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New Directions in the Study of Low-Frequency Sound in Baleen

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6. AUTHORS
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13. ABSTRACT *(Maximum 200 words)*

Integrated field research was conducted on the potential impact of man-made underwater sound on marine mammals and the functions of the low-frequency sounds of whales. This was accomplished using passive acoustics, active acoustics, tagging, vessel survey, biopsy sampling, and photo-ID. Relationships were determined between low-frequency vocal rates of individual fin (*Balaenoptera physalus*) whales; the identity and sex of singers; and the presence, number and distribution of animals. All singers (n=9) were males. There were correlations between number of whales seen, level of vocal activity and number of singers. There were associations between where and when males sang, food distribution and feeding activity. Contrary to previous assumptions singers concentrated near high densities of food and sang more during periods of high feeding activity. Resultant data are important for estimating relative abundance based on passive acoustic monitoring systems and for models (e.g., AIM) used to predict acoustic impact for mitigation purposes. By placing the biologically important behavior of acoustic communication within the appropriate ecological context, hypotheses on communication functions (e.g., whale sounds are detected throughout the oceans on IUSS) can be tested. This should result in a more rigorous understanding on the potential impact of human-produced LFS on large whales.

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Final Technical Report

Grant: N00014-99-1-0244

PI: Christopher W. Clark (e-mail: cwc2@cornell.edu) (see grant to Don Croll, UC Santa Cruz)

PI Institution: Cornell University, Lab of Ornithology, 159 Sapsucker Woods Rd., Ithaca, NY 14850

Grant Title: New Directions in the Study of Low-Frequency Sound in Baleen Whales

Award period: June 1999- December 2001

Program objective: The objectives were to understand the potential impact of man-made underwater sound on marine mammals and the functions of the low-frequency sounds of whales, and to examine whether low-frequency vocalization rates can be used to indicate the presence of animals and number of individuals in an area. An addendum to this primary research objective was to design, build and deliver oceanographic instrumentation for real-time and remote monitoring, detection, location and tracking of marine mammals.

Approach: The working hypotheses were that marine mammal sounds are produced for communicating, navigating, and finding food. To test these hypotheses we used an integrated approach involving scientists with expertise in whale acoustics; foraging and tagging; vessel survey; biopsy sampling; and photo-ID. This combination allowed us to place the various vocal behaviors, often from known individuals, within the proper ecological framework. By this procedure, interpretations of vocal functions were related to the sex of the individual and the proper context within which the behavior occurred.

Accomplishments: Field research was conducted in winter/spring 1999 and 2000. A seafloor array of autonomous recording units (pop-ups) were deployed in the field for 18 and 21 days, respectively. These data were post-processed to yield positions and movements of all vocal animals throughout the study area. During daily fieldwork, we integrated information on prey fields, water temperature, marine mammal sighting density, individual diving/movement patterns, and acoustic activity (from 16-element towed array). Directions to individual animals producing long sequences of 20-Hz sounds (songs) were computed in real-time and coordinated with visual sightings to direct the biopsy team to vocal animals. All singing fin whales (n=9) were males. Systematic visual survey and Photo-ID efforts were conducted. These combined with the pop-up data allowed us to compare the total number of animals utilizing the study area by three independent methods.

As an addendum to this main research project, six pop-up data collection modules and six signal conditioning interface units were sent to John Potter at the University of Singapore.

Significance: The new evidence from the Sea of Cortez shows that there is a definite correlation between total number of animals seen and the level of vocal activity and number of singers. Furthermore, there are positive associations between where and when males sing, food distribution and feeding activity. Contrary to previous assumptions that singing is a male reproductive display only associated with breeding, singers were concentrated near high densities of food and more singing occurred during periods of high feeding activity. The relevance of these new findings is that the impact of man-made sounds on baleen whale communication must be extended into the feeding context which involves a significant portion of the year in various habitats. By placing this biologically critical singing behavior within the appropriate ecological context, we can now focus on the most appropriate hypotheses regarding the biological function of these common vocal productions (e.g., they are detected throughout the oceans on IUSS). This should result in a more rigorous understanding on the impact of human-produced LFS on large whales.

We now have data that will allow us to directly measure natural variability in male sound production (e.g., song duration, source level). Such data on natural variability are important for models (e.g., AIM) used to predict acoustic impact for mitigation purposes. These sound production data are also critical for estimating relative abundance based on passive acoustic monitoring systems.

From this research, we can now compare estimates of relative abundance based on three independent sampling methods (acoustic monitoring, visual survey, and photo-id), collected simultaneously and systematically for a relatively well-defined population of animals. These results provide a quantitative basis for evaluating the effectiveness of acoustic techniques to monitor marine mammal seasonal distributions and occurrence on a broader scales. This addresses the need to reliably and efficiently determine the presence and density of animals, and to reliably detect changes in their distribution and abundance under conditions when human-produced LFS is and is not present.

Pop-up technology was transferred to another ONR-funded project (John Potter at the University of Singapore). Four units were deployed, three were lost, and the unit that was successfully retrieved contained useful data.

Refereed Publications (published or in press):

Croll, D.A., Clark, C.W., Calambokidis, J., Ellison, W.T., and Tershy, B.R. 2001. Effect of Anthropogenic Low-Frequency Noise on the Foraging Ecology of *Balaenoptera* Whales. Animal Conservation 4:13-27.

Croll, D.A., Clark, C.W., Acevedo, A., Tershy, B., Flores, S., Gedamke, J. and Urban, J. Accepted. Most powerful biological sounds in the ocean likely male breeding displays. Nature.

Book Chapters:

Bass, A. H. and Clark, C.W. In press. The physical acoustics of underwater sound communication. Pp. XX-XX, in Springer Handbook of Auditory Research (A. M. Simmons, A. Popper and R. R. Fay, eds.). Springer-Verlag.

Clark, C. W., and Ellison, W.T. In press. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. Pp. XX-XX, in Echolocation in Bats and Dolphins (J. Thomas, C. Moss and M. Vater, eds.). The University of Chicago Press.

Potential Use of Low-Frequency Sounds by Baleen Whales for Probing the Environment: Evidence from Models and Empirical Measurements

C. W. Clark[a], W. T. Ellison[b] and L. Hatch[c]

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Natural variability within a population is the fodder for selection, and an organism with traits best adapted to its environment is most likely to transfer genes to the next generation. Here we take the simplistic view that acoustic characteristics shared broadly across multiple species are considered more ancestral than features only shared at the species level. This conceptual framework is the basis for gauging the degree to which, and the approximate order in which the physical environment has effected the features of baleen whale (mysticetes) sounds. Comparison of mysticete sound characteristics and evaluation based on several predictions of sonar equations support the hypothesis that sounds from shallow water and deep water species are matched to their respective environments so as to optimize underwater sound transmission for long-range communication. We propose that in the marine environment the influences of physical acoustics imposed strong selective pressures on the acoustic features of whale sounds. In some species for which selection has favored very long-range communication signals, we propose a secondarily derived function, that animals use reflections of their sounds as a simple form of echo-ranging to navigate and orient relative to physical features of the ocean.

WHALES AND SOUND PROPAGATION

Within the group of whales known as mysticetes, bowhead and right whales are considered the least evolutionarily derived, while blue and fin whales are considered to have evolved more recently. All mysticete species produce calls, while blue, bowhead, fin and humpback whales also produce long, patterned sequences of sounds referred to as songs which are sung by males. The primary function of calls and songs is assumed to be for communication between individuals.

In the marine habitat, the physical environment strongly influences acoustic transmission range. From an evolutionary perspective, and assuming that many mysticete whale sounds function for long-range communication, we propose that the physical environment would have imposed strong selective pressures on the acoustic features of whale sounds. Given the dramatic differences between sound propagation in shallow and deep water environments, we predict major differences between the acoustic characteristics for species that spend significant portions of their lives in coastal versus pelagic habitats. These concepts are developed by careful consideration of the broadband sonar equation, with particular attention to signal features that increase transmission range and signal detection [1,2].

SIGNAL FEATURE PREDICTIONS

The implications from these considerations indicate that selection should favor whales that produce signals matched to a frequency band with low transmission loss and low ambient noise. In biological terms, center frequency and bandwidth are predicted as two signal features that selection should act upon to increase detection probability and recognition. Further advantages would be gained by increased signal intensity, redundancy and stereotypy, and by auditory thresholds matched to low level ambient noise conditions in the signal frequency band. Signal bandwidth is an enormously beneficial factor as it offers the possibility for a receiver to successfully detect and recognize the signal in environments where portions of the signal are lost due to such factors as frequency dependent multi-path effects or masking. Bandwidth removes peaks and nulls that would otherwise be present in a pure tone transmission. The result is a more well behaved signal and one that is easier to detect and recognize. Therefore, selection should favor animals with sensory perception and processing mechanisms that take advantage of signal bandwidth within a frequency band window of low transmission loss and low ambient noise.

RESULTS

In shallow coastal habitats (<100m), empirical and modeled physical acoustic transmission loss and ambient noise evidence predict that selection should favor whale sounds in the intermediate, 100-500Hz frequency band. In deep (>1000m) water, similar considerations indicate that selection should favor whale sounds in the low frequency, 10-100Hz band. Phylogenetic evidence supports the working assumption that early mysticetes were shallow water grazers that later moved offshore into deeper water where they could exploit major food resources that occur seasonally along up-sloping edges as found around seamounts and along continental shelves. At such locations, the ocean temperature varies dramatically with depth, and refraction, in combination with extremely low levels of absorption, can lead to exceptionally low levels of transmission loss and extremely long ranges of acoustic transmission [3]. Low-frequency, ambient noise in the deep ocean is probably dominated by wind from high latitudes, while the present-day dominant source is from commercial shipping. In general, ambient noise level in the deep ocean is inversely related to frequency. However, there appears to be a plateau in ambient noise in the 10-100 Hz band. A comparison of mysticete sound characteristics shows that signal features are well matched to the acoustic constraints of the shallow and pelagic habitats. Bandwidths and peak frequencies for calls and songs of the three coastal species, are between 25-600 Hz, and 150-400 Hz, respectively, while bandwidths and peak frequencies for the two pelagic species are between 3-25 Hz and 18-35 Hz, respectively. Both these sets of acoustic characteristics are well matched to the acoustic transmission properties and ambient noise conditions of the respective environments. Further pronounced differences between songs for species in these two environments are found in signal redundancy and stereotypy. We conclude that the most sounds of baleen whale have acoustic characteristics that are well adapted for long-range communication within a species' predominant breeding and feeding environment.

SECONDARY HYPOTHESIS

Through further consideration of a more speculative nature, but grounded in basic principles, we propose that in some species for which selection has favored extremely low-frequency, stereotypic and redundant signals, a secondary function for these sounds has evolved. This secondary function is a form of echo detection and ranging. We propose that some species use the reflections of their sounds from natural ocean boundaries to navigate and orient. An empirical example for a blue whale approaching Bermuda shows that in this scenario physical acoustics is not a limiting factor in the detection of a reflection off the base of Bermuda. We conclude that there is no *a priori* reason, based on transmission properties of the environment and other physical acoustic considerations, to reject the hypothesis that certain baleen whales could use sounds for echo-ranging. However, there are presently no direct, unequivocal data to support this hypothesis. Despite this lack of evidence, we propose the following mechanism for the evolution of an echo-detection and echo-ranging function. As low-frequency signals became increasingly better adapted for very long-range communication within the deep-sea environment, selection favored signals that were infrasonic, intense, stereotypic and redundant. These last three features are also advantageous for detection of reverberation and reflection. Thus, there was a secondary selective advantage to individuals producing and perceiving these signals as an aide in long-range navigation and orientation along the shelf edge and in the deep ocean.

ACKNOWLEDGMENTS

Research support was provided by the National Geographic Society, New York Zoological Society, National Science Foundation, Naval Research Lab, North Slope Borough Department of Wildlife Management, and the Office of Naval Research. Jack Bradbury, Donald Croll, and Kurt Fristrup all provided helpful insights and stimulating comments.

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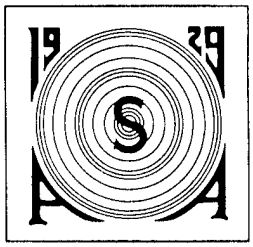
2. F. B. JENSEN, W. A. KUPERMAN, M. B. PORTER, AND H. SCHMIDT, *Computational Ocean Acoustics*, American Institute of Physics, New York, 1994.

3. R. PAYNE AND D. WEBB, Annals of the New York Acad. Sci. 188,110-141 (1971.).

FLT =1039 C.W CLARK

THE JOURNAL of the Acoustical Society of America

Vol. 106, No. 4, Pt. 2, October 1999 http://asa.aip.org



138th Meeting
Acoustical Society of America

Hyatt Regency Columbus Hotel
Columbus, Ohio
1–5 November 1999

Table of Contents on p. A5

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Session 4aUW

Underwater Acoustics, Acoustical Oceanography and Animal Bioacoustics: The Effect of Man-Made Sound on Marine Mammals I

James F. Lynch, Chair
Woods Hole Oceanographic Institution, 203 Bigelow Building, Woods Hole, Massachusetts 02543

Chair's Introduction—8:00

Invited Papers

8:05

4aUW1. An acoustic integration model (AIM) for assessing the impact of underwater noise on marine wildlife. William T. Ellison (Marine Acoust., Inc., P.O. Box 340, Litchfield, CT 06759), Karen Weixel (Marine Acoust., Inc., Middletown, RI 02842), and Christopher W. Clark (Cornell Univ., Ithaca, NY 14850)

In recent years there has been a heightened awareness of the environmental impact of noise, especially man-made noise, on marine wildlife. The National Environmental Policy Act (NEPA), Executive Order 12114, The Endangered Species Act, The Marine Mammal Protection Act, and the Coastal Zone Management Act each provide for varying levels of regulation and control in protection of the environment and marine wildlife. In order to assess the environmental impact of a sound source, one must predict the sound levels that any given species will be exposed to over time in the locale of the source's radiated field. This is a three-part process involving (1) the ability to measure or predict an animal's location in space in time, (2) the ability to measure or predict the sound field at these times and locations, and finally, (3) integration of these two data sets so as to determine the net acoustic impact of the sound source on any specific animal. This paper describes a modeling methodology for accomplishing this task. Model inputs required to specify the acoustic environment, animal distribution and behavior, and sound source characteristics are discussed in detail. The AIM model output capabilities are described together with topical examples.

Session 4pUW

Underwater Acoustics, Acoustical Oceanography and Animal Bioacoustics: The Effect of Man-Made Sound on Marine Mammals II

Peter L. Tyack, Chair

Department of Biology, Woods Hole Oceanographic Institution, 45 Water Street, Woods Hole, Massachusetts 02543-1049

Chair's Introduction—1:30

Invited Papers

1:35

4pUW1. Acoustic responses of Baleen whales to low-frequency, man-made sounds. Christopher W. Clark (Bioacoust. Res. Prog., Cornell Univ., Sapsucker Woods Rd., Ithaca, NY 14850), Peter L. Tyack (Woods Hole Oceanogr. Inst., Woods Hole, MA 02543), and William T. Ellison (Marine Acoustics, Inc., P.O. Box 340, Litchfield, CT 067591

In the last 5 years, two projects were undertaken to evaluate impacts of man-made sounds on whales. Baleen whales were identified as "at risk" because of their use of low-frequency sound for communication, their endangered status, and studies showing responses to continuous noises at exposure levels >120 dB, re: 1 μPa. To evaluate the potential impact of operational ATOC (195-dB source intensity), humpback whales off Kauai were studied during the breeding season. To evaluate the potential impact of U.S. Navy SURTASS LFA sonar, playback experiments were conducted on four species at exposures of 120–155 dB. LFA research was designed to obtain responses during feeding (blue and fin whales, southern California, September–October), migration (gray whales, central California, January) and breeding (humpbacks, Hawaii, March). For the ATOC source, humpbacks showed statistically significant but subtle responses over small time and spatial scales. There were no changes in singing, or larger-scale changes in distribution or relative numbers. For LFA experiments off southern California, whales did not change vocal rates or leave the testing area, and there were no immediately observable responses, even at exposure levels up to 150 dB. Tyack (this session) will discuss results from the gray and humpback whale LFA experiments.

The Journal of the Acoustical Society of America

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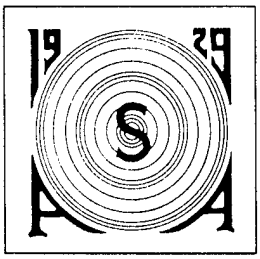
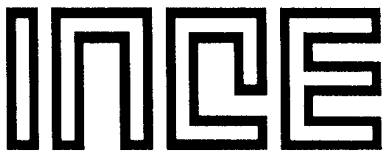


Acoustical Society of America



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Program of the 140th Meeting

NOISE-CON 2000

Newport Beach Marriott Hotel
Newport Beach, California
3–8 December 2000

Table of Contents on p. A5

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Session 3aABa

Animal Bioacoustics: Use of Acoustics for Wild Animal Surveys

3aABa3. Multi-modal surveys of fin whales in the Sea of Cortez, Mexico. Christopher W. Clark, Don A. Croll, Alejandro Acevedo, and Jorge Urban-Ramirez (Cornell Lab. of Ornithology, Bioacoustics Res. Prog., 159 Sapsucker Woods Rd., Ithaca, NY 14850, cwc2@cornell.edu)

A population of fin whales (*Balaenoptera physalus*), resident to the Gulf of California, Mexico, was studied over two seasons using an integrated approach. Systematic vessel-based visual survey and photo-ID efforts were conducted every 5–7 days to independently estimate the number and distribution of whales within a 10×30 mi^2 study area. Some whales were tagged with time-depth-recorders. Sets of 5–6 distributed autonomous seafloor acoustic recorders, operating continuously during each season's research period, were used to detect, locate, and track vocalizing whales. A 16-element towed array tracked individual vocal whales in real-time concurrently with visual observations, allowing biopsy samples of known vocal animals. Active acoustics was used to collect data on the density and distribution of krill so as to place measured variation in whale numbers, distribution, and behavior within an ecological context. The primary whale activity was feeding. Whale feeding patterns and survey distribution followed prey distribution. Vocal whale distribution followed dial feeding patterns and prey distribution. All biopsied vocal animals were males. Numbers of whales estimated by vessel survey, photo-ID, and passive acoustics were correlated. Results suggest that under certain conditions, vocal activity is a reliable measure of distribution and relative abundance. [Work supported by ONR.]

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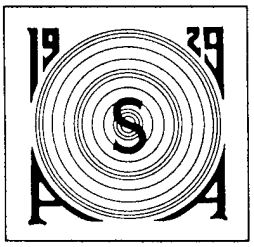

142nd Meeting
Acoustical Society of America

Greater Fort Lauderdale ♦ Broward County Convention Center
Fort Lauderdale, Florida
3–7 December 2001

Table of Contents on p. A5

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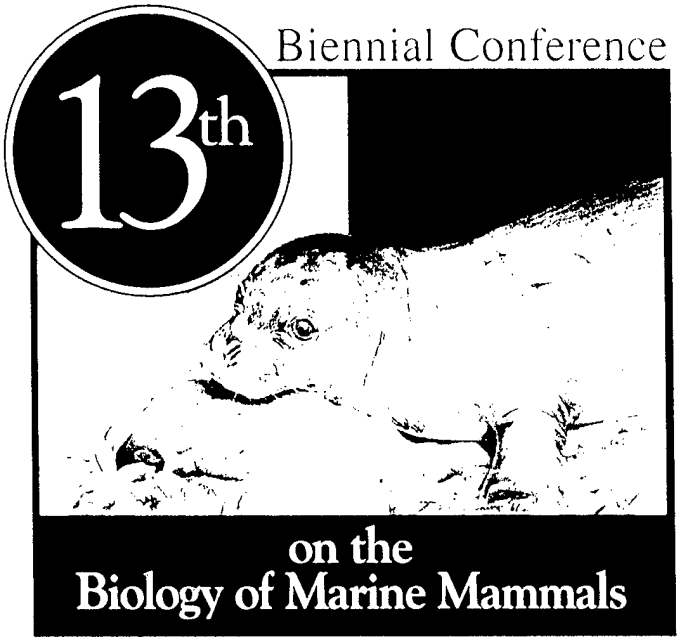
4pABb4. Baleen whale responses to low-frequency human-made underwater sounds. Christopher W. Clark and Kurt M. Fristrup (Bioacoustics Res. Prog., Cornell Lab of Ornithology, 159 Sapsucker Woods Rd., Ithaca, NY 14850)

Baleen whales are vulnerable to impact from human-made underwater sounds. Most species produce communication calls and some sing, with most sound energy between 20 and 2000 Hz. Cochlear mechanics indicate inner ears well adapted for hearing below 1000 Hz. Many species breed and calve in coastal habitat, or feed along shelf edges or areas of ocean upwelling, and are frequently exposed to noise from commercial and recreational activities. Humans have become increasingly more adept at and dependent on exploring the ocean with acoustic probes. Sound sources are typically high intensity and in the primary acoustic production and perception frequencies of the baleen group. Evaluation of impact is difficult, confounded by a general lack of basic knowledge on baleen whale behavioral ecology, distribution, and abundance, and signal function. Results from three integrated research projects investigating whale responses to controlled exposures to Navy low-frequency sonar (LFA) indicate relatively low levels of short-term responses, even at received exposures as high as 150 dB *re*: 1 Pa. Results are interpreted relative to possible population level impact from an operational source. Results support a conceptual shift in impact from a single source, while emphasizing the need for a coherent, cautionary policy regarding cumulative and long-term impacts on the ocean environment. [Research supported by ONR.]



Nov. 28 - Dec. 3, 1999
The Society for Marine Mammalogy

ABSTRACTS

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RELATIONSHIP BETWEEN FIN WHALE VOCAL ACTIVITY, DISTRIBUTION, ABUNDANCE, AND PREY DISTRIBUTION IN THE SEA OF CORTEZ, MEXICO

Clark, Christopher[1], Croll, Don[2], Tershy, Bernie[2], Acevedo, Alejandro[2], Gedamke, Jason[2], Urban-Ramirez, Jorge[3]

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The biological significance of long, patterned sequences of whale sounds has traditionally been attributed to male reproductive displays. Several recent studies have documented high levels of fin and blue whale vocal activity at high latitudes during periods of summer feeding. We examined the relationship between temporal and spatial patterns in fin whale distribution, abundance, and vocal activity and sea surface temperature and prey concentrations in the Sea of Cortez, Mexico. Net sampling and whale diet revealed that whales fed exclusively upon dense schools of Nyctiphanes simplex aggregated between 80-120m during the day and in the upper 40m at night in close proximity to regions of steep topographic relief. The horizontal and vertical, spatial and temporal distribution and abundance of whales correlated with temporal and spatial distribution patterns of euphausiids. During the day, whale dive depth matched the vertical distribution of krill (80-120m). During the night, when euphausiid schools disperse and move vertically to within 40 m of the surface, whales remained in this shallow layer. Vocal activity also followed a diurnal pattern, with lower sound rates (300-600 sounds/h) between 2300-0600h and high rates (600-1000 sounds/h) between 900-1300 and 1800-2200h. Period s of lower sound rates corresponded to periods when whales were traveling (shallow dives, directed movement, and shorter surfacing intervals) in areas with relatively low prey. We propose that fin whales: 1) are attracted to areas of seasonally abundant, predictably high densities of euphausiids; 2) concentrate their foraging efforts on dense aggregations of euphausiids found at discrete water depths, following distinct diel prey patterns; and 3) produce patterned sequences of sounds at relatively high rates throughout weeks of intense feeding and in close association with diel feeding patterns, not to directly find food but to coordinate feeding activity.

INVOLUTION OF LYMPHOID TISSUES IN BOTTLENOSE DOLPHINS OF THE WESTERN GULF OF MEXICO

Clark, Lance S.[1], Turner, Jason P.[3], Cowan, Daniel F.[2]

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Involution of lymphoid tissues in relation to age has not been defined for bottlenose dolphins (*Tursiops truncatus*). Twenty-seven bottlenose dolphins were examined, which had either: stranded alive and died, stranded already deceased, or were incidental net-captures. Animals were collected by the Texas Marine Mammal Stranding Network and sampled within 24 hours of death. Collection area encompassed the entire Texas coast and western Louisiana. Ages (determined by growth layer groups) ranged from several days to 27 years. Histology of four lymphoid tissues (thymus, tonsil, large intestine, and anal canal) was assessed by assigning a numerical value to its condition or stage of involution. Thymus values included: type of lobules (0-3), differentiation between cortex and medulla (0-1), presence of and degree of fibrosis (0-3), and formation of cysts (0-2). Tonsil scoring included: presence of germinal centers (0-2), presence of mucous glands (0-2), and condition of crypts (0-1). Anal canal scoring included: lymphoid aggregates (0-2), presence of germinal centers (0-2), presence of mucous glands (0-2), and condition of crypts (0-1). Large intestine scoring included: lymphoid aggregates (0-2), and presence of germinal centers (0-2). By assigning a score to lymphoid tissues and comparing them to age, we were able to follow involution over time. Young animals (<6 yrs), showed minimal involution by having fully developed thymus (scoring an average of 2.8 "2.5) and tonsils (1.9 "1.2). These animals also showed numerous lymphoid aggregates in large intestine (1.8 "1.4) and anal canal (1.8 "0.8). Older animals (>6 yrs), showed a high degree of involution within thymus (5.0 "2.2), a lack of lymphoid aggregation in large intestine (3.1 "0.6) and anal canal (2.9 "0.9), and tonsils showed minimal involution (2.5 "1.5). Although the thymus is thought to be completely involuted in older animals, it was present in animals as old as 24 yrs.

ANALYSIS OF FOOD REMAINS FROM STOMACHS OF ELEVEN *KOGIA BREVICEPS* (CETACEA, PHYSETERIDAE) STRANDED IN HAWKE BAY, NORTH ISLAND, NEW ZEALAND

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Stomach contents were examined from eleven adult *Kogia breviceps* stranded in Hawke Bay, on the East coast of North Island, New Zealand. Five were males and three were females and, those measured, were between 220cm and 308cm in length. The stomachs contained cephalopod beaks, intact and partial remains of Gnathophausia ingens, and a few fish bones, including otoliths. All but 4 of the 980 cephalopods, represented by lower beaks, were oceanic, midwater squids belonging to at least 29 species in 16 families. Two octopod species were only represented by 4 beaks. The major cephalopod constituents of the Kogia diet were Histioteuthis spp. (65% by number and 72% by estimated wet weight), Cranchiids (20 % by number, 9% by weight), Ganeledonines (only 0.2% by number but 4.2% by weight), Pholidoteuthis sp. (only 0.6% by number but 3.4% by weight) and ommastrephids (1.1% by number and 3.2% by weight). Comparisons with similar collections from Kogia made elsewhere and Physeter catodon caught near New Zealand by commercial activities in the 1960s and one stranded on the West side of North Island, New Zealand indicate that Kogia and Physeter overlap in the choice of midwater cephalopods. However, Kogia avoids the largest species (e.g. Architeuthis), targets smaller individuals of the same species and includes smaller species than those eaten by Physeter (e.g. enoploteuthids). In contrast to the sperm whales, cephalopod species in the diet suggest that none of the Kogia had been in Antarctic waters immediately prior to stranding.

STABLE ISOTOPES IN COASTAL SYSTEMS: IMPLICATIONS FOR FOSSIL MARINE MAMMAL STUDIES

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Coastal systems are some of the most productive ecosystems in the modern world and the location for the initial evolution of modern marine mammal lineages. The ability to differentiate habitats within this complex ecosystem would help in deciphering the steps involved in the evolution of several marine mammal groups, including sirenians, cetaceans, and pinnipeds. Stable isotopes provide one possible means of characterizing

14th BIENNIAL CONFERENCE ON THE BIOLOGY OF MARINE MAMMALS

ABSTRACTS

NOVEMBER 28 - DECEMBER 3, 2001 VANCOUVER B.C. CANADA

1 1 using the Simple Ratio Index (0 = never photographed ways photographed in the same group). The overall mean was 0 04 (SD 0.19), with the highest associations, alf pairs, found between adult females (mean 10, SD 0 25). In contrast, adult males were never ith each other, but were photographed either in ales or as solitary individuals. Our results suggest that area, *M. densirostris* exhibits a relatively fluid system of ation in which associations within and among age/sex classes escribed by a harem mating system.

Comparative Analysis of Baleen Whale Songs: Predictions from Acoustic Propagation and Implications for Mating Strategies

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All baleen whale species produce sounds and at least five species (blue, bowhead, fin, humpback and minke) produce long, patterned, hierarchically organized sequences of sounds referred to as songs. The primary assumed function of all these vocal behaviors is communication. It is assumed that singing is a male reproductive display and that selection should favor songs with acoustic features adapted for long-range communication. Physical acoustic models and empirical evidence predicts selection should favor different acoustic characteristics for coastal and deep ocean habitats. Quantitative comparison supports the prediction and reveals that humpback and bowhead songs share features well adapted for shallow-water propagation, while blue and fin songs share acoustic characteristics adapted for deep-water propagation. Songs for both groups are well matched to the frequency band of low ambient noise and low transmission loss for the species' primary habitats. Differences between song characteristics for the two ecological regimes include bandwidth, time-bandwidth product, center frequency, redundancy and stereotypy. Songs of coastal singers are centered in the 100-400 Hz band, have high time-bandwidth products, and individual sound units are highly variable. Songs for pelagic singers are centered in the 10-40 Hz band, have modest time-bandwidth products, and are highly redundant and stereotypic. Propagation considerations predict that communication ranges for coastal and pelagic species are different by at least an order of magnitude. Increased spatial and temporal sampling reveals that singing occurs throughout a large portion of the year and over large portions of a species range, and is often associated with regions of prey productivity. The results imply that food resource distribution and density may play a larger role in baleen whale mating strategies than presently considered.

Blood Cells of Australasian Otariids: Characteristics of Cell Morphology Based on Light and Electron Microscopy

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Little has been published on the haematology of southern otariids (New Zealand fur seal (*Arctocephalus forsteri*, Af), Australian fur seal (*A. pusillus doriferus*, Apd), subantarctic fur seal (*A. tropicalis*, At), Australian sea lion (*Neophoca cinerea*, Nc) and New Zealand sea lion (*Phocarctos hookeri*, Ph). There are no reports on cell morphology or cellular changes associated with inflammation or other pathologies. This can hinder the interpretation of findings in the investigation of unusual mortality events. Blood was collected from captive and free-ranging animals (19 Af, 2 Apd, 8 At, 2 Nc, 11 Ph). Blood films were made on collection and, stained and examined by light microscopy. Transmission electron microscopy (TEM) was carried out on Ph cells while scanning EM was carried out on Af cells. Examples of erythrocytes, leukocytes, and platelets are described. In brief, the neutrophils, lymphocytes and monocytes had similar morphology in all species examined. Some variation in the number, size, hue and density of the granules of the granulocytes was noted between species. The eosinophils of sea lions appear to have "muddy" coloured cytoplasm at lower power examination and are easily misidentified as neutrophils. The basophilic cytoplasm should not be interpreted as "toxic" neutrophils. Platelet aggregation was noted in all samples and was probably an artefact of venepuncture. This should be considered when determining platelet concentration. There was a good correlation between the ultrastructure and the light microscopic interpretation of various kinds of leukocytes. The ultrastructure of Ph leukocytes is similar to those from terrestrial mammals.

Environmental Mitigation of a Navy Ship Shock Trial

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The U.S. Navy conducted a ship shock trial of an Aegis Class Destroyer, the Winston S. Churchill, offshore Mayport FL in May and June of 2001. Environmental mitigation to minimize the impact of the shock trial on marine life was an essential component in the planning of the shock trial. The objectives of the mitigation and monitoring plan included: assisting in the selection of a test site which posed the least risk to the marine environment; monitoring the test site prior to each detonation in an effort to ensure it was free of visually and acoustically detectable marine mammals and sea turtles; and conducting post detonation surveys of the test site to measure the effectiveness of mitigation procedures. Three shots were detonated between 24 May and 11 June. Pre-detonation monitoring included visual observations from dedicated observation aircraft and the Winston S. Churchill as well as passive acoustic monitoring. Post-detonation examination of the detonation site and areas down-current was carried out via visual monitoring from dedicated observation aircraft and the Marine Animal Recovery Team (MART) vessel. No dead or injured marine mammals or turtles were detected during broad-scale post-detonation monitoring. Lessons learned from this shock trial will be incorporated into planning for subsequent shock trials.

Seasonality in Hector's Dolphin Distribution and Density in the Banks Peninsula Marine Mammal Sanctuary, New Zealand

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New Zealand's endemic and endangered Hector's dolphin (*Cephalorhynchus hectori*) is notably regional and coastal in its distribution. This species was rapidly declining throughout the 1980s due to fisheries by-catch and slow growth rates. Attempts to reduce fisheries impacts began in 1988 with the establishment of the Banks Peninsula Marine Mammal Sanctuary. Despite this, recent population viability analyses have shown that the Sanctuary population still has a 94% probability of decline. Fifteen years of sighting data within the Sanctuary were analyzed to determine spatial and temporal distribution and density patterns. During the warmest of the Austral summer months, January and February, standardized estimates of dolphins observed within the Sanctuary ranged between 350-400 per day. Akaroa Harbour had the highest annual and overall density of Hector's dolphins recorded. Several relatively smaller yet temporally consistent "hotspots" of dolphins were also pinpointed along the Southern and Eastern sides of the Peninsula. Fewer dolphins, approximately 60-90 animals per day, were observed within the Sanctuary boundaries during the coldest of the Austral winter months (June and July). Winter "hot spots" differed from those in summer being relatively less dense and located farther offshore (43% of sightings occurring between 2-4 nautical miles of shore). During the winter, the Banks Peninsula Marine Mammal Sanctuary is effectively protecting only 17-23% of the dolphins estimated to reside there during summer months. Dolphins may be migrating north, south, and/or offshore of the boundaries and possibly subjected to increased levels of fisheries by-catch. These results emphasize the urgent need to understand this species' movement patterns in particular during the colder months when there may be an increased overlap with fisheries effort. Without this data, the effectiveness of the Sanctuary alone to aid the recovery of this population is in question.

Fractographic Analysis of Manatee Rib Bone

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