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13. ABSTRACT (Maximum 200 words) A three-phased research program was completed to study the effects of SURTASS-LFA sounds on three different species of mysticetes under three different biologically critical contexts. A suite of data collection protocols and techniques were combined to document evidence of response from whales over time scales from a few minutes up to one month, and over distances of approximately 1 to tens of kilometers. Playback experiments were designed to expose whales to received levels of < 155 dB re 1 μ Pa, but it proved difficult to expose animals to levels > 150 dB, and few were exposed to levels >140 dB. A whale's reactions to the LFA sound varied depending on RL, social context and proximity to the coast. Some whales did respond at levels between 110-150 dB range, but all of the observed responses lasted less than an hour and occurred over ranges of less than several kilometers. None of the observed reactions were considered biologically significant even for received levels as high as 150 dB. These results are surprising. They require critical rethinking of existing assumptions about sound exposure impacts on individuals and populations, and a re-evaluation of existing regulations regarding permissible levels of underwater sound exposure.				
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FINAL REPORT

GRANT #: N00014-97-1-1027

PRINCIPAL INVESTIGATOR: Dr. Christopher W. Clark

GRANT TITLE: Responses of Whales to Experimental Playback of Low-Frequency Sound from the Navy SURTASS LFA.

AWARD PERIOD: 15 Aug 97 - 30 Sept 98

OBJECTIVE: The motivation for the research was to study whether and under what conditions LFA acoustic exposures would disrupt the behavior of free-ranging mysticete whales.

APPROACH: The specific research studied the effects of LFA sounds on three different species of mysticetes under three different biologically critical contexts. A three-phased research program was developed. Phase I was conducted during September-October 1997 off San Nicolas Island, California, studying the responses of feeding blue whales (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) to the SURTASS LFA operating from the R/V Cory Chouest (Clark, Tyack and Ellison 1998). Phase II was completed in January 1998, studying the responses of migrating gray whales (*Eschrichtius robustus*) to LFA sounds projected from a source deployed from a vessel moored in the migration area of Pt. Buchon, California (Tyack and Clark, 1998). Phase III was conducted off the Kona coast of the Big Island of Hawaii between February and March 1998, studying the responses of singing humpback whales (*Megaptera novaeangliae*) to the SURTASS LFA operating from the R/V Cory Chouest.

A suite of data collection protocols and techniques were combined to document evidence of response from whales over time scales from a few minutes up to one month, and over distances of approximately 1 to tens of kilometers. These protocols were designed to allow evaluation of impact at a variety of analysis levels ranging from individual animals before, during and after a one hour series of LFA transmissions to distributions of animals during blocks of time with and without LFA transmissions. A major task was to determine how an individual whale's reaction to the LFA sound varied depending on the sound field to which it was exposed.

ACCOMPLISHMENTS: This intensive three-phase field effort was completed between September 1997 and early April 1998. At the end of each phase, the scientific team compiled a Quicklook report that contained a description of the basic methods used for the field research, provided an accounting of the data obtained during the field work, and included some of the preliminary results of the analysis of those data.

Aerial surveys, shipboard visual scans and shipboard visual observations were used to document the occurrence, distribution and behaviors of animals as they appeared at the surface. Acoustic recordings were made from towed hydrophone arrays, autonomous bottom-recording units, and Sound Surveillance System (SOSUS) arrays to describe the underwater sound field (ambient and LFA generated) and the vocal behaviors of whales. Whales were tagged with time-depth-recorders to

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document diving histories and short-term movements. Prey field surveys were conducted to measure the occurrence and characteristics of the food resources within the research area. The research was conducted under NMFS permit #874-1401 with two amendments. An Environmental Assessment (EA) was prepared by others for this research and was a companion to the NMFS permit.

Phase I: The first phase of the SURTASS-LFA-SRP investigated the responses of blue and fin whales in the southern California Bight. The primary research site, centered approximately 10 miles west of San Nicolas Island, was an area where concentrations of feeding blue and fin whales have occurred in recent years. The research was conducted between 5 September and 21 October 1997.

The experimental period occurred between 18 September and 5 October when the SURTASS LFA system on the R/V Cory Chouest was used for transmission loss tests and a series of controlled acoustic playback experiments with blue and fin whales. During this period there were four complete and two partial aerial surveys, two fin whales were successfully tagged with recoverable TDRs, and four prey field surveys were conducted. On 18-19 September the R/V Cory Chouest and R/V Dariabar completed two days of sound measurement work and verified that models for predicting the transmission loss sound field were reliable. Observation efforts from the R/V Dariabar were successful in collecting 4 blue whale focal-follow observations and 15 fin whale focal-follow observations. Four pop-ups were deployed on 29 September.

There were no immediately obvious responses from either blue or fin whales as noted during observations made from any of the research vessels during playback of SURTASS LFA sounds. This was true for all seven focal follow animals (1 blue and 6 fin whales) that were under close observation from the R/V Dariabar during LFA playback. Estimates of the received level for a focal animal during a playback ranged from as low as 115 ± 5 dB re $1 \mu\text{Pa}$ (where the received level is given as the average intensity of the 42 s LFA signal) to as high as $148 \text{ dB} \pm 5$ dB. There was at least one case (on 5 October) when a whale continued to swim past the R/V Cory Chouest in a normal manner at a range of approximately 200 - 300 m while a direct-path playback was underway. The estimate of the maximum received level at this animal was as high as $155 \text{ dB} \pm 5$ dB.

Phase II: The second phase of the SURTASS-LFA-SRP occurred between 8 and 27 January, 1998 and studied the behavioral responses of gray whales during their southward migration past Pt. Buchon, California to SURTASS LFA signals and related stimuli. In addition to determining how the response scaled with received level, we wished to characterize whether the extent of the avoidance response depended on whether the source was in the middle or outside of the migration corridor. For a few playback trials, a pseudo-random noise signal of the same bandwidth as SURTASS-LFA was used to test whether the response was specific to the SURTASS-LFA. Whales were tracked from shore stations for over 150 hours during 18 days, yielding tracks of about 1400 migrating whales using methods that provided highly sensitive measures of avoidance response.

During playback from the nearshore mooring position avoidance responses were often immediately obvious to observers at the shore stations. For the 170 dB source level playbacks conducted from the nearshore position, the avoidance response was similar in scale to the avoidance response reported by Malme et al. (1983, 1984) using a 163 dB source level. Whales appeared to initiate an avoidance response several kilometers north of the source such that their closest range to the playback source was on the order of several hundred meters. For the

higher source level playbacks at 185 dB conducted from the nearshore position, whales avoided the source at greater ranges, indicating that the amount of the avoidance response scales with the source level and therefore presumably the whale's received level. Responses to playbacks from the offshore position were not similar to those from the nearshore position for either the 185 or 200 dB source level. Avoidance responses for the offshore source were greatly reduced compared to responses to the inshore source and did not appear to scale with source level.

Phase III: The third phase of the SURTASS-LFA-SRP was conducted between 26 February and 29 March, 1998 and studied the responses of humpback whales, primarily singers, off the west coast of the Big Island of Hawaii.

A variety of methods were used to study the distribution and abundance of whales during the month of playbacks. Three aerial surveys conducted as part of a separate research project that included the LFA playback area indicate that whales were as abundant or more abundant during 1998 than during either of the two previous years, 1993 and 1995. The distribution of humpbacks during the March 1998 research period was similar to the distributions in the two other years. In all three years, before mid-March, whales on the west coast of the Big Island far outnumbered those on the east coast. After mid-March this ratio approached one-to-one. Shore-based scans and vessel-based sightings showed high day-to-day variability, coupled with a slow decline in the last half of March, a pattern consistent with shore station data from an earlier year.

Estimates of the received level for focal animals during playbacks ranged from as low as 115 ± 5 dB re $1 \mu\text{Pa}$ (where the received level is given as the average intensity of the 42 s LFA signal) to as high as $151 \text{ dB} \pm 5 \text{ dB}$. Many of the whale subjects continued to sing and interact during playback. Some behavioral responses of focal whales were observed during playback. We have only started to analyze the data, but responses observed include cessation of song and an avoidance response. Both of these responses are similar to the responses shown by whales to vessels other than the PBV that approached closely, including the OV. Most of the whales that did respond resumed activities normal for the breeding area within less than an hour. Responses did not scale consistently to received level, and it will be difficult to extrapolate from these results to predict responses at higher exposure levels.

CONCLUSIONS: These playback experiments were designed to expose whales to received levels of < 155 dB re $1 \mu\text{Pa}$. Given the operating constraints for our playback design, it proved difficult to expose animals to levels > 150 dB, and few were exposed to levels > 140 dB. A tremendous effort was invested into using and integrating multiple techniques that provided sensitive measures of response at a number of different temporal and spatial scales. Many of these techniques were developed during previously funded ONR research (time-depth recorder tags, acoustic tracking via passive arrays, autonomous seafloor recorders, dual-mode survey). Responses were measured, but all were over time scales of less than an hour and spatial scales of less than several kilometers. None of the responses resulted in a prolonged disruption to a biologically important behavior (e.g., feeding, migrating, breeding), and nothing that occurred during any of the three phases was considered biologically significant.

SIGNIFICANCE: The U.S. Navy has been developing a high intensity, low-frequency sonar system, SURTASS LFA, for detecting submarines. Prior to this research, an exposure level of 120dB was considered high enough to

cause harassment to marine mammals. As a result of this assumption the potential zone of influence for high intensity manmade sources was enormous and for SURTASS LFA would have included a large percentage of an ocean basin. The motivation for this research was to study whether and under what conditions SURTASS LFA acoustic exposures would disrupt the behavior of free-ranging mysticete whales. A major success of the research was that we were able to determine how an individual whale's reaction to the LFA sound varied depending on the empirically verified sound field to which it was exposed. As a result of this research, some whales were observed responding to levels in the 110-150 dB range, but all of the observed responses lasted less than an hour and occurred over ranges of less than several kilometers. We did not detect any immediately obvious and consistent reactions that were considered biologically significant even for received levels as high as 145 dB. These results, therefore, require that careful reconsideration be given to previously held assumptions about the scales and ranges over which responses to high intensity, low-frequency sounds would occur, and the impact of any reactions on an individual animal's reproductive success and on a population's long-term survival.

PATENT INFORMATION: No patents

AWARD INFORMATION: PI honored with endowed chair.

PUBLICATIONS AND ABSTRACTS:

Clark, C.W. (1998) Whale voices from the Deep: Temporal patterns and signal structures as adaptations for living in an acoustic medium. Abstract presented in May 1998 at the Acoustical Society of America, Seattle, WA

Ellison, W.T. and C.W.Clark (1998) Exploring the form and function of biological sounds in shallow water from the perspective of a systems designer. Abstract presented in Oct. 98 at the Acoustical Society of America Conference in Norfolk, VA.

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4aAB4. Whale voices from the deep: Temporal patterns and signal structures as adaptations for living in an acoustic medium. Christopher W. Clark (Section of Neurobiology and Behavior, Bioacoustics Res. Prog., Cornell Univ., Ithaca, NY 14850, cwc2@cornell.edu)

Whales produce long, rhythmic patterns of sounds and some sounds travel many hundreds of miles underwater. Species can be distinguished by temporal features, but there has been a history of infatuation with melodic qualities as the primary features of measurement. Temporal rates and time-bandwidth products are generally related to bathymetry and transmission properties, suggesting that signal features are adapted for communication and navigation. Pelagic species such as blue and fin whales rely on signals in the 10-30-Hz band, presumably to take advantage of the excellent low-frequency propagation properties of the deep ocean, with 10-200-s patterns of sound delivery. Examples will be presented illustrating the remarkable cadence of signal delivery and that animals retain a rhythm after minutes of silence. Shallow water species produce mid-frequency signals (50-1000 Hz) with temporal patterns on the order of seconds. These species with faster rhythms have greater signal variability covering a greater frequency range. At what level is this relationship between temporal pattern and spectral bandwidth indicative of adaptation to optimize for communication and navigation? Is temporal pattern a retained, conservative feature and spectral variability more of an embellishment by individuals to adjust to local conditions?

ABSTRACT

Exploring the form and function of biological sounds in shallow water from the perspective of a systems designer. William T. Ellison (Marine Acoustics, Inc., PO Box 340, Litchfield, CT 06759) and Christopher W. Clark (Laboratory of Ornithology, Cornell University, 159 Sapsucker Woods Rd., Ithaca, NY 14850)

The potential utility of biological sounds is examined from a sonar system perspective. Evaluation of the temporal, spatial and spectral properties of these sounds from a system designer's view can provide significant insight as to their possible function. The broadband sonar equations for both passive and active operations are used to evaluate this functionality with special attention paid to issues of shallow water propagation as well as those sound properties that most effect signal processing; time-bandwidth product, spatial and temporal resolving characteristics, and signal repetition rate. Specific examples are used to illustrate these findings, including blue and fin whale calls recorded in the near-shore waters off Southern California, bowhead whale calls from the spring migration off the coast of Barrow, Alaska, and humpback whale sounds recorded off the Island of Hawaii. The use of a systems approach to evaluating biological sounds also provides insight into several related areas of recent interest: 1) the effects biological sounds may have on man-made systems, 2) the effect man-made sounds may have on the ability of animals to communicate as well as acoustically sense their environment, and 3) designing underwater experiments to evaluate these issues.