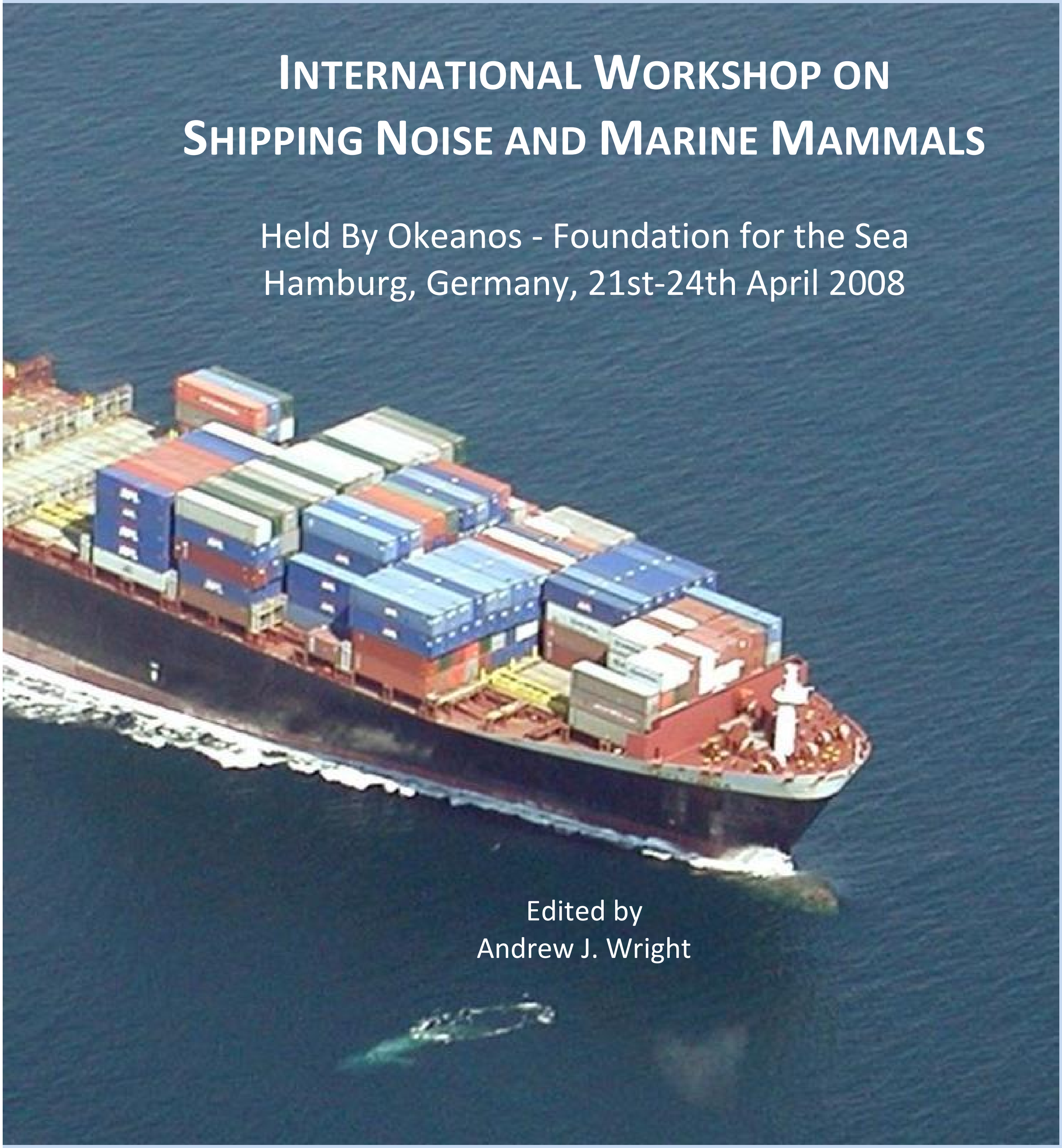
# INTERNATIONAL WORKSHOP ON SHIPPING NOISE AND MARINE MAMMALS

Held By Okeanos - Foundation for the Sea
Hamburg, Germany, 21st-24th April 2008



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Cover photo courtesy of the Channel Islands National Marine Sanctuary, U.S. National Oceanic and Atmospheric Administration.

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# Prologue

By Dieter Paulmann

There are more than 90,000 ships larger than 100 gross tons in the world of very different types. Each is introducing noise into the marine environment. Although not directly lethal, noise from shipping is, in larger and larger portions of the world's oceans, the dominant source of underwater noise at frequencies that are central to the way that marine mammals, as well as many sea turtles, fish and invertebrate species, sense their surroundings and communicate. Research into much of the ultimate impacts of exposure to ship noise on the ability of animals to survive and reproduce, or the consequences for the long-term viability of populations (many of which are already heavily endangered or threatened), is in its infancy. However, enough is currently known to confirm that increased noise levels associated with shipping can interfere with communication, foraging, prey evasion and other important life history functions in marine mammals. It can also disrupt their behaviour and may act synergistically with other human-induced stressors with detrimental effects, as has been studied for humans living near highways and airports or working in noisy environments.

The U.S. National Oceanographic and Atmospheric Administration (NOAA) has held two symposia specifically on the issue of ship-introduced noise, its effects on marine fauna (especially marine mammals) and possible solutions to the problem. The wider issue of the effects of sound on marine mammals has also been discussed in various domestic and international arenas. However, to date several key parties have not been involved (e.g., IMO and ship builders/owners) and thus the format of some discussions has been limited.

To address this limitation, 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 April 2008 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, and had a number of goals:

- To increase the shipping industry's awareness of and sensitivity to the need for the protection of marine mammals and other marine fauna from noise from ship operations.
- To introduce the concept of noise from ship operations as an important issue in ship construction.
- To introduce the concept of noise from ship operations to appropriate national and international regulatory bodies for appropriate consideration.
- To generate material that can be used for many applications, such as to engage the public and gain the interest of public funding sources.
- To build upon the developing knowledge base on the issue with technical discussion of potential solutions.
- To initiate discussion within the industry and related companies about potential solutions for reducing noise, as well as any research required to further such efforts.

Hamburg was seen to be the best location for this as Germany is a globally important supplier of ship equipment and the world's 4th leading shipbuilding nation, with Hamburg a capital of ship owners and operators (representing 36% of the world's containership fleet). Hamburg is also home to Germanischer Lloyd, which classes most of the worlds' containerships.

To facilitate open discussions, most of the presentations were scheduled for the first full day only, with several free-flowing discussions planned for the following two days. The group then proceeded to lay the groundwork for a submission to the International Maritime Organisation's Marine Environmental Protection Committee (IMO's MEPC), which participants agreed to be the appropriate body to consider and manage the issue of noise from shipping. Accordingly, a summary in the form of a Statement of Participants was written by all the participants and subsequently released. Background papers summarising much of the information contain within the presentations were also written by the participants, in the hope that these documents might spur and support a submission by a Member State to the MEPC.

Many articles and books have been written on the subject of the effects of noise on marine mammals, international maritime law, and the various means of reducing the amount of noise introduced into the marine environment by ships. In contrast, the statement and background documents are short, highly focused and written in simple language with a potentially wide, international audience that is generally unfamiliar with these issues. To that end, jargon has been avoided where possible. Similarly, many caveats and much of the fine detail often found in the wider literature have also been left out. They should thus be seen as an introduction to the issue: a place from which an interested party can begin to build their knowledge.

This report combines the above-mentioned documents, of participants and guest presenters and a list of presentations with abstracts.

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# International Workshop on Shipping Noise and Marine Mammals

Held By Okeanos - Foundation for the Sea
Hamburg, Germany, 21st-24th April 2008

## Statement of Participants

A diverse group of stakeholders from around the world was convened with expertise in the areas of underwater acoustics, naval architecture, marine engineering, ship building, marine mammal bioacoustics, marine operations, and noise control, as well as in international maritime and environmental law and policy.

Marine mammals are acoustic specialists and depend on sound for survival (e.g., communicating, navigating, finding food and mates, detecting predators). For example, blue and fin whales produce intense infrasonic songs that can be heard over an entire ocean, while humpback songs can be heard over many hundreds of miles. With the advent of modern shipping, ocean noise in the low-frequency range (10-300 Hz) has been doubling approximately every decade,1 drastically reducing these ranges. Although the long-term impacts on marine mammals from this increased noise are not yet known with certainty, increased noise obscures an animal's ability to hear, and therefore has serious implications for reproduction and survival. This is a global problem.

There is a relationship between commercial shipping and the amount of underwater noise. Given that shipping is increasing and expected to expand into new areas, e.g., the Arctic, incidental noise from shipping will continue to rise.

Unlike chemical pollution, noise does not persist in the environment. Thus, if a source of noise is reduced, the amount of noise energy in the water is immediately lowered. Under these favorable circumstances, the goal is to reduce the amount of incidental underwater noise from shipping to mitigate or eliminate the impacts of noise on marine mammals.

To achieve this goal we call for initial global action that will reduce the contributions of shipping to ambient noise energy in the 10-300 Hz band by 3dB in 10 years and by 10dB in 30 years relative to current levels. This goal would be accomplished by reducing noise contributions from individual ships.

The engineering tools and methodologies currently available are sufficient to reduce radiated noise from ships, or can be developed with limited effort. Some operational measures can be implemented immediately.

The widespread application of technical and operational noise reduction measures applied on an individual ship basis would lead to the 3 dB reduction in ambient noise within a decade and would result in an overall increase in potential communication/hearing ranges for marine mammals. It was clearly recognized that shipping noise is a trans-boundary, international issue. All participants called for the coordination of action at the international level, i.e. by the International Maritime Organization and its members.

[1] In sound level terms, a doubling in the power of sound is measured as 3 dB, while a ten-fold increase is measured as 10 dB.

# 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

[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.

(i.e., within the lifetimes for many baleen whales) primarily as a result of increased commercial shipping (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).

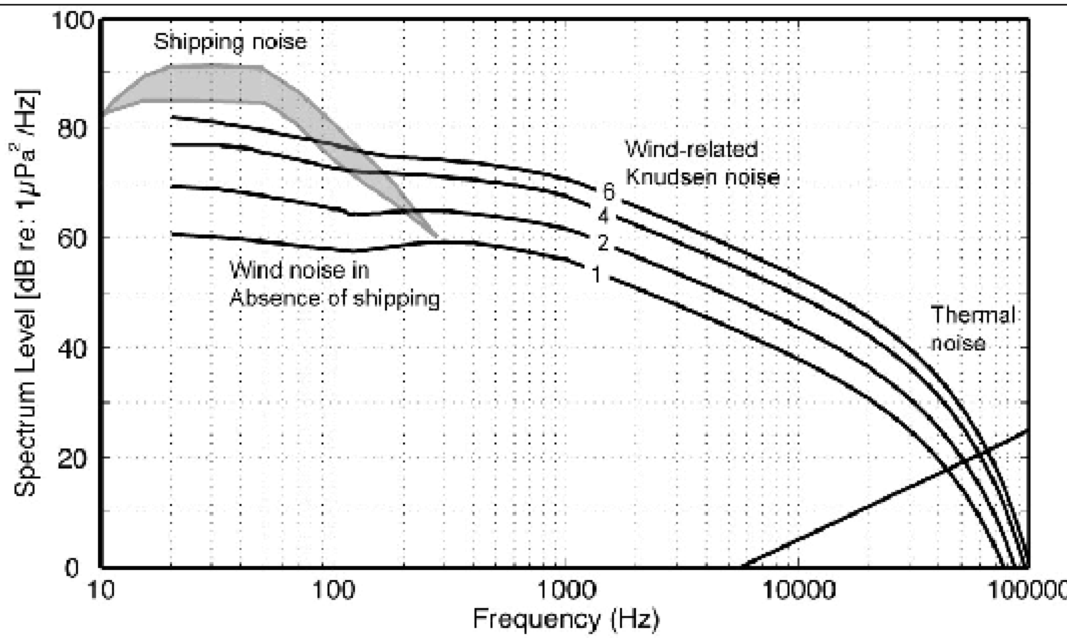


**Figure 1. Ocean ambient noise for frequencies between 10 Hz and 100 kHz. This plot has the same form as the underwater noise curves developed by the U S Navy in the 1960's (Wenz 1962), but it has been modified to reflect modern levels of shipping noise (shaded area), which exceed natural wind-noise,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

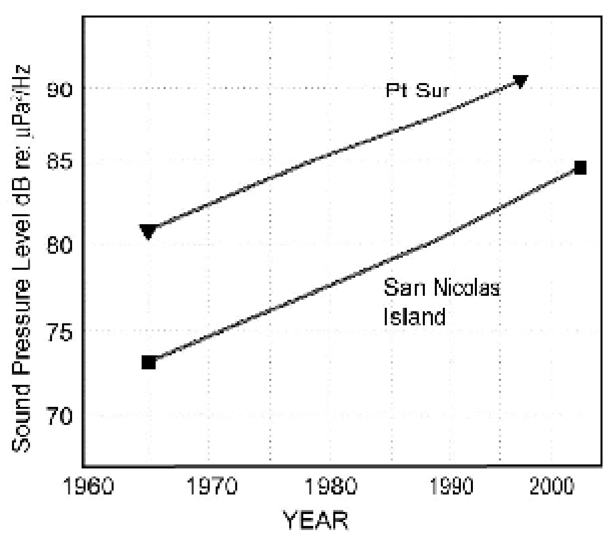


**Figure 2. Ocean ambient noise has been increasing by about 3 dB per decade, docu-mented at two sites off California by comparing U S Navy data from the 1960's (Wenz, 1969) with recent measurements (Andrews** *et al***. 2002, McDonald** *et al***. 2006).**

## 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.

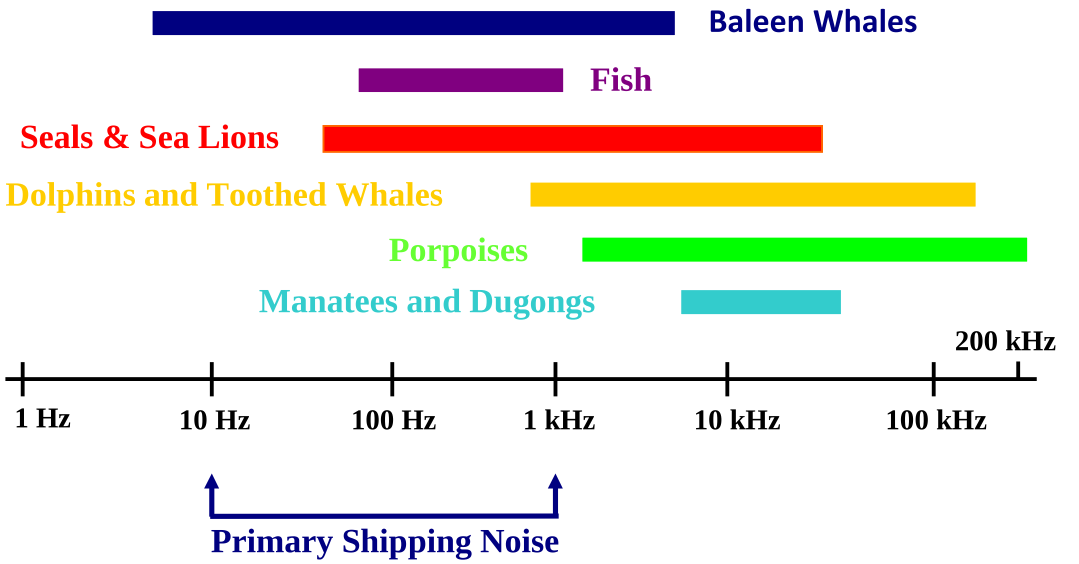


**Figure 3. Frequency Relationships Between Marine Animal Sounds and Sounds from Shipping. Figure courtesy of B. Southall, NMFS/NOAA**

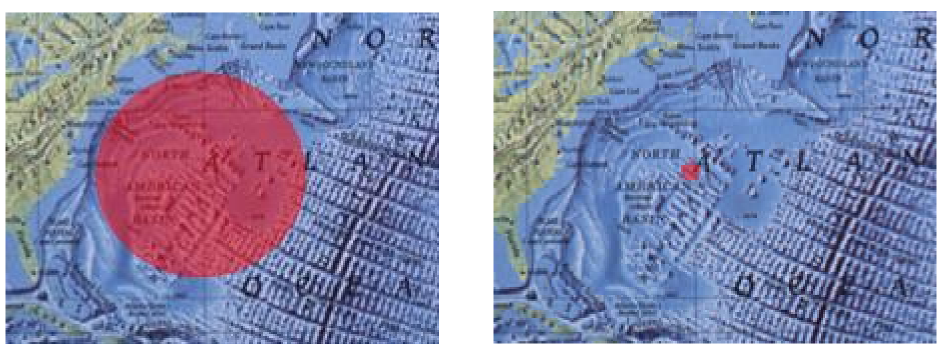

**Figure 4. Estimated reduction in baleen whale communication range from (left) prior to the advent of commercial shipping to (right) the expected ranges of today. Figure courtesy of C. W. Clark, Cornell University.**

### *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

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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).

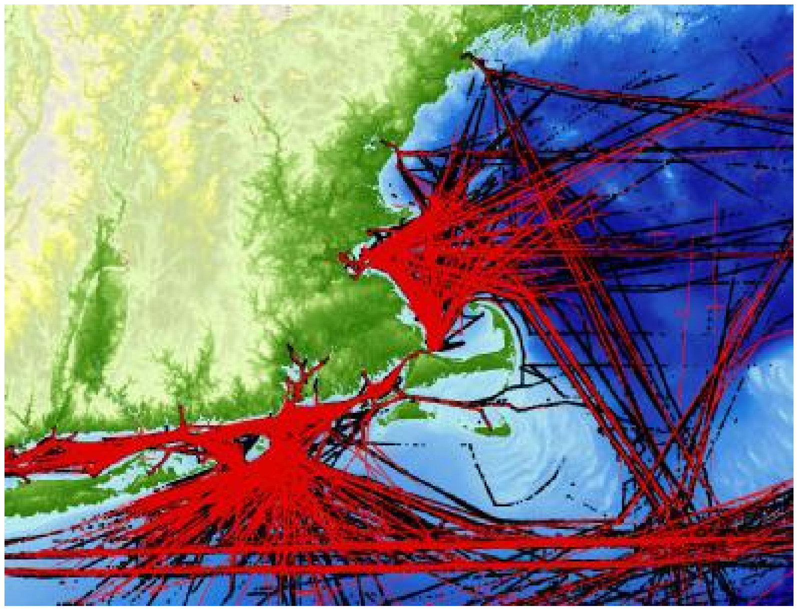
## 3. Spatial and temporal considerations

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 deepwater 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)

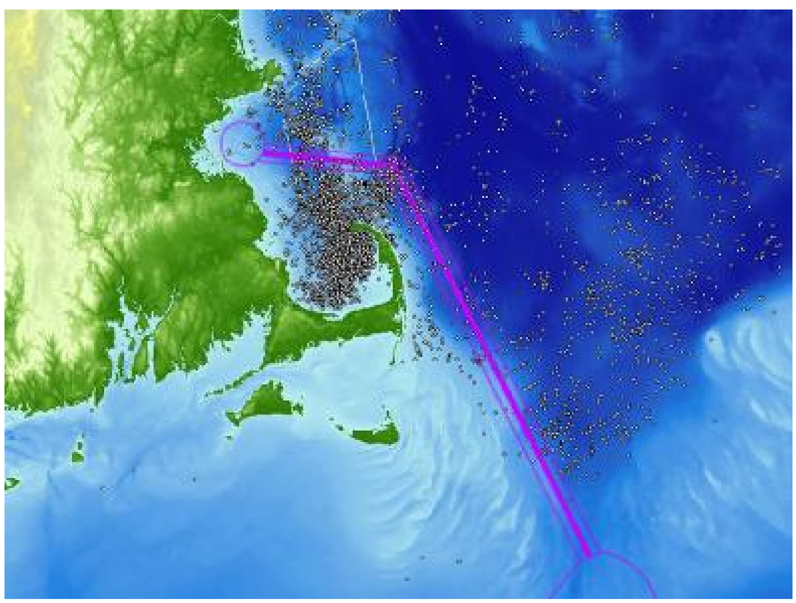

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**Figure 5. The distribution of (a) two months of large commercial vessel transits and (b) over 20 years of right whale sightings (North Atlantic Right Whale Consortium) off the northeastern coast of the U.S. In (b), the boundary of Stellwagen Bank 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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# Underwater Radiated Noise of Ocean-Going Merchant Ships

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 currently available technology for addressing the effects of shipping noise and marine mammals.

## 1. Introduction

Ocean background noise results from both anthropogenic and natural sources; different sources will dominate specific frequency bands. Standard ship operations produce underwater noise at a range of frequencies. Low frequency sound waves experience little attenuation and will propagate over long ranges (100s km). As a result, noise from shipping activity dominates low frequency (< 300 Hz) ambient noise levels throughout the ocean (Figure 1). Based on deep-water studies in the Northeastern Pacific, the contribution of shipping to ambient noise has approximately doubled (i.e., an increase in power of 3 dB) in each of the past four decades. This has resulted in at least a 15-20 dB increase in ambient noise conditions compared to pre-industrial levels. Other studies have produced similar estimates of the contributions of shipping to the low-frequency noise elsewhere in the world, indicating a global increase of ocean noise due to shipping, with higher levels in the northern hemisphere and in proximity to shipping lanes or other traffic concentrations. Further increase in global background noise levels is expected without the initiation of countermeasures to incidental production of underwater noise by shipping activity.

The elevated ocean noise levels from ships can interfere with sounds produced and/or used by marine organisms, especially marine mammals (Figure 2). Sound is an efficient way to propagate energy through the ocean. Marine mammals rely on sound as a means of communication, for finding food and mates, and for detecting predators. Increasing the background noise levels decreases communication ranges, and may potentially also modify behaviour and/or induce a stress response.

Ships are known to radiate noise in all frequency bands, with the highest sound levels at the lowest frequencies (below 150 Hz). Surveys of shipping noise in the last decades provide some information about noise levels under various ship conditions (e.g. speed, ship type), but measurements have been made in numerous ways, in different areas and with various purposes, making comparisons difficult. These particular studies have not specifically addressed the impacts of shipping noise on marine mammals, but some others have begun to investigate these impacts. Knowledge about the characteristics of noise from ships and its distribution relative to locations and movements of marine organisms is important for understanding the potential impacts on marine mammals.

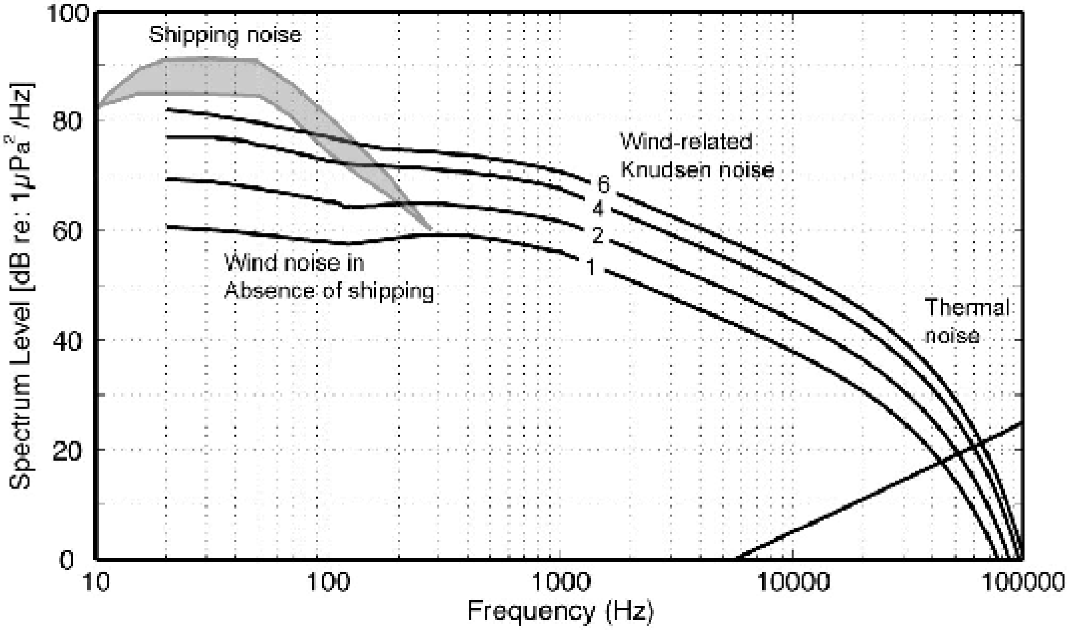


**Figure 1. Ocean ambient noise for frequencies between 10 Hz and 100 kHz. This plot has the same form as the underwater noise curves developed by the U S Navy in the 1960's (Wenz 1962), but it has been modified to reflect modern levels of shipping noise (shaded area), which exceed natural wind-noise,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

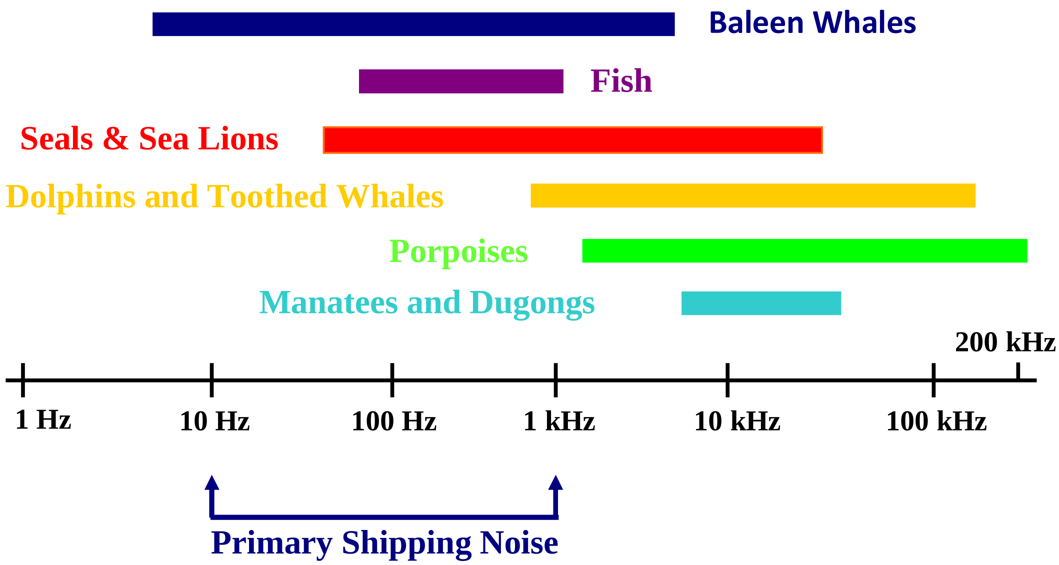


**Figure 2. Frequency Relationships Between Marine Animal Sounds and Sounds from Shipping. Figure courtesy of B. Southall, NMFS/NOAA**

## 2. Shipping noise levels and their cause

The predominant sources of underwater noise produced by a ship are the propeller and the machinery required for propulsion and power generation. The machinery noise and other structure-borne sources of noise radiate into the water through the hull of the ship, whereas noise from the propeller is generated in the water.

### *1.1 Propellers*

Ship-generated noise at lower frequencies (below 50 Hz) is dominated by sound produced through *propeller cavitation*. Cavitation is a consequence of high thrust loading[1] and/or the non-uniform inflow (wake) of water into the propeller. The presence of the ship in front of the propeller causes the non-uniform inflow. Thrust loading and non-uniform inflow generate conditions at certain points along the path of the rotating propeller blades where water vapor bubbles are rhythmically formed. Strong pulses of sound are produced. The pulses of sound induce vibrations into the ship structure above the propeller and the structure transmits the vibrations to various parts of the ship. The vibrations can radiate into the air as noise with consequences for crew and passenger comfort.

To limit onboard noise levels from the propeller, reliable prediction procedures, model testing methods and verification procedures have been developed and are applied on a routine basis. With some modifications, as well as a database of parameters and values specific to underwater noise radiation, these procedures can be adopted to predict both underwater radiated noise and the effectiveness of modifications to ship design.

At higher speeds, or under unfavorable operating conditions, propeller cavitation may also dominate the spectrum above 50 Hz. There is not yet sufficient data available to describe the relationship between operating states and the levels of noise produced through cavitation. However, our knowledge is potentially adequate enough to mitigate cavitation noise in this frequency region in some cases.

The working conditions of the propeller are strongly dependent on ship form design (influencing uniformity, or ‘homogeneity’, of the inflow to the propeller) and propeller design. Propellers are generally designed for optimum fuel efficiency, which in most current designs is in conflict with the need to limit cavitation because of shipboard noise levels as discussed above. However, cavitation noise limitation can also be included in the propeller design process.

For certain types of ships speed is not controlled by adjusting the rate of propeller rotation, but rather by adjusting propeller pitch and keeping shaft speed constant. This may lead to cavitation at speeds other than those for which the ship was specifically designed. The relationships between propeller pitch settings, propeller loading, and other propeller design parameters need to be investigated with respect to underwater radiated noise.

Typical measures to reduce propeller noise from cavitation are improved hull form design, improved propeller arrangement, improved propeller design and attachment of wake field homogenizing appendages (e.g. ducts, turbulence generators etc.). In some cases a modified propulsion concept, such as twin-screw instead of single-screw, may become useful.

The model testing and new computer-based calculation tools should be applied in the early design phase of ships with potentially high noise levels. Quality assurance and quality control of the propeller design is possible by numerical calculations and model scale testing. Criteria for acceptable levels of noise produced by propeller cavitation should be derived for both models and full-scale vessels.

[1] High thrust loading refers to the large amount of thrust required to propel a ship with a comparatively small propeller.

### *1.2 Machinery*

Primary sources of machinery noise are propulsion engines and ship service generators. Diesel engines are employed in almost all ships for both purposes.

The majority of large ships are propelled by a low speed, 2-stroke diesel engine directly driving a single propeller. These engines work at low revolutions (70 to 120 rpm) and are heavy (e.g., a 12-cylinder, 60 MW, approx. 2500 t). Due to the size, the engines are rigidly connected to both the ship hull and the propeller shaft. Vibrations generated by the engine will vibrate the hull of the ship and transmit into the ocean. At present, their contribution to underwater radiated noise is not adequately known, but the large ships are potentially quiet because of the low speed. The contribution to radiated noise could be identified through a structure-borne noise investigation on ships currently in operation.

Other diesel-powered ships employ medium speed, 4-stroke diesel engines, which connect to the propeller shaft via reduction gear. Typical speeds of these engines are around 500 rpm. The engines can be rigidly or resiliently mounted.[2] Contributions of medium speed engines to radiated underwater noise can be identified in recordings. In some recordings the machinery noise dominates the sound produced across a wide range of frequencies, but the contributions can be masked by propeller cavitation noise, particularly at the lower frequencies.

Almost all ships use medium speed diesel engines to drive generators for supplying alternating current for ship services (e.g., the electrical needs of the crew and passengers). Because of the need to deliver constant alternating current, the service engines always operate at one speed independent of ship speed. The diesel generator can dominate radiated noise across a wide range of frequencies for ships propelled by a low speed diesel engine, depending on the speed of the ship.

While no technologies exist to isolate the low speed diesel engines from the structure of a ship, abatement measures exist that reduce radiated noise in medium speed diesel engines. The most popular is the resilient foundation, already employed with all modern diesel generators as well as for some medium speed propulsion diesel engines. The foundations result in a reduction of radiated noise by 15 to 20 dB. Additional design improvements are possible and information can be derived from experiences with military ship design. Quality assurance and quality control of shipboard noise reduction measures can also be derived from military ship operations.

## 3. Other propulsions systems and special ships

Twin-screw ships may have smaller propeller loading and a more homogeneous wake field, therefore better working conditions for the propellers. As a result, propeller cavitation, and hence the noise it produces, is reduced compared to single-screw ships.

Special ships may have other propulsion systems such as pump-jets, Voith-Schneider propellers, water-jets, super-cavitating propellers or surface piercing propellers. Radiated noise outputs of these systems need to be investigated further.

## 4. Small ships

Many small ships (< 1000 t displacement) do not undergo a design process where noise and vibration is considered. Furthermore, propellers may not be matched with the hull for optimum performance. The noise contributions of these ships and modifications necessary to reduce noise needs to be investigated.

[2] Resilient mounting isolates the engine from direct contact with the hull through the use of flexible mounts.

## 5. Old ships

A survey of existing ships is needed to identify ship types, individual ships or design principles that are associated with above-average noise levels. Possible reduction measures are new propellers, wake improving appendages, air injection, etc.

## 6. Operational measures

Apart from design, noise radiation is also influenced by the operating condition of the ship. The most important factors are speed and loading condition.

Most ships with cavitating propellers will be quieter when propeller shaft speed is reduced. As a result, 'slow-steaming' as an air emissions-reducing measure may, in some cases, also reduce the amount of noise introduced into the marine environment. However, noise reduction is limited by noise sources that do not depend on ship speed (i.e. diesel generators).

The effect of different working conditions of the propeller on radiated noise has not yet been investigated in sufficient detail. Investigation of radiated noise variation of representative ships with speed and loading conditions should be made.

## 7. Implementation of noise limits or guidelines for individual ships

Controlled reduction of global shipping noise should be achieved by implementation of noise limits or guidelines for individual ships, which will likely benefit the health and wellbeing of the crews aboard the vessels as well as marine mammals and other marine animals. Any noise criteria under these limits or guidelines would need to be defined with consideration of existing technology. To achieve noise reduction, the criteria should be incorporated into ship building standards and integrated into the design and building process of a ship. Verification of achieving the noise standard and minimization of economic impact on ship construction and operation should be included in the implementation process.

## 8. Necessary activities to identify and develop engineering measures for reduction of propeller and machinery noise

Measuring radiated noise from ships is a routine task in military ship handling. Noise abatement technology is part of the design process. Some of the understanding and many of the concepts of noise reduction engineering could be tailored to the merchant fleet. However, given that the design of a merchant ship and the propulsion and power generating systems is very different from those of a military vessel, little of the proven noise-reduction design technology of military ships can be applied directly to merchant ships.

Several studies must therefore be conducted to establish a reliable basis for standards of underwater radiated noise from merchant ships and effective implementation, including economic considerations. Actions that are needed include:

- Review of existing acoustic data on ships in the frequency range in question (10 to 300 Hz). Data processing should include identification of sources of noise generated by the ship and ship operating status. Expansion of current studies to include the relevant frequency range (< 300 Hz).
- Measurements of on-board structure-borne noise from machinery for calculation of underwater noise radiation.
- Measurements of underwater radiated noise from representative ships for assessment of the influence of speed, loading, pitch setting, etc.

- Extension of model scale prediction of propeller noise currently used for on-board vibration to underwater radiated noise.
- Investigation of model scale and numerical design parameters that influence radiated noise of ships and propellers.
- Development, extension and validation of numerical computer models for prediction of noise radiation.
- Establishment of design, construction and trials processes for reliable prediction and control of noise radiation.
- Investigation of economic consequences of technical changes to ships for noise reduction, with regard to building and operating costs
- Define a standard measurement procedure for underwater radiated noise to allow the creation of comparable data bases and criteria

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# Participants

## 1. Participants (Chair, then in alphabetical order)

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- Iwer Asmussen, Dipl. Ing., Executive Secretary of The German Society for Maritime Technology, Germany.
  - Assisted by Christof Weißenborn, Ph.D., Project Engineer, Germanischer Lloyd, Hamburg, Germany.
- Michael Bahtiarian, INCE Bd. Cert., Vice President, Noise Control Engineering Inc., Billerica, MA USA.
- Chris Clark, Ph.D., Director Bioacoustics Research Program, Cornell Lab of Ornithology, Cornell University, 159 Sapsucker Woods Rd., Ithaca, NY 14850 USA.
- Axel Friedrich, Head of Environment and Transport, Noise Division in the German Federal Environment Agency, Germany
- Juergen Friesch, Managing Director, Hamburg Ship Model Basin, Germany.
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- Henning Luhmann, MEYER WERFT, Germany.
- Megan McKenna, Ph.D. student (Replacing John Hildebrand, PhD), Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093-0205, USA.
- Kathy Metcalf, J.D., Director, Maritime Affairs, Chamber of Shipping of America, USA
- Eckhard Praefke, Dipl.-Ing., Schaffran Propeller+Service GmbH, Lübeck, Germany.
- Tullio Scovazzi, Professor of International Law, University of Milano-Bicocca, Milan, Italy.
  - Assisted/replaced by Irini Papanicolopulu, University of Milano-Bicocca, Milan, Italy.
- Brandon Southall, Ph.D., Director, NOAA Ocean Acoustics Program, National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Office of Science and Technology
- Thomas Stoye, Naval Architect, Basic Design, Flensburger Schiffbau-Gesellschaft mbH & Co. KG, Batteriestraße 52, D-24939 Flensburg, Germany.
- Rolf Thiele, Ph.D., DirProf FWG a.D., 24105 Kiel, Niemannsweg 162 a, Germany.
- Lindy Weilgart, Ph.D., Department of Biology, 1355 Oxford St., Dalhousie University, Halifax, Nova Scotia B3H 4J1, Canada.
- Dietrich Wittekind, Ph.D., DW-ShipConsult, Lindenstrasse 20, D-24223 Schwentinental, Germany.

## 2. Additional Presenters (in alphabetical order)

- Andreas Chrysostomou, Chair of Marine Environmental Protection Committee (MEPC), International Maritime Organization (Cyprus).
- Blair Kipple, M.Sc., Naval Surface Warfare Center, U.S. Navy, USA.

# Workshop Presentations

### 1. Session 1: Sound in the Sea – An Introduction

- Rolf Thiele: An introduction to noise propagation in the sea: 15 mins
- Lindy Weilgart: Known effects of underwater noise on marine mammals: a review and a summary of the workshop on noise-related stress in marine mammals: 15 mins
- Dietrich Wittekind: An introduction to propellers and other sources of noise from ships: noise radiation of commercial ships: 15 mins

### 2. Session 2: Sound, Noise and Marine Mammals

- Brandon Southall: Effects of non-pulsed noise on marine mammals: 15 mins
- Chris Clark: Effects of noise on marine mammals: results from recent “whale-scale” research and mitigation efforts: 15 mins
- Leila Hatch: Ships and Whales: characterising and managing noise spatially: 15 mins

### 3. Session 3: Current Situation

- Kathy Metcalf: The story so far – U.S. Industry perspective: 15 mins
- Tullio Scovazzi: International efforts in the regulation of shipping noise: 15 mins
- Dietrich Wittekind: A Summary of the Luebeck Meeting: 10 mins
- Andreas Chrysostomou: Noise and the IMO: 15 mins

### 4. Session 4: Ship Noise and Air Pollution

- Axel Friedrich: Overlapping aspects of noise and air pollution from ships and their regulation in Germany and Europe: 20 mins

### 5. Session 5: Sources of Ship Noise and Their Measurement

- Megan McKenna & John Hildebrand: An overview of ocean ambient noise from shipping: 15 mins
- Eckhard Praefke: Noise generated by merchant ship propellers: 15 mins
- Jürgen Friesch: The influence of cavitation on pressure fluctuations and noise: 15 mins
- Blair Kipple: Measured radiated sound from large commercial vessels: dominant sources of radiated noise from large modern cruise ships and dependence on propulsion type and vessel speed: 15 mins

### 6. Session 6: Technology and Operations

- Thomas Stoye: Propulsion designs for RoRo- and RoPax-vessels: 15 mins
- Detlef Kurth& Steffen Stauder: Noise aspects of medium speed engines: 15 mins
- Henning Luhmann: Considering noise in cruise ship design and operation: 15 mins

### 7. Session 7: Ship Noise and Classification

- Michael Bahtiarian: A standard for the measurement of vessel underwater noise: 15 mins
- Iwer Asmussen: Consideration of noise in ship classification: 15 mins

### 8. Session 8: The Business of Ship Noise

- Wolfgang Hintzsche: Overview of the business of ship owners and operators: 30 mins

# Presentation Abstracts

## 1. Session 1: Sound in the Sea – An Introduction

### *1.1 Rolf Thiele: An introduction to noise propagation in the sea*

Fundamentals of transmission loss and noise levels are provided, starting with the logarithmic notation of acoustical quantities. The propagation in a homogeneous free field is presented. This shows that normally the frequency dependence of sound propagation can be neglected below 1 kHz.

The dominant effects of deep water propagation as Lloyd mirror effect, surface duct propagation, shadow zone and convergence zone are discussed. The shallow water propagation is demonstrated with some empirical observations.

Finally we will speak shortly about the well-known Wenz curves of ambient noise with the different regimes of noise sources.

### *1.2 Lindy Weilgart: Known Effects of Underwater Noise on Marine Mammals: A Review And A Summary of the Workshop on Noise-Related Stress in Marine Mammals*

Marine mammals are highly dependent on sound. Underwater noise can have a large range of impact, even over millions of square kilometers. Some observed impacts of noise on marine mammals are: change in vocalizations, respiration, swim speed, diving and foraging behavior, displacement, stress, strandings, and deaths at sea. Shipping or boat noise in particular has been linked to changes in vocalizations, avoidance, reduced foraging efficiency, and changes in dives. Masking, or when background noise obscures or interferes with an animal's ability to hear or be heard, can both reduce the a) range of transmission of signals; and b) signal quality and information. Reactions of marine mammals to noise can be subtle and hard to detect from the surface. Responses can also be highly variable, dependent on the individual, species, prior experience, behavioral state, etc. There are also cases of apparent tolerance to noise, though hearing impairment can be mistaken for tolerance. Noise is thought to contribute to some species' declines or lack of recovery. Behavioral responses to noise and acoustically-induced strandings may cause population-level impacts.

A workshop on noise-related stress in marine mammals was held in Lanzarote, Canary Is., in June 2007. A multi-disciplinary group of experts in fields such as human noise epidemiology, bioacoustics, and neuroscience attended. It was concluded that short-term stress responses may have long-term consequences. The context of the noise exposure is also very important. Young animals seem particularly sensitive and can suffer permanent neurological damage from noise. The physiological stress response appears highly conserved among animal species and can thus be extrapolated to marine mammals. Anthropogenic noise, by itself or in combination with other stressors, can reduce the fitness of individuals and decrease the viability of populations. However, much research on noise stress responses in marine mammals is still needed.

### *1.3 Dietrich Wittekind: An introduction to propellers and other sources of noise from ships: Noise Radiation of Commercial Ships*

Noise radiation of commercial ships at normal service conditions is discussed based on a measuring campaign in the English Channel in September 2007. Noise levels could be recorded at frequencies down to 10 Hz under favorable conditions. The results show that ships can be categorized in 1. Ships with fixed pitch propeller, which control speed by adjusting shaft speed. They show pronounced low frequency levels at propeller blade rate harmonics and machinery contributions from medium speed diesel generators, 2. Ships with constant shaft speed and controllable pitch propellers, which adjust speed by controlling pitch. They seem to contribute also to low frequency noise, likely increasing, when reducing speed, and machinery contributions from medium speed propulsion diesels and 3. Ships with high medium frequency levels for no obvious reasons. Comparing results with other measurements and literature there are significant contradictions which need to be clarified by further investigations. Also the current models in use for noise generation, radiation and propagation needs further atttention. However, the current knowledge may serve as first basis to define a direction for noise limitation and regulation.

## 2. Session 2: Sound, Noise and Marine Mammals

### *2.1 Brandon Southall: Effects of non-pulsed noise on marine mammals*

Sufficient information exists to conclude that there are a wide variety of consequences of "non-pulsed" (or "non-impulsive) noise exposure (which includes shipping noise) on marine mammals, their type and magnitude depending on many factors. While there is scientific uncertainty regarding essentially all of these areas, and particularly their interaction and cumulative nature, there are substantial data in key areas. Following a brief consideration of the functional hearing capabilities (and frequency bandwidths) of the marine mammal taxa as they are currently understood, this presentation will consider these various effects of noise exposure. How noise is believed to interfere with basic hearing capabilities, including temporary and permanent losses of sensitivity and the critically important aspect of communication "masking" will be discussed. Additionally, there will be some consideration of other effects of chronic noise exposure on non-auditory systems, attention and cognition, and complex processes such as spatial orientation and navigation.

### *2.2 Chris Clark: Effects of noise on marine mammals: results from recent "whale-scale" research and mitigation efforts*

The great whales produce a wide variety of sounds in the low-frequency (<1000Hz) and very low-frequency (<100Hz) ranges. The characteristics of these sounds are well adapted to the sound propagation features of the habitat (e.g., coastal versus pelagic) as determined by physical acoustics and result in potentially very large acoustic habitats that include very large communication ranges (many hundreds of km), areas (many hundreds of thousands of $km^2$) and time periods (many months per year). There is now considerable evidence that anthropogenic sources of low-frequency ambient noise (e.g., shipping and seismic exploration) have been increasing steadily over the last half century. This rising tide of ocean noise that is a bi-product of human activities is resulting in a dramatic reduction in the area and times over which animals can communicate. Thus, the very same habitats with physical propagation conditions that selected for the exceptionally long-range bioacoustic communication signals in whales, are now, when injected with anthropogenic noise, leading to an acoustic smog and an acoustic bleaching of the whales' long-range, low-frequency acoustic habitat. Low-frequency ambient noise conditions in some habitats have now risen to the point that a whale's acoustic ecology, measured as the product of its communication area and the time period over which that communication is effective, is reduced to approximately 10% of what it was half a century ago.

Science is elucidating the spatio-temporal scales of great whale acoustic ecology and documenting the detrimental increases in ocean noise, but these scientific gains alone are likely not enough to motivate significant changes in fundamentals. Individuals and the body politic must collectively decide and lead that course of action.

### *2.3 Ships and Whales: characterising and managing noise spatially*

Meeting conservation and management objectives for marine protected areas necessitates identifying contributors to each area's total underwater noise budget and evaluating their possible impacts on the survivorship and fitness of resident marine animals. Stellwagen Bank National Marine Sanctuary (SBNMS) is home to many acoustically-active marine species. Placed right in the middle of Massachusetts Bay, this urban sanctuary is also a busy place for human commerce and recreation, both of which contribute noise to the underwater acoustic environment of the sanctuary.

Since 2006, low frequency (10-1000 Hz) acoustic data have been collected throughout SBNMS waters and used to address multiple questions regarding the distributions, behaviors and potentials for hearing loss and masking among sanctuary species. In addition, the Universal Shipborne Automatic Identification System (AIS) has been used to track large commercial ships transiting the sanctuary and adjacent waters. AIS and acoustic data have been integrated to quantify relative noise contributions made by different types of vessels to regional underwater noise. Analysis of received levels (10-1000 Hz, RMS dB re 1 µPa ± standard error) at high traffic locations were found to average 119.5 ± 0.3, with high traffic locations averaging double the acoustic power of less trafficked locations. Tankers were estimated to contribute two times more acoustic power to the region annually than cargo ships, and over one hundred times more than research vessels. These results indicated that noise produced by large commercial traffic is at levels and within frequencies that warrants concern among managers regarding the ability of many endangered, protected and/or commercially-valuable marine animals to maintain acoustic contact within greater sanctuary waters. Current research is focused on integrating empirical noise data and ship tracking information with data from acoustic propagation models and tagged whales to examine whale behaviors in their acoustic context.

## 3. Session 3: Current Situation

### *3.1 Kathy Metcalf: The story so far – U.S. Industry perspective*

In 2003, the US Marine Mammal Commission established a federal advisory committee (Advisory Committee on Acoustic Impacts on Marine Mammals) in response to legislation enacted by the US Congress. Unable to agree to a consensus report, the final report of this committee to the Marine Mammal Commission was composed of caucus reports, one of which was submitted by the single maritime industry representative on the committee. Other caucuses reporting included the US federal government agencies, environmental groups, energy producers and scientific researchers. The MMC also co-hosted an international workshop on sound in the oceans with the Joint Nature Conservation Committee in September 2004.

Parallel with the work of this committee, the National Oceanic and Atmospheric Administration's (NOAA) Office of Protected Resources began to assess strategies by which the various noise sources could be analyzed and managed. Recognizing the political volatility of a single forum which attempted to address all noise producers which was clearly evident from the deliberations of the federal advisory committee, NOAA developed a program which focused on noise production from commercial shipping. In May 2004, its first outreach conference, entitled "Shipping Noise and Marine Mammals: A forum for Science, Management and Technology" was held with a strong focus on scientific research findings and was most valuable in laying the groundwork and providing information for further interface with the shipping industry. Unfortunately, progress on technological solutions was somewhat diluted due to the absence of marine vessel design engineers and naval architects. In May 2007, NOAA held its second outreach conference, entitled "Potential Application of Vessel Quieting Technologies on Large Commercial Vessels" which refocused the discussion on vessel design and operational changes which might be used to mitigate the impact of commercial shipping on the global noise budget. The attendees at this second conference came from a variety of technical backgrounds including marine engineers, naval architects and acoustic engineers specializing in sound reduction technologies in both land and marine applications.

The Chamber of Shipping of America (CSA) participated in all of these programs, first as a member of the federal advisory committee and later as a steering committee member and presenter at both NOAA conferences. Throughout these processes, CSA has been pleased to serve in the role as the industry outreach entity, focused on getting the message out that commercial shipping noise was an emerging issue to which the industry must respond.

This presentation will briefly summarize the activities of the three initiatives described above as they related to commercial shipping noise, the role of CSA in these initiatives and our outreach program to our colleagues in the global maritime industry. The presentation will then review the current state of discussions within the industry and in related fora and then conclude with a summary of possible technological and operational solutions with which the industry could address this issue in a proactive manner and possible ways forward to further highlight the issue to the industry and national governments.

### *3.2 Tullio Scovazzi: International efforts in the regulation of shipping noise*

According to the definition of marine pollution contained in the United Nations Convention on the Law of the Sea, the introduction by man of noise into the marine environment may be considered as a form of pollution if it results or is likely to result in deleterious effects. States have accordingly the obligation to adopt measures in order to protect the marine environment also from this kind of pollution. Other treaties relating to the protection of marine species contain similar provisions.

The production of noise by ships constitutes a form of pollution as it may harm marine living organisms and may affect fisheries. States are therefore under the obligation to reduce such noise emissions.

Resolutions calling for the regulation and reduction of noise-producing activities have been adopted within various international contexts (IWC, ASCOBANS, ACCOBAMS, the European Union).

There is however no international treaty specifically addressing the issue. The MARPOL, as actually framed, applies only to pollution caused by substances and not by energy (such as noise). The IMO has nonetheless taken into account the need to protect the marine environment from acoustic pollution in the 2005 Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas, which identifies noise as a potential threat to the marine environment and therefore as a basis for the establishment of such areas.

Even if there are some fragmentary international law provisions dealing with the issue of underwater noise, a more organic regime is needed. But the main problem still remains the lack of political will by certain States to address the issue and the dilatory strategies that are easily available to them.

### *3.3 Dietrich Wittekind: A Summary of the Luebeck Meeting*

On January 22nd 2008 a workshop took place in Lübeck on ship efficiency and air quality in harbours. Talks concentrated on ship efficiency by improving hull and propulsion and measures to reduce $SO_2$, NOx and particulate matter emissions. Among these were use of marine diesel fuel, LNG as fuel, pier side power supply and exhaust gas after treatment. Special emphasis was on the Baltic Sea harbour of Lübeck, Travemünde, which today is a climatic health resort. Travemünde faces loss of this attribute due to shipping emissions, which would result in noticable economic consequences. The Baltic Sea is already a Sulphur Emission Control Area (SECA) which limits sulphur content in fuel to 1.5%. Another issue adressed by speakers were lack of developed technical solutions and cumbersome approval procedure for environmentally friendly equipment.

### 3.4 Andreas Chrysostomou: Noise and the IMO[1]

The presentation explained the procedures that have to be followed for a submission for a new work program item in the MEPC´s work program.

Specifically, the document pointed out that the Committee can decide to include a new item in its work provided that the need for the measure proposed has been documented and, in case of proposals calling for new conventions or amendments to existing Conventions, has a compelling need been demonstrated and also the subject addressed by the proposal considered to be within the scope of IMO's objectives;

Further the presentation explained that MEPC has to examine also whether adequate industry standards exist or are they being developed; in the event that this is true then the Committee shall determine whether further action by IMO is necessary.

The presentation ended explaining that in all cases benefits vis-à-vis enhanced protection of the marine environment shall be expected to be derived from the inclusion of the new item proposed and the analysis of the issue sufficiently addresses the cost to the maritime industry as well as the relevant legislative and administrative burdens

## 4. Session 4: Sources of Ship Noise and Their Measurement

### 4.1 Megan McKenna & John Hildebrand: An Overview of Ocean Ambient Noise from Shipping

Ambient noise in the deepwater (> 1000 m) North Pacific basin has been shown to be increasing at a rate of about 3 dB per decade over the past four decades. Repeat ambient noise measurements at the San Nicolas and Pt. Sur SOSUS array sites (offshore southern and central California), reveal about 12 dB of increased noise in the low frequency band (10-80 Hz) between the early 1960's and the early 2000's. Noise levels at these sites are primarily due to distant shipping, and not significantly affected by the presence of local ships. These data suggest that basin-wide increases in the number of commercial ships, as well as increased radiated noise from individual ships, have contributed to deep-water ambient noise. Extrapolation to pre-industrial conditions suggests a ambient noise increase of at least 20 dB in the deepwater North Pacific, owing to commercial shipping.

Repeat ambient noise measurements at a shallow-water (110 m) site near San Clemente Island were conducted to determine if noise increases also extend into coastal waters. This is an area of Naval activity, but with little commercial shipping. Local ship noise was observed at the San Clemente Island site for 31 percent of the recordings in 1963 and for 89 percent of the recent recordings, suggesting increases in noise associated with ship presence. However, when noise from local ships is excluded from the recent recordings, median sound levels were the same today as those observed in 1958 and 1963 at this site, suggesting that deep-water noise does not propagate to this shallow water site.

[1] The views expressed in this paper are the views of the author and shall not be considered as been the views of the International Maritime Organisation or its Secretariat, or of the speaker's employer in this case the Government of the Republic of Cyprus.

Broadband acoustic data and Automatic Information System (AIS) ship tracking data are being collected in the Santa Barbara Channel, a region of intense shipping activity. These data are being used to assess the level of shipping noise in the Santa Barbara Channel region, and to construct a catalog of radiated sound from individual ships. Average noise levels in the Santa Barbara Channel exceed deepwater ambient noise by about 10 dB, suggesting as much as 30 dB increase over pre-industrial conditions.

### 4.2 Eckhard Praefke: Noise Generated by Merchant Ship Propellers

Beside the main and auxiliary machinery, propellers are a main source of noise on merchant ships. Propeller noise is generated at frequencies typically ranging from 30 Hz to 30 kHz. There are several propeller noise generating mechanisms: General flow noise, blade vibrations, varying blade forces and cavitation. The latter two are most important and, at the same time, the most promising fields of improvement with regard to radiated noise levels.

While it is common practice to attenuate machinery generated noise by damping or isolating the noise source against the environment, the same approach implies severe efficiency penalties for most merchant ship propellers, limiting the use of shrouded propellers to special applications. As a consequence, the propeller radiates its noise directly to the environment, and propeller noise reduction should aim at the noise generation mechanisms, not at noise propagation.

The author provides a short introduction into basic propeller theory and “normal” design criteria today. He explains the governing mechanisms related to noise generation and the trade-off to be accepted when targeting lower radiated propeller noise levels.

Current practice in merchant ship propeller design is to maximise propulsive efficiency (low fuel consumption, low operational costs, low environmental impact) under the prerequisite of limited propeller-induced hull pressure pulses, aiming at the comfort of the crew rather than at the protection of sea life. Propeller radiated noise is a design requirement only for special applications, e.g. warships or sonar equipped research ships. While the related design technology exists and is being further developed, the successful design of low noise propellers requires much more sophisticated procedures and knowledge than the present average state of propeller design.

Finally, the author would like to state that exploiting the full potential of propeller noise reduction is not only a matter of propeller design by itself, but also of an improvement of propeller working conditions, also affecting propeller arrangement, ship design and ship operational aspects.

### 4.3 Jürgen Friesch: The influence of Cavitation on Pressure Fluctuations and Noise

Over the past years significant advances have been made in identifying the causes of excessive vibrations and noise of all types of ships. The principal source of forced excitation occurring in modern ships has been identified as the partially cavitating propeller characterized by sheet cavity in the upper half of the propeller disc and by strong, developed tip vortex cavitation. Knowledge about and consideration of scale effects are important for the judgement of model test results. This is why HSVA started propeller testing in the test facility HYKAT which was developed as an adequate hydrodynamic/hydroacoustic facility for testing complete hull propulsor arrangements to meet all needs of the maritime industry. Results of detailed research projects had shown that ship models need to be tested with the complete hull propulsor- appendage system as an integrated unit to get reliable answers concerning the cavitation behaviour and related problems. Observations of full scale cavitation extension on propeller blades and measurements of pressure fluctuations and noise on full scale ships indicate that good agreement with the corresponding results from the test facility is obtained. For twin screw ships like fast ferries, ROPAX-ships and cruise liners the data correlate very well.

This is also true for tankers and bulk-carriers. For the very large containerships the situation is somewhat mixed and more diffuse. After many years of tests in the tunnel it has shown to be the most useful tool for all kinds of cavitation investigations and related problems. Most prediction nowadays is done using this facility by designers from all over the world and as a consequence, cavitation induced pressure fluctuations and noise have been significantly reduced. Passenger vessels are reaching amplitudes as low as 1kPa and HYKAT can predict these levels accurately. Correlation investigations for different ships showed that also the higher harmonic components of the pressure signal and therefore the broad band noise excitation are in good agreement with full scale data. But the prediction of the broadband noise excitation of ships is still difficult and needs further improvement. Most of the open questions are related to tip vortex cavitation. New techniques and approaches are still necessary to gain a better understanding of the physical mechanism involved.

### *4.4 Blair Kipple: Measured radiated sound from large commercial vessels: Dominant sources of radiated noise from large modern cruise ships and dependence on propulsion type and vessel speed*

The radiated underwater sound from eight large cruise ships was measured and characterized at the U.S. Navy's Southeast Alaska Acoustic Measurement Facility (SEAFAC). Cruise ship sound level, character, and controlling acoustic sources were significantly vessel dependent. Propulsion system type and vessel speed were typically important factors. One-third octave band levels of up to 125 dB re 1 microPa at 500 yards were measured. The principle sources of acoustic energy were typically related to the power generation and propulsion systems, and from the ship's propellers. Sound from some vessels exhibited significant speed dependence, particularly with regard to propeller related energy. Sound from other vessels showed little speed dependence over the range of speeds that were tested.

## 5. Session 5: Technology and Operations

### *5.1 Thomas Stoye: Propulsion designs for RoRo- and RoPax-vessels*

The presentation will explain aspects of the design of RoRo and RoPax-vessels with focus on propulsion concepts. The influence of environmental and customers restrictions on the ship design and criteria for the assessment of propulsion concepts will be presented. Design methods and criteria will be discussed with focus on noise and vibrations with respect to the capability of present numerical methods.

### *5.2 Detlef Kurth & Steffen Stauder: Noise aspects of medium speed engines*

The item „medium speed engines“ classifies diesel or gas engines with nominal speeds in the range between 300 rpm and app. 1000 rpm. They are used as prime mover for container ships (Feeder ships), ferries, cruise vessels, bulk carrier, tug boats etc. Also ships with different prime movers (e.g. Two stroke engines) have often medium speed engines in marine gensets for power supply.

The noise emission of medium speed engines has to be separated in two bands. The lower band is the range between 6 Hz and app. 150 Hz. The noise in this range is generated by mass forces of the moved pistons, conrods and crankshafts and by gas forces arising from the internal combustion process. The noise signal shows distinct frequencies which are integer or half integer multiple of the actual speed frequency. This is the reason why the identification diesel engine noise is so easy. Navy specialists are able to identify an individual ship only by the combined engine and propeller noise.

For higher frequencies engine noise is more broad band. Excited by the internal combustion, thump noise of pistons, gear wheels and valves. Only Turbo chargers give a tonal noise. The turbo charger noise could occur in the range of 2000 Hz to 5000 Hz and more.

There are three ways of noise transmission between engine and environment.

The first one (most important for underwater noise) is the structure borne noise transmitted via foundation and all pipes and couplings. Most of the prime movers are rigidly mounted. Hence is negligible isolation and damping on the way to the ship hull. The ship structure may have certain natural frequencies of the hull or inner structure. If this frequencies comply with an engine frequency, there will be a noise amplification.

The second way of noise transmission is the air borne noise. This is most important for the people working near the engine. The emitted noise of a regular diesel engine in 1 m distance could exceed 110 dBA. However the effect of this noise to the outside area of the ship is very low. It is reduced in a range of 25-30 dB outside of the engine room.

The last noise transmission way is via the exhaust gas chimney. This noise is most significant above the water surface.

For the most time medium speed diesel engines do run at nominal speed. Hence noise frequencies generated by the mass forces (i.e. speed frequency and double speed frequency) remain stabile. The other noise frequencies are related to the actual engine output.

The most efficient noise reduction method for underwater noise is a resiliently mounted engine. Navy ships which want to have a very low underwater noise emission often use double resilient mounting systems. For long time resiliently mounted prime movers were an exception for merchant shipping because this applications are more expensive. But lately there are two movements which abet resiliently mounted engines. One is the high price for steel and the other the increasing demand for more comfort and occupational safety.

### *5.3 Henning Luhmann: Considering Noise in Cruise Ship Design and Operation*

The cruise industry is a continuously growing industry with an increase of 8% per year. This growth continuously forces the operators to build new ships and to find new itineries. The problem of underwater noise is not directly focussed at the moment however due to the strong requirements for the passenger comfort with regard to noise and vibrations many efforts are undertaken to minimize any source of noise. This has a positive influence on the underwater noise as well.

The different sources for underwater noise will be discussed and the main focus is given the different propulsion concepts for twin-screw cruise vessels. There are significant differences in the noise for the different concepts and the development over the last two decades will be presented.

The operational aspects are very difficult to assess, as underwater noise is for the majority of cruise ships operators not an issue at the moment. However with the increase of passengers and the need for new operating areas this aspect will be part of the various environmental programs of the cruise lines.

## 6. Session 6: Ship Noise and Classification

### *6.1 Iwer Asmussen: Consideration of noise in ship classification*

After briefly introducing general activities of a classification society, aspects are touched on how Germanischer Lloyd (GL) supports its clients to ensure that noise limits laid down in a newbuilding specification are maintained when operating the vessel. A newbuilding specification forms an integral part of the contract between ship owner and shipyard, and it is the responsibility of the shipyard to undertake all necessary steps to meet these limits. These on-board noise limits normally refer to IMO regulations or specific national requirements. Since many shipyards, however, do not have sufficient expertise to carry out relevant noise predictions they may be supported by e. g. GL with over 30 years experience in this field. Scope and technology used to predict noise levels depend on the kind of ship and on the novelty of the design. The different steps of a prediction including the state of the art developments will be discussed. It will be demonstrated, for instance, that structure borne sound radiated from relevant noise sources (engine, water jets, pumps, thrusters, etc.) into the whole ship structure including the outer shell can be predicted with high accuracy. Two examples illustrate that the advanced prediction method can be used to make structural design decisions based on noise considerations. Due to the vast knowledge of GL in the entire field of ship technology, the noise prediction services are widely sought after and accepted, especially by shipyards. However, also ship owners frequently resort to this knowledge, for example, to be supported in cases of trouble-shooting for ships in operation.

Once the structure borne noise level is known on the outer shell it can be used as noise source to calculate the radiation into the water in a subsequent step using the same well proven tool box.

To a large extent, the success of further activities of this initiative regarding marine mammals will depend on the definition of realistic noise limits these animals can bear. However, initiatives undertaken by, e. g., IMO and other national authorities to accept these limits are of utmost importance. One day, such limits may enter into building specifications, and ships will then be designed accordingly.

### *6.2 Michael Bahtiarian: A Standard for the Measurement of Vessel Underwater Noise*

The development of an entirely new commercial standard for “Underwater Noise Measurement of Ships” started in early 2007. Currently, no voluntary consensus standard exists for performing underwater noise measurements of ships. For many years, the field of underwater noise from ships has been the exclusive specialty of the Navy. However, non-navy vessels are looking to be just as quiet so that they can perform better science. “Green Ships” are being conceived in order to have less emission into the ocean.

The goal of the project is to develop an American National Standard for the measurement of underwater noise levels of ships using commercial technology. One aim is that the standard would be applicable to any open ocean site in the world and not require traveling to special acoustic test range. The committee’s scope of work includes neither regulatory actions nor the development of any underwater noise level limits.

This presentation will be an update of the committee work to date. The first draft of the standard has been reviewed and detailed work is currently underway. A presentation of three measurement grades (A, B & C) will be presented along with the basic methodology. The standard is being developed by the Acoustical Society of America (ASA), S-12 Committee on Noise, Working Group 47. When completed, it will be distributed by American National Standards Institute (ANSI) & ASA.

For more information go to www.noise-control.com/wg47/.

## 7. Session 7: Ship Noise and Air Pollution

### *7.1 Axel Friedrich: Overlapping aspects of noise and air pollution from ships and their regulation in Germany and Europe*

No Abstract Provided.

## 8. Session 8: The Business of Ship Noise

### *8.1 Wolfgang Hintzsche: Overview of the business of ship owners and operators*

The worldwide shipping business is facing since a few years the biggest challenge due to steady growth in transport capacities and ship sizes.

An overview will be given on the structure of the world fleet and ship types and special focus will be put on the german merchant fleet, the newbuild-program and investments and the owners behind.

Further aspects are the international regulatory aspects by IMO and flag state administrations in the respect of Safety and Environmental protection i.e. Green-Ship-Technology, Air Emission reduction etc. Not to forget the new work item at the IMO-Maritime Safety Committee (MSC) for Noise on/from ships. A few ideas will be presented regarding reduction of ship's speed, related consequences etc.

Finally it should never be forgotten in all current discussion, that the transport by ship for 95% of the total world trade is still the most safest, most economical and environmental friendliest way ! But there's always room for improvement, so let's talk together.

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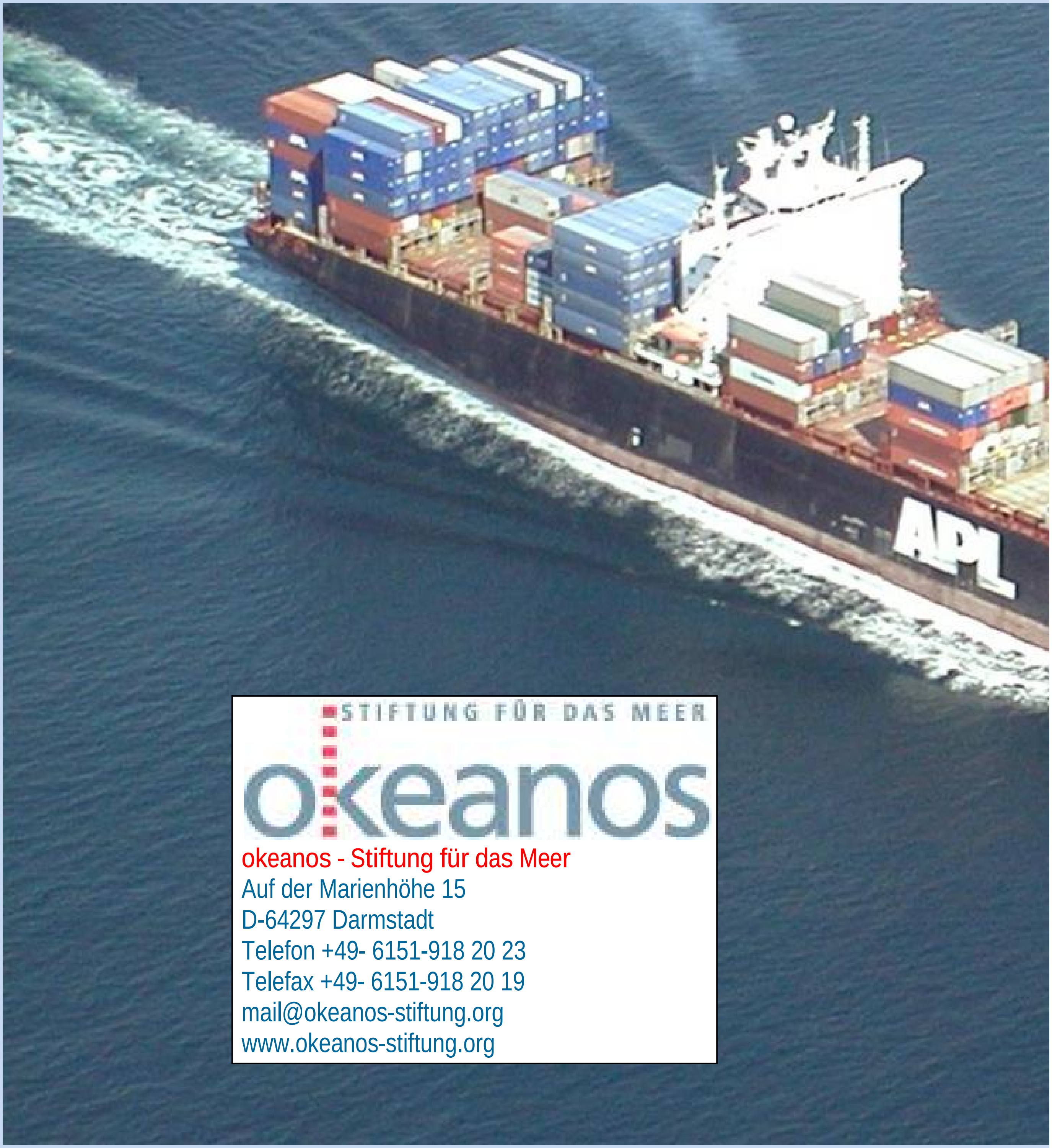


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