



photograph: David. O. Brown

Anthropogenic Noise and the Channel Islands National Marine Sanctuary

*How Noise Affects Sanctuary Resources,
and What We Can Do About It*

A report by the Environmental Defense Center, Santa Barbara, CA

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Table of Contents

Executive Summary.....page 1

Introduction.....page 6

Large Vessel Traffic.....page 9

Active Sonar.....page 19

High Energy Seismic Surveying.....page 26

Small Ships, Boats and Personal Watercraft.....page 30

Oil and Gas Development.....page 34

Acoustic Thermometry.....page 35

Recommendations and Ideas for Research.....page 37

Citations.....page 42

Appendix A: Basics of Acoustics Science.....page 48

Appendix B: Masking.....page 50

EXECUTIVE SUMMARY

I. Background

In recent years, the emergence of human activities and technologies that emit extremely high levels of sound into the ocean have focused public, scientific and, to a lesser extent, regulatory attention on anthropogenic noise and its known and potential impacts on marine ecology. Concurrently, an array of data has arisen suggesting that the diverse array of anthropogenic noise sources in the ocean have a similarly broad spectrum of implications— from neutral to fatal— for marine wildlife. This increased scrutiny has also revealed a disturbing lack of understanding of marine bioacoustics and biological interaction with human-generated noise.

From this context, the Environmental Defense Center (EDC), a Santa Barbara-based non-profit environmental law firm, and the Conservation Working Group (CWG) of the Channel Islands National Marine Sanctuary Advisory Council, identified the need to investigate and better understand a) the acoustic environment of the Channel Islands National Marine Sanctuary (the Sanctuary, or CINMS), b) how the biological communities of the Sanctuary interact or depend on sound, and c) how the array of human activities off the South Coast of California alter or impact the Sanctuary's acoustic environment and sound-sensitive or sound-dependant wildlife. EDC, the CWG and other parties believe that the research necessary for answering these questions can also be applied to management of current activities that emit harmful noise into the Sanctuary, and to proactively inform and advise management of noisy human activities before emitted sound levels become deleterious to the Sanctuary's unique and precious biodiversity.

This document aims to initiate such a process through identification of all activities producing significant noise in CINMS, and through review and discussion of existing marine bioacoustics research and expertise that are pertinent to the wildlife in and around CINMS. Each sound-producing activity is identified and discussed individually in terms of physical characteristics, projected trends in noise output in CINMS (based on proliferation or decline of the activity), and the local biological communities affected by that activity's noise. Activities are arranged in order of their assessed threat to Sanctuary resources. This format organizes the vast field of anthropogenic noise and marine ecology into a set of locally pertinent topics more tractable to both resource managers and the public.

Finally, the report concludes with specific recommendations for research in the areas of science and policy. These recommendations are intended to assist CINMS in responding to threats and minimizing acoustic impacts to Sanctuary wildlife.

II. Findings

At present, researchers have documented that sound that is short in duration but sufficiently loud, such as underwater explosions, pinging from tactical naval sonar, and airgun blasts from seismic surveying, can cause harmful to fatal physical damage to organs and hearing tissues of certain marine life— particularly marine mammals and fishes— which suffer such exposure (Todd et al. 1996; Evans and England 2001; McCauley et al. 2003). Cumulative exposure to less intense sound over a longer duration, such as vessel traffic noise next to busy harbors, ports, or shipping lanes, can also cause temporary or permanent damage to hearing tissue in marine animals, as well as obscure, or *mask*, biologically vital or important sound from predators, prey, mates or other conspecifics (i.e. other members of an individual’s species) (Richardson et al. 1995). All such impacts can be associated with costs in survival and reproduction; such impacts also imply costs for the ecosystems of which impacted species are a part (NRC 2003). The Sanctuary’s biological resources are exposed to anthropogenic sound of both types, from a variety of human activities within or around CINMS that have occurred historically, that occur today, and that may resume or will likely continue in the future.

In the field of bioacoustics (the study of animal sounds and hearing), cetaceans (marine mammals such as whales and dolphins) and pinnipeds (seals and sea lions) are the most studied of marine wildlife (Popper 2003). While researchers have much more to learn about the importance of listening and sound production to these creatures in marine ecosystems, little doubt remains that anthropogenic noise can impact these species. Simmonds and Dolman (1999) summarize the documented spectrum of effects on individual cetaceans from anthropogenic noise:

- *Physical: non-auditory (damage to body tissue, induction of air bubble growth and tissue bends) and auditory (gross damage to ears, permanent hearing threshold shift, temporary hearing threshold shift);*
- *Perceptual: masking of communication with conspecifics, masking of other biologically important noises, interference with ability to acoustically interpret environment, adaptive shifting of vocalizations (with efficiency and energetic consequences);*
- *Behavioral: gross interruption of normal behavior (i.e. behavior acutely changed for a period of time), behavior modified (i.e. behavior continues but is less effective/efficient), displacement from area (short or long term);*
- *Chronic/Stress: decreased ability of individual, increased potential for impacts from negative cumulative effects (e.g. chemical pollutants combined with noise-induced stress), sensitization to noise (or other stresses) - exacerbating other effects, habituation to noise - causing animals to remain close to damaging noise sources;*
- *Indirect effects: reduced availability of prey. Consequently, physiological consequences are various: energetic implications, stress, hearing impairment (auditory damage and masking), non-auditory physical damages, strandings. In addition, noise can also alter feeding, foraging, resting, socializing and*

breeding behaviors, and 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.

Synergetic effects with other human activities and environmental alterations are worth re-emphasizing: examples include increased shipstrike of sperm whales due to threshold shift (hearing loss) from, or habituation to, large-vessel traffic noise exposure (André *et al.* 1998), and in killer whales, chronic stress from constant exposure to small vessel traffic noise reducing immune response to anthropogenic pollutants (e.g. PCBs), and pathogens (Erbe 2002). Because CINMS provides habitat for populations of many endangered cetacean species recovering from industrial whaling, and because human activities continue to impinge on population recovery in a variety of ways, anthropogenic noise must be considered for the impact it contributes both in isolation and in concert with other environmental factors.

While Simmonds and Dolman compiled this impact list specifically for cetaceans, our less developed understanding of noise impacts to fish suggests that many species may suffer individual and population impacts in similar ways. Recent studies reveal that some fish species have significant aural acuity, which they depend on for reproduction, foraging, predator avoidance, navigation and other biologically critical behavior. Evidence is also emerging that some fish produce sounds for communication with conspecifics, associated with reproduction and schooling behavior. All these biologically important phenomena may be impinged upon by excessive increases in background noise or through damage to the hearing tissue from excessive exposure. Furthermore, fish egg viability may be reduced by excessive exposure to sound waves, impacting a population's recruitment (Popper 2003).

Anatomical and ecological acoustical research on pinnipeds continues to progress, revealing more about the hearing specialties of known pinniped species, as well as the potential for anthropogenic noise to mask critical acoustic signals such as conspecific vocalizations and prey noises, which seals and sea lions are believed to rely heavily on in foraging (Southall *et al.* 2000).

At present, little is known about hearing or sound production in marine reptiles or invertebrates, or the impacts of anthropogenic noise on such species. However, exposure to impulsive sound at close range from airguns or underwater explosions is likely to be harmful or fatal merely from the energies involved in such discharges (NRC 2003).

Of the consequential activities in CINMS discussed below, large vessel traffic (defined as ships 85m and longer) represents the preeminent source of anthropogenic noise and the primary acoustic threat to Sanctuary resources. This primacy emerges from a combination of factors, including the levels of pervasive low-frequency sound emitted underwater by individual cargo ships and tankers (Ross 1976), and the volume of such vessel traffic through CINMS. Traffic volume is a factor of the geographic location of the Sanctuary vis-à-vis major commercial ports such as Los Angeles/Long Beach and San

Francisco, and the continuing growth of international trade, specifically between the US and Asia, which depends enormously on ship transport (Wignall and Womersley 2004, Westwood et al. 2002). Roughly 17 large commercial vessels pass through or near the Sanctuary daily. Based on current research, the sound emissions from this ship traffic comprise the greatest contribution of noise pollution into Sanctuary waters, emissions that may significantly impact the hearing anatomy, intraspecies communication, navigation, foraging and reproduction of resident cetaceans, fishes and pinnipeds.

Mid- and low frequency active sonars used by the US Navy, and scientific and commercial seismic surveying, also represent significant if relatively isolated and sporadic threats to Sanctuary ecology (Evans and England 2001, NRC 2003). Sound from these activities has been shown to cause trauma and death in fishes and marine mammals (life-threatening trauma to marine mammals from seismic surveying has yet to be conclusively demonstrated, though circumstantial evidence exists) (CBD v. NSF 2002). While some guidelines exist that protect areas of rich biological diversity such as marine sanctuaries from these activities (e.g. Evans and England 2001, HESS 1999), trends in the proliferation of military technology, deep-water oil exploration and production, and geological research suggest that CINMS may be faced with noise from these activities in the future.

The limited data available for review suggest that small ship and boat traffic (roughly, vessels under 85meters in length) is not currently a significant acoustic threat to CINMS wildlife, due to a diffuse temporal and spatial distribution of these smaller engine-powered vessels within the Sanctuary. Nonetheless, deliberate, illegal chasing and harassment of marine mammals by motorboaters occurs in CINMS and can have significant impacts on the subjected animals (NRC 2003, Howorth 2004). Also, research elsewhere has shown that at high densities (i.e. groups of commercial and private whale watching boats following a group of whales), small vessel traffic noise can have significant impacts on groups of cetaceans, through the induction of hearing loss and the associated increased difficulties in foraging and intraspecies communication, and through the reduction of individual health associated with chronic stress (NRC 2003, Erbe 2002).

Acoustic emissions from oil production and acoustic thermometry are discussed; scientific and anecdotal evidence suggest that sound from these activities have little ecological impact within the Sanctuary at present compared with other noise sources.

In sum, science to date supports the conclusion that anthropogenic noise represents a potential threat of sufficient magnitude to Sanctuary resources to warrant precautionary management. While understanding of the biological and ecological importance of noise and sound remains incomplete, significant data exists to strongly implicate anthropogenic noise in major impacts to individuals and populations of cetaceans and fishes. Factors such as long-range transience, long life span, slow birth rate and size combine to make conclusive investigation of the short and long-term effects of human noise on great whale survival and reproduction extremely challenging at present, perhaps unfeasible. Because significant data and expert consensus support the conclusion that human noise has

significant impact on marine wildlife, specifically noise of a similar character to that presently emitted in and around the Sanctuary, waiting for such data to implement conservation-oriented management of harmful human noise may further imperil already endangered great whale species, as well as endanger other CINMS biological resources. The potential for environmental detriment to the Sanctuary from anthropogenic noise that is suggested by current scientific research outweighs the potential benefits from further inaction.

III. Recommendations

To acknowledge and address noise pollution in the Sanctuary, two sets of recommendations are proposed for adoption by the CINMS Sanctuary Advisory Council (SAC). The first set, “*Sources and Impacts*,” outlines scientific research needed to assess Sanctuary impacts from noise and to inform decision making. It includes recommendations to: (1) Initiate Sanctuary-wide noise monitoring; (2) Study the hearing capabilities of Sanctuary wildlife; (3) Study anthropogenic noise impacts on Sanctuary ecology; and (4) Research indirect anthropogenic noise impacts to Sanctuary ecology.

The second set, “*Policy and Partnerships*,” includes recommendations for generating momentum and leadership to address Sanctuary noise pollution through both collaboration and regulation. Specifically, recommendations include: (1) Establish a vessel traffic monitoring program to log and quantify ship traffic through the Sanctuary; (2) Develop inter-agency partnerships; (3) Engage the shipping industry in dialog and collaboration; (4) Research international policy and regulatory options; and (5) Create a role for the CINMS Advisory Council’s Scientific Advisory Board to assist the CINMS in designing and implementing relevant research projects as well as in reviewing and responding to acoustic activities that may impact Sanctuary resources.

INTRODUCTION

Since the industrial revolution, the character and scale of human interaction with the ocean has changed dramatically. The emergence of mechanization facilitated a vast expansion in human oceanic activity, from the exploitation of marine resources to sea-borne transportation. The onset of steam, diesel and nuclear-powered engines also brought to bear an unprecedented ensonification (filling with sound) of the global oceanic environment, a phenomenon that has continued and expanded since industrialization as noise-producing human marine activity increases and spreads.

Many marine animal species, especially vertebrates such as fish and marine mammals, have evolved to rely heavily on hearing and sound production for an array of biologically critical behaviors, because of how efficiently acoustic energy moves through seawater (in contrast to light or scent). However, the variety of sound-based adaptations, such as echolocation, intra-species vocal communication, and acute hearing (used variously for navigation, detecting threats, and finding food or mates), all emerged in a pre-industrial acoustic environment much quieter than that of the heavily human-exploited oceans of today. Consequently, the significant increases in anthropogenic noise and the associated alteration of the marine acoustic environment may have biological implications on an array of levels, from the usefulness of an individual animal's hearing systems to the reproductive success of entire populations. Depending on the character of human noise pollution and the animals involved, known impacts from exposure have ranged from barely perceptible avoidance behavior, to severe physiological trauma and death.

Today, many human activities that purposefully or incidentally generate underwater noise are conducted throughout the world ocean, including: commercial and military shipping; use of active sonars for naval navigation, tactical and strategic operations; seismic surveying for fossil fuel prospecting and geologic research; operation and maintenance of oil drilling and production platforms; acoustic thermometry of oceans; marine aviation; marine construction including use of explosives, dredging and pile-driving; and commercial and private small vessel traffic for activities such as fishing, ferrying, whale watching, and recreational boating.

The extraordinarily productive and diverse ecology of the Channel Islands National Marine Sanctuary (CINMS, or the Sanctuary) today faces an extraordinary level of exposure to anthropogenic noise from many of these activities. With waters situated between two of the world's busiest ports, above active oil leases, and near major naval centers, CINMS sustains ongoing noise emissions from an array of human activities conducted within its boundaries related to these characteristics. What's more, the same ecological diversity and productivity of the Channel that provoked marine sanctuary designation will continue to attract noise-producing motorboat traffic for fishing, whale watching, and sight-seeing. Finally, certain scientific and military activities, and the passage of the largest tankers and cargo ships, produce extremely loud sound that can still

be detectable or influential to certain species within Sanctuary waters even if those activities occur tens or hundreds of kilometers away.

A complex mix of sound produced by human activities, in concert with sound from ongoing natural phenomena including weather, seismological dynamics, wave action and animal noises, comprise the general background din of any marine environment. However, based on measured sound emissions from large ships and the volume and consistency of freighter and tanker traffic traveling through and around the Sanctuary, large cargo vessel traffic represents the single greatest contributor—and thus the single greatest ongoing threat—to the CINMS acoustic environment. Military use of low- and mid- frequency active sonars, and commercial and scientific high-energy seismic surveying, while much more isolated and incidental in occurrence, also represent threats of negative impact to CINMS biodiversity based on the significant physical trauma, alteration of behavior, and even lethality to marine wildlife associated with these activities in other areas around the world. And, central to examination of anthropogenic noise pollution in the Sanctuary, economic and geopolitical trends strongly suggest global and local increases in shipping, and, longer-term, in seismic surveying and active sonar use as well.

Scientific research on marine bioacoustics and noise impacts on marine wildlife has accelerated and matured in the last ten years, since its (approximate) inception in the early 1970's. In the 1990's, proposals for activities such as shipshock trials by the US Navy, the ATOC project (Acoustic Thermometry of the Ocean Climate), and naval low-frequency active sonar decisively focused both public and scientific attention on the ecological impacts of anthropogenic noise, particularly on whales and dolphins. In 1995, William Richardson and colleagues published *Marine Mammals and Noise*, a text that continues to serve as the backbone of many marine bioacoustics and anthropogenic noise pollution investigations. Since then, scientists have expanded our understanding of cetacean and pinniped bioacoustics, as well as our understanding of fish biological and ecological use of sound, through field observations and laboratory experiments.

Unfortunately, due to both the relatively recent focusing of scientific investigation on marine bioacoustics, and the unique challenges associated with researching oceanic wildlife (particularly the large, endangered whale and dolphin species, which can be both highly elusive in the field, and for which laboratory-based research is prohibitively impractical due to their size), many important questions about how marine creatures use sound—and are impacted by noise—remain unanswered. For example, direct testing of hearing ability (to ascertain sensitivity and hearing range) has yet to be conducted for any baleen whale species, while little is known about how marine mammal acoustics depend on seasonal, diurnal, or geographical contexts beyond a few studied species. Despite the presence of much circumstantial evidence, little direct research has been done on the impact of elevated background noise (rather than isolated, impulsive sound) to various marine species. Significant discoveries in hearing and vocalizations in fish species (many of which aren't yet understood) have occurred just within the last few years, and reptile and invertebrate bioacoustics remain largely unexplored.

While current scientific understanding of the ecological impacts from anthropogenic noise remains incomplete, existing data on the impacts to marine mammals and fishes from human-generated sound demonstrates consequences ranging from negligible to traumatic to fatal for individuals of these biological communities. In fact, sufficient data exists to identify alteration of the underwater acoustic environment of the CINMS from anthropogenic noise as both a considerable and increasing threat to the Sanctuary's ecology. Of particular concern are the Sanctuary's rorqual whale species, already endangered from decades of commercial whaling, which may be especially sensitive to the types of noise pollution most prominent in CINMS.

This document reviews existing biological and bioacoustics research pertinent to the Sanctuary's acoustic environment and its sound-dependant marine species, and summarizes the noise-producing human activities in and around the Sanctuary that may be impacting them. Other human activities known to produce significant underwater noise but that don't appear to threaten CINMS resources at present, such as acoustic thermometry, will also be discussed. Taken collectively, existing data, anecdotes and bioacoustical/ecological expertise strongly indicate the need for prompt precautionary management of anthropogenic noise in CINMS, to countervail the dramatic— and increasing— alteration to the Sanctuary environment caused by human noise. The imperative to respond with precaution to anthropogenic noise in CINMS must be acted upon in concert with active, Sanctuary-specific research on the acoustics and acoustic ecology of its wildlife, toward the goal of management that balances conservation of the Sanctuary's special resources with the important economic activities of Southern California.

This document is organized by human activity. Sources of anthropogenic noise that impact or potentially threaten CINMS ecology are outlined and discussed in order of decreasing magnitude of threat, as assessed based on current research. Species and biological communities in the Sanctuary that are or may be impacted by each particular activity are detailed within each activity's section. Different anthropogenic noise sources may have the same or dramatically different known and potential impacts, based on differences in intensity, duration, character and proliferation of the causal human-generated activity, thus the necessity for a wide-ranging discussion. Beyond scientific review and discussion, the document will conclude with ideas for specific science and policy research with the potential to better inform and facilitate management of noise pollution in CINMS. A list of citations and an appendix appear at the end of the document, with background information on a few important acoustics concepts including measurement of sound intensity (including definition of the *decibel* and some basic physics of sound propagation), and the biological phenomenon of *masking*.

A final note: three documents, *Sounding the Depths* (NRDC 1999), *Oceans of Noise* (WDCS 2003), and *Ocean Noise and Marine Mammals* (NRC 2003) each attempt to provide summary coverage of underwater noise and marine wildlife. The latter two works provide up-to-date review and synthesis of research to date on marine bioacoustics

and anthropogenic noise, and were thus extensively relied upon for the present discussion. Similarly, *Marine Mammals and Noise* (Richardson et al. 1995) exhaustively gathers and organizes marine mammal bioacoustics science up to its date of publication, and is thus the core text for understanding many fundamentals of the field. These works are recommended for further information on anthropogenic noise and marine ecology.



A loaded southbound container ship passing by Anacapa Island (photograph courtesy of Channel Islands National Marine Sanctuary).

LARGE VESSEL TRAFFIC

Large vessel traffic is the principle source of noise in the World Ocean (NRC 2003, Croll et al. 2001), and in the Channel Islands National Marine Sanctuary (Pierson 2004, CINMS 2003(a)). This pre-eminence is due to a combination of factors, including the properties of sound emitted underwater by cargo vessels, the geographic location of the Sanctuary relative to major ports and shipping lanes, and the growth and increasing interconnection of the global economy and international trade.

Large cargo vessels, defined by Lloyd's Register as ships 100 gross tons (gt) or larger (Westwood et al. 2002), and loosely by Richardson et al. as ships approximately 85m or greater, individually produce significant sound emissions. Ship propulsion and electricity generation engines, engine gearing, compressors, bilge and ballast pumps, as well as hydrodynamic flow around the ship's hull and any hull protrusions all contribute to a large vessel's noise emissions (NRC 2003). All prop-driven vessels also generate noise through *cavitation*, a process in which the rotating propeller continuously creates bubbles in the water it passes through due to pressure gradients across the spinning propeller blades; the bubbles then immediately collapse under the ambient water pressure. Cavitation accounts for approximately 85% or more of a large vessel's noise, and tends to be lower in frequency and louder with vessel size (Ross 1976). In general, older vessels tend to produce significantly more noise per unit of capacity, due to greater inefficiency in design and poorer operating condition of older mechanical systems, and due to the increased cavitation of propellers with more imperfections such as imbalance, corrosion, damage and barnacles, which tend to accrue with vessel age (Richardson et al. 1995).

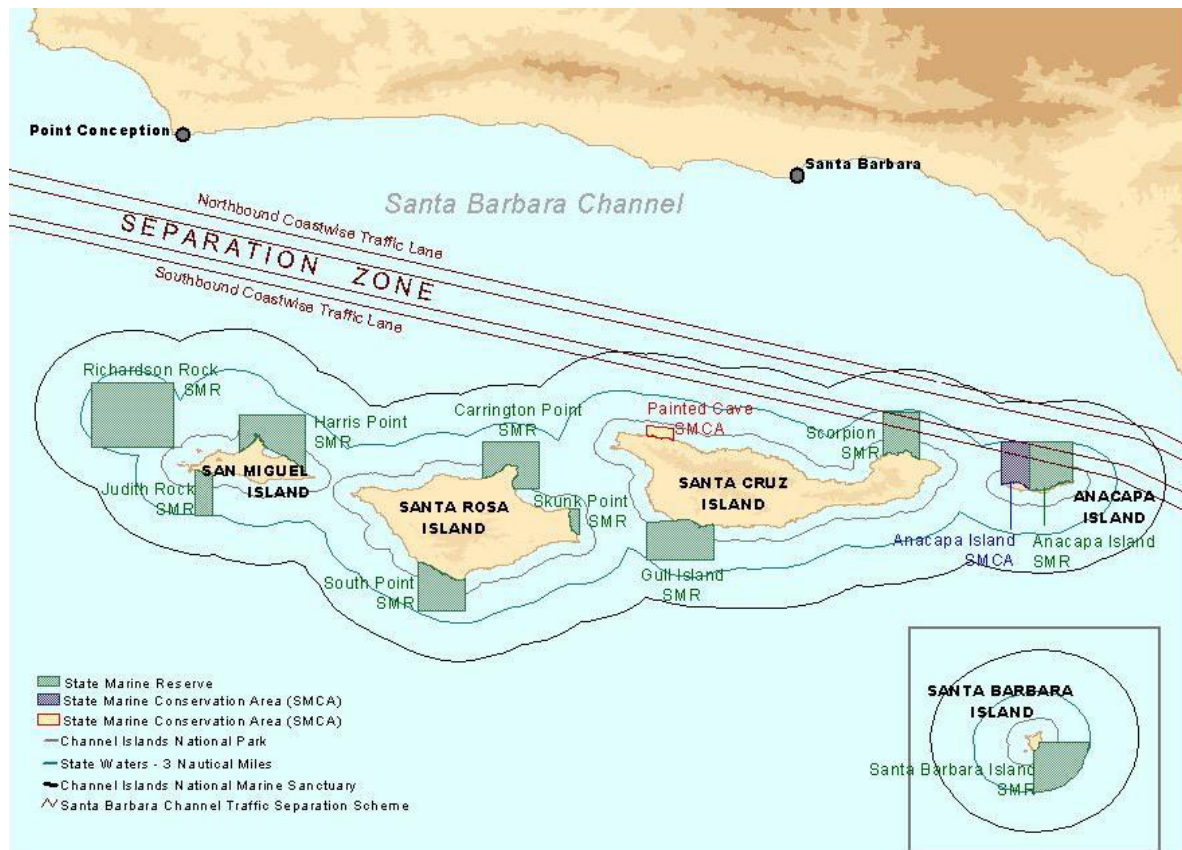
Sonically, large cargo vessel noise is characterized as low frequency, continuous, and tonal, while its intensity¹ and pervasiveness over long distances lead it to be characterized by some scientists as spatially and temporally indistinguishable (NRC 2003). Sound levels from cargo ships and tankers are approximately related to speed, burden, capacity and length (Gordon and Moscrop 1996, WDCS 2003, Richardson et al 1995). Large container vessels, freighters and tankers ranging from 135m to 337m generate peak source sound levels from 169 to approximately 200 decibels between 8Hz and 430Hz (WDCS 2003 summarizing an array of research, Richardson et al. 1995). Importantly, the physical properties of low-frequency sound and seawater combine to minimize sound absorption and facilitate sound propagation: sound energy travels approximately 4.5 times faster in seawater than in air, and while a high frequency sound of 100 kHz loses 36 dB in intensity per km, the intensity of a medium or low frequency sound (< 1 kHz) decreases no more than 0.04 dB per km (Richardson et al. 1995). As a result, low-frequency tones from a single large vessel are evident in sound readings 139-463 km away (Ross 1976), demonstrating the vast geographic area of ensonification from just a single large vessel. As NRC reports, the high sound levels of cargo vessel emissions make it so "very large geographic areas are affected," and even distant vessel traffic "contributes to the general acoustic environment" (2003).

Between 1985 and 1999, world sea-borne trade increased by 50 percent, to approximately 5 billion tons of cargo per year. During 1990-1998, annual growth in shipping-based trade averaged 3.2%; by 2002 more than 95% of world trade by tonnage was transported by large cargo vessels (Westwood et al. 2002). Because no transportation alternative exists to convey cargo at such scale, merchant vessel traffic will continue to increase in proportion to the growth of international trade and the global

1/ For definitions of important acoustic terminology and basic coverage of acoustics concepts such as *frequency*, *amplitude* and the decibel scale, see *Appendix A*.

economy (NRC 2003). While the number of vessels in the global merchant fleet is increasing, cargo vessels also continue to increase in size. Between 1982 and 2002, Lloyd’s Register data show that the world’s large vessel fleet grew from 73,832 to 88,168 ships (a trend that suggests a global fleet of more than 130,000 vessels (or similar shipping capacity) by 2026). Meanwhile, since 1970 the average vessel size has grown by 43% from 4,337gt to 6,201gt (Westwood et al. 2002).

Global shipping capacity is understood to be concentrated in the northern hemisphere, facilitating trade between the north’s industrialized nations (WDCS 2003), and along defined routes and coastlines (NRC 2003), all characteristics of the Santa Barbara Channel area. More specifically, the global expansion of large commercial ship traffic pertains to CINMS because of the Sanctuary’s location between the ports of San Francisco and Los Angeles/Long Beach, which, as the 18th and 10th busiest ports of call in the world respectively in 2000 (US DOT 2002) receive the bulk of Asian exports to the United States (Wignall and Womersley 2004). In fact, LA/LB and San Francisco are respectively the first and third busiest ports for container ship arrivals in the US, and projected to increase their containership arrivals by 5-10% per year over the next ten years (Wignall and Womersley 2004).



CINMS and the Santa Barbara Channel Vessel Traffic Separation Scheme (map courtesy of Channel Islands National Marine Sanctuary).

Large merchant vessels that arrive at or leave from these two ports bound for many other domestic and international ports travel the North- and Southbound Coastwise Traffic Lanes through the Santa Barbara Channel under the “Vessel Traffic Separation Scheme” (VTSS), which routes ships directly through the northeast end of the Sanctuary. Traffic enters and exits almost due east of Anacapa Island; northbound traffic exits the Sanctuary approximately 2 miles north of Scorpion State Marine Reserve on Santa Cruz Island, and southbound traffic enters the Sanctuary approximately six miles north of Painted Cave State Marine Conservation Area on the west end of Santa Cruz Island (NOAA/CINMS 2003). In 2002, approximately 6500 north and southbound cargo vessels traveled through the Channel and the Channel Islands National Marine Sanctuary, roughly 17 ships per day². Along with traffic between the various West Coast ports, container ship traffic traveling between LA/LB and Asian ports also passes through the Channel following navigation routes that trace a northerly arc across the Pacific.

As discussed, large vessels are *individually* very significant sources of underwater noise. However, because of the low attenuation rate of the characteristic low-frequency sound emission, and an average ship passage rate of about 84 minutes (yielding an estimated average vessel separation distance of 21 nautical miles), CINMS ecology faces essentially incessant, cumulative exposure to ubiquitous large vessel traffic noise. With about 120 ships transiting per week, any respites from large vessel noise are countervailed by concurrent passage of multiple ships. In addition, based on global trends, CINMS faces an increasing volume of vessel traffic, comprised of ships of increasing size (and, consequently, loudness) (Wignall and Womersley 2004).

In its preliminary draft Management Plan Update, CINMS identifies large vessel traffic as the “principle source of low-frequency noise” in the Sanctuary (CINMS 2003(a)). This conclusion is reinforced by the aforementioned data on the propagation and intensity characteristics of noise from ships (Richardson et al. 1995, Roussel 2002), by the proximity of the Sanctuary to the flow of commercial vessel traffic (the northern shores of all Channel Islands from Richardson Rock to Anacapa are less than 30km from the Southbound Coastwise Traffic Lane, and no more than 2km from the shores of Anacapa Island (NOAA/CINMS 2003)), the current and projected quantity of traffic in Southern California (Wignall and Womersley 2004) and thus low-frequency sound production, and the stated opinions of several experts (Pierson 2004, Clark 2004, Croll et al. 2001).

2/ Unfortunately, no systematic monitoring of large vessel traffic passing through the Santa Barbara Channel is known to exist. The Southern California Marine Exchange (a San Pedro-based non-profit non-governmental organization) maintains a database of all vessels entering and leaving LA/Long Beach, including each ship’s previous port of call and destination port. By counting ships arriving in LA/LB from a northern origin, or departing for a northern port, an estimate of passage rates through the Santa Barbara Channel can be achieved. However, this lack of direct traffic monitoring through the Sanctuary should be considered a significant gap in the needed management and understanding of noise and any other impacts large vessel traffic may have on the Sanctuary.

This assessment is also buttressed by anecdotes and marine acoustics research conducted in Central and South Coast offshore areas specifically. Ross (1976), using a Navy hydrophone array, documented a 15dB increase in 5-100Hz noise off Point Sur between 1950 and 1975 which he attributes solely to increased ship traffic (and noted that 6.8 Hz noise from a supertanker could be detected 139-463 km away). Andrew, et al. (2002), building from Ross's data through observations with the same Point Sur hydrophone array, document a 10 dB increase in ambient oceanic noise at 20-80Hz between the early 1960s and the late 1990s, representing more than another full order of magnitude of increase. They also attribute the increase to greater vessel traffic³. In 1998, MIT researchers attempted an acoustics experiment in which seafloor hydrophones in the Santa Barbara Channel were employed to ascertain the location of a moving, ship-towed sound source emitting up to 170dB between 0 and 500 Hz. The experiment essentially failed due to unpredicted and overwhelming masking of the towed sound source across its spectrum by cargo vessel traffic noise from the north and southbound lanes of the Vessel Traffic Separation Scheme (VTSS) just northeast of Anacapa. At over 11km from the passing ships, the hydrophones received vessel traffic noise of over 125 dB, approximately 300 times greater than the received intensity of the researchers' towed 170 dB sound source (MIT 2000).

These reports begin to illuminate both the power and the wide-reaching effect of large vessel traffic in the Central and South Coast regions: not only is large vessel traffic noise the primary anthropogenic contribution to the CINMS acoustic environment, but in absolute terms establishes CINMS as an exceptionally ensonified (i.e. noisy) marine environment within the world ocean. Compared with its pre-industrial ambience, and the acoustic environment of remote, rarely traveled locations (see, for example, Cato 1976 for measurements of ambient acoustics off Western Australia), the acoustic environment of the Southern California Bight could be considered "urbanized" (Clark 2004).

From this basic understanding of the physical magnitude of large cargo vessel traffic and the sound it produces, discussion of the extensive known and potential ecological significance can begin. In sum, research to date on the impact of low-frequency noise upon various marine species raises the possibility of several negative outcomes for CINMS biodiversity resulting from the intense and pervasive sound of large vessel traffic. These include persistent masking of ecologically vital sound for marine mammals and fishes, temporary and permanent threshold shift in marine mammals and fishes, avoidance of important and historical habitat and the manifold secondary ecological consequences of these impacts. Each will be discussed in turn below⁴.

3/ Perhaps more precisely, the increase is due to a combination of increase in total vessel numbers as well as average vessel tonnage.

4/ Marine bioacoustics research has to date largely focused on cetaceans (Popper 2003, NRC 2003). To a lesser extent, pinnipeds, fishes, sea turtles, and some cephalopods and crustaceans have also been studied or have had behavioral responses documented (NRC 2003, WDCS 2003). This discussion focuses on the biological communities for which meaningful acoustics research has been conducted and published, namely whales and fishes. Hopefully future bioacoustics research will broaden as well as

Several species of baleen whales (members of suborder Mysticeti) inhabit the Sanctuary area, including gray whales (*Eschrichtius robustus*), and at least four members of Family *Balaenopteridae*, including blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), sei whales (*B. borealis*), and humpback whales (*Megaptera novaeangliae*) (CINMS 2003(b)). Among the balaenopterids, recordings of vocalizations and documentation of conspecifics' reactions to those vocalizations imply significant reliance on sonic communication in the low frequency range, 5-500Hz (Croll et al. 2002, WDCS 2003, Roussel 2002), the same range in which large vessel traffic emits its most intense output (NRDC 1999, NRC 2003, Richardson et al. 1995). This overlap of the acoustic characteristics of anthropogenic sound and balaenopterid communication, i.e. masking⁵, has direct implications for CINMS blue and fin whale ecology and perhaps survival. These implications are just beginning to be elucidated.

Croll et al. (2002), through locating and sexing (via biopsy and DNA analysis) vocalizing fin whales in the Gulf of California, ascertained that all vocalizing animals were male. The researchers conclude that the patterned, 15-30Hz scooping calls characteristic of fin and blue whales are mating displays used by males to attract mates from long distances (to the order of hundreds of kilometers) to feeding and breeding areas, and they support this proposal with some key observations. First, "fin and blue whales do not aggregate in specific areas for breeding," unlike the related humpback whales, which gather in tropical waters during a definite breeding season. Second fin whales "use the Loreto (Baja California) study area to forage on dense aggregations of krill;" and finally, the "low-frequency vocalizations of [genus] *Balaenoptera* are optimal for long-distance communication in deep water" (Croll et al. 2002).

These findings illuminate the significance of the acoustic environment to balaenopterid reproduction, foraging and thus general survival; extremely pertinent to our discussion of CINMS acoustics, the researchers also address the interaction of anthropogenic noise and fin- and blue whale vocalizations:

Our results help to focus growing concern over the effects of human-produced sound on Balaenoptera species. Sound levels from commercial ships, military sonar, seismic surveys and ocean acoustic research are extremely high (190–250 dB) and, at least since the early 1960s, the amount of human produced sound in the frequency range used by large whales has increased (Andrew et al. 2002). A sound is detectable if its received level exceeds that of background noise by enough to be detected by the animal. An increase in ambient noise could thus reduce the distance over which receptive females might hear the vocalizations of males. To the extent that growth of Balaenoptera populations is limited by the

deepen current understanding, so that discussions such as this can include a more complete cross section of a region's ecology.

5/ NRC (2003) defines masking as "a reduction in an animal's ability to detect relevant sounds in the presence of other sounds."

encounter rate of receptive females with singing males, the recovery of fin- and blue whale populations from past exploitation could be impeded by low-frequency sounds generated by human activity. [Croll et al. 2002]

Fin and blue whales regularly inhabit CINMS and the greater Southern California Bight area, exploiting the productivity of waters in and around the Sanctuary to forage (CINMS 2003 (b)). Dr. Christopher Clark, a coauthor of Croll et al. (2001), Croll et al. (2002), and other cetacean bioacoustics studies, describes the Channel Islands area as rich with evidence of balaenopterid-whale breeding and feeding activity, including plumes of feces and vocalization noises (Clark 2004). Management of CINMS and its cetacean populations should thus be conducted with these conclusions, including orca whale sensitivity to low-frequency noise, in mind.

For all cetaceans, aforementioned mysticetes as well as the toothed whales (odontocetes), large vessel traffic noise may be associated with higher energy-costs involved in the modification of vocal echolocation and communication in noisy environments. Both baleen and toothed whales have been documented modifying vocalization to counteract masking from anthropogenic noise⁶, through increases in amplitude and frequency of vocalizations (NRC 2003). These modifications may also increase difficulty in foraging, navigation, and intra- and interspecies communication due to use of sub-optimal frequencies for these activities (NRC 2003).

In all known vertebrates, exposure to noise of sufficient intensity can result in temporary or permanent loss of sensitivity to sound at a given frequency range: threshold shift, as it is known, can occur instantaneously if the received sound levels are high enough, or can occur over time at lower intensities through continuous or cumulative exposure (Richardson et al. 1995). Temporary or permanent threshold shifting may occur in cetaceans, pinnipeds and fishes in the Sanctuary as a result of exposure to large vessel traffic noise because of its intensity, broad geographical effectiveness, and constancy, which collectively imply significant cumulative exposure to any individuals or populations exhibiting site fidelity. As discussed in the context of masking, impairment in sound sensing can significantly impinge on the survival of many marine species; published research on threshold shifting in marine wildlife, summarized below, suggests that harmful and fatal changes in normal behavior can result from hearing loss due to excessive exposure to underwater anthropogenic noise.

6/ NRC summarizes the key literature on masking and marine mammals: *Beluga whales increased call repetition and shifted to higher peak frequencies in response to boat traffic (Lesage et al. 1999). Gray whales increased the amplitude of their vocalizations, changed the timing of vocalizations, and used more frequency-modulated signals in noisy environments (Dahlheim 1987). The physiological costs of ameliorating masking effects have not been reported. Although these examples all appear to show animals adapting their vocal behavior to reduce the impact of masking, this does not imply that there were no costs resulting from increased levels of noise. Masking may have been reduced but not eliminated. [NRC 2003].*

André et al. (1997) studied the impacts of high-speed ferry traffic on sperm whales (*Physeter macrocephalus*) in the Canary Islands, including the application of low-frequency noise emitters from the ferries to deter sperm whales and reduce shipstrike. Sadly, attempts at acoustic deterrence with a variety of different sounds failed to significantly increase vessel avoidance, which the researchers suggest stemmed from sperm whale habituation to large vessels, or to threshold shift. Citing subsequent research by André et al. (1998), NRDC (1999) reports that two sperm whales in the Canary Islands were struck and killed by a cargo ship without any apparent attempt at avoidance. André et al. conducted necropsy on the whales, revealing discernable cell damage in the inner ears of both individuals. The researchers suggested that heavy vessel traffic was causing the discovered permanent threshold shift in the resident sperm whales, thus reducing or eliminating their awareness of approaching ships (1998).

Similar to the sperm whale research, Todd et al. (1996) reported on humpback whales in Newfoundland that were subject to potentially damaging levels of sound from underwater explosions (from marine construction) over the course of a season in historic and productive humpback feeding grounds. Explosions emitted maximum levels of sub-1000Hz sound estimated at 209 dB at the source, and measured at 153 dB approximately 1.8 km away. Humpback individuals were subject to the sound at a range of distances from the sound source, yet showed no significant change in behavior despite some extremely high, acute received sound levels. Over the subsequent two years, however, humpback entanglements in gill nets with sonic deterrence devices in the region dramatically spiked, from an average of 2.5/year from 1979 to 1990, to 19 and 14 recorded entanglements in 1991 and 1992 respectively.

The researchers suggest that the explosions resulted in threshold shifting sufficient to significantly impinge on the whales' ability to acoustically detect gill nets. While underwater explosions are dramatically different in acoustic character compared to large vessel traffic, the research of Todd et al. reveal that cetaceans, or at least humpbacks, may not flee from biologically important habitat despite physiologically traumatic sound levels.

All great whales known to inhabit CINMS (baleen and sperm whales) are understood to be transient (temporary or migratory inhabitants) (CINMS 2003(b), Calambokidis et al. 1998), which, in light of the aforementioned research, raises some troubling possibilities worth considering in the context of large vessel traffic and CINMS wildlife management.

First, balaenopterids that reside for any duration in the Sanctuary area are subjected to high ambient noise levels shown to both mask vital intraspecies communications for foraging and reproduction, and also cause either imperiling habituation to vessel traffic noise⁷ (and the ships themselves), or some degree of auditory threshold shift with the

7/ Bioacoustics researcher E. Gerstein points out the biological usefulness of habituation (in the context of Atlantic right whales): if whales in areas of heavy vessel traffic stopped feeding and fled at

same behavioral outcome of reduced avoidance. An increase in whale shipstrike over time could be the first telling result (analogous to that observed by André et al. (1997) in the Canary Islands), as sensitivity to aural cues and avoidance response diminishes. Such a hypothetical increase could be attributed simply to the ongoing increase in vessel traffic alone; nonetheless, an active and continuous monitoring program for shipstrike⁸ vis-à-vis vessel traffic volumes and whale distribution patterns would produce data valuable for understanding large vessel impacts on whale population dynamics. Furthermore, some form of active monitoring could provide opportunities to investigate the possibility of discernible damage to cetacean aural physiology through immediate necropsy of any ship-killed individuals.

Over a much longer period of time, a reduction in birth rate for balaenopterid whales inhabiting CINMS may also occur and be used as an indicator that the effective distance of male calls summoning females to krill plumes and sex in the Channel area is reduced due to masking from shipping noise (Clark 2004). Unfortunately, the long life spans and naturally slow reproduction rates of fin and blue whales make measurements in birth rate change a prohibitively long and slow process (such an endeavor would span human lifetimes), and passive observation of human-caused decline in these already endangered populations would be unacceptable.

Published reports on marine mammal avoidance and long term abandonment of historical habitat due to anthropogenic noise raise this scenario as a future possibility for CINMS and its surrounding waters, and should also be considered in light of increasing large vessel traffic. Bryant et al. (1984), studying gray whales (*E. robustus*) recorded abandonment of a calving lagoon in Baja California after initiation of dredging and an increase in small vessel traffic. Years later, cow-calf pairs were again seen in the lagoon after cessation of the noise-producing mechanical operations in the Lagoon. Similarly, Northwestern Pacific gray whales were documented abandoning historical feeding grounds near Sakhalin Island to avoid commercial seismic surveying noise (IWC 2004(a)) [this report is also discussed in the seismic surveying section]. Morton and Symonds (2002) report that in *orca* of the Pacific Northwest, transient and resident subpopulations were equally affected by the acoustic harassment devices (AHDs) deployed by the fish farms to deter predation from salmon pens in their study area. Both sub-populations completely abandoned their historical habitat within the study area until the AHD's were removed. While these subpopulations of *orca* are a unique feature of this species, the researchers' observation may be pertinent to our discussion in that two groups with distinct habitation and migration patterns both significantly altered their behavior due to introduction of anthropogenic noise.

every sign of an oncoming ship, they would never get to eat (informal comment at bioacoustics conference).

8/ NOAA Fisheries data report ten ship collisions with whales in the Santa Barbara Channel between January of 1983 and June of 1998 (NOAA Fisheries, California Marine Mammal Stranding Network Database 2004). However it is likely that not all strikes are observed or reported.

Whale survey data indicate that humpback and blue whale numbers have increased significantly in the Santa Barbara Channel, including around the VTSS, over the last 20 years (Howorth 2004). This hopeful information may disqualify the possibility of cetacean avoidance or abandonment of Channel Islands habitat due to shipping noise. Nonetheless, as discussed above, large vessel traffic is projected for roughly 5-10% annual growth for many more years. Barring a significant change in large vessel traffic patterns through the Santa Barbara Channel, it remains to be seen if a threshold of tolerance for habitat ensonification exists for CINMS whales. In the meantime, the several documented incidents of long-term abandonment of even critical habitat due to anthropogenic noise should implore Sanctuary stakeholders to be alert for changes in both the ambient noise levels and local whale population numbers in the Sanctuary.

Apart from marine mammals, fish also show sensitivity to anthropogenic noise. While no in-depth studies have yet been completed on impacts to fish specifically from large vessel traffic noise, current research of hearing in fishes and the impacts of sound on fish ecology strongly suggest that loud anthropogenic sound and increases in ambient noise level can have significant impact on fish species. Data from such studies, summarized below, should also be considered in the context of shipping noise and CINMS.

Most species of fish, including the cartilaginous species like sharks, rays and skates, have inner ear physiology very similar to terrestrial vertebrates, and are able to detect sounds from well below 50 Hz (some as low as 10 or 15 Hz) to 1,000 Hz (some species show acuity to 10 kHz and beyond); all species of fish tested have been able to hear (Popper 2003). This implies fish sensitivity to most, if not all, of the spectrum of emissions from large vessel traffic, and thus the potentiality of consequences similar to those faced by marine mammals, that could similarly impinge on individual and population survival, including masking of biologically important sound, auditory tissue damage (threshold shifting), avoidance of otherwise suitable habitat, and chronic stress.

Many fish species depend on sound for navigation, reproduction, foraging, and as a cue for avoidance of peril, whether emitted from their physical environment, from conspecifics (other individuals of the same species) or from predator or prey species (Popper 2003). An increase in ambient noise level, whether from constant large vessel traffic or another noise source, could alter fish behavior (NRC 2003); alteration of any of these crucial behaviors could obviously impact survival. As one example, Popper (2003) mentions how shark species are attracted to the sound of prey struggling in the water, and the increased difficulty in finding food in noisy environments in which such sound is masked. NRC summarizes important research on the impact of masking on recruitment in reef fishes whose life cycles have an offshore larval stage:

...at least some larval fish are likely to use the reef sounds to find the reefs and that the fish will go to regions of higher-level sounds (Tolimieri et al., 2003). Thus, if there are intense offshore sounds, larval fish may be confused and not be

able to find the reef. Alternatively, such sound may mask reef sounds, again preventing larval fish from finding the reef. [NRC 2003]

That large vessel traffic noise has the potential to impact Sanctuary fishes reveals the need to better understand the magnitude and character of the threats to CINMS fishes specifically. Useful research may include necropsy of fish ears from animals with a high exposure rate to shipping noise, e.g. from near the north shore of Anacapa. Concurrently, continuous monitoring of the Sanctuary's acoustic environment in several locations would provide basic data on approximate exposure rates for all marine species, as well as establish a useful baseline to compare future anthropogenic output.

NRDC (1999) reports that, “*managers at Monterey Bay and other sanctuaries have thought to form voluntary associations with shippers, mainly to reduce the risk of oil spills sludging up protected waters, but also to guard against habitat degradation and acoustic harassment*”⁹. Currently this partnership routes volunteering oil tankers outside the Santa Barbara Channel to approximately 50 miles off the coast. From the perspective of managing the CINMS acoustic environment for wildlife conservation, encouraging the routing of the largest and loudest vessels a similar distance offshore may ameliorate the risk to Sanctuary ecology posed by the large vessel traffic output.

ACTIVE SONAR

Active sonar, in which sound is broadcast and its echoes recorded in order to “characterize physical properties and locate marine objects,” is divided into low-frequency (<1 kHz), mid-frequency (between 1 and 10 kHz), and high-frequency (>10 kHz) (NRC 2003). Currently, active sonar is not assessed to directly impact CINMS ecology. However, the extreme intensity of sound levels broadcast by low- and mid-range active sonar and the dramatic impacts associated with its application, as well as the national and global proliferation (NRDC 1999) of all ranges of active sonar technology, warrant its assessment as an ecological threat worthy of this discussion and for consideration from the standpoint of CINMS biological resource management.

High-frequency active sonar has an array of applications, including civilian use for fish-finding; vessel side-scanning or high resolution sea-floor imaging, and military use for side-scanning and mine hunting (NRC 2003). Development and testing is also currently underway for hull-mounted “whale-detecting” high frequency active sonar, aimed at reducing shipstrike.

Due to the physical characteristics of high frequency sound used by these systems (approximately 10 to 500 kHz), emissions are quickly absorbed in seawater and thus localized in effect. Detailed understanding of the impacts of high-frequency sonar on

9/ Personal communication between NRDC authors and Ed Cassano, former Manager, Channel Islands National Marine Sanctuary (July 23, 1997).

either specific species or general ecosystems has yet to be articulated¹⁰. However, delphinids (species of the dolphin family) such as bottlenose (*Tursiops truncatus*) and common dolphins (*Delphinus delphis* and *Delphinus capensis*) which rely heavily on echolocation have acuity at high frequencies (into ultrasonic range) for their own active sonar, and certain fishes of the family Alosinae that range through the Santa Barbara Channel, including American shad (*Alosa sapidissima*) (an introduced species) and Pacific herring (*Clupea pallasii*) have aural sensitivity of 10 kHz and beyond (perhaps for detection of predatory bottlenose dolphins, or communication with conspecifics) (Mann et al. 2001, Wilson et al. 2003). Use of high frequency sonar may thus impact behavior and survival of these species through masking or causing avoidance of habitat if used extensively or in ecologically sensitive areas within the Sanctuary.

In contrast, mid- and low-frequency active sonars are limited to naval (military) application. NRC (2003) summarizes the systems and their respective application:

Military sonars are typically operated at higher power levels than civilian sonars and are used for target detection, localization, and classification. Military low-frequency sonars are used for surveillance and are designed to gather information over large areas. If conditions permit, these sonars can collect information over entire ocean basins. The mid-frequency military systems are tactical sonars and are designed to look over tens of kilometers for the localization and tracking of targets.

The class of surveillance sonars presently in the fleet is designed to locate targets, primarily submarines and to some extent surface ships, at tens to hundreds of kilometers away to provide early alerts of potential threats to navy vessels. The U.S. Navy's Surveillance Towed Array Sensor System Low Frequency Active (SURTASS-LFA) system utilizes a vertical line array of up to 18 source projectors operating in the frequency range of 100-500 Hz. The source level of each projector is approximately 215 dB.

In addition, the U.S. Navy reports that the hull-mounted AN/SQS-53C tactical [mid-frequency] sonars can generate pulses in the 1-5 kHz band and have been operated at source levels of 235 dB, and that the AN/SQS-56 sonars generate pulses in the 5-10 kHz band and have operated at 223 dB source levels. [Evans and England 2001]

Impulsive sound of these extreme source-levels has very high potential for negative impact to marine wildlife on several levels, from individual physiology to general ecology. Pertinent implications for low and mid-range frequency sonar vary based on their respective frequencies, and thus will be individually addressed in turn.

10/ An effort to initiate commercial testing of high-frequency systems off the Central Coast for vessel-based detection and avoidance of whales has caused some controversy (See: San Francisco Chronicle, 1/17/04, "Judge allows tests of sonar for sake of finding whales").

The high intensity, impulsive sound in the 1kHz-10kHz range that characterizes mid-frequency sonar has been implicated in cetacean fatality stemming from acoustic trauma (Evans and England 2001) and decompression sickness (resultant from startle/flight response triggering ascension at excessive velocity) (Jepson et al. 2003), mass stranding (WDCS 2003; summarizing four incidents), severe damage to hearing physiology (Evans and England 2001), alteration of vocalizing behavior (Watkins et al. 1985, Rendell and Gordon 1999) and abandonment of habitat (Parsons et al. 2000).

Findings of the Evans and England (2001) report are worth highlighting. The joint report of NOAA and the US Navy stated that mid-frequency tactical sonar used by several ships within 24 hours of a mass stranding of Cuvier's beaked whales (*Ziphius cavirostris*) and a Blainville's beaked whale (*Mesoplodon densirostris*), on the northern Bahamas coastline, was the most plausible source of the acoustic trauma that caused the beaked whales to strand. The writers base this conclusion on recordings from NOAA operated hydrophone arrays in the Atlantic and Caribbean which reveal the tactical sonar as the only sound present during the time period capable of causing the physiological trauma suffered in the cranial cavities, aural structures and tissues of the odontocetes, and on the results of extensive computed tomography (CT) scanning and autopsy work performed for the investigation.

The Jepson et al. (2003) report is similarly worth elaborating upon, as the researchers also gathered detailed pathological data implicating tactical sonar in beaked whale mass stranding and death. In their case, "fourteen beaked whales were stranded in the Canary Islands close to the site of an international naval exercise in September 2002. Strandings began about 4 hours after the onset of mid-frequency sonar activity." Jepson et al. performed necropsy on eight Cuvier's beaked whales, a Blainville's beaked whale, and a Gervais' beaked whale (*Mesoplodon europaeus*), "six of which were very fresh." The necropsies of these individuals revealed "[i]ntravascular bubbles... present in several organs," which they propose, as mentioned, was representative of decompression sickness caused by excessively rapid ascension from depth. Unfortunately the researchers did not have hydrophonic data to reference with the incident, however they note that their observations are "unprecedented in marine mammal pathology," implying extraordinary causal circumstances.

Further incidents in which the use of mid-frequency active sonar has been implicated in cetacean harm or death, through coincidence with mass stranding, have occurred throughout the world. These include: Madeira, Spain (2000), Kyparissiakos Gulf, Greece (1996), Puerto Rico, and Washington state (2003) (NOAA 2002, WDCS 2003), and, in 2004, in Hawaii¹¹ (a "near-stranding") and the Canary Islands¹².

11/ "Navy's use of sonar suspected in near-stranding of whales: Hawaii incident intensifies debate on ocean noise." Marc Kaufman, September 1, 2004. Published by the *Boston Globe*.

12/ "Dead whales found after military exercise: Off Spanish coast, latest case follows new report blaming sonar tests." Reuters: Fuerteventura Coast, Spain. July 23, 2004. Published at <http://msnbc.msn.com/id/5488866/>.

Clearly, naval tactical mid-frequency sonar represents a danger to marine wildlife, particularly odontocetes such as beaked whales with particular aural acuity in frequencies typically used in these sonar systems. Pertinent to CINMS wildlife, specifically its odontocete communities¹³, NOAA and the US Navy (Evans and England 2001) have outlined mitigation measures to reduce marine mammal take from mid-frequency sonar deployment:

- 1. Forego multi-ship, peacetime active sonar transmissions from mid-range tactical sonar in the Northeast and Northwest Providence Channels [of the Bahamas] unless required for National Security reasons.*
- 2. The Navy will carefully assess and closely scrutinize future training and training areas with an eye toward avoiding those situations where the combination of factors presented in this report (oceanography, bathymetry, sonar usage, etc.) would be likely to occur.*
- 3. If the factors cited in this report are present in another location, and relocation is not feasible, and the Navy must proceed but has not received a Letter of Authorization (LOA) or an Incidental Harassment Authorization (IHA), then:*
 - Immediately before the operation use whatever facilities or assets are on hand to visually and acoustically survey for marine mammals*
 - Establish a zone of influence appropriate to the existing oceanographic conditions and source level settings*
 - Employ properly trained lookouts*
 - Implement shutdown procedures if marine mammals are detected within the zones of influence established for those species*
 - Immediately after the operation ends (where feasible, usually in near shore waters) survey for injured, disabled or dead marine mammals using whatever survey facilities and assets are on hand, and notify NMFS if any such animals are found so that an appropriate stranding response can be implemented.*
- 4. NMFS will continue to conduct broad area surveys of marine mammal locations, migratory pathways and habitats that can be used by Navy planners in selecting exercise sites. [Evans and England 2001]*

Measures (2) and (4) imply that the Navy and NOAA Fisheries must consider the biological richness of prospective mid-frequency sonar activities sites before deployment. Such consideration may suggest that CINMS will be outside the zone of influence of any future West Coast naval exercises involving tactical sonar. While this suggestion is reasonable and reassuring, the stringency of the Navy's application of the mitigation

13/ The acoustically sensitive Cuvier's and Baird's beaked whales are known to occur in Southern California, as well as several other beaked whale species including Blainville's, Hubb's, Ginko-toothed, Perrin's, and Stejneger's beaked whales (Leatherwood et al.1987).

measures is unknown, and thus the future impacts of tactical sonar on CINMS remains uncertain.

Low frequency active sonar (LFAS) is currently a more nascent and extraordinary technology than active mid-frequency sonar. Designed as a strategic oceanic surveillance system to monitor ultra-quiet “enemy” submarines that elude detection by passive hydrophones, the US Navy considers the technology a necessity for national security and protection against the “224 submarines operated by non-allied nations... prowling the world’s oceans” (US Navy 2004). LFAS takes advantage of the low attenuation rate of low-frequency sound waves in seawater, as well as the thermoclines in the oceanic water column that confine sound waves to layered channels of water of distinct temperature, to transmit sound and receive its echoes over thousands of kilometers (NRC 2003). NRDC summarizes the Navy’s Surveillance Towed Array Sensor System of low frequency active sonar (i.e. SURTASS LFA):

Eighteen separate loudspeakers, each one slightly smaller than a bathtub, are lowered from the vessel’s hull 300 to 500 feet downward. The speakers are synchronized through electrical lines running the length of a central cable, and when the proper code is entered on the ship’s computer and the LFA protocol is launched, they sound in tandem, creating at several hundred meters a focused beam of intense, deep noise: a series of pure tones and frequency sweeps pitched somewhere between 100 Hz and 500 Hz, and reportedly reaching over 230 decibels. The point at which the individual sound waves converge varies with their frequency. Given the length of the 18-speaker array (approximately 57 meters) and the average speed of sound in water (1500 meters/second), transmissions of 100 Hz and 500 Hz meet at roughly 110 meters and 540 meters, respectively. Within this range, zones of great intensity alternate with pockets of relative quiet.

In court proceedings, the Navy has acknowledged that SURTASS-LFA sound transmits at such intensity to have a received level of around 140dB more than 650 km from the sound towed array sound source (NRDC, *et al. v. Evans, et al.*, 2003). Obviously, huge geographic areas would be ensonified and thus potentially impacted by operation of even a single array. SURTASS-LFA has been in testing since 1994 at the latest (WDCS 2003) (including, in rather direct relation to our discussion, at least two test exercises in the 1990’s “south of the Channel Islands” (NRDC 1999)).

Study of potential biological impacts from LFAS to marine wildlife has thus far focused on cetaceans, specifically the great whales which, as mentioned earlier, have significant or primary aural sensitivity to low frequency sound. Dr. Peter Tyack, writing in NRDC (1999), summarizes three US Navy-sponsored studies in which he took part that attempted to assess great whale reaction to LFAS sound:

Three different species and settings were selected, the first involving blue and fin whales feeding in the Southern California bight (Sept.-Oct. 1997); the second,

gray whales migrating past the central California coast (Jan. 1998); and the third, humpback whales breeding off the Hawaiian Islands (Feb.-Mar. 1998). For each experiment, researchers broadcast a series of low-frequency pulses and waves that simulated the LFA signal (albeit at lower intensities), and monitored the reactions of the local whales. Our primary focus was avoidance-- but attention was also paid to such issues as whale vocalization and mother-calf behavior. Our preliminary analyses did reveal reactions of whales to LFA playbacks. During the first experiment, the number of fin and blue whales heard vocalizing decreased during playback. During the second experiment, gray whales deviated from their migration paths¹⁴: the louder the sound, the greater the avoidance reaction. During the third experiment, about a third of the singing [humpback] whales stopped singing in response to the LFA playback [see also Miller et al. (2000), describing humpbacks lengthening songs in response to LFAS sound.]. We determined the acoustic exposure for each whale that was a subject in these playback experiments; this allows us to develop a model of what exposure conditions evoke these different responses. There remains the critical issue of estimating the biological significance of these responses to low-frequency sound. [NRDC 1999]

While cessation or increase of duration of vocalization could be construed as a minimal impact, NRC cautions against such assumptions, stating:

Clearly there are opportunity costs associated with even the transient behavioral changes in response to noise. The movements require energy that might otherwise have been spent in acquiring food or mates or enhancing reproduction. Repetitive transient behavioral changes have the potential of causing cumulative stress. Even transient behavioral changes have the potential to separate mother-offspring pairs and lead to death of the young, although it has been difficult to confirm the death of the young. [NRC 2003]

Testing and deployment of the SURTASS-LFAS was suspended in autumn of 2003 as a result of a lawsuit by NRDC challenging the US Navy's compliance with the Marine Mammal Protection Act (MMPA). According to NRDC, the presiding judge "found that a permit issued to the Navy by the National Marine Fisheries Service to deploy LFA sonar violates the MMPA, the Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA) because it did not adequately assess or take steps to mitigate the risks posed by the system to marine mammals and fish¹⁵."

14/ "Migrating gray whales diverted around a stationary sound source projecting playbacks of LFA sonar when the source was located in the migratory path but seemed to ignore the sound source when it was located seaward of the migratory path. When the source was in the path, received levels of 140 dB re 1 μ Pa were sufficient to cause some path deflection." (NRC 2003, citing Tyack and Clark 1998, unpublished). As mentioned, LFAS sound can have a received level of 140 dB more than 400 miles from the source.

15/ <http://www.nrdc.org/media/pressreleases/030826.asp>

In the Autumn 2003 ruling, the Court issued an injunction against proceeding with deployment of SURTASS-LFAS, until a “carefully tailored” agreement is established between NRDC and co-plaintiffs, NOAA and the Navy that allows “the Navy to meet its needs for peacetime training and testing, *while also* providing reasonable safeguards for marine mammals and other sea animals.” Judge Laporte elaborates:

The Court’s injunction will permit the Navy to train and test LFAS in a wide range of oceanic conditions as needed, while restricting it from operating in certain sensitive areas when marine mammals are particularly abundant there. In particular, the injunction will extend the coastal buffer zone beyond the current twelve miles to include more of the continental shelf in the great majority of coastlines where the record shows that the Navy need not operate closer to shore. The injunction will also require the Navy to avoid certain areas of the deep ocean during seasons when data on marine mammals and other endangered species such as sea turtles shows that they are migrating, breeding, feeding or otherwise clustering there. The evidence in this case shows that this kind of data is available to enable the Navy to refine its operations in order to afford reasonable protections to marine life, while still meeting its testing and training needs. Indeed, the Court appreciates that, in response to the preliminary injunction issued earlier, NMFS and the Navy have decided to engage in further analysis of this kind of data for potential use in planning routes that minimize sea creatures’ exposure to the sonar. Further, where the Navy needs to operate close to shore in areas where sea life tends to be abundant and where conditions may make strandings of whales more likely, whenever feasible the Navy shall use additional measures to check for the presence of marine mammals before activating the sonar. In sum, the Navy and NMFS can fully comply with environmental laws and also meet the need to test and train with this new type of sonar. [NRDC v. Evans, 2003]

Clearly this injunction pertains to areas of biological richness and significance such as CINMS (and other national marine sanctuaries), and thus implies a level of protection for the Sanctuary.

Subsequent to the Court’s decision, the US Navy and NRDC reached agreement to restrict SURTASS-LFAS operation to certain areas of the Western Pacific (across the Pacific Ocean basin from CINMS), until the Navy corrects the legal deficiencies in the program identified by the court (Horowitz 2004).

While this litigation will likely lead to more ecologically-sensitive LFAS-SURTASS deployment by the US Navy in the future, proliferation of LFAS systems among other national and coalition navies not subject to environmental protection requirements is predicted (NRDC 2003), based on historical patterns of military technology dispersion (the globally imperiling one-upsmanship of an arms race). In support of this prediction, the *Taipei Press* reported on February 15, 2004 that the US has agreed to sell two land-mounted LFAS arrays to the Taiwanese navy, for deployment by 2006; subsequent

deployment by the Chinese navy of a countervailing LFAS system seems like a probable result. Meanwhile, the British Royal Navy continues to test their LFAS system, towards imminent deployment under NATO (NRDC 1999).

While LFAS currently remains a nascent technology of limited distribution, Sanctuary ecology may yet be impacted by its deployment. The acoustic background of CINMS would likely undergo discernable increase from sonar use hundreds of kilometers away, while arguably inevitable proliferation of LFAS could increase the chance of both direct impacts on the Sanctuary, or impacts on transient or migratory species that temporarily inhabit CINMS but suffer exposure to LFAS sound elsewhere.

HIGH ENERGY SEISMIC SURVEYING

Seismic-surveying involves synchronized firing of a towed airgun array. Airguns fire quantities of high-pressure (approximately 2000psi) air vertically into the water, directing 10Hz-300Hz (low-frequency) impulsive sounds toward the sea floor so that sound waves penetrate the geology and reflect back to sensors (Lissner and Greene 1998). Analysis of received echoes provides sub-sea geologic imagery, and thus yields information such as the presence of extractable hydrocarbons (oil and natural gas) and tectonic characteristics (WDCS 2003, NRC 2003). Peak source levels for seismic surveying typically exceed 200 dB, and exceed 250 dB in some surveys with a high total array volume (combined volume of all guns in the array, a number that captures both the size of the guns and number of guns involved) (Engås et al. 1996).



Seismic surveying. Note towed airgun array. (Photo: IEA Greenhouse Gas R&D Programme, UK)

The sub-sea geology of the Santa Barbara Channel area has been subject to seismic surveying in the past for both scientific and commercial purposes (Lissner and Greene 1998; Calambokidis et al. 2002; Pierson 2004). Future surveying for both purposes is possible: the imperative for greater understanding of the tectonically dynamic South Coast area may motivate researchers to conduct further surveying, while a significant increase in global oil and gas prices could stimulate future offshore prospecting for oil or gas in deep water areas currently considered uneconomical.

Acoustically, seismic-surveying sound is significantly directional; sound of 230-255 dB between 10Hz and 100Hz is typical in the downward direction (Richardson et al. 1995). This is of particular concern for deep diving marine mammals such as elephant

seals, sperm whales, beaked whales, and any fishes, reptiles or invertebrates that may be present in the water column between the targeted seafloor and the operating airgun array. Documentation of physiological impacts to wildlife from close range exposure to seismic surveying sound is limited, however the existing reported outcomes associated with such exposure, described below, suggest the potential for significant injury in at least cetaceans and fishes (no studies or documentation of impacts on marine invertebrates, reptiles or birds are known to exist).

McCauley et al. (2003), in perhaps the most comprehensive study to date on direct physiological impacts to wildlife from airgun noise, report on damage to hearing structures and tissue in several fish species subject (through cage confinement) to airgun blasts at a variety of distances. Necropsies of the subsequently sacrificed pink snapper revealed the following:

Fish exposed to an operating air-gun sustained extensive damage to their sensory epithelia that was apparent as ablated [destroyed or missing] hair cells. The damage was regionally severe with no evidence of repair or replacement of damaged sensory cells up to 58 days after air-gun exposure. [McCauley et al. 2003]

As discussed in “Large Vessel Traffic”, many fish species depend on hearing function for an array of behavior essential for survival. Hearing loss from excessive exposure to airgun sound could thus impinge on the survival of individual fish or fish populations.

No studies have yet been conducted to determine direct (physiological) impacts of airgun noise on marine mammals; research has been limited to recording of visually observed behavioral responses within a small radius of operating seismic surveying projects (WDCS 2003) (see Calambokidis et al. 2002, for example).

However, the body of incidental evidence continues to grow. In 2002, episodes of increased humpback whale strandings in coastal Brazil coincided with commercial seismic surveying in the area (IWC 2004(b)). Also in 2002, two Cuvier’s beaked whales (*Ziphius cavirostris*) that appeared to be in good physical condition and disease-free, stranded and died on Isla San Jose in the Gulf of California, in proximity to geology research involving seismic surveying. The project, conducted by the National Science Foundation’s (NSF) R/V *Maurice Ewing*, involved operation of a 2000 psi, 20 unit, 8300 cubic-inch, tuned airgun array with source levels of at least 263 dB at low frequencies (LDEO 2004). NOAA Fisheries scientists coincidentally in the area contemporaneous with the surveying testified that they believed the airgun sound caused the cetaceans to strand and die (in a manner similar to the stranding deaths of acoustically traumatized beaked whales in the Bahamas). Unfortunately both carcasses were too decomposed to investigate for the implicated acoustic trauma (WDCS 2003). Nonetheless, a temporary restraining order was subsequently issued in US District Court halting the experiment after Judge J. Larson found that operation of the airgun array was likely in violation of the National Environmental Policy Act and the Marine Mammal Protection Act, and

likely to cause irreparable harm to beaked whales in the Gulf of California where surveying was occurring (Teel 2004, *Center for Biological Diversity (CBD) v. NSF*, 2002). Judge Larson also pointed out that, as “easily-spooked” (resulting in diving response), and deep-diving foragers, beaked whales are both highly susceptible to injury from seismic surveying, and not likely to be spotted to trigger mitigation or shut-down protocols (*CBD v. NSF*, 2002).

A later settlement between CBD and the NSF formalized a more precautionary protocol for the *Maurice Ewing* to better prevent marine mammal harassment and injury while operating the airgun array (Teel 2004).

Strandings in Brazil and in the Gulf of California, and the US District Court decision indicate that, while comprehensive research has yet to be completed on the physiological impacts on marine mammals from seismic surveying sound, such exposure can likely have significant, even lethal consequences. Furthermore, until more comprehensive data on the impacts of airgun noise on marine mammals becomes available for permitting, any future seismic surveying in the CINMS area should be managed with precaution to preclude such impacts on Sanctuary species.

Significant sound propagation perpendicular to the aimed direction of firing airguns also occurs, implicating seismic surveying in substantial contribution to ambient sound levels in large areas around the shooting. WDCS (2003) reports that sound from seismic surveys conducted off Nova Scotia were “prominent in the acoustic background off the Bahamas and along the Mid-Atlantic Ridge, several thousands of kilometers away.” A study conducted in 1998 involving shooting with a small (8 unit) airgun array near Platform Harmony off Gaviota (northwest of Santa Barbara) determined that, with a measured peak source level of 232 dB, the airgun sound superseded ambient noise levels in the frequency range 20 Hz to 2000 Hz by up to 20 dB, more than 6 km away. The researchers also reported that between 130 and 180 meters from the airguns, received sound levels were still at 180 dB, the sound level threshold identified by NOAA Fisheries and the US Navy as detrimental to marine mammals (Lissner and Greene 1998). Seismic surveys designed to generate three-dimensional images of a geological region can involve thousands of low-frequency airgun shots of 220 dB or greater. The last full-scale survey in the Santa Barbara Channel, conducted in 1995, lasted over a month, and covered an area of approximately 300 square kilometers (Pierson 2004).

Studies of behavioral impacts on marine wildlife from airgun noise reveal that entire populations of a variety of species respond to surveying (or surveying sound). Dahlheim (1993) tracked route deviation in migrating gray whales exposed to a stationary sound source playing recorded airgun sound, and reported that avoidance of the noise resulted in course deviation from the noise roughly proportional to the sound level of playback. Corresponding data in the Western Pacific exist as well: displacement from a primary feeding area off Sakhalin Island by the endangered western North Pacific gray whale population because of seismic activity is reported (IWC 2004(b)).

Engås et al. (1996) studied the effect of seismic surveying (with an airgun array with peak levels at approximately 255 dB in the 20-150Hz range) on fisheries off the coast of Norway. Their abstract summarizes the information pertinent to this discussion:

Seismic shooting severely affected fish distribution, local abundance, and catch rates in the entire investigation area of 40x40 nautical miles. Trawl catches of cod and haddock and longline catches of haddock declined on average by about 50% (by mass) after shooting started, which agreed with the acoustic abundance estimates; longline catches of cod were reduced by 21%. Reductions in catch rates were observed 18 nautical miles from the seismic shooting area (3x10 nautical miles), but the most pronounced reduction occurred within the shooting area, where trawl catches of both species and longline catches of haddock were reduced by about 70% and the longline catches of cod by 45%; a relatively greater reduction was found (in catches and acoustic estimates) for large (>60 cm) than for small fish. Abundance and catch rates did not return to preshooting levels during the 5-day period after seismic shooting ended. [Engås et al. 1996]

Løkkeborg and Soldal (1993) also investigated seismic surveying impacts on fisheries through analysis of catch data obtained from commercial vessels operating on fishing grounds where seismic surveys were being conducted. They found a 56% reduction in longline catches of cod and a reduction of 81% in the by-catch of cod in shrimp trawling.

Engås et al. (1996) also report that seismic surveying at the levels they observed is sensed and reacted to by fish as far as 30-100km from the sound source, reinforcing the immensity of the range of impact of past and future surveying in the Santa Barbara Channel.

Collectively, this information suggests that any future surveying in the Santa Barbara Channel will contribute significantly to the Sanctuary's acoustic environment, and may impact cetacean individuals and communities, fish and fisheries, and other interdependent members of Channel marine ecology. Reinforcing this conclusion, the Scientific Committee of the International Whaling Commission recently stated that it "views with great concern the impacts on large whales in critical habitats from exposure to seismic sound impulses," and thus recommends that "all seismic surveys in areas that could have significant adverse demographic consequences for large whales should be planned so as to be out of phase with the presence of whales" (IWC 2004(a)). The importance of CINMS to large whales and other wildlife is well known-- the importance of implementing the IWC recommendation locally should be equally clear. Sanctuary resource managers must be aware of any future proposed seismic surveying that may impact CINMS wildlife and ecology, while mineral and biological resource managers must coordinate as recommended to minimize cetacean harassment and harm from survey noise.

SMALL SHIPS, BOATS AND PERSONAL WATERCRAFT

Small ships are characterized as typically diesel-powered, twin propeller craft roughly 55-85m in length, producing broadband (20-1000Hz) noise between 130-141 dB while operating. Nozzles are often fitted around the propellers to direct thrust and improve maneuverability, which also can significantly reduce sound emissions in some directions. Scientific research vessels such as the 70m *Maurice Ewing*¹⁶ (discussed in the Seismic Surveying section above), commercial, and military support or supply vessels exemplify this category (Richardson et al. 1995). Boats 55m or less, which include most ferries and whale watching vessels in South Coast Harbors (such as the dive boat *Vision* and the charter/whale watcher *Condor Express*, both at approximately 26m in length¹⁷), and personal water craft such as jet skies, are typically powered by outboard motors or jet-thrusters (Richardson et al. 1995). While these vessels all produce constant, tonal underwater sound through mechanical operation, hydrodynamic flow and cavitation as described for large vessels, peak amplitudes for vessel emissions tend to occur at increasingly higher frequencies inversely proportional to the length of the given vessel (i.e. the smaller the vessel, the higher the peak frequency) (NRC 2003, Richardson et al. 1995). Sound of higher frequency attenuates, or is absorbed much faster in seawater compared to low-frequency sound (Roussel 2002), implying a less general, more localized acoustic effect from small vessels operating in and around the Sanctuary. Noise from small vessel traffic also tends to be concentrated in shallower coastal areas (NRC 2003), and is not concentrated in lanes, implying much more scattered and isolated underwater ensonification compared to large vessel traffic.

Channel Islands, Santa Barbara, and Ventura harbors provide slips and moorings for over 5000 recreational, commercial, and research vessels, while “numerous recreational, commercial, research and military vessels traverse the region while in transit between other ports” (CINMS 2003(a)). In Santa Barbara Harbor, 58% of vessels harbored in its slips and moorings are sail-powered¹⁸; assuming a roughly similar proportion for Ventura and Oxnard Harbors suggests that between 2,000 and 3,000 engine-powered small vessels operate off the South Coast. Unfortunately, it is unknown how many of these vessels enter the Sanctuary, or at what rate.

In sum, these characteristics establish small vessel traffic noise as a potential issue to smaller odontocetes and pinnipeds primarily, species that generally tend to be aurally attuned to higher frequencies¹⁹ than the great whales, and tend to inhabit the shallower coastal regions where small vessels are prevalent (WDCS 2003, NRC 2003). However, unlike other baleen whales in the CINMS area, gray whales also tend to inhabit

16/ See specifications at www.ldeo.columbia.edu/res/fac/oma/ewing/index.html

17/ Vessel specifications found at www.truthaquatics.com and www.condorcruises.com, respectively.

18/ Personal communication, Santa Barbara Harbor Master’s office, April 29, 2004.

19/ Odontocetes commonly have good functional hearing between 200 and 100,000 Hz, although some species may have functional ultrasonic hearing to nearly 200 kHz. The majority of odontocetes have best hearing in the ultrasonic ranges, and moderate sensitivity to sounds from 1 to 20 kHz (NRC 2003).

shallower, coastal waters frequented by small vessels, and are thus also highly subject to potential impacts from small vessels noise.

NRC (2003) effectively captures the range of observed cetacean response to small vessel traffic noise in their discussion of beluga whales (*Delphinapterus leucas*):

At distances of up to 50 km from... ships operating in deep channels, beluga whales respond with a suite of behavioral reactions. The reactions include rapid swimming away from the ship for distances up to 80 km; changes in surfacing, breathing, and diving patterns; changes in group-composition; and changes in vocalizations. The initial response occurs when the higher frequency components of the ship sounds, those to which the beluga whale are most sensitive, are just audible to the whales.

Beluga whales in the St. Lawrence River appear more tolerant of larger vessels moving in consistent directions than they are of small boats, fast moving boats, or two boats approaching from different directions. Older animals were more likely to react than younger ones, and beluga whales feeding or traveling were less likely to react than animals engaged in other activities, but when the feeding or traveling whales did react, they reacted more strongly. In contrast to the lower rate of observed reactions of these beluga whales to larger vessels, a study of the response of beluga whale vocalizations to ferries and small boats in the St. Lawrence River showed more persistent reactions to the ferries. The whales reduced calling rate from 3.4 to 10.5 calls per whale per minute to 0.0 or under 1.0 calls per whale per minute while vessels were approaching. Repetition of specific calls increased when vessels were within 1 km, and the mean frequency of vocalizations shifted from 3.6 kHz prior to noise exposure to frequencies of 5.2-8.8 kHz when vessels were close to the whales.

In Alaska, beluga whale response to small boats varies depending on the location. Beluga whales feeding on salmon in a river stop feeding and move downstream in response to the noise from outboard motorboats, whereas they are less responsive to the noise from fishing boats to which they may have habituated. On the other hand, in Bristol Bay beluga whales continue to feed when surrounded by fishing vessels and resist dispersal even when purposely harassed by motorboats.

Thus, depending on habitat, demography, prior experience, activity, resource availability, sound transmission characteristics, behavioral state, and ever-present individual variability, the response of beluga whales can range from the most sensitive reported for any species to ignoring of intentional harassment. Beluga whales also show the full range of types of behavioral response, including altered headings; fast swimming; changes in dive, surfacing, and respiration patterns; and changes in vocalizations. [NRC 2003]

This lengthy excerpt reveals the complexity of small vessel traffic noise as an issue to consider in the context of Sanctuary Management. The sporadic exposure of small vessel traffic noise that Sanctuary wildlife are subject to could potentially induce stress in

individuals or groups of individuals of a given odontocete species, while other species or even conspecifics may be behaviorally impervious to the same sound due to habituation.

It's also critical to note that, in contrast to most of the baleen whales in the CINMS area, gray whales also tend to inhabit the shallower, coastal waters frequented by odontocetes, pinnipeds, and small vessel traffic, and thus also may be subject to impacts from small vessel traffic noise.

Useful to consider in this discussion are points raised in a study conducted by Erbe (2002) pertaining to orcas in the waters between British Columbia and the Olympic Peninsula. Resident pods of killer whales there face extreme levels of small vessel noise during the whale watch season, between mid-May and August. During this season in the years 1995-1999, groups of orcas were followed in the daytime by an average mean (the five-year average of each season's mean) of 21 private motorboats and commercial whale watch vessels at any given time; in the five seasons of Erbe's observation, a maximum of 60-70 pod-following motorboats were documented following at the same place at the same time.

Reviewing published literature on the behavioral impacts of whale watching on killer whales, Erbe shows that *orca* demonstrate a complex suite of effects similar to that of beluga whales, including avoidance of boats, attraction, shortened surfacing, longer dives, and interruption and termination of feeding and traveling behavior (2002). In general, however she states that "whales swam away from boats at speeds greater than those of undisturbed whales, and swimming speed increased with the number of boats present²⁰" (Erbe 2002). Unpublished reports from other orca researchers in the Pacific Northwest indicate physiological effects typical of stress inducement from pursuit by even one whale watching boat, including increased respiration and heart rates (Anderson 2001).

The biological significance of observed behavioral responses to small vessel traffic is still unknown; questions remain as to whether whales disturbed from feeding by small vessels move to forage elsewhere, or sustain a reduced energy intake, and whether there are impacts to mating or rearing behavior (Erbe 2002). Nevertheless NRC (2003) reports on chronic stress as causal of fundamental impacts to cetacean survival, through the modulation of immune response. Roussel (2002) similarly states that such stress from chronic noise exposure can reduce immune function and increase marine mammal susceptibility to environmental toxins.

Erbe (2002) suggests that exposure to the extreme level of motorboat presence and noise (as well as inhabiting waters near a "busy, noisy commercial shipping lane") may be responsible for the lack of recovery from historical human killing and capture by the studied orca community, as well as the population's decline by almost 20% between 1995

20/ Erbe (2002) also notes importantly that research (Schevill 1968) has shown boat noise, not the mere presence of the boat, evokes marine mammal response.

and 1999. In what may be further illumination of the connection between vessel traffic noise and the resident orca population decline, Foote et al. (2004) report a general increase in the duration of orca vocalizations in tandem with the increase in attendant small vessels. They conclude that, in the approximately five-fold increase in vessels attending the southern resident orca population between 1990-2000, a threshold level of disturbance may have been crossed, initiating “a response... to counteract anthropogenic noise” (Foote et al. 2004). This data may provide an empirical basis for hypothetical connections between reductions in critical sensory and communications capabilities, and increased stress and reduced survival in the orcas.

To assist in development of an appropriate conservation-oriented management approach to this situation, Erbe applied a software-based “sound propagation and impact assessment model” to generate quantitative estimates. Her modeling results showed that,

When boat source levels ranged from 145 to 169 dB (increasing with speed)... the noise of the fast boats was modeled to be audible to killer whales over 16km, to mask killer whale calls over 14km, to elicit behavioral response over 200m, and to cause a temporary threshold shift in hearing of 5 dB after 30-50 minutes within 450 meters. Superposed noise levels of a number of [multiple] boats circulating around or following the whales were close to the critical level assumed to cause a permanent hearing loss over prolonged exposure. [Erbe 2002].

CINMS wildlife do not currently face a concentrated acoustic threat from small vessel traffic like that facing the killer whales in Erbe’s study. Nonetheless, there are potentially important conclusions related to, and drawn directly from their straits to consider for future Sanctuary management. First, CINMS is likely to sustain an increase in whale watching and small vessel traffic proportional to Southern California population growth and tourism, which could bring us closer to the situation facing the orca north of the Olympic Peninsula. Research, consideration and planning initiated now could preempt similar negative impacts on CINMS whales and dolphins resultant from poorly managed growth in “eco-tourism.” Second, while no definitive connection has yet been drawn between excessive whale watching and the decline of the resident orca population (as Erbe (2002) herself points out), the circumstantial evidence indicating such a linkage is strong; preservation of the remaining resident orcas appears to necessitate a precautionary approach to conservation management, rather than an approach that waits on absolutely definitive science.

Finally, Erbe (2002) notes: “a major problem is posed by private whale-watchers, who can vastly outnumber commercial operators. Private people are unaware of the whale-watching code of ethics and often do not know how to watch whales properly.” Off Santa Barbara and in the Sanctuary, motorboaters do often illegally pursue migrating gray whales and other marine mammals to close range, and also unintentionally harass the same animals by navigating quickly through important migration paths. As discussed above, such contact is known to cause significant stress-inducing avoidance response in

marine mammals, and thus represents a distinct noise related impact on Sanctuary resources (Howorth 2004).

While the relatively dispersed character of motorized small vessel traffic in CINMS suggests that cumulative small vessel traffic is not currently a significant threat to the area, private power boaters that fail to adhere to the Marine Mammal Protection Act may negatively impact CINMS cetaceans due to both acoustic output and harassment associated with close following. Small vessel traffic will likely become more ecologically problematic for CINMS should total vessel numbers increase. The greater cumulative contribution to the Sanctuary's ambient noise level and the higher rates of motorboat noise/wildlife interaction would further heighten the need to address this acoustic threat to CINMS resource conservation. In the meantime, more Sanctuary-specific research is needed in this area, both to better determine small vessel traffic rates in the Sanctuary, and to gather quantitative data on the concomitant impacts to CINMS marine mammals. This could be particularly important in order to identify whether any CINMS animal communities suffer, or are near experiencing chronic exposure to small vessel traffic noise, which existing science suggests as potentially much more deleterious.

OIL AND GAS DEVELOPMENT

Offshore drilling and oil production in the Santa Barbara Channel may contribute to the acoustic environment of CINMS, however, current research suggests that direct acoustic contributions and impacts are low.²¹ The limited completed research on noise from one drilling platform and three combination drilling/production platforms in the Santa Barbara Channel found that noise was “nearly undetectable even alongside the platform[s] during sea states [equal to or greater than] 3 [small waves, moderate breeze of 12-16 knots, wave heights 1.4 – 3ft],” with the strongest sound from all four platforms at an extremely low 5 Hz (Gales (1982), in Richardson et al. (1995)).

While noise output from platforms may be moderate overall, having peak amplitude at such low frequencies implies minimal attenuation of the emissions: Richardson et al. (1995) predict that noise from a production platform is audible to mysticetes to about 2.5 kilometers. Platform noise has also been shown to have a discernable if modest behavioral impact: migrating gray whales were observed to swim away from playbacks of drilling noise at levels corresponding to distances of less than 100 meters from an operating platform (Malme et al. 1984).

The fixed position of the noise source (the operating drill, gearing, generators and pumps) implies the possibility of avoidance as well as habituation for marine species; within some ranges masking of acoustic environmental information or communication from predators, prey or conspecifics may occur. In the Santa Barbara Channel however, rig noise has minimal impact on an array of marine mammal species based on anecdotal

21 / For a discussion regarding seismic exploratory activities, see pp. 26-29 above.

evidence. According to MMS biologist Mark Pierson, “migrating gray whales, humpback whales, and dolphins are all frequently seen near platforms, and... California sea lions use the lower decks and mooring buoys at all the OCS platforms as haul-out areas” (Pierson 2004).

Drilling and oil production also add noise to the surrounding marine environment from the helicopters and vessel traffic required to support platform operations. Acoustic implications from aircraft and small craft are addressed elsewhere in this document.

ACOUSTIC THERMOMETRY

Acoustic thermometry exploits how the velocity of sound varies in seawater of different temperatures and pressures in order to measure average temperature of an entire ocean. The “Acoustic Thermometry of the Ocean Climate” (ATOC) experiment was the first such project, which in December of 1995 began five years of intermittently broadcasting high-intensity, low-frequency sound from two sources, one off Kauai, and the second on the Pioneer Seamount approximately 80 kilometers offshore Half Moon Bay. ATOC receivers were positioned off Hawaii, New Zealand, the Aleutian Islands, and other locations about the Pacific, up to more than 6000 kilometers away from the sound source (ATOC 2003). In order to maintain a coherent signal over such ranges, the ATOC sound source transmitted at source levels of 195 dB centered at 75 Hz with a 37.5-Hz bandwidth (Costa et al. 2003) (a signal very similar to the Navy’s low-frequency active sonar signal, due to being similarly optimized for transoceanic coherence and detectability).

During ATOC, biologists conducted monitoring and research to assess the impact of ATOC sound on whales and elephant seals, and reported minimal impacts:

In summary, all preliminary... results for the species so far selected for study reveal that a) animals do not vacate the Pioneer Seamount area during periods when the ATOC source is operating, b) northern elephant seals do not show any acute responses when exposed to the ATOC source, c) two species of odontocetes have poor hearing abilities in the 75 Hz range (a finding that is not unexpected and is in agreement with previous behavioral and anatomical evidence), d) humpback whales on the winter calving/breeding area off Big Island, Hawaii show no response when exposed to ATOC-like sounds at levels as high as 130 dB, and e) sperm whales on the summer feeding area off the Azores show no response when exposed to ATOC-like sounds at levels as high as 130 dB. Both these experimental playback received levels are as high or higher than the levels

*expected for animals directly above the operational ATOC source. [ATOC 2003]*²²

However, ATOC's marine mammal researchers also reported that both humpback and sperm whales were more likely to be observed further from broadcasting sound sources than when the speakers weren't operating (WDCS 2003, citing Calambokidis 1998). Logically, the relative biological importance of the avoided ATOC ensounded habitat dictates the magnitude of impact to each species, but the documentation of impact implies that the addition of thermometry noise to a given ecology could be detrimental to it. Furthermore, specific research has yet to be conducted on impacts from acoustic thermometry on marine fishes, invertebrates or reptiles.

Continued Pacific acoustic thermometry is currently conducted as the "Northern Pacific Acoustic Laboratory experiment" (NPAL), however only the Kauai sound source, 80 miles north of the island, at a depth of 807 meters, is now operated. NPAL is permitted from 2002 until 2007 (WDCS 2003).

Acoustic thermometry is a capital-intensive endeavor that, almost ten years after the first application of the technology, remains isolated in application. The high-intensity sound levels involved in ATOC focused significant popular and scientific attention on anthropogenic underwater noise pollution; however acoustic thermometry does not appear to present a threat to CINMS in the foreseeable future. Hypothetical future projects proposing to broadcast sound in proximity to the Sanctuary may raise a similar suite of potential impacts as the Navy's application of LFAS due to the similarity in sound characteristics. However, while the towed arrays of LFAS tend to signal from the top of the ocean water column, acoustic thermometry sound sources broadcast from depths of hundreds of meters, suggesting that different biological communities (surface versus benthic) may be more or less intensely impacted.

22/ Excerpt from ATOC Marine Mammal Research Program "Quick Look," a summary of independent findings published as monthly reports from researchers including W. Au, J. Calambokidis, C. Croll, D. Costa and others. Available directly at: <http://atoc.ucsd.edu/quicklookpg.html>

RECOMMENDATIONS AND IDEAS FOR RESEARCH

In summer of 2004, the Scientific Committee of the International Whaling Commission, comprised of approximately 200 of the world's leading whale biologists, met in Sorrento, Italy, and released its annual yearly review of "the major issues affecting cetacean conservation." The July 19, 2004 report, summarizing most recent scientific findings on the impacts of human noise on cetaceans, cites anthropogenic noise as among the major issues affecting whale and dolphin conservation worldwide.

The committee determined, "There is now compelling evidence implicating anthropogenic sound as a potential threat to marine mammals. This threat is manifested at both regional and ocean-scale levels that could impact populations of animals" (IWC 2004(b)). The Committee went on to note the potential for negative "cumulative or synergistic effects of sounds" with non-acoustic environmental threats such as pollution and loss of habitat (IWC 2004(a)). The Committee concluded:

*Whilst noting that there is considerably more scientific work needed, the Committee emphasises that measures to protect species and habitats cannot always wait for scientific certainty, as encoded in the precautionary principle. This is especially true for cases involving the exclusion of an endangered population from its habitat. ...As a result, the Committee **agrees** that noise should remain a standing priority item on its agenda. [IWC 2004(a), emphasis added.]*

Along with this recommendation for a precautionary approach to anthropogenic noise, the Committee identified the importance for resource managers to consider noise within marine protected areas (MPAs) such as CINMS. Specifically, it called for "Inclusion of anthropogenic noise assessments and noise exposure standards within the framework of national and international ocean conservation plans (e.g., consideration during designation of critical habitats, MPAs and ocean zoning)" (IWC 2004(a)), and for the investigation of "novel applications of conservation tools such as designation of... marine protected areas and ocean zoning... as a means to protect cetacean populations from chronic and intense-episodic anthropogenic noise" (IWC 2004(b)).

Within the discussion of anthropogenic noise and the natural resources of CINMS, the IWC call for action could not be more timely or more pertinent. What's more, it should be clear from the data reviewed in the pages of this report that the threats and recommended responses identified by the IWC are applicable to an array of non-cetacean marine wildlife including pinnipeds and fishes. Put simply, anthropogenic noise pollution represents a growing ecological problem that must be addressed globally and locally.

Today CINMS and the National Sanctuary Program have many opportunities for useful research, monitoring and management of noise pollution and its known and potential impacts on marine resources. By moving to address anthropogenic noise and realize these opportunities, Sanctuary management will make a significant step forward

in its mission to conserve CINMS and the natural resources harbored within it. Addressing and engaging the issue of noise pollution could benefit CINMS resource management and stakeholders, as well as contribute needed leadership and momentum in establishing the regional, national and intra-governmental partnerships that will be crucial in addressing marine noise pollution effectively.

Toward that end, two sets of specific recommendations for initiatives and research areas are outlined below.

The first set of recommendations, “Sources and Impacts,” targets the lack of quantitative physical and ecological data on noise and its impacts on CINMS resources. Fulfillment of these recommendations would provide fundamental data to illuminate patterns of noise emissions and related biological impacts, and thus inform future management of Sanctuary resources.

Sources and Impacts

1. *Initiate Sanctuary-wide noise monitoring.* An ongoing hydrophonic monitoring program should be initiated as soon as possible to gauge ambient sound levels within CINMS, identify what sound sources are significant and at what levels they occur in the Sanctuary, and track changes in these values over time. Such monitoring would provide insight into the human activities in and around the Sanctuary, while long term data on ambient sound levels and temporally discrete acoustic events would assist in investigations of the behavior, abundance and survival of various biological communities.
2. *Study hearing capabilities of Sanctuary wildlife.* Further study of received sound-level impact thresholds (e.g. frequency, amplitude and exposure durations that induce behavioral response, physical trauma, cumulative impact, etc.) for individual species resident in the Sanctuary would assist Sanctuary management, at least for conservation of endangered or acoustically sensitive species. More data on the sensitivity of marine reptiles and invertebrates to anthropogenic noise would help fill significant gaps in bioacoustics literature, as well as round out understanding and management of noise pollution impacts on CINMS resources.
3. *Study anthropogenic noise impacts on Sanctuary ecology.* Investigators should examine effects from particular noise sources on specific biological communities. As the primary noise producing activity with the highest potential for impact to Sanctuary ecology, scientific investigation of large vessel traffic sound should be aggressively undertaken. Direct research on shipping noise impacts on Sanctuary fish species, including impacts to reproduction, recruitment and foraging, would both enlighten Sanctuary and fisheries management, and shed light on a little studied area in fisheries ecology. Similarly, any research on shipping noise and marine invertebrates would be extremely useful in estimating whether such species are

subject to significant impacts from ensonification of their habitat from large vessel traffic noise.

4. *Research indirect anthropogenic noise impacts to Sanctuary ecology.* Establishment of an appropriate stringency of regulation for noise emissions (commensurate with the noise “budget” of the Sanctuary ecosystem) requires a more detailed understanding of the secondary ecological impacts of noise pollution. For example, what are the ecological consequences within the Sanctuary of hypothetical cetacean avoidance of heavily ensonified waters near the shipping lanes? Does an elevated ambient noise level reduce recruitment of any Sanctuary fish species, and if so, what are the impacts on predators of those fishes? Answers to such questions could eventually provide Sanctuary managers with data to craft more holistic, effective regulation.

The second set of recommendations, “Policy and Partnerships,” aims to identify and build potential for specific initiatives to reduce the impact of noise in the Sanctuary. In order to enact the precautionary management of noise pollution in CINMS advocated in this report, further data on the major noise-producing activities must be compiled, and research on the existing policy frameworks that regulate those activities must also be initiated. Gathered information will inform and empower Sanctuary resource managers to appropriately address Sanctuary noise pollution.

Policy and Partnerships

1. *Establishment of a vessel traffic-monitoring program to log and quantify vessel traffic through the Sanctuary.* The non-governmental Southern California Marine Exchange is the only organization known to systematically maintain large vessel traffic data related to Southern California, and its database captures Santa Barbara Channel traffic inefficiently and indirectly. This information should be gathered in CINMS directly. Such data would be highly useful for understanding other impacts to the Sanctuary from large vessel traffic as well as noise, such as airborne diesel exhaust emissions and chemical water pollution.
2. *Develop partnerships.* Establishing CINMS as a partner in regional and national noise pollution monitoring, research and management partnerships will be critical. Obvious examples of collaborative partners include west coast National Marine Sanctuaries, the University of California, and state and federal agencies, such as NOAA Fisheries, the Marine Mammal Commission, US Fish and Wildlife Service, and the US Coast Guard. The CINMS should explore opportunities for collaboration with the US Navy as a means to (a) access historical acoustical data, (b) encourage the distribution of ship quieting and other technologies, and (c) better inform the Sanctuary of future naval activities. Another example would be for NOAA’s National Ocean Service to coordinate with University of California researchers to locate and monitor hydrophones for acoustics research in CINMS and California’s other three National Marine Sanctuaries.

3. *Engage the shipping industry.* Fostering collaboration between CINMS and the shipping companies and consortiums whose fleets or member companies regularly pass through the Sanctuary will benefit all. Initiating dialog with shippers and shipping organizations could result in noise reduction in the Santa Barbara Channel as well as provide valuable information for shippers interested in reducing noise emissions for vessel efficiency or conservation of particularly sensitive marine areas.
4. *Research international policy and regulation.* Addressing noise pollution in CINMS may require securing international cooperation, and thus working through international policy frameworks such as MARPOL (International Convention for the Prevention of Pollution from Ships 1973/1978), and the International Maritime Organization. CINMS resource managers would greatly benefit from an assessment of the costs, benefits and feasibility of regulatory options available within these international frameworks, such as modification of the Southern California Vessel Traffic Separation Scheme (VTSS) to reroute some or all large merchant vessels currently passing through the Sanctuary, and establishment of CINMS as an internationally recognized marine protected area.
5. *Create a role for the Research Activities Panel (RAP).* The RAP for the Sanctuary Advisory Council (SAC) should review and report to the SAC on any scientific, commercial or non-classified military activities with significant acoustic emissions proposed to be conducted within range of influencing CINMS ecology. As discussed above, activities well outside the boundaries of the Sanctuary may produce noise that could impact CINMS resources. Sanctuary managers and stakeholders should be made aware of such activities, and avail themselves of the RAP's professional assessment of potential impacts.

Obviously such policy and partnership research will be most fruitful if conducted in conjunction with scientific research, so that quantitative data on noise impacts in the Sanctuary become available for the establishment of meaningful goals for future collaborative or regulatory initiatives.

Policy research could also be useful in enhancing the Sanctuary's role in the permitting process for the more temporally discrete noise production from peace-time military low and mid-frequency active sonar exercises, as well as commercial and scientific seismic surveying conducted in an influential proximity to the Sanctuary. For example, in 1999, the collaborative, stakeholder initiative resulting in the "High Energy Seismic Survey Review Process and Interim Operation Guidelines for Marine Surveys Offshore Southern California" delineated the review process and impact mitigation protocol for oil and gas seismic surveys (HESS 1999). However, the guidelines were intended to be interim pending additional research on the potential impacts of such activities. The HESS guidelines should be reviewed and updated with increased CINMS

involvement, and include investigation of how such guidelines should be applied to other major noise-producing activities such as military and scientific projects.

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APPENDIX A

BASICS OF ACOUSTICS SCIENCE [adapted from Roussel (2002) and WDCS (2003)]

For sound in a given medium (such as air or water), the *amplitude* of the soundwave is attributed to the amount of energy of the wave, or its wave height, and is associated with perceived loudness. Amplitude is called *intensity* when related to the density of the media through which the sound is traveling. Frequency is the distance between sound wave peaks, or the "rapidity" of the given wave, and is measured in cycles per second or Hertz (Hz). In other words, the intensity and the frequency of the soundwave make the molecules of the media move more or less far away from their original location and vibrate more or less fast respectively, and therefore are the two principal components used as descriptors of the nature of sound. For reference, the approximate range of human hearing stretches between 20-20,000 Hz (or 20 kHz). Sounds with frequencies below 20 Hz are called **infrasonic** and those above 20,000 are called **ultrasonic**. Ultrasonic waves are often used in human and animal sonars, and in medicine, to measure sizes and distances to obstacles. Dogs in general can hear as high as 45 khz, while cats and bats can hears frequencies as high as 75 -100 khz.

Ideally, acousticians would be able to measure intensity (what humans perceive as loudness) directly, but practically it is easier to measure and detect changes in pressure and then convert these to intensities. However, the use of pressure as a measurement unit presents the acoustician with two problems. The first is related to the range of pressure differences that the human auditory system can detect (10 – 100,000,000 *micro-pascals*, or μPa) and the second is related to the way in which the human auditory system processes differences in pressure, i.e. how it judges relative loudness. The former is a practical problem where the magnitude of pressure differences detectable by the human ear can make calculations clumsy, and the latter is a subjective problem whereby the human auditory system processes pressure differences logarithmically, and judges these relatively. For these reasons the **Decibel Scale** and the dimensionless unit the **Decibel** were introduced: sound intensity is measured in decibels (dB), which is a *logarithmic* scale comparing the intensity of the sound measured to that of a reference sound.

Logarithmic measurement is based on change in orders of magnitude (like the Richter Scale) rather than in individual units, which helps in the case of measuring and calculating sound intensity because of the enormous range of pressure variation (which our ears interpret as sound) that the human ear can detect. Thus, an increase of 3 dB is approximately a doubling of intensity, while an increase of 10 dB is equivalent to an order of magnitude increase in sound intensity (for example from 1,000 to 10,000 μPa in pressure).

Importantly, this reference value is different for sounds measured in the air and underwater due to the significant difference in media; roughly, an intensity of (x) dB in the water will be equivalent to an intensity of (x – 26) dB in the air. Given sound intensities stated formally include their standard reference pressures (which also take into account the differences in media), specifically,

pressure reference in water = 1 μ Pa
pressure reference in air = 20 μ Pa.

All noise levels given in this document are for underwater sound, and thus are in reference to 1 μ Pa. The pressure reference is omitted throughout for conciseness.

To help understand the meaning of intensity measurements, sound of Σ 90 dB re 20 μ Pa in air, or Σ 116 dB re 1 μ Pa in seawater, causes permanent damage to hearing in the human ear. Intensities between 120dB and 130dB re 20 μ Pa in air represent the threshold of causing pain in human listeners.

APPENDIX B

MASKING [Excerpted from NRC (2003); works cited below are not included in bibliography]

One of the most pervasive and significant effects of a general increase in background noise on most vertebrates, including marine mammals, may be the reduction in an animal's ability to detect relevant sounds in the presence of other sounds—a phenomenon known as masking. Masking, which might be thought of as acoustic interference, occurs when both the signal and masking noise have similar frequencies and either overlap or occur very close to each other in time. Noise is only effective in masking a signal if it is within a certain “critical band” (CB) around the signal's frequency. Thus, the extent of an animal's CB at a signal's frequency, and the amount of noise energy within this critical frequency band, is fundamentally important for assessing whether or not masking is likely to occur.

Marine mammals evolved in an environment containing a wide variety of naturally occurring sounds, and thus they show a variety of strategies to reduce masking. Vocal signals may be designed to be robust to masking effects. Signals can be more easily detected in noise if they are simple, stereotyped, and occur in a distinctive pattern. Signals may also show a high level of redundancy; they may be repeated many times to increase the probability that at least some will be detected. However, these characteristics all minimize the amount of information that a signal can convey. Animals can adapt their behaviors to minimize masking, and it is reasonable to interpret such behavioral changes as an indication that masking has occurred. For example, the vocal output of a beluga whale changed when it was moved to a location with higher levels of continuous background noise (Au et al. 1985). In the noisier environment, the animal increased both the average level and frequency of its vocalizations, as though it were trying to compensate for and avoid the masking effects of, the increased, predominantly low-frequency, background noise levels. Penner et al. (1986) conducted trials in which a beluga whale was required to echolocate on an object placed in front of a source of noise. The animal reduced masking by reflecting its sonar signals off the water surface to ensonify to the object. The strongest echoes from the object returned along a path that was different from that of the noise. This animal's ready application of such complex behavior suggests the existence of many sophisticated strategies to reduce masking effects.

Beluga whales increased call repetition and shifted to higher peak frequencies in response to boat traffic (Lesage et al. 1999). Gray whales increased the amplitude of their vocalizations, changed the timing of vocalizations, and used more frequency-modulated signals in noisy environments (Dahlheim 1987). Humpback whales exposed to LFA sonar increased the duration of their songs by 29 percent (Miller et al. 2000). The physiological costs of ameliorating masking effects have not been reported. Although these examples all appear to show animals adapting their vocal behavior to reduce the impact of masking, this does not imply that there were no costs resulting from increased levels of noise. Masking may have been reduced but not eliminated. Costs of the changed behavior, such as increased

energetic expenditure on higher-intensity vocalizations and use of vocalizations at suboptimal frequencies cannot be estimated yet.