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14. ABSTRACT

This was part of the first major project addressing the potential impact of an operational DoD LFS source on free-ranging marine mammals. Based on available prior research, the expectation was that we would detect obvious and statistically significant responses at received levels of around 120dB re 1 μPa, and that such changes would be manifested across multiple measures. This was not entirely the case. Although our measures were sensitive enough to detect subtle changes indicating that animals detected the sound, animals were tolerant of received levels between 120-130dB. Most tests for statistical significance were negative. The few statistically significant behavioral responses were subtle, short-term and small-scale. All responses were small relative to natural variation, leading to the interpretation that ATOC LFS has a negligible impact on marine mammals.

15. SUBJECT TERMS

Low frequency sound (LFS), marine mammals, ATOC, acoustics

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Final Progress Report

Grant: N00014-97-1-0571
Title: Potential Effects of Low Frequency Sounds on Marine Mammals
PI: Walter Munk and Christopher W. Clark (e-mail: cwc2@cornell.edu)
PI Institution: Scripps Institution of Oceanography, 9500 Gilman Dr., La Jolla, CA 92093-0225; Cornell University, Laboratory of Ornithology, 159 Sapsucker Woods Rd., Ithaca, NY 14850
Award period: April 1, 1997 through September 30, 1999
Reporting period: April 1, 1997 through September 30, 1999

Program objectives: The overall objectives were to establish methods and collect data to quantify the potential impact of Low Frequency Sound (LFS) on marine mammals, and to evaluate methodologies and resulting data to provide guidance for monitoring and mitigating for the impacts of DoD operations that produce LFS in the marine environment.

Approach: To test the hypothesis that marine mammals are affected by exposure to DoD LFS operations, we used an integrated approach involving acoustics, behavioral observation, tagging, aerial survey, and photo-ID on selected free-ranging marine mammal species (elephant seals, blue, humpback, and sperm whales) under control and experimental conditions. The LFS experimental condition used the underwater transmitters off Pioneer seamount (PSM) and Kauai, HI installed for the Acoustic Thermometry of Ocean Climate (ATOC) project. The integrated approach and use of the LFS transmitter allowed us to document potential responses under operational conditions and place any observed responses within the proper ecological framework.

Accomplishments: Field research was conducted at two sites (PSM, CA; Kauai, HI) during 1997 and 1998 as a continuation of earlier research. Data were analyzed for the significance of differences in measures (surface behaviors, vocal activity, movements, distribution and density) between control and experimental conditions. Levels of acoustic exposure were quantified based on empirical validation of sound field models for predictive value. For translocated elephant seals based on time-depth recorder and acoustic data logger tags there were statistically significant changes in dive profile and speed. For humpback (fall feeding) and sperm whales (winter) around PSM there were statistically significant differences in the distribution over time scales of several years. For humpback off Kauai, HI (winter calving and breeding) there were statistically significant differences in a few surface activity measures. There were no immediately obvious responses to the onset of the LFS-ATOC signal. All statistically significant differences for behaviors were subtle and of short duration (< 30min). The small but statistically significant differences in distribution for the PSM region do not appear to be long-term.

Significance: This was part of the first major project addressing the potential impact of an operational DoD LFS source on free-ranging marine mammals. Based on available prior research, the expectation was that we would detect obvious and statistically significant responses at received levels of around 120dB re 1 μPa, and that such changes would be manifested across multiple measures. This was not entirely the case. Although our measures were sensitive enough to detect subtle changes indicating that animals detected the sound, animals were tolerant of received levels between 120-130dB. Most tests for statistical significance were negative. The few statistically significant behavioral responses were subtle, short-term and small-scale. All responses were small relative to natural variation, leading to the interpretation that ATOC LFS has a negligible impact on marine mammals.

The broad integrated research approaches developed for this project spanning biology, oceanography, and acoustics were initially a challenge to implement. However, these working relationships paved the way for other integrated programs on LFS (e.g., DoD LFA SRP). This approach underscores the need for advances in technology (tags, acoustic methods, survey), statistical analysis of large spatial and temporal data sets, and the training of students in these various multidisciplinary fields. Of even greater challenge and a major source of energy drain were the nearly constant public hearings and presentations before various agencies, environmental groups and news organizations. These unexpected distractions to the science underscore the global need for scientists to better articulate to the public about the process of science and the value of research.

All these results for the ATOC LFS can be placed in a broader perspective now that the topic of LFS in general is better understood. The two operational 195 dB re 1 μPA ATOC sound sources produced an intentionally distinctive sound field that did not cause abandonment of critical habitat or abnormal behaviors within the local marine mammal communities. Most animals experienced relatively small levels (<130dB) of sound exposure and the probability of an animal receiving a high acoustic dose (>130dB) were extremely small. Careful thought has lead to identification of the specific fulcrums of uncertainty. Research has lead to quantification of biological response and a fuller understanding of potential environmental impact.

Work Plan: We have completed all the research and are in the final stages of analysis and write up of papers for submission to peer reviewed scientific journals.

Publications, Abstracts, Technical Reports, Patents, and Awards (all years):

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Blackwell, S.,B., Haverl, C.,A., LeBoeuf, B. J., and Costa, D. P. 1999. A method for calibrating swim speed recorders. Marine Mammal Science 15(3):894-905.

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Costa, D. P. 1999. Graduate Students of Kenneth S. Norris. Marine Mammal Science 15(4):645-946.

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Costa, D. P. and Crocker, D. E. 1999. Whales and Porpoises Pages 1015-1020 *in* Encyclopedia of Reproduction Vol. 4. Academic Press, New York.

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Costa, D. P. and Hayes, S. A. 2000. Underwater Sound and Marine Mammals. 2001 Yearbook of Science and Technology. McGraw Hill, New York.

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Costa, D. P., Crocker, D. E., Webb, P.M., Waples, D., Houser, D., Goley, D., LeBoeuf, B., and Calambokidis, J. 1997. The California Marine Mammal Research Program of the Acoustic Thermometry of Ocean Climate Experiment: Potential effects of low frequency sound on distribution and behavior of marine mammals. California and the World Oceans Symposium Volume.

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Frankel, A. S. and C. W. Clark. 2000. Behavioral Responses of Humpback Whales (*Megaptera novaeangliae*) to Operational ATOC signals. J. Acoust. Soc. Am. 108:

Hayes, S.A., Mellinger D.K., Croll, D.E. and Costa, D.P. 2000. An inexpensive passive acoustic system for recording and localizing wild animal sounds. Journal Acoustical Society of America: 107(6):3552-3555.

LeBoeuf, B.J., Crocker, D.E., Costa, D.P., Blackwell, S.B., Webb, P.M. and Houser, D.S. 2000. Foraging ecology of northern elephant seals. Ecological Monographs 70(3):353-382.

Mobley, J.R. Jr., Bauer, G.B., & Herman, L.M. (1999). Changes over a ten-year interval in the distribution and relative abundance of humpback whales (*Megaptera novaeangliae*) wintering in Hawaii. Aquatic Mammals 25(2):63-72.

Webb, P.M., Crocker, D.E., Blackwell, S.B., Costa, D.P. and LeBoeuf, B.J. 1998. Effects of buoyancy on the diving behavior of northern elephant seals. Journal of Experimental Biology 201: 2349-2358.

Wells, R.S., Rhinehart, H.L., Cunningham, P., Whaley, J., Baran, M., Koberna C., and Costa D.P. 1999. Long distance offshore movements of bottlenose dolphins Marine Mammal Science 15(4):1098-1114.

PAPERS SUBMITTED

Crocker, D.E., D.P. Costa, B.J. LeBoeuf, P.M. Webb and D.S. Houser. Impact of El Niño on the foraging behavior of female northern elephant seals. Submitted Marine Biology Progress Series.

Frankel, A. S., and Clark, C. W. Factors affecting the distribution and abundance of humpback whales off the North Shore of Kaua'i. Submitted Marine Mammal Science.

Costa, D.P., D.E. Crocker, J. Gedamke, P.M. Webb, D. Houser, S. Blackwell, D. Waples, S. Hayes and B.J. LeBoeuf. 2000. Effects of the ATOC sound source on the diving behavior of northern elephant seals, *Mirounga angustirostris* Submitted Ecological Applications.

REPORTS

Mobley, Jr., J.R., Grotefendt, R.A., Forestell, P.H. and Frankel, A.S. (1999). Results of aerial surveys of marine mammals in the major Hawaiian Islands (1993-98): Final Report to the Acoustic Thermometry of Ocean Climate Program (ATOC MMRP), 34 pp.

Mobley, Jr., J. R., Forestell, P. H. and Grotefendt, R. (1997). Preliminary results of 1993 and 1995 aerial surveys in Hawaiian waters. In: P.M. Payne, B. Phillips and E. Nitta (Eds.) Report of the workshop to assess research and other needs and opportunities related to humpback whale management in the Hawaiian Islands, April 26-28, Kaanapali, Maui, Hawaii. pp. 1-7.

Mobley, Jr., J. R., Forestell, P. H. and Grotefendt, R. (1994). Results of 1993 aerial surveys in Hawaiian waters. In: 1993 ATOC Marine Mammal Research Program Annual Report (Ann Bowles, editor), submitted to Advanced Research Projects Agency (ARPA).

Costa, D.P. and S.A. Hayes. 2000. Underwater Sound and Marine Mammals. 2001 Yearbook of Science and Technology. McGraw Hill, New York.

AWARDS

C.W. CLARK, 1998 elected to Fellow of the Acoustical Society of America.

ANNUAL REPORT QUESTIONNAIRE

1 April 1997 – 31 August 1999

Contract/Grant Number: N00014-97-1-0571

Contract/Grant Title: Potential Effects of Low Frequency Sounds on Marine Mammals

Principal Investigator(s): Walter Munk and Christopher W. Clark

PI Institution: Scripps Institution of Oceanography and Cornell University

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Your site URL:Cornell: birds.cornell.edu/BRP

Award Period: 1 April 1997 – 31 August 1999

Cognizant ONR Scientific Officer: Dr. Robert Gisiner

Technology Transfer: A combination of acoustic methods were developed for and applied during the research. The objective was to develop and implement tools to enable measurement of free-ranging marine mammal surface and dive behaviors, acoustic activity, and distribution. Several of the methods were extensions of tools initially developed with previous ONR support (e.g., elephant seal tags, vessel acoustics). Autonomous seafloor acoustic recorders, referred to as "pop-ups", were modeled after existing oceanographic tools but with modifications to make their use more amenable to marine mammal research. All methods were later employed in 1997-1998 for the LFA Scientific Research Program, and the lessons learned from this research significantly advanced their application in the LFA-SRP project. We have no immediate plans or funds for a technology transfer of these method to an operational DoD context. However, the techniques and protocols developed for this research could be readily transferred to other situations where realtime marine mammal mitigation and monitoring procedures are required (e.g., LFA, MF sonars).

There were extensive interactions with a wide range of organizations and agencies regarding the potential impact of the Acoustic Thermometry of Ocean Climate LFS on marine mammals. This included appearances in Congress and at State and Federal public hearings, participation in workshops, and supporting the development of the EISs for the project. The lessons learned for this project were incredibly valuable for the LFA SRP project and EIS process.

ONR Database Statistics:

a. Number of papers submitted to refereed journals but not yet published: 3
b. Number of papers published in refereed journals: 11
c. Number of books or chapters submitted but not yet published: 2
d. Total Graduate Students: 7
e. Number of books or chapters published: 2
f. Number of printed technical reports/non-refereed papers: 4
g. Number of patents filed: 0
h. Number of patents granted: 0
i. Number of invited presentations: 6
j. Number of submitted presentations: 2
k. Honors/Awards/Prizes for grant/contract employees (attach list): 1
l. Total number of Graduate Students and Post-Doctoral associates supported during this period, under this grant/contract: 19

Total Graduate Students: 12
Female Graduate Students: 4
Minority* Graduate Students: 0
Asian Graduate Students: 0
Total Post-Doctoral Associates: 7
Female Post-Doctoral Associates: 2
Minority* Post-Doctoral Associates: 0
Asian Post-Doctoral Associates: 0

m. Other funding - none

Potential Effects of Low Frequency Sounds on Marine Mammals

W. Munk, Scripps Institution of Oceanography and C.W. Clark, Cornell University

Objectives:

¥ Potential impact of low frequency sound (LFS) on marine mammals

¥ Data on monitoring and mitigating for guidance on impacts of DoD LFS operations in the marine environment

Approach:

¥ Integrated field studies on selected free-ranging species using operational LFS-ATOC system under control and experimental conditions

Accomplishments:

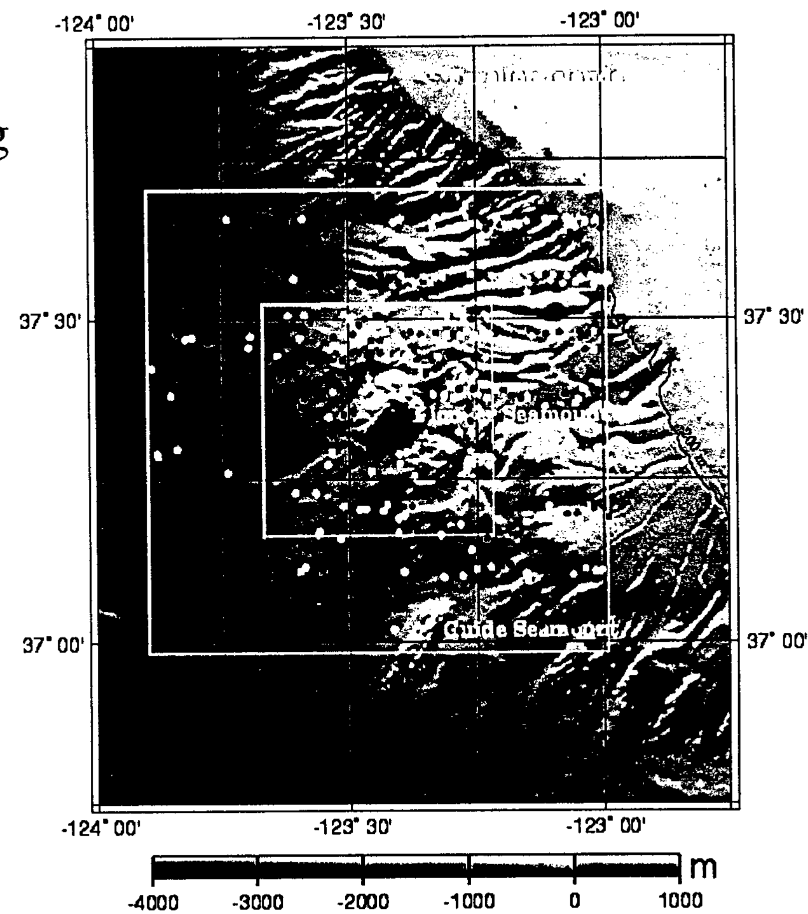
¥ Multiple field studies using sensitive measures of response

¥ Some short-term responses detected, but none considered biologically significant

Impact and Transition:

¥ Low potential for ATOC impact on marine mammals

¥ Techniques to improve mitigation and monitoring of LFS impacts



Humpback Whale Observations Through February 1997.

Control Period in Black   Experimental Period in White

Captions for supporting view graphs

1. (previous page) Distribution of humpback whales based on aerial survey sightings during control and experimental conditions, where experimental condition refers to blocks of days during which the LFS-ATOC source was transmitting for 25 minutes once every four hours.

2. Distribution of sperm whales based on aerial survey sightings during control and experimental conditions, where experimental condition refers to blocks of days during which the LFS-ATOC source was transmitting for 25 minutes once every four hours.

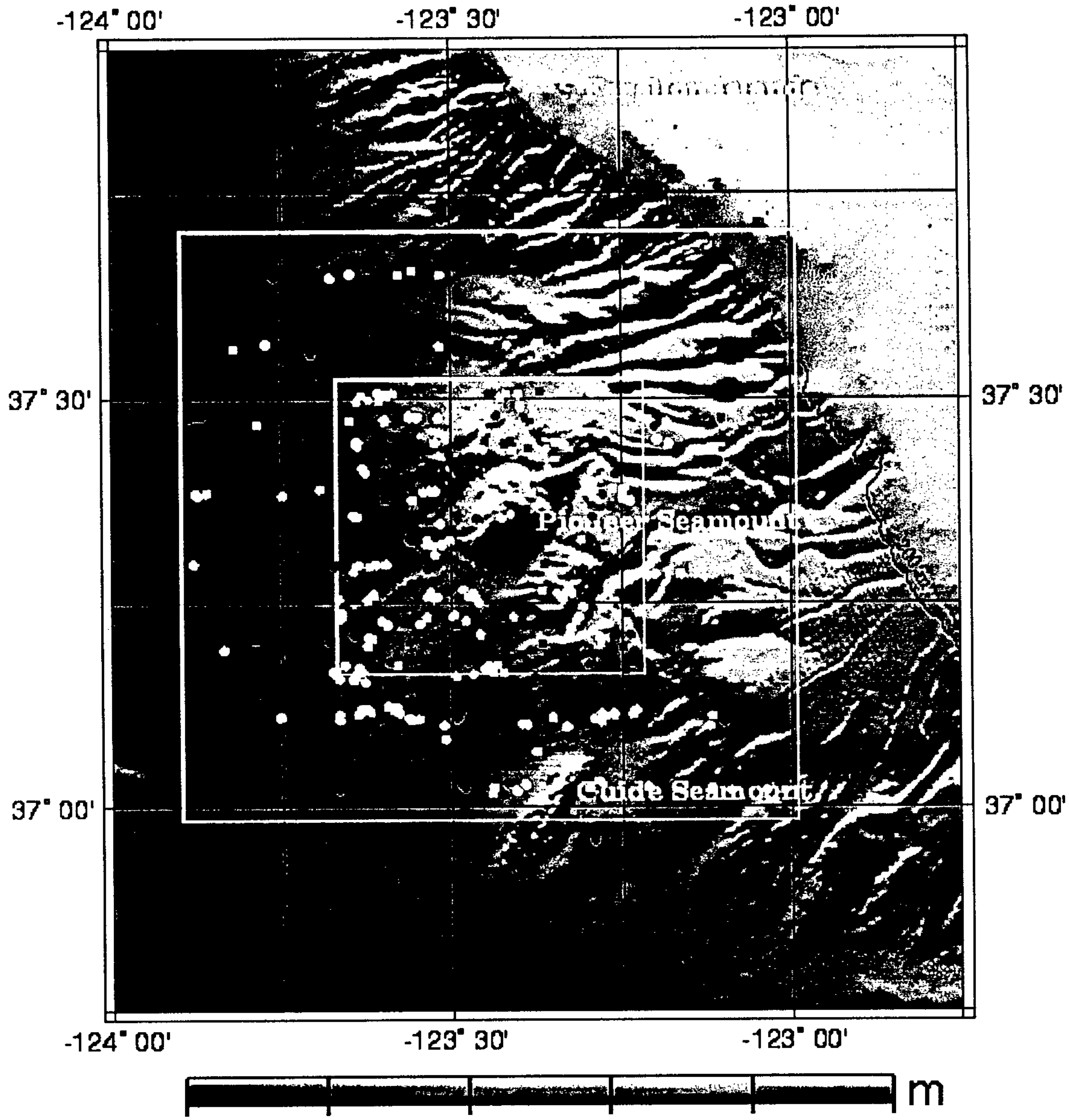
3. An example of the data collected on juvenile elephant seals that passed near the ATOC sound sources. The top chart is a sound spectrogram, the middle the swim speed record and the bottom the time-depth record. The 5-minute ramp up period is shaded in light gray and the 20 minutes full power operational period in darker gray. The 5-minute ramp started 5 minute prior to the hour and full power occurred on the hour. Points on the time-depth record delineate where the various sound pressure level measurements were taken from the spectrogram.

4. Spectrogram for 24-hour period on 3 September 19976 during experimental ATOC conditions. Data are for a single hydrophone from the Pt. Sur SOSUS array. Six ATOC transmissions are evident as well as considerable noise from vessel traffic.

5. Plot showing the measured received level as a function of range for the ATOC LFS source off north Kauai. This transmission loss (TL) plot illustrates a) the dramatic difference between the empirically based TL values (45 Log [range]) and TL predicted from spherical spreading (20 Log [range]), and b) the effect of shallow water on TL.

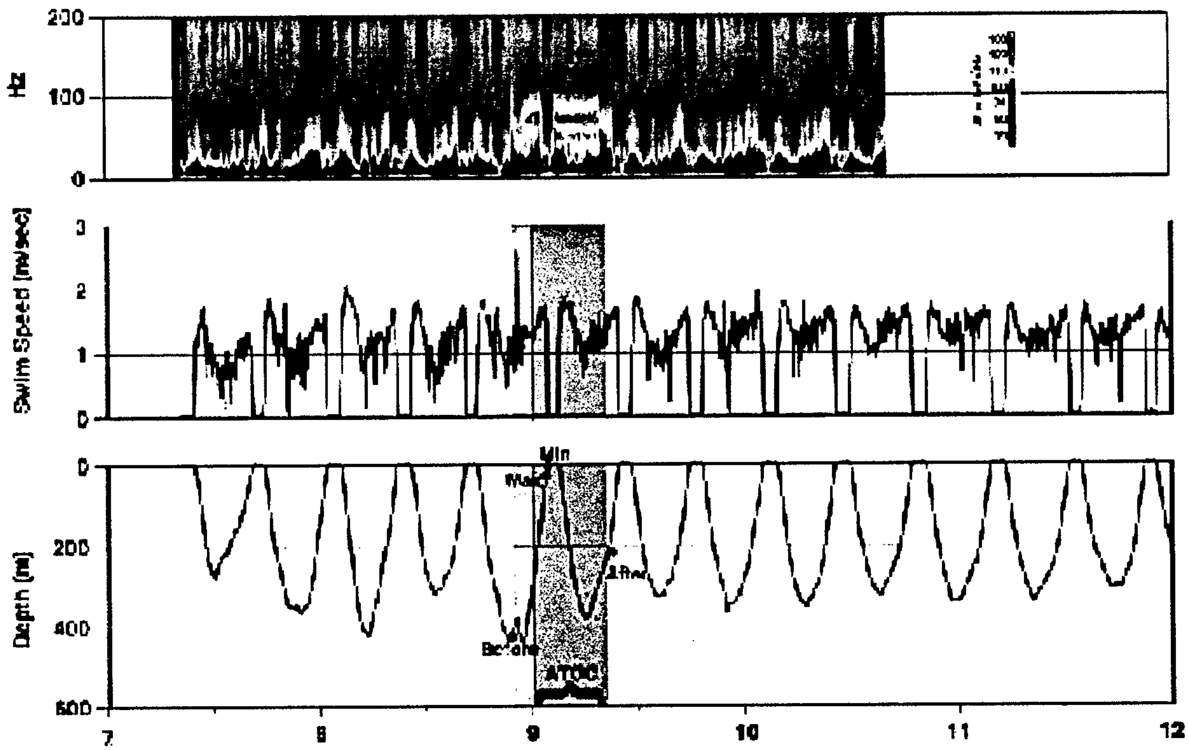
6. Plot of relationship between adjusted segment length (the normalized distance between two surfacings) for humpback whale pods off north Kauai and estimated received level of the ATOC sound at the pod. Multiple regression analysis revealed that received level was a significant factor affecting segment length.

7. Histogram comparing the relationship between number of humpback whale pods and their distance from the Kauai ATOC source during periods when the source was off (control) and on (ATOC). There was a very small, but statistically significant difference between these control and ATOC distributions.



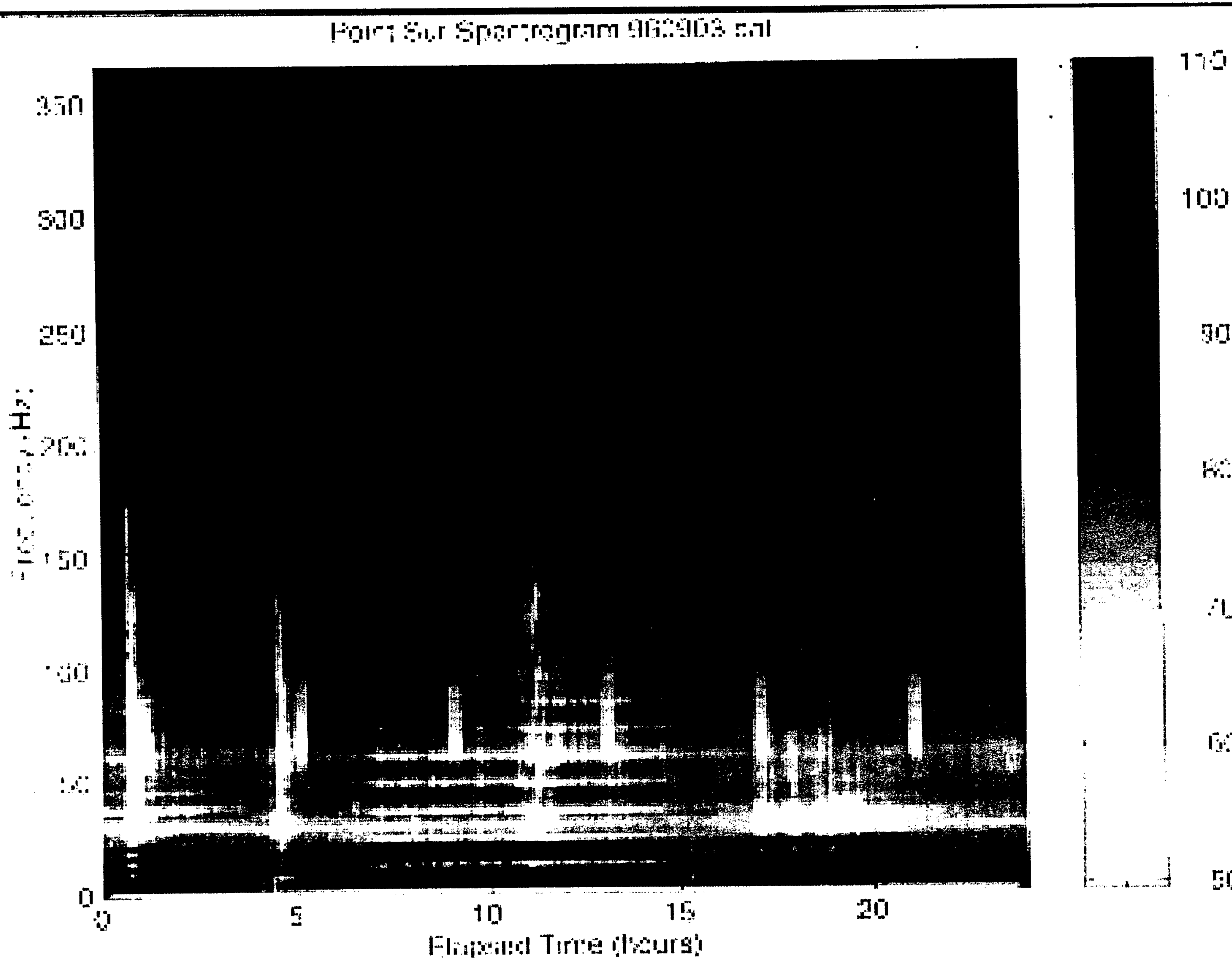
Sperm Whale Observations Through February 1997.

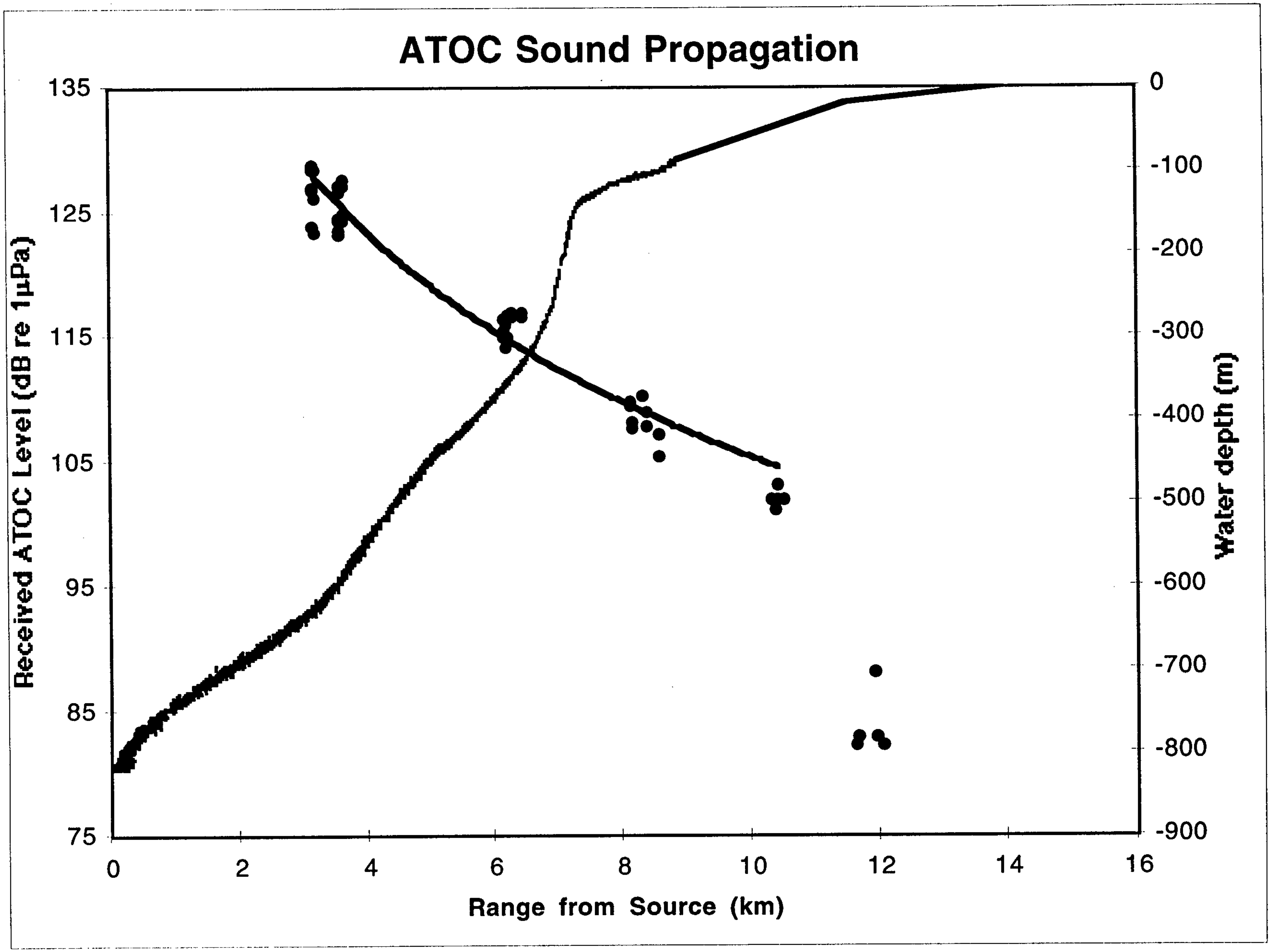
Control Period in Black Experimental Period in White



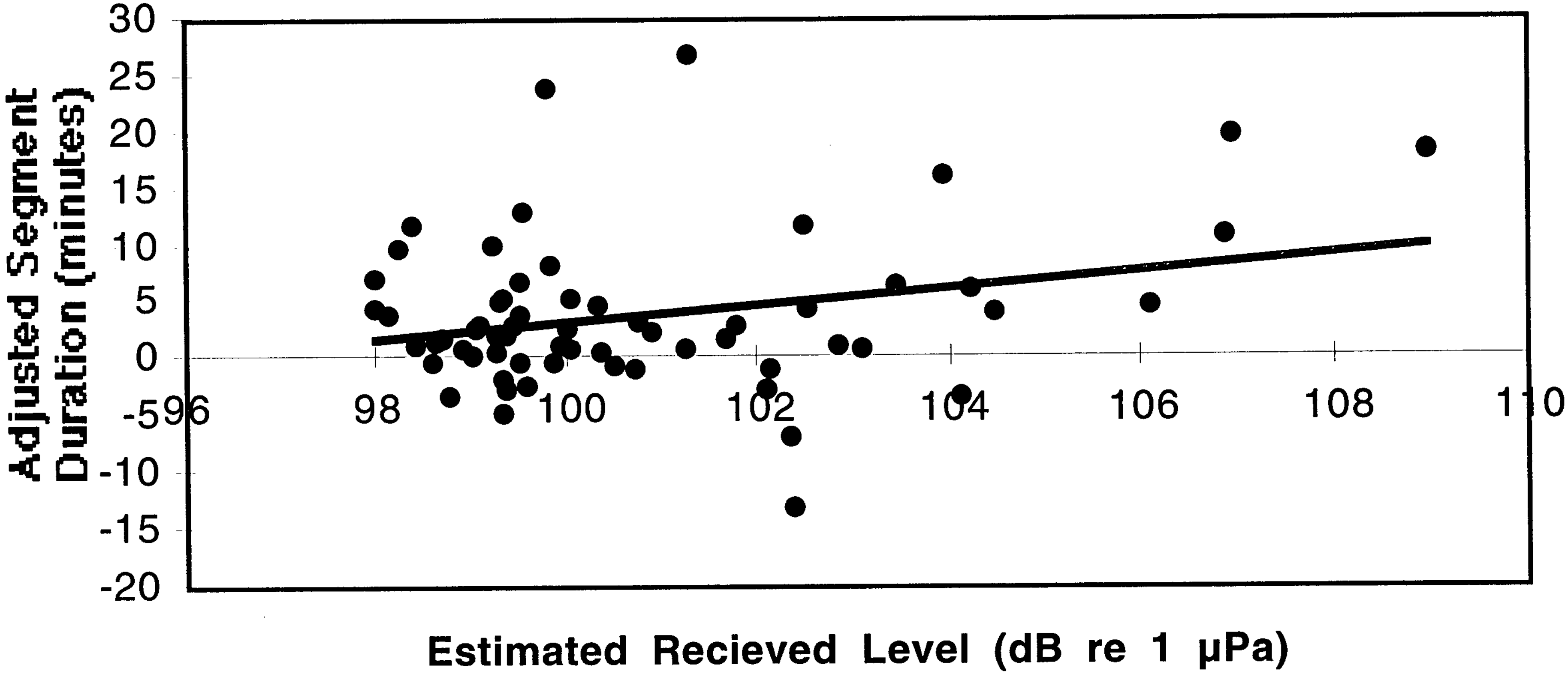
ATOC:	126 dB	Sound pressure integrated over entire ATOC transmission
Before:	102 dB	Ambient sound pressure before ATOC transmission
Max:	135 dB	Maximum sound pressure during ATOC transmission
Min:	123 dB	Minimum sound pressure during ATOC transmission
After:	104 dB	Ambient sound pressure after ATOC transmission

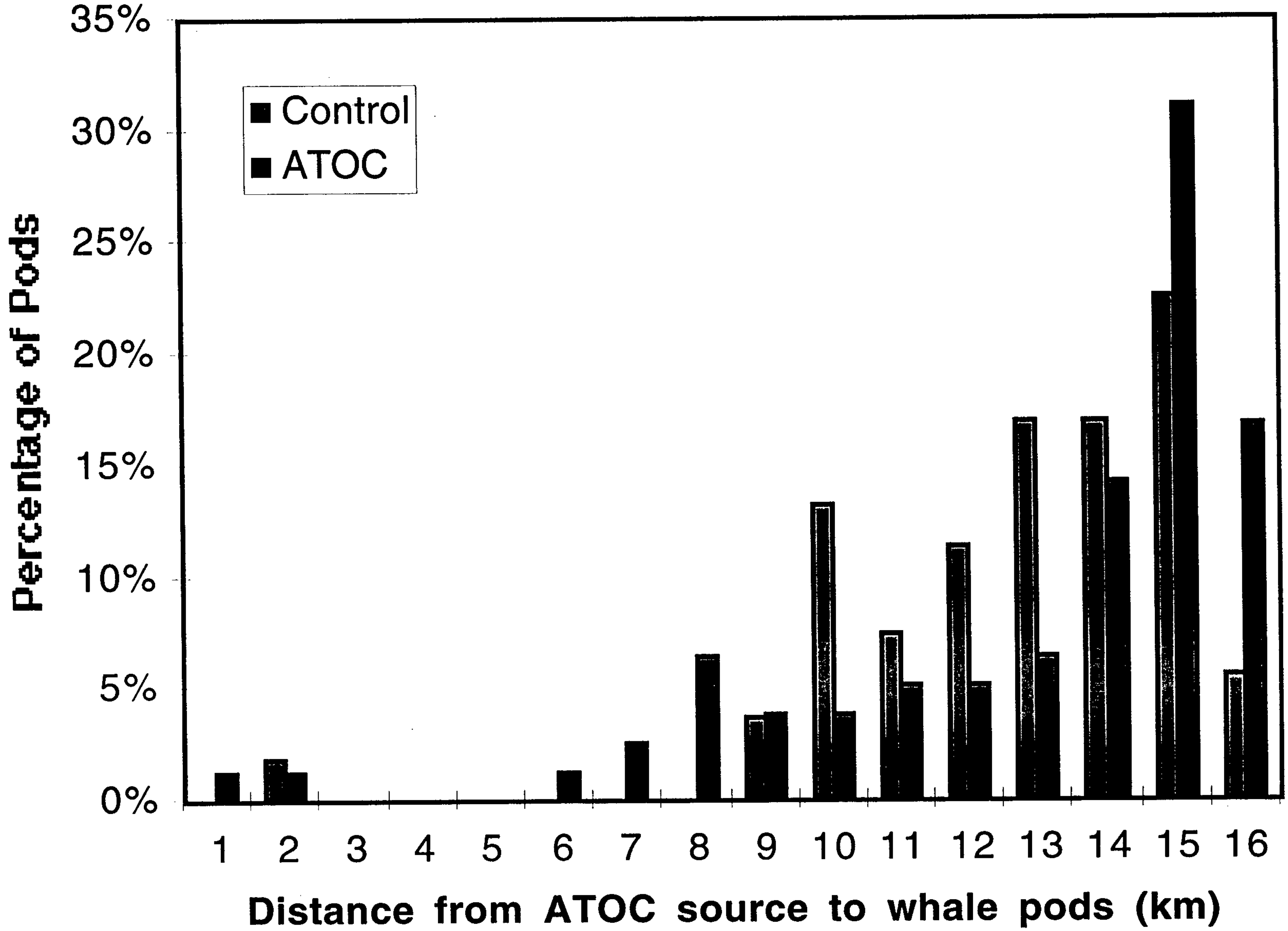
DAT96N2


Point Sur Spectrogram 960908.cal
350
300
250
200
150
100
50
0
0
5
10
15
20
Elapsed Time (hours)
110
100
90
80
70
60
50


ATOC Sound Propagation
Received ATOC Level (dB re 1µPa)
135
125
115
105
95
85
75
Water depth (m)
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
0
2
4
6
8
10
12
14
16
Range from Source (km)

Effect of Received Sound Level on Whale Movements




35%
30%
25%
20%
15%
10%
5%
0%
Percentage of Pods
Control
ATOC
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Distance from ATOC source to whale pods (km)