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REPORT OF THE NOAA WORKSHOP ON ANTHROPOGENIC SOUND AND MARINE MAMMALS, 19-20 FEBRUARY 2004

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U.S. DEPARTMENT OF COMMERCE
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Report of the NOAA Workshop on Anthropogenic Sound and Marine Mammals, 19-20 February 2004

Jay Barlow and Roger Gentry, Conveners

INTRODUCTION

The effect of man-made sounds on marine mammals has become a clear conservation issue. Strong evidence exists that military sonar has caused the strandings of beaked whales in several locations (Frantzis 1998; Anon. 2001). Seismic surveys using airguns may be also implicated in at least one beaked whale stranding (Peterson 2003). Shipping adds another source of noise that has been increasing with the size of ships and global trade. Overall, global ocean noise levels appear to be increasing as a result of human activities, and off central California, sound pressure levels at low frequencies have increased by 10 dB (a 10-fold increase) from the 1960s to the 1990s (Andrew et al. 2002). Within the U.S., the conservation implications of anthropogenic noise are being researched by the Navy, the Minerals Management Service (MMS), and the National Science Foundation (NSF); however, the sources of man-made sound are broader than the concerns of these agencies. The National Oceanographic and Atmospheric Administration (NOAA) has a broader mandate for stewardship of marine mammals and other marine resources than any other federal agency. Therefore, there is a growing need for NOAA to take an active role in research on the effects of anthropogenic sounds on marine mammals and, indeed, on the entire marine ecosystem.

This workshop was organized to provide background information needed by NOAA for developing a research program that will address issues of anthropogenic sound in the world's oceans. Experts from the Navy, academic research institutions, industry, and within NOAA were brought together at the NOAA Fisheries, Southwest Fisheries Science Center, La Jolla, CA on 19-20 February, 2004 to review ongoing and planned acoustic research on anthropogenic sound, both within and outside NOAA (see Appendix 1 for participant list). Nine research topics were identified (see Appendix 2 for agenda), and discussion leaders and a rapporteur were assigned to each topic. Discussion leaders presented information based on their own knowledge and solicited additional information from all members of the workshop. Acoustic population assessment methods for marine mammals were the subject of an earlier workshop (Mellinger and Barlow 2003) and were therefore not included in the topics covered here. Emphasis was on cetaceans during this workshop, but many of the same issues apply to pinnipeds, which should be considered more fully in future planning. Rapporteurs took notes on the discussions, and these became the basis for this report. The workshop identified gaps in current and planned research without considering whether NOAA should play a role in filling any specific gap. A brief meeting of NOAA personnel was convened after the workshop to plan research for NOAA and its partners that would help fill some of the identified gaps and that could become part of the FY-06 NOAA budgeting process. As NOAA develops a program to address the impacts of anthropogenic sounds, there will be a continuing need for NOAA to stay coordinated with researchers outside of NOAA to avoid duplication of efforts.

DISCUSSIONS

Discussion Topic I: Monitoring anthropogenic sound from shipping, military, airguns, and other sources (ambient noise and transients).

Discussion Leaders: Potter, Mellinger, and Hildebrand
Rapporteur: Potter

Acoustic research at the Northeast Fisheries Science Center (NEFSC) has been concentrated on passive acoustic studies for right whales in Cape Cod Bay, the Great South Channel, Georges Bank and the mid-Atlantic bight over the past three years. Most of this work has been with pop-up buoys, and this project has moved from developmental to operational status this past year. Currently there are pop-ups deployed in the mid-Atlantic listening for migrating right whales and on the northern edge of Georges Bank to record any right whales using this habitat in the winter. The next stage of development was funded in FY03 through the Right Whale Competitive Grants Program (RWCGP) to create a moored buoy array with real time uplinks. This is planned to be a three-year program to monitor right whale presence in specific areas, reduce aerial survey effort, and warn mariners/Navy of animal locations.

NEFSC has also funded the work of Peter Tyack (WHOI) and Doug Nowacek (FSU) using the WHOI D-Tag in a series of play-back experiments on right whales in the northern Gulf of Maine (in which potential warning sounds were played through underwater speakers). These continue through funding from the RWCGP. Staff of the NEFSC Protected Species Branch is working with Jonathan Gordon to investigate the utility of using passive acoustics (towed hydrophone arrays) to improve harbor porpoise abundance surveys. The SEFSC and SWFSC have also been using passive acoustics, both towed arrays and sonobouys, in their abundance surveys. In Feb/Mar 2004, the NWFSC used the SWFSC passive hydrophone array in a winter killer whale survey from central California to the Canadian boarder. David Mellinger (OSU) has been funded by the RWCGP in a multi-year study to monitor the presence of right whales in historic, un-surveyed habitats using pop-ups; fieldwork for this project is expected to begin in 2004.

NOAA's Pacific Marine Environmental Lab (PMEL) has collected a broad range of acoustic data as part of their ocean geophysical research. Acoustic data collected by PMEL include data from Navy SOSUS arrays as well as data collected using autonomous recording devices. The SOSUS arrays monitor low-frequency sounds (up to low hundreds of Hz) and, in the North Pacific, have been archived by PMEL since 1991. Autonomous recorders have been deployed in the eastern tropical Pacific (up to 110 Hz), on the mid-Atlantic ridge (up to 50 Hz), and in the Gulf of Alaska (up to 440 Hz).). In collaboration with Oregon State University, PMEL has analyzed marine mammal sounds (Stafford et al. 1999, 2001, 2003; Mellinger et al. 2004; Nieukirk et al. 2004) and, recently, anthropogenic noise (Nieukirk et al. 2004) within their recordings. In addition to PMEL's recordings, additional acoustic data are available from hydrophone arrays and autonomous recorders in many of the world's oceans, including the Pioneer Seamount (currently non-functional) and the Indian Ocean. These sources have various degrees of accessibility and are not all calibrated hydrophones. Efforts to record and archive underwater sounds have been supported by various agencies and universities, and recorded data are ripe for data mining to examine shipping and other sources of ambient noise and to study geographic and seasonal patterns of marine mammal vocalizations.

Airgun signals (from seismic research) are received at acoustic recording stations at the mid-Atlantic ridge and in the eastern tropical Pacific (ETP). An automatic detector for airgun signals has been built for ISHMAEL software (Mellinger 2001) so that large quantities of data can be quickly examined. In the Mid-Atlantic Ridge data, there are recordings of airgun firings every hour of every day during summer months, and these distant airguns are the dominant source of ambient noise in some frequencies (Nieukirk et al. 2004). In the ETP, the seasonality of the signals is not as strong. Marine mammal sounds can be heard and detected between the airgun events.

The reported number of ships using airgun arrays in the world's oceans varies with market forces; it was 155 in 2003, down from a high of about 200 vessels. The power of airgun arrays has generally been increasing as greater depths are explored. Sound source levels of some airguns are in the same range as most earthquakes. Because of differences in the typical location of these sources (offshore earthquakes vs. shelf based airguns) the effects on marine life could be very different. In general, there appears to be interest and funding for seismic event monitoring but not for ambient noise monitoring. This could be corrected by expanding the capabilities of the arrays to collect both types of signals.

The early planning for the FY06 NOAA budget has placeholders for OAR and NESDIS to begin collecting and archiving data on global ambient noise in the world's oceans. If this effort is funded, additional work will be needed to determine sampling rates and frequencies, monitoring locations, whether systems should be autonomous or hardwired to shore. A workshop including many of the world’s active researchers in the field of marine noise measurement was held in conjunction with the University of Rhode Island on 29-30 March 2004 to further develop this research plan.

It is clear that anthropogenic sound has increased the ambient noise levels in some areas of the world's oceans. One study (Andrew et al. 2002) showed a 10 dB increase in the levels of low-frequency sounds between the 1960s and 1990s off central California. Trends in other parts of the world are unknown. ONR Ocean Sciences Program is funding analysis of a long time series of Navy acoustic recordings in deep water of the Pacific (Roy Gaul and Church Opal, unpubl. data) to give additional insight into historical changes in ocean ambient noise. These two studies will not be sufficient to quantify global changes in ambient noise. This work would benefit from the identification and analysis of time series in other locations. It is important to establish monitoring sites in locations where historic data are not available so that future changes can be quantified.

John Hildebrand (SIO) reviewed some of the material he presented to a MMC meeting in the fall of 2003. He emphasized two major points: a) both sound pressure and vector velocity are needed to accurately describe sound in the ocean and b) the perception of sound radiated into the waters is grossly underestimated by both the public and scientists because so much acoustic intensity is lost when sounds cross the air/sea interface. With regard to the latter, it is estimated that 85% of vessel noise results from propeller cavitation and that this sound represents wasted energy from the perspective of efficiently moving ships through the water. Hildebrand noted that in some areas and at some frequencies, whale sounds dominate the ambient noise field. He also presented a revised version of his global anthropogenic noise budget previously presented at the Marine Mammal Commission Workshop in Portland, Oregon. That noise budget (expressed as energy - Joules per year) was dominated by four sources (nuclear tests, airguns, military sonar, and supertankers) (Fig. 1). The energy input from each of these decreases (from one source to the next) by almost an order of magnitude in the order listed above. Jim Miller of the University of Rhode Island, under contract from NMFS Protected Resources in Silver Spring, is producing a noise budget for the oceans that includes both anthropogenic and natural sources of noise.

With regard to noise from shipping, the NOAA Fisheries Acoustics Program will be hosting a symposium entitled "Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology" on 18 and 19 May 2004 in Arlington, Virginia. A group of highly regarded scientists and engineers from around the world will be discussing what is known about shipping noise, hearing and the effects of noise on marine mammals, and vessel quieting technologies.

Other noise monitoring projects were mentioned. The National Science Foundation's (NSF) Ocean Observatories Initiative may include ocean noise observations. The Ocean Research Interactive Observatory Networks (ORION) program was established by NSF to operate and manage ocean-observing sites (http://www.ocean.us). Future sites are likely to feature networks of ocean observatories linked to shore by undersea cables providing power and high-speed fiber-optic data lines. Project Neptune is a network of cabled observatories that is planned for the Pacific Northwest (off Oregon, Washington, and southern British Columbia) and may be the first cabled observing network to be built (Neptune/Canada has been funded). Broadband hydrophones for monitoring ambient noise or marine mammal calls may be added to or may be integral to some or all of these cabled networks. The NMFS plan for a Pacific Ocean Observing System (PacOOS) and NANOOS (http://www.nanoos.org) along the U.S. west coast is anticipated to include a component of ocean noise monitoring.

Identified actions to fill gaps in current and planned research:

1. Establish a coordinated network of monitoring stations to measure changes in anthropogenic sound throughout the world's oceans.
2. Identify, archive and analyze any calibrated hydrophone data that could be used to retrospectively examine changes in anthropogenic sound over the last several decades.
3. Identify and quantify the major sources of anthropogenic sound in different locations and at different frequencies.

Discussion Topic II: Establishing guidelines for safe levels of exposure to sound.

Discussion Leaders: Gentry and Frankel
Rapporteur: Southall

Scientific criteria for determining the effects of single noise exposures on individual marine mammals have been developed under the direction of Roger Gentry at NMFS Headquarters. As occurred in the development of human standards, the science-based noise exposure criteria are being developed by an expert panel of scientists, without consideration of policy implications. This science panel (convened by NMFS) plans to submit these noise exposure criteria in the open literature (Journal of the Acoustical Society of America) in 2004. The development of NMFS policy guidelines has begun and will include an environmental assessment; the estimated time to completion is at least 18 months.

The science panel found that they had to group animals and sound types for systematic comparison. They defined four sound types (single pulse, single non-pulse, multiple pulse, and multiple non-pulse) and five marine mammal groups (low-, mid, and high-frequency cetaceans, and pinnipeds in air and water). Distinctions were made based on the severity of impact (behavioral disturbance or injury) and on the sound metric (pressure or energy flux density). These subdivisions result in 4x5x2x2 or 80 separate criteria in a noise exposure matrix. Some of these decisions are based on direct empirical data; where this is lacking, a systematic chain of logic was employed based on available data from related species. The version of this matrix presented by Dr. Gentry contained a color-coding system that indicated the strength of the data and assumptions underlying each of these 80 criteria. Green cells indicate those criteria based on direct empirical data. Yellow cells indicate those based on data extrapolated from closely related species. Red cells indicate decisions based on data extrapolated from distantly related species. The matrix was shown in this color-coded manner to emphasize the research needed to convert the yellow and red cells to green. NMFS and the noise-exposure criteria group developed a list of needed research based on the data gaps identified in the construction of the matrix.

In developing these noise exposure criteria, slightly fewer animal groups were used than had been proposed by a National Research Council (NRC) panel that was convened to consider noise impacts on marine mammals. For pinnipeds, the NMFS-convened panel proposed an additional split for sounds received above and below water. Further splits within the new framework are included as "exceptions", and two identified exceptions are beaked whales and migrating baleen whales when exposed to certain sound types. It was noted that the criteria matrix was based on very little direct data on levels of sound that cause injury; there have not been, and likely will never be, direct measurements of exposures causing permanent hearing loss in marine mammals. Because of this and because of the costs of research, it is unlikely that we will ever eliminate all the uncertainties and extrapolations in the criteria matrix. However, a new approach that may speed up our ability to obtain the information is the development of new techniques called auditory evoked potential audiometry (estimating hearing capabilities by measuring neural activity rather than behavioral responses). Comparative studies of hearing capabilities using both behavioral and evoked potential methods are being conducted to determine the accuracy of the electrophysiological techniques for measuring hearing in field conditions. The relationship between laboratory measurements of marine mammal hearing and the effects of noise in terms of predicting behavioral reactions of animals in field conditions is somewhat unclear. Future research efforts using controlled exposure experiments involving broadcast noise in marine mammal environments will be helpful, in addition to validation of existing and proposed mitigation procedures.

The current noise exposure criteria (described above) represent the first of at least five efforts by NMFS to more fully understand and manage protected marine species. Beyond establishing criteria for the effects of single exposures on individual marine mammals, the following steps are proposed. 1) Establish a fish and turtle panel to determine exposure criteria for single exposures like the current mammal criteria. 2) Establish criteria for cumulative effects of noise exposure on individual marine animals. 3) Establish criteria for single exposures of populations of marine animals. 4) Establish criteria for cumulative effects of noise on populations of other marine animals.

Another NRC panel has been convened to address the question of when a behavioral modification (such as those caused by sound) is biologically significant. In the first meeting of this panel (October 2003), experts on animal behavior proposed using transfer function modeling to begin considering cumulative behavioral impacts. A second meeting was held on 5-6 March 2004 in Washington, D.C. The entire process is expected to take approximately 18 months.

Acoustic exposure criteria are based on received sound levels. A critical aspect of assessing noise impacts on marine mammals is estimating characteristics of received noise from knowledge of the sounds sources. One way of doing this is with integrative models. Two such models, the Acoustic Integration Model (AIM - developed by Marine Acoustics, Inc.) and ESME (ESME - developed by ONR and its contractors), make predictions about received levels and the number of animals affected from knowledge of the sound source. The model output provides a dose/response function with exposure level on the abscissa and some metric of response on the ordinate. There are three major components to AIM: 1) Source characteristics (What is the input?), 2) Environment characteristics – sound velocity profiles (How is sound transmitted from source to receiver?), and 3) Receiver characteristics (What are species-specific distribution and diving characteristics?). Exposure of animals is not only a function of range, but physical position relative to the source. AIM is a way of simulating how animals move through space considering typical movement patterns. The result is a way of estimating received levels on populations of animals. Exposure histories can be estimated for individuals in terms of pressure or integrated energy metrics. This type of predictive modeling can be used to estimate exposures for different sources for different times of the year. Earlier versions of AIM used propagation models that were not particularly appropriate for airguns, but new models are being incorporated that more adequately model propagation of the impulsive sounds generated by airguns. In running this type of simulation model, environments are typically overpopulated with animals to get clearer dosage curves with fewer iterations, and densities are then scaled back down to fit reality. One problem in applying these models is the significant gaps in information about the distributions, densities, and movement patterns of marine mammals, even in relatively well-studied areas (such as the Gulf of Mexico). AIM does not account for the speed of moving sources, directionality of sound sources or receivers, or the horizontal movement patterns of the mammals. Currently, a major limitation of AIM is the paucity of data on behavioral responses.

The motivation for integrative models was the development of Surveillance Towed Array Sensor System Low Frequency Active (SURTASS-LFA) types of sonar. The EIS for SURTASS-LFA involved the development of the straw-man dose response curve ("risk continuum") running from exposures of 140-180 dB re: 1μPa, with the upper value representing the estimated onset of temporary threshold shift (TTS - a temporary loss of hearing). Subsequently, TTS levels for bottlenose dolphins and belugas have been found to be much higher than 180 dB (Finneran *et al.*, 2000; 2002; Schlundt *et al.*, 2000). Also, the Single Ping Equivalent technique was established in which energy is summed across multiple exposures. One problem with the SURTASS-LFA Scientific Research Program (SRP) was that most of the empirical measures of exposure occur at the lower range of the proposed dose response function (below 160 dB), resulting in a significant gap in information about behavioral responses. During SURTASS-LFA trials, responses were expected at relatively low received levels and thus initial exposures were conservatively set at low levels; however, responses were not observed until much higher received levels.

The value of using the dose response approach (rather than a step function for estimating noise impact as is currently used by NMFS) is that it more realistically represents "take" as a probabilistic function. In reality, behavioral changes don't occur abruptly at a threshold (i.e., at 160 dB, but not at 159 dB. However, constructing such a function with a high degree of confidence generally requires more data than are currently available.

Identified actions to fill gaps in current and planned research:

1. Research to eliminate (to the extent possible) the extrapolations used in developing the noise exposure criteria.
2. Analysis of field observer/monitoring data already conducted as required by condition of permits.
3. Development of noise exposure criteria for populations of marine mammals and cumulative impacts.
4. Development of noise exposure criteria for fish (as an important food source for marine mammals).
5. Obtain more data on normal diving behavior for use with AIM.
6. Provide additional data on source and environmental characteristics for integrative models of sound exposure.
7. Analyze past survey data and direct future surveys to provide better data on animal distributions and densities to allow better estimates of sound exposure.
8. Improve understanding of behavioral impacts as a function of exposure level, especially for received levels above 160 dB re: 1µPa.
9. Improve assumptions made in predictive models involving dose response functions.
10. Measure exposures animals are now experiencing in typical habitats using digital recording tags .

Discussion Topic III: Facilitating data collection for stranding events associated with anthropogenic sounds.

Discussion Leaders: Wieting, Hastings
Rapporteur: Barlow

NMFS has three major programs that contribute to our ability to respond in the case of marine mammal strandings (from any cause): (1) The NMFS stranding response program includes six Regional stranding coordinators and one coordinator in Headquarters. The actual stranding responses are made by approximately 400 people nationally, most of them volunteers. A stranding database is maintained in each Region and contributes to a national stranding database. When responding to mortalities, stranding response teams collect basic data on species, size, sex, and cause-of-death. More detailed life-history data and tissue samples are collected in some instances for some species. (2) NMFS also has a program to establish an "unusual mortality event team" to coordinate more detailed collections, analyses, and studies in the cases when marine mammal strandings in a particular location increase to unusual levels. Such teams have been formed in the past to respond to unusual cases of disease or toxic algal blooms as well as strandings possibly associated with anthropogenic noise (including the 2000 Bahamas and 2003 Haro Strait events). (3) NMFS also administers a new Prescott Grant Program which distributes funds (now $4M per year) to aid local stranding response programs and rehabilitation facilities that deal with live strandings.

Within the NMFS stranding programs, sample collection to detect evidence of acoustic trauma is limited due to a lack of available expertise, standardized methods of data collection, and gaps in the stranding network itself. The detection of acoustic trauma may be one of the most difficult tasks demanded of our network, requiring the most rapid response, the most careful tissue collection protocols, and the freshest tissue materials. Indeed part of the problem is uncertainty regarding what to analyze in cases of possible acoustic trauma. A national workshop on stranding networks is planned by NMFS in October 2004. Methods of sampling to detect acoustic damage will be discussed at that workshop.

Methods have been developed to measure hearing sensitivity in marine mammals using similar Auditory Brainstem Response (ABR) or Auditory Evoked Potential (AEP) methods that are used to test hearing in human infants. ABR tests on live-stranded animals may provide an opportunity to test a much broader range of cetacean species than can be tested in captivity. The Navy's SPAWAR facility in San Diego is establishing a fast response (SWAT) team to quickly transport trained people and equipment to the site of marine mammal strandings to measure hearing. Additional development is needed to make the system more portable and to develop electrodes that will work effectively on larger whales. One critical aspect to this project will be public outreach, not only within the stranding network, but also for the general public to increase appreciation of the value of obtaining important data in these unique situations and to negate the perception that animals are being made to suffer. This Rapid Response Team approach may be appropriate to better respond to stranding events that might be caused by acoustic factors. NMFS Protected Resources in Silver Spring is funding AEP research on pinnipeds in 2004 through the National Ocean Partership Program (NOPP) grant to the University of California, Santa Cruz.

Identified actions to fill gaps in current and planned research:

1. Develop data collection methods and protocols to detect acoustic trauma.
2. Train stranding response teams on protocols of data collection.
3. Evaluate the costs and benefits of establishing a rapid response team for stranding events that may be related to anthropogenic noise.
4. Establish public outreach to make stranding response teams and the general public aware of the need for information on identifying acoustic trauma and measuring marine mammal hearing.

Discussion Topic IV: Determining causal mechanisms for stranding events associated with anthropogenic sounds.

Discussion Leaders: Gentry, Hastings
Rapporteur: Barlow

An joint NMFS/Navy review of the Bahamas stranding incident (Anon. 2001) concluded that military sonar exercises caused the strandings that resulted in the deaths of several beaked whales and other species. Other beaked whale stranding in Greece (Frantzis 1998) and the Canary Islands (Jepson 2003) have also been associated with military sonar use. The sound source that caused the stranding is known to be mid-frequency sonar, but the mechanism by which it acted is still unknown. A separate NMFS workshop was convened to discuss the potential role of acoustic resonance in causing tissue damage; that workshop was very productive and essentially eliminated two of three proposed hypotheses. A new hypothesis (decompression sickness caused by too rapid surfacing) has been put forward as an explanation for the Canary Island strandings in 2002 (Jepson *et al.*, 2003), but that explanation lacks empirical confirmation and has been questioned (Piantadosi and Thalmann, 2004). The possible role of panic or noise avoidance behavior in causing the strandings also remains as a possible cause or contributory cause for the strandings.

The Navy has funded a great deal of research in response to the sonar-related stranding events. Current Navy-funded research includes: 1) sound propagation modeling to estimate exposure levels, 2) characterization of beaked whale habitats, 3) development and deployment of acoustic data-logging tags to determine use of sound by beaked whales, 4) development of tags to monitor physiological and behavioral responses to sound, 5) development of methods for passive acoustic detection and localization of beaked whales and other cetaceans, 6) development of methods for controlled exposure experiments (tested on sperm whales, but hopefully soon on beaked whales), 7) development of a marine mammal sound library at Cornell University to facilitate research on marine mammal acoustics, 8) investigations of marine mammal hearing using auditory evoked potentials, 9) anatomical investigations and modeling of beaked whales to determine why they may be more susceptible to sounds, 10) integrative modeling of sound sources, sound propagation, and the effects on marine mammals, 11) training on sampling techniques to detect acoustic trauma, and 12) education and outreach. In addition to these research-oriented activities, the Navy has implemented changes in the way sonars are used to reduce the risk of another stranding event. [Mardi, I have a note here that you can provide me with a long list of information needs that have been identified by ONR.] NOAA continues to collaborate closely with Navy in several of these research endeavors. We may be close to the point when we can use controlled exposure experiments to gain information on the effects of sounds on beaked whale behavior.

Identified actions to fill gaps in current and planned research:

1. Develop passive acoustic detection and localization methods for beaked whales and other cetaceans.
2. Quantify density distributions for beaked whales and other marine mammals using data from NOAA marine mammal surveys.

3. Develop data collection protocols for determining the cause of acoustic-related strandings and to provide carcasses and tissues for anatomical studies and acoustic testing.

Discussion Topic V: Assessing population-level impacts of anthropogenic sounds.

Discussion Leader: Barlow
Rapporteur: Jones

NMFS has not conducted much research on assessing population-level impacts of sound on marine mammals. The extrapolation from individual behavioral responses to population level impacts involves many assumptions, and the resulting uncertainty is likely to be large. Sub-lethal effects such as call-masking (see section VI, below) or displacement may be very important for cetaceans, but population-level effects are extremely difficult to predict. Recognizing this, an adequate monitoring program is needed to detect population declines that might be caused by the cumulative, indirect effects of sound exposure. If declines are detected, factors can be identified that contribute to the decline.

Direct population monitoring to detect changes in abundance works more effectively for some species than for others. Based on line-transect and photo-ID monitoring program in California, blue, fin and humpback whale populations, collectively, appear to have increased at 6% to 8% per year from 1979/80 to 2001 (Barlow, pers. comm.). This occurred in spite of a general 10-dB increase in low-frequency ambient noise from the 1960s to the 1990s (Andrew et al. 2002). This monitoring approach worked for these baleen whale species because the level of effort and the number of sightings were sufficiently high to give a high statistical power to detect a change in abundance. However, the same approach would not work for beaked whales along the U.S. West Coast because the number of sightings on a 4-month survey is typically inadequate for assessing trends in abundance. Alternative methods, such as passive acoustic detection, are necessary to boost the sample size for monitoring beaked whales. Although acoustic detection may hold some promise, there are few data on beaked whale vocalization, and existing studies are contradictory. Efforts are underway to put acoustic recording devices on beaked whales (Tyack, pers. comm.) to improve prospects for acoustic monitoring.

In order to understand population-level effects on cetaceans, we need to have information on the noise levels in their environments. One approach would be to study effects of sound on a small population in a limited area. Two such studies were identified in which sound was a concern for a small population: southern resident killer whales in the Pacific Northwest and western gray whales off Sakalin Island, Russia. The NWFSC is studying effects of noise on southern resident killer whales as one of the risk factors for the population. Studies are also being conducted on the ~100 western gray whales that feed in a small area (10 x 70 km) off Sakalin each year. This is one of only a few whale populations to be listed as critically endangered on the IUCN Red List. Oil fields are being developed around this area with dramatic increases in seismic research, drilling, vessel traffic, and other industrial noise. There is some baseline data on behavior and noise off Sakalin. Based on the playback experiments by Marilyn Dahlheim in Baja California lagoons, there is reason to believe that gray whales are sensitive to anthropogenic sounds and that noise can drive gray whales from important habitat.

It is important to conduct research on population level effects of sound on beaked whales. This is one species group for which there is evidence of acoustic-related mortality, but the logistics of detecting population-level effects are more difficult for these species. Another approach to look at population effects would be to study harbor porpoise because this species is similarly sensitive to sound but easier to study and obtain results.

The difficulty in assessing population-level effects of noise should not be underestimated. It is important to have long-term monitoring to address this issue. The Navy training ranges are monitored acoustically, and this monitoring could provide information on noise levels. One approach for long-term studies is an integrated, cooperative long range monitoring system similar to SOSUS but specific to marine mammal vocalizations.

Identified actions to fill gaps in current and planned research:

1. Collect data to determine when behavioral changes are biologically significant to individuals and therefore are likely to be significant to populations.
2. Initiate detailed studies of the effects of sound on small populations in limited areas where sound is suspected to be a problem (such as for southern resident killer whales in the Pacific Northwest and western gray whales off Sakalin Island, Russia).
3. Establish frequent surveys to adequately monitor marine mammal populations and to detect cases where population declines may be caused by anthropogenic sounds.

Discussion Topic VI: Assessing the effects of shipping noise and call masking on baleen whales.

Discussion Leaders: Gentry, Frankel
Rapporteur: Mellinger

Masking is the reduction in hearing attributable to ambient noise. Although masking of hearing for simple tonal stimuli has been studied in a number of odontocete and pinniped species in the laboratory, no such data exist for mysticetes. Further, there has been no research on masking of calls or other more complex, biologically significant sounds in any marine mammal species. Erbe and Farmer (2000a, 2000b) used available data on hearing and critical ratios to construct models of zones of audibility, of masking, of behavioral disturbance, and of permanent and temporary threshold shift (brief hearing loss) in belugas. They addressed the question of the impacts of different levels of noise.

The inner-ear anatomy of marine mammals is fairly similar to that of terrestrial mammals, suggesting that masking should operate similarly in the two. Empirical measurements of various aspects of masking in terrestrial and marine mammals support this conclusion. Based on aspects of frequency processing evidenced using these experiments, masking noise of similar frequency to signals of interest are most effective at interfering with detection. Thus, masking from shipping noise is likely to affect most strongly those marine mammals with low-frequency calls, including most pinnipeds and most baleen whales (NRC 2003).

Andrew et al. (2002) reported a 10 dB increase in shipping noise between the 1960s and the 1990s in coastal California, an area with heavy shipping. How might this have affected call reception? In terms of the number of animals affected by anthropogenic sound, masking is likely a much more widespread phenomenon than other effects of noise exposure But untangling population-level effects of masking is a daunting task, as the number of confounding factors is quite large: pollutants, fishing, climate changes, non-sound effects of disturbance, etc. During the period covered by this study, the populations of baleen whales off California apparently increased at a rate of ca. 8%/year, which is near the maximum possible biologically. This suggests that, at past levels, noise may have had little effect on population growth. On the other hand, whale populations increased along with noise, but there may be a limit to animals' ability to adapt such that further increases might have population effects. We have no idea what that limit may be.

Mark McDonald and John Hildebrand have data showing that the frequency (pitch) of blue whale calls has decreased during the last 30-40 years. This is true for all of the blue whale populations for which data were available. This may be due to their avoidance of shipping noise, but it happened even in populations (such as in Antarctica) that have little exposure to shipping noise. Another explanation is that it is a behavioral response to the increased density of animals.

For animals communicating acoustically over long ranges, a seemingly small increase in background noise could cause a marked decrease in the range over which calls are audible. For instance, suppose a baleen whale has evolved to have a signal optimized to travel 100 km. A 10 dB increase in background noise in that frequency band would reduce that range to 10 km, and reduce the number of audible individuals by a factor of 100 (assuming a random distribution). It is possible that females may assess male quality by their sound. If females can now hear far fewer males than they could previously, will this lead (over long time scales) to poorer female choices and reduced fitness of a species? This is only speculation, and it is difficult to see how one could study it on any reasonable time scale.

There are definitive signs that whales can be displaced by human activity, including noise. Some examples include:

* In Baja California, a salt works was established in a gray whale breeding lagoon. The whale population went to zero nearly immediately, after which the salt works was moved elsewhere. It required about a decade for the population to recover there; the animals simply did not come back quickly, even though the disturbance that apparently displaced them was gone.

* Humpback whales in the Windward Islands were hunted to near-extinction in the whaling days. In areas where there is now substantial human activity, especially oil production (Gulf of Paria, and off Trinidad), there are still few or no whales present. In areas on the outside of the archipelago, where there is substantially less industrial activity, whales have returned. This effect may not be from only shipping noise, as there is noise from oil production, oil drilling, aircraft, etc., as well as visual disturbance from vessels and oil activity.

* Pinnipeds have been known to temporarily vacate rookeries in the presence of noise. This

can have consequences long after the noise is eliminated; some species are gregarious and have "founder effect" - they will populate an area only when others of their species are present, and substantial time can pass before that first individual comes back.

* Sometimes impacts are subtle, occurring over long time periods. Gray whales feed off Sakhalin Island and have to be there at certain times of year. If they are displaced to fringe areas, their physiology can be compromised from lack of caloric intake.

On the other hand, marine mammals are known to ignore noise sources, even loud ones, when there is a compelling reason to do so. Some examples of this include these:

* Harbor porpoises stay near salmon pens even in the presence of acoustic harassment devices operating at 195 dB SPL. They do this because food is available there -- there is an ecosystem built around uneaten food that washes out of the fish pens.

* Sperm whales did not react to the discharge of detonators off Norway (Madsen and Møhl 2000), perhaps because they were perceived as clicks from conspecifics.

* Southern resident killer whales in Puget Sound are continually exposed to noise from whale-watch boats, sonars, shipping, etc.

* Dolphins in harbors worldwide tolerate many types of noise and other disturbances.

The effect of masking depends on the characteristics of a noise signal. We know a fair amount about the masking of tonal stimuli by tones and noise bands. More research is needed on the detection of biologically significant signals over realistic levels of masking noise. What is the role of experience and learning? One way to address this question would be to play back vocalizations at various levels of noise and observe the responses. From this type of experiment, one could determine the signal-to-noise ratio at which response occurs.

For a study of masking in baleen whales, a source signal is needed that whales respond to in a predictable way. A good candidate for such a study might come from feeding calls of humpbacks in Hawaii. Such a sound has been seen to produce an extreme reaction (whales coming immediately from considerable distances). The feeding call is a tonal sound varying from roughly 500 to 550 Hz, and would make a good test case. Another possible test source is an alarm signal used with right whales. In studying behavioral responses of right whales to shipping noise, Nowacek et al. (2004) broadcast three stimuli consisting of right whale calls, shipping noise, and an alarm signal, and they found that whales did not respond to the ship sound, reacted mildly to the calls, and reacted strongly to the alerting sound (unfortunately, their response was to rise to the surface, putting them at greater risk to being struck by a ship). Nonetheless, distinct reaction of right whales to the alarm signal (the whales surface relatively quickly and remain near the surface) and could be used for a study of masking. Captive animals could also be tested for the effect of masking noise on biologically significant sounds. In doing such studies, it should be kept in mind that band-limited white noise is often more effective at masking than ambient noise. This happens presumably because animals have become skilled at detecting sounds within a field of natural noise.

Much of the low-frequency anthropogenic noise that could mask baleen whale calls comes from shipping. Many in the shipping industry do not realize that noise can be an issue of public concern. Navy research has shown that there are many simple, inexpensive things that can be done to quiet ships. But there is currently no incentive for shippers to act. International law on this topic, which will be the topic of a session at the NOAA symposium on "Shipping Noise and Marine Mammals", is fairly weak in this regard; the International Maritime Organization (IMO) has few if any regulations. At the shipping noise symposium, it will be important to present the issue tactfully. The first step will be simply to present the information to shippers, to show cost-benefit analyses, and perhaps simply to make shippers aware that this issue is looming. If they act in advance, perhaps they can avoid the sort of public-relations fiascos that have occurred with scientists (acoustic tomographers, geophysicists) and the Navy. The IMO has experience with marine mammal regulation, having had to obey requirements for right whale conservation including regulations designed to reduce ship strikes of right whales.

Mazzuca (2001) studied ways of quieting existing vessels by retrofitting. She shows a table itemizing ways to quiet a vessel, the degree of noise reduction, and a cost estimate. Some methods are highly cost-effective; for instance, some ways of reducing cavitation noise can increase propulsion efficiency. ONR has developed a super-conducting motor with a vertical shaft that places the propeller lower in the water and thus reduces cavitation.

Behavioral context can have a large influence on the impact of noise; an example is whale migration along narrow coastal corridors. Migrating gray whales have been seen to detour around sound sources placed in their migration path,), but do not detour when the sound source is placed outside the corridor but is still ensonifying the corridor to the same extent (Buck and Tyack 2000, US Navy 2001). A similar issue may arise with bowhead whales. There is concern in northern Alaska that bowheads may divert or even interrupt their migration to avoid icebreakers, which produce large amounts of sound. The width of the available migration corridor may be relevant here; bowheads are often limited to leads in the ice and can have little room to maneuver. Even small behavioral shifts in distribution in response to anthropogenic sound may be of concern to subsistence whalers because it can mean the difference in whether a whale will be accessible to hunters.

The issue of bowhead whales and icebreakers may become increasingly prominent. There are predictions that as the Arctic climate warms and the ice melts in the next 20-30 years, commercial ships will take advantage of the short distance across the Arctic between eastern Asia and Europe. The suggestion was made that NMFS should start monitoring noise in the Arctic now, so that baseline information is available as this increase continues. There is already more shipping traffic there now than there was previously, with many icebreakers (6-8/year) traveling past northern Alaska compared to the former case of a single annual trip. Measuring the impact of shipping noise will be quite difficult, given the expected huge impact on the Arctic ecosystem of having ice present a greatly reduced fraction of each year.

Identified actions to fill gaps in current and planned research:

1. Conduct studies of call masking in marine mammals with biologically meaningful sound sources and realistic levels of ambient noise.
2. Conduct research to determine when sound is likely to displace marine mammals from important habitat or activity and when sound will likely be tolerated by animals.
3. Develop effective methods to reduce noise radiated from ships that are compatible with the needs of the shipping industry.

Discussion Topic VII: Cumulative Impact of Sounds from Many Sources (e.g. southern resident killer whales).

Discussion Leaders: Jones, Cottingham
Rapporteur: Swartz

Southern Resident Killer Whale (SRKW) populations inhabit the inland waters of Washington state and British Columbia. There are three pods: "J" pod remains within Puget Sound all year; "K" pod ventures out of Puget Sound during part of the year, and "L" pod is the largest and leaves Puget Sound for 5-6 months each year, and when outside its whereabouts remains unknown. All pods are exposed to much anthropogenic sound from shipping and small vessel traffic in Puget sound, particularly whale watching. L pod has also demonstrated the greatest decline in recent years, suggesting that exposure to factors outside of Puget Sound may be contributing to L pod's decline.

The U.S. government listed the SRKW population as depleted under the MMPA in Spring of 2003, Canada's Species at Risk Act (SARA) lists it as endangered and lists the Northern Resident populations as threatened, and Washington State listed the SRKWs as endangered under state statute. Photo-ID and other records on the Southern Resident killer whale population date from the 1970's, and it is clear that commercial, recreational, and military vessel traffic and disturbance within Puget Sound have increased dramatically since that time. As a result, vessel noise and disturbance are suspected of contributing to the decline of the whales.

A number of risk factors have been identified that may be related to the population decline of southern resident killer whales, including interactions with vessels. The Northwest Fisheries Science Center (NWFSC), in conjunction with the Department of Fisheries and Oceans in Canada and the Washington Department of Fish and Wildlife, held several workshops to identify high-priority research needs and methods to address the risk factors. Over 30 research projects were initiated to address risk factors and data gaps, including several projects to characterize the sound environment of the whales and behavioral responses to vessels, as well as the energetic cost of vessel avoidance.

There may be some potential for studying the long-term changes in the exposure of killer whales to noise in Puget Sound. A 30-year time series of recordings exists for one location, and information is available on the number of commercial whale watch vessels over the same time period. However, even with the best efforts, teasing out specific effects of noise from an entire suite of environmental effects will prove difficult.

The identification and evaluation of the cumulative effects of anthropogenic and natural stressors on marine mammals is challenging. While large populations (e.g., > 5,000 individuals) are more easily studied and can yield adequate amounts of data to support conclusions, cumulative effects my not be clearly manifest in such large populations. In comparison, cumulative effects may be more apparent in smaller populations (e.g., 100s of individuals) and more easily detected. The down side is that their small size may make smaller populations more vulnerable to cumulative effects of anthropogenic and natural stressors (e.g., western gray whales).

Research on cumulative effects of noise disturbance might best be studied on a marine mammal population with a combination of known individuals and a known long-term history. One such population is the bottlenose dolphins (*Tursiops truncatus*) off the West Coast of Florida in Sarasota and Tampa Bays. The workshop participants were unaware if Randy Wells and his colleagues had ever attempted to assess the cumulative effects of noise on these populations of dolphin. Another small population where the influence of habitat may be assessable is the Cook Inlet, Alaska beluga whales, which also have a long history of native harvest.

The assessment of long-term cumulative effects will require basic data on key factors for retrospective analyses. Such factors include: 1. Long-term effects on the auditory system of an individual animal; 2. Behavioral responses to sound including habituation and de-sensitization and levels of noise that evoke a flight response and/or abandonment of preferred habitats; and 3. Characterization of sound exposure for long periods of time.

Displacement or changing location as a result of sound exposure may benefit animals and populations by lowering their exposure, but moving to an alternate habitat may still compromise survival if other threats are present and/or resources are inadequate.

Stress levels resulting from chronic exposure to noise need to be determined for marine mammals exposed to sound. Factors such as temporary threshold shifts (TTS), changes in heart rate, and blood chemistry analysis, and measures of stress need to be undertaken over the long term to identify trends associated with long-term chronic exposure. There are no such systematic studies focused on cumulative effects of exposure to noise, and there is a need to develop such research approaches to evaluating long-term exposure effects.

A recent National Research Council (NRC) Panel has been convened to look at "biologically significant behavior changes", and the behavioral significance of exposure to sound. This panel will also address population modeling as a sub-component of its deliberations. The panel's findings are expected later this summer.

Integrative models that estimate cumulative sound exposures (such as the AIM and ESME models, see above) currently assess exposure to noise for periods from days to weeks in a variety of habitats and ocean noise conditions. Perhaps such a model could be expanded to assess noise exposure effects for longer periods to evaluate noise effects on a seasonal basis and throughout migrations and various portions of a marine mammal's range.

Identified actions to fill gaps in current and planned research:

1. Collate and analyze historical data on sound levels within the habitat of southern resident killer whales to determine long-term changes.
2. Develop methods to measure the effects of long-term, chronic noise exposure on individuals, such as hearing threshold shifts, changes in heart rate or blood chemistry, or increases in factors associated with stress response in other mammals.
3. Modify existing integrative noise exposure models to allow modeling of chronic noise exposure from a variety of sources over a longer time frame.

Discussion Topic VIII: Improving knowledge base regarding beaked whales (behavior, distribution, density).

Discussion Leaders: Barlow, Hastings
Rapporteur: Frankel

NMFS sponsored beaked whale research is primarily being conducted at the SWFSC and NEFSC. The Southwest Center is concentrating on acoustic and diving behavior. They have attempted to record beaked whales, without much success, with Baird's beaked whale being the notable exception (Baird's beaked whale sounds have recorded often, typically on every encounter). The focus on dive times was to enable a refined estimate of g(0), the probability of detecting a beaked whale during a survey if it is directly on the trackline. Both NEFSC and SWFSC have collected and archived tissue samples from gillnet bycatches of beaked whales for future study.

The NEFSC beaked whale cruises have focused on habitat studies to identify environmental factors that predict the locations of beaked whales (*e.g.* Hamazaki 2002; Waring et al. 2001). Megan Ferguson, a UCSD/SIO grad student, is analyzing the SWFSC cetacean survey data to develop models to estimate beaked whale density as a function of oceanographic variables (e.g., temperature, salinity, thermocline depth) and fixed geographic effects (depth, bottom slope, distance from shore, latitude, and longitude). She has found that the physical predictor variables that have been identified in the Western Atlantic and Mediterranean Sea (such as bathymetric slope) do not appear to apply in the Pacific. It is likely that these physical parameters are proxies for enhanced productivity. Enhanced productivity in the Pacific occurs in areas other than those with sharp bathymetric relief. It suggests that a general model of beaked whale distribution should be based on productivity indices rather than the easier to measure physical features.

Recently, the Alaska Fisheries Science Center (AFSC) researchers have become interested in beaked whales. Paul Wade and John Durban proposed a study on Baird's beaked whale. This species was chosen largely for its accessibility and approachability. Their proposal focused on recording Baird's beaked whale with stationary and towed hydrophones and with acoustic recording tags. This proposal was not funded by NOPP, however.

Recently, Robin Baird has successfully attached time-depth recorders (TDRs) to *Ziphius* and *Mesoplodon* in Hawaii. A preliminary report of their diving behavior is currently being prepared (Baird et al. 2004).

NMFS researchers are also collaborating with the effort led by Colin MacLeod to create a worldwide database on beaked whale sightings and strandings and are collaborating with him on a paper on the worldwide distribution of all the beaked whale species. The SWFSC has also published recently on the distribution of *Mesoplodon* species in the eastern Pacific (Pitman and Lynn 2001).

Mardi Hastings reviewed work being sponsored by the Navy (ONR and N45). This includes numerous projects such as the effort led by Colin MacLeod and Angela D'Amico to refine the beaked whale worldwide sighting and stranding database. The Navy is also funding the beaked whale acoustic and habitat work at the SWFSC.

Two groups are working on the issue of beaked whale sound reception. Hildebrand and Cranford at Scripps are conducting CAT scans of a beaked whale neonate. These data are being used to create finite element models of the beaked whale head in order to examine for how sound waves interact with these tissues. Ketten and Mountain, of WHOI and Boston University, are continuing their work on auditory system models. Peter Tyack is being funded by the Navy to continue to refine and utilize the D-tags developed in his lab. His results, reported elsewhere, showed that beaked whales clicked at about 40 kHz, had source levels of 200-220 dB, clicked only when deeper than 200 m, clicked only while oriented toward the bottom, and had quiet times lasting three hours. Attempts to detect beaked whales acoustically must take these findings into consideration. For example, it is not likely that towed arrays would detect beaked whales. Most of the field effort is being directed to the Mediterranean, where the population density of animals is higher. The goal of this tagging effort is to better understand the behavior of beaked whales and to pave the way for controlled exposure experiments.

ONR is also indirectly supporting an initiative at the Atlantic Undersea Test and Evaluation Center (AUTEC) to develop passive acoustic monitoring capabilities. The ultimate goal is to be able to detect, locate and classify signals. It is known that beaked whales are found in the AUTEC range, and operators there have passively detected an unknown signal that is similar to the click trains reported from the two beaked whales tagged by the Wood Hole Oceanographic Institution (WHOI) group. It is possible, but unconfirmed that the AUTEC range has recorded a beaked whale. AUTEC is attempting to use their detection and tracking ability to direct a tagging vessel to an animal. They had some success in previous efforts, but have yet to succeed in placing a tag on an animal.

Mitigation of the negative effects of sound is extraordinarily difficult for such cryptic and rarely vocalizing species. The probability of visual detection is low, given that beaked whales dive for long periods of time and are not demonstrative at the surface. Furthermore it does appear that while we have now described some of their vocalizations, they do not vocalize frequently (with the exception of *Berardius*). The need for a different monitoring modality was expressed. The recent successful test of the Scientific Solutions, Inc. whale-finding sonar was brought up. This sonar operates between 20-30 kHz, within the range of beaked whale vocalizations. The question of how this sonar would be applied to species that can hear it was an issue of some concern. It was also pointed out that **IF** the sonar were an aversive signal for beaked whales, then it might function to keep them away from high-powered sources, such as airgun arrays.

Additional research on the use of passive acoustics may still be productive. While passive acoustics have been used for decades, only recently have groups been using equipment that operates at a sampling rate that is high enough to capture the vocalizations of some species. One probable detection of a beaked whale has been made at the Navy's AUTEC range. The seismic industry is putting a strong emphasis on passive acoustic detection of marine mammals, probably because it offers to be lower cost than visual observers and is able to operate at night. If the active whale-finding systems prove to be effective, they would be good candidates for augmenting the existing mitigation methods by detecting submerged whales.

Identified actions to fill gaps in current and planned research:

1. Expand efforts to create a database of beaked whale sightings and strandings.
2. Develop new methods to model and map beaked whale density in a particular habitat.
3. Collect more data on beaked whale behavior, notably the time and depth budgets for their dives.
4. Collect more data on the vocalizations and vocal behavior of most beaked whale species.
5. Improve time-depth recorders, acoustic recording tags, and tag application methods to facilitate collection of information on beaked whale diving and vocal behavior.
6. Conduct controlled exposure experiments with behavioral recording tags to determine how beaked whale react to sound exposure.
7. Evaluate the potential of detecting beaked whales using active acoustic techniques and the potential effects of these methods on beaked whale behavior.

Discussion Topic IX: Others special species projects: Sperm whale, gray whale, bowhead whale

Discussion Leaders: Moore, Mellinger
Rapporteur: Moore

The NMML has used passive acoustic recorders deployed offshore Alaska to detect North Pacific right and other 'listed' large whales (Fig. 2). Two types of recorders have been used: the PMEL-type instrument[1], also called HARU-phones, deployed in the Gulf of Alaska (GOA); and the Scripps-type instrument, also called ARPs[2], deployed in the southeastern Bering Sea (6), the western Beaufort Sea (2) and southeast of Kodiak Island (1). Both instruments are capable of continuous sampling to 500Hz for roughly one year. The PMEL-type phones in the central GOA have recorded both types of North Pacific blue whale 'broadcast' calls (Stafford, 2003), sperm whale clicks (Mellinger et al., 2004) and the calls of fin and humpback whales (Stafford, in prep.). Right whale calls were recorded on a PMEL-type instrument near Kodiak in summer 2000 (Waite et al., 2003), and an ARP was recovered in April 2004 after a one-year deployment at that location. Right whale calls were also detected on the western-most instrument (Fig. 2: WGOA red star) of the PMEL phones, although not on any of the other PMEL-type phones in the GOA (Mellinger et al., in review). In the Southeastern Bering Sea (SEBS), right whale calls were recorded from May through

1 http://www. pmel.noaa.gov/vents/acoustics
2 http://cetus@ ucsd.edu

early November (Munger, in prep.); numerous humpback and fin whale calls were recorded there as well.

The NMML will deploy three ARPs along the SEBS shelf break in May 2004, with a fourth ARP-type instrument linked to a PMEL mooring on the SEBS middle-shelf. These instruments will monitor waters where right whales aggregated historically in an effort to document seasonal occurrence. With funding from the Alaska Department of Fish and Game (ADF&G), two additional ARPs will be deployed for recording right whales in the locations complementary to the April 2004 deployments. Further south, two high-frequency ARPs (HARPs) with recording capability to 100 kHz will be deployed offshore Oregon or Washington States during July 2004. Proposed deployment locations are at the continental shelf break (water depth ~ 200 m) and within Quinault Canyon (water depth ~1,000m) west of Cape Elizabeth, Washington. These locations were selected to optimize potential recording of southern resident killer whale and/or beaked whale calls.

Additional information could be readily obtained from existing long-term acoustic data sets. All instruments record continuously, so seasonal measures of ambient noise levels (variability w/ storms and ice) and transient noise sources (e.g. vessels) could be extracted from the data files available from the PMEL and Scripps mooring sites[1,2]. Furthermore, cetacean calls from year-long recordings are often identified with the aid of computer-generated localization algorithms (e.g., Mellinger 2002) that search for species-specific signals. Often files are searched for only one or two species, such that data on additional species could be extracted if resources could be found to support this data mining. Results of such analyses could be integrated with other web-based products, such as CoML-OBIS3. Such integration is the specific focus of a NOPP proposal that was selected for funding in 2004 (POC: Bradbury/Cornell).

Woods Hole Oceanographic Institution (WHOI) has developed an acoustic and behavior recording tag called a D-tag. This tag was used on sperm whales in a controlled exposure experiment in the Gulf of Mexico (GOM). Tags were secured to three whales before exposure to seismic signals. Additional sampling is needed, but the seismic industry has withdrawn its support for this program. Tyack group at WHOI have also attached D-tags to Cuvier's beaked whales, and results should be published soon.

Dave Weller briefly described concerns regarding seismic noise in the feeding area of Western Gray Whales offshore Sakhalin Island in the Okhotsk Sea (Weller et al. 2002b). It appears that whales move away from prime feeding habitat when seismic ships are operating, and return after the air-gun surveys have stopped. There is continuing pressure to develop oil and gas resources in these waters and international lenders are now seeking advice on the impact of potential habitat disturbance from the multinational development activities.

Identified actions to fill gaps in current and planned research:

1. Conduct research on the distribution of marine mammals, especially for rare, endangered whales, such as the North Pacific right whale.

3 http://www.comL.org/descrip/obis.htm

2. Develop a program for deploying autonomous recorders to develop seasonal assessments of cetacean distributions and habitat use.
3. Analyze existing acoustic recordings to obtain information about many more marine mammal species.
4. Continue Controlled Exposure Experiments (CEE) on sperm whales and expand these studies to other species.
5. Expand the detailed population studies (Weller et al. 2002a) of the critically endangered western population of gray whale to determine the long-term effects of anthropogenic noise associated with oil exploration and extraction.

CONCLUSION

Research on the effects of anthropogenic sound has many facets. NOAA has a broader mandate on marine noise than any other federal agency because it implements the MMPA and ESA. The Navy has taken an early lead in conducting noise research, but it is responsible only for the forms of noise that Navy produces. The same is true of the Minerals Management Service (MMS), and the National Science Foundation (NSF). NOAA is concerned for all forms of noise, including natural sources, and all effects on animals. NOAA's ability to conduct research on these topics has been curtailed by budgetary restraints. But, NOAA has considerable expertise in marine mammal distribution and abundance, acoustics, and diving behavior and in the long-term monitoring of underwater sounds. Because it has developed noise exposure criteria, NOAA now has a detailed list of acoustic and behavioral research that is needed on tissue and behavioral effects of sound. Most of this research can be conducted through the National Oceanographic Partnership Program (NOPP). It is clear that NOAA should play a greater and more active role in marine mammal-sound research and in monitoring anthropogenic sounds. NOAA's research plan is in full agreement with the 2003 National Research Council report on ocean noise. Finally, it is clear that a multi-agency plan and coordination with industry are needed in the field of marine noise.

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Figure 1. Hildebrand's preliminary look at the global energy budget for anthropogenic sounds.

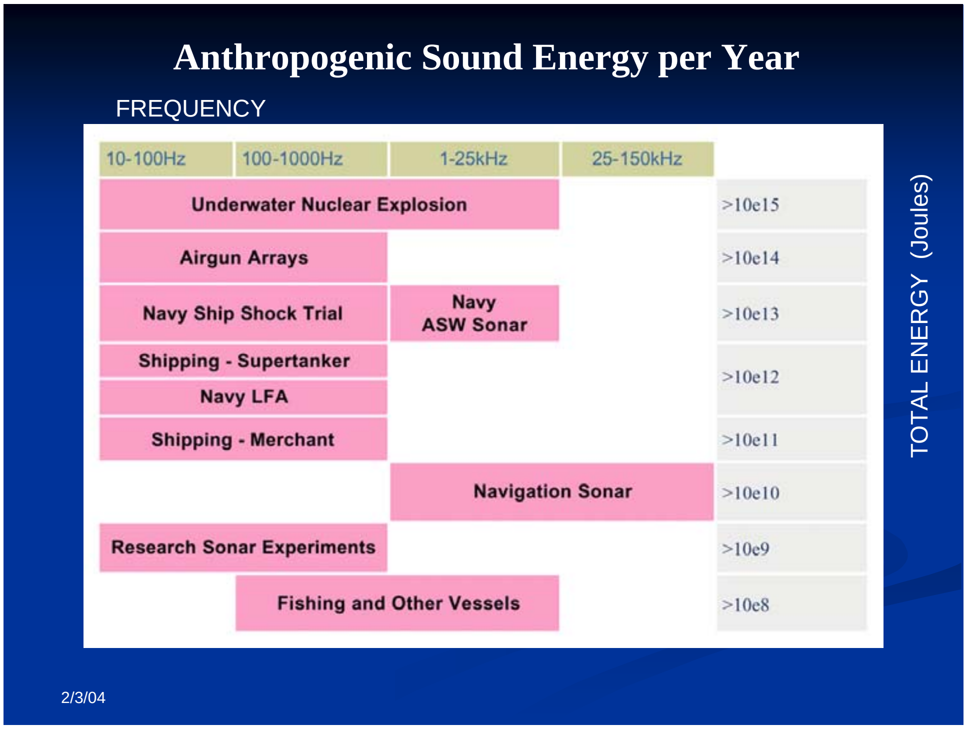
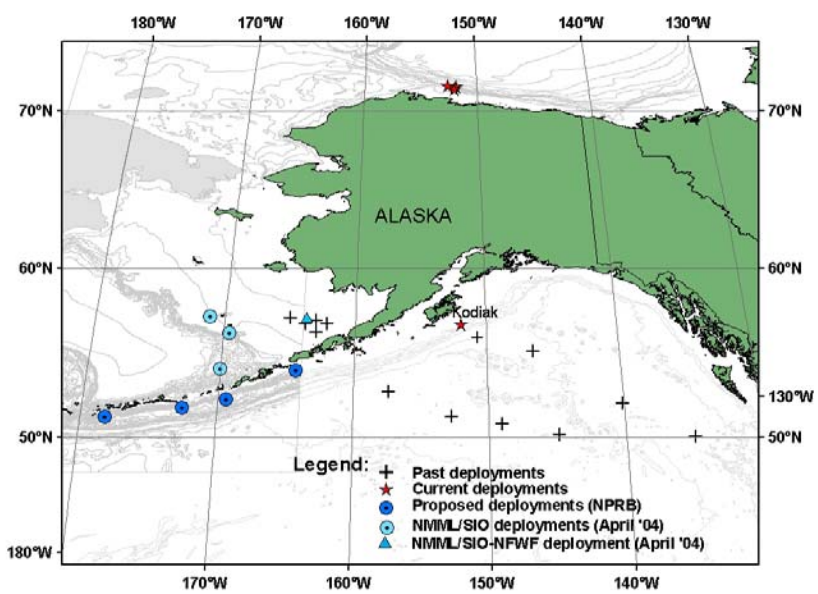


Figure 2. Past, current, and planned deployment of sea-bottom acoustic recording stations in waters of Alaska and the Gulf of Alaska.



APPENDIX 1: List of Participants

Jay Barlow (co-convenor)	NOAA Fisheries, Southwest Fisheries Science Center
Roger Gentry (co-convenor)	NOAA Fisheries, Office of Protected Resources
Bud Antonelis	NOAA Fisheries, Pacific Island Science Center
David Cottingham	US Marine Mammal Commission
James Finneran	US Navy, SPAWAR
Adam Frankel	Marine Acoustics, Inc.
Mardi Hastings	US Navy, Office of Naval Research
John Hildebrand	UCSD, Scripps Institution of Oceanography
Linda Jones	NOAA Fisheries, Northwest Fisheries Science Center
David Mellinger	Oregon State University and NOAA PMEL
Sue Moore	NOAA Fisheries, Alaska Fisheries Science Center
David Potter	NOAA Fisheries, Northeast Fisheries Science Center
Steve Reilly	NOAA Fisheries, Southwest Fisheries Science Center
Brandon Southall	NOAA Fisheries, Office of Protected Resources
Frank Stone	US Navy, Office of the Chief Naval Operations
Steven Swartz	NOAA Fisheries, Headquarters
David Weller	San Diego State University
Donna Weiting	NOAA Fisheries, Office of Protected Resources

APPENDIX 2: Agenda

NMFS Workshop on Anthropogenic Sound and Marine Mammals
AGENDA

THURSDAY: 19 Feb 2004

0900
Welcome (Reilly)
Introductions
General Overview and Goals (Gentry and Barlow)
Program Planning and Budgeting (Swartz)
FACA - More than you want to know (Swartz)
Review Agenda
Assignment of Discussion Leaders and Rapporteurs

0930
I. Monitoring anthropogenic sound from shipping, military, airguns, and other sources (ambient noise and transients).

1) review NOAA research in the area (Potter & Mellinger)
2) review outside research (Hildebrand)
3) identify gaps and needed research

1030
II. Establishing guidelines for safe levels of exposure to sound.

1) review NMFS research in the area (Gentry & Southall)
2) review outside research (Frankel)
3) identify gaps and needed research

1130
III. Facilitating data collection for stranding events associated with anthropogenic sounds.

1) review NMFS research in the area (Wieting)
2) review outside research (Hastings)
3) identify gaps and needed research

Working Lunch

1330
IV. Determining causal mechanisms for sound-related strandings.

1) review NMFS research in the area (Gentry)
2) review outside research (Hastings)
3) identify gaps and needed research

1430

V. Assessing population-level impacts of anthropogenic sounds.
1) review NMFS research in the area (Barlow)
2) review outside research (Frankel)
3) identify gaps and needed research

1530
VI. Assessing effects of shipping noise and "call masking" on baleen whales
1) review NMFS research in the area (Southall)
2) review outside research (Frankel)
3) identify gaps and needed research

FRIDAY: 20 Feb 2004

0900
VII. Cumulative Impact of Sounds from Many Sources (eg. southern resident killer whales).
1) review NMFS research in the area (Jones)
2) review outside research (Cottingham)
3) identify gaps and needed research

1000
VIII. Improving knowledge base regarding beaked whales (behavior, distribution, density, CEE).
1) review NMFS research in the area (Barlow)
2) review outside research (Hastings)
3) identify gaps and needed research

1100
IX. Others special species projects. Sperm whale, gray whale, & bowhead whale.
1) review NMFS research in the area (Moore)
2) review outside research
3) identify gaps and needed research

LUNCH

1330
X. Overall discussion
Writing assignments.

1430
Internal NOAA discussion of priorities and budget planning.