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3 July 1997

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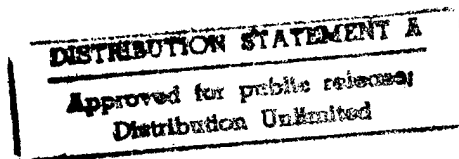
Dear Bob,

Enclosed please find your two copies of the final report for ONR grant N00014-94-1-0872. We have sent three copies to the ONR Scientific Officer (Code 323B), two copies to the Defense Logistics Agency, one copy to the ONR Administrative Grants Officer, and one copy to the Director of Naval Research Lab.

Sincerely,

Dr. Christopher W. Clark, Director
Bioacoustics Research Program
Senior Scholar/Senior Scientist
Section of Neurobiology and Behavior
Lab of Ornithology

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FINAL REPORT

GRANT #: N00014-94-1-0872

PRINCIPAL INVESTIGATOR: Dr. Christopher W. Clark

INSTITUTION: Cornell University

GRANT TITLE: Potential Effects of LFS on Mysticete Whales: An analysis of Bioacoustic Signals from IUSS under normal and conditions of human-made acoustic activity.

AWARD PERIOD: 6/15/94-2/15/97

OBJECTIVE: To describe seasonal variations in acoustic signals, distributions, and movements for blue, finback, and minke whales in the north Atlantic using data from LANTIUSS facilities. Data on seasonal occurrence of humpback whales (not covered in original proposal) were also analyzed. Such data provide an essential baseline for assessing impacts of man-made low-frequency sound (LFS) on whales, and for evaluating Navy compliance with marine mammal protection regulations.

APPROACH: Seasonal and geographic variation in the vocal behaviors of fin, blue, and minke whales throughout the western North Atlantic were characterized using data collected from established SOSUS arrays by the Naval Ocean Processing Facility (NOPF) at Dam Neck, VA. Studies focussed principally on (1) seasonal and geographic occurrence of whale vocalizations throughout the North Atlantic, and (2) seasonal and geographic variation in the structure of whale vocalizations (e.g., temporal patterning within call sequences from individual whales). The data used in these studies consisted of: (1) data forms summarizing whale detections and individual whale movements across array beams, as logged by Navy personnel at NOPF Dam Neck, and (2) beamformed acoustic time series data. Analysis of acoustic data relied on automatic call-detection algorithms developed for this and a previous ONR project.

ACCOMPLISHMENTS:

Protocols and tools for data collection and analysis: We established procedures for identifying, locating, and tracking individual whales. We developed and installed versions of the Advanced Canary workstation (Macintosh-based scientific digital signal processing (DSP) system), at NOPF Dam Neck and other IUSS facilities. We implemented refinements to an automated whale call detection algorithm that was originally developed under a previous ONR grant.

Seasonal and geographic variation in acoustic detections: We accumulated over 2.5 years of whale detection data from the operational WESTLANT SOSUS arrays; only one year of data were available from the Bermuda arrays, which were deactivated in November 1994. From these data we compiled summaries of acoustic detections for blue, fin, and minke whales over much of the western North Atlantic. We also compiled detection summaries for humpback whales for this same region (although humpbacks were not included in the original proposal). All four species exhibit annual cycles of calling (Figure 1).

Variation in acoustic structure of whale calls: Acoustic recordings from the three focal whale species (blue, finback, and minke) were systematically collected from SOSUS arrays throughout the western North Atlantic. We described typical sounds from blue, finback, and minke whales (Figure 2). We measured temporal and frequency characteristics of call sequences from 213 finback and 126 blue whales, and looked for patterns of geographic and seasonal variation in these parameters. Figure 3 illustrates how time and frequency data from a sequence of calls from a single fin whale are summarized.

CONCLUSIONS: Fin, blue, minke, and humpback whales all exhibit annual cycles of calling. Peak numbers of blue and finback whales occur in December, January, and February. Minke and humpback whales follow a similar annual pattern, but shifted about two months later, with their peak vocal activity in March and April. These seasonal patterns of calling appear to be the same throughout the western half of the Atlantic (from Newfoundland to Puerto Rico). Fin, blue, and minke whales all exhibit modest amounts of individual variation in the temporal and frequency characteristics of their call sequences. For the most part, these variations are not systematically related to season or location. However, in fin whales, the durations of pulse-sequences and the gaps between sequences both tend to be shorter at higher latitudes.

SIGNIFICANCE: The whale detection data collected by the IUSS have provided us with the first ocean-scale view ever compiled of the distribution of acoustic activity of pelagic whales. The analyses of the acoustic time-series data have provided the first large-scale assessment of variability in the acoustic behavior of fin, blue, and minke whales. These studies are unprecedented both in their geographical scope and in the level of detail available about the acoustic behavior of individual whales. They demonstrate the unique power of existing IUSS assets to collect large quantities of acoustic data on numerous individual whales across a vast geographic area. Such studies could not be undertaken without access to IUSS resources. The information on ocean-scale temporal patterns of vocal activity could be used to evaluate and minimize potential impacts of man-made LFS on acoustic communication in the four whale species that were studied. Data on individual-scale variation in acoustic features can provide critical baseline information for use in future studies of possible impact of human activities on the acoustic behavior of whales.

PATENT INFORMATION: None.

AWARD INFORMATION: Promoted to Senior Scientist-Senior Scholar at Cornell University.

PUBLICATIONS and ABSTRACTS (selected):

Clark, C.W. and Fristrup, K. M. in press. Whales '95: A combined visual and acoustic survey of blue and fin whales off southern California. Rep. int. Whal. Commn. 47:xx-xx.

Clark, C.W. 1995. Application of US Navy underwater hydrophone arrays for scientific research on whales. Annex M (Matters Arising out of a Discussion of Blue Whales), Rep. int. Whal. Commn. 45: p. 210-212.

(Complete publication list attached.)

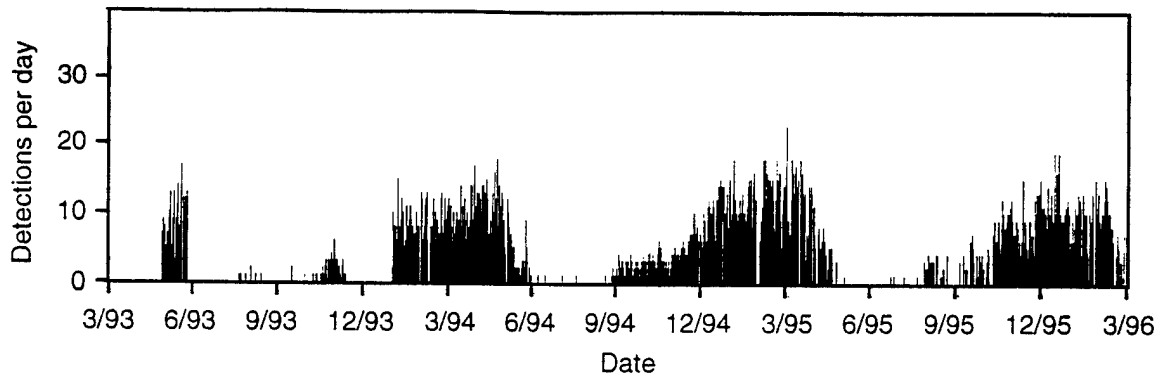


Figure 1. Numbers of finback whales detected per day on one WESTLANT SOSUS array over three years.

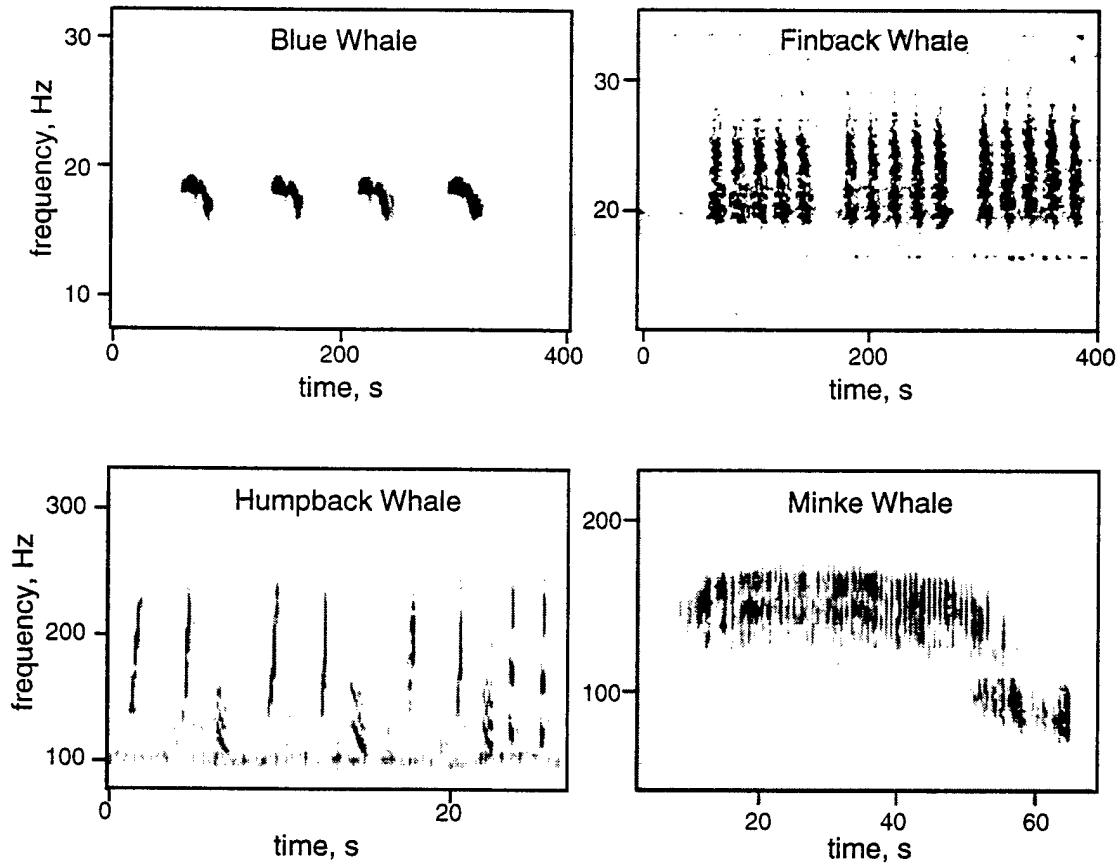


Figure 2. Sound spectrograms of typical acoustic signals from four species of baleen whales as detected by WESTLANT SOSUS arrays.

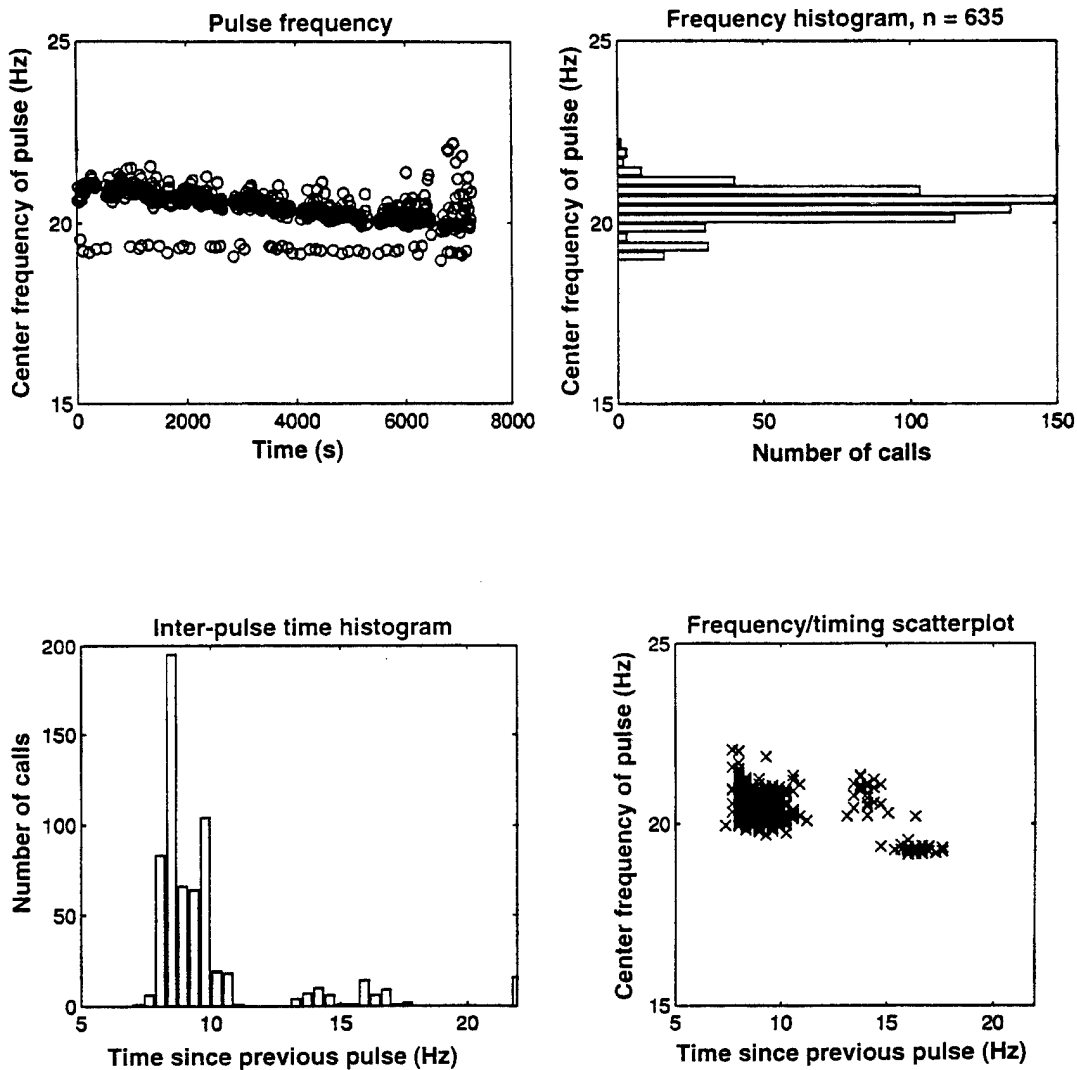


Figure 3. Sample plots summarizing frequency and temporal parameters of a single two-hour sequence of calls from one finback whale as recorded on a WESTLANT SOSUS array.

POTENTIAL EFFECTS OF LOW-FREQUENCY SOUND ON MYSTICETE WHALES:
ANALYSIS OF BIOACOUSTIC SIGNALS FROM IUSS UNDER NORMAL AND
CONDITIONS OF HUMAN-MADE ACOUSTIC ACTIVITY
Cornell University
PUBLICATIONS & ABSTRACTS

- Clark, C.W. 1995. Acoustic behaviors of blue and finback whales: insights from the Navy's dual uses program. Invited paper, XXIV International Ethological Conference, Aug. 1995, Honolulu, HI. Abstract, p.35.
- Clark, C.W. 1995. Application of US Navy underwater hydrophone arrays for scientific research on whales. Annex M (Matters Arising out of a Discussion of Blue Whales), Rep. int. Whal. Commn. 45: p. 210-212.
- Clark, C.W. 1995. Update on the Application of US Navy Underwater Hydrophone arrays for Scientific Research on Whales. Working Paper SCWP14 presented during the IWC Scientific Committee, Dublin, Ireland, May 1995.
- Clark, C.W. 1995. Acoustic tracking of whales using hydrophone arrays: implications for behavioral studies and population estimates. 129th Meeting of the Acoustical Society of America, Washington, D.C., May-June 1995. Abstract: J. Acoust. Soc. Am. 97(5), pt. 2, p. 3352.
- Clark, C.W. 1995. Application of hydrophone arrays for whale research. Invited Paper, European Cetacean Society February 1995, Lugano, Switzerland. Abstract. p 17.
- Clark, C.W. 1994. Blue deep voices: Insights from the Navy's Whales '93 program. Whalewatcher 28 (1):6-11.
- Clark, C.W. 1998. in press. Noise in the Ocean. In: 1998 McGraw-Hill Yearbook of Science and Technology.
- Clark, C.W., and D.K. Mellinger. 1994. Sound production from blue, finback and minke whales: implications for basic research and environmental monitoring. Abstract, International School of Ethology, 9th Workshop: Underwater Bioacoustics: Behavioural, Environmental & Evolutionary Perspectives. Erice-Sicily, 4-9 November 1994.
- Clark, C.W. and D.K. Mellinger. 1994. Application of Navy IUSS for whale research. 128th Meeting of the Acoustical Society of America, Austin, TX, Nov., 1994. Abstract: J. Acoust. Soc. Am. 96 (5), Pt.2, p. 3315.
- Clark, C. W., Tasker, M., et al. 1997. Monitoring the occurrence of large whales off North and West Scotland using passive acoustic arrays. Invited Paper. Society of Petroleum Engineers/UKOOA European Environmental Conference, Aberdeen Scotland, 15-16 April, 1997. 9pp.
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- Fristrup, K., and C.W. Clark. in press. Combining visual and acoustic survey data to enhance density estimation. Rep. int. Whal. Commn. 47:xx-xx.
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- Mellinger, D.K., and C.W. Clark. in press. Methods for automatic detection of mysticete calls. To appear in: Marine and Freshwater Physiology.
- Mellinger, D.K., and C.W. Clark. 1995. Characteristics of fin and blue whale vocalizations recorded from IUSS in the north and west Atlantic. Eleventh Biennial Conference on the Biology of Marine Mammals, December 1995, Orlando, FL. Abstract. p. 76.
- Mellinger, D.K., and C.W. Clark. 1994. Measuring regular whale call intervals with the summed autocorrelation. 128th Meeting of the Acoustical Society of America, Austin, TX, Nov., 1994. Abstract: J. Acoust. Soc. Am. 95(5), 2881. 1994.
- Mellinger, D.K., and C.W. Clark. 1994. A publicly-accessible database for marine mammal call classification research. 128th Meeting of the Acoustical Society of America, Austin, TX, Nov., 1994. Abstract: J. Acoust. Soc of Am., 96 (5), Par 2, p 3298. 1994.
- Potter, J.R., D.K. Mellinger, and C.W. Clark. 1994. Marine mammal call discrimination using artificial neural networks. Published in J. Acoust. Soc. Am., 96(3), p1255-1262..
- Spikes, C.H. and Clark, C.W. 1996. Whales '95 - Revolutionizing Marine Mammal Monitoring Technology. Sea Technology. April 1996; 49-53.

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