Anthropogenic Noise in the Marine Environment

Potential Impacts on the Marine Resources of Stellwagen Bank and Channel Islands National Marine Sanctuaries

Conservation and Development Problem Solving Team
Graduate Program in Sustainable Development and Conservation Biology
University of Maryland, College Park

Prepared for

the National Oceanic and Atmospheric Administration
and the Marine Conservation Biology Institute
December 5, 2000

EXECUTIVE SUMMARY

The oceans are full of sound. Many sounds originate in the natural environment: waves, rain, wind, and seismic events all contribute to ambient or background noise. Living organisms, such as certain species of whales, seals, fishes, and shrimp, also produce sounds that can be detected underwater. In addition to natural sounds, a substantial amount of anthropogenic (human-generated) noise is present in the marine environment, and there is growing concern that the proliferation of this type of noise may be adversely affecting marine life. Sources of anthropogenic noise include shipping (e.g., supertankers and cargo vessels), fishing fleets and other commercial vessels (e.g., whale watching boats), private recreational boats, military sonar, and seismic survey and blasting devices for oil, gas, and mineral prospecting.

Sound is used by many marine animals for basic survival activities, such as foraging, detecting predators, navigation, and communication. Human-generated noises can affect these behaviors and have an impact upon organisms in other ways as well. For example, masking (the drowning out of certain sounds by other sounds) can reduce the effective communication distance among conspecific organisms. Anthropogenic noise can also cause physiological impacts, such as temporary or permanent threshold shifts (temporary or permanent hearing loss and tissue damage).

There are currently no laws or regulations that specifically address anthropogenic noise and its impacts upon marine life; however, several pieces of legislation (e.g., the Marine Mammal Protection Act and the Endangered Species Act) do exist that could provide avenues for approaching the issue.

Human-generated noise has recently become an issue for the National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuary Program (NMSP). Sanctuaries are managed to protect and conserve living resources that depend on marine areas. However they also support multiple uses by humans, including commercial fishing, recreational activities, education, and research. The challenge for sanctuary managers is finding the appropriate balance between these multiple uses and the goal of protecting resources under their stewardship. During public meetings, held as part of the review process for updating the management plans for the Stellwagen Bank National Marine Sanctuary (SBNMS) and Channel Islands National Marine Sanctuary (CINMS), the impact of noise from human activities was identified as a major concern within the sanctuaries.

The greatest source of anthropogenic noise in SBNMS and CINMS is vessel traffic (whale-watching, recreation, commercial fishing, and shipping). Major shipping lanes pass through portions of both sanctuaries en route to and from Boston and Los Angeles, respectively. In CINMS, seismic surveys (using airgun arrays) for oil and gas exploration and earthquake hazard studies, and underwater blasts and explosions from mineral exploitation and naval training activities in the nearby Point Mugu Sea Range, are also important sources of noise that occur periodically.

The impact of the noise generated by these sources on sanctuary habitants has not been determined, but it could potentially be significant. SBNMS provides critical feeding ground for

many marine species, including baleen whales (humpback, fin, sei, northern right, and the occasional blue whale) and several types of fish (Atlantic cod, haddock, herring, and mackerel) vital to the New England economy. Baleen whales may be especially sensitive to noise because of their use of low frequencies (<1000 Hz) for vocalizations and communication. Vessels in SBNMS generate noise of 500 Hz or less, which could lead to masking effects upon these and other species. Similar problems may occur in CINMS, which lies in the migratory pathway of the California gray whale and provides habitat for resident minke whales. Fish species living in the sanctuaries may potentially be harmed if noises of 180 dB at 50-2,000 Hz are present. Other marine organisms within the sanctuaries that use, and thus may be susceptible to, low-frequency sound include sharks (e.g., great white, basking, and blue sharks) and sea turtles (e.g., Kemp's ridley and loggerhead in SBNMS).

CINMS contains rookery sites for four species of pinnipeds: the California sea lion, harbor seal, northern elephant seal, and northern fur seal. These species may be adversely affected by noises of long duration or airborne noises, which have been documented to cause stampedes and subsequent trampling of pups in pinniped haul out areas. Due to the close proximity of the Point Mugu Sea Range, such threats could also exist for CINMS.

Information on the effects of human-generated noise on fishes, invertebrates, and other non-mammal marine species is scarce. Fish use sound to form acoustic images of their environment, maintain cohesiveness in schools, and possibly to communicate (e.g., defend territories in coral reef habitats). Studies that do exist indicate that fish may be susceptible to masking from vessel traffic noise, startling due to seismic operations, as well as physiological damage (e.g., swim bladder injuries, eye hemorrhages, and lower egg viability and growth rates) in response to exposure to noises at ~220 dB. A few studies have been performed on other forms of marine life (typically using sounds associated with sonar and seismic exploration devices), including Dungeness crab larvae, bait shrimp, fish eggs and larvae. These studies have shown limited adverse effects from excessive noise exposure.

Recommendations

There are several opportunities for the NMSP to take a proactive role in managing anthropogenic noise in the marine environment. Sanctuary management staff should reevaluate the multiple-use activities currently allowed in sanctuary waters and manage "silence" as a resource. This can be accomplished by establishing noise limits within the sanctuaries, and sound buffers surrounding these areas. Biologically significant areas (e.g., breeding grounds) within sanctuaries can be identified and correlated with noise profiles to establish "acoustic hotspots" or areas of ecological significance already exposed to excessive amounts of human-produced noise. These areas can then be designated for additional protection (e.g., as marine protected areas), research, and monitoring.

The NMSP can also take a more active role in regulating marine vessels present in waters under their jurisdiction. For example, sanctuaries can regulate boat speeds and maintenance (e.g., removal of barnacle accretions from propellers to reduce cavitation), or provide incentives for implementing quiet ship technologies. The most often-cited recommendation, perhaps not surprisingly, is the need for further research. Currently, there is a clearly acknowledged dearth of information upon which to base solid assessments of effects. At present, long-term research and monitoring to investigate the extended impacts of noise on all types of marine life are lacking and sorely needed. NOAA should collaborate with other organizations to conduct joint, long-term investigations that are multi-faceted and anticipate future needs for mitigation and adaptation.

In general, all sanctuaries within the NMSP should be made aware of the rise of noise in the oceans. Education campaigns targeted at generators of noise in the marine environment should be a top priority, especially since establishing regulations and policies for many measures of protection could take a long time and may not be feasible until mechanisms for enforcement can be established. These entities should be educated on mitigation techniques, such as bubble curtains, ramping up, and adaptation of activities during particularly sensitive periods for animals. Guidelines should be established for these methods to provide clear direction. Voluntary incentives for compliance should be strongly promoted.

The authors of this report hope the information contained herein will assist NOAA Headquarters and sanctuary staff and MCBI to delineate management strategies, including goals and objectives for the NMSP, which will further safeguard the resources under their stewardship.

INTRODUCTION

Oceans are not silent worlds. Physical dynamics such as breaking waves, cracking ice and natural seismic disturbances are all detectable underwater. There is a biological repertoire of sound as well. For example, certain species of whales, seals, fishes, and even shrimp produce sounds that, to our ears, may resemble songs, trills, grunts, snaps, etc. (Würsig and Richardson 2000). Add to this the almost constant noise from human activities, including shipping, sonar, and seismic surveys, and one begins to realize that the oceans are quite noisy places.

There is growing concern within the scientific community that proliferation of anthropogenic (human-caused) noise in the oceans potentially has a negative effect on marine life (Gisiner *et al.* 1998). Many marine organisms rely on hearing as their primary sensory mechanism, due to the excellent ability of the marine environment to conduct sound and the tendency for darkness and murky conditions to reduce the range over which objects may be seen. Marine mammals, for example, use sound to navigate, communicate, and detect predators and prey (Richardson *et al.* 1995a). They produce many of their vocalizations in the low-frequency ranges (below 1000 Hz), which can travel great distances underwater. For example, it has been speculated that the calls of blue (*Balaenoptera musculus*) and fin (*Balaenoptera physalus*) whales link individuals traveling hundreds of miles apart (Payne 1995 in NRDC 1999). Many of the loudest human-produced sounds also occur in the lower frequencies of the sound spectrum and are thus thought to have impacts upon organisms that can hear or otherwise sense sound within this range (NRDC 1999).

Recent national concern regarding this topic stems partly from activities associated with large programs such as the Acoustic Thermometry of Ocean Climate (ATOC) Program and the U.S. Navy's surveillance towed array sensor system (SURTASS) low frequency active (LFA) radar, as well as the requirement for "shock tests" on new designs of Naval ships and submarines (Gisiner *et al.* 1998). The sounds generated by these activities are typically low frequency and very loud (in excess of 180 decibels) (Richardson *et al.* 1995a), and studies addressing their impacts upon marine mammals have recently made their way into mainstream journals. A study was recently published in *Nature* that indicated a lengthening of male humpback whale (*Megaptera novaeangliae*) songs during exposure to LFA sonar, although such responses were not considered to be an extreme change in behavior (Miller *et al.* 2000). The popular press has also discovered the issue. A recent *Washington Post* story purports a connection between the stranding and subsequent deaths of several species of whales in the Bahamas in the spring of 2000 and Navy sonar tests (Kaufman 2000).

Yet little is known with regard to the actual effects of anthropogenic noise on marine species. Over the past few years, several committees and working groups (Office of Naval Research (ONR), National Research Council (NRC), National Marine Fisheries Service (NMFS), Natural Resources Defense Council (NRDC)) have convened to review what is known about the effects of anthropogenic noise in the marine environment. The general outcome of these meetings has been that more research is necessary before particular courses of regulatory and legislative action can be recommended.

Purpose of this report

The National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuary Program (NMSP) was created in 1972 to serve as the trustee for the nation's system of marine protected areas (NOAA 2000a). Currently there are 13 marine sanctuaries within the NMSP. The mission of the NMSP is "to conserve, protect, and enhance [the] biodiversity, ecological integrity and cultural legacy" of these marine protected areas (NOAA 2000b). In addition to providing safe havens for numerous marine species, sanctuaries support many human uses including commercial fishing, boating, tourism, recreational activities, education, and research. The key to successful sanctuary management is finding the appropriate balance among these uses (NOAA 2000c). Currently, the Stellwagen Bank National Marine Sanctuary (SBNMS) and Channel Islands National Marine Sanctuary (CINMS) are reviewing and updating their management plans. Public meetings, held as a part of this review process, identified the impacts of noise from human activities as an issue of major concern within the sanctuaries.

To help address the issue of noise within the two sanctuaries, NOAA and the Marine Conservation Biology Institute (MCBI) jointly asked the University of Maryland Problem Solving Group 2000, as part of the Graduate Program in Sustainable Development and Conservation Biology, to review the current "state of the science" and assess opinions among those working in the field regarding the effects of anthropogenic noise in the marine environment. The group's findings are included within this report.

An important caveat: In assembling this report, the Problem Solving Group has drawn not only upon the published literature but also upon numerous "gray literature" sources, as well as extensive personal communications with researchers active in the field. Our reliance on these last two sources of information is in response to the request of NOAA and MCBI that we contact those working on the topic of anthropogenic noise and its effects on marine life in order to get the very latest information possible. We acknowledge the risk in using non-peer reviewed information of this type, and urge the reader to view personal communications (pers. comm.'s in the text) as expressions of the opinions of those interviewed at that time and as understood by the interviewer. Likewise, citations from news articles and other non-refereed media should be viewed with the appropriate caution. That said, any factual error contained in this report is the sole responsibility of the authors.

In its overall organization, this report initially provides some background information on general issues associated with noise in the marine environment and an overview of marine acoustics. Insight into the importance of sound to marine organisms, along with a brief explanation of how marine animals hear and use sound, is also provided. The next section provides overviews of some of the sources of human-related sound in the marine environment. Following this are brief summaries of some of the laws and regulations relevant to this issue.

The focus of the report then turns to the current research being conducted on the effects of noise on marine taxa. This section summarizes to the greatest extent possible the recent literature, as well as expert opinions gathered through interviews and correspondence on this topic. The report then examines in more detail the sources of noise in the two sanctuaries of interest, and discusses the potential impacts of such noise on sanctuary resources, including marine mammals (cetaceans and pinnipeds), fishes, birds, turtles, and invertebrates. After reviewing noise sources, possible sound mitigation measures are explored.

Recommendations and a discussion of management implications for addressing threats associated with anthropogenic noise conclude this report. Perhaps not surprisingly, the most often-suggested recommendation is the need for further research. Currently, there is a clearly acknowledged dearth of information upon which to base solid assessments of effects. At present, long-term research and monitoring to investigate the extended impacts of noise on marine life are lacking and sorely needed.

Thus, the goal of this report is to evaluate the potential impacts of noise within SBNMS and CINMS, and on the marine life they seek to protect. In a broader sense, this analysis is intended to assist NOAA and MCBI in defining the goals and objectives for resource management in CINMS and SBNMS, as well as to help shape programmatic policy for the NMSP as a whole. This report also seeks to educate and inform constituents of CINMS and SBNMS, and the sanctuaries program at the national level. The authors hope that the information contained herein will assist sanctuary staff in delineating management strategies that will further safeguard the resources under their care and stewardship.

NOISE IN THE OCEAN: THE WHAT, WHY AND HOW

Physics of Sound†

Sound is what we hear as the result of pressure exerted upon our ears by vibrating particles of fluid. For the sake of simplicity, we may also speak strictly of the physical phenomenon of sound apart from the listener. Sound can be more technically described as a longitudinal wave that sinusoidally alternates between compression and expansion of a fluid. All sound, whether in water or in air, can be characterized by a few basic variables: frequency, wavelength, and amplitude. Frequency is measured in cycles per second and in units called Hertz (Hz). The higher the frequency of a sound, the higher its pitch. The ideal range of frequencies audible to humans extends from 20 Hz to 20,000 Hz (or 20 kHz), although this range decreases with age and exposure. Wavelength is the length, generally measured in meters, of a single fundamental oscillation in the propagating fluid; i.e. the distance spanned by a full cycle of compression and refraction. Wavelength and frequency are inversely related. The amplitude of a sound wave is proportional to the maximum displacement of a particle from its resting position. Sound intensity is defined as the acoustic power per unit area in the direction of propagation. The units of acoustic intensity are watts/meter. However, sound intensity is difficult to measure, so sound pressure is measured instead. Pressure is defined as force per unit of area, and the basic unit is the Pascal. Sound pressure is measured in microPascals (microPa or µPa). Amplitude corresponds to the loudness of a sound.

A pure tone is produced by sinusoidal oscillation of particles at a single frequency. Surprisingly complex sounds can be produced by the interaction between just a few pure tones. Sound in the ocean, however, is rarely a pure tone. More often it consists of a continuous distribution of

† Note: information in this **Physics of Sound** section is condensed from Richardson *et al*. (1995a)

frequencies, with varying intensity at different frequencies.

Because the human ear perceives sound logarithmically, we speak of the loudness of sound in terms of decibels rather than sound pressure. Sound pressure can be expressed in terms of decibels (dB), in which case it is referred to as sound pressure level: sound pressure level (dB) = 20 log (P/Po), where Po is a reference pressure, usually 1 microPa. Reference pressure is needed because when we wish to get a feel for how loud something is we must relate the given sound to a sound of known intensity. Acousticians measuring sound in air have used 20 microPa as their reference pressure because it is roughly the minimum sound intensity that humans can detect. However, underwater acousticians have made 1 microPa their standard reference pressure. Distance from the source (usually one meter), as well as sound pressure, must also be designated for a reference sound. Because of the need for these references, underwater sound is typically expressed as dB re 1 microPa @ 1m. Because different reference pressures are used to express air and water sound pressure levels, the decibel measures in the two media are not equivalent (as noted in Table 1 below). A sound that would be designated as 100 dB re 20 microPa @ 1m in air would be 126 dB re 1 microPa @ 1m underwater.

Table 1: Sound in Air and Water

Pascals	dB re 1 microPa	dB re 20 microPa	Typical airborne sounds and human thresholds	Typical underwater sounds and marine mammal thresholds
1,000,000	240	214		2 kg high explosive, 100 m
				Beluga echolocation call, 1 m
100,000	220	194		
10,000	200	174	Some military guns	Airgun array, 100 m
1,000	180	154	Sonic booms	
100	160	134		Large ship, 100 m
10	140	114	Discomfort threshold, 1 kHz	Fin whale call, 100 m
1	120	94		
.1	100	74	15 m from auto, 55 km/h	Beluga threshold, 1 kHz
.01	80	54	Speech in quiet, 1 m	Seal threshold, 1 kHz
.001	60	34		Ambient, SS0, _-OB @1 kHz
.0001	40	14		Beluga threshold, 30 kHz
20 µ	26	0	Open ear threshold, 1 kHz	
10 µ	20	-6	Open ear threshold, 4 kHz	
1 µ	0	-26		

(Chart from Richardson *et al.* 1995a)

Measuring sound pressure is appropriate for continuous, constant sounds. For pulsed sounds, however, duration of pulse is also important and time should be included as a dimension. Pulsed sounds should be expressed in terms of energy, proportional to microPa's, rather than pressure or power.

In order to compare sounds they must all be expressed in the same units, with the same reference pressure and distance, as mentioned before. The sound of a supertanker, for instance, might be described as 200 dB re 1 microPa @ 1m. The sound of a tanker is not, most likely, measured at a distance of one meter. But expressing its sound level in this way says that the tanker emits noise approximately equivalent to the sound level one meter distant from a 200 dB re 1 microPa ideal point (i.e. dimensionless point) source. The actual characteristics of sound emanating from a tanker are not perfectly approximated by speaking of an ideal point, but for the purposes of sound comparison this assumption is useful.

Sound travels at different speeds depending on the compressibility of the medium through which it is traveling. It travels at about 340 meters per second in air, while in water it travels at roughly 1500 meters per second. The wave character of sound is such that sound is subject to refraction. When the nature of the medium through which sound is traveling changes in such a way that the speed of the sound is altered, the path of the sound is also altered. For instance, the speed of sound is strongly affected by water temperature and pressure, and to a lesser extent by salinity. As each of these factors increases, the speed of sound increases. At low- and mid-latitudes water temperature is highest near the surface and it decreases with depth, up to a certain depth. This zone of decreasing temperature is known as a thermocline. In this zone, sound travels more and more slowly the deeper it goes; it is, therefore, refracted downward in a curving path.

The refractive nature of sound gives rise to a number of interesting effects. For instance, in the thermocline sound is refracted downward. But at the bottom of the thermocline, pressure effects take over and the speed of sound begins to increase again. Therefore it is at the bottom of the thermocline that sound travels at its minimum underwater speed. Below the bottom of the thermocline sound is refracted upward. Sound waves may therefore travel at this depth, known as the “deep sound channel”, without transmission loss due to geometric spreading. Since low frequency sounds also undergo little absorption loss, they can travel enormous distances along the deep-sea sound channel; transmission distances of over 19,000 meters have been documented. The U.S. used this property of underwater acoustics during the Cold War to listen to submarines around the world. It is now used by some whale researchers to track whale movements at great distances.

Sound may also be reflected by the air-water interface at the surface, and by the ocean bottom. The efficiency of reflection by the bottom is strongly affected by the nature of the substrate. In deep water refraction, and its variability with depth, has the strongest influence over sound propagation, while in shallow water interactions with the surface and the bottom have greater effect. Note, however, that “deep water” in this context refers to water depth in relation to the wavelength of a sound. At 1500 m/s a 20 Hz sound will have a wavelength of 75 meters. In water of depths less than _ the wavelength of a sound, propagation loss is very high. Therefore, low frequency sound is quickly attenuated in depths of less than about 20 meters.

Sound intensity decreases with distance from the source, in a phenomenon that acousticians call transmission loss, or propagation loss. Three key factors influence transmission loss: geometric spreading, absorption, and scattering. Geometric spreading varies with location, depending on such factors as source depth, water depth, bottom topography, etc. However, two concepts that are useful are spherical spreading and cylindrical spreading. A sound far from the surface and the bottom will travel equally in all directions in the form of a sphere, and transmission loss (TL) will occur according to the equation: $TL = 20 \log (R/Ro)$, where Ro is a reference range, generally 1m. In spherical spreading sound decreases by 20 dB when distance increases by a factor of 10. In shallow water sound waves will be reflected from the surface and from the bottom. At distances that are large in comparison to water depth, the sound will spread in a cylindrical fashion according to the formula: TL = 20 log R1 + 10 log (R/R1), where R1 is the distance from the source where spreading becomes cylindrical instead of spherical. When spreading is cylindrical, sound level decreases by 10 dB when distance increases by a factor of 10. In shallow water, transmission loss is frequency dependent.

Absorption loss is due to the absorption of sound by both water molecules and particles suspended in the water. Seawater absorbs about 20 times as much sound as distilled water. Absorption increases with frequency; it is approximately equal to the square of frequency, so that attenuation is much greater in high-frequency than low-frequency sounds. Absorption also decreases with increasing water pressure. Absorption loss increases linearly with distance. The loss coefficient is based on the absorptive qualities of seawater for a given frequency and depth. Scattering losses also vary linearly with distance, and are due to refraction and reflection of sound waves by inconsistencies in the medium, surface and bottom irregularity, etc.

It is also worth considering the counterintuitive effects of changing water depth on the transmission of sound. One might expect that, if sound were transmitted from a shallow area into an increasingly deeper area, it would undergo geometric spreading and lose intensity quickly. However, because of the downward sloping bottom, the angle of incidence of sound with both the bottom and the surface are shallower. Thus, fewer reflections per unit of distance occur and less sound intensity is lost. Conversely, one might expect sound traveling from deep to shallower areas to be concentrated, but the loss of sound intensity on each reflection tends to increase the rate of transmission loss.

Ambient noise may be defined as "environmental background noise not of direct interest during a measurement or observation; may be from sources near and far, distributed and discrete, but excludes sounds produced by measurement equipment" (Richardson *et al.* 1995a). Ambient noise is present in any sound-propagating medium, whether air, water, or otherwise. But because sound travels such great distances in water, ambient noise is of particular concern in the marine environment. It comes from the sound of waves, seismic disturbances, precipitation over the water, sea ice, the crashing of the surf, shipping noises, etc. Its level may vary greatly as these sources vary. Most industrial noise is less than 1 kHz, and shipping noise tends to dominate ambient noise levels between 20 Hz and 300 Hz. Low frequency components of shipping noise may travel up to 4000 km. The propeller blades of oceangoing ships generate noise in the 1 Hz to 20 Hz range.

Ambient noise is a very important concept when looking at the effects of anthropogenic underwater noise on marine organisms, because sounds can only be heard if they are not masked by ambient noise. Masking is the obscuring of sounds of interest by interfering sounds. Sounds are masked primarily by other sounds of similar frequency. The range of frequencies that might mask a sound is called the critical band. The ratio of the sound level of a just-audible tone to the background level is called the critical ratio. Since decibels are logarithmic, the critical ratio can be estimated by subtracting the decibel level of the ambient noise from the decibel level of the just-audible sound. For example, if a sound must be 100 dB re 1 microPa @ 1m to be heard over an ambient noise of 80 dB re 1 microPa_/Hz at similar frequencies, then the critical ratio is 20 dB. If human activities are substantially increasing the ambient underwater noise level, then it is possible that animals are no longer able to hear some sounds, such as those giving environmental cues or coming from other organisms important to them.

The absolute auditory threshold of an animal is the minimal sound intensity level at which it may hear a sound of a particular frequency without significant ambient noise. The absolute auditory threshold varies with frequency, as well as from species to species, individual to individual, and even from time to time for a single individual. A graph of absolute auditory thresholds versus frequency for an organism is called an audiogram. We do not have audiograms for many marine species, but the general pattern is that animals have higher thresholds at the extreme frequencies of their hearing range, and more sensitive hearing at frequencies in the middle of their range.

In order to fully understand the effects of underwater noise on marine organisms, one must have information on sound level at the source, the transmission loss of the sound, and ambient noise near the animal, as well as an understanding of the effects of sound on the animal itself. Putting all of these factors together makes for a very complicated picture; one very difficult to predict based on theory. Empirical measurements are therefore to be preferred.

Non-Anthropogenic Noise

Ambient noise in the oceans spans across a broad frequency range from 1 Hz to 100 kHz (Scheifele 2000a). These frequencies emanate from both anthropogenic and non-anthropogenic sources, and both contribute to the total noise in marine environments. Sources of non-anthropogenic noise include: hydrostatic pressure changes, wind and surface waves, thermal noise, rain, and other organisms. A brief discussion of each is given below.

The low frequency end of the spectrum (0.1 to 1kHz) is dominated by changes in hydrostatic pressure that result from currents and tides (Scheifele 2000a). These changes are sources of noise at both the surface and at depth. Low-frequency noise is also produced by hydrostatic pressure changes on the ocean bottom due to topographic features (Scheifele 2000a).

Surface waves increase surface scatter and flow noise due to wind blowing over the sea surface (Isakovich and Kuryano 1970 in Scheifele 2000a). The generation of bubbles from surface waves and whitecaps causes surface cavitation and thus creates noise (Furduev 1966 in Scheifele 2000a). Wind and surface waves generally contribute to ambient noise at frequencies between 500 Hz and 25 kHz (Scheifele 2000a). Noise levels due to wind depend on the wind speed and the depth of the received sound. For instance, Wenz (1962 in Richardson *et al.* 1995a) found that the spectrum level at 1 kHz in deep water was 51 dB re 1 microPa^2/Hz when the wind speed was 5 knots. Wenz (1962 in Richardson *et al.* 1995) also found that there is generally a 5 dB increase with each doubling of wind speed between 2.5 to 40 knots.

Thermal noise is the result of the molecular interactions that occur in seawater (Scheifele 2000a). It is a significant source of noise at frequencies above 30 kHz (Mellen 1952 in Richardson *et al.* 1995a). Thermal noise has been found to limit the effective echolocation of some toothed whales that use very high frequency echolocation calls (Johnson 1979 in Richardson *et al.* 1995a).

Rain also contributes to ambient noise in the oceans. Rain generates noise between 1 kHz and 20 kHz and directly affects ambient noise depending on the rate of rainfall (Scheifele 2000a).

Of course, organisms in the marine environment also create noise. Biologics refers to sounds generated by any organism in the marine environment (Scheifele 2000a), including sound made by mammals, fish, invertebrates, etc. These sounds may be intermittent or constant. Nearly the entire frequency spectrum, from 5 Hz to 100 kHz, can be affected by biologics (Scheifele 2000a).

There are many other sources of non-anthropogenic noise that contribute to the total noise levels in marine environments. Some of these include seismic disturbances, meteorological disturbances, and sea ice noise (Richardson *et al.* 1995a; Scheifele 2000a).

Anthropogenic Noise

Vessels as a Source of Noise

Vessel traffic is a highly significant source of noise for marine environments. Scheifele (2000a) states that vessel noise generally dominates ambient noise at frequencies between 50 and 500 Hz. Vessel noise is a combination of narrow-band, tonal sounds at specific frequencies and broadband sounds over a range of frequencies. Frequencies and levels of both narrow-band and broadband frequencies tend to be related to vessel size. However, vessel design and vessel speed also have large effects on the amount of noise produced. In general, large ships tend to be noisier than small ships (Richardson *et al.* 1995a).

The primary sources of sounds from vessels are propeller singing, propeller cavitation, and propulsion machinery (Richardson *et al.* 1995a). Propellers "sing" when the frequency of the vortex shedding due to the motion of the propeller matches its resonance frequency, causing the propeller to oscillate. The result of propeller singing is a strong tone between 100 and 1000 Hz (Richardson *et al.* 1995a). Singing propellers are a particular problem for older and poorly maintained vessels, and often are a result of normal wear and tear of the propeller. A vessel that is in poor condition may generate more noise due to a singing propeller than one that is in good condition (McCauley *et al.* 1996). Propeller cavitation is the sudden formation and collapse of low-pressure bubbles due to the movement of a vessel's propeller. This cavitation, in turn, creates noise. Ships tend to cause more cavitation when they are fully loaded (Scheifele 2000a). Another source of noise originates inside the hull of a vessel from propulsion machinery and is transmitted to the water via the hull. Some of the sources of this type of noise are rotating shafts, gear teeth, engines, compressors, and mechanical friction (Richardson *et al.* 1995a).

Speed of vessels appears to be directly correlated with received noise levels. McCauley *et al.* (1996) state that speed has a greater effect on levels of received noise than the number of vessels. They found that a single class A vessel (>1 ton, high-powered outboard vessel) traveling at 10 knots gives a noise level 11 dB higher than a similar vessel at the same range traveling at 5 knots. They also pointed out that it would take 12 vessels traveling at 5 knots to produce the same received noise levels as 1 vessel of the same type traveling at 10 knots. Similarly, a single class G vessel (>20 m, fast multihull) moving at 25 knots gives off the same received noise levels as 100 vessels of the same type moving at 5 knots.

Received noise levels from vessels are different from source noise levels. Received noise levels depend upon the distance from the source. Richardson *et al.* (1995) estimate that received noise levels from small boats at 50 m may be 34 dB lower than source levels. However large distances do not appear to diffuse all vessel noise. Finley *et al.* (1990 in EIA 1998) documented a case where beluga whales (*Delphinapterus leucas*) appeared to be aware of a ship at a distance of 85 km.

Signatures and sound levels vary depending on the size of the vessel. Large commercial vessels and supertankers have powerful engines and slow turning propellers. Most merchant vessels run either a single five blade or a twin three or five propeller configuration (Scheifele 2000a). Richardson *et al.* (1995a) state that shipping traffic generally dominates ambient noise from 20 to 300 Hz.

Large vessels generate strong tones with low frequencies. Fundamental frequencies for the Chevron supertanker *London* were measured at 6.8 Hz from over 140 km away (Ross 1976 in Richardson *et al.* 1995a). But the strongest tones measured for the supertanker were 40 to 70 Hz, and sound levels were approximately 190 dB re 1 microPa @ 1m. In general, supertankers and container ships have low frequency tones and source levels in the range of 180-190 dB re 1 microPa @ 1m (Gisiner *et al.* 1998), although some supertankers can generate source levels that exceed 205 dB re 1 microPa @ 1m (Richardson *et al.* 1995a).

Small ships are characterized by support and supply ships. They are roughly 55-85 m in length and are generally diesel-powered with two propellers. Frequencies of vessels in this class are often broadband (20-1000 Hz) and source levels are approximately 170-180 dB re 1 microPa (Richardson *et al.* 1995a). Medium to large vessels generate tones up to approximately 50 Hz (Richardson *et al.* 1995a) and tugboats and ferries have source levels of approximately 150-170 dB (NRDC 1999). Small vessels typically create higher frequency noise than larger vessels, because smaller vessels have propellers with high rotation rates that result in cavitation noise at higher frequencies (Richardson *et al.* 1995a).

Richardson *et al.* (1995a) classify most boats as typically 30 m or less in length. This includes private boats, charter boats, commercial fishing boats, and whale watching boats. The noise associated with boats depends largely on the type of engine the vessel has. Fishing boats often have higher-speed engines and propellers than ships. Noise from fishing boats peaks around 300 Hz (Richardson *et al.* 1995a). Even small boats can generate large amounts of noise. For example, small boats with large outboard engines can produce sounds on the order of 175 dB re 1 microPa @ 1m. Boats in this class often create tones at frequencies up to several hundred Hz (Richardson *et al.* 1995a).

Acoustic Deterrents

Acoustic deterrents are used to deter marine mammals from entering certain areas. The two main types of acoustic deterrents are acoustic deterrence devices (ADDs) and acoustic harassment devices (AHDs).

ADDs, also known as pingers, are designed to stop marine mammals from getting caught in fishing nets. They emit strong, but brief noises with mid-frequencies (approximately 2 to 4 kHz) and source levels around 130 dB re 1 microPa @1m (Richardson *et al.* 1995a; NRDC 1999). ADDs that emit 300 millisecond pulses, with broad band source levels of 132 dB re 1 microPa @ 1m, have been used to reduce harbor porpoise (*Phocoena phocoena*) bycatch (EIA 1998). To date, ADDs have been widely successful at reducing entanglement of marine mammals in fishing nets (NRDC 1999).

AHDs, also known as ringers and squeakers, emit very short, high intensity pulses at mid-frequencies that actually seek to cause marine mammals pain (NRDC 1999). They are often used to deter marine mammals from aquaculture pens (EIA 1998). Source levels for these devices are usually greater than 190 dB (NRDC 1999).

Offshore Oil Exploration & Mining

In 1989 the Exxon *Valdez* oil spill off the coast of Alaska focused national attention on potential problems associated with offshore oil and gas operations. While measures have since been taken to limit these problems, until only recently the potential acoustic impacts of offshore oil exploration and mining activities have been largely ignored. Developing a better understanding of the noise levels associated with various oil extraction activities is an important first step in determining their potential acoustic impacts on marine life.

In the U.S. the Department of Interior's Minerals Management Service (MMS) manages offshore oil and gas exploration and development. These activities are limited to the outer continental shelf (OCS) of the Gulf of Mexico, Alaska, and California. Regional activities on the Pacific OCS will be highlighted here, due to their proximity to and potential impacts upon CINMS.

Oil drilling from standard bottom-founded platforms is estimated to emit low intensity sounds in the frequency range of 4 to 38 Hz, with the strongest recorded noise levels at around 5 Hz. The received (near field) sound level at this frequency is between 119 and 127 dB re 1 microPa (Richardson *et al.* 1995a). Intermittent sounds associated with building and repair activities (e.g. hammering pipelines) may produce higher noise levels (30 to 40 Hz, 131 to 135 dB re 1 microPa). While there is some indication that these conventional metal-legged platforms may produce substantial noise, the precise amount of noise varies among platforms and even a single platform can vary over time. In general, the noise emitted from these structures dissipates quickly and can no longer be heard within a few kilometers of the source. Underwater noise levels are particularly low when drilling occurs from manmade or natural barrier islands, which have a dampening effect. Likewise, onshore power supplies emit much less noise than gas turbines and generators operated on platforms (Richardson *et al.* 1995a).

Oil tankers, auxiliary vessels, seismic exploration, and the decommissioning of existing drilling platforms may prove greater acoustic threats than the day to day operations of offshore drilling structures (Dettmer pers. comm. 2000a; Fahy pers. comm. 2000; Richardson *et al.* 1995a). Oil tankers produce noise levels similar to other large cargo vessels (see section above). However they may not be a significant source of noise in the CINMS, because most lease-holding companies have voluntarily agreed to transport oil 50 miles from the California coast as a precaution against near-shore oils spills (Dettmer pers. comm. 2000a; Fahy pers. comm. 2000). This commitment keeps oil tankers out of the Santa Barbara Channel (except for those working at platforms in the Channel), a major shipping lane adjacent to the Channel Islands.

Drillships and semisubmersible drilling vessels also produce significantly more noise than their associated drilling platforms. Of the two, semisubmersibles generate less underwater noise because their machinery is mounted on deck. Noise levels have been recorded at broadband frequencies of 10 to 500 Hz and 80 to 4000 Hz. The estimated source level at both of these frequencies is 154 dB re 1 microPa. Drillship emissions are even higher (174 to 185 dB re 1 microPa), which is attributable to the fact that all motors, generators, and machinery are contained within the hull of each vessel. The close coupling of drillship hulls and water allows for direct sound transmission into the water, which accounts for the higher source levels observed in these ships. The frequency spectra associated with drill ships vary considerably, depending on the number of generators and types of activities occurring on board at any given time. Most strong tones are recorded at under 600 Hz, although some Arctic ships (reinforced for ice) can be even louder (20-1000 Hz; 191 dB during drilling) (Richardson *et al.* 1995a).

The decommissioning of oil rigs has yet to become a major issue in California, with only four platforms removed in 1996 and just a few slated to stop production in the near future. However as more leases expire, decommissioning may become a controversial issue from the acoustics standpoint. Activities involved in the removal of oil platforms often have transient acoustic impacts associated with explosions or other methods of physical removal (AMAP 1997).

Marine seismic exploration is the greatest potential acoustic threat associated with offshore oil and gas. Air gun arrays used in exploring operations emit very high-level pulses. Most pulses occur at less than 100 Hz, lasting less than a second with 10 to 15 second intervals (Richardson *et al.* 1995a). Beyond a few kilometers these pulses attenuate to between 100 and 250 Hz. Peak noise levels from air gun arrays are in the range of 240 to 250 dB re 1 microPa. These levels far exceed the standard safety level of 180 dB established by the High Energy Seismic Survey (HESS) team in February 1999 (Fahy pers. comm. 2000; MMS 2000; Richardson pers. comm. 2000). In fact, pulses can be detected at levels above 160 dB at distances over 100 km from the air gun blast. Received levels vary with depth, becoming several decibels stronger in deeper water (Richardson *et al.* 1995a).

The most recent seismic survey in the Pacific OCS region was conducted by Exxon Company in the Santa Barbara Channel in 1995 (County of Santa Barbara 1998). Since then, Venoco cancelled a proposed survey, slated to begin in 2001 (Fahy pers. comm. 2000; MMS 2000). Although there have been no seismic surveys in the past five years, oil companies are expected to begin exploration in the near future of the 36 undeveloped leases in the Pacific OCS (Dettmer pers. comm. 2000a). Despite attempts to mitigate the effects of these exploratory surveys, they will likely affect marine organisms in the CINMS.

Other Activities (ATOC and LFA)

The Acoustic Thermometry of Ocean Climate project (ATOC) uses low frequency sound to measure ocean temperatures in order to monitor the effects of climate change. It typically produces sounds up to 195 dB at 75 Hz and at ocean depths below 900 m (Buck 1995). The use of the deep-sea Sound Fixing and Ranging (SOFAR) channel to propagate low frequency transmissions allows the ATOC signal to be received thousands of miles away. ATOC is a joint project of several institutions, though principally carried out in the past by Scripps Institution of Oceanography (Buck 1995). Though expansion of its use to other oceans has been contemplated, ATOC has exclusively operated in the Pacific, on the Pioneer Seamount off California and on the coast of Kauai. The ATOC project moved its California operations from its initial location in Monterey Bay National Marine Sanctuary, due to NOAA's concerns about potential negative impacts on the marine environment (Clover 1995). ATOC underwent a National Environmental Policy Act (NEPA) review and, due in part to continued objections from the Marine Sanctuary, has decided not to seek authorization for continued testing in California waters. The project has requested permission to renew its operations in Hawaii as the North Pacific Acoustics Laboratory (Clark pers. comm. 2000). The associated Marine Mammal Research Project (MMRP) will not continue, however, although results of its research are still quite relevant to the management of the sanctuaries.

The U.S. Navy has been instrumental in the development of low frequency sonar. Politicians, citizens and scientists have raised concerns over the impact of these sonar systems on marine life. In particular, the potential impact of low frequency tests on baleen whales has elicited attention, as these animals are much more sensitive to low frequency sound and dive to depths at which these sounds are most intense (Clark *et al.* 1999). U.S. Navy sonar testing has the potential to affect both CINMS and SBNMS, although the degree of likely impact varies for each geographic region.

Surveillance Towed Array Sensor System / Low Frequency Active Sonar (SURTASS LFA or LFA, as referred to in this document) is the U.S. Navy's most recent tactical development in anti-submarine warfare. Its operation could potentially affect marine sanctuaries. LFA uses low frequency active sonar and a system of passive sound receivers to detect and locate quiet submarines over 100 km away (Tyler 1992). The Navy initiated new research into anti-submarine warfare in 1985 in response to the threat of quiet, diesel submarines that are not detectable using older passive sonar techniques. The Navy perceives LFA to be of use in future conflicts fought in shallow coastal areas.

The Navy has tested LFA in both the Atlantic and Pacific Oceans and a proposal for its continued use is currently under NEPA review. The Navy plans to develop a sonar network of four transmitting ships that will operate independently in both oceans (U.S. Navy Draft 2000). These ships will broadcast 215 dB pulses of sound at 100-500 Hz for 10-20% of the time during the 108 days per year that LFA will be active. Sites along the North American coast including the Sable Island Bank, southeast of San Nicolas in CINMS, and offshore central California, have already been used by the Navy to test low frequency sonar.

Clark (pers. comm. 2000) commended the U.S. Navy for evaluating its sonar operations under public scrutiny and for its efforts to address public concerns though mitigation and monitoring of the LFA project. The proposal to continue LFA includes plans for a 12 nautical mile "mitigation zone" around coasts and "biologically important areas." In this zone, testing sound levels would be held to no greater than 180 dB (U.S. Navy Draft 2000). Another zone would limit sound levels to 145 dB in the vicinity of commercial diving areas. In his comments on the environmental impact study for LFA, Jeffrey R. Benoit, Manager of NOAA's Office of Ocean and Coastal Resources, requested that the Navy extend the 180 dB mitigation zone to include national marine sanctuaries (Benoit 2000).

Several researchers have examined the impact of Navy sonar testing on marine mammals with varying results (Bowles *et al.* 1994; Clark *et al.* 1999; Frankel and Clark 1998). The most commonly identified effect was a change in behavioral response. Dr. Ann Bowles monitored the impact on cetaceans of the Heard Island Feasibility Test, the U.S. Navy's first successful long–range test of low frequency sonar. Using a network of hydrophones, she recorded whale vocalizations in the test area and found a cessation of sperm whale (*Physeter macrocephalus*) calls during tests (Bowles *et al.* 1994). A displacement of baleen whales from the test area was detected, but a low sample size limited the significance of the finding.

Frankel and Clark (1998) observed that the distance and time between humpback whale surfacings increased during exposure to the ATOC transmission (Frankel and Clark 1998). However, the significance of this reported behavioral response is not fully known. Tyack (1999) studied gray whale (*Eschrichtius robustus*) migration past a mobile ATOC source off the coast of California. He reported that whales deviated from their migratory path when exposed to transmissions from an inshore location. Responses to low frequency sound depend on the hearing frequency ranges of the animals engaged. For example sea lions, Risso's dolphins (*Grampus griseus*), and false killer whales (*Pseudorca crassidens*), none of which hear low frequencies well, were exposed to low frequency sounds without observable avoidance or other responses (Au *et al.* 1997; Costa and Calambokidus 1999). Despite some indication that ATOC-like sounds affect marine mammal behavior, researchers have not determined the implications of low-frequency sound exposure on survival and reproduction (NRC 2000). Clark (pers. comm. 2000) stated that few impacts were detected in studies he carried out, but noted that these were short-term studies. He stressed the need to conduct research into the long-term effects of acoustical disturbance on marine mammals.

Critics and observers have alleged that LFA has much more catastrophic effects on marine mammals than the above research would indicate. There have been several reports of stranding events in the Mediterranean Sea coinciding with NATO operations and sonar tests in the area (Frantzis 1998; Simmonds and Lopez-Jurado 1991). These stranding events were unusual given that beaked whales, a group of whales that rarely strand, were found beached in large numbers. They are predominantly deep divers and could possibly be more susceptible to low frequency sounds. A panel convened by NATO in response to concerns concluded that evidence was lacking for an acoustical cause in the whales' strandings. The panel did confirm, however, that sonar testing occurred at the same time as a beaked whale stranding in Greece, and that sounds as loud as 230 dB were transmitted at low and mid-frequencies (U.S. Navy Draft 2000). The most recent unusual stranding occurred during the spring of 2000 in the Bahamas, where 16 whales and dolphins stranded during LFA testing. Six beaked whales died in the stranding and when examined were found to have experienced trauma in their hearing, sound production, and respiratory tissues (Los Angeles *Times* 2000). Though there is currently no conclusive evidence linking the Bahamas or Mediterranean strandings to military testing activities, the events have elicited concern on the part of some researchers (Los Angeles Times 2000).

Humans have also been exposed to low frequency Navy sonar and could potentially suffer hearing damage or other physiological effects. There have been several anecdotal accounts of several scuba divers in Hawaii and California who allege that they have been harmed by exposure to ATOC transmissions. One diver off the coast of California claims he experienced the ATOC signal and that the low frequencies made his lungs vibrate. That broadcast was taking place approximately 150 miles away (Murray 2000). Another diver remained in the water during an ATOC broadcast in Hawaii and experienced sounds estimated at 120 dB. Following this exposure, she experienced disorientation and, when examined by a doctor, was found to have acute trauma (Green 1999).

Opinions regarding the harmful impacts of low frequency sound are mixed. The U.S. Navy suggests that neither LFA nor ATOC pose a significant threat to marine life. Although they acknowledge the potential of LFA to interrupt biologically significant behavior, i.e., feeding and mating (U.S. Navy Draft 2000), they do not believe that a substantial percentage of the stock at any one time would be exposed long enough to warrant concern. Clark (pers. comm. 2000) recognizes the potential for LFA to cause damage to marine mammals within a certain range. The NRC, in its 2000 review of the ATOC project's MMRP, stated that inconclusive data precluded a determination of the impact of ATOC on marine mammals. The Environmental Protection Agency (EPA), in its review of the U.S. Navy's environmental impact statement for LFA, concluded that there was insufficient information to evaluate the project and expressed environmental concerns (EPA 2000).

There are several potential developments in Navy sonar that may arouse attention in the future. One of these is the use of High Frequency Marine Mammal Monitoring (HF/M3) sonar as a mitigation measure for LFA. This high frequency sonar would emit 220 dB pulses of sound at 30,000 Hz in order to detect cetaceans or sea turtles in LFA's mitigation zone. The HF/M3 would be ramped up to full volume over 5 minutes and would be decreased to below 180 dB if an animal were detected in the mitigation zone. This form of sonar would more likely affect odontocetes due to their higher range of audible frequencies (U.S. Navy Draft 2000). Richardson (pers. comm. 2000) mentioned the testing of a new naval sonar system at Point Mugu Sea Range near CINMS. Information about the testing and an impact statement for it were not available at the time of this writing.

The possibility also exists for the development and expanded use of low-frequency sonar by other navies of the world. Though the U.S. and NATO countries have been first in the field, other nations will likely obtain the technology to develop similar systems in order to achieve an equivalent submarine detection capability. The race to develop better technology for detection and concealment presages a new type of military engagement -- acoustic warfare (Tyler 1992). The spread of low frequency sonar to all the world's oceans could pose an even greater impact to marine life, by affecting migratory marine animals throughout their ranges.

Some Relevant Laws and Regulations

This report found no laws or regulations specifically addressing the issue of anthropogenic noise and its impacts upon marine life. However, legislation and regulations currently in effect do provide NOAA and others with the means to address, or at least begin to address, this issue in and around National Marine Sanctuaries.

The Marine Protection, Research, and Sanctuaries Act (Title III) of 1972 (as amended), also known as the National Marine Sanctuaries Act, led to the establishment of the NMSP (NOAA 2000d). Regulations for that Program found in the Code of Federal Regulations (Title 15, Chapter IX, Part 922) state that resource protection is its primary objective (NOAA 2000e).

Much of NOAA's control over National Marine Sanctuaries lies in its permitting authority, vested in the Director of the NOAA Office of Ocean and Coastal Resource Management. The Director may grant nontransferable permits for activities otherwise prohibited in a sanctuary. She can also regulate the exercise of existing leases, permits, licenses, or rights of subsistence use or access already in place when a sanctuary is designated. The Director may also amend, suspend, or revoke a permit issued under the regulations of the Program if a permittee or applicant has violated either its terms and conditions or Program regulations (NOAA 2000e).

Additional regulations in the Code of Federal Regulations address individual sanctuaries. Those for CINMS prohibit oil and gas exploration, development, and production, except as necessary for the national defense, to respond to an emergency, or pursuant to leases executed prior to March 30, 1981. They also limit: the discharging or depositing of materials in the sanctuary; construction, drilling, or dredging; flights of motorized aircraft under 1000 feet; and the removal or damage of historical or cultural resources. The Director may issue permits for any of these activities for research related to sanctuary resources, to further the educational value of the sanctuary, and for salvage and recovery operations (NOAA 2000e).

Regulations specific to SBNMS prohibit: discharging and depositing certain materials in the sanctuary; exploration for, development and production of minerals; drilling into, dredging or otherwise altering the seabed and the construction of most structures on the seabed; removing or injuring a historical resource or attempting to do so; and the taking of any marine reptile, marine mammal or seabird in or above the sanctuary, except as permitted by the Marine Mammal Protection Act (MMPA), the Endangered Species Act (ESA), and the Migratory Bird Treaty Act. At-sea transfer of petroleum-based materials is also prohibited; as is possessing historical resources and any marine mammal, marine reptile or seabird taken in violation of the above three laws; as well as interfering with enforcement activities. Department of Defense actions may be exempt from many of these prohibitions. The Director may issue or agree to permits for most of these activities, with the exception of mineral exploration and development, the disposal of dredged materials, and interfering with enforcement of the National Marine Sanctuaries Act or of regulations under it and permits subject to it (NOAA 2000f).

The nature of the prohibitions reflects concerns specific to the two sanctuaries. Oil and gas exploration is a major issue for CINMS, while in the case of SBNMS mineral exploration and dredging are primary concerns. All of these activities have potential acoustic impacts on wildlife in the sanctuaries. It is also interesting to note that the regulations do not appear to directly address shipping. There is an "Emergency Regulations" provision in the general section of the regulations that could include shipping and would allow for the temporary regulation, including prohibition, of activities leading to the destruction of, loss of, or injury to a sanctuary resource (NOAA 2000e).

Fishing concerns are left to the Secretary of Commerce, who has overall responsibility for NOAA. The Secretary is to work with the appropriate Regional Fishery Management Council to develop these regulations (NOAA 2000g).

Other relevant legislation includes the Coastal Zone Management Act (CZMA), the MMPA, and the ESA. The CZMA allows a state with an approved coastal management program to certify that the proposed activities of applicants for federal licenses or permits are consistent with the state's program. This "consistency authority" applies to proposed activities occurring either within or outside a state's coastal zone, as long as they would affect that coastal zone (O'Grady 1998). The CZMA thus provides state coastal management programs with powerful veto authority over certain federally licensed or permitted activities. For example, this authority could allow the California Coastal Commission to certify proposed oil and gas exploration in the area of CINMS, since it would require permits from the MMS (Dettmer pers. comm. 2000b). CINMS' location, both within and outside state waters, and concerns over oil and gas activities off of California (where there are more than thirty existing leases that could be pursued for exploration), has led to a high degree of cooperation between the California Coastal Commission and sanctuary officials. Cooperation between the Massachusetts Coastal Zone Management Authority and SBNMS appears to be more limited, possibly due to the fact Stellwagen Bank lies entirely outside state waters and that oil and gas exploration is not an issue (Smrcina pers. comm. 2000). The CZMA provides those states having federally-approved management programs the ability to become involved in issues that affect their coastal zones. These issues could potentially include acoustic effects.

The MMPA comes into play given the existence of numerous marine mammal species in each sanctuary. Under the MMPA, it is unlawful for any person or vessel subject to U.S. jurisdiction to take a marine mammal. "Take" means to harass, hunt, capture, etc. "Harassment" has two definitions under the Act (O'Grady 1998). "Level A harassment" is any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild. "Level B harassment" is any act of pursuit, torment, or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering (O'Grady 1998). MMPA has obvious relevance to anthropogenic noise concerns associated with sanctuaries. It has driven much of the acoustic research focusing on the question of whether or not anthropogenic noise constitutes harassment of marine mammals and at what levels it does so.

The ESA extends beyond marine mammals to cover threatened and endangered species of all animal and plant taxa. It also makes it unlawful for any person subject to U.S. jurisdiction to take a listed endangered species and defines "take" to include "harass," although it does not include a separate definition of harassment (O'Grady 1998). Nevertheless, the ESA is another means of potentially addressing acoustic concerns in and around sanctuaries, perhaps made even more relevant by its attention to maintaining species habitats.

Although these laws and regulations do not directly address the potential effects of anthropogenic noise on marine life, they offer several potential legal approaches to the issue at both federal and state levels.

EFFECTS OF NOISE ON MARINE LIFE: WHAT WE KNOW

Effects of Anthropogenic Noise on Marine Mammals

Currently, we lack the research to understand fully the short- and long-term consequences of marine mammals' exposure to noise. Existing data suggest that anthropogenic acoustical signals may lead to a variety of adverse effects in marine mammals, possibly including hearing loss, physiological damage, alterations in feeding and breeding behavior, and changes in cetacean migration patterns (EIA 1998). This report explores the range of these effects.

Effects on Hearing

Little information is available on the effects of man-made noise on the hearing of marine mammals. Extensive experimental work on the topic only began recently and by a handful of researchers (Richardson pers. comm. 2000). The effects of noise on hearing include masking and threshold shifts. Masking refers to the fact that a sound of interest must reach a certain intensity relative to ambient noise before it can be distinguished. Increased ambient noise levels may therefore "mask" sounds that are important to marine mammals and other organisms (Richardson *et al.* 1995a; Southall *et al.* 2000). Threshold shift refers to the elevation of the hearing threshold of an animal as the result of exposure to intense sound. Threshold shifts alter an organism's absolute ability to hear, as opposed to the drowning out of sound by other sounds seen in masking. Of course in reality, threshold shifts also occur in the presence of ambient noise and masking (Schlundt *et al.* 2000). Threshold shifts may be temporary, in cases in which an animal's hearing ability returns to baseline levels, or they may be permanent. Both temporary threshold shift (TTS) and permanent threshold shift (PTS) may result from exposures to intense sound levels (Finneran *et al.* 2000). PTS is the result of permanent damage to the hearing mechanism of the ear. Thus it is more than just an effect of noise on hearing; it is a physical trauma.

Mammalian hearing sensitivity differs at different frequencies. As noted earlier, sounds are masked only by noises of a similar frequency. Noises at widely different frequencies, even if intense, do little to mask a particular sound. Therefore, masking tests generally project noises in a frequency band centered around the frequency of interest. As a general rule, the sound of interest or signal must exceed the ambient noise level before it can be detected (Richardson *et al.* 1995a). Data on masking (and also for threshold shifts) exist for only a few species of marine mammals. All data come from experiments on animals in captivity. No studies have been done on baleen whales or large odontocetes due to the inability to work with them in captivity, and the difficulty of performing similar experiments on wild animals.

Southall *et al.* (2000) documented masking in three species of pinnipeds: a northern elephant seal (*Mirounga angustirostris*), a harbor seal (*Phoca vitulina*), and a California sea lion (*Zalophus* *californianus*). They looked for auditory masking at six different frequencies between 100 and 2500 Hz. At sound levels of 86 to 115 dB, critical ratios ranged from 10 to 22 dB. These critical ratios are somewhat lower than those found for most other animals at similar frequencies (Southall *et al.* 2000). The investigators conclude that these pinnipeds hear relatively well in the presence of noise (Southall *et al.* 2000), perhaps as an adaptation to the noisy surf environment in which they spend much of their time. Even so, they argue that masking may be of concern to these species, citing an example in which a supertanker 10 km distant might reduce the effective underwater communication distance between two harbor seals from 160 m to 8.1 m.

The work of Erbe, Farmer *et al.* has primarily explored masking in beluga whales and developing an "accurate, reliable, and fast model to replace lengthy and expensive animal experiments" (Erbe 2000). A captive beluga whale was subjected to three different types of masking noise to see if it could detect the desired signal, which was a typical beluga whale vocalization. The masking noises, in order of most severe masking effects to least, were icebreaker bubble system noise, propeller cavitation, and natural thermal ice cracking noise (Erbe and Farmer 1998; Erbe *et al.* 1996). A software model was developed to estimate the zones of impact of icebreaker noise on beluga whales in the arctic (Erbe 2000; Erbe and Farmer 2000a, 2000b; Erbe *et al.* 1999). Impact zones vary depending on the depth of water in which noise occurs and on the depth of the hearer, as well as whether the noise comes from the bubbler system or from propeller cavitation. Erbe and Farmer (2000b) estimated that the noise of the Canadian icebreaker *Henry Larsen* was audible to beluga whales at distances of up to 78 km. Masking was predicted to occur in all scenarios at any distance less than 6 km, and in almost all scenarios at any distance less 14 km. At the far extreme, masking effects could extend out to 71km. They predicted a TTS of 4.8 dB between 10 and 20 kHz if a beluga whale were to spend more than 20 minutes within 2 kilometers of the icebreaker, at any depth up to 1400 meters. In some situations, it was estimated that a TTS could occur within 20 minutes inside a 4 km radius of the icebreaker. However, the noise levels or number of incidences of TTS leading to PTS are not known.

A set of experiments has also recently been performed to measure masked temporary threshold shifts (MTTSs), which are TTSs in the presence of masking sound (Finneran *et al.* 2000; Schlundt *et al.* 2000).

Schlundt *et al.* (2000) measured hearing thresholds in five bottlenose dolphins (*Tursiops truncatus*) and two beluga whales before and after exposure to intense tones of one second duration at 0.4, 3, 10, 20, and 75 kHz. They found that tone intensity levels of 192 to 201 dB were generally needed in order to cause a 6 dB threshold shift, although no shift was detected at 0.4 kHz at levels up to 193 dB, the maximum level tested at this frequency. All tests were conducted in San Diego Bay in the presence of a high level of ambient noise. The authors note that in humans, masking reduces the measured level of TTS. At the end of the series of experiments, the masked auditory thresholds of the subjects had returned to baseline values. Schlundt *et al.*'s conclusion: "cetaceans are susceptible to TTS, and small levels of TTS may be fully recovered."

Finneran *et al.* (2000) (mostly the same group that performed the aforementioned experiment) also tested MTTS in two bottlenose dolphins and one beluga whale in San Diego Bay, measuring their hearing thresholds before and after exposure to simulations of distant underwater explosions of varying strengths. Sound pressure levels varied from 170 to 221 dB re 1 microPa. No threshold shifts of greater than 6 dB were observed, though the investigators believed that they were nearing the necessary sound levels to cause MTTS. All of the subjects' hearing returned to baseline threshold levels after the experiment. Threshold shifts of less than 6 dB were not considered significant, because such shifts may have been simply the result of day-to-day or session-to-session variation in subjects' hearing abilities. Again, because the experiment was carried out among high ambient noise levels, absolute threshold shifts may have exceeded 6 dB, though MTTS did not.

Kastak *et al.* (1999) have obtained data on unmasked TTS in three species of pinniped, one harbor seal, two California sea lions, and one northern elephant seal. The test subjects were exposed to octave-band noise with frequencies centered at 100 Hz, 500 Hz, 1000 Hz, and 2000 Hz, for 20 to 22 minutes, at sound levels 55 to 75 dB above their absolute auditory thresholds. Temporary threshold shifts averaging 4.6 to 4.9 dB were observed. Again, auditory thresholds returned to baseline levels within 24 hours.

One important distinction between the studies by Kastak *et al.* (1999) and Finneran *et al.* (2000) on the one hand and those by Schlundt *et al.* (2000) on the other, is that the former examine the effect of broad band noise (one continuous and one impulsive) as opposed to continual tonal noise. However, the effects on TTS or PTS of the various parameters of impulsive broadband noise, such as peak frequency, duration, rise time, peak pressure, and total energy, are still unknown.

Ridgway and Carder (1997) looked at absolute auditory thresholds in four male and four female bottlenose dolphins. Paralleling findings in humans, hearing disability was predominant in males and in older individuals. Three of the males had very poor hearing at frequencies above 80 kHz, and one female could not hear well above 100 kHz. Interestingly, one of the male's absolute auditory threshold had been measured 13 years before, and showed significant deterioration in the interim. It is pointed out that in circumstances where ambient noise is high in mid-ranges (e.g. in the presence of snapping shrimp), bottlenose dolphins may shift to echolocation calls above the 100 kHz level. Individuals with hearing deficits would be disadvantaged in such situations. However, Ridgway and Carder (1997) do not offer any information on the potential impacts of increasing anthropogenic noise on the rate of hearing degeneration in marine mammals.

Some limitations of masking and threshold shift experiments are that they require trained animals. Therefore, they have all involved exceedingly small sample sizes and have been performed in laboratory situations rather than in the field. Erbe (2000) has had some success designing a neural network computer model to replace animal experiments. However, it is based on a single beluga whale's behavior. While such models are promising, the complexity of animal behavior and underwater acoustics, the fact that good masking experiments have yet to be done in natural situations, and the fact that many species have yet to be studied, all take away from the utility of current computer simulations. They are not yet capable of providing the same information as experimentation.

The experiments cited above conclusively demonstrate that masking and TTS do occur in marine mammals. Both masking and TTS could also present real problems for marine mammals in the wild. It is not clear, however, how frequent are incidences of these phenomena in wild animals. At least one marine mammal acoustics expert considers low frequency masking to be the biggest danger that man-made noise poses to marine mammals (Gentry pers. comm. 2000a). Most anthropogenic marine noise is at frequencies less than 1 kHz. However many parameters of these phenomena remain to be investigated. Although concerns are real, details must still be filled in before the information is adequate for regulatory purposes.

Physiological Effects

The impact of sound on marine mammal physiology has yet to be thoroughly investigated. The difficulty of carrying out such studies is widely recognized among marine mammal experts (NRC 2000; Richardson pers. comm. 2000). In the few studies that have been done, some light has been shed on possible consequences of sound upon the organism. Possible mechanisms for physiological effects include: damage to air cavities, physical damage to cochleae in the mammal ear, and tissue damage from air bubble growth (NRC 2000). The psychological impact of sonar has also been recognized as an area needing research. Currently only limited research has been carried out to examine whether low frequency sounds create stress for marine mammals (Curry 1999).

One of the primary physiological concerns for marine mammals exposed to low frequency sounds is the effect on body cavities. Though almost no data on marine mammals exists to analyze the impact of sound on the lungs, research on humans has indicated possible consequences. Despite the difficulties associated with extrapolation of data from humans to cetaceans, Richardson (pers. comm. 2000) suggests that results of tests on humans can be used to "raise warning flags" as to the possible implications for marine mammals. He also points out the usefulness of human data in formulating hypotheses regarding marine mammals. The U.S. Navy has applied the results of tests on humans exposed to low-frequency sound to cetaceans for modeling purposes (U.S. Navy Draft 2000).

Martin *et al.* (2000) conducted experiments for the Navy on the resonant properties of the human lung and found that the resonant frequency of the lung varied with depth, ranging from 39 Hz at the surface to 71 Hz at 120 feet of seawater. The resonance caused the amplitude of lung motion to increase 5 to 7 fold. The authors acknowledged the possibility that the increase in amplitude could cause lung damage.

The Navy also conducted tests to determine the likelihood of divers aborting their mission when exposed to low frequency sounds. Results indicated that 15% of subjects aborted their dives when exposed to 148 dB. At lower frequencies (<250 Hz) dives were aborted due to reported sensations of vibration in the head and chest cavities (NRC 2000). According to Green (1999), the Navy's test showed a reduction in vestibular function when the resonant frequencies of the lung were matched at 160 dB.

Crum and Mao (1996) examined the growth of air bubbles within tissues under varying pressures and exposures to different levels of low frequency sound. In their calculations, they found that sound pressure levels above 210 dB could cause significant bubble growth and risk to human divers and marine mammals. The risk of bubble growth at lower decibels was reduced, although still present under conditions of high nitrogen saturation associated with increased dive depth.

Another area of physiological concern centers on the impact of low frequency pulses on the inner ears of cetaceans. The NRC advised that research into this area be conducted in order to ascertain if damage to cochleae was occurring in marine mammals exposed to noise. They suggest the development of a Standard Whale Auditory Team (SWAT) to conduct autopsies of stranded cetaceans and examine their auditory organs in order to analyze them for injury (NRC 2000). Several instances of whales with cochlear damage due to sound exposure have been reported.

The autopsies of two sperm whales hit by a cargo vessel off the Canary Islands revealed auditory nerve damage and dense tissue growth in the inner ear. As no there was no sign of previous direct injury to the ear, researchers suggested that the nerve damage and tissue buildup may have been caused by exposure to noise from vessel traffic and may have led to the collision with the cargo vessel (André *et al.* 1997). One issue here is whether or not similar nerve damage and tissue buildup have occurred in other mammals exposed to excessive noise levels. Ketten reported auditory damage in all six of the beaked whales that stranded in the Bahamas in March 2000. The whales were reputedly in otherwise healthy condition (Los Angeles *Times* 2000). Although due to a much greater percussive force, the auditory systems of two humpback whales exhibited severe mechanical trauma after they were killed in an explosion in Newfoundland (Ketten *et al.* 1993).

The role of sound in producing stress is another area of concern. Though little research has been done with marine mammals, there is considerable data on how terrestrial mammals cope with stress (Richardson *et al.* 1995a). Stress is an adaptive mechanism that elicits physiological and hormonal changes in an organism in order to deal with a stressor. Under natural circumstances the stress response is a positive adaptation in the short term and helps organisms to avoid danger. Noise may cause a variety of stress related effects. In humans, a single sound of extremely high sound pressure level may cause acute stress akin to shellshock. Long-term exposures and unpredictable intervals of exposure can lead to chronic stress in animals. This syndrome may cause increased hormone levels, exhaustion and other physiological consequences that can inhibit reproduction and immune function and lead to the development of pathologies (Curry 1999).

Stress studies on terrestrial animals have been shown to elicit changes in heart rate as well as endocrine responses, i.e., heightened levels of cortisol and catecholamines in the blood (Richardson *et al.* 1995a). Burgess *et al.* (1998) monitored elephant seals for possible changes in heart rate during exposure to the ATOC signal in California. The seals were outfitted with acoustic recording tags to measure internal and environmental sounds. Though behavioral changes, such as the cessation of swimming, were correlated with periods of high vessel traffic, no changes in heart rate were noted during these times. Furthermore, no distinct physiological response was detected as the seals swam directly past the ATOC source in California and were exposed to 130 dB low frequency sound.

A number of researchers have carried out studies on capture stress and its biological impact on dolphins (Curry 1999). Thompson and Geraci (1986) showed that captive dolphins exhibited elevated hormone levels such as a three-fold increase in cortisol after being herded and captured. In one of the few studies on sound and stress, Thomas *et al.* (1990) examined the catecholamine levels in the blood of beluga whales. They found no significant difference in these hormone levels before, after, and during exposure of the whales to a playback of noise from an oil-drilling platform. Thomas cautions against extrapolation of her results to wild belugas however, as the experiment did not address the consequences of long-term exposure or the possibility of previous habituation of captive whales to stress from low-frequency sound.

Effects on Behavior

While most studies on marine mammals focus on behavioral effects, one problem with them is that nearly all the data are collected through observations at the surface, while these species spend relatively little time there. Consequently, conclusions drawn from brief glimpses of marine mammals at the surface can present a biased view (Würsig and Richardson 2000).

Cetacean behavior varies naturally according to numerous factors, such as the animal's age, sex, and state of activity, as well as environmental influences such as the location, season, and time of day (EIA 1998). Effects of anthropogenic noise on marine mammals vary by species, age, sex, habitat conditions, time of day, and season (Hofman pers. comm. 2000).

Typical short-term responses of cetaceans to anthropogenic noise are sudden dives, orientation away from the sound source, changes in vocal behavior, longer dive times, shorter surface intervals with increased blow rates, attempts to physically shield young, increased swimming speed, and departure from the affected area. In general, cetaceans appear more sensitive to sound when it is novel, or its intensity level is increasing (Edds and Macfarlane 1987).

Mammal species are often less responsive to disturbance when engaged in feeding or mating than when resting (Richardson and Würsig 1997). Few studies have monitored cetacean behavior before, during and after exposure to known levels of anthropogenic noise. In addition, it is rarely known if a behavioral change is a response to a specific noise, rather than to a visual or other disturbance (Richardson *et al.* 1995b).

Field studies have demonstrated variations in mammal responses to anthropogenic noise. These may depend on the level of source noise relative to ambient sounds, the degree of experience of the animals with the source noise, on-going activity at the time of exposure, and the species involved (Myrberg 1990).

Abnormal growth and reproductive processes have been documented in several species of marine mammals in the presence of high levels of anthropogenic noise (Myrberg 1990).

Migrating gray whales have been shown to alter their migration route away from a stationary seismic pinger producing sound at about 160 dB received noise level. This is equivalent to the effect on animals passing 5 to 10 km from operating seismic vessels in deep water (Würsig and Richardson 2000).

During the fall migration of a population of between 120 and 140 bowhead whales (*Balaena mysticetus*), none ever approached nearer than 9.5 to 10 km to an operating drillship, and only a few came closer than 15km, even though the ship was directly on their migratory route (Davis *et al.* 1987). The noise level was between 104 and 114 dB (peaking at approximately 120 dB), and the noise band was between 20 and 1000 Hz, which is the band that contains most of the energy in bowhead whale vocalizations (Myrberg 1990). When the drillship left the area, whales moved back to their original migration route, showing no further avoidance (Davis *et al.* 1987).

Playback studies have found that most bowhead whales avoid drillship or dredging noise with broadband (20 to 1000Hz) received levels around 115dB levels that could occur 3 to 11 km from typical drilling and dredging vessels (Richardson *et al.* 1990). Bowhead whales endure higher intensity noise if the only migration route requires close approach to the source (Richardson and Greene 1993)

As mentioned briefly above, Frantzis (1998) has linked a mass stranding of 12 Cuvier's beaked whales (*Ziphius cavirostris*) in the Kyparrisiakos Gulf in Greece to noise from tests of the NATO LFA sonar. The LFA system can produce broad-band pressure levels up to 230dB, centered at frequencies between 250 and 3000Hz. The tests were carried out between 11 and 15 May 1996, and the strandings occurred on 12 and 13 May. Given that Cuvier's beaked whales rarely strand it is unlikely that the strandings and the sonar testing were independent events. Autopsies on the dead whales revealed no diseases or physical abnormalities, and the animals had recently fed. Another reported occurrence of beaked whale strandings in the Canary Islands coincided with times when naval fleets had been operating sonar equipment in the area (Simmonds and Lopez-Jurado 1991).

Simmonds and Mayer (1997) have also suggested that a series of multiple sperm whale strandings along the North Sea and north of Scotland over the winter of 1994-1995 could have resulted from a shift in their normal southerly migration route due to seismic and other industrial noise in the area. They noted that the North Sea is outside the normal range of sperm whales, as it is shallow and lacks their usual squid prey.

In another case, in September and November 1995, three dead humpback whales were found close to an ATOC source in California. This low frequency, long-distance sound source was in operation for engineering tests during the estimated times of death for all three whales (Hall 1996). Furthermore, one week after ATOC transmissions began in Hawaii, fishermen sighted a dead whale (probably a humpback or sperm whale) near the ATOC source, and a dead juvenile sperm whale washed up on the northeast shore of Oahu, Hawaii shortly thereafter. That sperm whale strandings are rare in Hawaii (only ten strandings in 58 years) suggests that the ATOC sound source may be linked to these events (Weilgart 1998). However, as autopsies were not carried out for any animal, other factors cannot be ruled out (EIA 1998).

As noted, mammal species are often less responsive to disturbance when engaged in feeding or mating than when resting (Richardson and Würsig 1997). Stewart (1982) conducted experiments with simulated seismic booms at levels ranging between 140 and 163 dB in the Channel Islands during the non-breeding season. He reported alert behavior in elephant seals in 74% of males and 65% of females, while only 26% of pups reacted. The same experiment on sea lions showed more than 70% of males immediately moved during non-breeding season. During breeding season animals were far less responsive: few males reacted, and although most females were alert for about one minute, they never moved more than one meter from their pups (Stewart 1982).

Richardson *et al.* (1987) performed studies on feeding bowhead whales using equivalent sound levels and frequency as used by Davis *et al.* (1987) for migrant bowheads. While feeding, bowhead whales stayed in the area even when received noise reached levels between 104 and 114 dB, equivalent to the sound 3 to 6 km from an operating ship-based drill (Richardson *et al.* 1987).

Baker *et al.* (1982 in Richardson *et al.* 1995a) studied the responses of feeding humpbacks to vessels. At 2 to 4 km from the vessels the responses included shorter dive times, longer blow intervals and faster swimming speeds. At less than 2 km, the responses were longer dive times, shorter blow intervals, and slower swimming speeds (i.e. the whales avoided vessels by remaining submerged).

Noise-induced disruption of feeding, breeding, migration, and care of young has the potential to result in less food intake, lower breeding success, or reduced survival rate of offspring. The detrimental impact is likely to be particularly severe in cases where cetaceans are temporarily or permanently displaced from areas that are important for feeding or breeding (EIA 1998).

Effects on Vocalization and Communication

It is known that pinnipeds (sea lions, fur seals, seals, and the walrus (*Odobenus rosmarus*)), sirenians (manatees and dugong), and cetaceans (dolphins, porpoises, and whales) use sound both passively to listen to the environment and actively to communicate (Würsig and Richardson 2000).

Baleen whales tend to use lower frequencies of sound, usually below 1 kHz, reaching into infrasound in fin and blue whales. Frequencies of sound-production and hearing sensitivities of pinnipeds and sirenians are about 1 to 10 kHz (Würsig and Richardson 2000). For more details on frequencies used in communication and echolocation by marine mammals, please see the information in Appendix II.

Levels of sounds produced differ significantly among marine mammals. While vocalizations of smaller dolphins and porpoises can be heard at distances of several hundred meters, killer whale (*Orcinus orca*) screams, social sounds of pilot whales, and the staccato clicking of sperm whales travel several kilometers. The sounds of these latter species have been estimated at between 160 and 180 dB, while it is probable that the clicks of sperm whales are even louder (Würsig and Richardson 2000). Male bearded (*Erignathus barbatus*) and Weddell seals (*Leptonychotes weddelli*), which appear to use their complicated tonal repertoires as advertising displays to warn off other males (and possibly to attract females), have sounds as loud as about 180 to 190 dB (Thomson and Richardson 1995). However, the sounds of these seals are exceptional among pinnipeds (Würsig and Richardson 2000).

As marine mammals depend on the acoustic sensory channel for many of their activities, forcing an animal to modify its vocal behavior could reduce its ability to search for food, to navigate, or to contact conspecifics (Fletcher and Busnel 1978; Richardson *et al.* 1995a).

Modifications in vocal behavior have been reported in a few marine mammals exposed to high underwater noise levels, but results vary within and among studies (Lesage *et al.* 1999). Singing behavior of male humpback whales was altered when they were exposed to LFA sonar (Miller *et al.* 2000). Humpback whale songs were 29% longer during LFA playbacks and returned to normal after exposure, suggesting (1) that humpback whales sang longer songs during LFA sonar transmissions to compensate for acoustic interference, and (2) that this response had a limited duration (Miller *et al.* 2000). As the song of humpback whales is associated with reproduction (Tyack 1981), widespread alteration of their singing behavior may also affect demographic parameters (Miller *et al.* 2000).

Belugas exposed to the sounds of an icebreaker emitted a high proportion of falling tonal and noisy pulsive calls (thought to be alarm calls), while narwhals (*Monodon monoceros*) became silent when exposed to the same noise source (Finley *et al.* 1990). There is also some indication that gray whales and bottlenose dolphins shift their primary frequencies of communication in order to avoid background noise (Würsig and Richardson 2000). In a study on gray whales, call detection rates increased when whales were exposed to outboard motor noise (a familiar noise source in the area), but declined when whales were exposed to the unfamiliar noise from a drillship or to killer whale vocalizations (Dahlheim 1987).

Reductions in call detection rates have also been reported for sperm whales exposed to seismic pulses and sonar (Watkins *et al.* 1985; 1993) and for harp seals (*Phoca groenlandica*) exposed to shipping (Terhune *et al.* 1979). It is uncertain, however, whether these changes resulted from the departure of animals (Lesage *et al.* 1999). Sperm whales were also found to stop vocalizing in response to relatively weak seismic pulses from a ship hundreds of kilometers away (Bowles *et al.* 1994). Studies by Rankin and Evans (1998) in the northern Gulf of Mexico indicate that seismic exploration has a negative impact on aspects of communication and orientation behavior in sperm whales, but no effects on the distribution of other odontocetes.

Lesage *et al.* (1999) studied vocal behavior of beluga whales before, during, and after exposure to noise from a small motorboat and a ferry. Vocal responses were more persistent when whales were exposed to the ferry. These changes included (1) a progressive reduction in calling rate from 3.4 to 10.5 calls per whale per minute to less than 1 call per whale per minute while vessels were approaching; (2) brief increases in falling tonal calls and three-pulsed tone call types; (3) an increase in the repetition of specific calls at distances less than one km; and (4) a shift in frequency bands used by vocalizing animals from a mean frequency of 3.6 kHz prior to exposure to noise to frequencies of 5.2 to 8.8 kHz when vessels were close to the whales (Lesage *et al.* 1999).

Watkins *et al.* (1985) noted that sperm whales reacted to military sonar at distances of 20 km or more from the source. Sonar at frequencies of 6 to 28 kHz caused cessation of calling and sometimes avoidance (Watkins *et al.* 1985; 1993).

A series of playback experiments have recently been carried out to test the impact of LFA at received sound pressure levels no greater than 160 dB. No overt responses have been observed in feeding blue and fin whales off southern California. However, a consistent decrease in the number of whales producing long-patterned sound sequences has been found (Clark *et al.* 1999).

Maybaum (1993) found that humpbacks in Hawaii showed avoidance behavior in response to playbacks of sonar pulses of 3.3 kHz, and sonar sweeps of 3.1 to 3.6 kHz, and suggested that the reactions probably stemmed from the similarity of sonar signals and sounds that whales associate with threats or warnings.

A feasibility test of the ATOC system, near Heard Island in the Indian Ocean, transmitted sound for one hour of every three, with source levels of 209 to 220 dB at a depth of 175 m. The center frequency was 57 Hz, with a maximum bandwidth of 30 Hz. Sperm whale and pilot whale signals were heard in 23% of 1181 minutes of baseline acoustic monitoring before transmission, but were absent in 1939 minutes of monitoring during transmission (Bowles *et al.* 1994). Sperm whale clicks were eventually heard 36 hours after the end of the transmission.

High-frequency pingers and submarine sonar pings are known to affect sperm whale vocalization rates and behavior (Watkins and Schevill 1975; Watkins *et al.* 1985). Low-frequency sound also may affect sperm whales because their wide-band clicks contain energy between 100 and 2,000 Hz, which is expressive of low-frequency hearing (Moore *et al.* 1993; Watkins *et al.* 1985).

Effects on Social Structure

As it is believed that acoustic contact largely binds whale societies together (Tyack 2000; Wells *et al.* 1999), noise that diminishes distances across which whales can communicate should also at least diminish the spatial scale of their societies (Würsig and Richardson 2000).

Bauer *et al.* (1993) found that swimming speed, respiration, and social behaviors of wintering humpback whales were affected by vessel traffic (in particular with respect to vessel numbers), speed, and proximity. A case study indicated that after a calf was sensitized by sounds from a large vessel, the calf subsequently breached in response to noise from a small boat engine, which had not previously elicited a response (EIA 1998).

Glockner-Ferrari and Ferrari (1985) studied the same humpback population in their breeding ground near Hawaii, and attributed a consistent decrease in the percentage of mothers and calves in inshore waters to high levels of boating activity and aircraft. Green (1991) also found that parasail boats displaced Hawaiian humpback whales, including cow/calf pods, from near-shore areas.

Fast, erratic approaches of boats close to blue whales can cause the separation of pairs of animals (Gordon and Moscrop 1996). It has also been observed that when a supply ship came within about two kilometers of a group of feeding bowhead whales, the whales scattered (Würsig and Richardson 2000).

Heimlich-Boran *et al.* (1994) noted significantly longer dive times and closer grouping of short-finned pilot whales (*Globicephala macrorhynchus*) in response to a large number of whale-watching boats in the Canary Islands, and unusual aggressive behaviors were also documented during the observations.

Anthropogenic noise in the air can also have an impact on pinnipeds on land. Low-flying airplanes can cause animals on land to stampede into the water, and if this occurs on a birthing/nursing beach, adults will trample pups in their rush to escape the perceived danger. Hundreds of newborns have been killed in this manner (Würsig and Richardson 2000). However, it remains speculation as to whether sound or sight is more responsible for these behaviors (Würsig and Richardson 2000).

Effects on Habitat Use

Humpback whales moved away when a sonar pulse of 3.3 kHz was emitted experimentally in their habitat in Hawaii (Maybaum 1990). The observed responses consisted of slightly increased swimming speed and path linearity. It was suggested that avoidance reactions might have arisen due to similarities between sonar signals and biological sounds associated with threats or warnings (Maybaum 1990).

A study conducted on ninety sperm whales in 1993 in the Gulf of Mexico demonstrated a strong correlation between seismic operations and whale distribution in the area (Mate *et al.* 1994). From a distribution of 0.092 whales/km before the seismic operation began, whale abundance dropped significantly to 0.038 whales/km during the first two days (seen only around the periphery of seismic area), and then to 0 whales/km for the following five days (Mate *et al.* 1994).

Polacheck and Thorpe (1990) found that harbor porpoises exhibited an avoidance reaction to survey vessels. Evans *et al.* (1994) found that harbor porpoises avoided vessels of all sizes, sometimes moving right out of the area. They also discovered that porpoises were more likely to avoid infrequent vessels than routine vessels, such as the daily ferry.

Finley *et al.* (1990) studied the reactions of belugas and narwhals to ice-breaking ships in the Canadian High Arctic. Belugas reacted with a flee response and narwhals with a freeze response, the characteristics of which were typical of their responses to predation by killer whales. Belugas avoided the approaching ships at ranges of 45 to 60 km, and seemed aware of an approaching ship at a distance of 85 km (indicated by what were considered to be alarm signals). The reactions began when broadband (20-1000 Hz) received levels of ship noise were 94 to 105 dB. The belugas moved up to 80 km from their original location in response to the ship's passage, and remained absent for 1 to 2 days (Finley *et al.* 1990; Finley and Greene 1993). This extreme sensitivity may result from a combination of good sound propagation, and a scarcity of ships in the area (Richardson and Würsig 1997).

Grey whales in San Diego Bay responded to vessel noise by abandoning calving lagoons, returning only after vessel traffic decreased (Reeves 1977 in Richardson *et al.* 1995a). It has been reported that grey whales abandoned the Guerrero Negro Lagoon for several years while it was subjected to human disturbance, including intense shipping and continuous dredging (Gordon and Moscrop 1996). After a decrease in shipping activities, grey whales reoccupied the lagoon.

Sightings surveys show that sperm whales were displaced to a distance of 60 km from an area in the Gulf of Mexico where seismic surveys were taking place (Mate *et al.* 1994). Bowhead whales subjected to industrial seismic emissions may move away from the activity until (after some hours) few or no animals remain within about 20 km of the sound source (Würsig and Richardson 2000). Others observed that at noise levels of 142 to 157 dB, initial behavioral changes of bowheads started more than 8 km away (Ljungblad *et al.* 1988). On the other hand, Richardson *et al.* (1986) observed bowhead whales engaging in normal activities as close as 6 km to vessels, where estimated received sound levels were 158 dB. However, Richardson *et al.* (1985) did find subtle alterations in surfacing, respiration and dive cycles in response to seismic vessels, indicating that the absence of a conspicuous response does not necessarily prove that an animal is unaffected.

ADDs emitting 300 millisecond pulses, with a broadband source level of 132 dB and fundamental frequency of 10 kHz, were effective in dramatically reducing harbor porpoise entanglements in fishing nets (Kraus *et al.* 1997). However, it is not known whether the reduction in porpoise entanglement resulted from a direct effect of noise on porpoises, or an indirect effect as their preferred food (herring) were driven away (Popper pers. comm. 2000).

Displacement of populations of bottlenose dolphins (Evans *et al.* 1993), harbor porpoises (Evans *et al.* 1994), beluga whales (Finley *et al.* 1990), and sperm whales (Mate *et al.* 1994) has been reported in association with seismic exploration and vessel traffic. It is thought that humpback whales (Glockner-Ferrari and Ferrari 1985; Green 1991), blue whales (Gordon and Moscrop 1996), grey whales (Reeves 1977 in Richardson *et al.* 1995a), and bowhead whales (Richardson *et al.* 1987) have abandoned areas in response to boating activity, aircraft, and industrial activity such as dredging.

While it is possible to argue that a human-caused decrease in safe havens might be impacting marine mammal survival, to date there is no information on such population-wide effects (Würsig and Richardson 2000).

Cumulative Impacts

It is hard to predict the short- and long-term consequences of mammalian exposure to noise, not only due to insufficient research, but also due to difficulties involved in judging noise effects in isolation from other threats (EIA 1998).

Coastal ecosystems are already threatened by pollution, over-exploitation of natural resources, increases in shipping and recreational boating, development and global climate change (DeFontaubert *et al.* 1996). The synergistic interactions of these environmental threats, in conjunction with exposure to continuous anthropogenic noise, are likely to have the most severe consequences for cetacean populations in coastal areas (EIA 1998).

Richardson *et al.* (1987) compared the distribution of bowhead whales and industrial activities in the Canadian Beaufort Sea, and suggested that a decrease in bowhead use of the main industrial area since 1980 was a result of cumulative effects of industrial activity that started in 1976.

Even if marine mammals are protected on a case-by-case basis from individual acts of harassment extreme enough to have an adverse impact, they may well require additional protection from repeated milder harassments that might have a cumulative negative impact (NRC 2000). As has been stated, more research in this area is required.

Acoustic Effects on Marine Fishes

Marine fishes rely upon sound for a variety of purposes. Fishes use sound during courtship and aggressive interactions, when spawning and schooling, while escaping from predators and searching for prey, and potentially to navigate (Mann 1997; Croll *et al.* 1999; Myrberg 1978a).

Hearing in Fishes

Sound detection in fishes is the province of the octavolateralis system, which combines two mechanosensory hair cell-based systems -- the ears and the lateral line. In fishes the ears detect relative motion between the otoliths (ear stones) and the rest of the body, and function much like an accelerometer. Some species of fish can also detect sound pressure that is transduced by an auxillary structure such as the gas-filled swim bladder in the abdominal cavity (Popper and Fay 1993). The otoliths exist in fluid-filled chambers in which they come into contact with the ciliary bundles of sensory hair cells. Fish bodies, having the same density as water, tend to move at the same amplitude and phase as the sound impinging upon them. However, their otoliths have a greater density and are thus prone to lags in their responses to sound impinging upon the fish. The relative motion between the fish's body and the otolith bend the cilia of associated mechanoreceptive hair cells, which in turn send neural messages to the brain (Popper 1997a). Individual hair cells respond at different levels to different directions of stimulation and therefore are directionally sensitive to motion. Response frequencies for the fish ear range from several Hz in some species to several thousand Hz in others (Popper and Fay 1993).

The lateral line runs along the head and body of fishes, often in canals with pores allowing water to enter and exit. It senses relative motion between the fish and the surrounding water. The frequency range over which it responds is narrower than and at the lower end of the ear's range, running out to approximately 200 Hz. In general, the lateral line is sensitive to sources that are close in distance (only one to two body lengths away) whereas the ears sense sounds over far greater distances (Popper 1997b; Popper and Fay 1993).

In addition to the ears and lateral line, the swim bladder plays an important role in the hearing of certain fishes. Known generally as "hearing specialists," these fishes have a connection that couples the swim bladder (or another internal air bubble) with the ear (Popper 1997a). In otophysan fishes, a primarily freshwater group, this connection is established by bones called the Weberian ossicles (Popper and Fay 1993). Herrings have an extension of the swim bladder that enters the cranial capsule and lies close to the inner ear (Moyle and Cech 1988). In whatever way the connection between the swim bladder and ears happens to be made, the fishes that have it tend to respond to wider bandwidths than those without it, particularly at higher frequencies (Popper and Fay 1993). For example, while most fishes appear not to detect sounds above 1000 Hz, the American shad (*Alosa sapidissima*), a member with the herrings and others of the family Clupeidae, can sense sounds up to 180,000 Hz (Mann *et al.* 1997).

Fish also use swim bladders for sound production. Toadfish (*Opsanus* sp.) produce quite loud sounds for fish (140 dB//1 microPa) by contracting muscles on their swim bladders. Some fish also produce sound by grinding their pharyngeal jaws or by rubbing their pectoral spines (Mann 1997).

Although this section explores the potential effects of anthropogenic noise on marine fishes as a group, it is important to point out that there is a tremendous amount of variation among taxa when it comes to the structures that are associated with hearing (Popper and Fay 1993). Making extrapolations from one group to another is fraught with peril. Of approximately 25,000 species of fishes, hearing range estimates are only available for fifty or so. Based on the scant data available, one can say (somewhat cautiously) that marine fishes typically sense sound at frequencies between 50 and 2000 Hz, with peak sensitivities usually less than 800 Hz (Myrberg 1978a). However, as noted above in the case of the American shad, there are exceptions to this generalization.

An interesting physiological note having relevance to the present study is the fact that fishes add large numbers of sensory hair cells to the ear as the fish ages and grows. Whether this addition of hair cells results in improved hearing over time or simply allows fishes to maintain stable hearing as they age is not known (Popper and Fay 1993; Popper 1997a). Regardless, there is evidence of hair cell recovery in fishes (unlike the situation in mammals) that would seem to compensate for damage to hair cells and resulting hearing loss, although the degree of compensation is unknown (Popper 1997a).

Uses of Sound by Fishes

While research on fishes' use of sound is limited, this section explores some of what is known. Popper and Fay (1993) provide a broad context for fishes and sound. They posit that the most general function of hearing in fishes may not be decoding acoustic messages but rather enabling the formation of an acoustic image of their environment. Given the advantages of sound communication relative to visual or chemical means in seawater, fishes may well rely on sound to provide a basic understanding of the world around them. Myrberg (1978a) suggests that the acoustical sense probably constitutes the most important distance receptor system for all aquatic animals.

Many members of the family Clupeidae and Atherinidae (the silversides) form large schools. The sounds that they make may play a key role in keeping these schools together (Croll *et al.* 1999). The already mentioned ultrasound detection capabilities of the American shad may allow them to detect the high-frequency echolocation pulses of cetaceans seeking to prey upon them (Mann *et al.* 1997). The Sciaenidae (the drums) are a noisy family with multibranched swim bladders and very large otoliths. They produce loud sounds using their swim bladders during spawning bouts (Moyle and Cech 1988). Myrberg and Riggio (1985) discuss the ability of male bicolor damselfish (*Pomacentrus partitus*) to recognize individual vocalizations of other males. They hypothesize that this ability may help males maintain territories in their coral reef habitats. Based on the loudness of fish sounds and the natural levels of background noise it appears that, unlike certain whales communicating over vast distances, fishes tend to use sounds over distances of less than tens of meters (Mann 1997).

A number of studies have documented the manner in which sharks utilize low-frequency sounds. As they are members of a different class (Chondrichthyes), hearing in sharks is in some ways quite different from that of the majority of marine fishes. Nelson and Gruber (1963) recorded sounds of struggling fish and found peak sound pressure occurring below 100 Hz (amplitude about 138 dB re 1 microPa). They were able to reproduce the low-frequency characteristics and the pulse rate within bursts of the sounds made by struggling fish by passing white noise through a filter. These sounds attracted a variety of sharks to an area where none had been previously seen. In his review of sharks and sound, Myrberg (1978b) reports that the attractiveness of a sound to sharks increases at lower frequencies to around 40 Hz or below and that irregular pulses are more attractive than regularly-pulsed tones. Frequencies above 800 to 1000 Hz appear to have little or no attractive effect. Sharks habituated to sounds that came in rapid succession and were not reinforced with food. Klimley and Myrberg (1979) found that lemon sharks (*Negaprion brevirostris*) would withdraw in response to a rapid increase in the magnitude of a sound in the 500 to 4000 Hz noise-band. Both the magnitude of the signal and the speed at which it was reached appeared to determine whether a shark would approach or withdraw.

Effects of Anthropogenic Noise on Marine Fishes

While research into the uses of sound by fishes is somewhat sparse, research addressing the effects of anthropogenic sounds on fishes is almost nonexistent.

Given levels of ambient noise in their environments, many types of fishes may be hearing at the thresholds of their sensitivity levels. Myrberg (1978a) emphasizes the importance of the effect of ambient or background noise on the hearing of marine animals. He compares hearing levels in fishes and marine mammals to ambient noise levels in an attempt to determine how close these animals are to their hearing thresholds and the potential of ambient noise to mask sounds. For example, members of the family Gadidae (cod and relatives) hear at the low end of the frequency scale between 10 and 500 Hz. Myrberg (1978a) suggests that the masking effect of low-frequency ambient noise depends on the sea state, calm seas show negligible masking but higher sea states likely produce masking in this family. Myrberg (1978a) focuses on the context for sounds in the marine environment and finds that the effects of ambient noise may be of paramount importance to the hearing abilities of fishes. Ambient noise in this context refers to a mixture of various sound types, including ship traffic/industry, wind, and sounds of marine animals. The possibility that ambient noise from shipping, climatic, and biological sources is already masking sound for many fishes should give pause to those considering potential augmentation of ambient noise levels.

Hastings *et al.* (1996) note that sound levels greater than or equal to 180 dB at 50-2000 Hz would be harmful to fishes while levels below 150 dB should not cause physical harm. Hastings *et al.* (1996) also conducted one of the few studies on the impacts of intense sounds on fishes.

They subjected several specimens of the oscar (*Astronotus ocellatus*), a freshwater species and not a hearing specialist, to one hour of pure tones varying in frequency (60 Hz and 300 Hz), duty cycle (20% or continuous), and intensity (100, 140, or 180 dB re: 1 microPa). Upon examination of sensory hair cells from the ears and lateral line, four of five fish exposed to 300 Hz at 180 dB with a continuous wave signal showed a small amount of damage to ciliary bundles in the ear. From this controlled experiment, the authors offer the observation that sound levels on the order of at least 220-240 dB re: 1 microPa at 300 Hz would be necessary to produce more extensive damage to sensory hair cells in fishes (like the oscar) not specialized for hearing. Most fishes fall in this non-specialist category.

There have been several reports that have examined the impacts of seismic operations on fishes. Pearson *et al.* (1987) looked at changes in behavior and in catch-per-unit-effort resulting from exposure to the firing of a single air gun among several species of rockfish (Scorpaenidae) off the coast of California. A second experiment found startle responses in some rockfish species above 200 dB re 1 microPa with a possibility of subtle changes occurring down to 161 dB re 1 microPa. A field experiment focusing on catch-per-unit-effort saw it decline by 52.4%, resulting in a 49.8% drop in the cash value of the rockfish caught (Pearson *et al.* 1987).

Dalen and Knutsen (1987) used sonar to check the distribution of fishes before and after firing an air gun. Certain demersal species (*Gadus* spp., etc.) tended to go to the bottom after the firing. The experimenters also exposed the eggs, larvae, and fry of cod to two different air guns and a water gun. After exposure to the smaller air gun (222 dB//1 microPa re 1m and 640 cm_ chamber volume), larvae and younger fry showed no effects while older fry experienced some balance problems, which disappeared within minutes. Exposure to the larger air gun (231 dB//1 microPa re 1 m and 8610 cm_ chamber volume) also resulted in temporary balance problems among older fry (in this experiment the only group exposed). In contrast, when fired at a distance of 2 m the water gun (229 dB//1 microPa re 1 m and 8610 cm chamber volume) caused 90% mortality among older fry (again, the only group exposed). Dalen and Knutsen (1987) attributed these very different effects to the fact that air guns generate positive pressure pulses whereas water guns generate negative ones. The authors felt these tests actually used relatively low exposure levels since only one gun was fired at a time as opposed to the arrays of air guns normally used for offshore oil exploration.

In a review of nonexplosive energy-releasing devices for seismic exploration, Chamberlain (1991) claimed that these types of energy sources (e.g., air guns) do not constitute a significant source of harm for marine organisms. He did say that they could have adverse economic impacts on commercial fishermen by causing declining catches. More recent work (McCauley *et al.* 2000) has raised additional concerns about the impacts of air guns on marine life.

Kostyuchenko (1973) exposed the eggs and larvae of sixteen Black Sea fish species to an air gun, an electric pulse generator, and a TNT charge. The TNT charge had the most negative impact on eggs, injuring them within a larger radius of up to 10 m. The air gun and electric pulse generator only caused damage up to 5 m.

Linton (1991) delved further into the effects of explosions. He looked at 16 different species in West Bay, Galveston County Texas. Cages of fish were arranged at different distances, ranging from 0.0 m to 143.9 m, from 40 lb charges of dynamite placed in holes 120 feet below the sediment/water interface. Not surprisingly, fishes closest to the test site showed the greatest number of organ abnormalities, but the sediment type, depth of water above the hole, and the degree of filling of the hole also appeared to affect the occurrence and severity of abnormalities.

Non-hearing physiological effects of intense sound on marine fishes may include: swim bladder injuries, eye hemorrhages at peak sound pressure levels of 220 dB, and lower egg viability and growth rates (a damage prevalence of 8-17% in reduced viability at ranges of 223-236 dB peak sound pressure levels) (Gisiner *et al.* 1998).

While the potential for adverse effects appears large, there has been very little research exploring the area of anthropogenic noise impacts on marine fishes. Thus, one should be wary of statements that give definitive sound pressure levels at which noise harms marine fishes. We simply do not have enough data to generate reliable estimates. The field appears wide open to future research on how fishes use sound and how anthropogenic noise affects fishes. More research is necessary.

Effects on Other Taxa

As is the case with fishes, there is still very little known about the hearing of most marine organisms and even less is known about the potential for harm from excessive sound. More research on organisms like turtles, birds, and marine invertebrates is crucial. Invertebrates may or may not be affected, depending on the acoustic impedance of their organs and tissues, their ability to hear, and their response to sound. Vertebrates like birds and turtles have air-filled cavities which are vulnerable to damage (US Navy Draft 2000). Hearing damage in birds is well documented, at least on land. Effects from marine sound may depend on how often and deeply seabird species dive, and their tendency to be disturbed by noise.

Clearly the potential for direct physical damage from sound must be explored, but beyond that it is vitally important to know something about the natural history of the species when assessing the possible effects of noise on animals. Species differ by more than their exact hearing thresholds. Some may not be bothered by sounds that they do not associate with a threat, while others may startle easily at the least provocation. Even within a species considerable variation can exist. Populations that are disturbed frequently may habituate; more isolated populations may be profoundly affected by new sound sources. Reactions may very well depend on the history and associations of that group (Insley pers. comm. 2000). The timing of the disturbance can be important. Some species of birds may be sensitive during brood rearing, but not while breeding (Kuchel 1977 in Voisey's Bay Mine/Mill Project EIS 1997). Researchers must determine a baseline for reactions of the particular population under study. Issues of learning become increasingly important with increased taxonomic complexity. In the absence of an obvious immediate response such as death, long-term studies are needed to assess the impact of anthropogenic noise. The ultimate criterion is reproductive success (Insley pers. comm. 2000).

Sea Turtles

Sea turtles have a thick layer of subtympanal fat. Because their tympanum is so thick, it conducts sound better through water and bone than through air (Lenhardt 1982 in Bartol *et al.* 1999). Based on the limited data available it appears that turtles can detect low frequency sounds (Croll *et al.* 1999). How important that hearing is to them, and how easily it is damaged, is much more uncertain. There are no studies on either TTS or PTS in sea turtles (U.S. Navy Draft 2000).

Studies of leatherback (*Dermochelys coriacea*) and loggerhead (*Caretta caretta*) turtles indicate that they can hear sounds between 250-750 Hz (Eckert pers. comm. 2000; Bartol *et al.* 1999, respectively). These results are not substantially different from work on green turtles**,** which showed that they hear best between 200-700 Hz, with high sensitivity around 400 Hz (Ridgway *et al.* 1969).

According to one theory, turtles use low frequency hearing for predator avoidance (Eckert pers. comm. 2000). The main predator of the leatherback turtle is the killer whale, which happens to use sounds within turtle hearing range (Hall and Johnson 1971; Eckert pers. comm. 2000). It has been hypothesized that turtles can identify their natal beaches by the acoustic signature created by crashing waves (Mrosovsky 1972). Storms change beach characteristics, but perhaps turtles are able to identify beaches with good nesting properties by the sound of waves hitting them (Eckert pers. comm. 2000). On the other hand, since it is now known that turtles use geomagnetic fields to navigate (Lohman pers. comm. 2000; Musick pers. comm. 2000), it may not be necessary to invoke hearing for navigation to beaches (Musick pers. comm. 2000). It has been suggested that sea turtles use sound for communication (Mrosovsky 1972 in U.S. Navy Draft 2000) but the evidence is inconclusive. It is Dr. Eckert's opinion that turtles probably do not use sound to communicate with each other (Eckert pers. comm. 2000).

Turtle hearing may be damaged by high-energy sources, though the levels required for damage, if any, are unknown. Hearing damage is more likely than tissue damage (Eckert pers. comm. 2000) and there is some evidence that hearing may recover over time (Eckert pers. comm. 2000; Musick pers. comm. 2000).

The effects of anthropogenic noise on turtles are unclear. Preliminary research shows that noise from vessels or air guns causes turtles to move away and avoid the source (O'Hara and Wilcox 1990). In an unpublished report for the U.S. Army Corps of Engineers, Musick *et al.* (pers. Comm. 2000) tested the efficacy of seismic pressure guns to scare turtles away from channels about to be dredged. At about 50 m most turtles moved away from the noise source, but at that distance it took them a minute or two to determine the source of the sound. One turtle blundered into within less than a meter of the sound source and sustained hearing damage. Using auditory evoked potentials it appeared that this turtle's hearing was normal two weeks later (Musick pers. comm. 2000). In another study of air gun effects, turtles showed an alarm response at 2 km and an avoidance response at 1 km from the sound source (McCauley *et al.* 2000).

Evidently, one of the problems is that avoiding damage may depend on how quickly the turtle moves away from the sound source. It appears from the available information that turtles do not begin to withdraw until the sound source is relatively close, and then they are not fast enough to effectively avoid it by clearing the area. Leatherback turtles swim between 0.6-0.8m/sec, so there would not be time for them to withdraw from the area during a 10 minute ramping up period, even if they were so inclined (Eckert pers. comm. 2000).

Certain sounds could displace turtles from preferred habitat and move them into areas with more dangerous human activities. It is also possible that low frequency sound could alter the movement of female turtles and hatchlings as they travel to and from nesting beaches (Croll et el. 1999). On the other hand, if noise sources are largely ignored by turtles then harassment is not a problem, but turtles may fail to move away from a dangerous noise source and be injured or killed as a result. For example, because their migration routes are so precise, turtles may fail to deviate from their path even when exposed to damaging noise levels.

Increased turtle strandings have been observed following the explosion of offshore petroleum platforms. Some necropsies showed damage consistent with impacts from underwater explosions (Klima *et al.* 1988). In experiments, safe distances from the explosion vary widely (Klima *et al.* 1988; O'Keefe and Young 1984). In some cases**,** turtles are knocked unconscious and show prolonged physiological effects, while in other instances they appear completely unharmed. Unconscious turtles may drown or be vulnerable to predation, and many dead or injured turtles sink and go unrecovered (Klima *et al.* 1988). It is also worth mentioning that turtles appear to use manmade structures, and they are often missed even when surveys are conducted prior to detonation (Klima *et al.* 1988).

Flora

Since plants have no sensory system and their gas cavities are minimal, there is little likelihood of damage to plants from anthropogenic noise (US Navy Draft 2000).

Invertebrates

Invertebrates were largely excluded from analysis by the EIS for SURTASS LFA sonar on the grounds that they lack the appropriate structures to be affected by low frequency sound. Sound can pass right through organisms with a similar sound impedance value to seawater**,** causing no damage. However, American lobsters (*Homarus americanus*) have a hearing threshold of about 150 dB, which is within the range of LFA SURTASS sonar (Offutt 1970 in U.S. Navy Draft 2000), and so they potentially could be affected.

A study of Dungeness crab (*Cancer magister***)** larvae experimentally exposed to air gun arrays showed no difference in survival than unexposed larvae, although in one condition noise-exposed larvae took slightly longer to molt (Pearson *et al.* 1989).

Captive bait shrimp exposed to the sound of an electrohydraulic vibrator, a device used in seismic exploration, did not show any behavioral changes or increased mortality in comparison to the unexposed control group. A similar study using air guns as the sound source also showed no ill effects on the shrimp (Linton 1995). On the other hand, a French study of brown shrimp (*Crangon crangon*) showed decreased growth and increased mortality with constant exposure to sound (Lagardere 1982).

Though not invertebrates, fish eggs and larvae are frequently classified as zooplankton, and are often considered in the same context (U.S. Navy Draft 2000). A study of cod eggs, larvae and fry exposed to air guns showed no effect on either eggs or larvae, and only temporary effects on fry. Exposure to water guns resulted in substantial mortality of fry (Dalen and Knutsen 1987). Sheepshead minnow (*Cyprinodon vairegatus*) eggs and larvae showed decreased viability after exposure to noise levels of 20 dB/mb (Banner and Hyatt 1973).

When captive squid were exposed to air gun fire, they startled. It appeared that their behavior would be highly altered within 2-5 km of a large seismic source (McCauley *et al.* 2000). It is possible that other cephalopods might be similarly affected. Octopuses have hair cells that respond to stimulation in much the same way as sensory hair cells in the ears of vertebrates (Budelmann and Williamson 1994). These hair cells might have the same reactions to noise as vertebrate hair cells.

Birds

Sound is extremely important to birds, though their exact use of sound varies slightly among species, as does their ability to adapt to excess noise. In general**,** birds seem to hear frequencies between 1 and 5 kHz (Dooling 1978). They appear to be sensitive to low frequency sound, at least in air (Croll *et al.* 1999). Within their primary frequency range bird hearing is comparable to that of mammals. Outside this range, their hearing is inferior to mammalian hearing. Birds show TTS from excessive noise exposure (Dooling 1978), but show evidence of regeneration after damage to cochlear hair cells.

Impacts on birds have often been dismissed from environmental impact statements, such as the one for SURTASS LFA, on the grounds that only an insignificant number of birds would be exposed to damaging levels of sound. Sounds made underwater should not affect birds outside the water because of the attenuation at the air-water interface (Popper pers. comm. 2000). Diving birds near noise sources at Ballard Locks show no effects or alterations in behavior (Fahy pers. comm. 2000), but there have been few actual studies of this issue. There is a great deal more information about the effect of sound on birds in air. Sounds travel upward quite easily, and so move farther vertically than they do along the surface (Griffin and Hopkins 1974). Sounds at ground level or on the water are heard by balloonists as high as 3000 m, and so it is quite possible that they are audible to birds flying overhead as well (D'Arms and Griffin 1972).

Terrestrial studies of the effect of sonic booms on bird colonies vary by species. Studies of sooty terns (*Sterna fascata*) showed that sonic booms resulted in alarm responses and nest abandonment on a large scale (Austin *et al.* 1970). Colonies of herring gulls (*Larus argentatus*) exposed to supersonic aircraft showed no physiological effects from the noise itself, but nesting success suffered because of the birds' startle response to the planes. Birds took flight quickly, crushing eggs, and exposing nests to predation (Burger 1981). In some areas, the resulting decrease in nesting seabird populations has been blamed for a decline in the population of certain raptor species, such as the peregrine falcon (*Falco peregrinus*) in the Channel Islands (Jehl and Cooper 1980). Studies of colonial nesting birds have shown many of them to be very sensitive to noise and visual disturbance, abandoning nests and leaving important habitat if disturbed (DND 1994 in Voisey's Bay Mine/Mill Project EIS 1997).

Birds may fall victim to other effects of multiple uses of the sanctuaries. While the use of pingers may frighten off birds, resulting in a beneficial decrease in bycatch (see **Potential Effects of Anthropogenic Noise on CINMS Species**), noise may also alter bird behavior when it is not desirable.

Any noise that causes disturbance could be damaging, as it would result in increased energy expenditure. This is particularly a problem for juvenile birds because they require high levels of energy and so may lack sufficient reserves to deal with increased expenditures (DND 1994 in Voisey's Bay Mine/Mill Project EIS 1997).

SANCTUARIES: SOUND SOURCES AND EFFECTS

Introduction to Stellwagen Bank National Marine Sanctuary

SBNMS is located 25 miles east of Boston, at the mouth of the Massachusetts Bay. It was designated a sanctuary in 1992 and protects almost 2200 square km of marine area. Within the sanctuary are the submerged lands of Stellwagen Bank, Tillies Bank, and southern portions of Jeffrey's Ledge. The Stellwagen Bank lies at an average depth of 30 m below the water's surface and stretches approximately 32 km between Cape Cod and Cape Ann, Massachusetts (USGS 2000a).

SBNMS is home to a variety of species. Over a dozen cetacean species use the sanctuary, including humpback whale, Atlantic white-sided dolphin (*Lagenorhynchus acutus*), and the highly endangered northern right whale (*Eubalaena glacialis*). Over 40 species of sea birds make use of the sanctuary, including loons, fulmars, and storm petrels. Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*), and winter flounder (*Pseudopleuronecte americanus*) are among the 130 species of fish that can be found there. Endangered leatherback and Kemp's ridley (*Lepidochelys kempii*) sea turtles can also be found in the sanctuary (USGS 2000a).

The topography of the sanctuary was largely influenced by glacial activity some 14,000 years ago. Today, the geographic features of the sanctuary include sand and gravel banks, muddy basins, vast boulder fields, and rocky ledges. Stellwagen Bank is also the site of several shipwrecks, some of which may still lie within the sanctuary's boundaries (NOAA 2000h).

Sources of Anthropogenic Noise in SBNMS

The main source of anthropogenic noise in the SBNMS is the large numbers of vessels that use the sanctuary (Scheifele 2000a). Over 200,000 vessels travel over the bank annually. Among these are merchant vessels, such as supertankers and supply ships, and charter boats used by anglers, bird watchers, whale watchers, and researchers (NOAA 2000h). Most of these vessels operate at frequencies of 80-500Hz (Scheifele pers. comm. 2000b)

Ships and Supertankers

The largest source of noise in the sanctuary is from merchant vessels (Scheifele pers. comm. 2000b) The main shipping lane to Boston passes directly through SBNMS, with both the inbound and outbound lanes passing directly above Stellwagen Bank itself. Over 2700 commercial vessels use the Boston shipping channel annually (USGS 2000b). Of this number, approximately 800 are large ships such as tankers, bulkships, and container ships (Hennis pers. comm. 2000). Signatures for most merchant vessels in the sanctuary range from 100-180 Hz (Scheifele pers. comm. 2000b) More research is needed in order to quantify sound levels for certain types of vessels (Sheifele pers. comm. 2000b) and to determine exactly how much the shipping lane is contributing to the total amount of ambient noise (Scheifele 2000a).

Commercial Fishing

Commercial fishing is an important activity in the sanctuary. Some 200-250 commercial fishing vessels harvest fish in the waters of SBNMS annually (NOAA 2000h). This fleet generates about $15.3 million in revenues per year (NOAA 2000h). The frequencies and sound levels of these vessels depend on the type of vessel, the size of the vessel, engine type, speed, as well as other factors (see section on *Vessels as a Source of Noise*). However, Scheifele (pers. comm. 2000b) has found that many small fishing vessels in SBNMS have signatures around 220 Hz. Some commercial fishermen operating in the SBNMS vicinity are using ADDs, which are also a potential source of noise in the sanctuary (see section on Acoustic Deterrents). These have been successful at reducing by-catch of harbor porpoises in the area (Palka pers. comm. 2000).

Whale Watching Boats

Notable among the charter boats is the large whale watching fleet. There are currently about 30-40 whale watching boats that cruise the sanctuary. Whale watching has grown steadily as a business since 1976 (USGS 2000a), and now accounts for $25-30 million in annual revenues. Many whale watching companies offer four trips per day (in season) in the sanctuary in search of whales (Van Dine pers. comm. 2000).

There are a variety of different whale watching boats that operate in and around the sanctuary. For instance, Boston Harbor Whale Watch operates a 100 foot, quad-diesel powered whale-watching boat (Boston Harbor Whale Watch 2000). Massachusetts Bay Lines operates a quad-diesel powered catamaran of approximately 100 feet (Massachusetts Bay Lines pers. comm. 2000). Seven Seas Whale Watch operates a 90 foot powerboat (Seven Seas Whale Watch pers. comm. 2000). The New England Aquarium Whale Watch operates two vessels: a 111 foot catamaran and a 101 foot single hulled vessel (New England Aquarium Whale Watch pers. comm. 2000). Richardson *et al.* (1995a) estimate that boats in this class produce strong tones up to several hundred Hz, and source levels may be between 140 and 170 dB re 1 microPa-m. However, as with other vessels, the size, engine, propeller, hull, and speed of individual vessels will yield slightly different sound levels and acoustic signatures.

Private Boats

The numerous private boats near the Bank present a potential problem in SBNMS. Private boat captains often do not follow regulations with regard to approaching whales. They have been seen going too fast near whales, which increases the chance of collisions as well as the amount of noise produced (see section on *Vessels as a Source of Noise*). A particular problem is the mosquito fleet, a fleet of private boats whose captains race to see as many whales as possible (Lindholm pers. comm. 2000; Van Dine pers. comm. 2000).

Scientific Research

Both research vessels and research equipment generate noise in SBNMS. According to Scheifele (pers. comm. 2000b), signatures for research vessels are in the range of 80-150 Hz. Research using sonar has been conducted in order to map the topographic features within the sanctuary. In 1994, the southern third of the sanctuary was surveyed with a high speed SWATH vessel of the Canadian Hydrographic Service. The vessel was equipped with a 95 kHz multi-beam system, designed to collect digital bathymetric and sea floor backscatter imagery (USGS 2000c). Other research utilizing 100 kHz side-scan sonar imagery was used to image markings on the surfaces of Stellwagen Bank, Georges Bank, and Block Island Sound (USGS 2000c). This type of research adds to the total amount of noise generated within the sanctuary.

Potential Effects of Anthropogenic Noise on SBNMS Species

It appears that anthropogenic noise in SBNMS is dominated by the cumulative sounds of vessel traffic (whale watching, other types of recreation, commercial fishing, and shipping). SBNMS, in general, does not have the threat of fixed sound sources that may affect species in CINMS. Seismic inputs and air-gun arrays from oil and gas exploration are not typical activities in SBNMS. Therefore, underwater blasts and explosions are less of a threat to the marine life in sanctuary waters than the cumulative effect of ambient noise from vessel traffic.

Much of this noise is varied and seasonal (whale watching and fishing). Noise levels in sanctuary waters fluctuate as the number of vessels changes hourly, daily, and annually. Furthermore, natural conditions such as wind, waves, and storms also vary in their contribution of sound, possibly creating synergistic effects with anthropogenic noise inputs. Given this variation, it is difficult to draw direct and quantitative relationships between noise levels and specific effects on marine organisms. What is known about noise sources in SBNMS can be linked with what is known about general effects of sound on marine organisms to predict potential effects of noise on marine life. The following section attempts to draw some conclusions by integrating knowledge of anthropogenic noise in SBNMS and data summarized in preceding sections on noise effects on various groups of marine organisms, including fish, turtles, and marine mammals.

With over 200,000 charter boats, 2,700 merchant shipping vessels and 200-250 commercial fishing vessels using and transecting the Bank annually (NOAA 2000h; USGS 2000b), serious attention needs to be given to the cumulative contribution of noise from vessel traffic generated in sanctuary waters. Though the decibel level of output is difficult to estimate given the variation in traffic throughout the year, preliminary conclusions can be made. Certainly, the summer is the noisiest time of year on the Bank. As whales concentrate to feed, tourist vessels gather to view them. The noise from the congregation of 30-40 commercial whale watching vessels is compounded by noise from numerous private recreation vessels, as well as the several hundred fishing vessels on the Bank. Though variation exists depending on size and structure of the vessel, in general source levels of noise from small individual boats are estimated to fall between 140 and 170 dB (re 1 microPa @ 1m). The cumulative effect of low-frequency noise emitted at these levels from hundreds, if not thousands, of vessels on the Bank is difficult to calculate, reinforcing the need for long-term research and monitoring.

Vessels in SBNMS are contributing noise generally acknowledged to be at frequencies of 500 Hz or less. Therefore, most anthropogenic noise present in the sanctuary is low frequency in nature and has the potential to affect species that produce and receive sound at these levels.

Seabirds

Over 40 species of marine birds are found throughout the year in SBNMS (CCS 2000). These include species of loon, albatross, fulmar, shearwater, storm petrel, gannet, cormorant, phalarope, alcid, gull and tern (SBNMS Final EIS Management Plan 1993). As the sanctuary is entirely marine and does not include islands, etc. for nesting sites or colonies, avian activity in the sanctuary is entirely focused on feeding. Many species found in SBNMS spend 50 to 90 percent of their lives at sea (CCS 2000). Although noise impact studies evidencing alarm response, nest abandonment and increased mortality in breeding colonies (see **Effects on Other Taxa** section) are not directly applicable to birds' pelagic activities in the sanctuary, they do show that birds are responsive to sound and exhibit changes in behavior when disturbed. Research is necessary to determine if the cumulative, ambient sounds of vessel traffic in the sanctuary affect bird behavior, particularly that of diving birds.

Cetaceans

It is likely that toothed whale species are less impacted by current noise frequencies on the Bank than many other species. Perceiving sound at high frequencies, sanctuary odontocetes such as the Atlantic white-sided dolphin, bottlenose dolphin, common dolphin (*Dephinus, delphis*), striped dolphin (*Stenella coeruleoalba*), orca, harbor porpoise and pilot whale may not directly experience the low-frequency noise of vessel traffic. However, noise sources directed at many of these species in the form of pingers and other acoustic deterrent devices are of concern and need to be investigated.

The greatest concern over noise impacts should be focused on baleen whales or mysticetes that hear at low frequencies. In SBNMS, this group includes humpback, fin, sei (*Balaenoptera borealis*), northern right, minke (*Balaenoptera acutorostrata*) and occasionally blue whales. Long-term research needs to be conducted in the sanctuary to determine whether masking is occurring, thereby preventing animals from communicating with conspecifics, finding prey, or avoiding predation. Parameters to determine possible behavioral effects and physiological trauma in response to sound need to be developed. Noise impacts are of particular concern for many of these species as SBNMS is a critical feeding ground along the eastern coast of the United States for them. Due to the unique glacially formed shallow bank of SBNMS, its waters are highly productive and provide a virtual feast during summer months. For an animal such as a 45-ton humpback whale, its metabolic requirements are such that it requires a highly concentrated source of prey in order to sustain itself. There is no substitute for Stellwagen; if noise levels become intolerable or lead to shifts in food web dynamics, few alternatives exist to find such productive feeding grounds.

Noise effects at lower trophic levels could result in indirect effects on higher trophic levels. Stellwagen is a critical feeding ground for many Atlantic mysticetes. As such, any effects on food sources for baleen whales could have dramatic repercussions. In particular, research should be conducted to determine possible effects of noise on American sand lance (*Ammodytes americanus*), the major diet for humback, sei, fin and minke whales in SBNMS (see following section on fish).

Fish

Over 130 species of fish are found in SBNMS. Fish species are incredibly important in the sanctuary, not only for their role in the complex marine food chain on the Bank, but also as an economic resource contributing millions of dollars annually to the New England economy. It is likely that most fish hear at low-frequency ranges below 500 Hz, the range of most anthropogenic noise on the Bank.

In examining the effects of noise, special consideration should be given to species of economic and biological importance, such as the Atlantic cod. Since the Gadidae family of cod and their relatives in SBNMS -- haddock, pollock and hake -- hear at frequency levels between 10 and 500 Hz, they may be particularly susceptible to introduced noise. Herring, capelin (*Mallotus villosus*) and mackerel are also important both economically and biologically in SBNMS, supporting populations of larger fish like bluefin tuna (*Thunnus thynnus*), harbor and gray seals (*Halichoerus grypus*), cetaceans, and a variety of birds including fulmars, shearwaters, murres, puffins, cormorants and gannets (CCS 2000).

Vessel traffic noise may affect schooling behavior of fish species such as those that may be using sound to maintain group formation (see **Acoustic Effects on Marine Fishes** section). In this respect, vessel noise might also alter the schooling patterns or viability of sand lance concentrations eaten by baleen whales. Sand lance are crucial to the food web dynamics in SBNMS; they are an important food source not only for mysticetes, but also for schools of larger fish that are in turn eaten by toothed whales and pinnipeds.

Based on the literature, it appears that sound levels of 180 dB at 50-2000 Hz would be harmful to fish species (see **Acoustic Effects on Marine Fishes** section). In various studies, exposure to sound has induced startle responses, damage to hair cells, balance effects, and reduced catch of certain species. It should be noted that most of these are limited experiments, usually conducted with an explosive sound simulating seismic or air gun sources. Given that these types of noises are not typically present in SBNMS, extrapolations should be made very cautiously. However, as the body of research conducted on fish species and anthropogenic noise is scant, any source-effect studies that relate a response in organisms due to sound should be noted. In this case, rather than seismic survey responses, it is particularly necessary for SBNMS to consider studies on long-term, cumulative, ambient noise effects.

Sharks in SBNMS such as the spiny dogfish (*Squalus acanthias*), porbeagle (*Lamna nasus*), great white (*Carcharodon carcharias*), basking (*Cetorhinus maximus*), makos (*Isurus* sp.) and blue (*Prionace glauca*) sharks (CCS 2000) may also be affected by anthropogenic noise. A number of studies have shown how sharks utilize low frequency sounds (see **Acoustic Effects on Marine Fishes** section). One study indicated that sharks were attracted to sounds of struggling fishes, another study examined their responsiveness to low frequency sounds. If shark species use sound as a component of finding prey, vessel traffic in SBNMS may have a masking effect on sharks' ability to feed.

Other Species

Five species of sea turtle can be found in SBNMS: the regularly seen leatherback, Kemp's (Atlantic) ridley, and loggerhead, as well as the less often seen green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) species (CCS 2000). All of these species are listed as either endangered or threatened. As turtles can likely hear frequencies between 250-750 Hz, it is quite possible that they perceive frequencies generated by vessel traffic in the sanctuary. One theory postulates that turtles use sound for predator avoidance (Eckert pers. comm. 2000), continuous noise generated by vessel traffic could mask the animals' ability to protect themselves. This could occur between the leatherback turtle and its primary predator, the killer whale, both found in SBNMS. Further research is necessary to understand turtles' use of sound. Indirect effects may also be a problem for turtle species. Cumulative noise that might affect invertebrate population viability could also influence turtle populations in SBNMS that rely on jellyfish, salps, and siphonophores for the majority of their diet.

Unfortunately, little data currently exists to document noise effects on invertebrates. In fact noise impact studies on invertebrates have been excluded from previous analysis in light of the fact that they lack the appropriate structures to be affected by low frequency sound (see **Effects on Other Taxa** section). Noise effects on sanctuary echinoderms such as sea urchins, sand dollars, sea stars and sea cucumbers have not been investigated. Similarly, noise effects on molluscs such as the deep sea scallop (*Placopectin megellanicus*) and surf clam (*Spisula solidissima*) are unknown. Research into effects on these species is worth exploring as they are important links in the SBNMS food chain, as well economically significant species for the New England seafood market.

Studies should be initiated on sanctuary arthropod species such as the horseshoe crab (*Limulus polyphemus*) and the American lobster. Little is known about the population status of the horseshoe crab in the North Atlantic (CCS 2000). As a species which is already threatened by extensive harvesting for the conch bait industry, further investigation into human impacts such as sound are certainly warranted. Based upon studies of American lobsters that determined a hearing threshold of approximately 150 dB for the species, they could potentially be affected by noise in the sanctuary. Research into the effects of noise on lobster populations in the sanctuary is recommended as areas within SBNMS are thought to be nurseries for young lobster populations. Additionally, the species is heavily harvested for the New England seafood fishery and contributes significantly to the economy of the region.

Long-finned squid (*Loligo pealei*) and short-finned squid (*Illex illecebrosus*) are a primary food source for many species in SBNMS. They are a food source for most toothed whales, minke whales, gray and harbor seals, fulmars, shearwaters, alcids, cod and other fish species (CCS 2000). Squid exhibit startle responses to sound; one study indicated their behavior would be highly altered 2-5 km away from a seismic sound source (McCauley *et al.* 2000). Although studies have not been conducted on cumulative ambient effects, this provides initial evidence that perhaps cephalopods are responsive to noise and may sustain negative effects from high ambient noise levels. As an important part of the marine food chain in SBNMS, research should be conducted on potential effects to these significant species.

Zooplankton are the food base for a majority of marine ecosystems, and research is necessary to determine whether these populations are subject to any deleterious effects from introduced noise. However, even if zooplankton are not affected physiologically by noise, there may be other effects on population concentrations. Studies of zooplankton are particularly important in SBNMS, where upwelling creates enhanced primary productivity. Populations of copepods and krill are the major component of blue, sei, and right whale diets; many fish and bird species in SBNMS also rely on these zooplankton as a primary food source.

Introduction to Channel Islands National Marine Sanctuary

CINMS was designated in 1980 to protect the exceptional natural beauty and marine resources that make this area one of national significance (NOAA 2000i). The Sanctuary is located between 8 and 40 nautical miles (nm) (15 to 74 km) off the southern California coast, just north of Los Angeles and immediately south of the Santa Barbara Channel. It encompasses 1,252 square nautical miles (4,287 square kilometers or 1,658 square miles) of water surrounding the San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands. The boundaries extend from mean high tide to 6 nm (11.1 km) offshore around each island. The terrestrial portions of the islands comprise the Channel Islands National Park (managed by the National Park Service) (NOAA 1983). This special area has been designated as a United Nations World Biosphere Reserve (NOAA 2000i).

The submarine topography this region is characterized by a "complex of basins, canyons, ridges, and shelves skirting high-cliffed islands" (NOAA 1983). Active seismic faults, shallow oil and gas reservoirs, and natural oil and gas seeps are characteristic of this area, particularly in the northern portions of the Santa Barbara Channel (NOAA 1983).

Located within the southern California bight, the Sanctuary contains a mixing zone of cold-temperature waters flowing from the north, and warm-temperate waters flowing from the south. As a result, the Sanctuary harbors a diverse abundance of marine life, including multitudes of fish and invertebrates species, many of which are found only in this unique transition zone; large giant kelp forests; and a wide variety of resident and transient cetaceans, pinnipeds, and seabirds (NOAA 1983).

Twenty-seven species of cetaceans have been sighted in the sanctuary, 18 of which are considered “residents.” These include a variety of dolphin species (e.g., Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Dall’s porpoise (*Phocoenoides dalli*), and common dolphin), as well as pilot, killer, and minke whales. In addition, the sanctuary is situated along the migratory pathway of the gray whale and other large baleen and toothed whales. Gray whales caring for calves have been sighted in the kelp beds of the Sanctuary (NOAA 1983). There are four species of pinnipeds that breed in the Sanctuary: the California sea lion, northern fur seal (*Callorhinus ursinus*), northern elephant seal, and the harbor seal. The Guadalupe fur seal (*Arctocephalus townsendi*) and Steller sea lion (*Eumetopias jubatus*) are occasional sanctuary visitors (NOAA 2000i).

Closer to the islands, kelp forest rock-bottom and shallow-bottom sand habitats predominate. Kelp forests support large communities of fish and invertebrate fauna, including garibaldi (*Hypsypops rubicundus*), opal eye (*Girella nigricans*), California sheephead (*Semicossyphus pulcher*), and sea perch fishes, and sponge, kelp crab, octopus, squid, sea stars, and sea urchins. Species common in the sand habitats include “sea pansies, polychaetes, sand dollars, several species of rays, sand dabs, and turbot” (NOAA 2000i).

CINMS provides nesting, feeding, and resting habitat for over 60 species of resident and migratory seabirds. Eleven of the 16 resident species breed in the sanctuary. Several nationally and internationally significant marine birds nest within the Sanctuary. In particular, Santa Barbara Island harbors the largest nesting colony for Xantus' murrelet (*Synthliboramphus craveri*) and the only U. S. nesting site for black storm-petrels (*Oceanodroma melania*). The endangered brown pelican (*Pelecanus occidentalis*) maintains its only permanent rookery in California on Anacapa Island (NOAA 1983).

While the priority goal of the Sanctuary is to protect its marine and cultural resources (e.g., historically significant shipwrecks and cultural artifacts), it also supports many other uses, including recreational and tourism activities, commercial fishing, education, and research. Recreational uses include boating (sailing and bower boating), windsurfing, sport fishing, diving, and nature viewing (e.g., whale watching). Commercial fishing and mariculture are also permitted within the Sanctuary. Several year-round and seasonal fisheries catch jack and mackerel, California halibut (*Paralichthys californicus*), rockfish, and swordfish (*Xiphias gladius*). Sea urchin, abalone, lobster, rock crab, and kelp are all harvested. Several major shipping lanes run adjacent to the Sanctuary. In particular, two major traffic routes pass through the eastern portion of the Sanctuary (between the Sanctuary and mainland) within 2 nm (3.7 km) of Anacapa Island and within about 20 nm (35 km) of San Miguel Island at the western end of the Sanctuary. Numerous organizations conduct marine research here (e.g., University of California, Scripps Institution of Oceanography, Minerals Management Service (MMS), U.S. Fish and Wildlife Service (USFWS), etc). Public educational programs are also an important part of sanctuary management (NOAA 1983).

Offshore oil and gas drilling occur in the vicinity of the Sanctuary, but not within its boundaries. In addition, both the Navy and the Air Force conduct training exercises in the Point Mugu Sea Range to the west of the Sanctuary, and the Vandenberg Air Force Base serves as a launch site for unmanned space rockets (NOAA 1983).

Sources of Anthropogenic Noise in CINMS

According to Pierson (pers. comm. 2000), there are a number of sources of sound in CINMS. These include seismic surveys, vessel traffic from the Santa Barbara Channel, Navy exercises, air traffic from Vandenberg Air Force base, fishing boats, and recreational boats. Seismic exploration using air guns and explosives is a major noise source of concern, according to Cavanagh (pers. comm. 2000a), author of environmental impact surveys for the Navy in areas around CINMS. He also states that aircraft noise from the Air Force and Navy is a significant noise source, while recreational noise is likely not.

The use of air guns to obtain data for the purpose of mineral resource exploration is considered a high-energy seismic survey. Although there is a moratorium on new leasing for offshore oil and gas exploration on the Gulf of Mexico Outer Continental Shelf (OCS) (Pierson pers. comm. 2000), high-energy seismic surveys continue in the existing leasing area. Cavern Point Unit, which includes 2 existing leases in the Santa Barbara Channel off Ventura County, is bounded by CINMS on the south. The operator has submitted a proposal to conduct exploration including a high-energy seismic survey (MMS 2000).

The sound levels of air gun array can be large, with peak source pressures (at an effective distance of 1 m) exceeding 250 dB re 1 microPa @ 1m. A relatively small 600 in^3 array may produce a peak pressure of 235 dB re 1 microPa @ 1m (Richardson *et al.* 1995a).

In 1998**,** Exxon had a Vertical Seismic Profile (VSP) test on a well at Platform Harmony, located in the Santa Barbara Channel. The air gun array consisted of 8 airguns, 4 at 40 in^3 and 4 for 150 in^3, with a total array volume of 760 in^3. It was predicted that 190 dB re 1 microPa sound pressure level (SPL) would project to a distance of 20 m, and 180 dB re 1 microPa would project to 82 m (HESS 1999). This prediction was based on the measurement of the performance of an 18-air gun array (volume 3959 in^3) used in the Santa Ynez Unit in 1995. For that air gun array, the 190 dB SPL was at 77 m, the 190 dB SPL was at 316 m, and the 160 dB SPL was at 3700 m (HESS 1999).

In addition to oil and gas exploration, USGS does some small-scale seismic surveys in order to measure earthquake hazards (Pierson pers. comm. 2000). These seismic surveys are much smaller than those done for oil and gas exploration. Usually, only one airgun or airgun array is used, as compared to 10-18 dual arrays used in oil and gas exploration. Generally one USGS air gun emits about 200 dB, but it depends on the type of gun and size (Pierson pers. comm. 2000).

An estimated 7,600 bulk carriers and container vessels travel through the Santa Barbara Channel every year (McKenna pers. comm. 2000). Furthermore, there are approximately 500,000 registered recreational vessels within a 100-mile radius of Long Beach Harbor. While many of these boats frequent nearby Catalina Island, recreational boaters attempting to avoid the crowds often travel to the CINMS. Although exact levels of recreational boating traffic are unknown, they likely contribute to cumulative noise levels within the sanctuary (McKenna pers. comm. 2000). These large commercial vessels and supertankers have powerful engines and produce high sound levels, primarily at low frequencies. Overall, boats (lengths 5-34 m) with outboard engines produce noise frequencies from 37 to 6300 Hz, and estimated source levels are from 145 to 170 dB re 1 microPa @ 1 m. For small ships (lengths 55-85 m) broadband (20-1000 Hz) levels could be 130 to 141 dB at distance of 0.56 km. The frequencies produced by these ships (lengths 135-340 m) are from 6.8 to 428 Hz, and the source levels of dominant tone are from 169 to 198 dB re 1 microPa @ 1 m (Richardson *et al.* 1995a).

Although exact aircraft traffic data in this area are not available, some does exist for aircraft used offshore. Dominant tones in noise spectra from helicopters and fixed-wing aircraft are generally below 500 Hz. For details see table 2 below.

Table 2: Estimated Aircraft Noise

Aircraft	Frequency (Hz)	Aircraft altitude (m) as measured	Estimated source level (dB re 1 micro Pa-m)
Helicopter			
Bell 212	22	152-610	149-150
Fixed Wing			
B-N Islander	70	152	142
Twin Otter	82	457-610	147-150
P-3 Orion	56-80	76-305	160-162

Although supersonic noise might be produced in this area, Cavanagh (pers. comm. 2000a) indicates that it is not a significant factor. The angle of incidence at which the noise energy hits the water is so low that little noise penetrates the water. He argues that sub-sonic noise (e.g., from helicopters) is a greater problem than supersonic noise.

Recreational activities in this area include whale watching, sailing, and diving. Anywhere from 4-8 whale watching companies operate around Santa Barbara, using boats from 15 to 26.4 m in length (Channel Island National Marine Sanctuary 2000; Whale-Watching Web 1999). Daily whale watching trips are offered during two time periods: from December to mid-May, and from July to September (Condor Cruises 1998a; Condor Cruises 1998b; Island Packers 1999; Santa Barbara Sailing Center 1999; Truth Aquatics 2000a; Truth Aquatics 2000b).

Potential Effects of Anthropogenic Noise on CINMS Species

The CINMS is truly a multi-use sanctuary, with recreational, commercial, military, and scientific interests simultaneously competing for use of its own and nearby waters. The combined activities of all of these groups make the CINMS quite a noisy place. Although little research has been conducted to determine the acoustic impacts of these activities on the marine resources that the CINMS seeks to protect, some broad conclusions can be drawn based on the information presented in this document and anecdotal evidence from experts in the field.

Much like the SBNMS, the major acoustic threat to marine life at CINMS is thought to be vessel traffic. Located just 2 km off of Anacapa Island, the Santa Barbara Channel is a major avenue for commercial and cargo vessels of all sizes and is suspected to be the biggest single source of underwater noise in the sanctuary (Fangman pers. comm. 2000; Schusterman pers. comm. 2000). Commercial fishing may be another major source of noise, with an annual average of 1085 commercial fishing vessels present within Santa Barbara Channel harbors between 1990 and 1999. These vessels may be equipped with ADDs and AHDs, which are an additional source of noise. Kelp harvesters are one noise source that is unique to the CINMS, although its acoustic emissions have not been researched in depth, making it difficult to extrapolate its acoustic effects. The cumulative noise associated with all types of vessel traffic is of particular concern because it represents a relatively continuous acoustic source.

In addition to vessel traffic the CINMS may be subject to a number of more intense, transient acoustic sources. These include seismic surveys for oil, oil drilling, and naval activities, such as LFA, submarine testing, and other operations. The sanctuary's close proximity to naval activities conducted from Point Mugu may pose a threat to a number of species. Underwater missile testing may expose sanctuary species to supersonic sounds and sonic booms. Explosions associated with shipshock tests and training sessions, as well as falling debris, represent additional (and poorly documented) sources of sound in the sanctuary (Fahy pers. comm. 2000). A brief discussion of the potential effects of all of these acoustic sources on the marine organisms residing at CINMS is provided below.

Seabirds

At least eleven species of seabirds are known to breed within the CINMS; these include the endangered California brown pelican, common terns (*Sterna hirundo*), storm petrels, and Xantus' murrelets (Holdman 1990). Although little research has been done to determine precise hearing thresholds in seabirds, data from terrestrial birds indicates that they hear best at frequencies between 1 and 5 kHz (Dooling 1978). The widespread use of pingers (ADDs) in commercial fisheries has already significantly reduced the bycatch of seabirds, suggesting that they are able to detect pulsed noises (2 kHz) between 120 and 132 dB re 1 microPa (Melvin pers. comm. 1999). One acoustic source of particular concern for seabirds may be the "light boats" used in nighttime squid fisheries. These boats operate at night, using large, on-deck generators to power lights that provide 35,000 - 100,000 watts of illumination. The noise from these generators, not to mention the bright lights, has been associated with brown pelican abandonment of nests on Anacapa Island (Fangman pers. comm. 2000). Since this island houses the only permanent rookery for this species in California, such disruptions may prove highly detrimental to the health of the population (Holdman 1990). Little research has been done into the acoustic effects of these light boats underwater or their impacts on other species. Such research into their impacts and potential mitigation is crucial in order to ensure the health and survival of sanctuary populations.

Cetaceans

With over 27 species of cetaceans found in the region, the Santa Barbara Channel is touted as one of the best places in the world for whale watching (Holdman 1990). Odontocete species, including the Pacific white-sided dolphin, the Dall's porpoise, Pacific bottlenosed dolphin, common dolphin, and Risso's dolphin may not be directly affected by the low-frequency noise associated with many vessels. However, they may be affected by higher-frequency noises within their hearing range. The presence of ADDs and AHDs in the sanctuary has significantly reduced bycatch of these mammals, but potential side effects of these acoustic devices on dolphins and porpoises have not been extensively studied. While most agree that the benefits associated with such pingers and AHDs far outweigh their costs (Fahy pers. comm. 2000), research into the cumulative impacts of these devices, particularly in important feeding grounds, is certainly warranted.

Baleen whales are thought to be particularly susceptible to low frequency noise sources. Potentially impacted baleen whales occurring in the CINMS include Minke (resident), fin, blue, sei, humpback, and Bryde's whales (*Balaenoptera edeni*). The effects of cumulative vessel traffic on these species is not clear but, since most receive and produce sound at low frequencies, they are likely affected by the cumulative vessel traffic occurring at 500 Hz or less. Of particular concern for these species is the potential acoustic threat posed by oil development and extraction activities. Seismic surveys using air gun arrays usually produce sounds exceeding 200 dB at extremely low frequencies (100 Hz). A HESS form submitted for Venoco's proposed seismic survey at the Cavern Point indicated that cetaceans "reasonably expected to encounter seismic vessels in the Southern California Bight" included the following sanctuary species: California gray whale, fin whale, Minke whale, blue whale, humpback whale, common dolphin, northern right whale dolphin (*Lissodelphis borealis*), Pacific white-sided dolphin, Risso's dolphin, Dall's dolphin, bottlenose dolphin, and short-finned pilot whale. Although guidelines to minimize the impacts of seismic surveys have been developed (HESS 1999), the use of these intense air gun arrays may have unpredictable effects on marine species.

Venoco proposed a seismic survey in the Santa Barbara Channel for the coming year, but has since canceled the project due to expense (Fahy pers.comm. 2000). Although no seismic surveys have been conducted off the coast of California in the past several years, proposals such as Venoco's can be expected to become increasingly common in the coming years, as the 36 undeveloped leases in the area begin to be developed. The continued drilling of existing platforms, as well as the development of currently inactive leases or platforms will add to the noise level through drillships, construction, and other extractive activities. For example, Venoco plans to continue with plans to drill two new extended-reach wells from the existing Platform Gail in a unit adjacent to the CINMS (the Santa Clara Unit). The process, slated to begin in the next two years, is expected to take several months. The combined impact of all of these development activities is not clear, but monitoring and research in the face of these proposed projects might prove quite informative.

High-intensity noises associated with many naval activities may be of particular concern at the CINMS. The proposed LFA testing in the Pacific Ocean may expose species in and around the sanctuary to sound levels greater than 205 dB. Again, based on current knowledge, baleen whales and other cetaceans may be the most affected by these activities, but little is known about effects on non-marine mammal species. Circumstantial evidence for the sensitivity of whales to LFA is provided by the 1996 strandings of Cuvier's beaked whales in Greece (see **Effects of Anthropogenic Noise on Marine Mammals** section).

Pinnipeds

Rookeries for four pinniped species exist on San Miguel Island alone, making CINMS an important breeding ground. As previously mentioned, pinniped species are thought to produce and receive sounds at relatively high frequencies (1 - 10 kHz) (see **Effects of Anthropogenic Noise on Marine Mammals** section). The overall increase in ambient noise, both in air and in water, is of greater concern for these species than short-term, high intensity acoustic sources. According to Schusterman (pers. comm. 2000) longer duration noises are more deleterious to pinniped hearing (Schusterman pers. comm. 2000). Elephant seals may be particularly resilient in the face of noise, with many animals exhibiting rapid recovery after exposure to noise sources (Schusterman pers. comm. 2000). Nevertheless, the presence of noise from vessel traffic may impede underwater communication (Southall *et al.* 2000) in several species and may be cause for concern.

Airborne noise sources, such as rocket launches at Vandenberg Air Force Base and other flight test routes may be of particular concern for pinniped species in the area. Activities involving sonic booms and other loud noises may initiate stampedes of hauled out animals, but little information has been gathered regarding the long-term impacts of exposure to these noises. In theory, such stampedes could lead to trampling of pups, but there is little documentation of such events in the area (Fahy pers. comm. 2000). More research is needed to clarify the impacts of underwater and airborne noises on pinniped species in order to allow for more informed management decisions.

Fish

In the mid-1980s, the rockfish fishery was impacted by activities associated with offshore oil development and exploration. The noise associated with seismic surveys scattered rockfish, while extraction activities conducted in hard bottom areas commonly utilized by rockfish may also have impacted rockfish populations (Croll *et al.* 1999). Given that the sanctuary contains 62 species of rockfish, the implications of these activities for rockfish populations should be carefully examined.

A survey of the literature presented in this report suggests that frequencies of 50 to 2,000 Hz at levels exceeding 180 dB may cause physical harm to many fish species. Many of the activities in and around CINMS produce noise within this range and have been associated with startle responses, disrupted schooling behavior, damage to hair cells, and swim bladder injuries (see **Acoustic Effects on Marine Fishes** section). In light of these possible effects, the long-term impacts of seismic surveys, vessel traffic, and naval activities on fish species should be carefully examined. This is particularly true given the commercial and recreational importance of many of the fish species found in CINMS. Proper fisheries management, while not the direct responsibility of the CINMS, cannot be effectively carried out without consideration for the cumulative effect of all activities impacting fish stocks within the sanctuary

Shark species may also be sensitive to low frequency sounds (see **Acoustic Effects on Marine Fishes** section), possibly using them to find prey. The presence of vessel traffic in the Santa Barbara Channel could affect the hunting ability of the 25 shark species found within CINMS (including: swell (*Cephaloscyllium ventriosum*), leopard (*Triakis semifasciata*), scalloped hammerhead (*Sphyrna lewini*), basking, great white, blue, and horn sharks (*Heterodontus francisci*)) by masking the sound of prey species. However, as is the case with other taxa, much research remains to be done to fully understand the effects of specific low frequency sounds on sharks in the Channel Islands.

Other species

Unfortunately, little is known about the effects of underwater noise on marine plants, such as algae and kelp, which provide vital habitat and food sources for so many sanctuary species. Likewise, effects on echinoderms (sea stars, sea urchins, and sea cucumbers), mollusks (clams, limpets, snails, octopus, etc.), and arthropods (barnacles, crabs, isopods, amphipods, shrimp, etc.) are largely unknown. Many of these species have been largely ignored because they have poorly developed auditory systems (see **Effects on Other Taxa** section). However, as we have seen, the potential effects of long-term exposure to low frequency sound extend beyond hearing damage. The possibility that acoustic sources may have unknown impacts is certainly worth exploring.

MITIGATION

A number of alternatives exist to mitigate anthropogenic noise in the marine environment. Some of these are already in use. A few techniques have been tested experimentally, while others are still untested ideas. The possibilities for implementation vary, depending on logistics, feasibility, available technology, and expense. The utility of different mitigation measures also depends on the specific source and species of concern, as well as the geographic location. Clearly a different technique would be used to muffle the sound of a whale-watch vessel engine than to minimize the impact of drilling activities or a seismic blast. Efforts to reduce the effects of noise include minimizing existing sources, and imposing stricter regulation of future sound-generating sources. All highlight the need for further biological research and monitoring. Methods currently in use with potential for future effectiveness include ramping-up, bubble-curtains, quiet-ship technologies, and operating in response to animal's behaviors, migrations and sensitivities.

One principal method currently in use is to monitor visually an area prior to and during the operation of a sound source for marine mammals and turtles (Cavanagh pers. comm. 2000b; HESS 1999; Richardson *et al.* 1995a). This is typically used with static, controlled sound sources to ascertain the presence or absence of potentially affected marine mammals. A preliminary survey conducted aerially, by vessel, or from land can confirm that animals are indeed in the area if they are visible at the surface. Operations can then be delayed until individuals or populations have left the impact zone. Consistent monitoring of this kind is important to understand further the daily and seasonal migrations and patterns of behavior. This understanding allows noise-producing operations to time their activity to coincide with the periods that the animals of concern are absent, in order to minimize impact.

Acoustic monitoring is a relatively new mitigation measure. This type of passive monitoring is a way to locate animals in an area by detecting their vocalizations. A DIFAR buoy detects both sound and its direction. The use of two buoys gives additional distance information (HESS 1999). Another passive approach is to tow an array from a vessel. Animals can be detected 1-3 miles from a static source or seismic vessel using these types of passive monitoring (HESS 1999). The use of active sonar is another option to monitor animal abundance around sound sources. It effectively allows the operator to "see" potentially affected animals. It generally involves two high frequency sonars (40-80 kHz) intended to reveal every hard or soft-bodied object in the water (Gentry pers. comm. 2000a). This is used not only to prevent animal exposure to high noise levels, but also to prevent ship collisions with large whales (Cavanagh pers. comm. 2000b). One concern with these kinds of active techniques is that they introduce additional sound to the marine environment, i.e. one source being used to assess another. While active sonar may be effective in detecting a large whale up to 1km. away, it may at the same time harass smaller whales or other species closer to the source (Cavanagh pers. comm.2000b). At this point, the impacts from such use of active sonar are unknown.

The use of satellites represents another potential technique to determine whether vulnerable marine life is near a sound source. Satellites can observe concentrations of krill and other zooplankton (Cavanagh pers. comm. 2000b), allowing one to infer the location of the target animals by the presence of their food source. Expanding the use of historical siting records and migration models may also help determine the proximity of local animals to a sound source.

A commonly employed method used with airguns and other industrial activities is to "ramp-up" in an attempt to "warn" animals away from a sound source. When "ramping-up" sound is introduced at a low level and systematically increased at a gradual rate. This technique is a standard mitigation measure for seismic operations in many areas (HESS 1999). In the case of airguns, firing begins with the smallest gun and sequentially moves to the largest, thereby gradually increasing the sonar field (Gentry pers. comm. 2000b). Cavanagh (pers. comm. 2000b) states that "ramping-up" is standard with Navy sonars; a typical rate might be a 6 dB increase every 10 minutes. However there is no conclusive evidence that "ramping-up" is actually effective in directing animals away from sound sources (Cavanagh pers. comm. 2000b; Gentry pers. comm. 2000b; HESS 1999; Richardson *et al.* 1995a). In fact, there is widespread concern that it may actually attract animals to the sound source rather than repel them (Würsig and Richardson 2000; Cavanagh pers. comm. 2000b). It is valid to advocate the technique on the basis of the precautionary principle (Gentry pers. comm. 2000b), but directed research needs to address the effectiveness of "ramping-up" before it can be considered a reliable mitigation method (Richardson pers. comm. 2000). The MMS is currently preparing to investigate this issue in the Gulf of Mexico (Gentry pers. comm. 2000b).

The use of bubbles is currently being explored as a potential mitigation measure. Bubbles inhibit the transmission of underwater noise by absorbing or reflecting the energy of sound waves (Würsig *et al.* 2000). Tests of "bubble curtains" have succeeded in offseting or reducing sound, particularly around industrial noise sources such as explosions, machinery, construction, and pile-driving (Cavanagh pers. comm. 2000b). In a study by Würsig *et al.* (2000), noise from pile-driving activity in the shallow waters (6-8 m) of western Hong Kong was reduced by a shrouding screen of bubbles emitted from a circle of perforated rubber hose. The bubble curtain provided a reduction of 3-5 dB in overall broadband sound, and effectively lowered sound levels within 1 km of the activity. The greatest reduction in sound was evident in frequencies between 400-6400 Hz. The effectiveness of bubble curtains at reducing sound in the low frequency bands of 400-800 Hz may lend itself particularly well to screen industrial noise from baleen whales, known to communicate at these frequency levels. Sanctuaries should investigate the use of bubble-curtains in and around their waters to mitigate the detrimental impact of industrial activities for these cetacean species. According to Gentry (pers. comm. 2000b) bubble-curtain mitigation is only moderately effective, but it may be a valuable precautionary measure within sanctuaries.

Mitigation directed at shipping appears to be high priority as it is generally accepted to be the greatest contributor to ambient anthropogenic noise in the ocean. While "quiet ship" technology has been developed and widely used for military purposes, it has only been employed to a limited extent by other sectors. The sound that a vessel produces depends on a combination of factors such as hull material, type of engine, number of propeller blades and the rate at which they turn. One method to reduce this source of noise is to isolate the engine from the hull with a rubber doughnut, thereby de-coupling the sound emitted and eliminating hull reverberation (Gentry pers. comm. 2000b). Another technique involves encasing the propeller within a rubber nozzle in order to reduce the low frequency hum. The effectiveness of this technique is not well understood, but the use of this kind of tubing is known to reduce the sound field by concentrating it and forcing it backwards (Gentry pers. comm. 2000b). Projecting jets of sound-attenuating bubbles is effective at screening propeller noise (Würsig and Richardson 2000). NMFS will sponsor a workshop with Navy engineers in 2001 to address these technologies. They hope to learn how much gain (reduction in sound) can be obtained from their use (Gentry pers. comm. 2000b).

The majority of shipping noise originates in the private sector, and so quieting technologies need to be directed at this group (Würsig and Richardson 2000). There is currently no mechanism to require the shipping industry to use quieting technologies; their participation and adoption of these methods is completely voluntary. However, if NOAA and other governing bodies make the reduction of anthropogenic noise in the ocean a priority, companies may be willing to negotiate by building these technologies into their plans. A forthcoming example may be a new fleet of ships under construction by British Petroleum. According to Gentry (pers. comm. 2000b), they are receptive to noise reduction arguments in designing the structure and operation of their new vessels.

Developing and enforcing speed regulations for vessels may also present an extremely viable mitigation measure. Most of the noise that a vessel produces is due to "cavitation," the production and subsequent collapse of bubbles around the blades of the propeller (NRDC 1999). The propeller must be operating at a certain level of speed to reach a cavitation point, and so slow-moving vessels do not contribute to this source of sound. It has been documented that with the onset of cavitation, propeller noise undergoes dramatic increase, and then continues to rise more gradually (NRDC 1999). Maintaining propeller blades free of barnacle accretions and ensuring that loose components are tightened may offset cavitation. Maintenance failure can result in elevating noise by 10 dB or more (NRDC 1999).

Another new area of research is the development of software models to predict the zone of impact for marine animals around anthropogenic noise sources. Though developed for marine mammals, the potential exists to use similar models for other species such as fish and turtles as more data become available. Erbe and Farmer (2000a) have developed an impact zone model based on ray theory using sound propagation parameters to calculate received noise levels which are then combined with known marine mammal noise threshold levels. The software requires the input of parameters such as source level, spectrum of noise, physical oceanography data, sound speed profiles, and animals' audiograms (vocalization spectra, reported levels of disturbance, hearing damage criteria). Data files and plots are produced that predict zones of audibility, disturbance, and potential hearing damage around a source of noise.

The University of Maryland Problem Solving Group recommends that the NMSP closely examine possibilities for mitigation, both within their waters and in adjacent areas. The following section on Recommendations discusses the possibilities for incorporating noise concerns into sanctuary management. Viable applications for mitigation techniques are addressed and adaptative management alternatives suggested for the NMSP.

RECOMMENDATIONS

This report summarized the current body of knowledge on the potential impacts of anthropogenic noise on marine life through a literature review and a collection of interviews with acoustic experts, managers, and marine scientists. Recommendations for the NOAA NMSP were gathered from this review and are presented in this section. Recommendations that can be implemented by sanctuary management staff are directed to the sanctuaries. Most of these are relevant for all of the sanctuaries within the national program and, therefore, are not directed solely to SBNMS or CINMS unless they specifically apply to a particular sanctuary. Other recommendations that may be more appropriately addressed at the programmatic level are directed to the NOAA NMSP. It is important to note that recommendations made at the sanctuary level would benefit from (and in some cases may require) support by the NMSP at the national level.

Recommendations for National Marine Sanctuary Managers

Manage Sanctuaries as Sanctuaries

The priority goal for managing sanctuaries, according to the National Marine Sanctuary Act, "is to maintain, restore, and enhance living resources by providing places for species that depend on marine areas to survive and propagate (The National Marine Sanctuary Act 16 U.S.C. 1431 et. seq., Sec. 301(b)(5)(9))" (NOAA 2000a). Sanctuaries have the opportunity to take a very proactive role in managing anthropogenic noise. This requires serious reconsideration of the "multiple-use" activities currently allowed in sanctuary waters. A shift in philosophy is necessary in terms of the role and purpose that sanctuaries serve (Gentry pers. comm. 2000a). The common analogy made for sanctuaries today is that they are managed as National Forests, supporting many uses (e.g., resource harvesting, recreation, protection of wildlife)(Fangman pers. comm. 2000). A better strategy to achieve the National Marine Sanctuary Act's priority goal would be to manage sanctuaries in a manner similar to National Parks or Reserves.

To protect the marine life within sanctuaries from potentially negative effects of anthropogenic noise, sanctuary management staff should incorporate into their Management Plans the concept of "silence" as a tangible resource to be managed (Gentry pers. comm. 2000a). This approach is currently being employed by the National Park Service (NPS), where the objective of managing "natural quiet" as a park resource is explicitly stated in NPS policy (Gentry pers. comm. 2000a; NPC 2000).

Establish Noise Limits

Sanctuaries should establish noise limits with their boundaries (Gentry pers. comm. 2000b). These limits should be based on sound scientific data (Gentry pers. comm. 2000b). Where data are not available, or not specific to the area of interest, sanctuaries should use a precautionary approach, adopting conservative limits based on the best available data and suggested evidence for avoiding harm to marine life (NRDC 1999). Sound sources in, or with the potential to influence, waters of sanctuaries should be surveyed and monitored. This must include stationary sites and areas heavily trafficked by marine craft (Cavanagh pers. comm. 2000b; Gentry pers. comm. 2000b). In addition, a general profile of noise levels within the sanctuaries should be generated. Activities that exceed these levels (e.g., oil and gas exploration or the construction of oil and gas wells, shipping, or LFA activity) should be prohibited within the sanctuary (Gentry pers. comm. 2000b), or operators should be required to implement mitigation measures (ramping-up, bubble curtains, adjusting operation in response to animal migrations, etc.). For example, in CINMS, bubble curtains could be required for oil and gas drilling. Such regulations implemented at the sanctuary level could also be applied categorically at the national level. Funding or incentives for implementing mitigation could be provided at the national level as well.

Regulate Vessel Traffic

Sanctuary management staff should develop and enforce speed limits for recreational boating and fishing vessels within sanctuary boundaries. Slowing boat speeds to a point below which cavitation is eliminated can significantly lower sound levels emitted by propellers (Lindholm pers. comm. 2000; Van Dine pers. comm. 2000). This recommendation may be especially applicable to commercial whale watching vessels when approaching whales, as well as to the private "mosquito fleet" of recreational vessels whale-watching in the SBNMS.

Sanctuary managers might adopt regulations similar to those enforced in Glacier Bay National Park in Alaska. The park completed its Vessel Management Plan in 1996, designed to protect natural resources while accommodating increased park visitation. This plan regulates the number of vessels entering the bay while implementing vessel direction and speed regulations in areas where humpback whales are present. Vessel speed in these designated "whale waters" is limited to 10 knots (NPS 2000). The NMSP should consider developing its own vessel management plans for individual sanctuaries, focusing regulations on biologically sensitive areas and species.

Create "Sound Buffers" Around Sanctuaries

Given that the boundaries of marine sanctuaries are biologically and acoustically porous, there is unfortunately no door to close against sound. To help protect sanctuary resources, "sound buffers" could be established along sanctuary boundaries, analogous to the buffer zones and transition areas established around protected terrestrial ecosystems. As the Sanctuary system does not have direct jurisdiction outside its waters, enforcement for noise level limits within the sanctuary may be coupled with *suggested* limits for waters outside official boundaries. It may be necessary to introduce these suggested limits and operational changes as guidelines to the public with potential for future regulation. In a buffer zone around SBNMS, for instance, NOAA could educate private vessel operators (whale-watchers, commercial fishing operations, researchers) about the potential effects of engine noise and encourage the use of quiet ship technology. NOAA already maintains buffer zones around certain sanctuary islands; this model could be extended to include all sanctuary boundaries (NRDC 1999).

Create Marine Protected Areas within Sanctuaries

Sanctuaries should delineate sensitive and biologically significant areas (such as pinniped haul out areas, species breeding grounds and feeding grounds) within their boundaries as areas for additional protection, research, and monitoring (Gentry pers. comm. 2000b). One way to do this would be to survey sanctuaries to determine the areas used by particularly susceptible and sensitive species (Gentry pers. comm. 2000b). These areas could then be correlated with noise profiles to establish "acoustic hotspots," or areas of ecological significance already exposed to excessive amounts of human-produced noise (NRDC 1999; NRC 2000).

CINMS is particularly fortunate in that the State of California recently passed The Marine Life Protection Act of 1999, which establishes a system for creating marine reserves in California waters to protect fragile habitat (NRDC 2000). In these reserves, noise potentially harmful to marine mammals would be controlled, and oil and gas activities and fishing would be prohibited (NRDC 2000). Currently, mangers for CINMS are considering the creation of marine reserves within the sanctuary, working with the state and various stakeholder groups for the designation of these areas (Fangman pers. comm. 2000). The impetus for creating these reserves is to address the decline of certain species populations (Fangman pers. comm. 2000). Protection from noise should also be considered a criterion for reserve designation.

Programs to establish marine protected areas (MPAs) have already been implemented in other countries. For example, British Columbia's Land Use Coordination Office (LUCO) is working to establish MPAs along the Pacific Coast of Canada and British Columbia. Important elements of this program include legal authority for MPAs, coordination among various levels of government (federal and provincial), public input, and the construction of a comprehensive system (LUCO 1998). Similar programs have also been established in Australia (Richardson pers. comm. 2000). The focus here is on establishing "no- take" zones where fishing is restricted or prohibited. The underlying concept is that protecting critical fish habitat and populations will ultimately yield a greater abundance of fish for harvest (Hooy and Shaughnessy 1991). NOAA and sanctuary management staff can look toward these programs for guidance on establishing

MPAs for waters under their jurisdiction.

Recommendations for the NOAA National Marine Sanctuaries Program Headquarters Managers

Support Updating the Marine Mammal Protection Act

NOAA should promote the revision of the MMPA to allow for the specific regulation of activities that generate potentially damaging levels of sound to marine organisms. Controls could include mandatory implementation of mitigation measures when sound levels reach a certain threshold, and requirements to implement "best available control technologies" that keep noise levels to certain permissible levels. Goals for achieving noise reductions by certain target dates in specific areas could also be incorporated (NRDC 1999). Changing the MMPA in this manner would require enforcement (Gentry pers. comm. 2000b). This task could be carried out by the U.S. Coast Guard (NRDC 1999).

NOAA should also support the expansion of type “B” harassment with regard to noise issues (NRC 2000).

Regulate Shipping

Shipping is the largest source of sound in the marine environment (Gentry pers. comm. 2000b; Richardson pers. comm. 2000), yet it is also one of the least regulated maritime activities (NRDC 1999). The merchant fleet of cargo ships and tankers, in particular, represents largest number vessels in the oceans today (Schiefele 2000a). Shipping is particularly problematic for SBNMS, where major shipping channels into Boston cut directly through the sanctuary (Lindholm pers. comm. 2000). In CINMS, shipping lanes cross over small portions of the sanctuary (NOAA 1983). To address noises generated from these sources, it is recommended that NOAA:

- Promote "quiet ship" technology in the private sector. Knowledge of quiet ship technology within the U.S. Navy should be expanded to the private sector, and incentives and/or requirements for the shipping industry to incorporate quiet ship technology into their design plans should be established (Clark pers. comm. 2000; Würsig and Richardson 2000).
- Require regular maintenance of ships to reduce noise, including the removal of barnacle accretions from propellers to reduce cavitation, and the securing of any loose plates and bearings (NRDC 1999).
- Research the potential for regulating noise emissions from ships, and the possibility of charging emissions fees that would encourage ship owners to reduce noise (Clark pers. comm. 2000). An inspection program similar to the ones used for automobiles could be implemented.
- Support the addition of noise standards in international treaties and conventions. For example, a protocol on noise could be “annexed” to the International Convention for the Prevention of Pollution from Ships (similar to the annex for air quality), which regulates noise pollution in international waters (Hofman pers. comm. 2000).
- Where possible, relocate shipping lanes out of and away from sanctuaries. To accomplish this NOAA would need to work with states and the International Maritime Organization

(Gentry pers. comm. 2000b; Hofman pers. comm. 2000).

Research, Research, Research…

There is a general consensus among the experts and marine scientists contacted for this report that further research is needed. Although a large body of literature exists on the short-term behavioral responses of marine mammals to anthropogenic sound, there are still too many uncertainties regarding the potential long-term cumulative effects of anthropogenic noise on marine organisms (Erbe and Farmer 2000a). The types of responses made by marine mammals are highly variable and depend on many factors (Richardson pers. comm. 2000). Similarly, no data exist on permanent hearing loss due to noise exposure in marine mammals (Erbe and Farmer 2000a). Even less is known about non-mammal marine organisms (fish, invertebrates) (Gentry pers. comm. 2000a). These uncertainties preclude development of much sound sanctuary management policy or guidelines to address potentially detrimental sounds for marine life (Gentry pers. comm. 2000b; NRC 2000; Richardson pers. comm. 2000). Currently, available guidelines are based on best "guesses" (e.g. 180 dB safety-radius in the HESS guidelines) and are not fully supported by scientific data (Schiefele 2000a; Pierson pers. comm. 2000). It is therefore recommended that NOAA conduct and support research aimed at:

- Determining the long-term affects of human-produced noise on all types of marine organisms, including effects on species distributions and sizes, individual productivity and survival, as well as behavior, social, and physiological stresses and impacts (Richardson pers. comm. 2000; Clark pers. comm. 2000; NRC 2000; Hofman pers. comm. 2000).
- Establishing baseline knowledge of sound sensitivities for species of concern (in particular baleen whales), and the thresholds at which noises can cause TTS, PTS, and non-hearing physiological disruptions (Würsig and Richardson 2000; Schiefele pers. comm. 2000b). Studies should take into consideration the variation of sound sensitivities at various age-classes and between sexes. In addition to audibility thresholds, "viability thresholds" should also be determined. These are the "levels above which an animal's ability to maintain itself in the wild is significantly reduced" (NRDC 1999).
- Studies that employ more effective experimental design (Gentry pers. comm. 2000b). Although long-term field studies with replication are desperately needed, they are extremely challenging to conduct. A relatively new and growing method of research that should be explored by NOAA involves the use of miniature data loggers and telemetry transmitters that are attached to animals in the wild (Würsig and Richardson 2000). Peter Tyack has recently developed a tag that can be adhered to animals and which records noise levels at the receptor point (Boness pers. comm. 2000).
- Developing types of research for particular sounds or sources of sound (Gentry pers. comm. 2000b).
- Examining the current 145 dB noise threshold permitted in sanctuaries. This threshold is based on human divers, but the effectiveness for marine organisms needs to be determined (Gentry pers. comm. 2000b).
- Determining the effects of noise on fish, invertebrates, sea plants, and other non-mammal species. In particular, Gentry (2000a) recommends studying the effects of LFA on fish since LFA is often conducted near fish schools and populations.

NOAA should collaborate with other organizations, including ONR, to conduct joint, multi-agency investigations (Clark pers. comm. 2000; NRC 2000). Such investigations could use teams of investigators to perform sets of integrated, systematic studies on different aspects (hearing, behavior) of responses of marine organisms to various types of sounds (NRC 2000). This would also be helpful since marine research is very expensive, and costs could be spread out over several agencies, or departments within agencies (NRC 2000). In general, funding for this type of research should be provided in long-term increments (>20 years), as opposed to the 1-2 year tenures that are typically used (Hofman pers. comm. 2000; NRC 2000).

In addition to research, long-term monitoring should be implemented (Cavanagh pers. comm. 2000b). For example, fisheries that use pingers and ringers should monitor the effectiveness of these devices, and third-party researchers should monitor any adverse impacts these may be having on marine life. Similarly, the effects of ongoing seismic surveys and mining operations should be monitored to determine impacts on marine species in the area. Generally, research should be multi-faceted and should anticipate future needs for mitigation and adaptation (Hofman pers. comm. 2000; Boness pers. comm. 2000).

Another opportunity for collaborative, inter-agency, long-term monitoring could be in the implementation of an acoustic monitoring program in vulnerable sanctuaries. A model for this can be found in Glacier Bay National Park. In May 2000, the park initiated an underwater acoustic monitoring program with the Navy. Navy acousticians and park staff installed a hydrophone to detect humpback whale vocalizations and vessel engine signatures in the bay. The data will be analyzed, summarized and shared between the park and the Navy. From the data collected on vessel noise, marine mammal exposure levels and daily variability of sound, the park will work with Navy acousticians to develop "noise goals" to guide future management practices (NPS 2000).

Sanctuaries can provide good opportunities for long-term research (e.g., monitor the effectiveness of management strategies) (Cavanagh pers. comm. 2000b). Research could be done comparing multiple sanctuaries based on their different environments and the different anthropogenic factors affecting each (Clark pers. comm. 2000).

Bring Noise to the Forefront of Marine Management Issues

All sanctuaries within the NMSP should be made aware of the rise in ambient noise levels in the oceans (Gentry pers. comm. 2000b). Education campaigns targeted at generators of noise in the marine environment should be implemented. This is especially important as establishing regulations and policies for many of the aforementioned measures of protection could take a long time. Industries, including commercial fishing, shipping, and tourism (whale watching, excursion tours), should be targeted. Public education is also important. All of these entities should be educated on mitigation techniques, such as quiet ship technologies, and adaptations, such as reducing speeds to lower noise generated from cavitation and adjusting activities around particularly sensitive periods for animals (e.g., breeding and migration times). Guidelines should be established for these methods to provide clear direction, and voluntary incentives for compliance should be strongly promoted.

REFERENCES

André, M., C. Kamminga, and D. Ketten. 1997. Are low frequency sounds a marine hearing hazard? A case study in the Canary Islands. Proceedings of the Institute of Acoustics 19(9):77-84.

Arctic Monitoring and Assessment Programme (AMAP). 1997. Arctic pollution issues: A state of the environment report. "Petroleum hydrocarbons." http://www.amap.no/assess/soaer10.htm (16 November 2000).

Au, W.W.L., P.E. Nachtigall, and J.L. Pawloski. 1997. Acoustic effects of the ATOC signal (75 Hz, 195 dB) on dolphins and whales. Journal of the Acoustical Society of America 101(5):2973-2977.

Austin, O.L., W.B. Robertson, Jr., and G.E. Woolfenden. 1970. Mass hatching failure in Dry Tortugas sooty terns (*Sterna fauscata*). Pages 627 in K.H. Voous, editor. Proceedings of the 15th International Ornithological Congress, The Hague, Netherlands.

Baker, C.S., L.M. Herman, B.G. Bays, and W.F. Stifel. 1982. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. Report from Kewalo Basin Marine Mammal Laboratory, Honolulu, Hawaii, for U.S. National Marine Fisheries Service, Seattle, Washington.

Banner, A., and M. Hyatt. 1973. Effects of noise on eggs and larvae of two estuarine fishes. Transactions of the American Fisheries Society 102:134-136.

Bartol, S.M., J.A. Musick, and M.L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia 3:836-840.

Bauer, G.B., J.R. Mobley, and L.M. Herman. 1993. Responses of wintering humpback whales to vessel traffic. Journal of the Acoustical Society of America 94(5).

Benoit, J.R. 2000. Comments on the LFA EIS in U.S. Navy. 2000. Preliminary final overseas environmental impact statement and environmental impact statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar. SURTASS LFA Sonar OEISS/EIS Program, Arlington, Virginia.

Boness, D. 2000. Head of the zoological research department at the Smithsonian National Zoo, Washington, D.C. Personal communication via telephone with Aleria Jensen. 8 November 2000.

Boston Harbor Whale Watch. 2000. www.bostonwhale.com/welcome.html (11 November 2000).

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island feasibility test. Journal of the Acoustical Society of America 96(4):2469-2484.

British Columbia Land Use Coordination Office (LUCO). 1998. "Marine protected areas: A strategy for Canada's Pacific coast. Discussion Paper, August 1998." http://www.luco.gov.bc.ca/pas/mpa/dispap.htm#1.0 Introduction (22 December 1998).

Buck, E.H. 1995. Acoustic thermometry of ocean climate: Marine mammal issues. Congressional Research Service, Washington, D.C.

Budelmann, B.U., and R. Williamson. 1994. Directional sensitivity of hair cell afferents in the Octopus statocysts. Journal of Experimental Biology 187:245-259.

Burger, J. 1981. Behavioral responses of herring gulls (*Larus argentatus*) to aircraft noise. Environmental Pollution 24:177-184.

Burgess, W.C., P.L. Tyack, B.J. Boeuf, and D.P. Costa. 1998. A programable acoustic recording tag and first results from free-ranging northern elephant seals. Deep-Sea Research II 45:1327-1351.

Cavanagh, R.C. 2000a. Senior scientist, Science Applications International Corporation in Mclean, Virginia. Personal communication via telephone with Tanya Code. 8 November 2000.

Cavanagh, R.C. 2000b. Senior scientist, Science Applications International Corporation in Mclean, Virginia. Personal communication via telephone with Aleria Jensen. 14 November 2000.

Center for Coastal Studies (CCS). 2000. Stellwagen Bank. http://www.coastalstudies.org/stellwagen/index.htm (3 October 2000).

Chamberlain, D.W. 1991. Effects of nonexplosive seismic energy releases on fish. American Fisheries Society Symposium 11:22-25.

Channel Island National Marine Sanctuary. 2000. "2000 Sanctuary Cruise." http://www.cinms.nos.noaa.gov/cruises.stm (7 November 2000).

Clark, C.W. 2000. Personal communication via telephone with Ed Schwartzman. 24 November 2000.

Clark, C.W., P.L. Tyack, and W.T. Ellison. 1999. Acoustic response of baleen whales to low-frequency, man-made sounds. Journal of the Acoustical Society of America 106(4):2279-2280.

Clover, C. 1995. ATOC project moved out of sanctuary. SOS Sanctuary Watch, April 1995:3.

Condor Cruises. 1998a. "Condor Specifications." http://www.condorcruises.com/code/home/specs.html (9 November 2000).

Condor Cruises. 1998b. "Whale Watching." http://www.condorcruises.com/code/whales/index.html (9 November 2000).

Costa, D., and J. Calambokidus. 1999. Marine mammal research program for the pioneer seamount ATOC experiment. Journal of the Acoustical Society of America 106(4):2280.

County of Santa Barbara. 1998. "Offshore Oil and Gas Status Report." http://www.silcom.com/~sbcplan/energy/status/9807/seismic.htm (16 November 2000).

Croll, D.A., B.R. Tershy, A. Acevedo, and P. Levin. 1999. Marine vertebrates and low frequency sound: Technical report for LFA EIS. University of California, Santa Cruz.

Crum, L.A., and Y. Mao. 1996. Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. Journal of the Acoustical Society of America 99:2898-2907.

Curry, B.E. 1999. Stress in mammals: The potential influence of fishery-induced stress on dolphins in the Eastern Tropical Pacific Ocean. Southwest Fisheries Science Center, La Jolla, California.

D'Arms, E., and D.R. Griffin. 1972. Balloonists' reports of sounds audible to migrating birds. Auk 89:269-279.

Dahlheim, M.E. 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. thesis, University of British Columbia, Vancouver, British Columbia.

Dalen, J., and G.M. Knutsen. 1987. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. Pages 93-102 in H.M. Merklinger, editor. Progress in underwater acoustics. Plenum Press, New York.

Davis, R.A., C.R. Greene, Jr, C.R. Evans, S.R. Johnson, and W.R. Koski. 1987. Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, Autumn 1986, LGL Limited, King City, Ontario, and Greeneridge Sciences Inc., Santa Barbara, California. Report 15 November 1987, for Shell Western E & P Inc., Anchorage, Alaska.

DeFontaubert, A.C., D.R. Downes, and T.S. Agardy, editors. 1996. Biodiversity in the seas: Implementing the Convention on Biological Diversity in marine and coastal habitats. IUCN, Gland and Cambridge.

Department of National Defense (DND). 1994. EIS: Military flight training. An environmental impact statement on military flying activities in Labrador and Quebec. Ottawa, Ontario.

Dettmer, A. 2000a. California Coastal Commission. Personal communication via telephone with Marcia Macedo. 16 November 2000.

Dettmer, A. 2000b. California Coastal Commission. Personal communication via telephone with Woody Turner. 14 November 2000.

Dooling, R. 1978. Behavior and psychophysics of hearing in birds. Journal of the Acoustical Society of America 64, Supplement No. 1, Fall 1978, page S4.

Eckert, S. 2000. Hub Sea World Institute. Personal communication via telephone with Hannah Harris. 17 November 2000.

Edds, P.L., and J.A.F. Macfarlane. 1987. Occurrence and general behavior of balaenopterid cetaceans summering in the St Lawrence estuary, Canada. Canadian Journal of Zoology 65:1363-1376.

Environmental Investigation Agency (EIA). 1998. "A review of the impact of anthropogenic noise on cetaceans." Paper SC/50/E9, presented to the International Whaling Commission's Scientific Committee, Oman 1998. http://www.eia-international.org/Campaigns/Cetaceans/Briefings/noise.html (30 October 2000).

Environmental Protection Agency (EPA). 2000. Comments on the LFA EIS in U.S. Navy 2000. Preliminary final overseas environmental impact statement and environmental impact statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar. SURTASS LFA Sonar OEISS/EIS Program, Arlington, Virginia.

Erbe, C. 2000. Detection of whale calls in noise: Performance comparison between a beluga whale, human listeners, and a neural network. Journal of the Acoustical Society of America 108(1):297-303.

Erbe, C., and D.M. Farmer. 1998. Masked hearing thresholds of a beluga whale (*Delphinapterus leucus*) in icebreaker noise. Deep-Sea Research II 45:1373-1388.

Erbe, C., and D.M. Farmer. 2000a. A software model to estimate zones of impact on marine mammals around anthropogenic noise. Journal of the Acoustical Society of America 108(3):1327-1331.

Erbe, C., and D.M. Farmer. 2000b. Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. Journal of the Acoustical Society of America 108(3):1332-1340.

Erbe, C., D.M. Farmer, and M.J. Yedlin. 1996. Auditory masking of whale communication by ship noise. Journal of the Acoustical Society of America 100(4):2611.

Erbe, C., A.R. King, M. Yedlin, and D.M. Farmer. 1999. Computer models for masked hearing experiments with beluga whales (*Delphinapterus leucas*). Journal of the Acoustical Society of America 105(5):2967-2978.

Evans, P.G.H., E.J. Lewis, and P. Fisher. 1993. A study of the possible effects of seismic testing upon cetaceans in the Irish Sea. Sea Watch Foundation, Oxford, United Kingdom.

Evans, P.G.H., Q. Carson, P. Fisher, W. Jordan, R. Limer, and I. Rees. 1994. A study of the reactions of harbour porpoises to various boats in the coastal waters of southeast Shetland. European Cetacean Society Newsletter No. 21.

Fahy, C. 2000. National Marine Fisheries Service. Personal communication via telephone with Marcia Macedo. 17 November 2000.

Fangman, S. 2000. Research program specialist, Channel Islands National Marine Sanctuary. Personal communication via telephone with Tanya Code and Marcia Macedo. 10 November 2000.

Finley, K.J., and C.R. Greene. 1993. Long-range responses of belugas and narwhals to ice-breaking ships in the Northwest Passage. Journal of the Acoustical Society of America 94(5).

Finley, K.J., G.W. Miller, R.A. Davis, and C.R. Greene. 1990. Reactions of belugas (*Delphinapterus leucas)* and narwhals (*Monodon monoceros*) to ice breaking ships in the Canadian High Arctic. Canadian Bulletin of Fisheries and Aquatic Science 224:97-117.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. Journal of the Acoustical Society of America 108(1):417-431.

Fletcher, J.C., and W.E. Busnel, editors. 1978. Effects of noise on wildlife. Academic Press, New York, New York.

Frankel, A.S., and C.W. Clark. 1998. Results of low-frequency playback of M-sequence noise to humpback whales (*Megaptera novaeangliae*) in Hawaii. Canadian Journal of Zoology 76:521-535.

Frantzis, A. 1998. Does acoustic testing strand whales? Nature 392:29.

Furduev, A.V. 1966. Undersurface cavitation as a source of noise in the ocean. Akad. Nauk. SSR Izv., Atmos. Oceanic Phys. 2:523.

Gentry, R. 2000a. Acoustic coordinator, NOAA Office of Protected Resources. Personal communication via telephone with Aleria Jensen. 6 November 2000.

Gentry, R. 2000b. Acoustic coordinator, NOAA Office of Protected Resources. Personal communication via telephone with Aleria Jensen. 31 October 2000.

Gisiner, R., E. Cudahy, G. Frisk, R. Gentry, R. Hofman, A. Popper, and W.J. Richardson. 1998. Proceedings of a workshop on the effects of anthropogenic noise in the marine environment, 10-

12 February 1998. Office of Naval Research, Arlington Virginia.

Glockner-Ferrari, D.A., and M.J. Ferrari. 1985. Individual identification, behavior, reproduction, and distribution of humpback whales (*Megaptera novaeangliae*) in Hawaii. MMC-83/06. U.S. Marine Mammal Commission, Washington, D.C.

Gordon, J., and A. Moscrop. 1996. Underwater noise pollution and its significance for whales and dolphins. In M. Simmonds and J.D. Hutchinson, editors. The conservation of whales and dolphins.

Green, M.L. 1991. The impact of parasail boats on the Hawaiian humpback whale. Paper presented at the annual meeting of the Animal Behavior Society, June 1991, Wilmington, North Carolina.

Green, M.L. 1999. "The U.S. Navy's Low Frequency Active Sonar: Cause for concern." http://www.geocities.com/shootdaguy/navytesting.html (11 October 2000).

Griffin, D.R., and C.D. Hopkins. 1974. Sounds audible to migrating birds. Animal Behavior 22:672-678.

Hall, B. 1996. ATOC project delayed (temporarily) by dead whales. Cetacean Society International, Whales Alive! 5(1).

Hall, J.D., and C.S. Johnson. 1971. Auditory thresholds of a killer whale (*Orcinus orca linnaeus*). Journal of the Acoustical Society of America 51:515-517.

Hastings, M.C., A.N. Popper, J.J. Finneran, and P.J. Lanford. 1996. Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. Journal of the Acoustical Society of America 99:1759-1766.

Heimlich-Boran, J.R., S.L. Heimlich-Boran, R. Montero, and V. Martin. 1994. An overview of whale watching in the Canary Islands. European Cetacean Society Newsletter No. 21.

Hennis, M. 2000. Boston Shipping Association. Personal communication via telephone with Peter Blank. 17 November 2000.

High Energy Seismic Survey (HESS) Team. 1999. "High energy seismic survey review process and interim operational guidelines for marine surveys offshore southern California." http://www.mms.gov/omm/pacific/lease/fullhessrept.pdf (November 9, 2000).

Hofman, R. 2000. Personal communication with Problem Solving Group at the University of Maryland, College Park. 9 November 2000.

Holdman, A. 1990. Window to the channel: A guide to the resources of the Channel Islands National Marine Sanctuary. Channel Islands National Marine Sanctuary/Santa Barbara Museum of Natural History, Santa Barbara, California.

Hooy, T., and G. Shaughnessy. 1991. "Terrestrial and marine protected areas in Australia. Australian National Parks and Wildlife Service, Canberra." http://www.environment.gov.au/portfolio/anca/mpa/main.html (3 December 1996).

Insley, S. 2000. Hub Sea World Institute. Personal communication via telephone with Hannah Harris. 17 November 2000.

Isakovich, M.A., and B.F. Kuryano. 1970. Theory of low frequency noise in the ocean. Society of Physical Acoustics 16:49.

Island Packers. 1999. "Cruising the islands for education, recreation, and research since 1968." http://www.islandpackers.com/ (9 November 2000).

Jehl, J.R., and C.F. Cooper, editors. 1980. Potential effects of space shuttle booms on the biota and geology of the California Channel Islands: Research reports. Technical Report 80-1. Center for Marine Studies, San Diego State University, San Diego, California.

Johnson, C.S. 1979. Thermal noise limit in delphinid hearing. NOSC TD 270. NTISAD-A076206. U.S. Naval Ocean Systems Center, San Diego, California.

Kastak D, R.J. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. Journal of the Acoustical Society of America 106(2):1142-1148.

Kaufman, M. 2000. Navy tests linked to beaching of whales: Ear bleeding consistent with intense noise. Washington *Post*, Thursday, 15 June 2000, page A03.

Ketten, D.R., J. Lien, and S. Todd. 1993. Blast injury in humpback whale ears: Evidence and implications. Journal of the Acoustical Society of America 94(4):1849-1850.

Klima, E.F., G.R. Gitschlag, and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. Marine Fisheries Review 50:33-42.

Klimley, A.P., and A.A. Myrberg, Jr. 1979. Acoustic stimuli underlying withdrawal from a sound source by adult lemon sharks (*Negaprion brevirostris* (Poey)). Bulletin of Marine Science 29:447-458.

Kostyuchenko, L.P. 1973. Effect of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. Hydrobiological Journal 9:45-48.

Kraus, D.R., A.J. Read, A. Solow, K. Baldwin, T. Spradlin, E. Anderson, and J. Williamson. 1997. Acoustic alarms reduce porpoise mortality. Nature 388(6642):525.

Kuchel, C.R. 1977. Some aspects of the behavior and ecology of harlequin ducks breeding in Glacier National Park. M.S. thesis, University of Missoula, Montana.

Lagardere, J.P. 1982. Effects of noise on growth of *Crangon crangon* in rearing tanks. Marine Biology 71:177-185.

Los Angeles *Times*. 15 June 2000. Whale deaths linked to undersea blasts.

Lenhardt, M.L. 1982. Bone conduction in hearing in turtles. Journal of Auditory Research 22:153-160.

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. Marine Mammal Science 15(1):65-84.

Lindholm, J. 2000. Stellwagen Bank National Marine Sanctuary. Personal communication via telephone with Peter Blank. 13 November 2000.

Linton, T.L. 1991. Effects of buried dynamite detonations on marine life in West Bay, Galveston County, Texas (biological effects): Final report. Texas A&M University, College Station.

Linton, T.L. 1995. Results of field tests to determine the effects of the “marine vibrator” on white sturgeon (*Acipenser tramsmontanus*) and and gulf white shrimp (*Penaeus setiferus*). Completion Report, Department of Wildlife and Fisheries Sciences, Texas A&M Universtiy, College Station.

Ljungblad, D.K., B. Würsig, S.L. Swartz, and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41:183-194.

Lohman, K. 2000. University of North Carolina at Chapel Hill. Personal communication via telephone with Hannah Harris. 31 October 2000.

Mann, D. 1997. Behavioral uses of sound by fish. Pages 25-34 in T.J. Carlson and A.N. Popper, editors. Using sound to modify fish behavior at power-production and water-control facilities: A workshop, phase II, final report. Bonneville Power Administration, Portland, Oregon.

Mann, D.A., Z. Lu, and A.N. Popper. 1997. A clupeid fish can detect ultrasound. Nature 389:341.

Martin, J.S., P.H. Rogers, E.A. Cudahy, and E.L. Hanson. 2000. Low-frequency response of the submerged human lung. Journal of the Acoustical Society of America 107(5):2813.

Massachusetts Bay Lines. 2000. Personal communication via telephone with Aleria Jensen. 20 October 2000.

Mate, B.R., K.M. Stafford, and D.K. Ljungblad. 1994. Change in sperm whale (*Physeter* *macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. Journal of the Acoustical Society of America 96:3268-3269.

Maybaum, H.L. 1990. Effects of a 3.3 kHz sonar system on humpback whales (*Megaptera novaeangliae*) in Hawaiian Waters. EOS 71(2):92.

Maybaum, H.L. 1993. Responses of humpback whales to sonar sounds. Journal of the Acoustical Society of America 95(3):1848-1849.

McCauley, R.D., D.H. Cato, and A.F. Jeffrey. 1996. A study of the impacts of vessel noise on humpback whales in Hervey Bay. Prepared for the Queensland Department of Environment and Heritage, Maryborough Branch.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.N. Jenner, J. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000. Marine seismic suveys: A study of environmental implications. APPEA Journal 40:692-708.

McKenna, R. 2000. Deputy executive director, Los Angeles/Long Beach Marine Exchange. Personal communication with Marcia Macedo. 30 November 2000.

Mellen, R.H. 1952. Thermal noise limit in the detection of underwater acoustic signals. Journal of the Acoustical Society of America 24:478.

Melvin E. 1999. Washington Sea Grant, Seattle, WA. Personal communication with Christina Fahy. September 1999.

Miller, P.J.O., N. Biassoni, A. Samuels, and P.L. Tyack. 2000. Whale songs lengthen in response to sonar. Nature 405:903.

Minerals Management Service (MMS), Pacific OCS Region. 2000. "Cavern Point unit exploratory plan." http://www.mms.gov/omm/pacific/lease/cavern_point_unit.htm (14 November 2000).

Moore, K.E., W.A. Watkins, and P.L. Tyack. 1993. Pattern similarity in shared codas from sperm whales (*Physeter catodon*). Marine Mammal Science 9:1-9.

Moyle, P.B., and J.J. Cech, Jr. 1988. Fishes: An introduction to ichthyology. Prentice Hall, Englewood Cliffs, New Jersey.

Mrosovsky, N. 1972. The water-finding ability of sea turtles: Behavioral studies and physiological speculation. Brain Behavioral Evolution 5:202-205.

Murray, J. 2000. Comments on the LFA EIS in U.S. Navy 2000. Preliminary final overseas environmental impact statement and environmental impact statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar. SURTASS LFA Sonar OEISS/EIS Program, Arlington, Virginia.

Musick, J. 2000. Virginia Institute of Marine Sciences. Personal communication via telephone with Hannah Harris. 17 November 2000.

Myrberg, A.A., Jr. 1978a. Ocean noise and the behavior of marine animals: Relationships and implications. Pages 169-208 in J.L. Fletcher and R.G. Busnel, editors. Effects of noise on wildlife. Academic Press, New York.

Myrberg, A.A., Jr. 1978b. Underwater sound: Its effect on the behavior of sharks. Pages 391-417 in E.S. Hodgson and R.F. Mathewson, editors. Sensory biology of sharks, skates, and rays. Office of Naval Research, Arlington, Virginia.

Myrberg, A.A., Jr. 1990. The effects of man-made noise on the behavior of marine animals. Environment International 16:575-586.

Myrberg, A.A., Jr., and R.J. Riggio. 1985. Acoustically mediated individual recognition by a coral reef fish (*Pomacentrus partitus*). Animal Behaviour 33:411-416.

National Oceanic and Atmospheric Administration (NOAA). 2000a. "National Marine Sanctuaries Program." http://www.sanctuaries.nos.noaa.gov/natprogram/natprogram.html (12 September 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000b. "Channel Islands National Marine Sanctuary Management Plan Revision." http://www.cinms.nos.noaa.gov/nmpintro.html (30 September 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000c. "Marine Sanctuaries." http://www.sanctuaries.nos.noaa.gov/oms/oms.html (29 July 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000d. "National Marine Sanctuaries, National Program, Legislation, The National Marine Sanctuaries Act." http://www.sanctuaries.nos.noaa.gov/natprogram/nplegislation/nplegislation.html#NMSAct1 (November 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000e. "National Marine Sanctuaries, Channel Islands, Public Documents, Regulations." http://www.sanctuaries.nos.noaa.gov/oms/pdfs/ChannelIslandRegs.pdf (November 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000f. "National Marine Sanctuaries, Gerry E. Studds Stellwagen Bank, Public Documents, Regulations." http://www.sanctuaries.nos.noaa.gov/oms/pdfs/StellwagenBankRegs.pdf (November 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000g. "National Marine Sanctuaries, National Program, Legislation, The National Marine Sanctuaries Act." http://www.sanctuaries.nos.noaa.gov/natprogram/nplegislation/nplegislationact.html (November 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000h. http://www.sanctuaries.nos.noaa.gov/oms/omsstellwagen/omsstellwagenmanag.html (11 November 2000).

National Oceanic and Atmospheric Administration (NOAA). 2000i. "Channel Islands National Marine Sanctuary." http://www.cinms.nos.noaa.gov/ (30 September 2000).

National Park Service. 2000. Glacier Bay National Park, Acoustic Monitoring Program. http://www.nps.gov/glba/learn/preserve/projects/acoustics/index.htm (November 22, 2000).

National Research Council (NRC). 2000. Marine mammals and lowfFrequency sound. National Academy Press, Washington, D.C.

Natural Resources Defense Council (NRDC). 1999. Sounding the depths: Supertankers, sonar, and the rise of undersea noise. M. Jasny, editor. Natural Resources Defense Council Publications, New York, New York.

Natural Resources Defense Council (NRDC). 2000. "Channel Islands: Help create a network of marine reserves to protect ocean wilderness." http://www.nrdc.org/wildcalifornia/mar.html (16 November 2000).

Nelson, D.R., and S.H. Gruber. 1963. Sharks: Attraction by low-frequency sounds. Science 142:975-977.

New England Aquarium Whale Watch. 2000. Personal communication via telephone with Aleria Jensen. 20 November 2000.

Noise Pollution Clearinghouse (NPC). 2000. "Effects of overflights on National quiet." http://www.nonoise.org/library/npreport/chapter3.htm#1 (31 October 2000).

O'Grady, M. J., editor. 1998. Environmental law deskbook 1998-1999 edition. Environmental Law Institute, Washington. D.C.

O'Hara, J., and J.R. Wilcox. 1990. Avoidance responses of loggerhead turtles (*Caretta caretta*) to low frequency sound. Copeia 2:564-567.

O'Keefe, D.J., and G.A. Young. 1984. Handbook on the environmental effects of underwater explosions: Impact of explosives on mammals and turtles. NSWC TR 83-240, Dahlgren, Virginia.

Offutt, G.C. 1970. Acoustic stimulus perception by the American lobster (*Homarus americanus*) (*Decapoda*). Experientia 26:1276-1278.

Palka, D. 2000. National Marine Fisheries Service. Personal communication via telephone with Peter Blank and Woody Turner. 17 November 2000.

Payne, R. 1995. Among whales. Scribner Press, New York, New York.

Pearson, W., J. Skalski, and C. Malme. 1987. Effects of sounds from a geophysical survey device on fishing success. Report prepared by Battelle/Marine Research Laboratory, Sequim; Battelle Ventura Office, Ventura; and BBN Laboratories, Cambridge.

Pearson, W.H., J.R. Skalski, S.D. Skulkin, and C.I. Malme. 1989. Battelle studies the effects of acoustic energy on crustacean eggs and larvae. Interstate Coastal Zone Management Program.

Pierson, M. 2000. Minerals Management Service. Personal communication via telephone with Tanya Code. 8 November 2000.

Polacheck, T., and L. Thorpe. 1990. The swimming direction of harbor porpoise in relationship to a survey vessel. Report to the International Whaling Commission 40:463-470.

Popper, A.N. 1997a. Sound detection by fish: Structure and function. Pages 65-76 in T.J. Carlson and A.N. Popper, editors. Using sound to modify fish behavior at power-production and water-control facilities: A workshop, phase II, final report. Bonneville Power Administration, Portland, Oregon.

Popper, A.N. 1997b. Introduction to fish bioacoustics. Pages 7-11 in T.J. Carlson and A.N. Popper, editors. Using sound to modify fish behavior at power-production and water-control facilities: A workshop, phase II, final report. Bonneville Power Administration, Portland, Oregon.

Popper, A. 2000. Personal communication with Problem Solving Group at University of Maryland, College Park. October 2000.

Popper, A.N., and R.R. Fay. 1993. Sound detection and processing by fish: Critical review and major research questions. Brain, Behavior and Evolution 41:14-38.

Rankin, S., and W.E. Evans. 1998. Effect of low-frequency seismic exploration signals on the cetaceans of the Gulf of Mexico. Journal of the Acoustical Society of America 103(5):2908.

Reeves, R.R. 1977. The problem of gray whale (*Eschrichtius robustus*) harassment at the breeding lagoons during migration. MMC-76/06. U.S. Marine Mammal Commission. NTIS PB-272506.

Richardson, W.J. 2000. Conference call via telephone with Problem-Solving Group, University of Maryland, College Park. 10 November 2000.

Richardson, W.J., and C.R. Greene, Jr. 1993. Variability in behavioral reaction thresholds of bowhead whales to man-made underwater sounds. Journal of the Acoustical Society of America 94(5).

Richardson, W.J., and B. Würsig. 1997. Influences of man-made noise and other human actions on cetacean behaviour. Marine and Freshwater Behavior and Physiology 29(1-4):183-209.

Richardson, W.J., M.A. Fraker, B. Würsig and R.S. Wells. 1985. Behavior of bowhead whales (*Balaena mysticetus*) summering in the Beaufort Sea: Reactions to industrial activities. Biological Conservation 32:195-230.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1986. Reactions of bowhead whales (*Balaena mysticetus*) to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 79:1117-1128.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1987. Reactions of bowhead whales to drilling and dredging noise in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 82(Suppl. 1):98.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1990. Reactions of bowhead whales, (*Balaena mysticetus*) to drilling and dredging noise in the Canadian Beaufort Sea. Marine Environmental Resources 29:135-160.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, California.

Richardson, W.J., K.J. Finley, G.W. Miller, R.A. Davis, and W.R. Koski. 1995a. Feeding, social and migration behavior of bowhead whales (*Balaena mysticetus*) in Baffin Bay vs. the Beaufort Sea: Regions with different amounts of human activity. Marine Mammal Science 11(1):1-45.

Ridgway, S.H., and D.A. Carder. 1997. Hearing deficits measured in some *Tursiops truncatus*, and discovery of a deaf/mute dolphin. Journal of the Acoustical Society of America 101(1):590-594.

Ridgway, S.H., E.G. Wever, J.G. McCormick, J. Palin, and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. Procedings of the National Academy of Sciences 64:884-890.

Ross, D. 1976. Mechanics of underwater noise. Pergamon, New York.

Santa Barbara Sailing Center. 1999. "Come sail on the Double Dolphin." http://www.sbsailctr.com/dolphin/index.htm (9 November 2000).

Scheifele, P. 2000a. Noise levels and sources in the Stellwagen Bank National Marine Sanctuary. August 2000.

Scheifele, P. 2000b. Director of bioacoustic research, National Undersea Research Center, University of Connecticut. Personal communication via telephone and email with Aleria Jensen and Peter Blank. 6 November 2000 and 1 December 2000.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masked hearing thresholds of bottlenose dolphins (*Tursiops truncatus*), and white whales (*Delphinapterus leucas*) after exposure to intense tones. Journal of the Acoustical Society of America 107(6):3496-3508.

Schusterman, R. 2000. Personal communication via telephone with Marcia Macedo. 15 November 2000.

Seven Seas Whale Watch. 2000. Personal communication via telephone with Aleria Jensen. 20 October 2000.

Simmonds, M.P., and L.F. Lopez-Jurado. 1991. Whales and the military. Nature 351:448.

Simmonds, M.P., and S.J. Mayer. 1997. An evaluation of environmental and other factors in some recent marine mammal mortalities in Europe: Implications for conservation and management. Environmental Review 5:89-98.

Smrcina, A. 2000. Education coordinator, Gerry E. Studds Stellwagen Bank National Marine Sanctuary. Personal communication via telephone with Woody Turner. 14 November 2000.

Southall, B.L., R.J. Schusterman, and D. Kastak. 2000. Masking in three pinnipeds: Underwater, low-frequency critical ratios. Journal of the Acoustical Society of America 108(3):1322-1326.

Stewart, B.S. 1982. Studies on the pinnipeds of the southern California Channel Islands, 1980-1981. Technical Report No. 82-136. Hubbs Sea World Research Institute, San Diego, California.

Terhune, J.M., R.E.A. Stewart, and K. Ronald. 1979. Influence of vessel noises on underwater vocal activitiy of harp seals. Canadian Journal of Zoology 57:1337-1338.

Thomas, J.A., R.A. Kastelein, and F.T. Awbey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. Zoo Biology 9:393-402.

Thompson, C.A., and J.R. Geraci. 1986. Cortisol, aldosterone, and leucocytes in the stress response of bottlenose dolphins (*Tursiops truncatus*). Canadian Journal of Aquatic Science 43:1010-1016.

Thomson, D.H., and W.J. Richardson. 1995. Marine mammal sounds. Pages 159-204 in W.J Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson, editors. Marine mammals and noise. Academic Press, San Diego, California.

Truth Aquatics. 2000a. "About us." http://www.truthaquatics.com/aboutus.htm (9 November 2000).

Truth Aquatics. 2000b. "The fleet." http://www.truthaquatics.com/fleet.htm (9 November

2000).

Tyack, P.L. 1981. Behavioral Ecology and Sociobiology 8:105-116.

Tyack, P.L. 1999. Responses of baleen whales to controlled exposures of low-frequency sounds form Naval sonar. Journal of the Acoustical Society of America 106(4):2280.

Tyack, P.L. 2000. Functional aspects of cetacean communication. In J. Mann, R.C. Connor, P.L. Tyack, and H. Whitehead, editors. Cetacean societies: Field studies of dolphins and whales. University of Chicaco Press, Chicago, Illinois.

Tyler, D.T., Jr. 1992. The emergence of low-frequency active acoustics as a critical antisubmarine warfare technology. Johns Hopkins APL Technical Digest 13(1):145-159.

U.S. Geological Survey (USGS). 2000a. http://vineyard.er.usgs.gov/char/frameset.htm (11 November 2000).

U.S. Geological Survey (USGS). 2000b. "Managing the sanctuary." http://www.sanctuaries.nos.noaa.gov/oms/omsstellwagen/omsstellwagenmanag.html. (16 November 2000).

U.S. Geological Survey (USGS). 2000c. "Examples of trawl and dredge marks from side-scan sonar records collected from Stellwagen Bank, Georges Bank, and Block Island Sound, and their geomorphic and sedimentary significance." http://vineyard.er.usgs.gov/msg00005.html (11 November 2000).

U.S. Navy. Draft 2000. Preliminary final overseas environmental impact statement and environmental impact statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar. SURTASS LFA Sonar OEISS/EIS Program, Arlington, Virginia.

Van Dine, K. 2000. Program manager of the Stellwagen Bank National Marine Sanctuary Management Review Plan. Personal communication via telephone with Peter Blank. 15 November 2000.

Voisey's Bay Mine/Mill Project EIS. December 1997. "Chapter 15: Seabirds and waterfowl, noise and human presence." http://www.inco.com/invest/voisey/mine-mill/chap15/chap15htm.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. Marine Mammal Science 2:251-262.

Watkins, W.A., and W.E. Schevill. 1975. Sperm whales (*Physeter catadon*) react to pingers. Deep-Sea Research 22(3):123-129.

Watkins, W.A., K.E. Moore, and P. Tyack. 1985. Sperm whale acoustic behaviours in the southeast Caribbean. Cetology 19:1-15.

Watkins, W.A., M.A. Daher, K.M. Fristrup, T.J. Howald, and G. Notarbartolo di Sciara. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. Marine Mammal Science 9(1):55-67.

Weilgart, L. 1998. Whales avoid ATOC, dead whales off Hawaii: Call to action. Cetacean Society International, 28 January.

Wells, R.S., D.J. Boness, and G.B. Rathbun. 1999. Behavior. In: J.E. Reynolds, III, and S.A. Rommel. Biology of marine mammals. Smithsonian Institution Press, Washington, D.C.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. Journal of the Acoustical Society of America 34(12):1936-1956.

Whale Watching Web. 1999. "California, USA: Whale watch." http://www.physics.helsinki.fi/whale/usa/californ/californ.html (7 November 2000).

Würsig, B., and W.J. Richardson. 2000(in press). Effects of noise. In W.F. Perrin, B. Würsig, and J.G.M. Thewissen, editors. The Encyclopedia of Marine Mammals. Academic Press, San Diego, California.

Würsig, B., C.R. Greene, and T.A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Marine Environmental Research 49:79-9

APPENDICES

Appendix I. Contact List for Experts and Sources Relevant to Marine Acoustics

Contact Information	Regarding	Date	Contacted?
Peter Auster, Science Director National Undersea Research Center University of Connecticut Avery Point, CT 860.405.9121	SBNMS fish impacts	Nov. 9, 2000 Nov. 13 2000	No Yes
Robert Benson Center for Bioacoustics Texas A&M University Corpus Christi. TX 361.994.5888 email: benson@cbi.tamucc.edu.	shrimp sounds	Oct. 30, 2000	Yes
Daryl Boness Dept. of Zoological Research National Zoological Park Smithsonian Institution Washington, D.C. 20008 202.673.4826 fax: 202.673.4686 email: dboness@nzp.si.edu		Nov. 8, 2000	Yes
Ann Bowles Senior Staff Biologist Hubbs Sea World Research Inst. 2595 Ingraham Street San Diego, CA 92109 619.226.3870 fax: 619.226.3944 email: annbl@san.rr.com abowles@hswri.org	non-mammal impacts, mitigation, general info.	Nov. 9, 2000	No
Dr. Raymond Cavanagh Science Applications International Corporation 1710 Goodridge Dr. McLean, VA 703.821.4300 email: RAYMOND.C.CAVANAGH@saic.com		Nov. 8, 2000 Nov. 14 2000	Yes Yes

Contact Information	Regarding	Date	Contacted?
Christopher Clark Bioacoustics Research Program Cornell Laboratory of Ornithology 159 Sapsucker Woods Road Ithaca, NY 14850 607.254.2405 fax: 607.254.2415 email: cwc2@cornell.edu	navy stuff (ATOC)	Nov. 17, 2000	Yes
Condor Whale Watching at Sea Landing 805.963.3564 email: info@condorcruises.com	whale watching near CINMS	Nov. 6, 2000 Nov. 8, 2000	No
Larry Crowder Duke University 252.504.7637 email: lcrowder@duke.edu	sea turtle impacts	Nov. 17, 2000	No
Edward Cudahy, Research Audiologist Naval Submarine Medical Research Lab Naval Submarine Base New London Box 900 Groton, CT 06349-5900 860.694.3391 fax: 860.694.4096 email: cudahy@nsmrl.naby.mil	military low frequency sounds and humans	Nov. 17, 2000	Yes
Mark Delaplaine, Federal Consistentcy Supervisor California Coastal Commission 45 Fremont Street, Suite 2000 San Francisco, CA 94105-2219 415.904.5289 mdelaplaine@coastal.ca.gov	acoustic sources for CINMS	Nov. 8, 2000 Nov. 9, 2000	Yes Yes
Sandy Dentino Administration SBNMS	SBNMS whale watching regulations	Nov. 13, 2000 Nov. 17, 2000	Yes Yes
Alison Dettmer, Manager Energy and Ocean Resources Unit California Coastal Commission 415.904.5246	oil exploration in CA; CZMA issues	Nov. 14, 2000 Nov. 17, 2000	Yes Yes

Contact Information	Regarding	Date	Contacted?
David Dow Massachusetts Sierra Club 508.540.7412 email: david.dow@noaa.gov	SBNMS fish impacts	Nov. 7, 2000	No
Scott Eckert Hub Sea-World Institute 2595 Ingraham Street San Diego, CA 92109 619.226.3872 email: seckert@hswri.org	turtle impacts	Nov. 17, 2000	Yes
Christina Fahy National Marine Fisheries Service, SW Regional Office 501 W. Ocean Blvd. Suite 4200 Long Beach, CA 90802 562.980.4023 fax: 562.980.4027 email: Christina.Fahy@noaa.gov	general impacts in Southern CA	Nov. 17, 2000	Yes
Sarah Fangman, Scientific Coordinator 113 Harbor Way Santa Barbara, CA 805.884.1473 email: Sarah.Fangman@noaa.gov	general info about CINMS.	Nov. 10, 2000	Yes
Mike Fisher Michael A. Fisher Coastal and Marine Geology Team U.S. Geological Survey, MS 999 345 Middlefield Rd. Menlo Park CA 94025 650.329.5158 fax: 650.329.5299 email: mfisher@usgs.gov		Nov. 16, 2000	Yes

Contact Information	Regarding	Date	Contacted?
Chris Gabriele, Wildlife Biologist and Coordinator of Acoustic Monitoring Program Glacier Bay National Park P.O. Box 140 Gustavus, AL 99826 907.697.2664 email: chris_gabriele@nps.gov		Nov. 29, 2000	Yes
Roger Gentry National Marine Mammal Laboratory NOAA/NMFS 7600 Sand Point Way NE Seattle, WA 98115 206.526.4032 fax: 206.526.6615		Oct. 31, 2000 Nov. 6, 2000	Yes Yes
Patricia Gerrior National Marine Fisheries Service 508.495.2264	commercial fishing noise and fishing practices near SBNMS	Nov. 13, 2000 Nov. 17, 2000	No Yes
Steve Gittings NOS Headquarters 1305 East West Highway Silver Spring, MD 20910-3282 301.713.3125, ext. 130 fax: 301.713.0404 email: Steve.Gittings@noaa.gov	airgun arrays and rockfish	Nov. 3, 2000	Yes
Robert Gisiner, Program Manager Marine Mammal Science Program Office of Naval Research BCT-1, Code 335 800 North Quincy Street Arlington, VA 22217-5660 (703) 696-2085 fax: (703) 696-1212 email: gisiner@onr.navy.mil	marine mammals, navy testing, general info.	Nov. 6, 2000	Yes

Contact Information	Regarding	Date	Contacted?
Charles Greene Greeneridge Science, Inc. 1411 Firestone Rd. Goleta, CA 983117 805.967.7720 fax: 805.967.7720 email: cgreene@greeneridge.com	airgun arrays, general info.	Nov. 16, 2000	No
Sean Hastings Policy Program Specialist Channel Islands NMS 805-966-7107 Sean.Hastings@noaa.gov	general info. on CINMS	Nov. 14, 2000	Yes
Maureen Hennis Boston Shipping Association Charlestown Navy Yard 197 8th Street, Suite 775 Charlestown, MA 02129-4208 (617) 242-3303	merchant shipping traffic into Boston Harbor	Nov. 9, 2000	Yes
Robert Hofman Marine Mammal Commission (retired) (301) 652-8236 email: rjhofman@erols.com	marine mammal impacts, general info.	Nov. 9, 2000	Yes
Stephen Insley Hub Sea-World Institute 2595 Ingraham Street San Diego, CA 92109 619.226.3879 email: sinsley@hswri.org	seal hearing	Nov. 17, 2000	Yes
Island Packers 805.642.1393 email: ipco@isle.net	whale watching near CINMS	Nov. 6, 2000 Nov. 8, 2000 Nov. 17, 2000	No No Yes
Michael Jech NOAA Northeast Fisheries Science Center Woods Hole, MA 508.495.2353		Nov. 9, 2000	Yes

Contact Information	Regarding	Date	Contacted?
Darlene Ketten Biology Department Woods Hole Oceanographic Inst. Room 201-202 Shivrick/MS #36 Woods Hole, MA 02534 508.289.2731 fax: 617.573.4275 email: dketten@whoi.edu		Nov. 1, 2000 Nov. 6, 2000	Yes No
Gregory A. Lewbart MS, VMD Associate Professor of Aquatic Medicine Department of Clinical Sciences North Carolina State University College of Veterinary Medicine Raleigh, NC 919.513.6439 email: Greg_Lewbart@ncsu.edu	turtle impacts	Nov. 20, 2000	Yes
James Lindholm, Science Coordinator Stellwagen Banks NMS 781.545.8026 email: james.lindholm@noaa.gov	acoustic sources in SBNMS	Nov. 1, 2000 Nov. 13, 2000	Yes Woody
Kenneth Lohman University of North Carolina Chapel Hill, N.C. 919.962.1332 email: KLohmann@email.unc.edu	turtle impacts	Oct. 31, 2000	Yes
Joe Luczkovich Associate Professor, Marine Ecology East Carolina University 252.328.1847	fish impacts and hearing	Nov. 9, 2000 Nov. 13, 2000	No Yes
Massachusetts Bay Lines Boston, MA 617.542.8000	acoustic sources in SBNMS	Nov. 7, 2000	Yes
Bill Michaels NOAA Northeast Fisheries Science Center Woods Hole, MA 508.495.2259		Nov. 9, 2000 Nov. 14, 2000	No Yes

Contact Information	Regarding	Date	Contacted?
Susan Moore Cetacean Assessment and Ecology Program Leader NOAA/NMFS/AFSC National Marine Mammal Laboratory Seattle, WA 98115 206.526.4021 email: sue.moore@noaa.gov	cetacean impacts	Nov. 1, 2000	Yes
John Musick Virginia Institute of Marine Sciences Head of Sea Turtle Stranding Network Co-chair of IUCN shark specialist group. 804.684.7317 jmusick@vims.edu	turtle impacts	Nov. 17, 2000	Yes
New England Aquarium Whale Watch Boston, MA 617.973.5200	whale watching in SBNMS	Oct. 20, 2000	Yes
Debra Palka National Marine Fisheries Service Northeast Fisheries Science Center 166 Water St. Woods Hole, MA 02543 978.281.9370 email: Debra.Palka@noaa.gov	by-catch of harbor porpoises in fishing nets	Nov. 17, 2000	Yes
Roger Payne Whale Conservation Institute 88 Crescent Lane London SW4 9PL United Kingdom 9.011.441.714.980.320 or 802.457.4450 fax: 9.011.441.714.983.184 or 802.457.4095 email: 74201.247@compuserve.com		Nov. 1, 2000	No

Contact Information	Regarding	Date	Contacted?
Judith Pederson, Coastal Resources Specialist and Manager Center for Coastal Resources MIT Sea Grant Program 617.252.1741 email: jpederso@mit.edu	non-mammal impacts	Nov. 8, 2000 Nov. 27, 2000	No Yes
Mark Pierson U.S. Department of the Interior Minerals Management Service 770 Paseo Camarillo Camarillo, CA 93010 805.389.7863 email: Mark Pierson@smtp.mms.gov	oil exploration in the Pacific OCS	Nov. 8, 2000	Yes
Art Popper Department of Biology Zoology-Psychology Building University of Maryland College Park, MD 20742 301.405.1940 fax: 301.314.9358 email: popper@zool.umd.edu	fish auditory systems; general info. on acoustic impacts on marine organisms	Nov. 1, 2000	Yes
Andy Read Duke University Marine Laboratory 135 Duke Marine Lab Rd. Beaufort NC 28516 252.504.7590 fax: 252.504.7648 email: aread@duke.edu	commercial fishing (effects of pingers on marine mammals)	Nov. 17, 2000	No
W. John Richardson LGL Ltd. Environ. Research Associates 22 Fisher Street P.O. Box 280 King City, ON L7B 1A6 Canada 905.833.1244 wjrichar@lgl.com	general info. on marine acoustics	Nov. 10, 2000	Yes

Contact Information	Regarding	Date	Contacted?
Sam Ridgway Navy Marine Mammal Program 49620 Beluga Rd. San Diego, CA 92152-6266 619.553.1374 fax: 619.553.1346 email: ridgway@spawar.navy.mil	marine mammals and hearing	Nov. 16, 2000	Yes
Sailing Center Double Dolphin Whale Watching 805.962.2826 anchor@sbsailctr.com	whale watching near CINMS	Nov. 6, 2000	Yes
Peter Scheifele Director of Bioacoustic Research National Undersea Research Center University of Connecticut Avery Point, CT 860.405.9103 email: scheifele@uconnvm.uconn.edu	acoustic monitoring in SBNMS	Nov. 6, 2000	Yes
Ron Schusterman Long Marine Laboratory University of California 100 Shaffer Road Santa Cruz, CA 95060 831.459.3345 fax: .408.459.3383 email: rjschust@cats.ucsc.edu	effects of noise on pinnipeds; general info. on acoustic sources in southern CA	Nov. 16, 2000	Yes
Seven Seas Whale Watch Gloucester, MA 800.238.1776	whale watching in SBNMS	Oct. 20, 2000	Yes
Dave Sherry U.S. Coast Guard, Waterways Management 617.223.3010	vessel traffic around SBNMS	Nov. 13, 2000	Yes

Contact Information	Regarding	Date	Contacted?
Anne Smrcina, Education Coordinator Stellwagen Bank NMS 781.545.8026	acoustics in SBNMS	Nov. 14, 2000	Yes
Truth Aquatics 805.962.1127 info@truthaquatics.com	whale watching near CINMS	Nov. 6, 2000 Nov. 8, 2000	
Peter Tyack Woods Hole Oceanographic Inst. Dept. of Biology, Mail Stop 34 Redfield 1-32 45 Water Street Woods Hole, MA 02543-1049 508.289.2818 fax: 508.457.2134 email: peter@cetacea.whoi.edu	cetaceans and acoustic impacts	Nov. 8, 2000	No
Page Valentine USGS Woods Hole Field Center Stellwagen Banks Project Leader 508.457.2239 fax: 508.457.2310 email: pvalentine@usgs.gov	topographic maps of SBNMS	Nov. 15, 2000 Nov. 16, 2000	No No
Kate Van Dine, Project Manager Management Review Plan for SBNMS Stellwagen Banks NMS 781.545.8026 ext. 203	vessel traffic in SBNMS	Nov. 13, 2000 Nov. 17, 2000	No Yes

Appendix II. Table

Appendix III. Class Profile

Peter Blank

Peter earned a B.A. in earth and planetary science from the Johns Hopkins University, and a certificate in wildlife ecology and management from the School for Field Studies in Kenya. He is currently working at the Baltimore Zoo Hospital, and has worked for the Eastern Neck National Wildlife Refuge in Maryland. During the summer of 2000, Peter assisted in the rescue of African penguins and other sea birds from an oil spill near the coast of Cape Town, South Africa.

Cory R. Brown

Cory graduated in 1996 from Dalhousie University in Nova Scotia, Canada, with a First-Class Honours Degree in biology. She has since worked as an assistant on neotropical migratory bird research, as a student instructor for the Audubon Society, and as an agroforestry extensionist with the Peace Corps in the Dominican Republic. She is currently working with The Nature Conservancy's Ecotourism Department.

Tanya Code

Tanya graduated *cum laude* with a B.S. in environmental science from Allegheny College in 1992, and earned a certificate in sustainable development and marine conservation from the School for Field Studies in Costa Rica. Since graduating, Tanya spent four years working as an Environmental Scientist with an engineering firm in upstate New York, and three years as a Project Manager with an environmental consulting firm in Arlington, Virginia. Currently, Tanya works with the EPA's Economic and Benefits Assessment Staff within the Office of Water/Office of Science and Technology, researching issues on ecological valuation.

Shelly Grow

Shelly graduated from Grinnell College in 1997 with a degree in cross-cultural environmental studies. Since her graduation, she has worked in Costa Rica at a butterfly farm and at the Institute for Central American Development Studies. Most recently she worked as a lobbyist with the Sustainable Agriculture Coalition, and has assisted in policy work with the Henry A. Wallace Center for Alternative Agriculture at Winrock International. She also works on a community-supported agriculture project with the Chesapeake Bay Foundation and the D.C. Capital Area Food Bank. The project provides local organic produce to urban residents in the D.C. metro area and hosts a farmers market in Anacostia.

Grady Harper

Grady earned a B.S. with a double major in biology and philosophy from Willamette University. He spent the next several years working for the U.S. Fish and Wildlife Service doing field biology, in northern Idaho and on the Yukon Delta National Wildlife Refuge in western Alaska. He chose the Sustainable Development and Conservation Biology program because of his interest in policy and ecological economic aspects of conservation issues. Most recently he spent a summer with Conservation International working on remote sensing with the purpose of monitoring deforestation in tropical countries.

Hannah Harris
Hannah graduated c*um laude* from UNC Greensboro in 1996, receiving a B.A. in psychology with an emphasis on animal behavior. She then completed further course work in zoology and ecology at UNC Chapel Hill. Hannah has experience in wildlife rehabilitation and is interested in wildlife management. Most recently Hannah worked on a project for the National Park Service, studying predation on American pronghorn in Yellowstone National Park. Her research involves ecosystem function in the presence and absence of top predators.

Chuan-Kai (Kevin) Ho
Kevin is an international student from Taiwan. He has a B.S. in botany and is interested in wildlife management at different scales. He has worked in a butterfly museum, a tropical national park, and has served in the Taiwanese army. He was also a freelance outdoor photographer. He is currently doing research with Dr. Doug Gill on grasshopper sparrows on Maryland's Eastern Shore.

Aleria Jensen
Aleria graduated from Macalester College in 1994 with a B.A. in biology and Russian. Her primary interests are in marine conservation and environmental education. She has worked as an educator for a Hawaiian marine conservation organization, and as a naturalist for Alaskan ecotourism companies. Aleria has field research experience in prairie ecosystem dynamics, humpback whale behavioral ecology, and whale-watching impact studies. She is currently working with NOAA on a marine protected area proposal for bowhead whales in the Russian Far East.

Jeni Keisman
Jeni graduated *magna cum laude* from St. Mary's College of Maryland with a B.A. in history. She currently works at USGS Patuxent Wildlife Research Center, on the North American Colonial Waterbird Monitoring and Inventory Program. Before joining the Sustainable Development and Conservation Biology program, she developed distributed information systems for the financial sector, working as a technical writer, project coordinator, software developer, and finally as a technical lead. More recently, she has worked as a field assistant in ecosystem ecology at Stanford University's Magma Lab in Hawaii. Jeni's current research interests focus on the impact of human activity on ecosystem processes.

Marcia Macedo
Marcia graduated c*um laude* from Duke University with a B.S. in biological anthropology and anatomy and a certificate in primatology. She has worked as a research assistant for the Amazon Conservation Association and as a consultant for Conservation International. Marcia has extensive experience in Portuguese/English translation, as well as research experience in primate behavioral ecology and tropical infectious diseases.

Jamarber Malltezi
Jamarber is currently working as Project Manager with the United Nations Development Program in Albania. He is National Coordinator in Albania for the Global Environment Facility-Small Grants Program. He is interested in sustainable development practices at the community level and in implementing community-based conservation projects that address global

environmental concerns.

Christopher S. Robbins
Chris received his B.S. from the University of New Hampshire in 1992, double majoring in natural resource management and international affairs. He currently works for TRAFFIC North America, the wildlife trade monitoring program of World Wildlife Fund (WWF) and the World Conservation Union (IUCN), specializing in plant trade and conservation. Chris is a second year graduate student in the Program in Sustainable Development and Conservation Biology and is focusing his studies on ethnobotany.

Edward J. Schwartzman
Originally from Baltimore, Maryland, Ed graduated from the University of Wisconsin in 1993 with a B.A. in sociology. He has lived abroad in Latin America, working as a translator and delegation coordinator for a non-profit organization. Ed has also worked as a field assistant with the National Park Service in Oregon and the Green Mountain Club in Vermont. Since returning to Maryland, Ed has volunteered with the Maryland Department of Natural Resources' Heritage and Wildlife Program. He recently completed a vegetation monitoring internship with the Massachusetts Nature Conservancy in Martha's Vineyard. His current interests include botany, restoration ecology, and land conservation.

Jennifer K. St. Martin
Jennifer graduated *cum laude* with a B.A. in biology from Bryn Mawr College, and earned a certificate in marine mammal biology and island biogeography from the School for Field Studies in Mexico. She taught high school biology at a private school in Maine for three years, and taught at Columbia University's Biosphere 2 in Arizona before returning to graduate school. Jennifer has recently interned at Conservation International, where she helped to develop a monitoring framework for the State of the Hotspots Program in the Center for Applied Biodiversity Science.

Woody Turner
Woody holds a B.A. in history and psychology from the University of North Carolina (1983) and a Master's in Public Affairs from Princeton University's Woodrow Wilson School (1987). He became a member of Phi Beta Kappa in college. Since 1987, he has worked for the National Aeronautics and Space Administration (NASA) in the areas of international relations and Earth science. Recently, he has sought to develop a conservation biology program in the NASA Office of Earth Science.

Linda Weir
Linda holds a B.A. in zoology from the State University of New York, College at Oswego. She currently works with the U.S. Geological Survey as the USGS Coordinator of the North American Amphibian Monitoring Program. This program is a partnership among federal, state, nonprofit, and academic institutions, which is active in 25 states and involves citizens in amphibian population monitoring. Previously, she worked as an exotic species monitor, educating the public about invasive species impacts upon water resources. Linda has also worked as a laboratory assistant in the fields of entomology and toxicology.