The distribution of (a) two months of large commercial vessel transits and (b) over 20 years of right whale sightings (North Atlantic Right Whale Consortium) off the northeastern coast of the U.S. In (b), the boundary of Stellwagen Bank National Marine Sanctuary, an area heavily utilized by multiple vocally-active and endangered marine mammals as well as soniferous (sound-producing) fish and invertebrates is outlined in white, with the Traffic Separation Scheme accessing the port of Boston outlined in pink. Figure courtesy of SBNMS/NOAA**

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