Bolt Beranek and Newman Inc.

Report No. 5366

Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior

November 1983

Prepared for:
U.S. Department of the Interior

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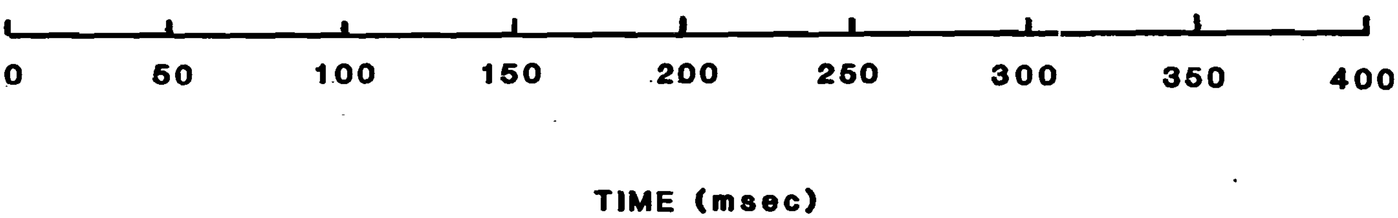

Report No. 5366

INVESTIGATIONS OF THE POTENTIAL EFFECTS OF UNDERWATER NOISE FROM PETROLEUM INDUSTRY ACTIVITIES ON MIGRATING GRAY WHALE BEHAVIOR

FINAL REPORT FOR THE PERIOD OF 7 JUNE 1982 - 31 JULY 1983

C.I. Malme and P.R. Miles
C.W. Clark, P. Tyack, and J.E. Bird

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Prepared by:
Bolt Beranek and Newman Inc.
10 Moulton Street
Cambridge, MA 02238

Prepared for:
U.S. Department of the Interior
Minerals Management Service
Alaska OCS Office
620 East 10th Avenue
Anchorage, AK 99510
Attn: Dr. Cleveland J. Cowles

PREFACE AND ACKNOWLEDGEMENTS

This report describes an experimental investigation of the behavioral response of migrating gray whales to sounds associated with oil and gas exploration and development activities. Extensive analyses of the resulting data, including statistical testing, quantify behavioral responses under various acoustic conditions. Data relating response to orca sounds also provide some indication of the hearing acuity of gray whales. As part of the project work, a survey and review of existing scientific literature on both gray whale and other baleen whale behavioral and migratory characteristics was performed and is included here as Appendix A. Initially, it was hoped the survey would reveal data on gray whale behavioral response to natural and industrial acoustic stimuli and that these would serve as a basis for comparison with results of the new experiments reported here. Very little quantitative information was uncovered. Therefore, the findings of the investigations under this contract are considered to be an important contribution to the field of whale behavioral research.

The work represented by this report was performed with the enthusiastic support of Dr. Cleveland J. Cowles, Alaska OCS Office of the Minerals Management Service and Mr. Gordon Reetz of the California OCS Office. Many other people and agencies demonstrated interest and provided support and scientific assistance to the project. We will attempt to summarize those contributions, all of which were very important to the performance of the project tasks.

The National Marine Fisheries Service and the U.S. Fish and Wildlife Service processed the required applications and issued the needed permits to perform the planned research. Without these permits the project would not have obtained important

quantitative information regarding behavioral response of gray whales and sea otters to acoustic stimuli.

Three oil and gas exploration companies indicated interest and support for the project even before it was finally established. Given compatibility of test schedules, Geophysical Services, Inc., ARCO Exploration Co., and Western Geophysical all offered to donate time and services of a seismic exploration air gun array system to the project for a period of 2-3 days each. As it turned out, vessel and test schedules were compatible for only one of these companies. Geophysical Services, Inc., donated 3 days of their vessel CECIL H. GREEN II, their crew, and air gun system to the project in the April tests. That work provided very valuable information to the project and their contributions are highly appreciated. Western Geophysical donated the use of an air gun system to the project which was mounted on the BBN charter vessel M.V. CROW ARROW, owned and operated by Logan and Logan, Inc. The large compressor required to operate that single air gun was loaned at no cost to the project by Price Compressor, Inc. These contributions were fundamental to the successful completion of the single gun work and demonstration that a single air gun is a valuable high level impulsive sound source for doing playback experiments. The interest of ARCO Exploration in contributing to the research effort was appreciated. Unfortunately, time and schedule did not permit completion of a working agreement.

The enthusiastic support of Mr. Russell Nilson, owner and operator of R.V. VARUA, the acoustic research vessel, and his skill in operating his vessel in highly variable sea conditions is particularly appreciated.

Dr. Thomas Dohl, UC Marine Laboratory, Santa Cruz, provided helpful aerial reconnaissance flights regarding location and counting of gray whales.

There were many scientists and technical assistants who provided needed advice and support at various levels of effort.

Dr. Roger S. Payne; whale behavioral research procedures

Ms. Victoria Rowntree; field observation services and data analysis

Mr. Donald Croll; Moss Landing Marine Labs, field observer

Ms. Melanie Würsig; field observer

Ms. Jane M. Clark; field observer

Ms. Jo Guerrero; field observer and data entry services

Ms. Michelle Whitney; field observer and data entry services

Dr. Bernd Würsig; field observer and advisor

Ms. Lisa Ballance; field observer and data analysis

Mr. Frank Cipriano; field observer

Mr. Greg Silber; field observer

Ms. Beth Mathews; field observer

Ms. Karen Miller; field observer.

Ms. Cynthia D'Vincent; field observer on VARUA.

All of these people provided valuable expertise and their contributions were critical to the successful completion of the work.

Ms. Mary D. Bird assisted, at no cost to the project, in the compilation of the literature review tables.

Dr. Marianne Riedman, while not retained directly under this contract, applied her skills in the field of sea otter behavioral research. The results of her efforts provide important and needed data regarding sea otter response to acoustic stimuli. She was assisted by Jud Vandevere, Ellen Faurot, and Steve Sinell in her behavioral observation effort. Their contributions are also appreciated.

Within BBN, the dedication and skills of Mr. Rafal Mlawski in the installation, maintenance, and operation of the acoustic systems on board R.V. VARUA and his analysis of acoustic data in the laboratory were very important to the project. Dr. Robert Pyle provided dedicated use of his talents in applying the BBN computer to the detailed development and analysis of whale tracks and behavioral data. His valuable contributions were essential to the completion of the analysis of the field data. Mr. Creighton Gogos, also of BBN, was the key individual in the assembly, test, installation, and operation of the single air gun system on board the air gun charter vessel. Without the availability of his skills, we probably would not have been able to assemble and operate the system within the required schedule.

Finally, the authors of this report had the following project responsibilities:

Mr. Charles I. Malme	Chief Project Scientist and Principal Investigator for Acoustics
Mr. Paul R. Miles	Project Coordination and assistant regarding acoustics

<u>Consultants to BBN</u>:

Dr. Christopher W. Clark	Co-Principal Investigator for whale behavioral research

Dr. Peter Tyack	Co-Principal Investigator for whale behavioral research
Mr. James E. Bird	Literature Survey and assistant regarding whale behavioral research.

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1. INTRODUCTION AND SUMMARY

1.1 Introduction

The research applied by Bolt Beranek and Newman Inc. and its whale behavioral consultant staff under Contract AA851-CT2-39 has the stated purpose of developing information which will contribute, ultimately, to a scientific means of predicting site-specific and/or cumulative effects of acoustic stimuli associated with OCS oil and gas exploration and development activities on migrating gray whales. This purpose was addressed through the performance of a detailed review of available literature and the acquisition and analysis of gray whale behavioral data before, during, and after their exposure to controlled acoustic stimuli during two migratory periods. Extensive quantitative as well as qualitative information on the subject has been accumulated in the execution of this project and it is the presentation of those findings which forms the body of this report.

Over 140 documents were reviewed to generate a summary of the present state of knowledge on the subject of the behavior of gray whales (Eschrichtius robustus) as well as other baleen whales. Much research has been performed on the natural or undisturbed behavior of the gray whale, particularly with regard to migration and population studies. Very little quantitative information relating behavior to specifically defined acoustic stimuli exist. Details of this literature review are contained in Appendix A with a brief summary of the findings given in Sec. 2.

An application for a permit to perform acoustic exposure and behavioral experiments on migrating gray whales (an endangered species) was submitted to the National Marine Fisheries Service. During their action on that application, it was determined that a similar application must be submitted to the U.S. Fish and Wildlife Service to cover the incidental and unintentional exposure of sea otters (Enhydra lutris nereis) to acoustic stimuli since they populate the coastal region of our experiments and are classified as a threatened species. Therefore, following extensive review, permits from both government agencies were obtained for the performance of the planned research.

MMS, the USFWS, and the California Department of Fish and Game provided a research scientist and observers, with some assistance from this contract, during both test periods to perform the sea otter behavioral research during the gray whale investigations. The results of that work have been reported* and will not be included as part of this final report.

The field measurement area selected for performing behavioral studies on migrating gray whales during both undisturbed conditions and periods when whales were exposed to controlled acoustic stimuli was located south of Monterey, California at Soberanes Point. There have been several studies in recent years performed in this region on gray whale population and their migratory behavior [e.g., Rice and Wolman (1971), Pike (1962), etc.]. The area has several easily accessible unpopulated sites which are ideal for theodolite tracking and visual observation of the animals as they pass close to shore during their migration. Two sites were manned during the southbound migration in January 1983 and three sites were operated during the northward migration late in April and early May 1983. Soberanes Point served as the primary observation site with one site located approximately 2.4 km to the north and the third site 2.4 km south of Soberanes. Measurement of the acoustic environment of the gray whales and

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*Riedman, M. "Studies of the Potential Effects of Noise Associated with Oil and Gas Exploration and Development on the Behavior of Sea Otters in California," Draft Report, 15 July 1983.

underwater playback of selected acoustic stimuli was performed from R.V. VARUA located offshore from Soberanes Point. The following sources of sound associated with oil and gas exploration or development operations were selected for the playback experiments:

- Drillship
- Semisubmersible drill-rig
- Drilling platform
- Production platform
- Helicopter noise.

Tape recordings of these sources of sound were obtained from the Naval Ocean Systems Center (NOSC) and from Polar Research Laboratories through MMS. In addition to these acoustic signatures, taped sounds of killer whales (Orcinus orca) were obtained from John Ford in Vancouver, B.C., with the intent of attempting to determine some measure of gray whale hearing sensitivity. Gray whales have been observed by others (Cummings and Thompson, 1971) to respond in a measurable way to orca sounds.

Standard seismic exploration air gun systems were operated along pre-selected tracks at various distances from shore to study behavior response to that major oil and gas exploration tool. Figure 1.1 provides a chart with observation site locations, acoustic research vessel positions, and air gun vessel tracks. Figure 1.2 shows the major long distance tracks of the air gun array vessel. Only playback experiments were performed during the January 1983 southbound migration of the general population of adult, juvenile, and occasional mother-calf pairs of gray whales. During the April-May 1983 measurement period, field work concentrated on the mother-calf pair portion of the

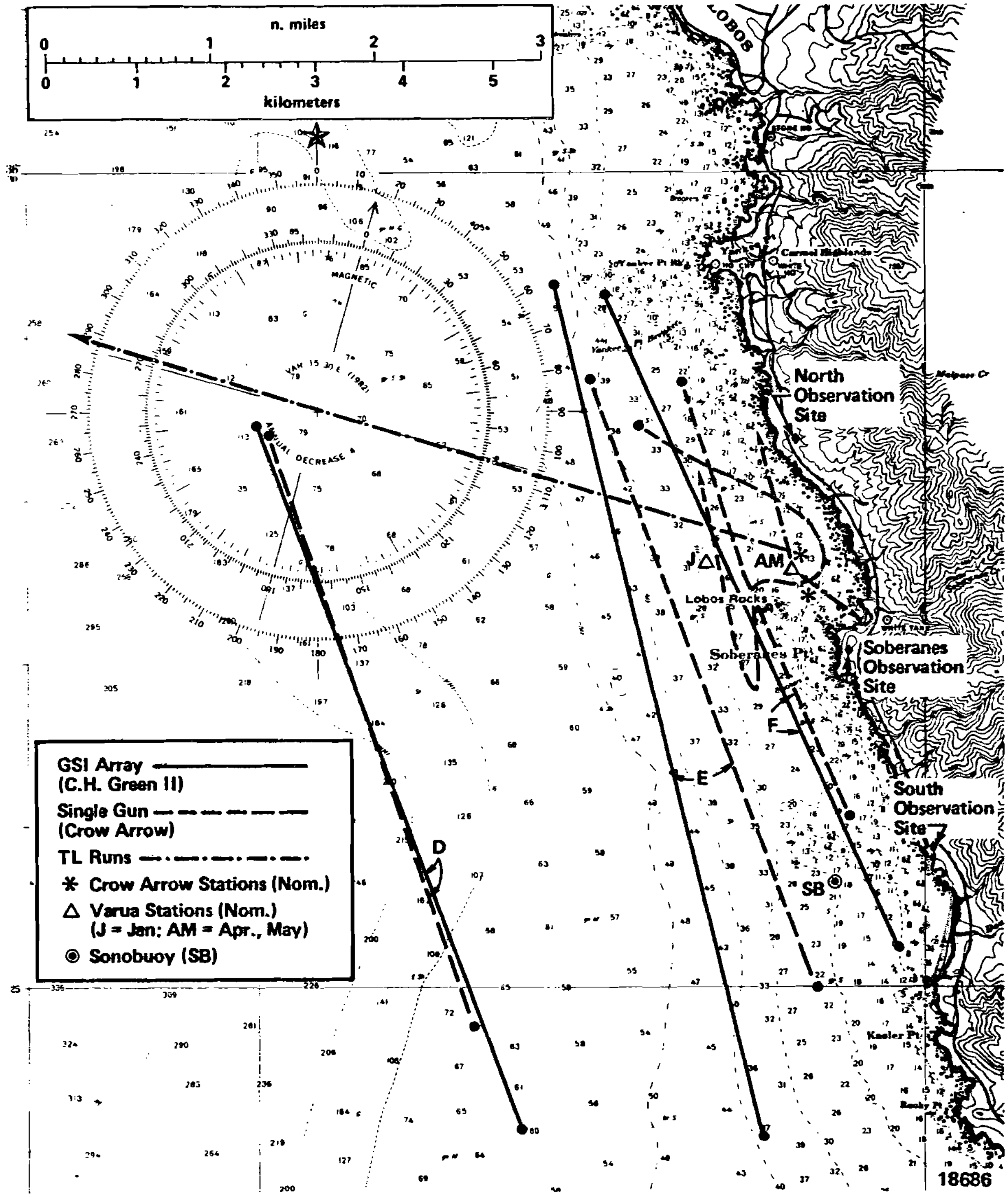


FIG. 1.1. GRAY WHALE OBSERVATION SITES AND ACOUSTIC RESEARCH VESSEL LOCATIONS INCLUDING NEARBY AIR GUN VESSEL TRACKS.

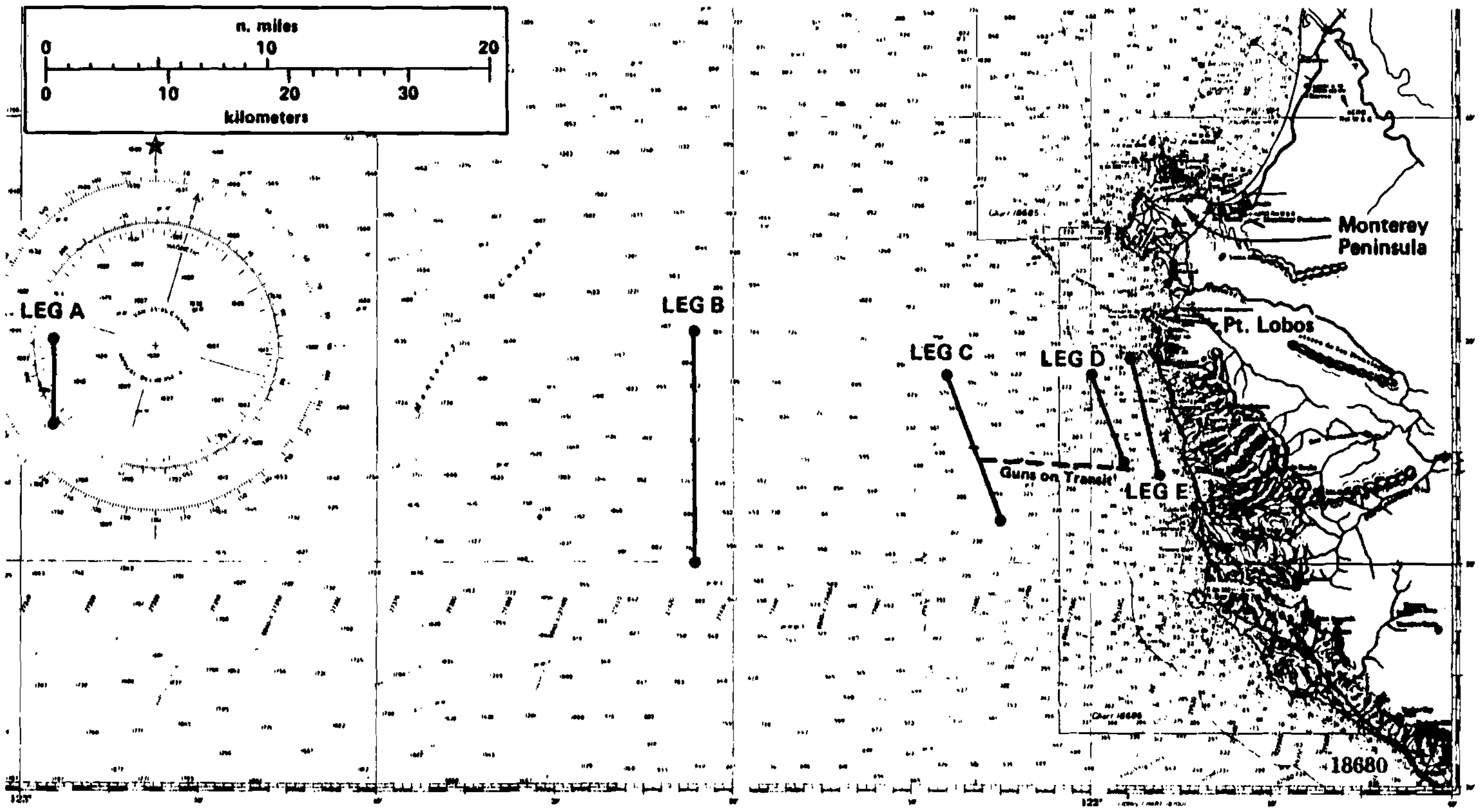


FIG. 1.2. SEISMIC AIR GUN ARRAY VESSEL TRACKS (M.V. C.H. GREENE II) FOR GRAY WHALE ACOUSTIC STIMULUS.

northbound migration, which usually occurs about seven weeks after passage of the single adult and juvenile portion of the gray whale population. During these tests priority was given to the air gun impulses of acoustic energy as a stimulus. A limited amount of tape playback data was also acquired. As seen in these figures, the air gun array was operated at distances of from 50 miles (91 km) away to as close as 0.5 miles (0.9 km) from shore. The single air gun was operated at distances of 3 miles (5.5 km) to 0.5 miles (0.9 km).

In addition to the projection of controlled acoustic stimuli to the environment of gray whales, it was necessary to measure their normal acoustic environment (ambient noise) in the test area. Ambient noise measurements were obtained at various random times during both test periods to determine variability and levels due to natural sources such as biological noise (pistol shrimp, etc.), surf noise, and industrial sources such as ships and aircraft. Data were also obtained in a series of acoustic transmission loss experiments to measure the characteristics of sound propagation in the test area.

Details of all of the acoustic test procedures, data analysis, and results are provided in the following sections of this report.

Double blind experiments were performed for all tests except for the air gun experiments. That is, the shore-based observation crews were not aware of when sounds were being radiated from the R.V. VARUA and the sound boat staff did not know what behavioral responses were being recorded. Time schedules were released only following completion of the field work. Undisturbed data were obtained on a non-ambiguous basis usually prior to arrival of the sound vessel at the measurement site or after departure. Air gun tests could not be performed on a blind basis since the airborne noise during operation was frequently detectable by the shore crews. Also, a series of moored single air gun tests were performed under control of the shore team to develop a history of whale response and recovery to the sound impulses.

The shore-based observation teams concentrated upon acquisition of gray whale behavioral data during times when there were no sources of potential disturbance (under control by the project) and when sources of sound could be or were being introduced by the project staff. Most of the undisturbed data was acquired either before arrival of any project vessels at the test site or following their departure. Extensive whale position data as a function of time were acquired by each site to permit reconstruction of swimming tracks of individuals and groups during undisturbed and potentially disturbed conditions. Behavior, such as various forms of aerial activity, blow-rate, blow interval, and dive time, milling, social activity, and swim speeds and direction were recorded or derived.

The southbound migration is characterized by a passage of a large number of animals during a relatively short period of time. (At the peak in January, more than 250 individuals passed the site within 9.5 hrs.) Because of the high rate of passage, it was not possible to obtain consistent blow-rate data. During the mother-calf migration in April/May, blow-rate data were acquired since there were significantly fewer animals to be observed.

A major part of this report describes the analysis procedures applied to the behavioral data and presents the results which include:

- Determination of specific behavioral response level to acoustic stimuli,

- Development of computer implemented whale tracking procedures during undisturbed and disturbed conditions,
- Kolmogorov-Smirnov, Watson's U^2 and other statistical analyses of whale enounters with acoustic stimuli,
- Analysis of behavioral parameters including milling index, swimming speed, aerial activity, blow-rate, dive time, etc., during undisturbed and potentially disturbed conditions.

Weather and other environmental factors reduced the efficiency of the acoustic and behavioral observation portions of the field work. A continuous 6-day period of clear weather graced the project during the January experiments. This six day period occurred between lengthy periods of heavy wind and rain. Similarly,in the April/May test period, the environmental conditions varied from clear to drizzle, rain and squalls with heavy wind (estimated to be 60 to 70 mph) to even an earthquake. Sea conditions consistently built up in the evening every day, preventing the possibility of R.V. VARUA staying on-site overnight, requiring a 4-hour round trip transit each day from Monterey, the nearest sheltered harbor.

A summary of the findings of the analysis of data acquired during both the January 1983 and April/May 1983 field measurement periods is given in Sec. 1.2 below. Section 2 is a summary of the literature review with the detailed output from that work contained in Appendix A. A detailed discussion of the experimental procedures used by the whale behavioral observation team and by the acoustics staff on board R.V. VARUA is given in Sec. 3. A summary and brief narrative of the work performed at the shore sites and the acoustic tests from VARUA is provided in Sec. 4. Section 5 includes a discussion of acoustic measurements and results. Section 6 contains a qualitative presentation of behavioral observations and Sec. 7 gives data analysis and the results of those analyses. Acoustic scaling procedures for relating the experimental results to full scale sources and for scaling air gun experiments are given in Sec. 8. Conclusions and recommendations are presented in Sec. 9.

The Appendices, in addition to the literature review (Appendix A), provide:

- Whale track and deflection plots for January (Appendix B)
- Whale track plots for April/May (Appendix C)
- Playback stimuli spectra (Appendix D)
- Acoustic monitoring of whale density (Appendix E)
- Error analysis regarding respiration rate measurements (Appendix F)
- Theodolite tracking system error analysis (Appendix G).

1.2 Summary

It was demonstrated during the January 1983 southbound migration of the general gray whale population and in the April/ May 1983 mother/calf pair portion of the northbound migration that behavioral responses of these mammals can be elicited through acoustic playback experiments and through controlled use of marine geophysical exploration air gun systems.

Tape-recorded acoustic signatures of typical oil and gas exploration and development sources of sound, as well as orca sounds, were played back through an underwater sound projector under a variety of background noise and range-of-opportunity conditions. Whale activity was measured from shore during a series of double blind experiments. Typical ambient noise and transmission loss measurements were also obtained to describe the acoustic environment of the whales. A measure of hearing sensitivity was obtained, demonstrating that the gray whale can detect the presence of anomalous sounds in the water having a 0 dB signal-to-noise ratio in the 1/3-octave band of maximum signal level. This was clearly demonstrated for orca sounds as well as drilling platform and helicopter sounds. These tests demonstrated annoyance and startle responses from the whales, particularly for the orca sounds and some of the air gun experiments. Lesser responses, which can be described as nonextreme, cautious maneuvers, were also demonstrated.

In the January playback experiments, a track deflection program was established to test for any possible changes in such parameters as distance from shore, speed, linearity of track, orientation towards the sound source, and compass heading of each whale group. Results of this analysis show that each playback stimulus caused statistically significant response compared with undisturbed whales, and each stimulus elicited a different pattern of response. The orca playback generated the most pronounced response, in which whales beyond the 2 km limit of measurable observation north of the sound source had already moved far offshore or inshore of the sound source, milled around and slowed down. Whales exposed to the drilling platform, helicopter and production platform stimuli also showed an avoidance response, less pronounced than the orca response, but still indicating deflections from the immediate vicinity of the sound source. The deflection from drilling platform noise occurred primarily before the whales passed the sound source, while deflections for the helicopter and production platform occurred just as the whales passed the source. The other response of whales to playback was to slow down relative to undisturbed conditions. Whales exposed to orca, drilling platform, and drillship sounds slowed down significantly before passing the sound source. Semisubmersible and helicopter sounds caused the whales to slow down both before and after passing the sound source.

Those whales exposed to production platform sounds slowed down only after passing the source. The response of slowing down during playback of industrial sounds appears to be neither an avoidance nor an annoyance response. Instead, the whales may be moving more cautiously when in the presence of such sound sources.

During the April/May mother/calf phase of the northward migration, the major potential disturbance used in experiments was air gun activity either from a 40 gun towed array or from a single air gun. The most dramatic responses of the whales to air gun activity occurred at received levels of > (greater than) 160 dB re 1 μPa when the air gun source was within 2 km of the animals. In general, whales would slow down, turn away from the source, and increase their respiration rates when exposed to air gun impulse sounds. In several cases, groups were seen swimming into the surf zone and also positioning themselves in the sound shadow of a rock, island, or outcropping. There were significant differences, independent of range or level of exposure, in milling indices, speed indices, and blow rates for groups prior to exposure and those same groups during exposure to the air gun noise. There were also significant differences in milling indices, speed indices, and blow rates for groups during exposure and after exposure to air gun noise.

All of these findings are quantified in the body of this report. Photographs of the test area are given in Figs. 1.3 and 1.4. Figure 1.3, taken from North site, shows Soberanes site in the upper left side of the photo and Lobos Rocks on the upper right. A view of Soberanes site from R.V. VARUA during the January tests is given in Fig. 1.4 with Lobos Rocks in the foreground.

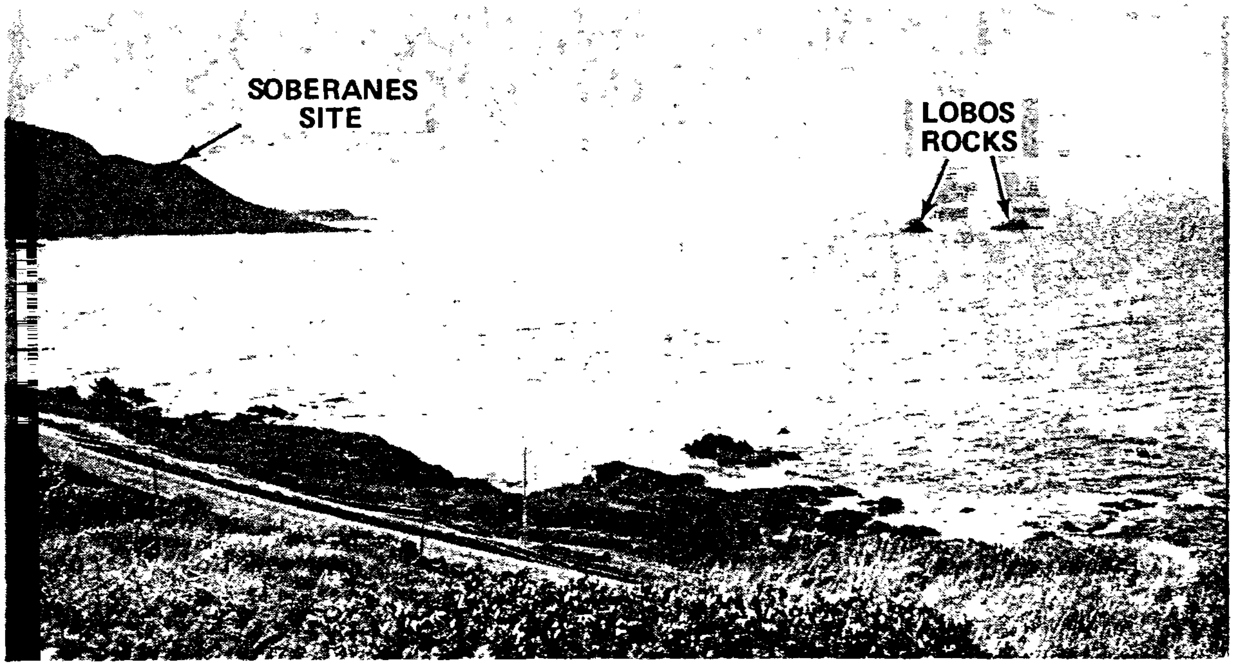


FIG. 1.3. VIEW OF GRAY WHALE TEST AREA FROM NORTH SITE.

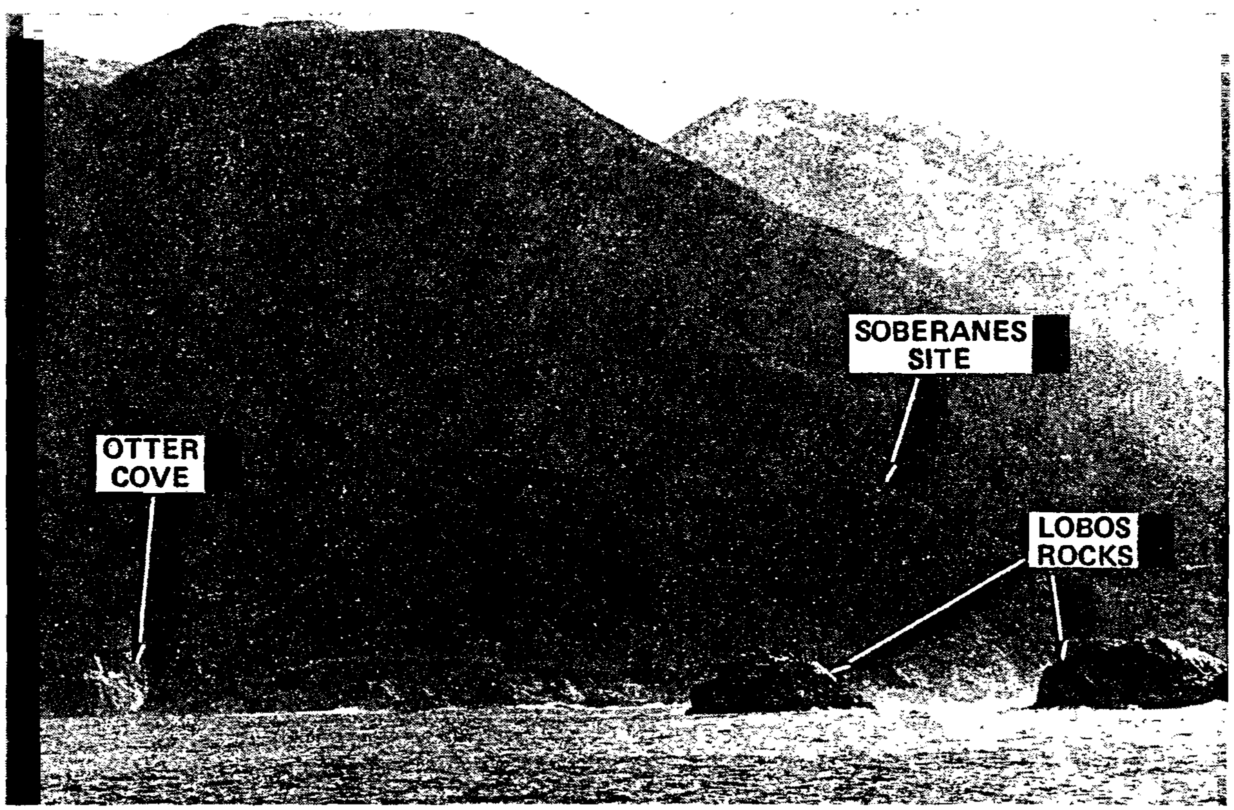


FIG. 1.4. VIEW OF SOBERANES SITE FROM R.V. VARUA (JANUARY 1983).

2. LITERATURE REVIEW SUMMARY

The literature search presented in Appendix A was performed to characterize the normal migratory behavior of the gray whale and to determine if introduced sound from a variety of sources, including offshore oil and gas development, would have an observable effect on that behavior. Because of the limited data on behavioral reaction of gray whales to noise and disturbance, we have also included in this literature review information on the behavioral reaction of other baleen whale species.

There is very little information on the migratory behavior of the gray whale with which to compare our behavioral observations under experimental conditions. Most of the literature on gray whale movements concerns migratory corridors and censusing with very little data on respiration rates and no information at all on rates of different types of behaviors. Because of this, our only database of presumably undisturbed behavior was our own field observations during the southbound and northbound migration.

The gray whale, because of its nearshore migratory route, is exposed to a variety of man-made sound sources, including offshore oil and gas operations. In order to determine if these man-made sounds have an effect on the normal migratory behavior of the gray whale, we examined the baleen whale literature and categorized the sound sources into the following types:

1. Aircraft,
2. Vessels,
3. Surface and underwater explosions,
4. Sonar,

5. Construction activity, and

6. Offshore oil and gas operations.

Because many of the observed responses of baleen whales to sound sources are reported as ancillary information to the main topic of the paper, acoustic information on the sound source is not given.

We have included non oil and gas related sound stimuli as possible sources of gray whale disturbance because the literature on the acoustic effects of petroleum-related activities on whales is not extensive. Because of the limited amount of data on reactions of gray whales to noise and disturbance, the comments here are a result of our findings related to baleen whales in general.

The responses of whales to aircraft was highly variable. This variability was caused by the type of survey being done (transient or behavioral observation), altitude, at which survey was flown, type of aircraft and position relating to the whales, and activity of the whales. At altitudes above 457 m (1500 ft), there was generally no visible response. However, below this altitude response varied. A summary of the literature on the response of whales to aircraft is presented in Tables A-1 and A-3.

In general, the responses of baleen whales to vessels were variable. We found that whales engaged in a specific activity, such as feeding, would continue that activity when a vessel was in the vicinity. However, if the vessel approached (usually within 100 m), the whales would usually move away or dive. Changes in respiration rate and surface active behavior, such as lobtailing, were noted concurrent with the close approach of a vessel, however,responses showed great variability. Much of the literature indicates a startle response to vessels when there is a sudden change in engine speed. The whales would dive and move away from the source at a rapid rate of speed. Researchers have found that gray whales in the breeding lagoons seem least disturbed when they were approached at speeds near to their own. Gray whale attraction to idling outboard engines was also observed.

Because of the limited number of reported responses of whales to surface and underwater explosions, sonar, and construction activity, we refer the reader to those sections in Appendix A.

In order to assess the reaction of gray whales to natural sounds in their environment, we examined in detail the one Orcinus orca playback experiment with gray whales. There was a high degree of avoidance shown by the gray whales exposed to these sounds. Also noted was a change in the gray whale surfacing and respiration characteristics.

There are few quantitative observations of whales in the presence of offshore oil and gas operations. Most of the observations concern bowhead whales in the Eastern Beaufort Sea, a Minerals Management Service project being conducted by LGL, Inc. In general, the evidence was inconclusive that the whales' respiratory characteristics were altered in the presence of ongoing seismic operations at distances of 6 to 20 km. Single air gun experiments at distances of 3 km and 5 km showed varying effects with whales exposed to the 5 km test showing a significant decrease in the number of blows per surfacing and surface times. These effects were possibly due to the onset of the experiment. Other researchers have observed reactions of bowhead whales to the onset of seismic operation, with whales clustering together and synchronizing their surfacings. These observed effects, however, are of a qualitative nature.

There are very few observations of gray whales in the presence of seismic operations. Gray whales at a distance of 36 km from an active seismic vessel, experiencing sound levels of 154 dB re 1μPa, showed no visible reaction.

Section A.2 summarizes the various sound sources from offshore oil and gas operations and discusses the theoretical detection ranges of these sounds by baleen whales and their possible auditory effects. Because there are few data on the auditory capabilities of baleen whales, much of the information regarding detection ranges of sounds and possible auditory effects of these sounds are speculative in nature.

Our study has provided base-line data on the normal migratory behavior of the gray whale and has quantified the effects of various sound sources associated with oil and gas exploration and production on this normal migratory behavior. Although more observations under control and experimental conditions are needed to begin to assess the long-term effects of offshore oil and gas production on gray whales, we have, in our study, added a significant amount of information to the present database.

3. EXPERIMENTAL PROCEDURE

3.1 Objectives

The principal research paradigm around which the experimental procedures were designed is based on testing the hypothesis that the projection of underwater sound to migrating gray whales does not affect their behavior. The verification or nullification of this hypothesis depends on comparisons between observations under normal (undisturbed) and experimental (potentially disturbed) conditions. Therefore, there were no differences in the behavioral observation techniques or efforts employed during the normal and experimental aspects of the project. There were differences in procedures, both playback and data recording, used during the January phase and April-May phase of the project. These differences are a result of the differences in the migration during these two seasons and the need to establish priorities regarding which sounds to employ during the two seasons. In brief (see the literature review in Appendix A, and field measurements, Sec. 4, for more details), the January migration consists of large numbers of whales in groups of typically two or more animals swimming south at a distance of > 1 km from shore, while the last phase of the April-May migration consists almost entirely of a evenly spaced sequence of mother-calf pairs, swimming north within 0.5 km from shore. Because of these rather dramatic seasonal differences in the migration, comparison between normal and experimental behaviors will be restricted to within season. Similar results from the two seasons will be interpreted as evidence that the response is a general one.

On the following pages we present a discussion of behavior monitoring, including tracking procedures and analysis procedures, acoustic playback procedures, acoustic exposure estimation, ambient noise monitoring and transmission loss measurement techniques.

3.2 Behavior Monitoring

A set of behavioral assays were selected in order to assess the level of response to any of the experimental treatments. The behaviors that were simultaneously monitored were swimming pattern, respiration times, and the occurrence of any other visible surface activities such as breaching, underwater blows, etc.

Behavioral monitoring was done simultaneously with theodolite tracking such that any observable behaviors were noted along with time and position. Observations were made using either the unaided eye, hand held binoculars (x8), dual Bausch and Lomb spotting scopes (x15), or through the theodolite eyepiece (x20). In a few cases behaviors could be associated with a specific individual within the group based on markings that were specific to that group member - for example, if there were differences in the degree of mottling on the back or when an individual had several distinctive white spots on or near the dorsal ridge.

3.2.1 Whale position tracking

The method of using a theodolite to track whales from a shore station was first developed by Roger Payne and has since been used frequently to follow whales and porpoises (e.g., Würsig, 1978, Clark and Clark, 1980, Tyack, 1981). By this method, one measures the horizontal angle from the whale to a fixed landmark for azimuth, and measures the vertical angle of depression from the horizon to the whale for derivation of range. Since the altitudes of the transit stations used in this study were low relative to the ranges of the whales observed, precision of measuring the vertical angle was critical. (See Appendix G for theodolite tracking systems error analysis.)

The theodolites used in this project were a Wild Model T2, a Leitz Model TM1A, a Leitz Model TM6, and a Pentax Model WD20. All theodolites had automatic vertical indexing (ensuring that the horizon reference for vertical angles was accurate); angles were measured with a precision of at least 10 seconds of arc. The actual precision of our localization of whales is discussed in Appendix G.

As soon as a new group of whales was sighted from the first transit station, it was given a unique group letter for the day. Each time a whale within the group was located by the theodolite operator, a notetaker recorded the time of the observation, the group letter, the vertical and horizontal bearings to the whale, and any displays observed. If the observers were able to count the number of whales within the group, this was also noted. Bearings indicating the positions of boats in the study area were also noted. As a boat or group of whales passed into the field of vision of another transit station, observers at both stations would communicate by CB radio to pass on group letters or other identifiers for whales or boats.

3.1.2 Track and position data analysis

Conversion of Bearing Data

All transit sightings of whales and boats were entered into an Apple II^{+} computer using the editor for Apple Pascal. A separate file was made for each day's records from each transit station. Data from each sighting were entered on one line per sighting in the format:

TIME GROUP LETTER VERTICAL BEARING HORIZONTAL BEARING

These data were then converted into position in rectangular coordinates, in units of meters, with the Soberanes transit station as the origin, with true North as the positive x axis and West as the positive y axis. The transit bearings were converted into rectangular coordinates using an iterative correction for the curvature of the earth developed by J. Wolitzky (Würsig, 1978). A correction for refraction of light was found to be unnecessary for the ranges at which whales were typically tracked, but the tidal excursion was large enough that the altitude of the station was corrected for tidal fluctuations.

After the field season was over, the files of rectangular coordinates were transferred from an Apple II+ computer to BBN System G, a DEC PDP-20 computer using the program PTERM.

3.2.3 Track data

Each point along the track of each whale group was checked after processing by a RATFOR program developed by R. Pyle which sorted entries into tracks of each group and listed the apparent speed between points. All points with unrealistically high speeds of > 18 km/hr were labelled not to be used in tracks unless they represented almost simultaneous sightings of different whales within a group. There were few such points in typical tracks and most were easily determined to be isolated bad points.

No effort was made to select tracks that were strictly linear, for track deflection was a potential response of interest. A small percentage of groups yielded a series of points requiring unreasonably high speeds to be fitted to a track, but in which it was impossible to determine unambiguously which one or two points were in error. These groups were not used to produce tracks.

If a group was only sighted several times over an interval of < 15 min or if the group was widely dispersed, its sightings were not used for tracks. In addition, if there was a gap in sighting a group of > 20 min, the track was terminated before the gap.

3.2.4 Plots

Plots of selected tracks were made using DISSPLA software and a Nicolet-Zeta 2300X plotter. The coastline of the study area was digitized using a Calcomp 9000 digitizing tablet; the coastline and position of the playback stimulus source were plotted along with the tracks of whales. Scatter plots indicating the locations of all whale sightings, including those not used for tracks were also generated.

3.2.5 Track deflection program

A track deflection program was developed by R.W. Pyle of BBN and P. Tyack. This program was written in RATFOR and run on the PDP-20 computer at BBN. The program uses DISSPLA software to generate plots of cumulative frequency distributions.

3.2.6 Respiration times

In January, respiration times were not recorded although blows were most often the means of sighting and coordinating theodolite positions for a whale group. We did briefly attempt to note respiration times but this proved extremely difficult since the whales were typically 1 - 3 km off shore and groups were large and there were usually more than 5 groups in the area at one time. Respiration times could be reliably collected if two observers concentrated on only one group that was within 2 km of shore.

In April/May a concentrated effort was directed at recording respiration data. These data were collected by recording the time of occurrence of each blow and the identity of the animal (e.g., mother, calf or single whale). In cases where a blow was seen but could not be linked to an individual in the group, the blow time was recorded along with the group identifier. Coincident with the respiration event, observers noted the confidence with which they were seeing all blows. This confidence level was designed to bracket the time periods when observers were absolutely confident that they were seeing all blows by an individual or the group in total. The eventual intent was to collect reliable data on intervals between respirations. Periods containing reliable intervals were then noted by deciding in the field whether or not observers felt confident they had not missed any respirations. (See Appendix F for an evaluation of the respiration data.)

3.2.7 Other behaviors

At the same time that theodolite positions and respiration rates were being recorded, other behaviors were noted. These included: breaching, vertical flukes, fluke outs, underwater blowing, head ups, rolling, spyhopping, direction of movement (other than direction of migration), milling, groups joining and groups splitting.

In January, consistent observations on the variety of behaviors was difficult again because the groups were farther off shore and there were so many groups in the area at any one time. Breaching, direction of movement, milling, splitting and joining were relatively easy to observe but noting these other behaviors was problematical.

3.3 Acoustic Instrumentation, Measurement, and Analysis Procedures

This section describes the instrumentation and procedures used to obtain the required physical and acoustic data. The field measurements employed two types of sound sources during the whale behavior observations. For the playback work, the goal was to simulate as closely as possible the sound fields produced by a representative range of offshore oil and gas industry activities. This required the following considerations:

- Provision for establishing a calibrated relationship between the playback sound field and the sound field existing around the actual industry activity being simulated.
- Measurement of the acoustic propagation conditions at the playback site.
- Measurement of the ambient noise levels at the playback site during the observation period.

Similar considerations applied to the observations using air gun sources in that acoustic propagation data and ambient noise data were required. In this case, however, the source was real, not simulated. Thus, it was important to determine as accurately as possible the effective acoustic output level and spectra of the air gun sources so that sound pressure scaling equations could be derived. These equations would then permit estimation of the sound exposure for whales migrating through the observation area. Knowledge of the sound source level of the air guns (L_S) also permits estimation of the sound levels that would be produced for air gun operation in other areas, providing the sound transmission-loss characteristics (TL) for the area in question are known.

The instrumentation for the principal measurements was installed on the VARUA, a 73-ft (93-ft OA) brigantine shown in Fig. 3.1. In addition, a sound recording system was also deployed from a 13-ft Boston Whaler during sound transmission-loss (TL) measurements. The whaler was launched and retrieved using the cargo boom on the VARUA. For the April-May field

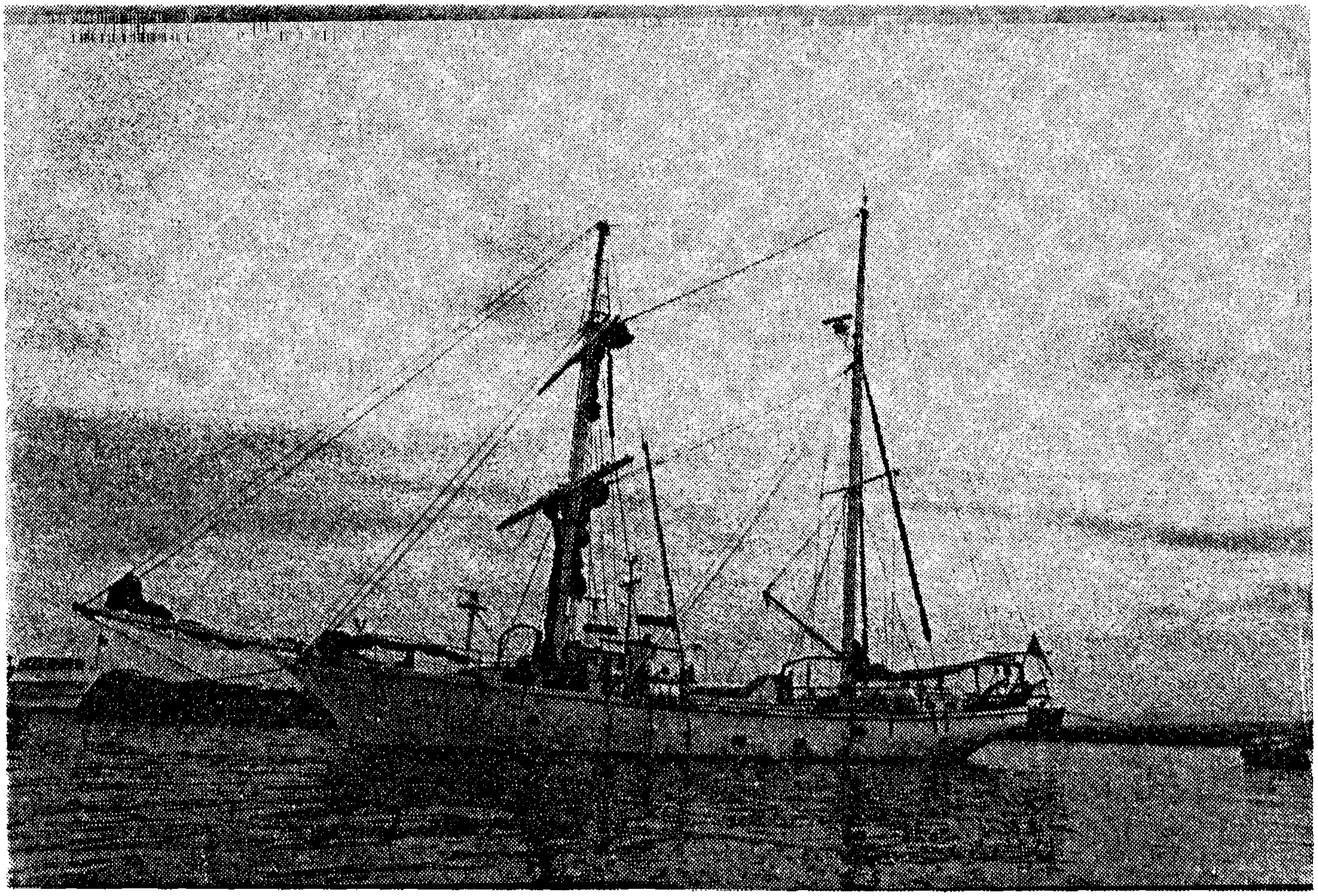


FIG. 3.1. R.V. VARUA.

period acoustic measurements were also made using spar-buoys to provide data from an extended measurement baseline.

3.3.1 Acoustic environmental measurements

Navigation

The radar on the VARUA was used for determining the location of the vessel relative to the local coastline. It was also used in conjunction with reflectors on the Whaler to determine range information during TL measurements and to determine ranges to passing ships which were contributing to the local ambient noise level. An optical rangefinder was used for range measurements under 400 m. Theodolite sightings from shore provided the final input data to the whale/sound-source range computation for the data analysis.

A recording fathometer was used for determining the water depth during anchoring and sound measurement procedures.

Physical Measurements

The variation of water temperature and salinity with depth was measured with a Beckman Model RS5-3 conductivity, temperature, and salinity probe. This instrument provided a salinity measurement based on the temperature and conductivity data. Measurements were made at selected depths down to 40 m. The measured data were then used to calculate the sound velocity profile.

Wind speed was measured using a pitot-type gauge. Wave height was estimated visually.

Ambient Noise Measurements

A standard hydrophone system that combined a USN/USRD Type H-56 hydrophone with a low-noise preamplifier and tape-recorder was used to obtain ambient noise data. The hydrophone sensitivity and electrical noise-floor characteristics are shown in Fig. 3.2. The acoustic noise measurement system block diagram is shown in Fig. 3.3. Overall frequency response of the measurement system was generally flat from 20 Hz to 15 kHz. All components of the system were battery operated during ambient noise measurement. Cable fairings and a support float system were used to minimize strumming and surge noise effects on the ambient measurement hydrophone.

Spar Buoy Acoustic Measurements

Two spar buoy acoustic measurement systems were assembled to provide extended area coverage for the spring field period. The anticipated large range of high acoustic levels from the air gun array tests required that concurrent measurement of received levels be made along the coastline covered by the shore observation sites to determine if any significant TL anomalies were present. Ideally, a sound survey along the coast when the array was in operation well offshore would have disclosed any significant sound "shadows," but, as it turned out, the local sea conditions prevented this. The spar buoys were thus intended to eliminate the need for a second large vessel to serve as an extended acoustic field sampling platform.

The spar buoy design incorporated a 6-in. diameter aluminum tube, 12-ft in length. The general arrangement is shown in Fig. 3.4. The lower end was ballasted to provide about 4 ft of freeboard when the buoy was deployed. A high sensitivity hydrophone together with an adjustable gain amplifier and a modified sonobuoy transmitter were used in the buoy electronic system. A battery pack in the buoy provided about 3 days of continuous operation after deployment. The RF transmission range for moderate sea-state conditions was about 3 to 4 miles (5.6 - 7.4 km).

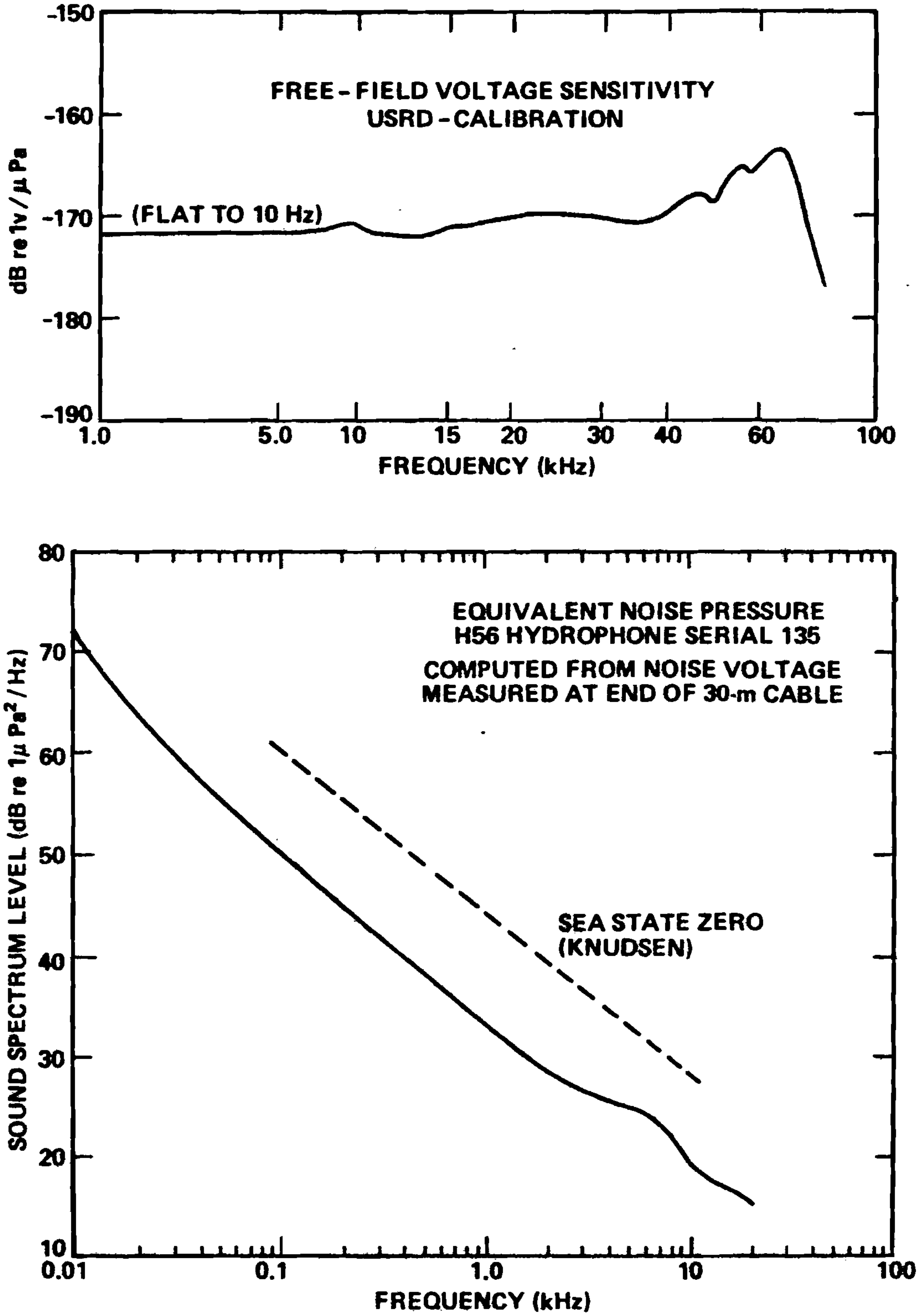


FIG. 3.2. H-56 HYDROPHONE CHARACTERISTICS.

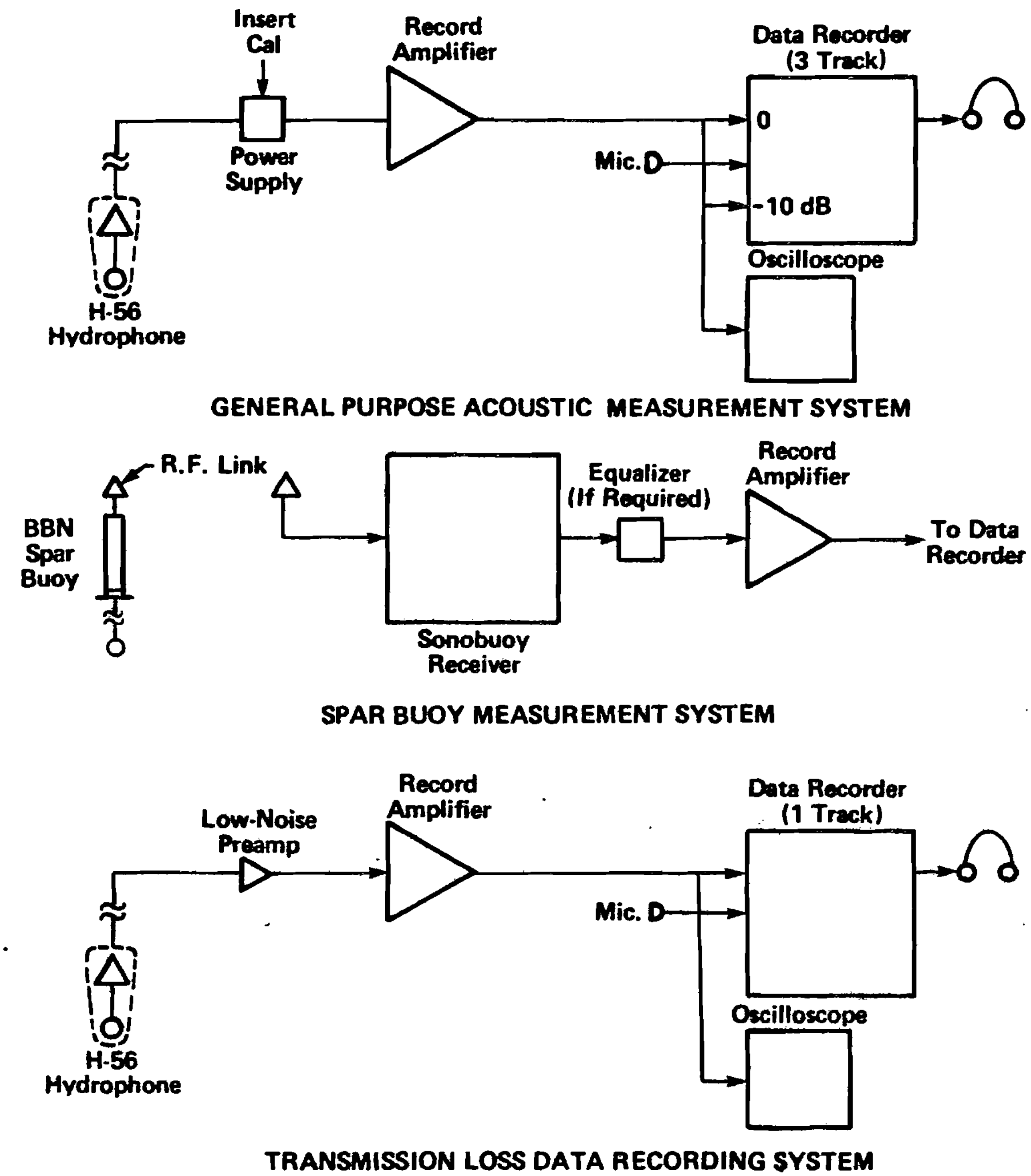
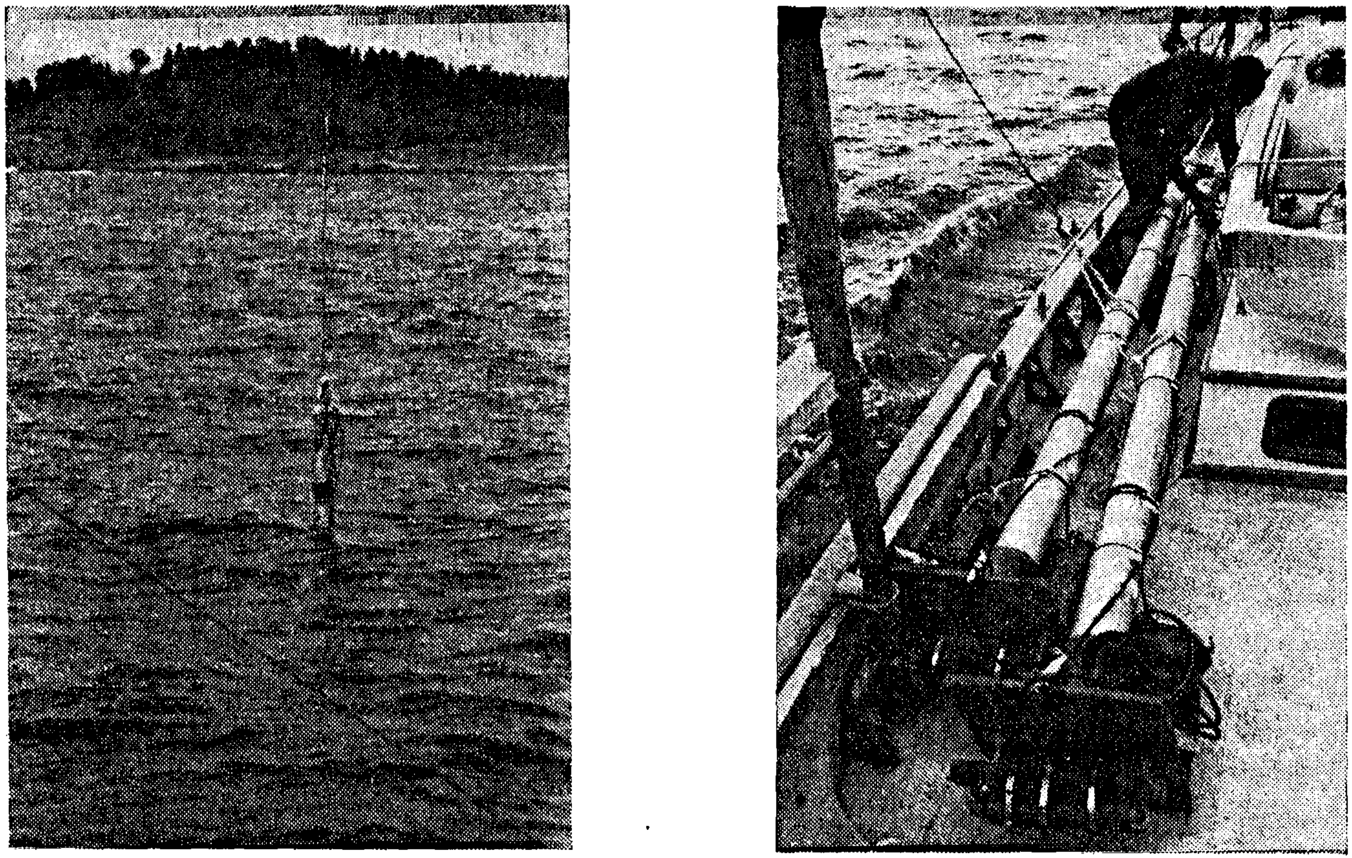


FIG. 3.3. ACOUSTIC MEASUREMENT SYSTEMS.



A. DEPLOYED

B. STOWED ON DECK

FIG. 3.4. SPAR BUOY OPERATIONS.

Transmission Loss Measurements

The acoustic transmission loss in the observation area was measured using the playback system projector as a sound source and a hydrophone system deployed from the Boston Whaler as the receiver.

During a TL measurement sequence, a prerecorded program on a cassette tape was used to generate a standard test sequence. This sequence contained a format of 15 sec of warble tone, 1/3 octave in bandwidth, centered at a standard octave reference frequency, followed by a short-duration chirp at the same frequency repeated four times at 15-sec intervals. This same sequence was then followed at successive octave intervals over the range from 100 Hz to 16 kHz.

The smaller acoustic recording system shown previously in Fig. 3.3 was installed in the Whaler for recording the sound signals projected from the VARUA. The tone sequence was received and recorded at selected progressively spaced distances ranging from 180 m to 1 km. Subsequent analysis of the recorded tone sequence data provided the transmission loss information required to predict the sound level exposure at observed whale positions during playback and air gun tests. The details of the analysis procedure are discussed in Sec. 5.5.

The transmission loss data obtained using the projector system were supplemented by measurements using the air gun array or the single air gun as sources. The high levels of these sources permitted transmission loss measurements out to 90 km (for the array). The source vessels maneuvered along predetermined courses while the received levels were measured at the VARUA position about 1 km offshore. LORAN C fixes were used to obtain range information for the more distant offshore data runs. This was supplemented by radar and theodolite observations during the near-shore courses.

3.3.2 Acoustic playback procedure

Projector System

The acoustic playback system was designed to provide sound levels and frequency response capable of realistically simulating the designated range of oil industry activities. In order to keep the system within the required operational constraints, it was necessary to limit the low frequency response to 50 Hz and also limit the maximum average sound level to about 160 dB//1μPa. In addition to the industrial sounds, we also wished to play back orca (*Orcinus orca*) vocalizations to provide a control stimulus for which definite gray whale reactions had been reported (Cummings and Thompson, 1971). This required an upper frequency response extending beyond 10 kHz.

Because of the required broad frequency range, two underwater sound projectors were used. The USN/USRD Type J-13 projector was applied for low frequencies up to 2 kHz, and the USN/ USRD Type F-40 projector provided for the high-frequency sound. An electrical equalization and cross-over network was used to enable both projectors to be driven concurrently from a Crown 300-watt power amplifier. The playback system and its response curve are shown in Fig. 3.5.

The two projectors were mounted in a support frame to facilitate handling. The assembly, shown in Fig. 3.6, was lowered to a depth of 15 m with the cargo boom on the VARUA. A "wind vane" was also mounted on the projector assembly to keep the J-13 projector pointed away from the current. This minimized drag forces on the projector piston which could cause signal

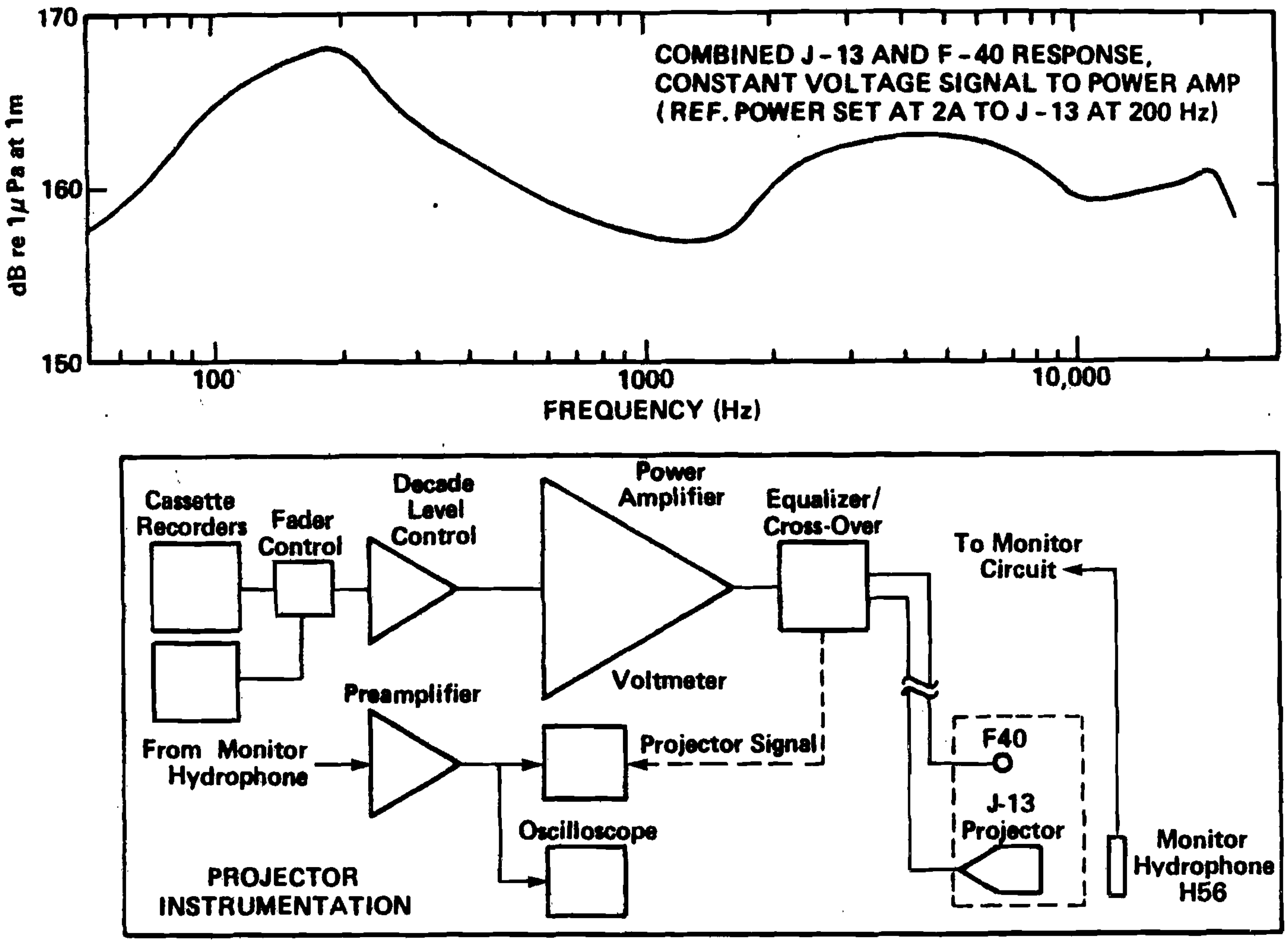


FIG. 3.5. PROJECTOR SYSTEM AND COMBINED RESPONSE CHARACTERISTIC.

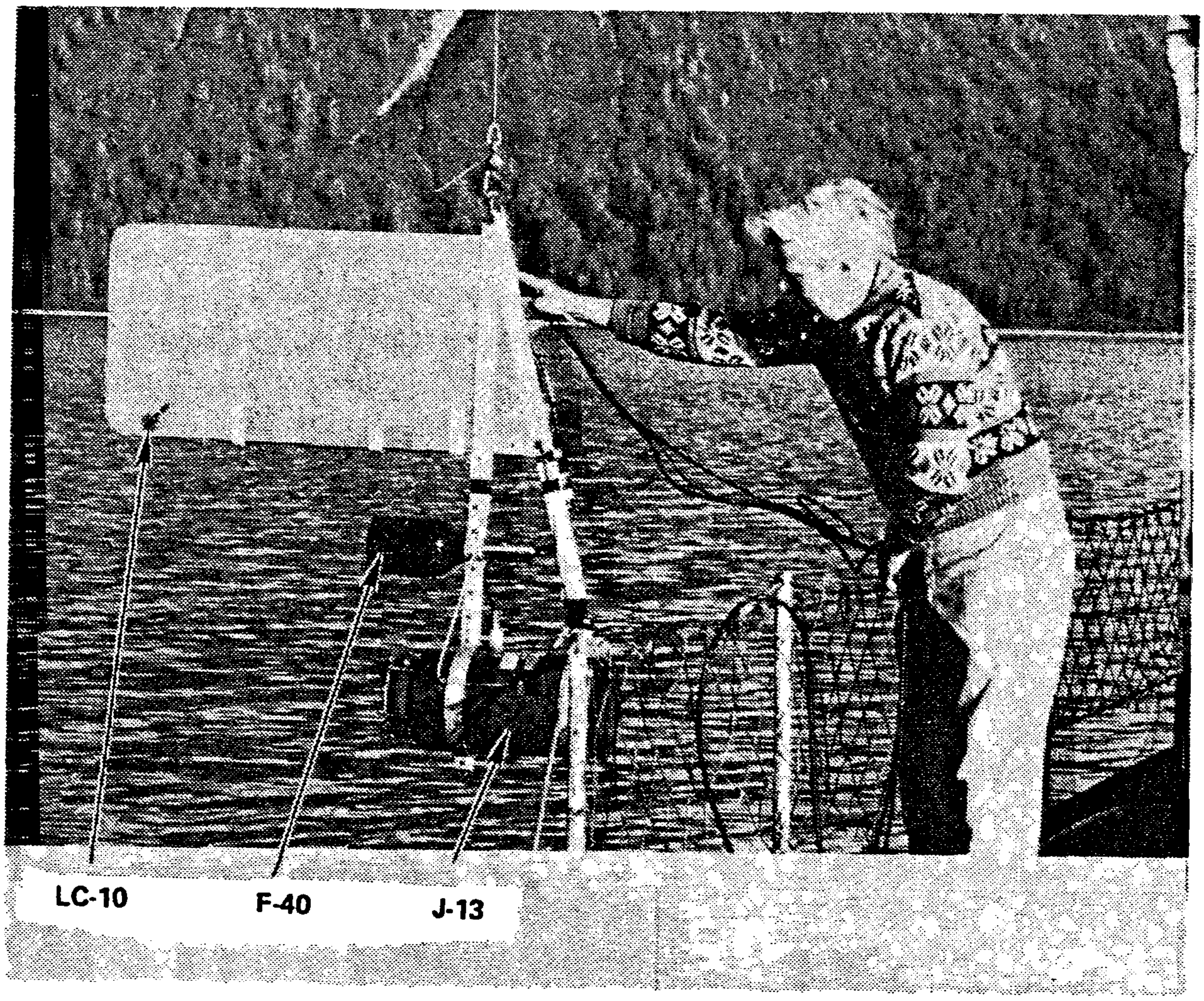


FIG. 3.6. UNDERWATER SOUND PROJECTOR SYSTEM.

distortion and facilitated operation during high tidal current conditions.

A reference monitor hydrophone (USN/USRD Type H-56) was mounted at a distance of 6 m from the projector system to maintain calibration of the projected sound levels.

During a playback sequence, a pre-recorded industrial noise or control stimulus on a cassette tape was used to generate a test signal. Two cassette recorders coupled to a fader control (previously shown in Fig. 3.5) permitted uninterrupted continuous sound for as long as desired. Playback periods of 1.5 to 2 hrs were generally used.

Stimuli Projection and Monitoring

For most of the playback sequences, the output level of the projector system was set to the maximum obtainable within the peak factor constraints of the recorded stimulus. This provided the maximum test range and hence the maximum number of subject whales. The sound levels obtained were subsequently scaled to levels reported for the actual source and a range correction was derived by using the transmission loss characteristics measured at the test site. This procedure will be described in detail in Sec. 5.

Selection and Level Calibration

Five petroleum industry development and production noise examples were used for the playback stimuli. These were representative examples of drillship, semisubmersible, drill rig, drilling platform, and helicopter operations. In addition, a control example of orca vocalizations was used. Descriptive information for these test examples is contained in Table 3.1.

TABLE 3.1. PLAYBACK STIMULI INFORMATION.

Stimulus (Code)	Original Recording Dist. Meters	Dominant Frequencies Hz	Reported Level dB//µPa	Est. 100 m Level dB//µPa	Playback 100 m Level dB//µPa	Difference (PB-Orig) dB	Data Ref.
DRILLSHIP (DS)	185	278 (t)	123	126	117	-9	Greene
(EXPLORER II)		50-315 (bb)	133	136	127	-9	p. 322
Helicopter (H)	152	20 (t)	114	84*	-	-	Greene
(Bell 212)	(altitude)	32 (t)	99	69*	101	32	p. 311
		50-200 (st)	99	69*	119	50	
Semisubmersible (SS)	12	28 (t)	129	111	95	-16	Gales
(OCEAN VICTORY)		63-250 (st)	119	101	122	21	p. 65
Drilling Platform (DP)	30	5 (t)	119	109	-	-	Gales
(HOLLY)		13 (t)	107	97	99	2	p. 66
		80-315 (st)	99	89	120	31	
Production Platform (PP)	9	20 (t)	134	118	104	-19	Gales
(SPARK)		63-250 (st)	125	109	119	10	p. 64
Orca (O)	-	800-1600 (bb)	-	-	116	-	**

Key:

(t) tonal, (bb) broadband, (st) summed tonals.

*Estimate based on relationships developed for aircraft-underwater sound transmission in deep water. In shallow water, levels would be higher, depending on the acoustic properties of the bottom material. (Barger and Sachs)

**No data are available for orca vocalization source levels.

As shown in the table, the acoustic recording used for each of the test stimuli was obtained at various ranges from the respective source. Hence, to standardize the playback comparison process, we corrected the reported acoustic level data to an equivalent 100 m range from the source. Since the water depth and sound propagation characteristics differed for the various sources, we considered that correction to a 100 m range represented a smaller potential error than correction to the usual 1 m range. In each case measured transmission loss data were used, if available, or the best estimate of transmission loss was used based on stated range and water depth values. In deriving the appropriate comparison with the projected playback level, a 100 m sound level estimate was also used. Thus we were able to derive a scaling factor for the playback level which allowed us to compensate for local transmission loss characteristics and for differences between acoustic levels from the actual sources and the achievable levels from the playback projector. Table 3.1 shows the differences in levels between the playback stimuli and the reported values as corrected to an equivalent 100 m range. Since we wished to maximize the achievable signal-to-noise ratio (S/N), the projector was operated near maximum output for all stimuli. Thus, as shown in the table, the projected level was louder than the actual source for some stimuli, and quieter than the actual source for others.

Table 3.1 lists the maximum measured levels for the stimuli when they were originally recorded. These sound levels are based on the reported data for the actual tape dubs used. The reference cited was used as the basis for establishing the original sound field level because of the difficulty in recovering and preserving a calibration chain through the dubbing and playback process. The original data were used to determine the dominant spectrum components of the original sound field and the frequency region of the principal output. Because of the low frequency limitations of the J-13 projector below 50 Hz, it was not possible to reproduce the required levels for sources with very low dominant frequencies. In this case the degree to which the frequency response above 50 Hz matched the original source was examined independently by comparison of this part of the playback spectrum with the comparable part of the reported original source spectrum. This is shown as the "summed tonal level" value in Table 3.1.

The sound level output produced during playback is compared with the original sound source values in the last column of the table. The comparison shows that, while low frequency components are often appreciably reduced on playback, the components above 50 Hz are generally above the original in level. The exception to this is the drillship stimulus where the achievable level is below that of the actual source at all frequencies. The procedure for scaling level differences between playback and actual sources will be discussed in Sec. 5 using the measured TL and ambient noise data for the observation site.

Playback Schedule Considerations

The playback schedule which was designed for the six sound stimuli in the repertoire involved requirements to:

- Maximize the number of different sequences presented each day to obtain a sufficient data base for each type of sound and be able to average over the influence of weather on whale behavior.
- Provide a sufficiently long exposure period for each sequence so that a large number of whales swimming at 3 to 5 kts would traverse a pre-exposure zone, a test zone, and a recovery zone within visual range of the observation sites.

- Provide a no-playback interval between test sequences to minimize the number of whales exposed to two different types of test stimuli.
- Provide a no-playback control period prior to the commencement of the daily schedule and at the end of each observation day.

The schedule which evolved was organized around 1.5 to 2 hr playback periods separated by 0.5 to 1 hr quiet periods. This enabled 3 to 4 playback sequences per day, weather permitting.

The test period was preceded by 3 days of observations without a playback vessel on station. VARUA was on station with no playback for a 0.5 day period in addition to the pre-playback and post-playback intervals. Post test observations were made for 2 days. The tests were performed using the double-blind method after two days of initial playback testing. An observer on the VARUA provided information on the number of whales passing nearby during each playback sequence. An adjustment of the number of times each sequence was repeated was planned if it appeared that the distribution in the number of subject whales for each stimulus was becoming imbalanced. This adjustment was not needed. The playback schedule was organized into blocks with each block containing a complete set of 5 industrial source samples. The source schedule within each block was random. The orca control stimuli was presented less frequently and only when the observer on the VARUA noted that a sufficient number of whales were in sight with none in the immediate vicinity of the VARUA.

3.3.3 Air gun source measurements

The purpose of the observations using an air gun array vessel and a single air gun vessel was to subject migrating whales to a controlled sequence of sound exposure in order to determine the levels for which observed behavior changes occur. In addition, we also wished to determine the air gun source characteristics and the test site sound propagation conditions using the air guns as a source. Since the first available air gun vessel was the loudest - 4000 cu. in. at 2000 psi - it was necessary to schedule a conservative series of test ranges in which the sound exposure was gradually increased in amplitude until a significant behavior change occurred. Preliminary calculations showed that received levels would be significantly above ambient noise, but probably below whale disturbance level, at an initial test range of 50 miles. Thus, a test plan with the sequence of tracks shown previously in Fig. 1.2 was designed.

The single air gun tests were planned in a similar sequence, except a beginning range of 3 miles was used to allow for the expected lower level for this source (100 cu. in., 4000 psi). The initial tracks followed by the air gun vessel were nearly identical with tracks D and E shown in Fig. 1.1 for the array test. Following these test sequences a series of tests at ranges closer to the migration area was performed. This provided data on the feasibility of range scaling tests with single air guns to simulate the sound field produced by a large array. A more detailed discussion of these tests is included in Section 5. A series of measurements to provide data on the source level of the single air gun was also performed.

4. FIELD MEASUREMENTS

In this section, we will describe the January and April/May field seasons. Included in this discussion will be the rationale behind the study site selection, the timing of the field seasons, and an overview of the types of data collected, acoustic stimuli used and acoustic measurements made.

4.1 January Field Season

4.1.1 Field observation in January 1983

After an extensive review of the literature on the south-bound migratory characteristics of the gray whale (see Appendix A, pp. A5-A13), we determined that the ideal location to observe the migration would be the Yankee Point-Granite Canyon area, approximately 22 km south of Monterey, CA. This area is easily accessible by ground transportation and has served in the past as the research site for the National Marine Fisheries Service in the work on population assessment (see Appendix A, pp. A8-A10). Preliminary reconnaissance of the area by P. Tyack and C. Malme determined that one site should be located at Soberanes Point and the second site 2.4 km to the north (see Fig. 1.1). The sites offered excellent viewing conditions north to Yankee Point, 3 km north of North Site, and south to Rocky Point, 4 km south of Soberanes. Soberanes and North Sites, at elevations of 75.7 m and 63.4 m, respectively, allowed reliable transiting of whale groups. (See Sec. 3.1 for an explanation of the transiting technique and Appendix G for error analysis of this technique.) Because our study was dependent on the transfer of observation information from one site to the next, a prime consideration in choosing these two sites was that effective radio communication could be maintained between sites and with the acoustic research vessel VARUA.

Based on our literature review, we determined that the peak numbers of southbound migrants would pass the central California coast during mid-January. We planned our field season so as to bracket this period. Our data collection began on 6 January and ended on 21 January.

For maximum effectiveness in data collection, we stationed three personnel at each site, a transit operator, a data recorder, and an observer. In practice, the transit operator was a second observer and the data recorder, to a lesser extent, a third observer. Observers were rotated periodically so that all personnel were involved in all phases of data collection.

Whale hours were calculated by multiplying the number of whales in each group by the number of hours the group was under observation and then summing these values for either the hour of the day, the entire day, or the experimental condition. The total whale hours for the control period and the various experimental conditions are given in Tables 7.10 through 7.13 of Sec. 7.

Table 4.1 presents a summary of shore-based observations by date and site. Most observations during control conditions began at approximately 0800 and ended at approximately 1700. The start and stop time depended mainly on the weather conditions. From 11-16 January, the observation period was slightly longer because of the presence of the VARUA. We had good to excellent viewing conditions with observation on all days except 18 January when inclement weather prevented us from data collection. Weather conditions also forced us to suspend operations early on 17, 19, and 21 January. A total of 209.6 hrs of field observation was achieved during January.

TABLE 4.1. SUMMARY OF LAND OBSERVATIONS, 6 JAN - 21 JAN 1983.

Date	Obs. Per.	Exp. Boat	No. of Obs.	No. of Groups	No. of Whales	Mean Group Size	No. of Theodolite Sightings	Theodolite Sightings per Group	Boats	Tankers	Aircraft	Calves	Conditions
6 Jan-N	0912-1623	n[1]	3	46	79	1.7	159	3.5	2	0	1	0	Visibility good to excellent. a.m. haze, wind up, whitecaps p.m.
M	1031-1605		3	45	87	1.9	221	4.8	0				
7 Jan-N	0812-1256	n	3[2]	33	71	2.2	110	3.3	1	0	0	0	Good to excellent a.m. wind up to NW 20-30 kts whitecaps by early p.m. fair by end.
M	0811-1309		3[3]	22	45	2.1	137	6.2	3				
8 Jan-N	0740-1702	n	3[4]	56	105	1.9	170	3.0	2	0	0	0	Good early a.m. wind up to NW 20-30 kts by late a.m., early p.m. good to fair, wind down to 15 by end.
M	0919-1710		3[5]	43	85	2.0	209	4.9	1				
9 Jan-N	0800-1647	n	3	61	103	1.7	298	4.9	0	0	1	0	Good to fair a.m., early p.m. NNE-wind up p.m. whitecaps poor by late p.m.
M	0810-1703		3	44	74	1.7	134	3.1	0				
10 Jan-N	0806-1657	n	2/3[6]	66	112	1.7	273	4.2	6	0	1	0	Good to excellent all day. Wind variable. Whitecaps 2-3 km off in p.m.
M	0831-1629		2/3[7]	52	90	1.7	326	6.3	4				
11 Jan-N	0755-1653	pb	3	63	127	2.0	358	5.7	3	5	5	0	Excellent to good all dey with light wind and Some haze in mid to late p.m.
M	0801-1712		3	58	123	2.1	393	6.8	2				

TABLE 4.1. (Cont.) SUMMARY OF LAND OBSERVATIONS, 6 JAN - 21 JAN 1983.

Date	Obs. Per.	Exp. Boat	No. of Obs.	No. of Groups	No. of Whales	Mean Group Size	No. of Theodolite Sightings	Theodolite Sightings per Group	Boats	Tankers	Aircraft	Calves	Conditions
12 Jan-N	0753-1701	pb	3/2[8]	47	84	1.8	176	3.7	5	7	2	0	Very good to excellent early a.m. Smoke, haze late a.m. to early p.m. Good late p.m. with haze.
M	0756-1705		3	63	128	2.0	437	6.9	6				
13 Jan-N	0759-1736	pb	3	84	172	2.1	521	6.2	6	5	8	0	Good to excellent all day. Some smoke haze late a.m. and late p.m.
M	0752-1735		3	72	143	2.0	428	5.9	3				
14 Jan-N	0755-1730	pb	3	80	148	1.9	435	5.4	10	3	5	0	Good to excellent. Some smog.
M	0758-1734	pb	3	75	138	1.8	435	5.7	10	3	5	1	
15 Jan-N	0807-1544	pb	3	62	145	2.3	330	5.3	16	0	4	0	Fair, haze and wind came up from the south. Rain in p.m.
M	0821-1545	pb	3	46	108	2.3	336	7.3	16	0	4	0	
16 Jan-N	0812-1733	pb	3	98	268	2.7	731	7.4	14	0	6	1	Good to excellent, rain in a.m.
M	0821-1726	pb	3	97	202	2.1	592	6.0	14	0	5	1	
17 Jan-N	0813-1212	pb	3	37	79	2.1	233	6.3	1	1	1	2	Fair, worsened in p.m. VARUA weighs anchor and observations terminated.
M	0835-1235	pb	3	45	95	2.1	272	6.0	1	1	1	1	
19 Jan-N	1344-1427	n	2[9]	4	4	1.0	10	2.5	0	0	0	0	Poor. Rain and high wind. Observationa terminated.
M	1338-1427	n	3	7	15	2.1	25	3.2	0	0	0	0	
20 Jan-N	0826-1509	n	3	53	88	1.7	160	3.0	3	3	5	0	Fair, lots of chop and big swells.
M	0834-1506	n	3/4[10]	51	107	2.1	223	4.4	3	3	5	1	

TABLE 4.1. (Cont.) SUMMARY OF LAND OBSERVATIONS, 6 JAN - 21 JAN 1983.

Date	Obs. Per.	Exp. Boat	No. of Obs.	No. of Groups	No. of Whales	Mean Group Size	No. of Theodolite Sightings	Theodolite Sightings per Group	Boats	Tankers	Aircraft	Calves	Conditions
21 Jan-N	0921-1034	n	3	8	16	2.0	64	8.0	1	0	0	0	Foggy and rain. Occasional fair to good viewing. Observations terminated.
M	0920-1025	n	3	6	14	2.3	23	3.8	0	0	0	0	

NOTES: [1]See Table 4.3 for experimental boat schedule.
[2]C. Cowles to 1030, assisting regular observers.
[3]C. Cowles 1200 to end, assisting regular observers.
[4]C. Cowles to 1343, assisting regular observers.
[5]C. Cowles 1245 to end, assisting regular observers.
[6]Two observers to 1256, three to end.
C. Cowles 1300-1430, G. Reetz 1315-1430.
[7]Two observers to 1404, three to end.
[8]Three observers to 1000, two to end.
[9]G. Reetz 1344-1427, assisting regular observers.
[10]G. Silber 1330 to end, assisting regular observers.
N = North Site
M = Mid-site (Soberanes)
No. of Obs. = Number of observers
n = No experimental boat
pb = Playback

The peak of the migration passing our study sites occurred on 16 January with a high count of 268 whales in 98 groups. We should make brief mention here that there were discrepancies between North and Soberanes sites on the number of whales and whale groups passing by on any given day. These differences occurred because of three factors: 1) variable viewing conditions, 2) groups joining or splitting, and 3) groups that were not observed. Tabulation of the number of whales and whale groups observed by either site results in the finding that during the January field season a minimum of 1699 whales in 825 groups was observed.

Table 4.2 presents a summary of the total number of whale group tracks in January. A track was included if it extended over a 10 min. period. The table is categorized by control and the various experimental conditions. The analysis of track data is presented in Sec. 5. Because of the stricter criteria used in the statistical track analysis, the figures on the number of tracks in Table 4.2 are higher than the numbers actually analyzed. A complete explanation of the table is given in the extended caption.

4.1.2 Acoustic stimuli during southbound migration

Controlled playback of acoustic signatures of typical sources of sound associated with oil and gas exploration and development operations was performed during the southbound migration in January. As described previously, these signatures were for

- Drillship
- Drilling Platform
- Semisubmersible Drill Rig

TABLE 4.2. NUMBER OF TRACKS OF GRAY WHALES OBTAINED FROM THE JANUARY 1983 FIELD PERIOD (ITEMIZED BY ACOUSTIC EXPOSURE AND BOAT PRESENCE).

Date	No Boat	Boat No PB	Partial NB	Fully Exposed to Playback (PB)							Partially Exposed to Playback (PB)							No Boat	Day Totals			
				PP	DP	TL	HE	OR	SS	DS	PP	DP	TL	HE	OR	SS	DS		Boat No PB	Fully Exp.	Part Exp.	Partial N.B.
1/07/83	18																	18				
1/08/83	30																	30				
1/09/83	35																	35				
1/10/83	35																	35				
1/11/83	7	12	8	5	8						12	8						7	12	13	20	8
1/12/83		5				27				3			2				8		5	30	10	
1/13/83		7			7		4		17			13		7		17			7	28	37	
1/14/83		12		12			2	5		4	9			3	8		9		12	23	29	
1/15/83		13		7	12					6	4	6					3		13	25	13	
1/16/83		19					11	3	19					21	14	14			19	33	49	
1/17/83		28	4																28			4
1/18/83	NO DATA																					
1/19/83	4																	4				
1/20/83	45																	45				
1/21/83	7																	7				
TOTALS	181	96	12	24	27	27	17	8	36	13	25	27	2	31	22	31	20	181	96	152	158	12

(Total Tracks = 599)

Key: PP = Production Platform; DP = Drilling Platform; TL = Transmission Loss Experiments; HE = Helicopter; OR = Orca; SS = Semi-Submersible; DS = Drillship; PB = Playback; NB = No Boat.

Note: A track may apply to a single animal or a group of animals traveling together.

EXPLANATION OF TRACK TABLE:

1) Fully exposed to Playback (PB) means that the whale group was first observed and transited during a specific PB and that the last transited observation was made during that same PB.

2) Partially exposed to PB means that the whale group was first observed and transited during a specific PB and that the last transited observation was made after that specific PB had ended (during no PB condition). This also works the other way, i.e., a whale group picked up before a PB had started and was last seen and transited during a PB. In approximately 5 cases, whale groups were observed and transited during one PB and was last seen during another PB period with an intervening no PB condition. These groups are placed in both PB categories in the table.

3) Partial no boat (NB) means that the whale group was first observed and transited while the VARUA was on station and the last transited observation occurred during the time period the VARUA was moving off station. This is only true for 1/17/83. The 8 partial NB tracks on 1/11 were the reverse of the 1/17 conditions.

- Production Platform
- Helicopter

and were obtained from NOSC-San Diego and Polar Research Laboratory through MMS. In addition to these acoustic stimuli, killer whale (Orcinus orca) vocalization sounds were obtained from Dr. John Ford for playback experiments. Playback timing and schedules were selected on a random basis, with no-playback periods interleaved in the schedule to permit investigation of undisturbed and recovery behavior of the migrating whales. The sound vessel crew did not communicate at any time with the whale behavioral shore observation teams throughout each full-day observational period in order to insure the performance of a "blind" experiment. Release of the playback schedule was withheld until completion of the January field measurement work. A description of the acoustic playback system was presented in Sec. 3.3.

The playback schedule for the gray whale behavioral investigation during southbound migration is given in Table 4.3. Notice, in particular, that an average of three playbacks per day were accomplished in a six day period, representing an unusually open and weather-free period for that time of the year. In fact, heavy weather prevented deployment of equipment immediately prior to this test period and then began building again on 17 January. The limited playback work on 12 January was due to lack of observation site-to-whale visibility from heavy smoke caused by brush fires. Shipping noise contributed to the background noise on an intermittent basis. Occasional aircraft, including helicopters, flew over the test area, impacting the noise environment at uncontrolled and unpredictable times. The natural ambient noise was dominated, particularly at high frequencies, by snapping shrimp (believed to be pistol shrimp),

TABLE 4.3. ACOUSTIC STIMULUS PLAYBACK LOG FOR THE JANUARY 1983 FIELD PERIOD.

Date/Time		Stimulus	Stimulus Duration
1/11	1150-1216	None (Ambient Meas.)	
	1217-1341	Production Platform	1 hr 24 min.
	1342-1436	None	
	1437-1607	Drilling Platform	1 hr 30 min.
	1608-1710	None	
1/12	0830-1000	Drillship	1 hr 30 min.
	1200-1730	Transmission Loss Msmts.	
1/13	0918-1048	Helicopter	1 hr 30 min.
	1049-1209	None	
	1210-1510	Semisubmersible	3 hrs
	1511-1544	None	
	1545-1715	Drilling Platform	1 hr 30 min.
1/14	0845-1010	Drillship	1 hr 25 min.
	1011-1207	None	
	1208-1338	Helicopter	1 hr 30 min.
	1339-1414	None	
	1415-1545	Production Platform	1 hr 30 min.
	1544-1614	None	
	1615-1710	Orca	55 min.
1/15	0845-1045	Drilling Platform	2 hrs
	1046-1129	None	
	1130-1330	Production Platform	2 hrs
	1331-1431	None	
	1432-1600	Drillship	1 hr 28 min.
	1601-1700	None	

TABLE 4.3. (Cont.) ACOUSTIC STIMULUS PLAYBACK LOG FOR THE JANUARY 1983 FIELD PERIOD.

Date/Time		Stimulus	Stimulus Duration
1/16	0932-1200	Helicopter	2 hrs (effective)
	1200-1244	None	
	1245-1445	Semisubmersible	2 hrs
	1446-1544	None	
	1545-1700	Orca	1 hr 15 min.
1/17	0800-1200	None	

Total Playback Time:

Stimulus	Time	Test Periods
Production Platform	4 hrs 54 min.	3
Drilling Platform	5 hrs 0 min.	3
Semisubmersible	5 hrs 0 min.	3
Drillship	4 hrs 23 min.	3
Helicopter	5 hrs 0 min.	3
Orca	2 hrs 10 min.	2

where shrimp noise levels increased with decreasing distance to shore.

Acoustic propagation (transmission loss) data were acquired on 12 January, and ambient noise measurements were made throughout the 11-16 January period.

As summarized in Table 4.3, each stimulus was used on three separate occasions during the test period except for orca sounds, which were used twice. A total time of 24 hours 17 minutes in the six day period was given to broadcast of oil and gas operations noise.

All acoustic work was completed on 17 January, and behavioral observation work, to obtain undisturbed whale data, was continued until 21 January.

4.2 April/May Field Season

4.2.1 Field observation in April/May 1983

Our literature review of the gray whale's northbound migratory characteristics (see Appendix A, pp. A13-A20) showed that this migration has two phases separated by approximately seven weeks. The first phase comprises the majority of the migrating population with the exception of mothers and calves while the second phase is almost exclusively mother/calf pairs. Primary emphasis during this migration period was on the study of the impact of seismic air gun noise on whale behavior. The air gun vessels CECIL H. GREEN II and CROW ARROW carrying a seismic array and a single air gun, respectively, but no receiving hydrophone streamers, were used during the mother/calf portion of the northward migration. The rationale behind this decision was that mother/calf pairs would presumably be the most sensitive group to seismic experiments. Another factor in this decision was that the nearshore migratory path of mother/calf pairs would make them less difficult to monitor from shore observation sites.

Because of our success in monitoring the southbound migration, Soberanes and North sites were used during this phase of the field work. A third observation site was deemed necessary in order to observe the whales over a longer shore baseline distance than was done in the January field season because of expected extent of air gun acoustic impact along the shore. A longer observation period was required since the effects of both playback stimuli and airgun stimuli were to be investigated. Because mother/calf pairs travel in shallow water which in our study yielded a nearshore path (20 to 250 m offshore) along a narrow corridor, theodolite track data were of less importance during this phase of the field work. The third observation site was located north of Kasler Point (see Fig. 1.1), approximately 2.4 km south of the Soberanes Point site.

Our literature review showed that peak numbers of mother/calf pairs should pass our study site during the last week in April and the first week in May. We planned our field season to bracket this period, beginning on 16 April and ending on 5 May.

As in the January field season, three observers were stationed at each site. Since only one or two groups were under observation at any time, the theodolite operator could also function as a second observer for respiration and behavior data acquisition. We attempted to keep every group under continuous observation for these data.

Table 4.4 presents a summary of our shore-based operations by date and site. The normal start time was between 0700 and 0900 with observations ending between 1700 and 1800. The weather conditions in this phase of the fieldwork were not as favorable as those in January, with five observation days being terminated

TABLE 4.4. SUMMARY OF LAND OBSERVATIONS, 16 APRIL - 5 MAY 1983.

Site Data									Day Totals							
Date	Obs. Per.	No. of Obs.	No. of M/C Groups	No. of M/C Pairs	No. of Singles	No. of Theodolite Groups	Theodolite Rdg. per Group	No. of Boats	No. of M/C Pairs	No. of M/C Groups	No. of Singles	No. of Whales	Exp. Boat	No. of Tankers	No. of Aircraft	Observation Conditions
16 Apr-N	0827-1812	2/3[2]	10	11	0	132	13.2	0								Very good to excellent
M	0829-1750	2/3[3]	10	11	0	82	8.2	3	11	10	0	22	n[1]	8	8	all day. Wind up to
S	Station not in operation															S 5-10 kts by early p.m. Some haze.
17 Apr-N	No data collected because of weather conditions															
M																
S	Station not in operation															
18 Apr-N	0810-1348	3	6	6	4	73	7.3	1								Good in a.m., fair to
M	0842-1326	3[4]	6	6	4	48	4.8	0	9	9	3	21	n	2	1	poor p.m. Wind up to SE
S	0815-1335	3	5	5	3	42	5.3	0								20-30 kts by early p.m., whitecaps, observations terminated.
19 Apr-N	0730-1200	3	5	7	1	79	13.2	0								Fair to poor all day with
M	0735-1150[5]	3	6	8	0	29	4.8	0	7	7	1	17	n	0	3	wind SE/SW 15-25 kts by
S	0730-1201[6]	3	4	5	1	22	4.4	0								early a.m. Increasing all day. Whitecaps and intermittant rain. Observations terminated.
20 Apr-N	0645-1534	3	5	6	0	61	12.2	0								Good to excellent until
M	0658-1734	3	6	6	0	48	8.0	0	6	5	0	12	y	6	7	mid p.m. then fair with
S	0639-1732	3	5	6	0	64	12.8	1								fog, haze, light rain. Wind calm early a.m. increasing to NW 5-10 kts.
21 Apr-N	0639-1800	3	6	6	0	49	8.2	0								Good early a.m., fair to
M	0647-1800	3	4	4	0	23	5.8	2	6	6	1	13	n	6	7	to poor with clearing by
S	0645-1800	3	3	3	1	11	2.8	0								end. Wind NE/NW 10-20 kts all day. Light rain, mist mid-day.

N = North site

M = Mid-site (Soberanes)

S = South site

TABLE 4.4. (Cont.) SUMMARY OF LAND OBSERVATIONS, 16 APRIL - 5 MAY 1983.

Site Data									Day Totals							
Date	Obs. Per.	No. of Obs.	No. of M/C Groups	No. of M/C Pairs	No. of Singles	No. of Theodolite Groups	Theodolite Rdg. per Group	No. of Boats	No. of M/C Pairs	No. of M/C Groups	No. of Singles	No. of Whales	Exp. Boat	No. of Tankers	No. of Aircraft	Observation Conditions
22 Apr-N	0730-1725	3[7]	6	8	0	92	15.3	1	8	6	0	16	y[6]	5	6	Good to excellent in a.m. Good to fair in p.m. with SW wind increasing to 15-20 by mid p.m., whitecaps, some haze.
M	0738-1805	3	7	8	0	58	8.3	1								
S	0730-1756	3[8]	7	7	0	73	10.4	0								
23 Apr-N	1532-1846[9]	3	7	7	0	71	10.1	0	9	9	0	18	y[6]	2	0	Good to poor all day with wind S 15-25 kts by late p.m. Intermittent rain.
M	1540-1851	3	7	7	0	25	3.6	0								
S	1536-1904	3	8	8	0	40	5.0	1								
24 Apr-N	0743-1938	3	21	24	2	142	6.2	1	28	22	1	57	y[6]	3	5	Good to mid p.m. then fair to poor to end. S/SW/SE wind increasing all day to 10-25. Highwinds at mid station late a.m. White-caps, increasing swell.
M	0757-1930	3	19	24	1	83	4.2	0								
S	0750-1930	4	19	25	2	122	5.8	0								
25 Apr-N	0800-1928	3	11	16	2	215	16.5	0	16	13	2	34	y[6]	3	18	Good to excellent all day. Wind from N 10-20 kts by mid p.m.
M	0811-1910	3[10]	11	15	2	143	11.0	0								
S	0811-1906	3	9	11	4	139	10.7	0								
26 Apr-N	0900-1811	3/4[11]	10	19	1	150	13.6	0	19	12	1	39	y[6]	4	5	Good to excellent all day. Wind up in mid p.m. to S/SE 10-15 kts, some whitecaps.
M	0900-1745	3	10	19	1	176	16.3	0								
S	0900-1708	3/4[12]	12	19	1	149	11.5	1								
27 Apr-N	0811-0914	3	1	1	0	7	7.0	0	1	1	0	2	n			Good at north site for ~1 hr. Wind increasing to 25-30 SE, rain. Observations terminated.
M	0806-0908	3	0	0	0	0	-	0								
S	0831-0910	3	0	0	0	0	-	0								
28 Apr-N	1038-1259	3	2	3	0	18	9.0	0	4	3	0	8	n	0	3	Fair to poor, wind increasing to S/SW 15-20. Rain, whitecaps. Observations terminated.
M	0957-1152	3	3	4	0	0	-	0								
S	1013-1127	3	3	3	0	6	2.0	0								

N = North site

M = Mid-site (Sobaranes)

S = South site

TABLE 4.4. (Cont.) SUMMARY OF LAND OBSERVATIONS, 16 APRIL - 5 MAY 1983.

Site Data									Day Totals							
Date	Obs. Per.	No. of Obs.	No. of M/C Groups	No. of M/C Pairs	No. of Singles	No. of Theodolite Groups	Theodolite Rdg. per Group	No. of Boats	No. of M/C Pairs	No. of M/C Groups	No. of Singles	No. of Whales	Exp. Boat	No. of Tankers	No. of Aircraft	Observation Conditions
29 Apr-N	0828-1408	3	8	9	0	74	9.3	0								Excellent early a.m. to
	1701-1955	3	7	7	0	49	7.0	0								poor by end. S wind
M	0823-1405	3/4[13]	8	10	0	40	5.0	0	14	11	0	28	y[6]	2	1	increasing to 20-25, rain.
	1653-1939	4	6	6	0	45	7.5	0						1	0	Good to fair with S wind
S	0828-1404	3	9	11	0	68	7.6	0								10-20.
	1648-2000	4	7	7	0	31	4.6	0								
30 Apr-N	0930-1930	3	3	4	0	37	12.3	0								Good to excellent early
M	0930-1239	3	4	5	0	20	5.0	0	10	4	0	20	y[6]	2	2	a.m. S wind increasing
S	0944-1228	3	5	5	0	38	7.6	0								20-30 kts by end, white-caps. Observations terminated.
01 May-N	1125-1911	3	6	7	1	87	12.4	1								Very good to excellent to
M	0834-1845[15]	3	6	7	1	65	10.8	0	9	6	2	20	y[6]	2	13	mid p.m. Good to fair by
S	1130-1846	2	4	5	1	37	9.3	0								late p.m. with wind up to N/NNW 12-15 kts.
02 May-N	1245-1800	3	3	4	0	46	14.7	0								Good to fair all day. Wind
M	0634-1800[16]	3	3	4	0	32	10.7	0	4	3	0	8	y[6]	2	7	up to N/NW 10 kts by mid
S	1237-1800	3	3	4	0	15	5.0	0								p.m.
03 May-N	0930-1045	3	0	0	0	0	-	0								Excellent in a.m. Fair to
	1300-1609	3	0	0	0	0	-	0								good p.m. Wind NW 30 at
	1735-1853	3	1	0	0	7	7.0	0	1	1	0	2	y[6/7]	6	10	mid-day dropping to NNW
M	0915-1300	3	0	0	0	0	-	0								8-10 kts by mid p.m.
	1300-1841	3	1	1	0	12	12.0	0								
S	0920-1300	3	0	0	0	0	-	0								
	1300-1725	3	1	1	0	1	1.0	0								
	1740-1849	3	0	0	0	0	-	0								
04 May-N	0819-1818	3/4[18]	2	3	0	45	22.5	4								Excellent to good all day
M	0850-1830	4	2	3	0	64	32.0	4	3	2	0	6	y[6]	5	1	with S/SW wind up to 10
S	No observations from this site															kts by mid p.m.

N = North site

M = Mid-site (Soberanes)

S = South site

TABLE 4.4. (Cont.) SUMMARY OF LAND OBSERVATIONS, 16 APRIL - 5 MAY 1983.

Site Data									Day Totals							
Date	Obs. Per.	No. of Obs.	No. of M/C Groups	No. of M/C Pairs	No. of Singles	No. of Theodolite Groups	Theodolite Rdg. per Group	No. of Boats	No. of M/C Pairs	No. of M/C Groups	No. of Singles	No. of Whales	Exp. Boat	No. of Tankers	No. of Aircraft	Observation Conditions
05 May-N	0758-1820	3	2	3	0	38	19.0	0								Good to very good at mid and south sites with intermittent rain. Wind up to SW 25 kts late a.m. (squall). Fair to poor at north site, wind S/SW 8-20 kts all day.
M	0740-1830	3	2	3	0	54	27.0	0	3	2	0	6	Y[6]	4	1	
S	0741-1832	3	2	3	0	42	21.0	0								

Footnotes:

1. See experimental boat schedule.
2. Two observers 1200-1230.
3. Two observers 1200-1330.
4. G. Reetz 1015-1045, assisting regular observers.
5. No observation 0930-1000.
6. No observation 0945-0954.
7. Two observers 1200-1240.
8. Two observers 1500-1540.
9. Weather delay until 1532.
10. Two observers 1000-1030, 4 observers from 1735 to end.
11. Four observers 1744 to end.
12. Four observers 1119 to end.
13. Four observers 1230 to end.
14. Census only 1300-1930, four m/c pairs seen (two observers).
15. Census only 0834-1130, two m/c pairs and one single seen (two observers).
16. Census only 0634-1237, three m/c pairs seen (no observers).
17. No experimental boat 0915-1300.
18. Four observers 1312 to end.

early and late starts on two days, because of adverse weather conditions. No observations were made on 17 April due to inclement weather. We had a total of 427.6 hrs of observation during this phase of the field research. On 16 April, our first field day, we observed 11 mother/calf pairs. Based on research by Poole (see Appendix A, pp. A13-A15), this was a high number of mother/calf pairs to appear so early in the migration. Poole's data show a peak number of mother/calf pairs passing Pt. Piedras Blancas (105 km south of our site) during the last week in April and the first week in May 1980-81. Our high count of 28 mother/calf pairs occurred on 24 April with a total number of 63 mother/calf pairs between 24-26 April. Because of these high numbers so early in the peak period and the very low numbers seen between 1 to 5 May (20 mother/calf pairs), we feel that the peak period of migration was about 3 to 5 days early. Since the nearshore migration path groups were seldom missed by the observation sites, an accurate figure for the total number of mother/calf pairs passing each day could be determined. We observed 347 whales during the April/May field season. Of these, 336 (96.8%) were mothers and calves (168 pairs) and 11 (3.2%) were single whales. The mean size of mother/calf groups was 2.54.

4.2.2 Acoustic stimuli during northbound migration

The major emphasis of the spring migration test period was upon investigation of the behavioral response of mother-calf pairs to geophysical (seismic) exploration air gun impulsive noise. Playback tests with the same stimuli used in January were to be performed whenever possible when air gun systems were not available to the project. Figures 1.1 and 1.2 in the Introduction outline the field observation sites used in the April/May measurement period and the air gun and acoustic research vessel positions for the various tests. As noted previously, the late April - early May time period coincided with the expected arrival in the Monterey area of the mother-calf pairs of gray whales which follow the general population of northerly migrating whales by about seven weeks. This natural bi-modal northward migration pattern offered unusual opportunity to study one particular segment of the gray whale population.

Table 4.5 summarizes the times during the period of 25 April to 5 May when various sounds were used under controlled conditions. The seismic air gun array vessel provided high level impulses of sound during transects that were 50, 20, 8, 3.8, 3, 1, and 0.5 nautical miles from shore and adjacent to the observation sites at and near Soberanes Point. Similarly, the single air gun system was applied for transects 3, 1, and 0.5 miles from shore as well as special runs nearshore and stationary air gun experiments when on-time was controlled from the Soberanes observation site.

Several acoustic transmission loss (TL) tests were performed during this test period to supplement TL data acquired in January.

Only two playback tests were performed, drillship and orca, due to limited available test time because of weather conditions. Sea conditions were frequently too heavy to permit safe deployment of the sound transducer system over the side of the VARUA. In the 16-day period available for acoustic testing from 20 April until 5 May, there were five days of weather which was severe enough to make acoustic tests and measurements impossible. Two days were used for system set up and calibration. All acoustic and shore observation work was completed on 5 May.

TABLE 4.5. ACOUSTIC STIMULI FOR THE APRIL/MAY 1983 FIELD PERIOD.

Date	Time On	Comments
AIR GUN ARRAY (CECIL H. GREEN II SEISMIC VESSEL):*		
4/23/83	1641-1932**	Line A; Parallel to shore at ~ 50 miles range
4/24/83	0815-1233	Line B; Parallel to shore at ~ 20 miles range
	1235-1250	Parallel to shore at 20 miles (pulses at 30 sec. intervals)
	1250-1309	Parallel to shore at 20 miles (pulses at 15 sec. intervals)
4/24/83	1447-1653	Line C; Parallel to shore at ~ 8 mile range
	1653-1807	Run from 8 miles to 3.8 miles toward shore
	1807-1906	Run parallel to shore at 3.8 mile range (approx. Line D)
4/25/83	0926-1135	Line D; parallel to shore at 3 mile range
4/25/83	1231-1400	Line E; parallel to shore at 1 mile range
	1612-1717	Line E; parallel to shore at 1 mile range
4/25/83	1759-1850	Line F; parallel to shore at 0.5 mile range
	(1759-1809)	(air gun volume 2000 in^3)
	(1809-1819)	(air gun volume 3000 in^3)
	(1819-1850)	(air gun volume 4000 in^3)
TAPE PLAYBACK SOUNDS		
4/29/83	1354-1411	Drillship playback (DS)
	1702-1906	Drillship playback (DS)
5/1/83	1646-1831	Orca Playback (O)
5/2/83	1541-1555	Trial Drilling Platform (PD) (no whales in sight)

*Nominal firing rate = 15 sec pulse interval, 2000 psi pressure, volume = 4070 $in.^3$ unless noted otherwise.

**Pacific Standard Time; all other times are Pacific Daylight Time.

TABLE 4.5. (Cont.) ACOUSTIC STIMULI FOR THE APRIL/MAY 1983 FIELD PERIOD.

Date	Time On	Comments
TRANSMISSION LOSS TESTS		
5/1/83	1324-1400	100 Hz warble tone; TL from VARUA to Otter Cove
5/1/83	1514-1554	100 Hz warble tone; TL from VARUA to North site
5/1/83	1625-1635	100 Hz warble tone; TL from VARUA due West
J-13/F-40 CALIBRATION TESTS		
5/5/83	~1000-1100	Tones from 100 Hz to 22 kHz, "no whales" in area.
SINGLE AIR GUN from M.V. CROW ARROW:		
	(Volume = 100 in^3 at 4000 psi; Pulse interval = 10 sec.)	
5/3/83	1315-1424	System trial and setup; R ~ 3 miles
	1425-1625	3 mile run parallel to shore (Line D)
	1705-1740	1 mile run (Line E) parallel to shore (northward)
	1748-1824	1 mile run (Line E) parallel to shore (southward)
	1829-1839	CPA run on VARUA; range to shore ~ 800 yds
	1846-1903	CPA run on VARUA; range to shore ~ 800 yds
5/4/83	0915-1100	Prep time; air gun operating
	1100-1148	0.5 mile run (Line F) parallel to shore (south to north)
	1205-1339	10 fathom contour run from north site into Otter Cove to Lobos Rocks and south beyond west side Lobos Rocks
	1448-1531	Anchored air-gun operation (CROW ARROW at ~ 500 yds north of bight between Lobos Rocks and Soberanes Point)
5/5/83	1158-1203	Main engines on, anchored CROW ARROW at ~ 800 yds north of bight
	1203-1206	Mains and compressors on
	1210-1213	Mains and compressors and air gun operating
	1308-1334	Anchored; gun operating
	1407-1446	Anchored; gun operating
	1904-1956	Underway; gun operating for TL run at 288° T heading away from Otter Cove

5. ACOUSTIC MEASUREMENTS AND RESULTS

5.1 Transmission Loss and Air Gun Source Measurements

Measurement of acoustic transmission loss (TL) in the test area was a necessary part of determining the acoustic source characteristics of the air gun array and the single air gun. Hence, we are integrating the discussion of these measurement results. The TL results obtained using the projector system are also included and compared with those obtained with the air gun sources.

Acoustic transmission loss in shallow water is highly dependent on the acoustic properties of the bottom material since, in most areas, sound energy is transmitted mainly by rays that are multiply reflected from the bottom and surface in travelling from the source to the receiver. The average number of reflections (or "bounces") depends on the water depth, on the acoustic properties of the water column (sound velocity gradient), on acoustic properties of the bottom, and on any directional properties of the source and receiver. In most shallow water areas, the relationship between acoustic pressure and distance from the source (range) has been found to be modeled quite well by considering a spreading loss which is midway between that of unbounded deep water (spherical spreading or 20 log range) and that of ducted horizontal spreading (cylindrical spreading or 10 log range) (Urick, 1975, Sec. 6.6). To the spreading loss must be added a loss due to molecular absorption in the water, a loss due to the scattering and absorption at the surface and bottom, and an energy increase due to the surface and bottom "image" sources. The resulting sound propagation model can be expressed in equation form as:

$$L_r = L_s - 15 \text{ Log}(R) - A_v(R) - A_r(R) + I \text{ (dB//1}\mu\text{Pa)} \qquad (1)$$

where

L_r = Received level at range R (dB//1μPa)

L_s = Source level (dB//1μPa at 1 m)

R = Range in meters

A_v = Molecular (volumetric) absorption (dB per meter)

A_r = Reflection loss at surface and bottom (dB per meter)

I = Change in effective source level due to proximity of surface and/or bottom (dB).

This model was modified to fit the requirements of the measurement area and experimental conditions. Since our primary concern was low frequency sound propagation, we have neglected the volumetric absorption loss as not being significant below 500 Hz for the ranges of interest. Much of the data we obtained was for conditions where the source and receiver were in regions with appreciably different depths; also, for a number of measurements the source depth was a significant fraction of the range. Thus, the number of reflections was not constant with range, and the spreading loss would not be expected to be 15 log(R) for the entire propagation path.

The model was modified by assuming the bottom to be uniformly sloping between the source and receiver. The effective loss per bounce was then determined by considering the total number of bounces to be proportional to R/d(avg) where d(avg)= (source depth, d_s, + receiver depth, d_r)/2. Thus, if A_b is defined as the effective attenuation per bounce, then

$$\text{Number of bounces (avg)} = 2R/(d_s + d_r)$$

$$\text{Total attenuation} = A_b(R/(d_s + d_r))$$

where A_b includes the factor of 2 obtained in averaging.

Sound spreading loss in the region of the source was assumed to be 20 log(R) out to a range equal to the depth d_s, where bottom reflections would become a significant factor in the received sound. Thus, the propagation model was modified to consider a near-source region and a region where bottom and surface reflections control the propagation. Equation (1) was rewritten as

$$L_r = L_s - 20 \log(d_s) - 15 \log(R/d_s) - A_b(R/(d_s + d_r)) + 6 \text{ dB}. \tag{2}$$

This can be simplified to

$$L_r = L_s - 5 \log(d_s) - 15 \log(R) - A_b(R/(d_s + d_r)) + 6 \text{ dB}. \tag{3}$$

Here, the 6 dB correction term assumes a 3 dB contribution each from surface and bottom source images.

When the source and/or receiver are very close to the surface, the surface reflection (image source) interacts strongly with direct sound radiation. The reflected sound is out-of-phase with the direct sound so that an interference pattern is produced. This pattern, known as the Lloyd mirror effect, causes range-dependent fluctuations in the received sound level measured using a constant receiver depth along a horizontal path from the source. The Lloyd mirror effect is strongest at low frequencies and in calm sea conditions. For a source closer than 1/4 wavelength ($\lambda/4$) to the surface, the source and its image become a dipole sound source which has a vertical directionality given by $\sin\theta$ where θ is measured from the surface. For shallow water propagation with a normal spreading loss of 15 log(R), it can be shown that the effect of the dipole source directivity is to introduce an additional 10 log(R) spreading loss (Grachev, 1983).

The above example also applies to a receiver that is within $\lambda/4$ of the surface so that an additional 10 log(R) spreading loss would be required to account for the shallow receiver. Thus, propagation from a shallow source to a deep receiver in shallow water would be expected to have a 25 log(R) spreading loss and propagation from a shallow source to a shallow receiver in shallow water would have a 35 log(R) spreading loss.

5.1.1 Sound Velocity Measurements

The above discussion concerned propagation modeling where most of the sound rays were contacting the bottom (nonducted). Measurements made from the VARUA in January, off the Soberanes Point test site in the region of highest whale migration density, showed a nearly neutral sound velocity profile (SVP) down to a depth of 40 m (near the bottom). This was probably the result of tidal mixing since the current was observed to run at 0.5 kt or higher. Examination of archival SVP data for the region seaward of the test area disclosed that bottom contacting sound propagation could be expected out to about 35 miles after which depth excess could exist.* Thus, the sound propagation model described above appears appropriate for most of the test region with the possible exception of the more distant track segments of the air gun array.

5.1.2 Air Gun Source Characteristics

The sound propagation characteristics in the test area were measured initially with the projector system during the January field period. The data obtained for TL tests out to about 1 km showed that a 15 log(R) propagation model was probably appropriate.

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*Depth excess conditions occur when the sound speed measured for increasing depth equals and exceeds that measured at the surface. This produces sound ducting.

Sea conditions limited the amount of data we were able to obtain using the 13-ft Whaler as a receiving platform. Fortunately, the availability of the air gun sources during the April-May test period provided the opportunity to obtain a good TL data base for acoustic exposure calculations.

Operation of the air gun array at the test ranges, shown previously in Fig. 1.2, provided signature data which were analyzed to provide narrowband spectra, pressure-time signature, and average pulse pressure level as a function of range. Several parameters of the air gun signature were measured since we did not know which one would ultimately correlate best with observed whale behavior. The literature on human response to impulsive sounds reports that "perceived noisiness" correlates well with the total acoustic energy of the pulse for pulse durations up to 100 sec. In experiments on human subjects, Fidel et al. (1970) varied the waveform of test pulses greatly but no significant noisiness change was noted unless pulse durations or power spectra were changed. Assuming that all mammals have similar auditory response for impulsive sounds, we have quantified the acoustic energy of air gun pulses in terms of an average pulse pressure, a parameter which is independent of phase-related waveform details.

This procedure is described by defining the average pulse pressure as being the equivalent peak sinusoidal pressure level for a constant amplitude pulse of time duration T equal to the effective time duration of the original pulse and having the same acoustic energy (Urick, 1975, Sec. 4.4), or in equation form,

$$E = \frac{1}{\rho c} \int_0^\infty p^2(t)dt = \frac{\overline{p}^2 T}{2\rho c} \quad \text{(Joules)} \tag{4}$$

where

ρc = the specific acoustic impedance of water

$p(t)$ = the original pulse pressure waveform

$\overline{p}$ = the average pulse pressure

T = the effective pulse duration (the time required for $p^2(t)$ to decay to less than 10% of the initial value).

The instrumentation used for data analysis is shown in Fig. 5.1. The energy analysis system incorporated a bandpass filter to eliminate high frequency ambient noise and hydrophone flow noise. A squaring and integrating circuit provided a voltage output proportional to the integrated acoustic energy of the pulse. The pressure-time waveform signal was recorded concurrently with the integrator output on an optical chart recorder. This provided a record as illustrated in Fig. 5.2. Here, the contributions of the successive pulse components due to multipath propagation can be seen adding to the integrator output. The final voltage on the integrator, V_e, was used to determine the average pulse pressure by calibrating the system using a known energy input. The following computation method was derived:

$$L_{\overline{p}} = 10\log(V_e) - 10\log(T) - S_h - G_r - G_p + A_d - 59 \text{ (db//1}\mu\text{Pa)} \quad (5)$$

where

$L_{\overline{p}}$ = Average pulse pressure level

V_e = Integrator output voltage (volts)

T = Pulse duration (seconds)

S_h = Hydrophone sensitivity (dB//1 volt/μPa)

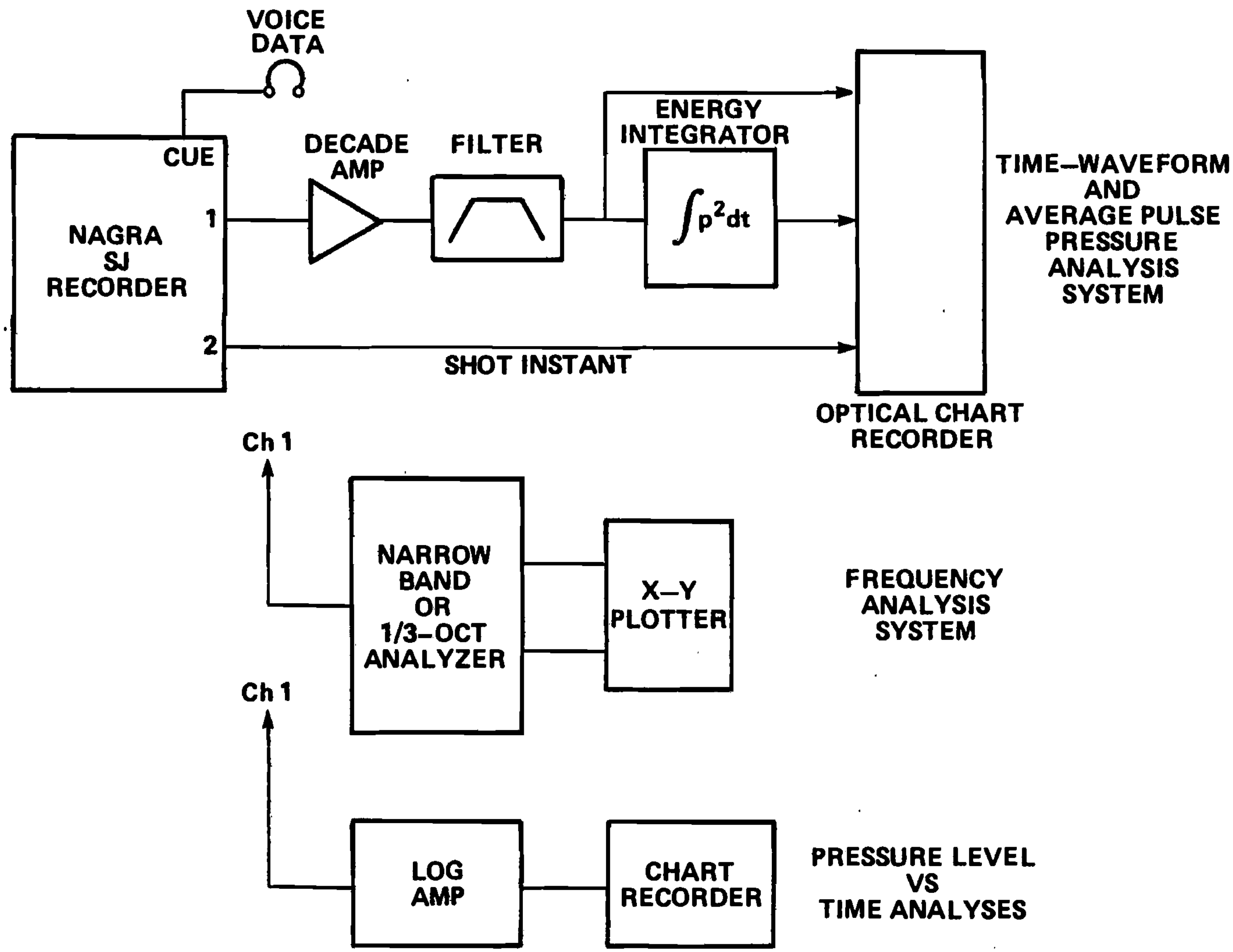

FIG. 5.1. DATA ANALYSIS SYSTEMS.

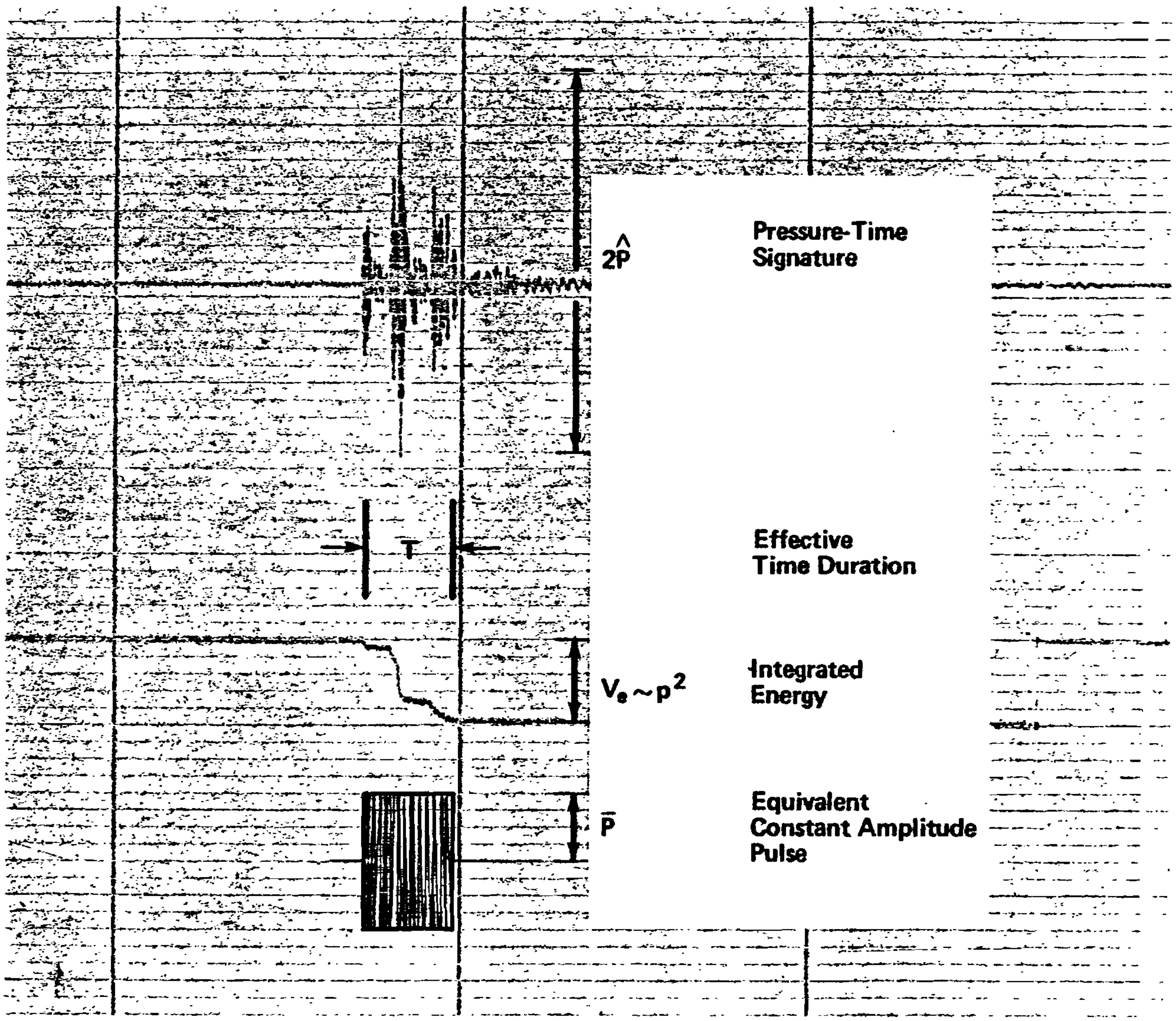

FIG. 5.2. CHART RECORD SHOWING PULSE SIGNATURE AND PULSE ENERGY INTEGRATOR OUTPUTS.

G_r = Record gain (dB)

G_p = Playback gain (dB)

A_d = Detector-Integrator Attenuation (dB)

59 = Constant based on MKS system units.

A narrowband analyzer was used in the transient-capture mode to obtain analyses of air gun and air gun array signatures for various ranges. The time waveform of the captured signal was also recorded to obtain peak pressure data. Because of the multi-path transmission, peak pressure values were quite variable - particularly at the most distant transmission ranges. Average pulse pressure measurements provided more consistent results; hence these data were used in developing the propagation model for noise exposure estimation at observed whale positions.

The results of average pulse pressure measurements at various ranges for both the array and the single air gun are shown in Fig. 5.3. The general trend of the TL data for the array follows a 25 log(R) spreading loss slope. This is consistent with dipole type directivity either due to the proximity of the surface, as discussed previously, or to the arrangement of the array. The trend of the TL data for the single air gun follows a 15 log(R) spreading loss slope. The propagation loss model of Eq. (3) was used as the basis for deriving equations for estimation of sound levels in the test area. For the array, a 25 log(R) spreading loss was used but the loss per bounce was assumed to be the same as that for the single air gun when both sources operated in the same area. By doing a best fit analysis with the TL data, the following relationships were derived. (A reference distance of 1 km was used.)

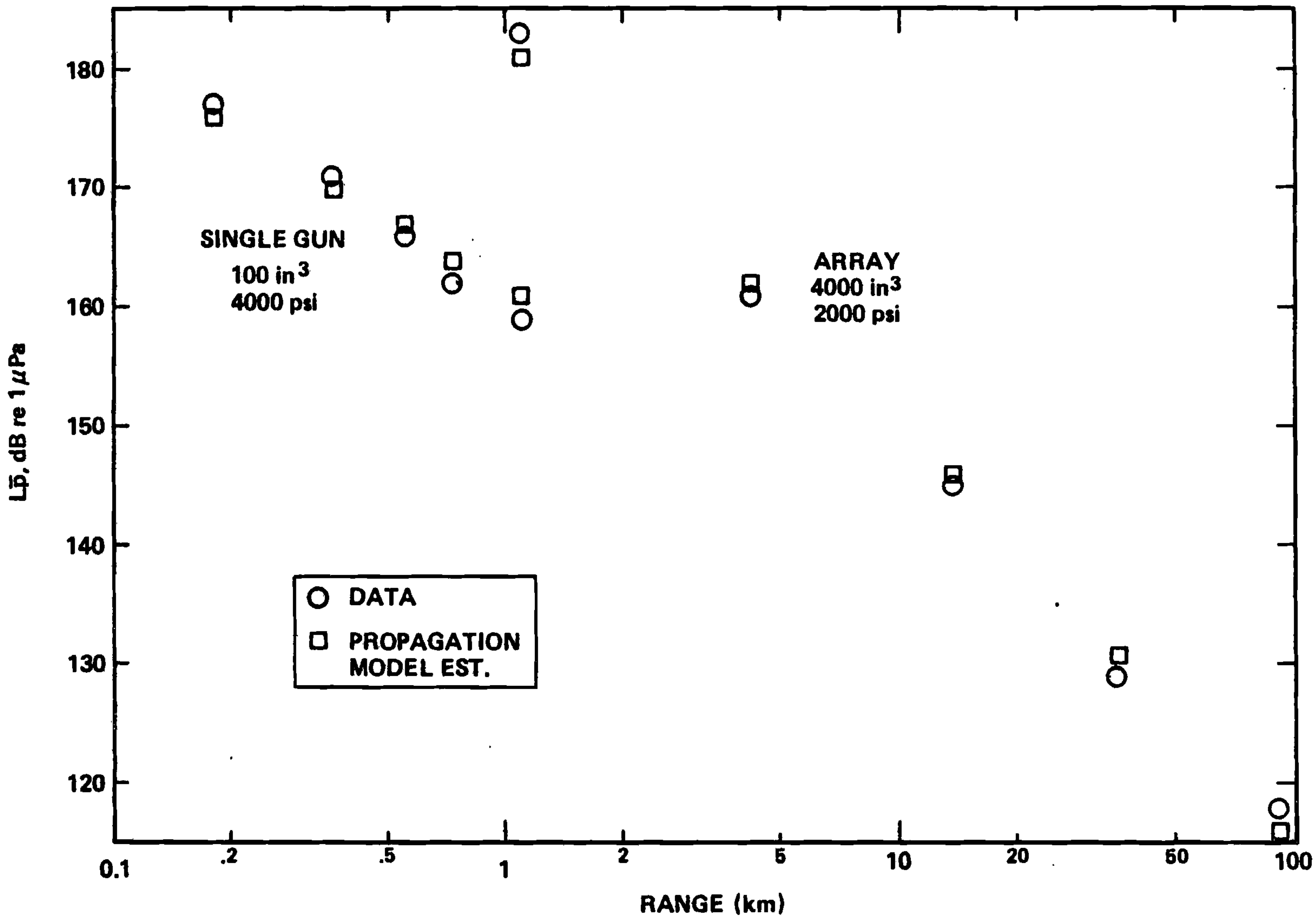

FIG. 5.3. AVERAGED PULSE LEVEL ($L_{\bar{p}}$) VERSUS RANGE FOR AIR GUN SOURCES IN TEST AREA OFF SOBERANES POINT.

$$L_r = 190+(DI) - 5\log(d_s) - 25\log(R) - 440(R/(d_s+d_r)) + 6 \text{ (dB//1}\mu\text{Pa)} \quad (6)$$

for the air gun array, where DI is a directivity factor which will be described later.

$$L_r = 168 - 5\log(d_s) - 15\log(R) - 440(R/(d_s+d_r)) + 6 \text{ (dB//1}\mu\text{Pa)} \quad (7)$$

for the single air gun.

For both equations, R is the distance from source (km), and d_s, d_r are the source and receiver water depths (meters). Received level values calculated using these models are also shown in Fig. 5.3. The water depths varied from 30 m at the receiver position to 3100 m at the 91 km position for the array.

5.1.3 Air Gun Signature Analysis

A series of measurements was made at short range in deep water to obtain examples of the air gun signature free of interfering reflections. An example of the pressure waveform is shown in Fig. 5.4. Narrowband frequency analyses were performed using total bandwidths of 5 kHz and 1 kHz. The results are shown in Fig. 5.5 and Fig. 5.6. The dominant energy of the signature can be seen to be at 100 Hz and below. A signature more typical of those seen in the test area is shown in Fig. 5.7. This example was obtained at a range of 1.1 km in a depth of about 60 m. The effect of multiple bounce propagation can be seen. A frequency analysis of this waveform is shown in Fig. 5.8. Propagation losses have reduced the high frequency components of the signature.

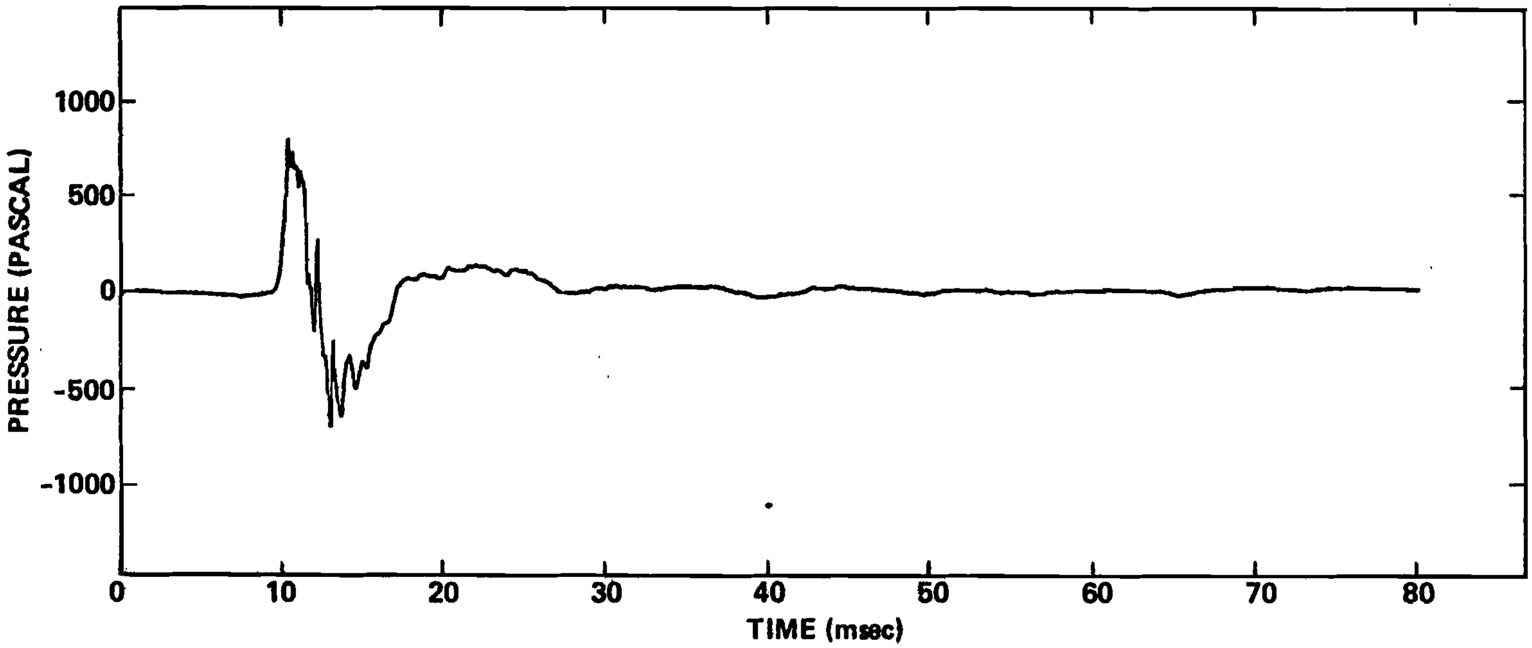

FIG. 5.4. AIR GUN SIGNATURE, 100 cu in., 4000 psi, RANGE = 137 m.

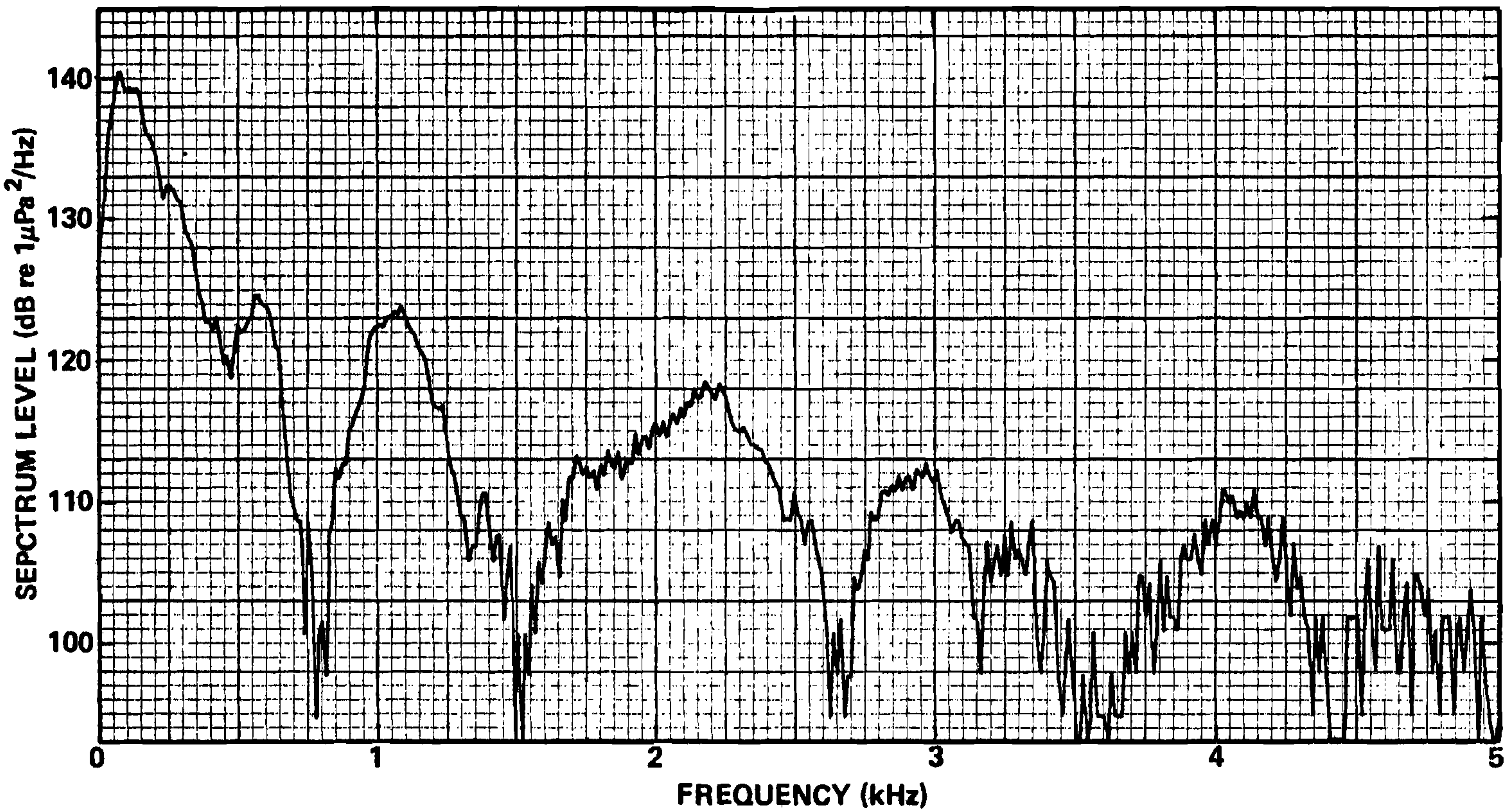

FIG. 5.5. AIR GUN SPECTRUM, 100 cu in., 4000 psi, RANGE = 137 m.

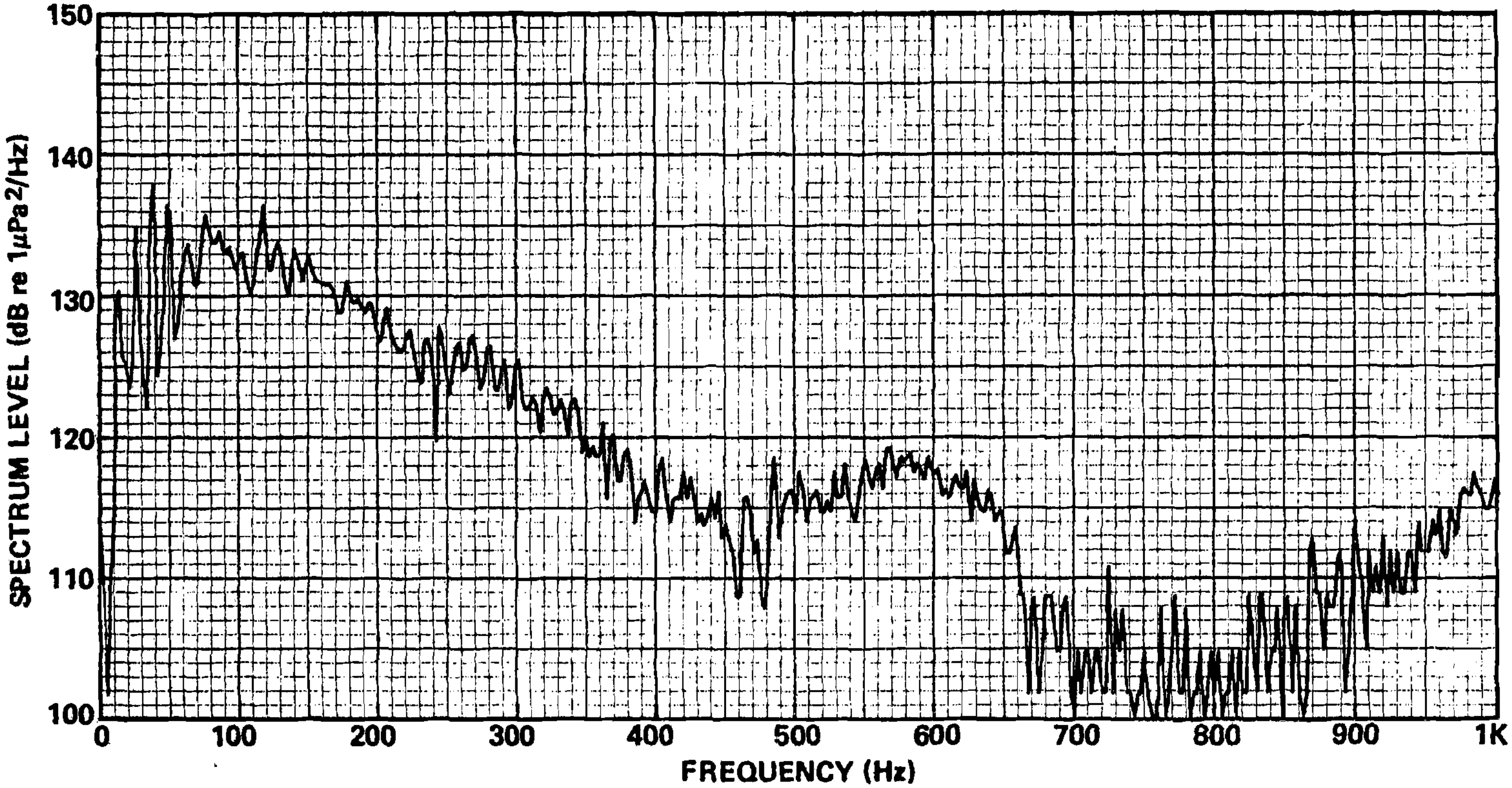

FIG. 5.6. AIR GUN SPECTRUM, 100 cu in., 4000 psi, RANGE = 137 m.

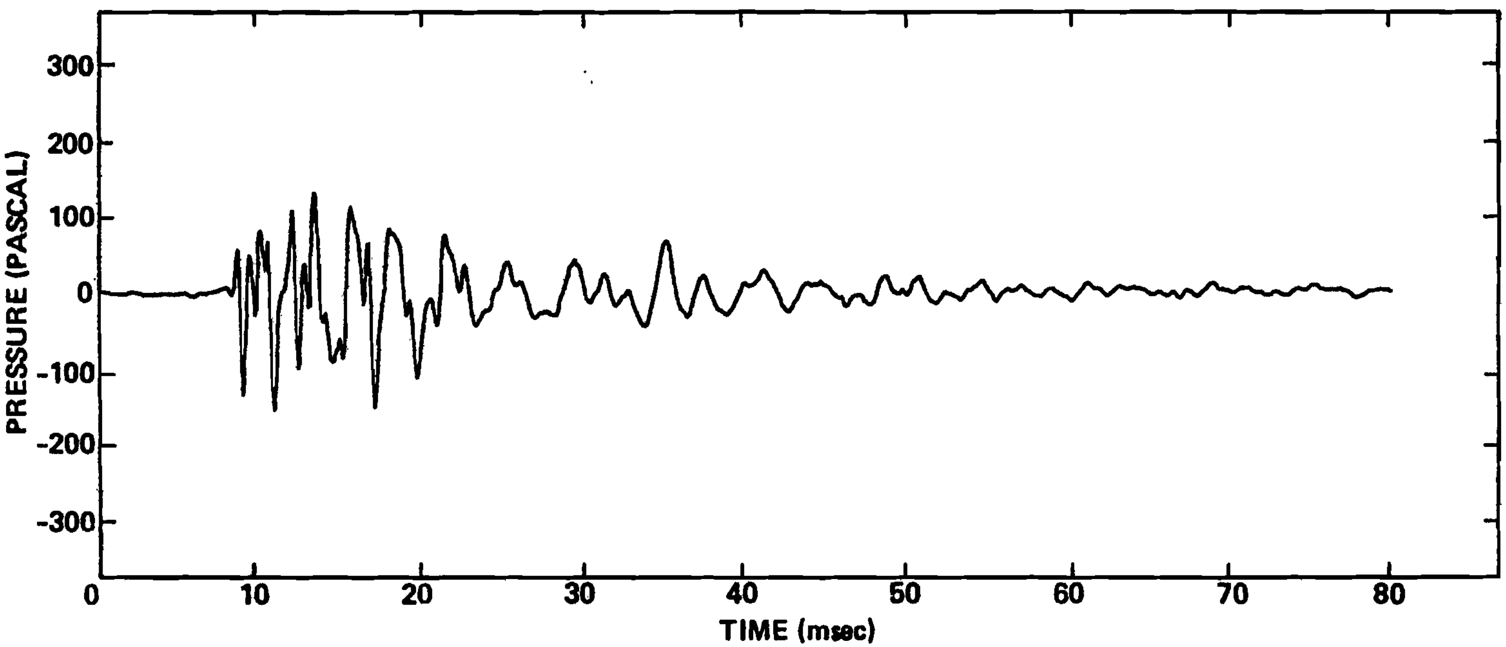

FIG. 5.7. AIR GUN SIGNATURE, 100 cu in., 4000 psi, RANGE = 1.1 km.

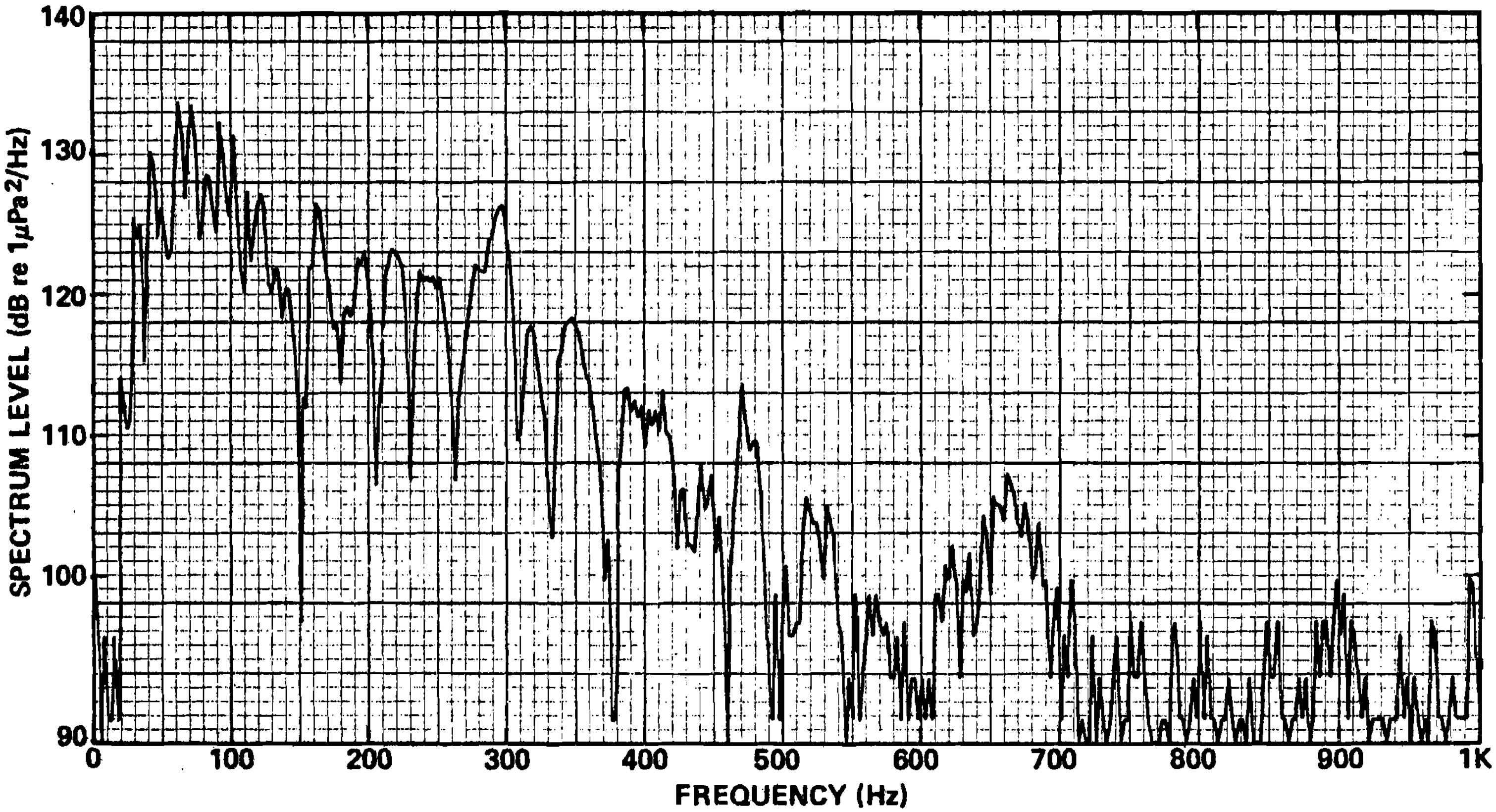

FIG. 5.8. AIR GUN SPECTRUM LEVEL, 100 cu in., 4000 psi, RANGE = 1.1 km.

A similar analysis was performed on signature data from the air gun array. Figure 5.9 shows the pressure signature from the array at a range of 1.1 km. This signature was obtained when the array was directly abeam of the VARUA position. The signature is more complex than that of the single air gun, as expected. Frequency analysis of this signature provided the data shown in Fig. 5.10. The frequency components of the array signature are similar to those of the single air gun with considerable enhancement of frequencies below 100 Hz. The 50 Hz component shown in the spectrum is considerably attenuated because of the horizontal propagation geometry. The design of the array is optimized for vertically directed propagation of low frequencies. Because of this design, the dominant frequency on the horizontal beam axis of the array* was about 100 Hz. Since the array was about one wavelength (λ) at 100 Hz, it could be expected to have considerable horizontal directivity. Confirmation of the expected directivity is shown in Fig. 5.11, which is a pressure signature for the array at an angle of about 75° off broadside. During these measurements, the array was following a straight course past the VARUA. The drop in level and the shift toward high frequencies shown in the figure is considered to be primarily a directivity effect rather than the result of increasing range. The corresponding frequency analysis is shown in Fig. 5.12. Here, the drop in level of the overall spectrum and the shift to higher frequencies are demonstrated. The dominant frequency in this spectrum is around 160 Hz rather than 100 Hz.

An analysis to determine the horizontal directivity pattern of the array was performed by analyzing the data obtained for a

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*A line source produces a directional sound field which is conveniently described by its pressure pattern in the plane of the array with a 0° reference angle at right angles to the midpoint of the array.

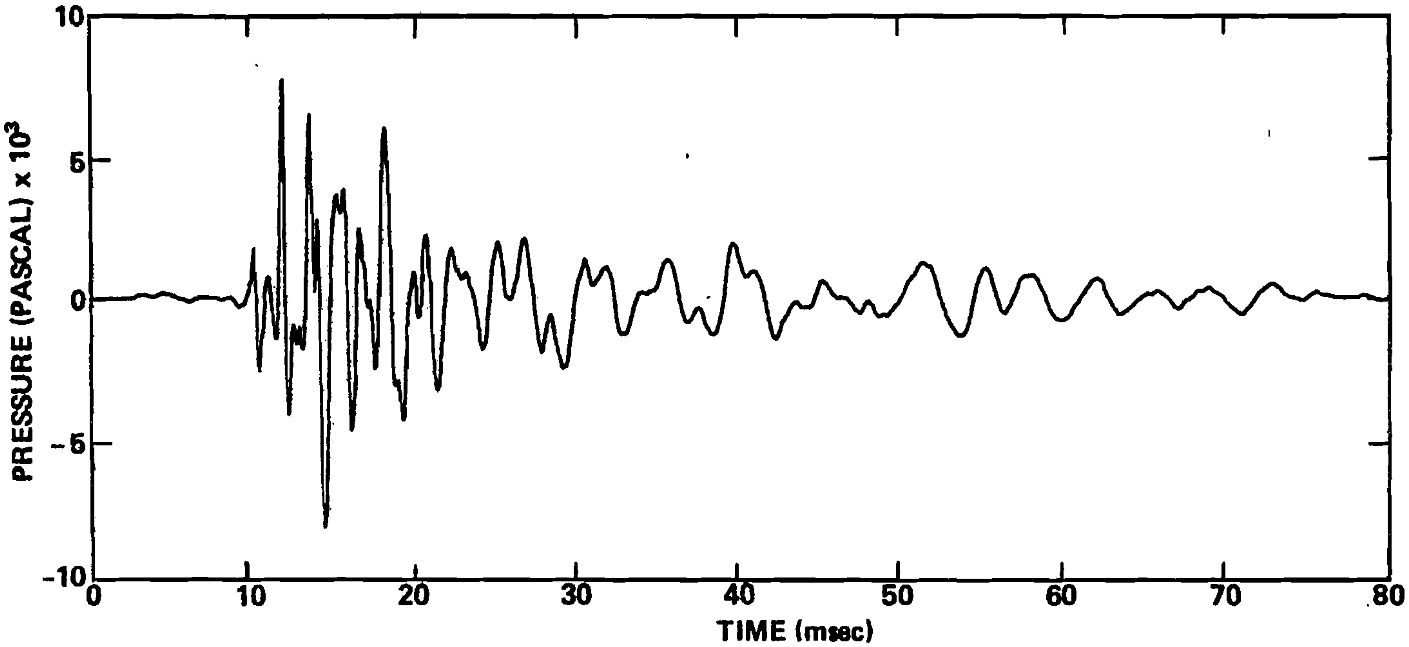

FIG. 5.9. AIR GUN ARRAY SIGNATURE, 4000 cu in., 2000 psi BROADSIDE, RANGE = 1.1 km.

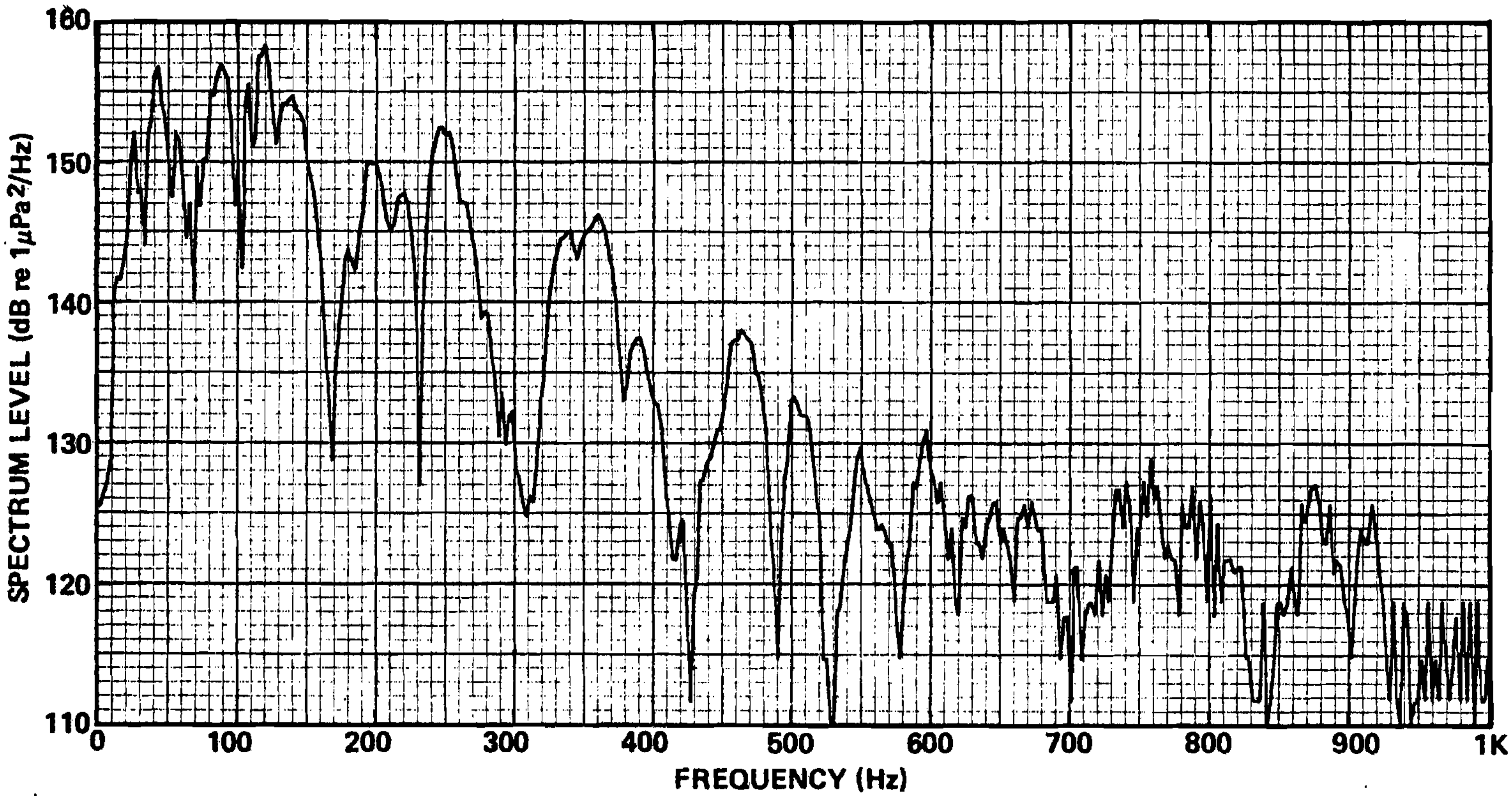

FIG. 5.10. AIR GUN ARRAY SPECTRUM LEVEL, 4000 cu in., 2000 psi RANGE = 1.1 km.

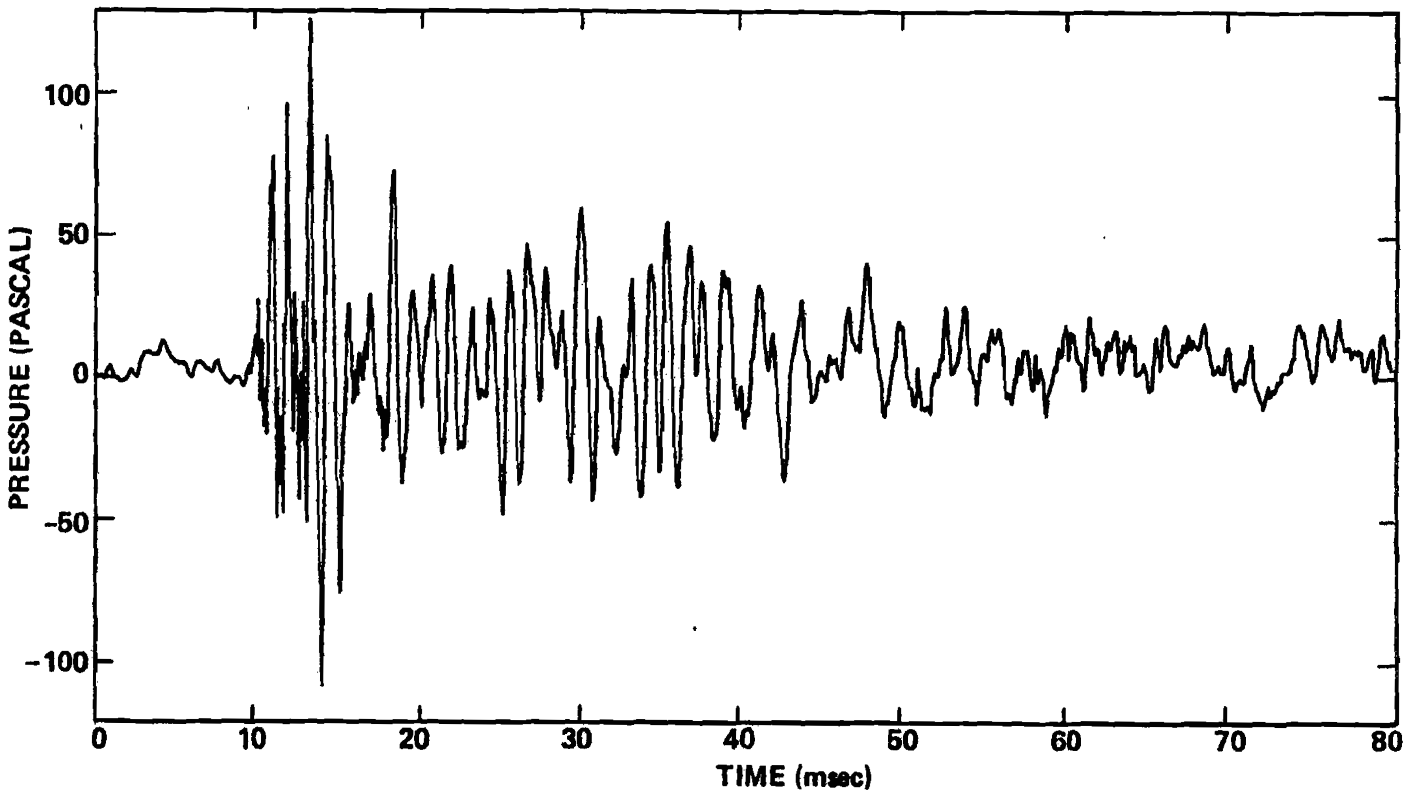

FIG. 5.11. AIR GUN ARRAY SIGNATURE, 4000 cu in., 2000 psi 75° OFF BROADSIDE, RANGE = 4.1 km.

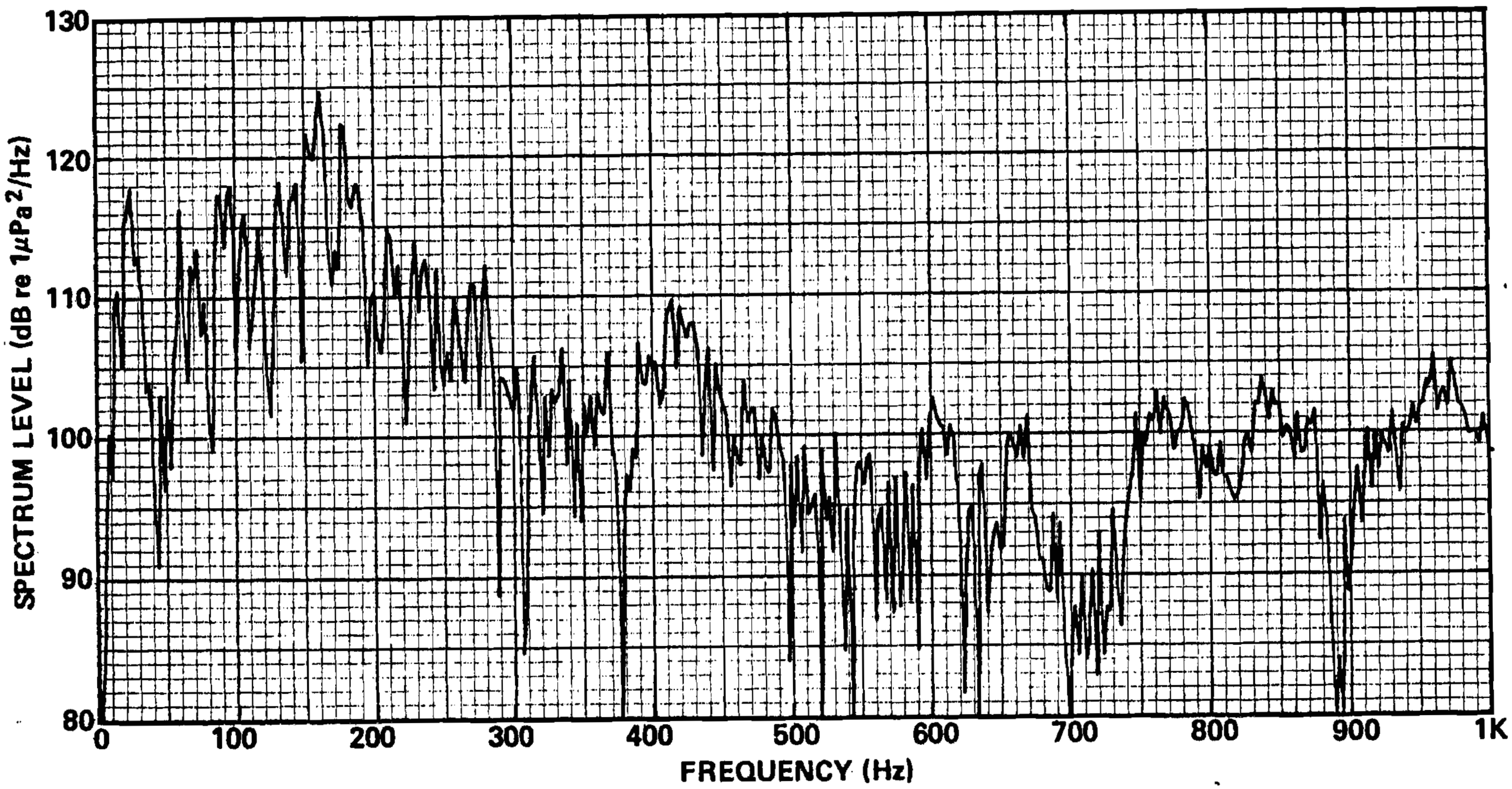

FIG. 5.12. AIR GUN ARRAY SPECTRUM LEVEL, 4000 cu in., 2000 psi 75° OFF BROADSIDE, RANGE = 4.1 km.

traverse of the array along track E as shown previously in Fig. 1.1. The average pulse levels were obtained and then range corrected using the propagation model of Eq. (6). The resulting directivity pattern is shown in Fig. 5.13. This pattern is compared to the theoretical beam pattern for a line array 1-λ in length. It can be seen to be quite similar except for angles greater than 50° where the higher frequency components in the array output begin to dominate. The pattern is normalized to the broadside output. The DI value to be used in the array propagation loss model (Eq. 6) is the dB value in the figure at the desired angle from the beam axis.

5.1.4 Transmission Loss Data from Projector Measurements

During the January field period, two TL measurement sequences were made using the projector with warble tone signals. These tests were made along tracks extending north from the VARUA position for a distance of about 1 km. The results of these tests are shown in Fig. 5.14 and Fig. 5.15.

The results of these tests are compared with the calculated values which were obtained by using Eq. (7) which was developed using air gun data. The calculated values agree quite well except for the scatter in the data at low frequencies. The measurements were made during an unusually calm period, and as a result, Lloyd mirror interference patterns were probably responsible for the anomalous results at 200 m.

A short series of TL measurements using the projector was performed during the April-May field period. These measurements were made using a warble tone centered at 100 Hz with two measurement courses directed toward shore areas where whales and sea otters were frequently observed. Several receiver depths were also used to permit evaluation of sound pressure - depth variation. The results are shown in Fig. 5.16 and Fig. 5.17.

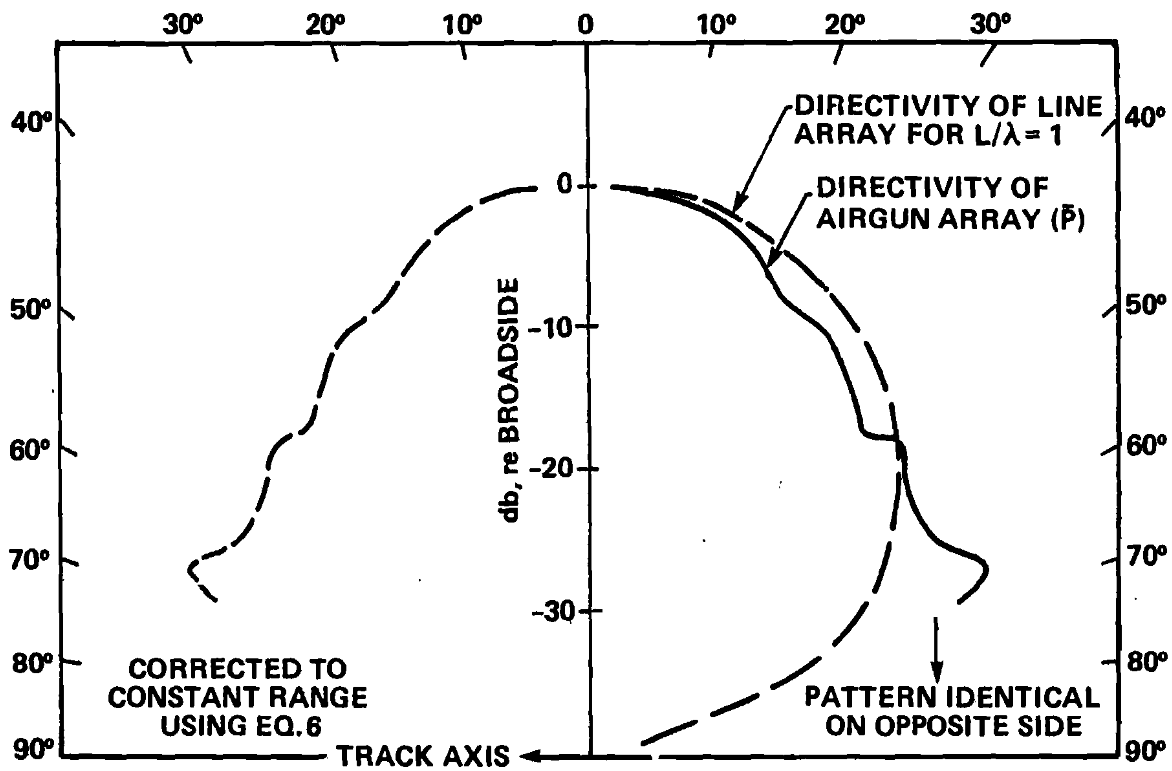

FIG. 5.13. DIRECTIVITY PATTERN OF 4000 cu in. AIR GUN ARRAY BASED ON MEASUREMENTS OF AVERAGE PULSE LEVEL.

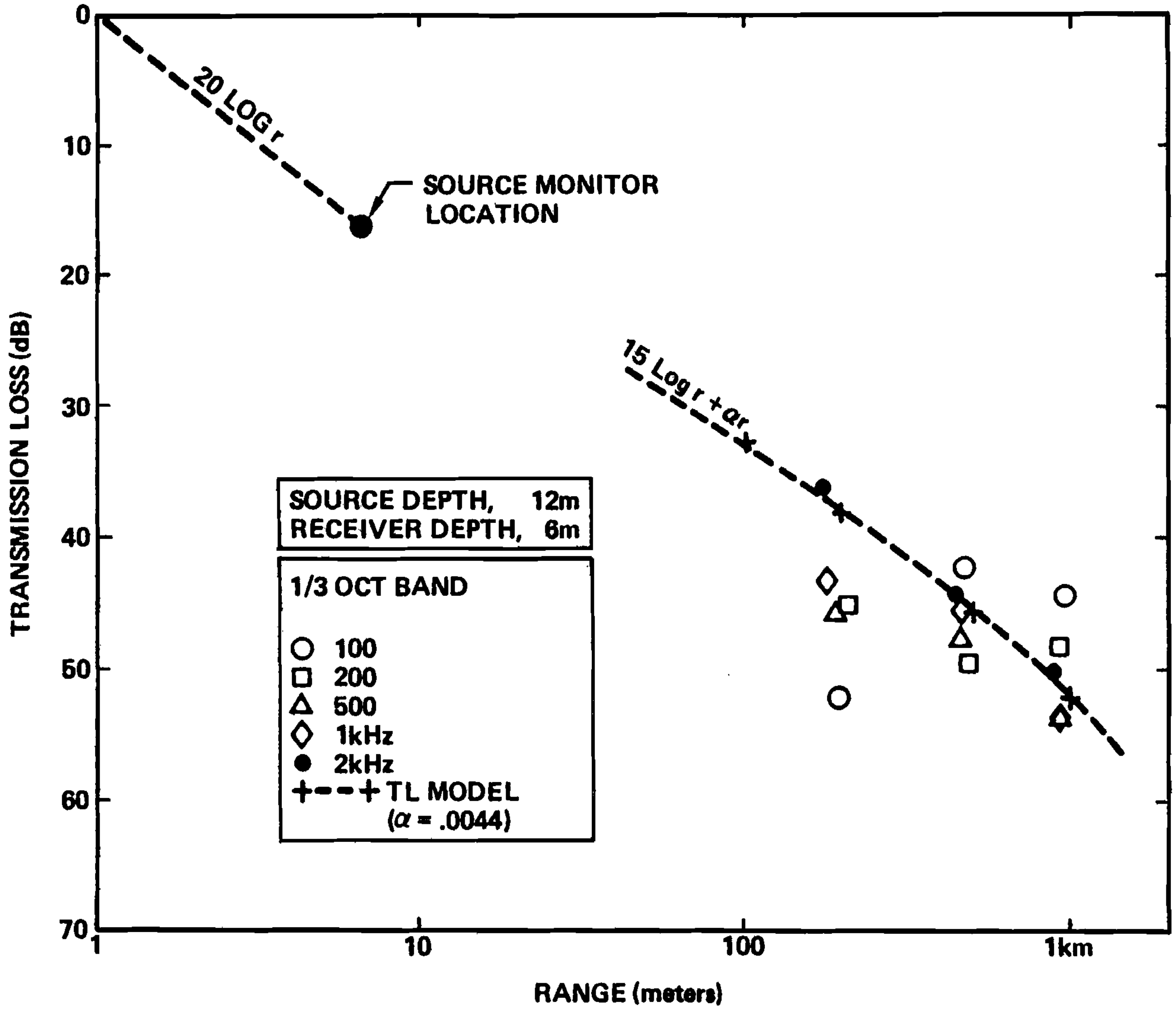

FIG. 5.14. TRANSMISSION LOSS, JANUARY DATA, NNW TRACK.

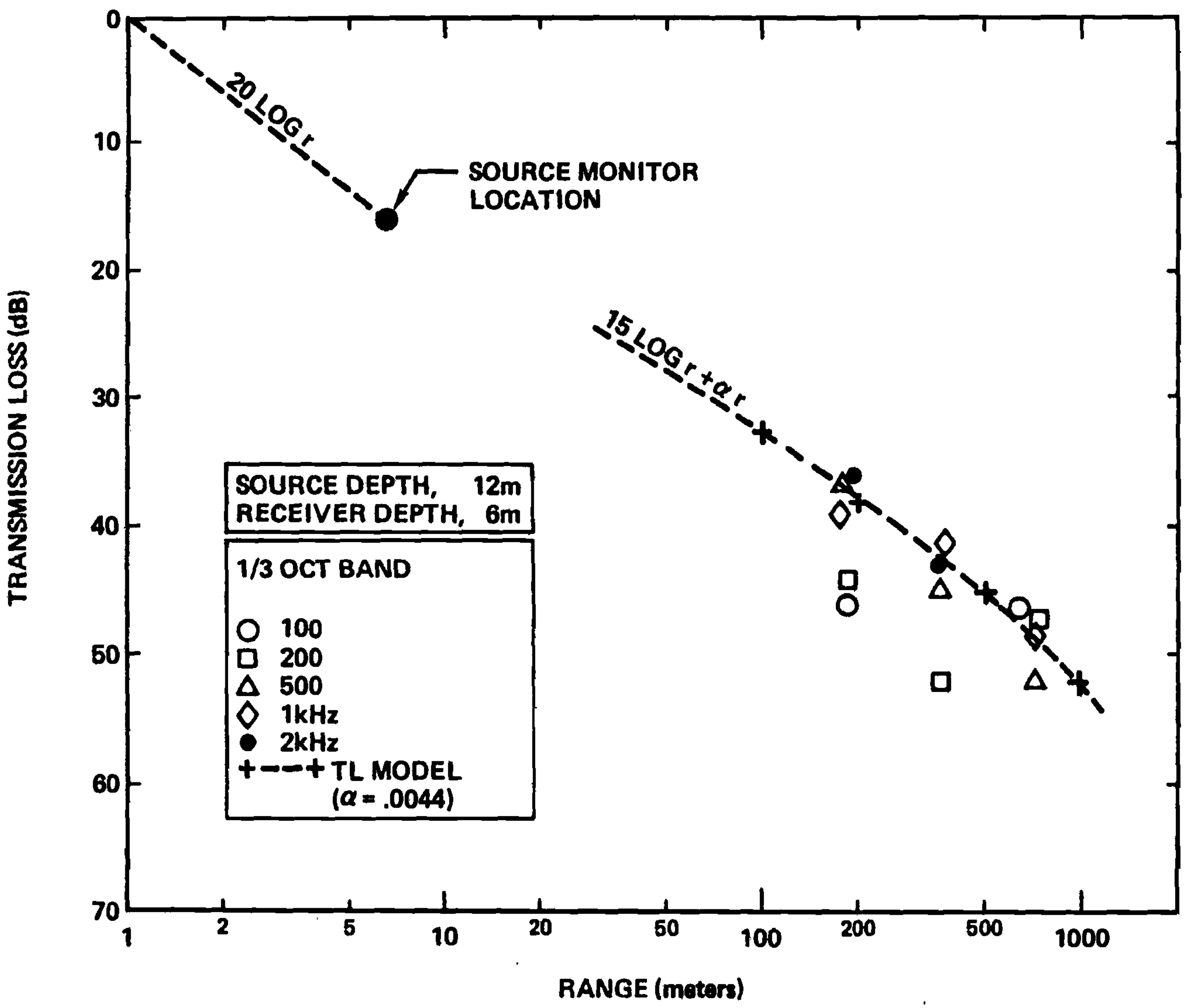

FIG. 5.15. TRANSMISSION LOSS, JANUARY DATA, ENE TRACK.

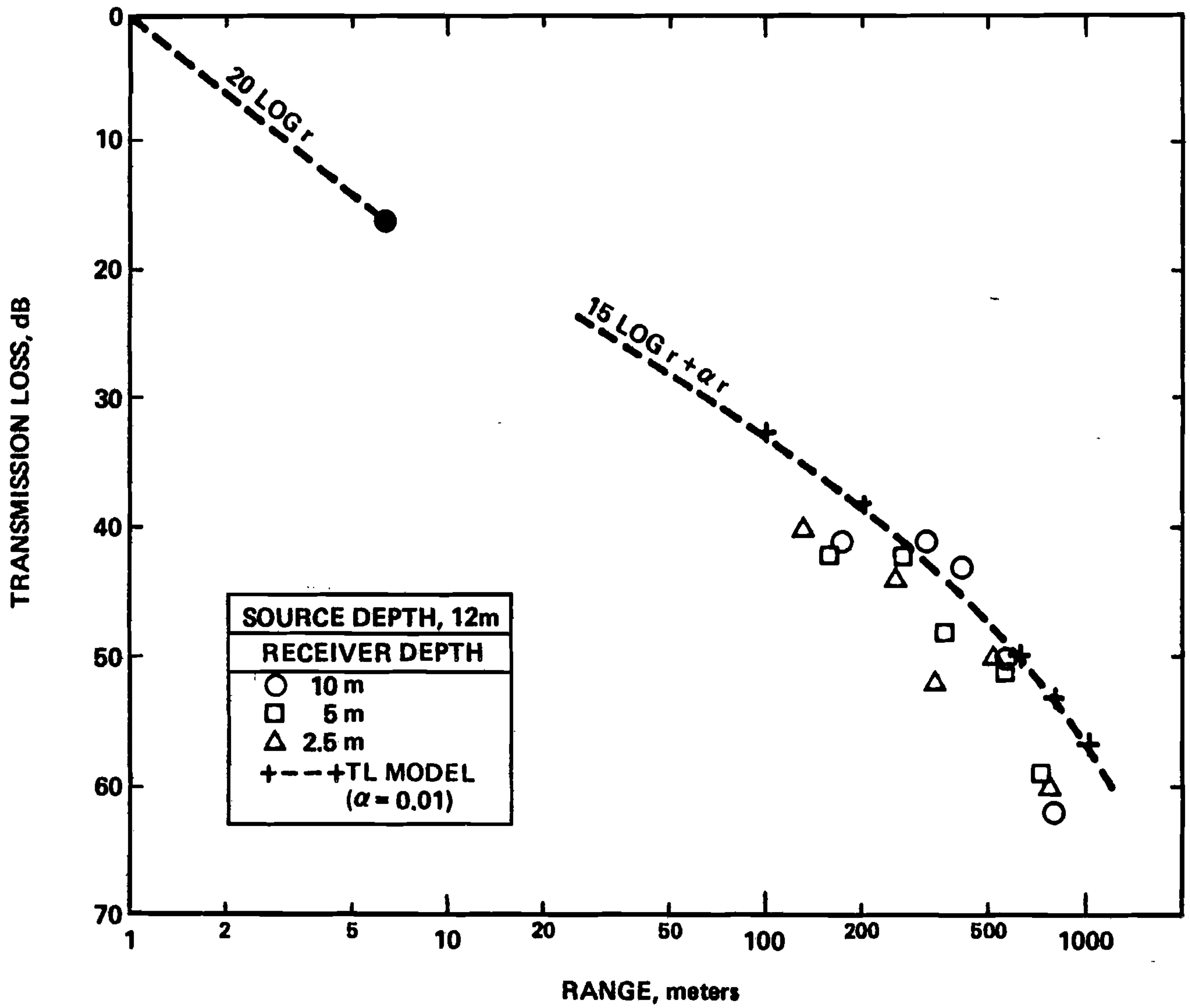

FIG. 5.16. TRANSMISSION LOSS, APRIL-MAY DATA, NE TRACK.

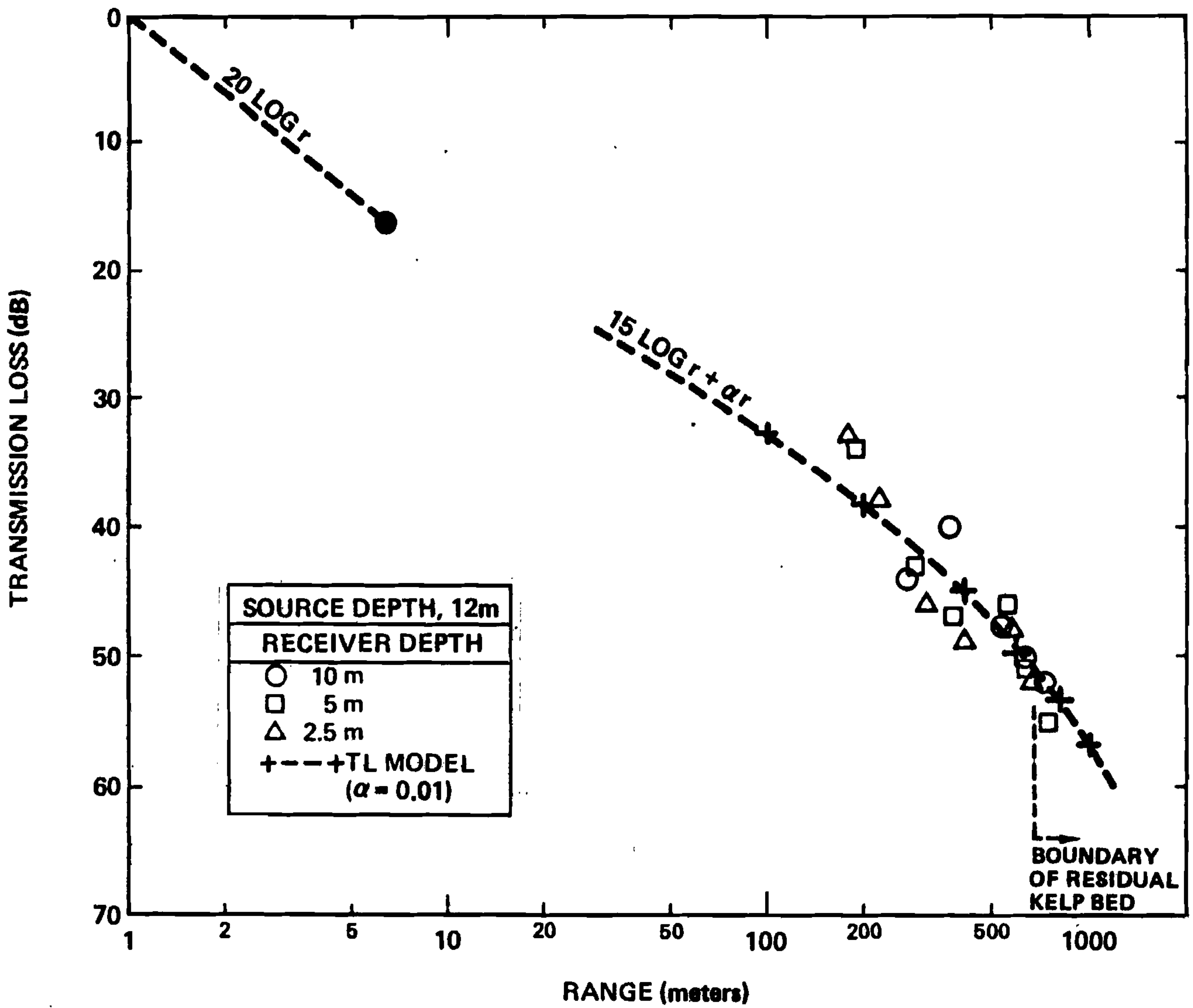

FIG. 5.17. TRANSMISSION LOSS, APRIL-MAY DATA, SE TRACK INTO "OTTER COVE".

Again, a comparison with calculated values is shown. The calculated values shown here differ from those for the January period because of the corrections for the shallower receiver water depth. An average value of 15 m was used for the receiver water depth rather than the specific value for each receiver location. Hence, there is a greater difference between the calculated value and the measured one for locations near shore than probably would be the case if the actual depth were used.

The data obtained for receiver depths of 10.5 and 2.5 m showed some variability between similar range TL values at the 10 and 5 m positions with no definite trend in the data. The shallowest receiver depth of 2.5 m produced somewhat higher TL values than did the deeper measurement positions. This is expected because of the surface reflection interference effect discussed previously. Note that while the last two measurement positions in Fig. 5.17 were within the kelp zone, no significant additional attenuation was observed. The kelp was badly depleted because of winter storms. Hence, the potential sound attenuating effect of kelp could not be evaluated properly.

5.2 Playback Experiments

In analyzing and reporting the results of the playback experiments, we have considered that any observed behavioral changes which may have occurred in nearby migrating gray whales may be a defense reaction to detection of a potential threat signal above the general ambient noise or an annoyance reaction to an unpleasant, loud sound. Accordingly, we have analyzed the playback data to provide information not only on the absolute level and spectrum of the reproduced signals but also on their relative level in relation to local ambient noise conditions.

The sound level produced by a playback stimulus at the position of an observed whale was estimated by applying the propagation model described in the preceding section to the area involved. To do this, Eq. (7) was modified by recognizing that $TL = L_s - L_r$, which resulted in the following relationship:

$$TL = 5 \log(d_s) + 15 \log(R) + .44(R/(d_s+d_r)) - 6 \text{ (dB)}. \qquad (8)$$

The reference range has been changed to 1 meter for convenience.

The distance at which the projected signal could potentially be detected was estimated by measuring the local ambient noise spectrum and comparing the noise spectrum with the spectrum of the projected stimulus. This process was complicated by the lack of knowledge of the frequency dependence of the hearing threshold and critical bandwidths of gray whales. Based on available data from other marine mammals and nonmarine mammals, such as Homo sapiens, we made the following assumptions concerning the auditory capabilities of Eschrichtius robustus:

- The hearing threshold is below the general ambient noise level and covers a frequency range at least as broad as the reported vocalization range.
- The critical bandwidths are 1/3 octave or narrower* (Herman and Tavolga, 1980).
- The sensation of loudness or noisiness follows a logarithmic relationship.
- The masking relationships between sounds at different frequencies are similar to those determined for human hearing.

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*A critical bandwidth is defined as the bandwidth of noise at constant spectrum level required to mask a pure tone at the same center frequency and RMS pressure level.

5.2.1 Playback System Response Measurements

The projector output was monitored by an H-56 hydrophone and its output was recorded. The accuracy of the playback projector system in reproducing the source stimuli was examined by comparing a narrowband frequency analysis of the original tape dub with a narrowband analysis of the projector output for the same stimulus. In addition, 1/3 octave-band analyses were made of both the original recording and of the projector output. This type of analysis simulates the frequency filtering response of mammalian ear systems to broadband noise sources.

Examples of the results of these frequency analyses are shown in Figs. 5.18 and 5.19. In these figures, the measured levels as reported for the drillship are compared to the tape spectrum and to the spectrum of the projector output. Both narrowband and 1/3 octave spectra are shown. A complete set of comparison spectra is contained in Appendix D for all of the industrial noise stimuli.

5.2.2 Ambient Noise Measurements

Ambient noise in the test area was influenced by ship traffic at low frequencies and by snapping (pistol) shrimp at high frequencies. A typical example is shown in Fig. 5.20. In this case, a tug and barge are passing offshore, producing the peaks shown at 315 and 630 Hz as well as the general increase in levels below 80 Hz. Shrimp noise is responsible for the broad peak at 6.3 kHz. In the absence of nearby ship traffic, the ambient noise spectrum shown in Fig. 5.21 was obtained. Here, the shrimp peak is at the same level as in the previous figure but the low frequency ambient is much lower. No marked diurnal cycle in shrimp noise level was observed as reported by some observers (Urick, 1975). The general noise level produced by the shrimp increased toward shore with decreasing depth. Figure

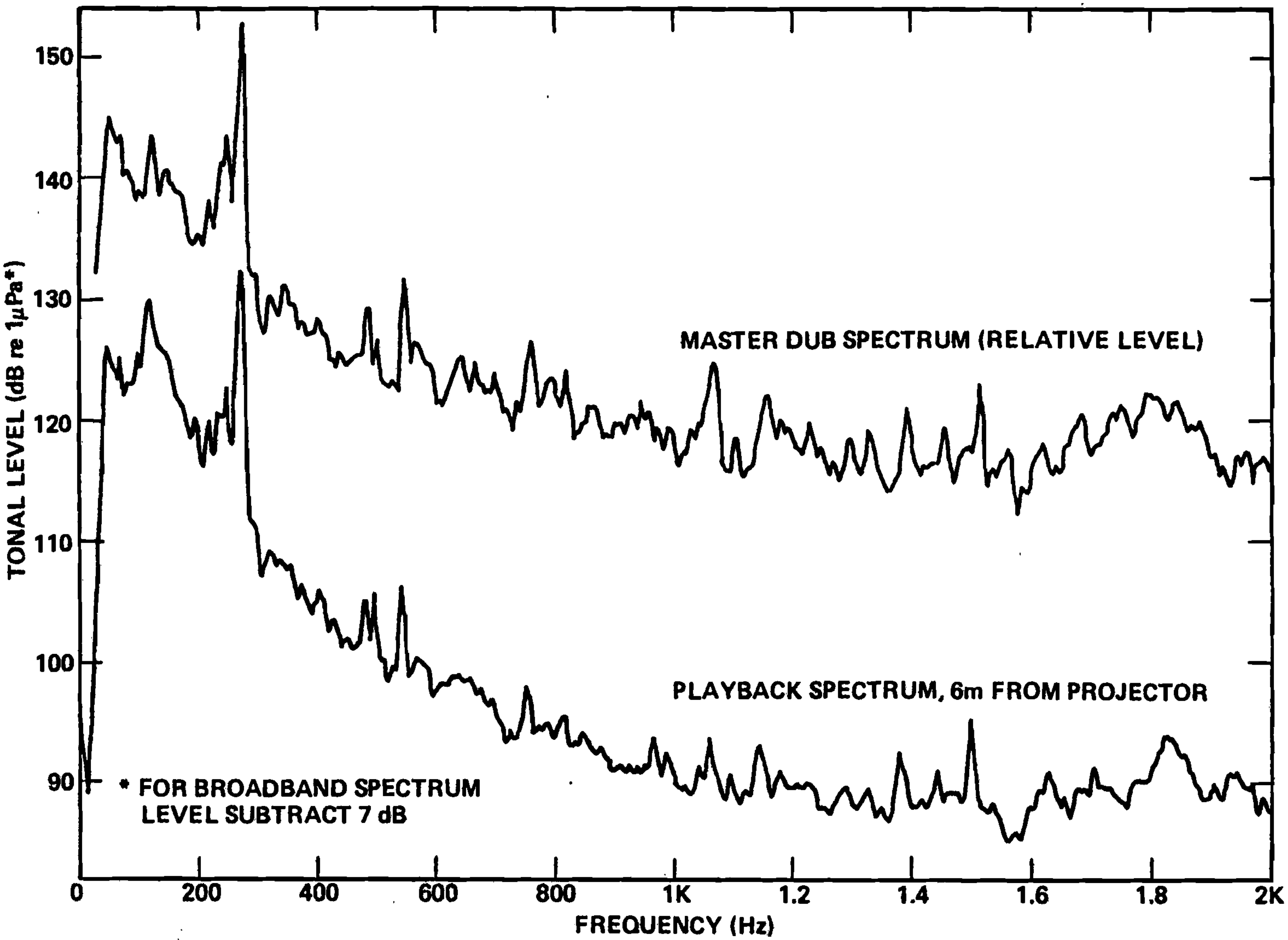


FIG. 5.18. COMPARISON OF RECORDED DRILLSHIP SPECTRUM WITH PLAYBACK SPECTRUM (NARROWBAND ANALYSIS).

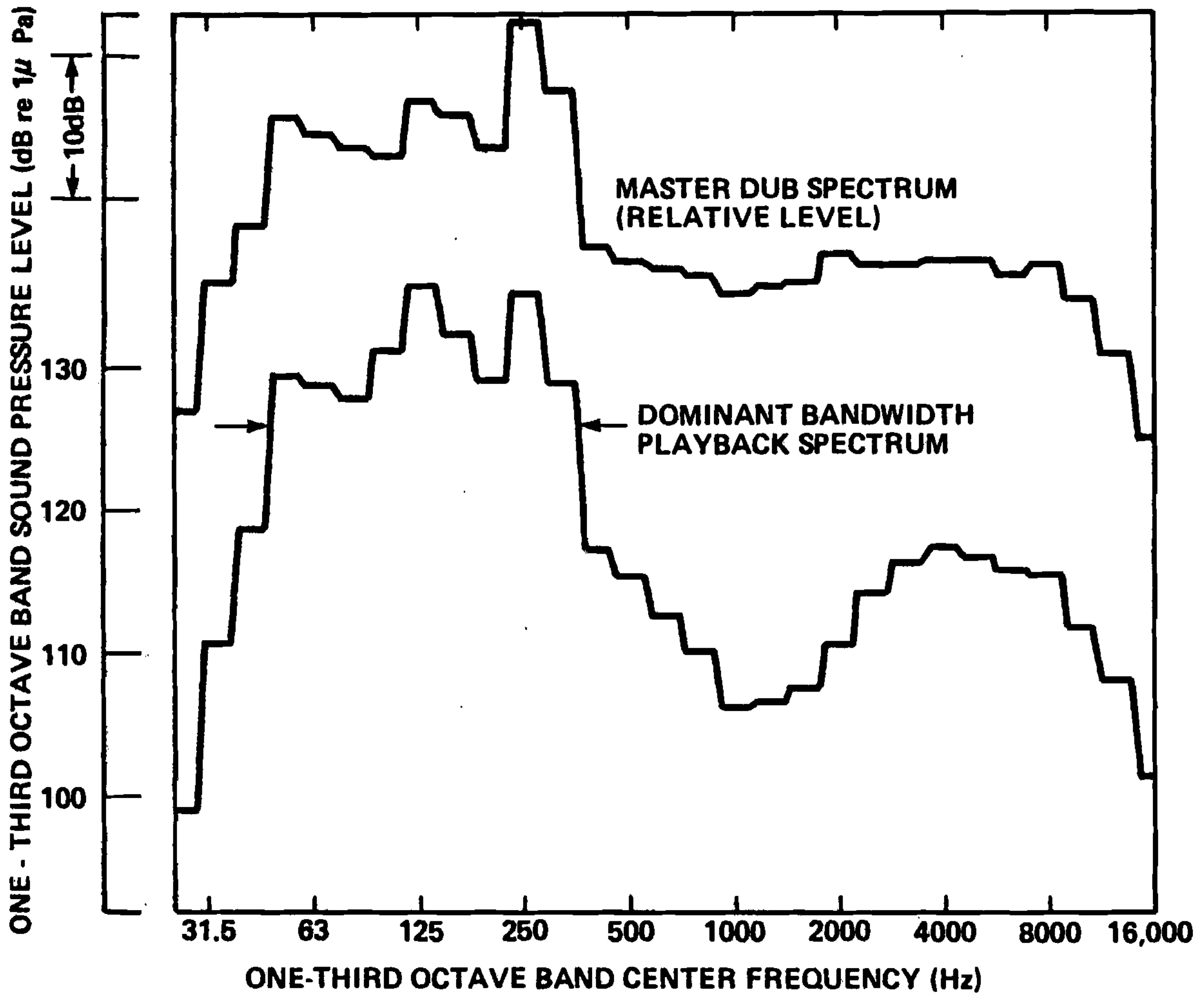


FIG. 5.19. COMPARISON OF RECORDED DRILLSHIP SPECTRUM WITH PLAYBACK SPECTRUM (1/3 OCTAVE ANALYSIS).

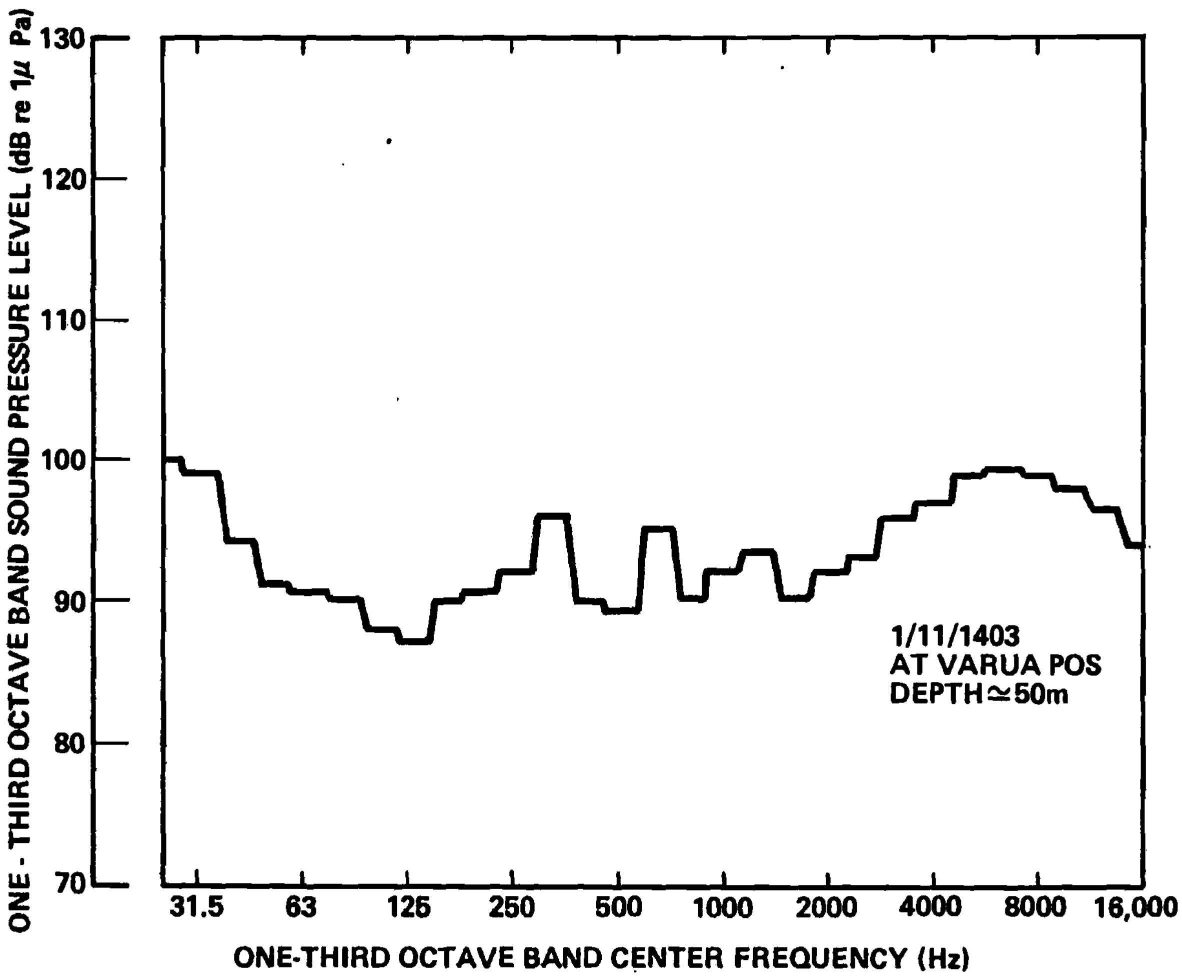


FIG. 5.20. AMBIENT NOISE IN TEST AREA WITH TUG AND BARGE PASSING AT ABOUT 3 km.

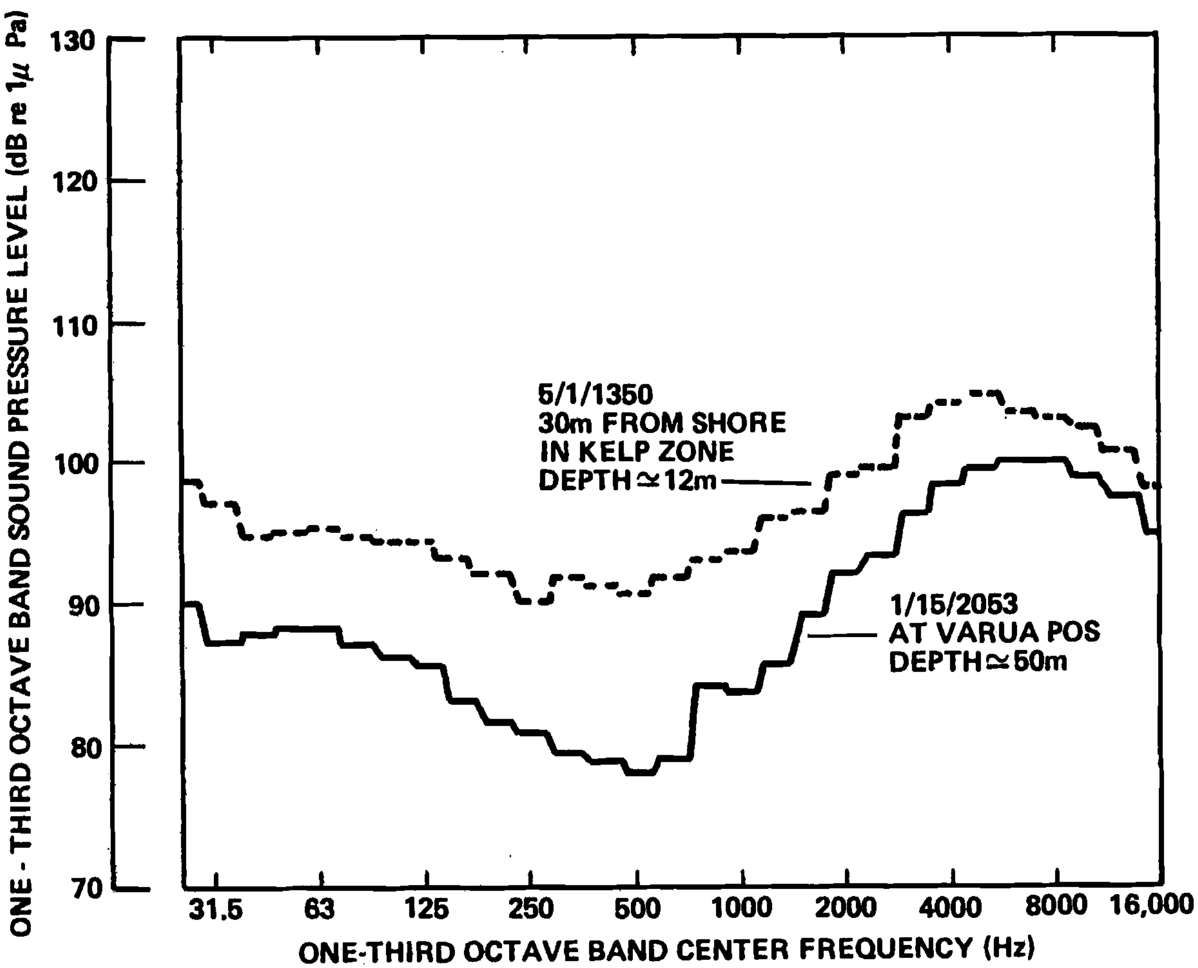


FIG. 5.21. AMBIENT NOISE IN TEST AREA WITH NO NEARBY SHIPPING.

5.21 also shows the ambient noise measured near "Otter Cove" on the north side of Soberanes Point in a depth of about 5 m. The shrimp noise can be seen to be about 6 dB louder here than in the data taken at the VARUA position in a depth of 35 m.

5.2.3 Determination of Playback Signal-to-Noise Ratio

The high frequency ambient noise produced by the shrimp was of concern because of its potential masking effect on the playback sound. In human hearing, the masking of one sound by another is greatest when both sounds are within a critical bandwidth. However, upward and downward masking effects do occur. In this case, downward masking is the concern. Fortunately, the dominant spectrum components of the playback stimuli are about one decade lower in frequency than the peak of the shrimp noise (with the exception of the orca sound). Studies of downward masking by bands of noise (Spieth, 1957) have shown that the masking threshold is 40 dB below the peak noise spectrum level, one decade below the noise spectrum peak frequency. In the case of the shrimp noise spectrum, this would imply that a 1/3 octave band signal level of 50 dB or greater at 600 Hz or below would not be masked by the shrimp noise. Fortunately, as was shown in Fig. 5.21, local ambient levels are generally higher than this. Thus, we have assumed in developing our estimated signal-to-noise (S/N) ratios for the playback stimuli that the dominant masking effect for the playback signal will be due to ambient noise in the same frequency range.

The "available S/N ratio" was estimated for each playback stimulus using the following procedure. The effective signal level for the playback signal was determined by calculating the RMS signal level for the "dominant" bandwidth. Referring back to Fig. 5.19, the dominant signal bandwidth was determined by observing the highest 1/3 octave band level in the signal as measured by the monitor hydrophone, and then including the total number of 1/3 octave bands which had levels within 10 dB of the maximum. The ambient noise spectra measured before and after the playback sequence were averaged and the RMS noise signal for the same dominant bandwidth was calculated. The available S/N ratio was obtained by subtracting the effective masking noise level (dB) from the dominant signal level (dB).

5.3 Acoustic Exposure Estimation

Table 5.1 lists the results of analyzing the playback stimuli and the ambient noise levels at the time of projection according to the procedure discussed in the preceding section. The results are presented in terms of available S/N ratio, 1 m from the projector, and the estimated range for an effective S/N ratio of 0 dB or 10 dB. These ranges are presented both for the entire dominant bandwidth as well as for the highest 1/3 octave band in the respective stimulus. The last measure is appropriate for determining if observed response changes are the result of stimulus detection at low levels.

The TL calculation procedures provided by Eq. (8) was used to obtain the range values given in Table 5.1. To simplify the procedure, a set of fixed depth values was assumed for the January field period data. Since most of the migration was centered around the same depth contour as the VARUA position, a calculation for TL vs range was made for that depth (50 m), and plotted as shown in Fig. 5.22. Note that the available S/N for the 0 dB maximum range criterion is equal to the TL. The general whale migration route during the April-May field period was closer to shore - generally following the 10 to 15 m contours. The VARUA was anchored in 30 m during the period. Thus, a second general TL calculation was necessary and is also plotted in Fig. 5.22. The ranges listed in Table 5.1 for the spring playback sequences were based on this calculation.

TABLE 5.1. PLAYBACK SIGNAL/NOISE DATA AND ESTIMATED EFFECTIVE RANGE.

Date/Time		Stimulus Code	BW_{eff} Hz	L_S dB//1μPa	L_N dB//1μPa	S/N dB	R_0 km	R_{10} km	B_M Hz	S/N dB	R_0 km	R_{10} km
1/11	1216-1340	PP1	63-250	156	96	60	1.9	0.8	125	66	2.7	1.4
	1436-1606	PD1	80-315	158	104	54	1.2	0.4	250	61	2.0	0.9
1/12	0829-0959	DS1	50-315	159	100	59	1.8	0.7	125	65	2.5	1.3
1/13	0917-1047	H1	50-200	154	91	63	2.3	1.1	100	68	3.0	1.6
	1209-1509	SS1	63-250	157	91	66	2.7	1.4	160	71	3.5	2.0
	1510-1543	SS2	63-250	157	102	55	1.3	0.5	250	63	2.3	1.1
	1544-1714	PD2	80-315	158	98	60	1.9	0.8	250	64	2.4	1.2
1/14	0844-1009	DS2	50-315	159	105	54	1.2	0.4	250	65	2.5	1.3
	1207-1337	H2	50-200	154	103	51	0.9	0.3	100	54	1.2	0.4
	1415-1544	PP2	63-250	156	100	56	1.4	0.5	125	63	2.3	1.1
	1614-1709	O1	800-5 kHz	154	103	51	0.9	0.3	1 kHz	67	2.8	1.5
1/15	0844-1044	PD3	80-315	158	96	62	2.1	1.0	125	65	2.5	1.3
	1129-1330	PP3	63-250	156	96	60	1.9	0.8	125	65	2.5	1.3
	1431-1559	DS3	50-315	159	98	61	2.0	0.9	125	67	2.8	1.5
1/16	0931-1159	H3	50-200	154	99	55	1.3	0.5	100	59	1.8	0.7
	1245-1444	SS3	63-250	157	96	61	2.0	0.9	250	67	2.8	1.5
	1544-1759	O2	800-5 kHz	148	103	45	0.5	0.14	1.25 kHz	64	2.4	1.2
4/29	1702-1906	DS4	50-315	159	98	61	1.3	0.7	125	67	1.7	1.1
5/1	1852-1900	O3	800-5 kHz	154	113	41	0.3	0.1	1 kHz	54	0.9	0.4

Key: L_S = Source Level, 1 m
L_N = Noise Level
R_0 = Range to 0 dB S/N
R_{10} = Range to +10 dB S/N
B_M = 1/3 octave band with highest level in signal.

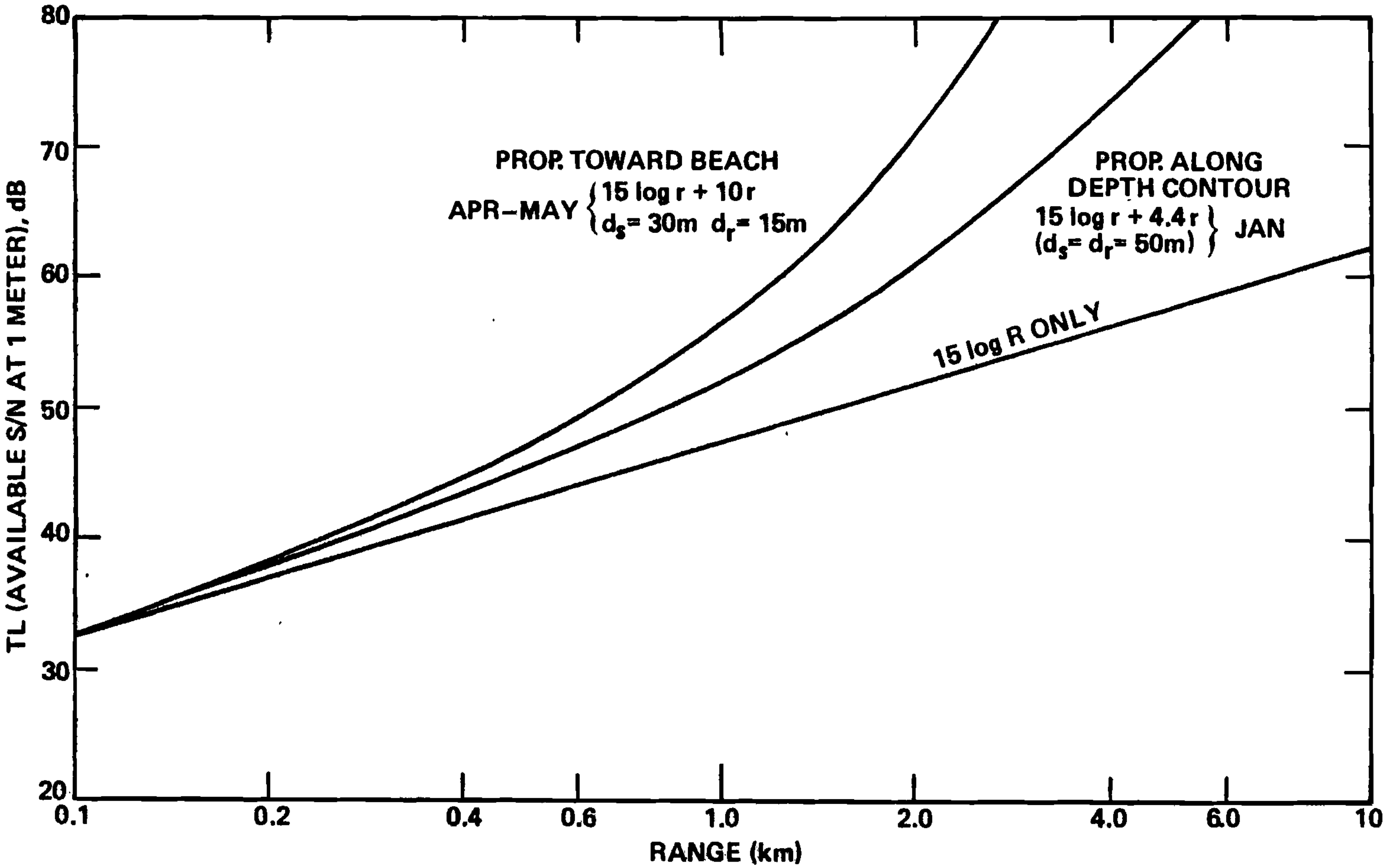


FIG. 5.22. MAXIMUM RANGE VERSUS SIGNAL-TO-NOISE RATIO FOR PLAYBACK SEQUENCES (FOR 0 dB S/N AT RECEIVER).

6. BEHAVIORAL OBSERVATIONS AND DESCRIPTIONS

As we have emphasized previously, knowledge of and familiarity with the normal migratory behavior of gray whales is imperative for a proper interpretation of results obtained under potentially disturbed conditions. What follows is a series of descriptions based on observations made under both undisturbed and potentially disturbed conditions. These descriptions are derived from field notes and daily summaries written in the evening after observation had ended. They are included in order to present a qualitative description of the migration. In particular, we have included descriptions of behaviors that were considered distinct from those typically observed - "Bubble Cove," orca playback, and air gun experiments. (Typical behaviors are defined in Sec. 7.)

6.1 Observed Behavior Under Normal and Experimental Conditions During January

6.1.1 Normal behavior

The southbound migration was characterized by whales passing by at 5 to 10 km/hr in pulses of 1 to 3 hrs in duration, followed by no-whale periods of between 20 to 40 min. We observed that most groups followed a track at distances from 1 to 3 km offshore with larger groups (> 2 whales) tending to be further offshore, about 2 to 3 km, and smaller groups (1 to 2 whales) generally about 1 to 2 km offshore. Because of the limited time budgeted for analysis, we did not quantify the observed migratory pulses or our impression that groups of different sizes had different distributions of distance offshore. However, we do have the data required to perform this analysis. Since Herzing and Mate's comparison of aerial and shore-based censuses indicates that shore observers may tend to miss small groups far offshore (see

Appendix A, pp. A7-A8), our general impression regarding distance off-shore and group size may be in error.

Because many whale groups observed in January were several km offshore and because of our concentration on theodolite tracking during this period, most of the behaviors observed in January fell into two categories which were easy to discriminate at a distance - surface active and breaching. We have distinguished breaching from other surface active behavior since breaching was, in all but one case, observed to be a discrete event not associated with other surface activity.

Most of the surface active behavior involved groups of 3 or more whales. In such groups we observed whales engaged in social interaction, making contact with one another with their flukes or pectoral fins. On two occasions, we observed an extended penis in groups that were rolling at the surface. During one observation (see description below), two whales were seen rolling together, belly to belly.

Breaching was observed on 81 occasions involving 43 groups of undisturbed whales. We did observe more breaching groups during 1400 - 1500 hrs than in any other time period (22% of all breaching groups). Since the playback experiments were conducted during the peak of the migration, we do not know if this difference in the diurnal pattern of breaching holds for the peak of migration under undisturbed conditions.

6.1.2 Behavioral observations under experimental conditions

During the January field season, we observed two changes in behavior that were presumably attributable to playbacks and one change that was probably the result of a single-engine aircraft circling at approximately 60 m above a whale group. This aircraft was not a part of our experimental procedure; its effect on the group was an opportunistic observation. The following is a description of observations made during the Orcinus orca playbacks on 14 and 16 January and the aircraft/whale interaction observed on 15 January.

Orca playback, 14 January:

The killer whale (orca) playback commenced at 1614 and ended at 1710. At approximately 1620, North site noted a dramatic change in the movement pattern of several groups of whales that had been traveling steadily south. Such a change had to be dramatic for shore observers to note, for they knew nothing of the playback schedule, in keeping with the double blind study design. The whales suddenly stopped their southward movement just north of North site and began to mill about with many direction changes and moved closer to shore, something that had not been observed on previous days. It was very difficult to keep track of individual groups of whales at this point since all of the animals were very close together in a narrow N-S corridor (± 0.25 km) and then oriented themselves in an E-W corridor. One group (UUU) composed of 2 whales was observed in a kelp bed with one whale draped in kelp. This type of behavior in the presence of killer whale sounds has been reported by Cummings and Thompson (1971). Because of the number of whales involved (18-20 in 9 groups), individual groups could no longer be separated with certainty. By 1655, when the whales started to move south again, different group letters had to be assigned. It was our impression that during the period from 1620-1700 several of the groups joined and split several times. It is of possible interest to note that the whales did begin to move south again approximately 10 min before the end of the playback. At this point, shore observers were able to distinguish different groups again, but the groups were closer together than was typical. The behavioral log kept by the VARUA personnel during this time period confirmed our observations, noting that the whales passing within sight of the ship were moving at a slower pace than under pre-playback conditions.

Orca playback, 16 January:

The orca playback began at 1544 and ended at 1700. As during the previous orca playback on 14 January, the first indication we had that the whales' southbound movement had changed was the milling and directional changes of several groups of whales traveling approximately 1 km offshore. Group L, composed of 3 whales, was observed at 1547 to stall and turn toward shore. This group milled about within 300 m of shore for approximately 18 min; then it moved slowly south, closely following the shore for approximately 0.5 km before speeding up rapidly, still following a nearshore route. This same pattern was followed by 3-4 other groups of whales. During the southbound migration, it was our observation that larger groups (3 or more) tended to follow a 2-3 km offshore track. But during this playback experiment, groups of as many as 4 whales closely followed the shore within 200 to 300 m of it.

At the same time that Group L had dramatically increased its speed, a group of 3 killer whales was sighted moving rapidly toward the VARUA which was anchored 1.5 km from shore. The group was composed of a male, a female, and a juvenile. The killer whales reacted to the presence of the VARUA (presumably to the killer whale playback) by lobtailing, pectoral slapping, and spyhopping. At 1720, both Soberanes and North site observed the killer whales moving rapidly southeast to an area directly off shore of Soberanes. Both stations observed a gray whale lying on its side, pectoral fin in the air, with killer whale dorsals near by. Almost immediately, the group of 2 gray whales headed rapidly toward shore. The killer whales did not follow.

Because of the presence of the killer whales during the playback, it is unclear whether the reactions of the gray whales were caused by the killer whales or the playback. However, during both killer whale playback periods (14 and 16 January), the gray whales reacted in essentially the same manner.

Low Flying Aircraft, 15 January (Group WW8)

Group WW, first sighted by North site at 1307 was composed of 2 whales moving south. At 1324, North site reported that this group was headed southeast and noted two surface active behaviors, a head up and spyhop. Group XX, a large group of 5 to 7 whales, was very close to WW, and at 1328 some members of Group XX joined with Group WW. At this point, Group WW contained 4 whales moving rapidly south. Soberanes site started following this group at 1334. The whales continued to move south until 1359 when the group split, with 2 whales moving to the east, toward shore. At 1414, Soberanes observed a member of the group that continued to move south, rolling on its side with fluke tip and pectoral extended. At 1430, another whale group, called #8, composed of two adults, was observed south of Group WW by approximately 150 m. At 1431, the number of surface active behaviors increased dramatically in whale Group WW. By 1434, Groups WW and #8 joined. We speculated that Group #8 was the original pair of whales that had split off from Group WW at 1359, but this could not be confirmed. We should note here that at 1431, the VARUA began a drillship playback, and both groups, WW and #8, were within the 3-dB signal-to-noise range. Although the start of the drillship playback may have been responsible for the increase in observed behaviors, we believe this is unlikely because of the relatively low S/N ratio, since behaviors were observed before the playback started and because of the approach of another whale group that was about to join WW.

The surface active behavior continued, with much rolling, pectoral slapping, and side swimming until 1446. During this time, whales were seen to roll belly to belly, and we speculated that we were witnessing sexual activity. On two previous occasions, we had observed whale groups behaving in the same manner and in both of those groups a penis was observed. At this point, a single-engine high-wing aircraft (not associated with our project), which had been circling over the surface active whales at approximately 400 m, dropped down to approximately 60 m, circled once and left the area. At the point when the aircraft was closest to the whales, all observable behavior stopped, the whales dispersed into two groups, separated by approximately 50 m, and continued south, paralleling one another. By 1454, the aircraft had left the immediate area and the whales again joined, exhibiting the same types of behavior observed before. Although we cannot say for certain that the presence of the aircraft altered the group's behavior pattern, it seemed to the three observers at Soberanes that this was the case. (For a track plot of this whale group, see Appendix B, Fig. 1.)

6.2 Behavior Observed Under Normal and Experimental Conditions in April/May

6.2.1 Normal behavior

In April/May, the nearshore migratory path of the mother/calf pairs and the smaller number of whales relative to January observations, allowed us to categorize and quantify the observed behaviors to a far greater extent than was done in January. Table 7.11 gives a quantitative presentation of the behaviors observed under control conditions. Most mother/calf pairs followed the coastline at distances from 25-200 m from shore, permitting observation of any direction changes, underwater blows, and surface active behavior without difficulty. During control periods, the whale groups generally moved steadily north, with very few instances of directional changes and milling, except for several groups observed in the "Bubble Cove" area (see Sec. 6.2.2). The directional changes and milling observed were usually associated with groups joining or splitting. (See Appendix B, Figs. 2 through 5, for representative track plots of whale groups during control conditions.)

6.2.2 "Bubble Cove"

Approximately 150 to 200 m south of South site (Fig. 1.1) is the northern edge of Garrapata Beach, a gradually sloping sandy beach. This beach is bounded on the south by a point of land just north of Kasler Point and a series of nearshore rocks and on the north by an outcropping of rocks extending from shore approximately 50 m. The usual migration path of the whales led them around the nearshore rocks and across the beach toward shore at or near South site. On several occasions, the whales would turn directly toward the beach area, mill about for a short time (less than 2 min), and then continue north. On seven occasions during control periods, groups moved to the north end of Garrapata Beach and milled in the cove created by the rock outcropping. One of the most common behaviors seen in this sandy shallow area was underwater blowing, and for this reason, we labelled the area "Bubble Cove". Whales would mill about in this area for periods of 5 to 20 min, displaying a variety of surface active behaviors and underwater blowing. On one occasion, however, the whales stayed in the same general area for a period of 2 hrs.

On 26 April, Group K, a single mother/calf pair, entered this area at 1344. Over the next 2 hrs, this group remained in the same general area and was joined by four more groups of single mother/calf pairs. During this time period, the following behaviors were observed (the figures in parentheses are the number of each behavior): underwater blows (90), head-up (74), vertical flukes (87), rolls (8), mouths open (3); spyhops (2). The whales' orientation was constantly changing. On many occasions, calves were seen oriented toward the beach in very shallow water (< 6 m). We observed sand streaming from the mouths of calves on four occasions. Because this could indicate feeding, two members of the crew (D. Croll and P. Tyack) dove in the area where the whales were milling. Their report showed that the bottom was sandy with a few rock outcroppings near the northern boundary of the beach. There was no indication of any food source in the water column or in the first 10 cm of the sand where the calves had been observed with sand streaming from their mouths. M. Poole, who studies the mother/calf migration at Pt. Piedras Blancas and was with us for approximately 1 hr during these observations, noted that he had witnessed similar behavior, including sand streaming, in his study area.

During the time that the whales were in the cove, a tanker traveled from south to north approximately 8 km from shore. This was the closest to shore that we had observed a tanker, and we speculated that the noise level in the vicinity of the whales had increased, perhaps causing the behavioral display we were witnessing. The VARUA made an ambient noise measurement 1 km off South site and reported that the ambient level showed no significant increase over levels measured without tanker traffic.

Because of the very high number of behaviors observed while the seven groups were in this area, compared to other whale groups observed in similar undisturbed conditions (i.e., 99 underwater blows in 13.8 whale hours vs 6 underwater blows in 246.5 whale-hours), we considered these whale groups separately and did not include them, when comparing behaviors during control periods and experimental periods. For a comparison between the behavior observed at Garrapata Beach with that observed during experimental conditions, see Sec. 7.5.

6.2.3 Seismic air gun array runs and single gun experiments

No reactions by mother/calf pairs were noted by shore observers at the time of observation during the GSI seismic air gun array line runs of the CECIL H. GREEN II at distances of 3 - 50 nm. However, during the close in runs of 0.5 and 1 nm, shore observers noted the following changes in behavior: the whale groups exposed to sound levels of > 160 dB were seen to change direction (orienting south), move inshore, and mill about for varying lengths of time. In Sec. 7.5, we compare the behavior seen during "Bubble Cove" observations with behavior observed during the seismic air gun array line runs. During the time periods when the whale groups were exposed to sound levels of > 160 dB, we did observe some surface behaviors but the predominant behavioral changes were changes in orientation with few surface behaviors observed. (See Appendix C, Figs. 4, 5, 6, and 9, for representative track plots of whale groups during seismic air gun array and single gun experimental conditions.)

The following are two examples of typical behaviors observed during close-in array and single gun experiments. On 25 April, Group K, a single mother/calf pair, was observed during the GSI air gun array run at 0.5 nm. It was picked up at 1529, after it had rounded the outer rocks north of Kasler Point (see Appendix C, page C-8). The group was observed by South site until 1606. During this time, no behaviors were noted; however, the group was farther offshore than normal (150 to 200 m). Soberanes picked up Group K at 1610, approximately 0.5 km south of their site. At 1612, the air gun array was activated and the array vessel CECIL H. GREEN II began moving north at a distance 0.5 nm offshore. (It was initially south of group K.) At 1617, Group K was 200 m south of Soberanes and was oriented to the south. On the next surfacing, however, Group K was again moving north but closer to shore. The mother/calf pair rounded Soberanes Point and headed into the bay, north of the point called Otter Cove. They continued north for 10 min at a slow pace. At 1644 they stalled and turned south at the north end of the bay. At this point, the array vessel was directly offshore of their position, while the animals were 10 to 15 m offshore. They remained in the same general position until 1701 when the vessel was about 3 km north of them. Group K then continued north and was not observed again until 1712 when they were approaching North site. At this point, the array vessel was north of them by more than 5 km. Group K was seen sporadically until 1739, when it was nearing Yankee Point. No further behavioral observations were made on Group K once it left Otter Cove.

During each stationary single air gun experiment with CROW ARROW, we observed a group turn to the south at the onset of the sound and then head toward shore with many direction changes and milling. The following is a behavioral description of Group A during a stationary air gun experiment on 5 May (see Appendix C, page C-11).

Group A was first sighted rounding the outer ledges of Rocky Point. The group, a mother/calf pair, was headed northeast toward shore. During this passage, the pair remained in the same general area for approximately 3 min, and no direction changes were observed. The group then proceeded north, exhibiting no observable behavioral change until 1308, when the stationary air gun was turned on. The whales, at this point, were directly in front of Soberanes site. The whales immediately changed direction, heading south for approximately 2 min, stalled, remained in the same area for a short time (< 2 min) and then continued in a northerly direction, much closer to shore than before and with some direction changes. On one occasion the mother/calf pair surfaced, but was oriented south; however, their general movement was toward the north. The group rounded the point on the north edge of Soberanes and moved to the middle of the bay, where they milled for a short time (between 1327 - 1329) and then continued north at 1330. The air gun was turned off at 1334. Group A observation was transferred to North site at 1345, and the group was seen to continue to the north without further unusual behavior, rounding Yankee Point at 1405.

7. BEHAVIORAL DATA ANALYSIS PROCEDURES AND RESULTS

7.1 Definitions of Behavioral Measures

For both the southward gray whale migration observed in January and the northward migration observed in April/May, we reduced the observational data to a set of variables that characterize the behavior of each whale group. During January, we observed few behavioral displays and concentrated on following the tracks of whale groups through repeated transit sightings. We followed so many groups at one time and so many groups passed several km offshore that it was impossible to record all blow intervals or behavioral displays with confidence. Thus, the statistical analysis from the January season concentrates on track data. The measures calculated for each track were: track deflection, distance from shore, speed, milling index, course, and angle to VARUA.

During the April/May migration, over 95% of the groups observed were mother/calf pairs migrating north within 20 to 200 m of shore. Seldom were more than two or three groups simultaneously observed by the same shore station, so observers were able to concentrate on blow intervals and behavioral displays. Since few whales showed track deflection during April/May and since during most air gun experiments the sound source was moving, we did not perform the same track deflection analysis as was used for January data. The variables calculated for the April/May data include respiration rate, blow intervals, position of the calf relative to the mother, milling index, speed, and the number of occurrences of a variety of behavioral displays. The measures used in January and in April/May are defined as follows.

7.1.1 Track statistics

The form of track data is a set of points $(x_1,y_1)\ldots(x_n,y_n)$ with associated times $t_1\ldots t_n$.

For every track or interval of a track one can calculate different measures for the pattern of motion. The measures used in this study were net speed, cumulative speed, milling index, course bearing, and VARUA bearing. They are defined as follows.

Net speed is defined as the distance between the first point of the track or track interval (x_1,y_1) and the last point (x_n,y_n) divided by the difference in times associated with these two points:

$$\text{Net Speed} = \frac{\sqrt{(x_n-x_1)^2 + (y_n-y_1)^2}}{t_n-t_1} . \tag{9}$$

Cumulative speed is calculated by accumulating the total length of the path taken by the track from beginning to end and dividing this length by the difference in times t_n and t_1.

$$\text{Cumulative Speed} = \frac{\sum_{i=1}^{n-1} \sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2}}{t_n-t_1} . \tag{10}$$

Milling index is a measure of the directness or linearity of the route taken by the whale from point (x_1,y_1) to (x_n,y_n).

$$\text{Milling Index} = \frac{\text{Net Speed}}{\text{Cumulative Speed}} . \tag{11}$$

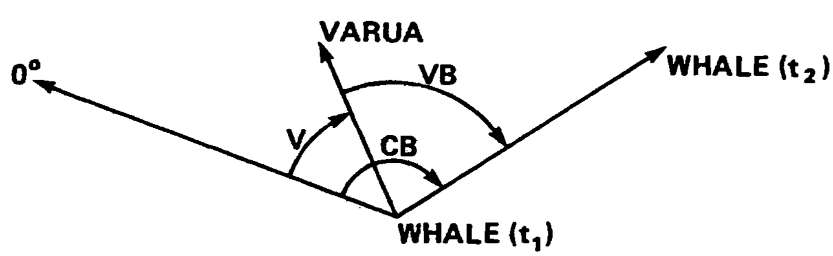
The milling index is 1 if the cumulative speed equals the net speed - i.e., if the whale took a straight line course. The milling index approaches zero as the group takes a more and more tortuous course.

Course bearing gives the bearing in degrees of the course of the track relative to the coordinate system for x and y, with 0° corresponding to the positive x-axis and 270° corresponding to the positive y-axis.

$$\text{Course Bearing} = \arctan\left(-(y_n - y_1)/x_n - x_1\right). \quad (12)$$

The numerator for the arctangent is $-(y_n-y_1)$ to rotate the bearing around the 0° to 180° axis. This converts the angle from counterclockwise as measured by trignometric functions, to clockwise as measured by a compass rose.

VARUA bearing is a measure of how directly whales are oriented towards the VARUA. It is derived from two bearings, the compass bearing of the whale's motion as defined above (called CB in the figure below) and bearing from the whale's position at the start of the interval (t_1) to the VARUA (called V in the figure below). The VARUA bearing is the clockwise angle from V to CB; VARUA bearing = CB-V.



7.1.2 Respiration rate

Respiration rate refers to the rate at which blows were observed. Because it was assumed that each blow represented an exhalation followed by an inhalation, the term respiration rate was chosen. This value was calculated by dividing the number of blows from a whale or group by the the total observation time for that whale or group. Three respiration rates were computed for mother/calf groups: mother respiration rate, calf respiration rate, and total group respiration rate. Total respiration rate includes all mother and calf blows plus blows that could not be assigned to either the mother or calf with certainty but which we knew came from one of the two animals. Blow rates were computed only for mother/calf groups that were observed for an uninterrupted period of 10 min. or more. A Wilcoxon paired sample t-test revealed no significant difference between the respiration rates calculated from the first 10 min. of observation and the respiration rates calculated from 15 or more min. of observation. This result was true for mothers ($n = 52$, $T_s = 569.5$, $p \gg 0.05$), calves ($n = 25$, $T_s = 144$, $p \gg 0.05$), or totals ($n = 25$, $T_s = 152$, $p \gg 0.05$).

7.1.3 Blow interval

Blow interval is defined as the time between successive blows from the same individual (mother or calf). Blow interval data are considered only for observation periods of 10 min. or more, during which all blows from that individual were seen. Periods of 10 min. or longer were used in order to minimize the bias introduced by sampling over short observation times. Blow intervals for an individual are not reduced to a mean and standard deviation but were instead combined with other blow intervals from all the mothers or all calves exposed to similar treatments.

7.1.4 Position of the calf relative to the mother

In order to determine whether the four types of playback stimuli had an effect on the calves' positions relative to their mothers, we looked at the number of times calves were observed offshore and inshore of their mothers during control periods and during experimental periods. We also wanted to determine if any of the controlled acoustic stimuli affected the number of times calves changed their positions on two consecutive surfacings. The criteria used for this analysis were the following:

1. Only single mother/calf pairs were used.
2. In determining whether a calf changed position, only those periods were used when we were certain that no surfacings were missed.
3. The time period between playbacks was not used.

7.1.5 Other behaviors

Other behaviors noted included: breaching, vertical flukes, fluke-ups, underwater blows, head ups, spyhopping, rolling, direction changes, milling, group joining, and group splitting. The definitions of these behaviors are as follows:

a) Breaching is the term applied when a whale leaps out of the water.

b) Vertical Flukes/Pects occur when a whale rolls onto its side and a fluke tip is seen above the water's surface; this behavior may also be accompanied by an extended pectoral fin.

c) Fluke-up is the raising of the entire tail above the water's surface, usually just before an extended dive.

d) Underwater blows are underwater exhalations causing a mass of bubbles to disturb the water's surface, usually in an area of several meters diameter.

e) Head up describes an event when the anterior portion of the rostrum is seen above the water but not as far back as the eyes.

f) Spyhopping refers to the behavior of raising the anterior portion of the body out of the water so that the eyes are above the water.

g) Rolling is rotating on the long axis of the body, so that either the sides or belly of the animal are facing up.

h) Direction changes refer to movements in a direction other than the direction of migration. In the following analysis, we will consider only two types of direction changes: 1) movement toward shore, perpendicular to the direction of migration and 2) turning about and facing or swimming in a direction opposite to the direction of migration. For example, groups were observed occasionally turning east and moving towards shore. Each group observed behaving in such a manner would be scored as one instance of heading in-shore (east). If the group turned south, it would be scored as heading south (south).

i) Milling refers to the behavior that results when a group temporarily stops moving in the direction of migration and, instead, changes direction frequently while remaining in approximately the same location.

j) Group joining is when two groups converge and swim together.

k) Group splitting occurs when two or more mother/calf pairs which were swimming together diverge and swim separately (greater than about 5 body lengths) from each other.

It is obvious that milling index, speed index, reversals of direction, milling, group joining, and group splitting are somewhat redundant, but never identical, measures of response. For example, milling index and net speed both use minimum distance between the first and last data point but milling index relates this distance to the total distance traveled by the whale or group, while net speed relates distance to total time spent. In terms of the rationale behind scoring the other behaviors, there were instances when a group would turn 180° (for example, turn south during the northward migration) but would not swim south or mill. In such cases, milling or speed index would not be sensitive to such a reversal of direction yet the behavior was rare enough to deserve notation.

Because the southward migration in January was so different from the mother/calf northward migration in April/May, the variables used to assess response in January and April/May are not entirely the same. For this reason further presentation of data analysis and results will be divided into two sections, January and April/May.

7.2 Analysis and Results of Track Data from January

During the January southward migration field season, observers did not recognize in the field any unusual responses of whales, except during the two orca playbacks. In order to test for possible changes in the movement patterns of whales during playback of industrial sound vs control conditions, we developed a program to evaluate the track deflections.

Simple calculation of movement scores for overall tracks could mask many possible responses since most tracks begin with a pre-exposure period, starting at a < 0 dB S/N level (presumably beyond the whale's threshold of detection), pass through a zone of exposure with increasing sound levels at decreasing ranges to the source as the animal approaches, then enter a zone of decreasing levels as the animal passes by the source, leading finally to a post exposure period when the animal passes again into a < 0 dB S/N level.

7.2.1 Method used by track deflection program

To measure possible variation in movements as a function of range to the playback source, the track deflection program calculates the values of various indices of motion for each segment of a whale track that passes adjacent pairs of grid lines set at fixed distances from the source of sound playback. The coordinates of this grid system are shown in Fig. 7.1.

Each whale sighting was transformed from the original transit coordinates to a new coordinate system in which the x-axis was parallel to the coastline and its origin was set at the average position of the R/V VARUA, the source of playback sounds. The coastline was digitized from a chart and a line parallel to the coast was determined by linear regression of the coastline points.

This coordinate system was chosen so that the tracks of whales would typically travel along the x-axis with little deflection in y. The origin was set at the source of playback sounds so that variation in y from grid to grid could easily be related to deflections away from the expected track path, as measured inshore or offshore of the sound source.

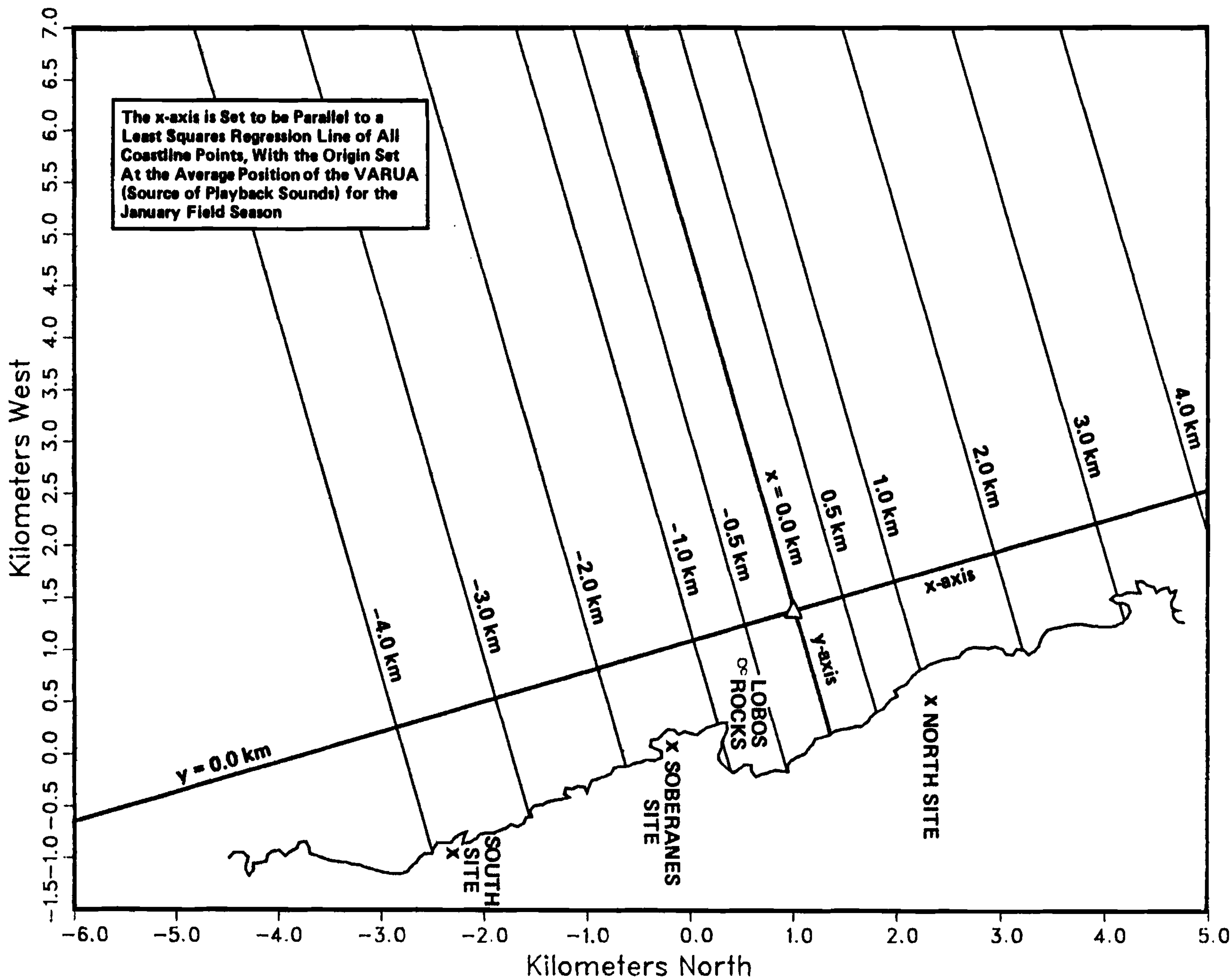


FIG. 7.1. GRID COORDINATE SYSTEM FOR TRACK DEFLECTION PROGRAM.

For the analysis presented here, grid lines were established at x_{grid} = 4.0, 3.0, 2.0, 1.0, 0.5, 0, -0.5, -1.0, -2.0, -3.0, and -4.0 km from the VARUA. Whenever the track of a whale group passed one of the grid lines - i.e., two points of the track straddled the grid line $x_i < x_{grid} < x_{i+1}$ - the time, t_{grid}, and value of y_{grid} were calculated by linear interpolation for the point at which the x value of the track equaled the value of the grid line:

$$factor_i = (x_{i+1}-x_{grid})/(x_{i+1}-x_i) \quad (13)$$

$$factor_{i+1} = (x_{grid}-x_i)/(x_{i+1}-x_i) \quad (14)$$

$$y_{grid} = (factor_i)(y_i) + (factor_{i+1})(y_{i+1}) \quad (15)$$

$$t_{grid} = (factor_i)(t_i) + (factor_i)(t_{i+1}) \; . \quad (16)$$

The y value at the grid was stored as an index of track deflection called D_y. The distance from point (x_{grid}, y_{grid}) to the nearest point of the shore was also stored as a measure called D_{shore}. This way, if one found deflection in y from grid to grid, one could test if the deflection was caused by whales following small changes in the coastline.

In all further discussions, a portion of a track bounded by two adjacent grid lines will be referred to as a grid interval and "cumulative speed" as speed.

For every track that passed a grid interval, four indices of motion were calculated for the track interval between grid lines. The indices calculated were speed, milling index or MI, course bearing, and VARUA bearing. These indices are defined in Sec. 7.1. The MI was calculated only for those grid intervals with at least one sighting falling within the boundaries of the interval.

The track deflection program accumulates the values of all six measures. D_y and D_{shore} are associated with each grid crossing; and speed, MI, course bearing, and VARUA bearing are associated with each track segment that passed two adjacent grid lines. These measures are calculated for a specified time window within a specified input file. The program allows one to accumulate all six scores for data from different days or time periods within a day.

Once the program has finished accumulating track deflection scores, it sorts all of the values for each score and each grid line or grid interval into numerically ascending order. The program plots the cumulative frequency distribution for each of three linear scores - D_y, speed, and MI. Scores for D_y are associated with grid lines, while scores for speed and MI are associated with grid intervals. (Typical plots are shown in Appendix B.) For each of these scores, the program calculates the maximum difference in the cumulative frequency distributions for every possible pair of grid lines in the case of D_y or D_{shore} and for every possible pair of grid intervals in the case of speed and MI. This difference is the variable D for the Kolmogorov-Smirnov two sample test (Siegel, 1956). The program uses a lookup table derived from Table M of Siegel (1956) to calculate the probability that D is large enough to indicate that the two sample distributions are drawn from different populations. Since there is no <u>a priori</u> assumption about the direction of expected changes, the two-tailed test is applied.

The scores, course bearing, and VARUA bearing yield circular samples. The test used to analyze differences in the samples of course bearing or VARUA bearing for each pair of grid intervals was the Watson's U^2 test for nonparametric two sample testing (Zar, 1974). Both for course bearing and VARUA bearing, the track deflection program calculates the value of U^2 for every possible pair of grid intervals and prints out these values. Critical values of U^2 must be looked up in Table D.44 of Zar (1974).

The track deflection program stores the values of all six measures for each grid (D_y and D_{shore}) or grid interval (speed, MI, compass bearing, and VARUA bearing) for the particular time windows during particular days selected for a run of the program. A second program compares the distributions of each of the six measures for two different such files at each identical grid or grid interval. In this way, the differences in the distributions of each measure can be compared between control and experimental conditions.

7.2.2 Results of track deflection analysis

Description of Control and Playback Periods

As is mentioned in Sec. 3.2, a total of six different sound stimuli were played back to migrating gray whales from 11 to 16 January 1983, during the January field season. Three 1.5- to 2.0-hour playback sessions were performed for each of the five industrial sound stimuli, Production Platform (PP), Drilling Platform (DP), Drill Ship (DS), Helicopter (H), and Semi-submersible (SS). These stimuli were presented in three blocks with each block containing one presentation of each of the five industrial playback stimuli. Thus, the presentations of each stimulus were distributed throughout the playback period. The sixth playback stimulus, a recording of *Orcinus orca*, was presented on two occasions - on the afternoons of 14 January and 16 January.

As Table 4.2 indicates, the number of tracks per stimulus presentation ranged in January from 2 to 19 for whales fully exposed to the playback and from 2 to 21 for whales partially exposed to playback. Since these sample sizes were so small, data from each presentation of a particular stimulus were pooled together for the experimental conditions of the track deflection analysis. If a track started or ended outside of a playback period, the start point or end point of the track was derived by linear interpolation of the two points straddling the time of playback start or stop.

As is mentioned in the introduction to this section, the track deflection analysis is designed to separate information from each track into pre-exposure intervals far north of the VARUA, exposure intervals of increasing received level as the group approaches the VARUA, and decreasing levels as the group passes the VARUA, and then post-exposure intervals as the group passes out of the response range of the playback. This approach has the strength of allowing each track to be used as its own control. The study design called for two shore observation stations specifically to maximize the range over which tracks could be followed, and to allow double the number of observers for the vicinity near the VARUA, where responses were expected to occur.

However, as will be seen in the remainder of this section, responses were observed at much greater ranges than anticipated, near to the 0 dB S/N detection level of the playback signals. The equipment used for playback proved remarkably effective at producing sounds with source levels as high as the original stimuli, in some cases even exceeding the original source level. The effective ranges of these playbacks, defined as the range at which the signal-to-noise ratio of the one-third octave band with the highest level reached 0 dB, averaged 2.5 km, with effective ranges estimated as high as 3.5 km (see Table 5.1).

The accumulation of pre-exposure control data was hindered by the difficulties encountered in tracking many whale groups more than 3 km from the VARUA, even with one observation station set well to the north of the VARUA. As Table 7.1 indicates, under control conditions, there were less than 10% as many track crossings at +4 or -4 km as there were at 0.5, 0.0, or -0.5 km. These small sample sizes at the extremes often preclude the use of potential pre-exposure or post-exposure track segments for effective statistical analysis in the January playback data.

Both for this reason and for comparison of potential disturbed responses with those of completely undisturbed migrating whales, another control condition was created by pooling track observations for all seven days when the playback vessel was not present, (7 to 10 and 19 to 21 January). This control condition will be used as the primary control for comparison with all six experimental conditions in the track deflection analysis. Wherever the comparison of different grid crossings or grid intervals within one experimental condition yields significant differences, these results will also be presented. Both kinds of control observation yielded similar and complementary results.

The comparison of a pooled experimental condition with a pooled control condition is not optimal, for it does not correct for possible variation in response due to diurnal variability or changes as the migration season progresses. The playback schedule, which was set up to maximize the number of playbacks, at some expense to control observation, and to maximize the double blind quality of observations, at the expense of a rigid playback schedule, allowed each experimental observation to be matched with a control for time of day and stage within the migration. A new playback schedule is proposed in Sec. 8 of this report to allow better matching of control and experimental observations.

TABLE 7.1. SAMPLE SIZES FOR EACH GRID CROSSING UNDER THE SIX EXPERIMENTAL AND ONE CONTROL CONDITION FOR JANUARY PLAYBACKS.

Grid Crossing	Control	Orca	Drilling Platform	Drill-ship	Semi-Submersible	Heli-copter	Production Platform
4	13	0	5	0	0	1	4
3	50	0	11	1	4	7	5
2	110	11	19	11	22	17	18
1	167	19	37	20	54	22	34
0.5	171	17	35	21	53	20	33
0	166	17	33	20	54	28	29
-0.5	164	17	35	19	52	28	29
-1	146	18	29	16	47	26	29
-2	78	8	21	15	29	23	13
-3	36	4	7	11	9	10	3
-4	14	1	1	3	3	1	0

By comparing the track plots from 7 to 8 January or 9 to 10 January in the Undisturbed, No Ship Present condition with those from 19 to 21 January, the reader can determine that the tracks from the 19 to 21 January period appear to be distributed farther offshore than those from the first field observations. This difference is significant for grid intervals +2 to -2 km, but there are no other significant differences in any other track measures under these two control conditions.

It is thus possible that the stage of the migration season might affect D_y values. This effect is minimized by the pooling of data from early and late control periods and by the pooling of data from the individual playbacks for each experimental condition. The pooled experimental data are distributed throughout the 6-day playback period (Table 4.3).

However, the pattern of results derived from comparing control and experimental conditions make such a confounding effect of seasonal variation appear very unlikely, for each playback stimulus elicited a different pattern of response. Since playbacks within each condition are distributed throughout the playback period, if any significant difference were due to a seasonal effect, it would be expected to be the same for all playback conditions. Furthermore, for all playback conditions, except Drill Ship, which showed no significant differences between grids or grid intervals, comparison of differences between grids with a stimulus condition yielded significant results that were similar with the comparisons to the pooled control condition.

During the January playback period, the VARUA arrived on site on the morning of 11 January; it conducted two playback experiments that afternoon. Playback or transmission loss experiments were conducted every day during the entire 6-day period the ship was on station. The ship left at noon on 17 January. There were few intervals suitable for use as a control condition with the VARUA present. A control "VARUA-Present" condition was constructed, using tracks prior to the first playback at 0918 on 13 January and 0930 on 16 January and tracks prior to the departure of the VARUA on 17 January. A comparison of all six deflection measures for this control VARUA Present condition with the Undisturbed No Ship Present condition for 19 to 21 January yielded no significant differences in response. Furthermore, we will see that each playback stimulus condition elicited different responses from gray whales. Since the non-playback stimulus from the VARUA was constant during different playbacks, it cannot have produced the differential response.

Variation in Measures Between Different Grids in Control Condition

As mentioned in the previous section, the measure D_y is simply the interpolated value of y of the track at each grid line the track crosses. Since the x-axis is set parallel to a linear regression of the coastline in the expected direction of whale migration, motion in the y direction constitutes a measure of track deflection. The measure D_{shore} was also calculated as the minimum distance between each grid point (x_{grid}, y_{grid}) and the shore. D_{shore} was included as a measure, in case whales followed the coastline so closely as to produce site-specific variation in D_y from grid to grid due to deviation in the actual coastline from its linear regression.

The results of a pairwise comparison of the distribution of D_y at each gridline compared with every other gridline in the control condition yielded no pairs of D_y distribution that were significantly different to the $p < 0.10$ level by the Kolmogorov-Smirnov two sample test. D_{shore}, on the other hand, yielded many such significant differences, as can be seen in Table 7.2.

TABLE 7.2. MATRIX LISTING THE p VALUES OF ALL POSSIBLE PAIR-WISE COMBINATIONS OF AND PAIRS FOR D SHORE UNDER THE CONTROL CONDITION.

Transition Between Adjacent Grid Lines

Following Grid Line	Initial Grid Line: 4 →	3 →	2 →	1 →	.5 →	0 →	-.5 →	-1 →	-2 →	-3 →	-4
4	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
3		-	NS	p<.05	p<.025	p<.001	NS	NS	NS	NS	p<.025
2			-	NS	NS	p<.005	NS	NS	NS	NS	NS
1				-	NS	p<.001	NS	NS	NS	NS	NS
.5					-	p<.005	NS	NS	NS	NS	NS
0						-	p<.001	p<.001	p<.001	NS	NS
-.5							-	NS	NS	NS	NS
-1								-	NS	NS	NS
-2									-	NS	NS
-3										-	NS
-4											-

The upper right half of the matrix in Table 7.2 contains all 45 possible combinations of grid pairs. The p values listed in the matrix at row i and column j indicate the probability that the frequency distribution of D_s for the grid labeled for that row i is drawn from the same population as the frequency distribution for the grid labeled for column j. All cells labeled NS indicate $0.10 < p < 1.0$. To conserve space, we have listed only the upper bound for the probability figures. The thresholds for evaluating the critical values of p correspond to p = 0.10, 0.05, 0.025, 0.01, 0.005, and 0.001. Thus, the lower bound for all probability levels indicated in the table is the next number in the series after the upper bound. The p-values derive from the Kolmogorov-Smirnov two sample test (Siegel, 1956).

The lack of variation in D_y combined with highly significant variation in D_{shore} between grids clearly demonstrates that undisturbed whales during the January migration did not significantly respond to small scale variation in shore topography in our study area. The significant variation in D_{shore} between grids makes it much less useful as a test statistic than D_y, and it will, therefore, not be used in further analysis.

In a similar comparison of all possible pairs of grid intervals, the speed measure also showed very few pairs of sample distributions that were significantly ($p < 0.05$) different by the Kolmogorov-Smirnov two sample test. Only three pairs of grid intervals differed significantly:

Grid From → To	Grid From → To	Probability that the 2 speed distributions are from the same pop.
2.0 → 1.0	1.0 → 0.5	$0.025 < p < 0.05$
2.0 → 1.0	0.5 → 0.0	$0.025 < p < 0.05$
2.0 → 1.0	-2.0 → -3.0	$0.010 < p < 0.025$

In all of these cases, whales moved more slowly during the passage from the grid at x = 2 km to x = 1 km than during the other interval. This behavior may reflect some site-specific response to some feature of one or more of these intervals, particularly since they all involve the 2.0 → 1.0 grid, but it may also reflect sampling error since so many statistical tests were performed. It is not unreasonable to expect that one might find two samples from the same population appearing to differ at the $p < 0.05$ level and one sample appearing to differ at the $p < 0.025$ level, when one compares two different samples 45 times. Since speed appears to show only very slight shore-specific effects, if any, it is, like D_y, a good measure for estimating the strength of response to playback as whales approach and move past the playback source.

When one applies the same Kolmogorov-Smirnov two sample test to all possible combinations of grid intervals for the milling index, none of the comparisons suggests site-specific differences at the $p < 0.05$ level. Thus, MI could be a useful measure for estimating strength of response at different grid intervals. However, if one examines the cumulative frequency distributions of MI under the undisturbed condition, one sees that, for almost all grid intervals, over half of the MI values were close to 1.0. This comes about not only because most whales swam along a close to linear course, but also because there were seldom more than several sightings per grid interval. Since the end points of grid intervals were interpolated, the fewer sightings per grid interval, the less chance a track had of generating a MI far from 1.0.

Because the size of the interval between grids for this analysis was often close to the distance between sightings, the MI calculated per grid interval is not a particularly sensitive measure to the deflection responses of gray whales to our January playback experiments. Results of the MI analysis thus will not be tabulated; instead we describe the MI for the one case of a statistically signficant result.

The VARUA bearing is an inappropriate measure for differences in the responses of whales between grid intervals, because if a whale maintains a constant y position as it approaches the VARUA by moving parallel to the x-axis, its bearing to the VARUA will change even when the whale's course is constant. This result is reflected in Watson's U^2 two sample comparisons of all combinations of grid intervals; all but two of the comparisons show significant ($p < 0.05$) differences.

Even though there is no a priori reason to expect the same systematic variation in compass bearing, and even though this measure is similar to D_y, compass bearing also shows many significant deviations from the null hypothesis that the circular samples from different grid intervals are drawn from the same population. The upper right half of the matrix in Table 7.3 contains all 45 possible combinations of grid intervals. The p values listed in the matrix at row i and column j indicate the probability that the frequency distribution of the compass bearing for the grid interval labeled for row i is drawn from the same population as the frequency distribution for the grid interval labeled for column j. All cells labeled NS indicate $0.10 < p < 1.0$. To conserve space, we have listed only the upper bound for the probability figures. The thresholds for evaluating the critical values of p correspond to $p = 0.10, 0.05, 0.02$, and 0.01. Thus, the lower bound for all probability levels indicated in the table is the next number in the series after the upper bound. The p-values derive from the Watson's U^2 two sample test (Zar, 1974).

TABLE 7.3. MATRIX LISTING THE p-VALUES OF ALL PAIR-WISE COMBINATIONS OF GRID INTERVALS FOR MEASURE "COMPASS BEARING" UNDER CONTROL CONDITIONS.

	4 → 3	3 → 2	2 → 1	1 → .5	.5 → 0	0 → -.5	-.5 → -1	-1 → -2	-2 → -3	-3 → -4
4 → 3	-	NS	NS	NS	NS	$p<0.05$	NS	NS	NS	$p<.05$
3 → 2		-	NS	NS	NS	NS	NS	NS	NS	$p<.05$
2 → 1			-	NS	NS	$p<.02$	$p<.01$	NS	NS	$p<.01$
1 → .5				-	NS	NS	NS	NS	NS	$p<.01$
.5 → 0					-	NS	$p<.05$	NS	NS	$p<.01$
0 → -.5						-	NS	$p<.05$	NS	NS
-.5 → -1							-	NS	NS	$p<.05$
-1 → -2								-	NS	$p<.02$
-2 → -3									-	NS
-3 → -4										-

As Table 7.3 shows, 12 of the 45 possible pairs of grid intervals show significant ($p < 0.05$) differences by Watson's U^2 test. This result is particularly striking, since the mean vectors for compass bearing at the 11 grids are very similar:

Grid Interval	Mean Vector of Compass Bearing: Bearing	Length
4.0 → 3.0	181	.9904
3.0 → 2.0	180	.9792
2.0 → 1.0	182	.9630
1.0 → 0.5	181	.9610
0.5 → 0.0	182	.9540
0.0 → 0.5	183	.9490
-0.5 → 1.0	185	.9663
-1.0 → -2.0	181	.9693
-2.0 → 3.0	185	.9684
-3.0 → -4.0	194	.9840

The Watson's U^2 comparison of compass bearing distributions appears to be a very sensitive test. However, since it does show so many significant differences between grid intervals under control conditions, it is not well suited for comparisons of different grid intervals under experimental conditions.

Responses to the Orca Stimulus Condition

The orca stimulus was the one playback condition for which field observers recognized a response under the double blind experimental procedure. Even though whale observers at the shore station did not know when playbacks were occurring nor which stimuli were presented, they recognized the response described by Cummings and Thompson (1971) for gray whales exposed to orca sounds; as can be seen in the orca track plot in Appendix B, most whales turned sharply inshore compared to control or other experimental conditions.

These observations are borne out in the Kolmogorov-Smirnov two sample comparisons between orca and control conditions at each grid line, as shown in the D_y column of Table 7.4. This table lists the differences between the distributions of four measures under orca or control conditions.

The whale groups showed highly significant responses in all grid comparisons for D_y until they were 2 km south of the source of orca playbacks. The differences in the distributions of D_y between orca can be most easily visualized if the reader makes a transparency of the cumulative frequency plots for D_y under the control condition. If one overlays such a transparency onto the cumulative frequency plots for D_y under the orca condition, it is immediately evident that most D_y values under orca conditions are shifted dramatically inshore of control D_y values. However, particularly at the +0.5 and 0 grids there is also a tendency for some whale groups to pass offshore of the control distribution. This result reflects the few tracks that started farther offshore than the VARUA and that moved even farther offshore in an apparent offshore deflection from the sound source. (See the orca track plot in Appendix B.)

The speed measure shows significant deviations between orca and control conditions only at two grid intervals, 2 km to 1 km (2 → 1) and 1 to 0.5 km (1 → 0.5) north of the sound source. In both cases, whales tend to slow down in response to orca playback.

The VARUA bearing shows a pattern of variation between orca and control conditions that mirrors the D_y variation. Since the compass bearings showed no significant variation between orca and control, it appears that the differences in VARUA bearing derive from the differences in D_y. When a whale group has come inshore, its bearing to the VARUA changes, even when its compass bearing does not.

It is clear from Table 7.3 that when whales were first sighted north of the VARUA, they already showed significant

TABLE 7.4. RESPONSES TO THE ORCA STIMULUS CONDITION.

Grid Crossings (km)	Track Deflection D_y	Speed	Course Bearing	VARUA Bearing
4	-			
		- -	-	
3	-			
		- -	-	
2	$0.025<p<0.05$			
		$0.005<p<0.01$	NS	$0.002<p<0.005$
1	$0.01<p<0.025$			
		$0.01<p<0.025$	NS	$0.0<p<0.001$
0.5	$0.0<p<0.001$			
		NS	NS	$0.0<p<0.001$
0	$0.001<p<0.005$			
		NS	NS	$0.0<p<0.001$
-0.5	$0.0<p<0.001$			
		NS	NS	$0.0<p<0.001$
-1	$0.0<p<0.001$			
		NS	NS	$0.005<p<0.01$
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population), while "______" means that there were no data for that grid crossing or grid interval.

deviation from control observations. Since whales were inshore compared to control conditions but showed no significant changes in compass bearing, they must have turned inshore before the start of the track records at more than 2 km north of the VARUA. This result is remarkable, since the 0 dB S/N ratio of the one-third octave band with the highest energy level (a common detection threshold) occurred at ranges of 2.4 and 2.8 km for the two orca playbacks (Table 5.1).

Table 7.3 shows that there appears to be variability in the strength of response to orca sounds (judged by significance levels) as a function of distance to the source (judged by grid or grid interval). However, results of a Kolmogorov-Smirnov two sample comparison of all possible pairs of grids or grid intervals for the two measures D_y and speed show no significant ($p < 0.05$) differences between the distributions at any pair of grids or grid intervals.

There was a significant difference for this analysis of compass bearing, however, even though there was no difference in the compass bearings for orca and for the control condition. The compass bearings at grid interval $2.0 \rightarrow 1.0$ for the orca condition showed significant differences from those of the 0 to 0.5 km south ($0.0 \rightarrow -0.5$) grid interval ($p < 0.01$) and the $-0.5 \rightarrow -1.0$ grid interval ($p < 0.02$).

The responses of gray whales to the playback of orca sounds clearly are avoidance responses. As soon as the whales can detect the signal, they show a strong response and maintain this response of keeping a large distance from the source as they migrate south. This avoidance response was even stronger than is indicated by the track data, for many whale groups were observed by the northern observation station to cease their southward migration at 3 to 4 km north of the playback source. These whales milled around the area in groups that could not be easily differentiated until the playback stopped, so their tracks could not be used in the track deflection analysis.

Responses to the Drilling Platform Stimulus Condition

Table 7.5 lists the differences between the distributions of four measures under Drilling Platform or Control conditions. D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test.

Only one grid crossing showed a significant difference in D_y for Drilling Platform (DP) vs Control and only one grid interval showed a difference for compass bearing. The difference in D_y at grid 0.5 stems from the gap in sightings from the sound source out to 500 m offshore of it. This boosted the frequency of sightings both inshore and farther offshore. The compass bearing at grid interval 3 → 2 has a mean vector bearing of 196° vs 180° under control conditions, indicating that whales tended to deflect offshore of the VARUA during this interval. Given that a battery of tests for significance was performed, such isolated differences might have arisen by sampling error. However, both speed and VARUA bearing show more robust differences, which are similar and complementary to those found for D_y and compass bearing.

As whales approached the source of playback, they slowed down, as can be seen by comparing the cumulative frequency plots of speed for DP and Control conditions. While it appears that the response increased with decreasing range, a Kolmogorov-Smirnov two sample comparison of all pairs of grid intervals for speed under the DP condition shows no significant differences between distributions.

TABLE 7.5. RESPONSES TO THE DRILLING PLATFORM STIMULUS CONDITION.

Grid Crossings (km)	Track Deflection D_y	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	0.02<p<0.05	0.005<p<0.01
2	NS			
		NS	NS	0.005<p<0.01
1	NS			
		0.005<p<0.010	NS	0.002<p<0.005
0.5	0.025<p<0.05			
		0.001<p<0.005	NS	0.02<p<0.05
0	NS			
		NS	NS	NS
-0.5	NS			
		NS	NS	0.002<p<0.005
-1	NS			
		0.025<p<0.05	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: – = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant (p > 0.05 that samples came from the same population) while "______" means that there were no data for that grid crossing or grid interval.

The VARUA bearing also shows significant differences between DP and control conditions for those grid intervals where the whales were approaching the source. The bearings and lengths of the mean vectors for these VARUA bearings are as follows:

	CONTROL		DRILLING PLATFORM	
Grid Interval	Length	Bearing	Length	Bearing
3.0 → 2.0	.9664	11°	.8770	35°
2.0 → 1.0	.9326	17°	.9162	25°
1.0 → 0.5	.8844	26°	.7811	20°
0.5 → 0.0	.7702	40°	.6337	33°

Thus, for the 3 → 2 and 2 → 1 transition, whales were less oriented towards the VARUA under DP than Control conditions, while for the 1 → 0.5 and 0.5 to 0.0 transitions they did not show this response and, if anything, were oriented more towards the VARUA under DP. Reference to the track plots for the Drilling Platform condition will show that this result occurs because whale groups appeared to deflect away from the VARUA at ranges of approximately 3 km, while by the time they were within 0.5 km of the source they were already compensating for the deflection and turning back towards where their earlier track would have taken them.

As mentioned in the section comparing responses within the control condition, one cannot compare VARUA bearings for different grid intervals. However, the compass bearing results support the interpretation that the primary deflection response occurs at 3 to 2 km. Not only is this the only significant difference with respect to the undisturbed control condition, but also the only significant ($p < 0.05$) differences between grid intervals for the DP condition are between grid intervals 3.0 → 2.0 and intervals 1.0 → 0.5, 0 → -0.5, and -0.5 → -1.0.

The results of this effect can also be seen by comparing the cumulative frequency plots of the DP and Control conditions. At the 1.0, 0.5, and 0.0 grid crossings, there is a clear gap in the number of sightings near the VARUA, particularly from 0 to approximately 500 m in the DP condition (compared with Control). While the difference in D_y is significantly different only at the 0.5 grid, this lack of sightings at $D_y = 0$ boosts the number of sightings inshore and offshore of the VARUA in all three grid crossings.

In summary, these results indicate that whales significantly slowed down while approaching within 2 km of the Drilling Platform source and that they showed avoidance of the immediate vicinity of the playback source within several hundred meters, an avoidance that was produced by significant track deflections (measured by VARUA bearing) at ranges of up to 3 km north of the source.

Response to Drillship Stimulus Condition

Table 7.6 lists the differences between the distributions of four measures under Drill Ship (DS) or Control conditions, indicating that there was no significant deviation in scores of D_y and VARUA bearing comparing the DS with the Control condition. As one can see by examining the track plot for DS (Appendix B), whales did not show the same uniform avoidance of the immediate vicinity of the sound source that occured for both orca and DP conditions. In the DS condition, several tracks passed very close to the VARUA.

The only grid that showed a difference in D_y between the DS and Control conditions was grid -4.0. The only three tracks that extended to grid -4 were close to shore, as shown in the track plot for DS in Appendix B. This sampling error also led to a series of significant ($p < 0.05$) differences in pairwise

TABLE 7.6. RESPONSES TO THE DRILLSHIP STIMULUS CONDITION.

Grid Crossings (km)	Track Deflection D_y	Speed	Course Bearing	VARUA Bearing
4	–			
		–	–	–
3	NS			
		NS	NS	NS
2	NS			
		$0.001<p<0.005$	NS	NS
1	NS			
		$0.0<p<0.001$	NS	NS
0.5	NS			
		$0.005<p<0.01$	$0.02<p<0.01$	NS
0	NS			
		NS	$0.05<p<0.02$	NS
-0.5	NS			
		$0.010<p<0.025$	NS	NS
-1	NS			
		NS	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	$0.01<p<0.025$			

Notes: – = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population), while "______" means that there were no data for that grid crossing or grid interval.

comparisons between grid -4 and grids 2.0, 1.0, 0.5, 0.0, -0.5, -1.0, -2.0, and -3.0 under the DS condition.

There was a significant difference in compass bearing for the 0.5 → 0.0 km and 0.0 → -0.5 km grid interval. The mean vectors for these grid intervals were as follows:

	CONTROL		SHIP	
Grid Interval	Length	Bearing	Length	Bearing
0.5 → 0.0	.9540	182°	.9952	181°
0.0 → -0.5	.9490	183°	.9913	183°

It is obvious that the average bearings of the mean vector were very similar in the Control and DS conditions. The significant difference in the two distributions is that the compass bearings for these grid intervals under the DS condition show less variability (and therefore a greater mean vector length) than under Control conditions. While this result does appear to be statistically significant, it is not a change in bearing but rather represents less scatter in the direction of migration.

The other obvious significant response to the DS playback was in the speeds. This response showed significant differences, as whales approached the source in grid intervals 2.0 → 1.0, 1.0 → 0.5, and 0.5 → 0.0, as well as in interval -0.5 → -1.0. As one can easily see by comparing the cumulative frequency plots of speed for the DS and Control conditions, as whales approached the playback source they slowed down.

Response to the Semi-submersible Stimulus Condition

Table 7.7 lists the differences between the distributions of four measures under Semisubmersible or Control conditions.

TABLE 7.7. RESPONSES TO THE SEMISUBMERSIBLE STIMULUS CONDITION.

Grid Crossings (km)	Track Deflection D_y	Speed	Course Bearing	VARUA Bearing
4	–			
		–	–	–
3	NS			
		NS	NS	NS
2	NS			
		$0.005<p<0.01$	NS	NS
1	NS			
		$0.001<p<0.005$	NS	NS
0.5	NS			
		$0.0<p<0.001$	NS	NS
0	NS			
		$0.0<p<0.001$	NS	NS
-0.5	NS			
		NS	NS	NS
-1	NS			
		$0.25<p<0.05$	NS	NS
-2	NS			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: – = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "_____" means that there were no data for that grid crossing or grid interval.

The only measure that showed a significant difference between the Semisubmersible (SS) stimulus condition and the Control condition was speed. Speed under the SS condition showed a pattern of variation very similar to speed under the DS condition. Whales slowed down significantly as they approached within 2 km of the sound source and continued to move more slowly for every grid interval until $-1.0 \rightarrow -2.0$ with the exception of $-0.5 \rightarrow -1.0$. Results of a pairwise Kolmogorov-Smirnov two sample test for speed of all combinations of grid intervals under the SS condition do indicate that the response to this stimulus may scale with range. Of all 28 pairwise combinations of grid intervals, only two showed a significant ($0.025 < p < 0.05$) difference. These two pairs were $1.0 \rightarrow 0.5$ compared with $0.0 \rightarrow -0.5$ and $-1.0 \rightarrow -2.0$ compared with $0.0 \rightarrow -0.5$. In both cases whales moved more slowly when closest to the source in the $0.5 \rightarrow 0.0$ grid interval. Comparisons of the grid intervals closest to the VARUA with those even more distant from the source than $1.0 \rightarrow 0.5$ and $-1.0 \rightarrow -2.0$ yielded higher D_y values for the Kolmogorov-Smirnov test than the significant intervals, but these did not reach significance because of low sample sizes.

The Semisubmersible stimulus condition was the only one to show a potential response in the MI measure. In the $-1.0 \rightarrow -2.0$ grid interval, the probability that the sample distribution of MIs under SS was drawn from the same population as Control was $0.005 < p < 0.01$. As the reader can determine by comparing the cumulative frequency plots in Appendix B for MI under Control and SS conditions, the whales under SS appeared to have MIs closer to 1.0 or to have a more direct course. However, this one significant result may result from sampling error, given the large number of tests calculated for this measure.

Response to the Helicopter Stimulus Condition

Table 7.8 lists the differences between the distributions of four measures under Helicopter or Control conditions.

As Table 7.8 indicates, the measure that showed the largest number of grids with significant differences between the Helicopter (H) condition and Control was D_y. If one compares the cumulative frequency plots for D_y under the H and Control conditions, one sees that whales under the H condition tended to be distributed farther offshore than under the Control condition, particularly for those grids after (i.e., south of) the sound source. These plots also show that, as in the DP condition, whales appeared to avoid D_y values of 0 ± 250 m at the 0.5 and 0.0 km grid crossings. If one examines the track plot for Helicopter in Appendix B, it appears that groups of whales, both inshore and offshore of the VARUA, started to deflect away from the VARUA when still north of it, up to 2 km north for the offshore groups. Most groups appeared to compensate for the deflection even before passing the x = 0 grid line. Presumably, it is particularly the offshore deflection of the offshore whales that led to the significantly offshore D_y values for grids 2.0, -0.5, -1.0, and -2.0. The application of the two sample Kolmogorov-Smirnov test to all possible combinations of grid pairs yields 4 significant differences:

Grid	Grid	Probability that both samples are drawn from the same population
3.0	-3.0	$0.025 < p < 0.05$
2.0	-3.0	$0.001 < p < 0.005$
0.5	-3.0	$0.025 < p < 0.050$
0.0	-3.0	$0.010 < p < 0.025$

TABLE 7.8. RESPONSES TO THE HELICOPTER STIMULUS CONDITION.

Grid Crossings (km)	Track Deflection D_y	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	$0.025<p<0.05$			
		NS	NS	NS
1	NS			
		NS	NS	NS
0.5	NS			
		$0.025<p<0.05$	NS	NS
0	NS			
		NS	NS	NS
-0.5	$0.025<p<0.05$			
		$0.005<p<0.010$	NS	$0.02<p<0.05$
-1	$0.025<p<0.05$			
		NS	NS	NS
-2	$0.01<p<0.025$			
		NS	NS	NS
-3	NS			
		NS	NS	NS
-4	NS			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "_____" means that there were no data for that grid crossing or grid interval.

Since all of these deviations involve the -3.0 grid far to the south of the source, which does not itself show a significant difference from the Control, they presumably do not reflect a scaling of the response as a function of distance to the source.

Two grid intervals show a difference in speed between the H and Control conditions. In both of these cases, grid intervals 0.5 → 0.0 and -0.5 → -1.0, the speed tended to be slower in the H condition.

If one compares all possible pairs of grid intervals for speed under the H condition, three pairs of grid intervals yield significant differences by the Kolmogorov-Smirnov two sample test:

Grid Interval #1		Grid Interval #2		Probability that both speed samples are drawn from the same population
From	To	From	To	
3.0	2.0	1.0	0.5	$0.025 < p < 0.05$
3.0	2.0	0.5	0.0	$0.025 < p < 0.05$
3.0	2.0	-0.5	-1.0	$0.025 < p < 0.05$

There was only one track that crossed interval 4.0 → 3.0, not a large enough sample to be significant even with large values of D_y. The speed for this interval and for interval 3.0 to 2.0 were close to those observed in the Control condition, faster than speeds from intervals 1.0 → 0.5, 0.5 → 0.0, and -0.5 → -1.0. Grid interval 3.0 → 2.0 thus appears to serve as a good pre-exposure control for the Helicopter condition. The acoustic features of this stimulus also suggest that interval 3.0 → 2.0 is out of the detection range of most Helicopter playbacks. As Table 5.1 indicates, the Helicopter stimulus had the lowest source level, 154 dB, of all the industrial sounds, with 0 dB S/N thresholds for the one-third octave band, with the most sound energy at ranges of 1.2, 1.8, and 3.0 km. (The playback with the 3.0 km detection range contributed only 11 of the 48 tracks for the H condition.)

The only other significant ($0.025 < p < 0.05$) difference for Helicopter playbacks was in the VARUA bearing for grid interval -0.5 to -1.0. In this case the bearing of the mean vector was 133° vs 147° under Control conditions. An isolated difference of $p < 0.05$ might arise from sampling error, given the number of tests performed, but the differences in mean angle may be caused by the offshore orientation of whales at this grid interval.

Response to the Production Platform Stimulus Condition

Table 7.9 lists the differences between the distributions of four measures under Production Platform (PP) or Control conditions.

D_y measures yielded the primary differences between the Production Platform and Control conditions. For the first three grids south of the sound source, the distribution of whales tended to be farther offshore than under the Control condition. As one can determine by examining the track plot for the Production Platform condition, whales observed during this condition appeared to show a slight deflection just as they pass the sound source; those offshore appeared to maintain the deflection for a kilometer or so, before compensating for the deflection.

Grid crossings 4.0 and 3.0 had sample sizes of only 4.0 and 5.0 track crossings, respectively, not enough for the observed values of D_y (as large as 0.5, comparing grid 4 with grid -3) to yield significance to the $p < 0.05$ level. However, the results of the Kolmogorov-Smirnov two sample comparison of all possible pairs of grid indicate that all other grid crossings to the north

TABLE 7.9. RESPONSES TO THE PRODUCTION PLATFORM STIMULUS CONDITION.

Grid Crossings (km)	Track Deflection D_y	Speed	Course Bearing	VARUA Bearing
4	NS			
		NS	NS	NS
3	NS			
		NS	NS	NS
2	NS			
		NS	NS	NS
1	NS			
		NS	NS	NS
0.5	NS			
		NS	NS	$0.02<p<0.05$
0	NS			
		NS	NS	NS
-0.5	$0.025<p<0.05$			
		NS	NS	NS
-1	$0.005<p<0.01$			
		NS	NS	$0.01<p<0.02$
-2	$0.0<p<0.001$			
		NS	NS	NS
-3	NS			
		-	-	-
-4	-			

Notes: - = No Data

NS = Not Significant

D_y and speed were tested by the Kolmogorov-Smirnov two sample test, while course bearing and VARUA bearing were tested by the Watson's U^2 two sample test. D_y was measured at grid crossings, so D_y statistics are listed on the same line as the grid crossing. The other three measures were obtained from intervals between adjacent grids, so they are listed on the line between those for adjacent grid crossings. NS stands for Not Significant ($p > 0.05$ that samples came from the same population) while "_____" means that there were no data for that grid crossing or grid interval.

of the VARUA act as suitable controls for the responses elicited after whales passed by the source:

Grid #1	Grid #2	Probability that both D_y samples are drawn from the same population
2.0	-0.5	$0.025 < p < 0.05$
2.0	-1.0	$0.005 < p < 0.01$
2.0	-2.0	$0.001 < p < 0.005$
1.0	-1.0	$0.025 < p < 0.05$
1.0	-2.0	$0.001 < p < 0.005$
0.5	-2.0	$0.005 < p < 0.010$
0.0	-2.0	$0.001 < p < 0.005$

These results show that both Control conditions, observations of undisturbed whales from 7 to 10 and 19 to 21 January and the northern "pre-response" grids of the PP condition both yield very similar results. Under both controls, the most significant difference occurred for grid -2.0, the next in order was grid -1.0, and the smallest level of significance occurred for grid -0.5. In addition, the northernmost grid to yield a significant difference, grid 2.0, appears closest to the undisturbed control; as whales approached the source, they yielded fewer differences of significance.

The only other measures to show a significant difference between the PP and Control conditions were the VARUA bearings at intervals 0.5 → 0.0 and -1.0 → -2.0. The values for the mean vectors of the VARUA bearing under these conditions are the following:

	Control		PP	
Grid Intervals	Length	Bearing	Length	Bearing
0.5 → 0.0	.7702	40°	.8545	45°
-1.0 → -2.0	.8727	156°	.9600	136°

These values indicate that, at the 0.5 → 0.0 grid interval, whales in the PP condition were more oriented away from the VARUA than in the Control condition. For the -1.0 → -2.0 grid interval under PP, all but one of the tracks were offshore of the VARUA. These tracks at interval -1.0 → 2.0 were not oriented as directly away from the VARUA as in the Control condition, but were turning more inshore. These deviations in VARUA bearing probably arise from the initiation of track deflection between grids 0.5 and 0.0 and the compensation of tracks between grids -1.0 and -2.0.

7.3 April/May Analysis and Results

7.3.1 Type and level of potential disturbance

All data from April/May were reduced to a set of variables as discussed in Sec. 7.1. Since the aim was to relate these variables to experimental conditions, these data were grouped according to both the type of potential disturbance and the received sound level of the potential disturbance to which the whales were exposed. There were eleven types of potential disturbance (see Secs. 3.3 and 3.4 for details). These included seismic air gun array at 50, 20, 8, 3, 1, and 0.5 nm; underwater sound projector playback of Drill Ship and killer whale (*Orcinus orca*) sounds; and single air gun at 3 nm, 10 fathom contour and anchored positions. There were six exposure levels. In cases when exposure to air gun was the experimental treatment, exposure was divided into three received level (L_R) categories: $L_R < 140$ dB, $140 < L_R < 160$ dB, and $L_R > 160$ dB. In cases where sound playback was used, exposure was divided into three S/N categories: $S/N < 0$ dB, 0 dB $< S/N < 10$ dB, and $S/N > 10$ dB. Acoustic exposure levels were calculated (Sec. 3.2) for each theodolite sighting of a group during the different types of playback. These levels were then used to bracket the time periods during which a group was within a specific exposure condition.

Tables 7.10 through 7.13 show the results of categorizing the behavioral data according to experimental type and exposure level. Groups observed for less than 10 min. were not included in calculations of blow rates, blow intervals, or speed indices, while groups that moved less than a total distance of 1 km were not included in calculation of MI. Behaviors listed in Tables 7.12 and 7.13 include both the total number of events observed and the number of groups responsible for those events for all groups, regardless of observation time or distance traveled. Direction changes include only the number of groups observed doing a particular behavior and not the total number of times the behavior was seen. Thus, even if a group turned south three times during the observation period, it was scored only once in the south box for that condition. For purposes of standardization, the number of whale hours of observation for each condition is listed.

The data listed in Tables 7.10 through 7.13 are illustrated in Figs. 7.2 through 7.10.

7.4 Statistical Analysis; April/May

Five statistical tests were performed on these data. The Mann-Whitney U-Test (MWU) was used to test the significance of differences between variables recorded during experimental and normal conditions, where potentially disturbed includes all categories by exposure type and exposure level. The variables tested included blow rates, milling indices, and speed indices.

The Wilcoxon Signed-Ranks (WSR) test was used to test the significance of differences between variables recorded for groups observed prior to an experiment and during an experiment or during an experiment and after an experiment. These pairwise

TABLE 7.10. BLOW RATES (BLOWS/HR), BLOW INTERVALS (s), MILLING INDICES, AND SPEED INDICES FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO A VARIETY OF SOUND SOURCES (SEE TEXT FOR FURTHER EXPLANATION.

		Air Gun Array Runs							Stimulus Playback		Single Air Gun		
		Normal	A	B	C	D	E	F	Drillship	Orcinus orca	10 Fathom	Line E	Anchored
Blow Rates (Blows/hr)	Mother												
	$\bar{X}$	24.8	23.4	19.1	24.6	28.7	27.3	21.1	20.2	19.4	28.1	29.5	34.5
	Sd	13.8	5.4	10.3	6.1	5.1	6.7	5.4	6.9	-	-	-	13.8
	n	64	7	9	9	3	10	4	7	1	1	1	4
	Calf												
	$\bar{X}$	21.4	14.1	18.7	14.9	22.7	27.6	27.9	15.6	26.6	28.1	28.7	38.1
	Sd	13.8	8.8	14.7	7.3	3.6	14.6	14.2	4.4	-	-	-	14.2
	n	64	7	9	9	3	10	4	7	1	1	1	4
	Total												
	$\bar{X}$	57.8	40.5	48.8	44.9	73.2	60.8	51.1	44.1	46.9	67.5	65.4	75.6
	Sd	28.4	12.0	20.7	10.6	34.5	14.6	15.4	7.2	-	-	-	26.1
	n	64	7	9	9	3	10	4	7	1	1	1	4
Blow Intervals (s)	Mother												
	$\bar{X}$	130.0	108.9	83.8	113.7	107.5	103.7	-	99.7	137.7	82.3	85.6	81.2
	Sd	91.7	96.9	59.0	99.3	80.7	36.6	-	106.5	107.5	87.3	88.5	58.6
	n	973	78	25	52	26	27	-	61	34	8	14	13
	Calf												
	$\bar{X}$	98.0	70.4	67.7	100.1	91.6	-	-	84.4	81.9	-	-	104.7
	Sd	102.3	66.0	56.8	101.8	120.1	-	-	53.1	105.1	-	-	74.6
	n	462	54	19	53	19	-	-	39	42	-	-	11
Milling Index	$\bar{X}$	0.93	0.97	0.93	0.93	0.90	0.73	0.62	0.89	0.85	0.44	0.82	0.56
	Sd	0.05	0.02	0.10	0.08	0.07	0.22	-	0.10	-	-	-	0.09
	n	61	6	7	9	3	10	2	4	1	1	1	3
Speed Index (km/hr)	$\bar{X}$	5.2	5.6	4.6	6.0	6.0	4.3	3.8	4.9	3.5	2.9	6.7	3.3
	Sd	1.09	0.5	1.2	1.0	0.3	2.4	-	1.1	-	-	-	0.1
	n	61	6	7	9	3	10	2	7	1	1	1	3

TABLE 7.11. BEHAVIORS FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO A VARIETY OF SOUND SOURCES. "TOTAL" INDICATES THE TOTAL NUMBER OF BEHAVIORAL EVENTS OBSERVED, WHILE "# GROUPS" SPECIFIES HOW MANY GROUPS WERE OBSERVED ENGAGED IN MOST BEHAVIORS.

		Normal		Air Gun Array Runs						Stimulus Playback		Single Air Gun		
		Normal	Bubble Cove	A	B	C	D	E	F	Drillship	Orca	10 Fathom	Line E	Anchored
Whale-Hours		246.5	13.8	12.7	21.2	13.7	3.3	15.7	7.5	16.7	4.1	2.3	2.1	8.2
Total Groups		127	7	7	9	9	3	10	4	7	1	1	1	4
Breaches	Total	93	0	0	20	0	0	1	0	0	1	0	0	0
	# Groups	10	-	-	1	-	-	1	-	-	1	-	-	-
Vertical Flukes	Total	34	104	0	0	0	0	8	0	2	1	0	0	3
	# Groups	15	7	-	-	-	-	2	-	1	1	-	-	1
Fluke Out	Total	38	-	0	0	2	4	3	1	0	0	0	0	1
	# Groups	22	-	-	-	1	1	1	1	-	-	-	-	1
Underwater Blows	Total	6	99	0	0	0	0	2	7	0	0	1	0	2
	# Groups	4	7	-	-	-	-	1	1	-	-	1	-	1
Head Up	Total	21	81	0	0	0	1	3	0	0	0	0	0	3
	# Groups	11	7	-	-	-	1	1	-	-	-	-	-	2
Rolling	Total	10	8	0	0	0	0	0	0	0	0	0	0	0
	# Groups	8	7	-	-	-	-	-	-	-	-	-	-	-
Spyhop	Total	12	4	0	0	0	0	2	0	0	0	0	0	0
	# Groups	7	7	-	-	-	-	2	-	-	-	-	-	-
South		9	-	0	0	1	0	9	3	0	1	1	0	4
East		18	-	0	0	1	2	4	5	1	1	1	0	2
Milling		7	7	0	0	0	0	10	2	0	1	0	0	3
Splitting		8	1	0	1	0	0	3	4	0	0	0	0	1
Joining		14	1	0	0	1	0	7	2	0	0	0	0	2

TABLE 7.12. BLOW RATES (BLOWS/HR), BLOW INTERVALS (s), MILLING INDICES, AND SPEED INDICES FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO A VARIETY OF SOUND SOURCES AS EXPRESSED IN RECEIVED SIGNAL LEVEL (L_R) OR IN SIGNAL TO NOISE (S/N) RATIO.

		Air Gun Array Received Level L_R (dB)				Stimulus Playback S/N Level (dB)					Single Air Gun Received Level L_R (dB)			
						Drillship			*Orcinus orca*		Line E		10 Fathom	Anchored
		Normal	<140	140-160	<160	<0	0-10	>10	<0	>0	140-160	>160	>160	>160
Blow Rates (Blows/hr)	Mother													
	$\bar{x}$	24.8	22.2	32.9	33.0	19.0	19.7	21.6	26.3	24.6	29.1	60.0	28.1	34.5
	Sd	13.8	7.8	8.1	12.2	8.0	5.7	8.8	–	–	–	–	–	13.8
	n	64	25	7	9	10	7	6	1	1	1	1	1	1 4
	Calf													
	$\bar{x}$	21.4	15.7	30.2	32.0	16.5	15.8	23.0	46.8	24.6	28.1	60.0	28.1	38.1
	Sd	13.8	11.3	13.9	13.0	4.9	6.0	7.6	–	–	–	–	–	14.2
	n	64	24	7	9	10	9	6	1	1	1	1	1	4
	Total													
	$\bar{x}$	57.8	43.9	60.5	63.5	43.5	42.2	36.4	45.9	49.2	62.8	180	67.5	75.6
	Sd	28.4	16.2	18.5	19.1	10.2	21.7	14.2	–	–	–	–	–	26.1
	n	64	25	9	9	8	3	4	1	1	1	1	1	4
Blow Intervals (s)	Mother													
	$\bar{x}$	130.0	104.4	–	–	–	–	–	136.1	126.2	–	–	82.3	81.2
	Sd	91.7	93.3	–	–	–	–	–	103.2	115.1	–	–	87.3	58.6
	n	973	128	–	–	–	–	–	19	15	–	–	8	13
	Calf													
	$\bar{x}$	98.0	82.5	–	–	–	–	–	64.5	132.0	–	–	–	104.7
	Sd	102.3	82.8	–	–	–	–	–	72.4	183.0	–	–	–	74.6
	n	462	126	–	–	–	–	–	33	7	–	–	–	11
Milling Index	$\bar{x}$	0.93	0.93	0.86	0.68	0.94	0.94	0.90	0.93	0.77	0.82	0.74	0.44	0.56
	Sd	0.05	0.08	0.07	0.28	0.07	–	0.1	–	–	–	–	–	0.09
	n	61	22	8	10	7	1	3	1	1	1	1	1	3
Speed Index (km/hr)	$\bar{x}$	5.2	5.4	4.6	3.0	5.0	4.6	4.3	4.3	1.9	6.7	1.9	2.9	3.3
	Sd	1.1	1.1	1.4	2.2	0.9	–	0.4	–	–	–	–	–	0.1
	n	61	22	8	10	7	1	3	1	1	1	1	1	3

TABLE 7.13. BEHAVIORS FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO A VARIETY OF SOUND SOURCES. AS EXPRESSED IN RECEIVED SIGNAL LEVEL (L_R) OR IN SIGNAL TO NOISE (S/N) RATIO.

			Air Gun Array Received Level L_R (dB)			Stimulus Playback S/N Level (dB)					Single Air Gun Received Level L_R (dB)			
						Drillship			Orcinus orca		Line E		10 Fathom	Anchored
		Normal	<140	140-160	<160	<0	0-10	>10	<0	>0	140-160	>160	>160	>160
Whale-Hours		246.5	47.6	10.6	7.1	9.4	28.6	2.53	2.8	1.3	2.1	0.1	2.1	8.2
Total Groups		127	25	10	7	7	6	6	1	1	1	1	1	4
Breaches	Total	93	20	0	1	0	0	0	1	0	0	0	0	0
	# Groups	10	1		1				1					
Vertical Flukes	Total	34	0	5	3	0	0	0	1	0	0	0	0	3
	# Groups	15		2	2				1					1
Fluke Out	Total	38	2	4	4	0	0	0	0	0	0	0	0	1
	# Groups	22	1	1	2									1
Underwater Blows	Total	6	0	7	2	0	0	0	0	0	0	0	0	2
	# Groups	4		1	1									1
Head Up	Total	21	0	3	1	0	0	0	0	0	0	0	0	3
	# Groups	11		2	1									2
Rolling	Total	10	0	0	0	0	0	0	0	0	0	0	0	0
	# Groups	8												
Spyhop	Total	12	0	1	1	0	0	0	0	0	0	0	0	0
	# Groups	7		1	1									
South		9	1	4	8	0	0	0	1	0	0	0	0	4
East		18	1	2	9	2	0	0	0	1	0	0	0	3
Milling		7	0	2	10	0	0	0	0	1	0	0	0	3
Splitting		8	1	3	4	0	0	0	0	0	0	0	0	1
Joining		14	1	7	2	0	0	0	0	0	0	0	0	2

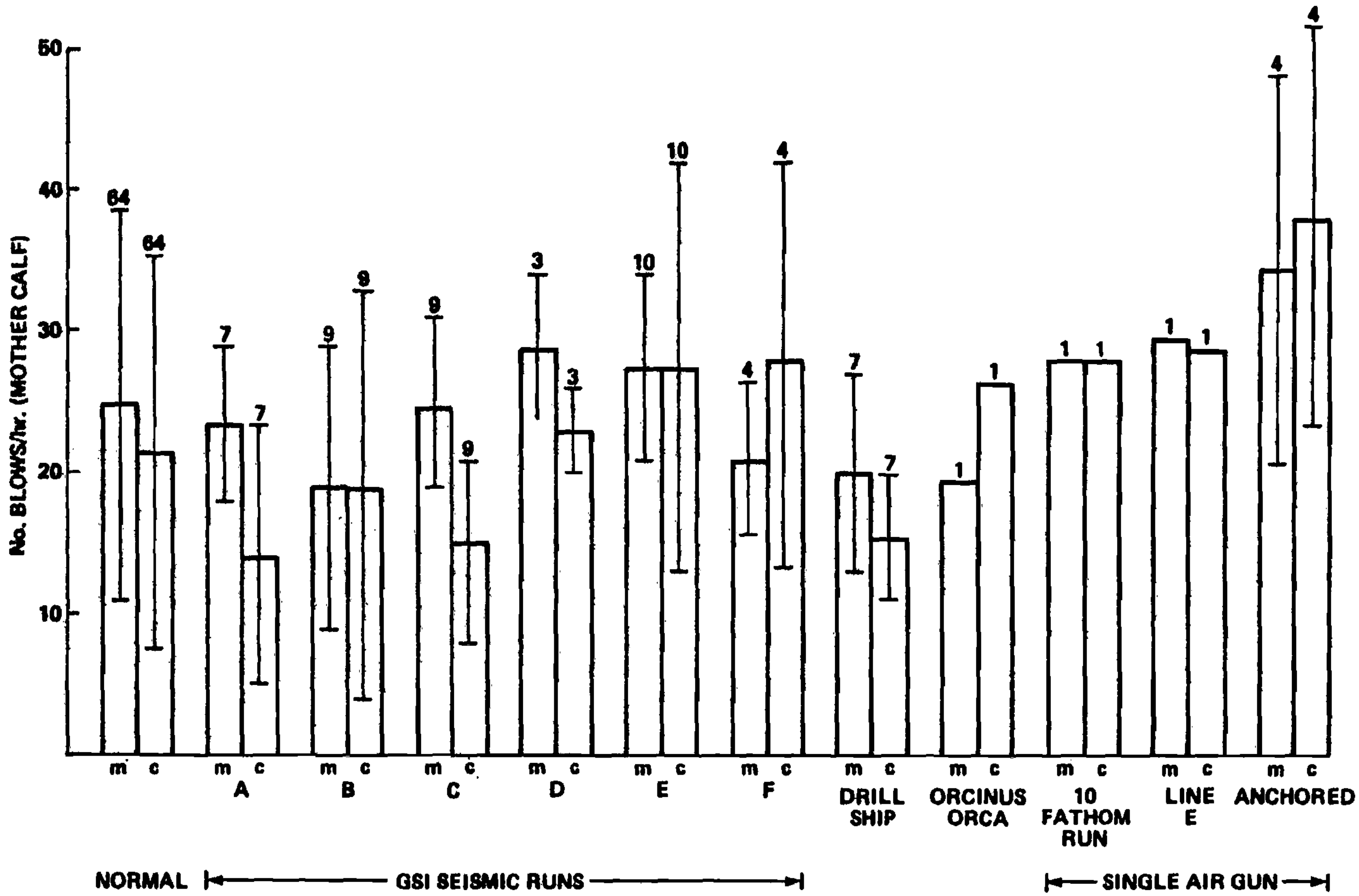


FIG. 7.2. THE MEAN BLOW RATES FOR MOTHER/CALF PAIRS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO VARIOUS SOUND SOURCES. (VERTICAL LINE IN EACH COLUMN = 1 STANDARD DEVIATION AND NUMBER IS THE SAMPLE SIZE): APRIL/MAY.

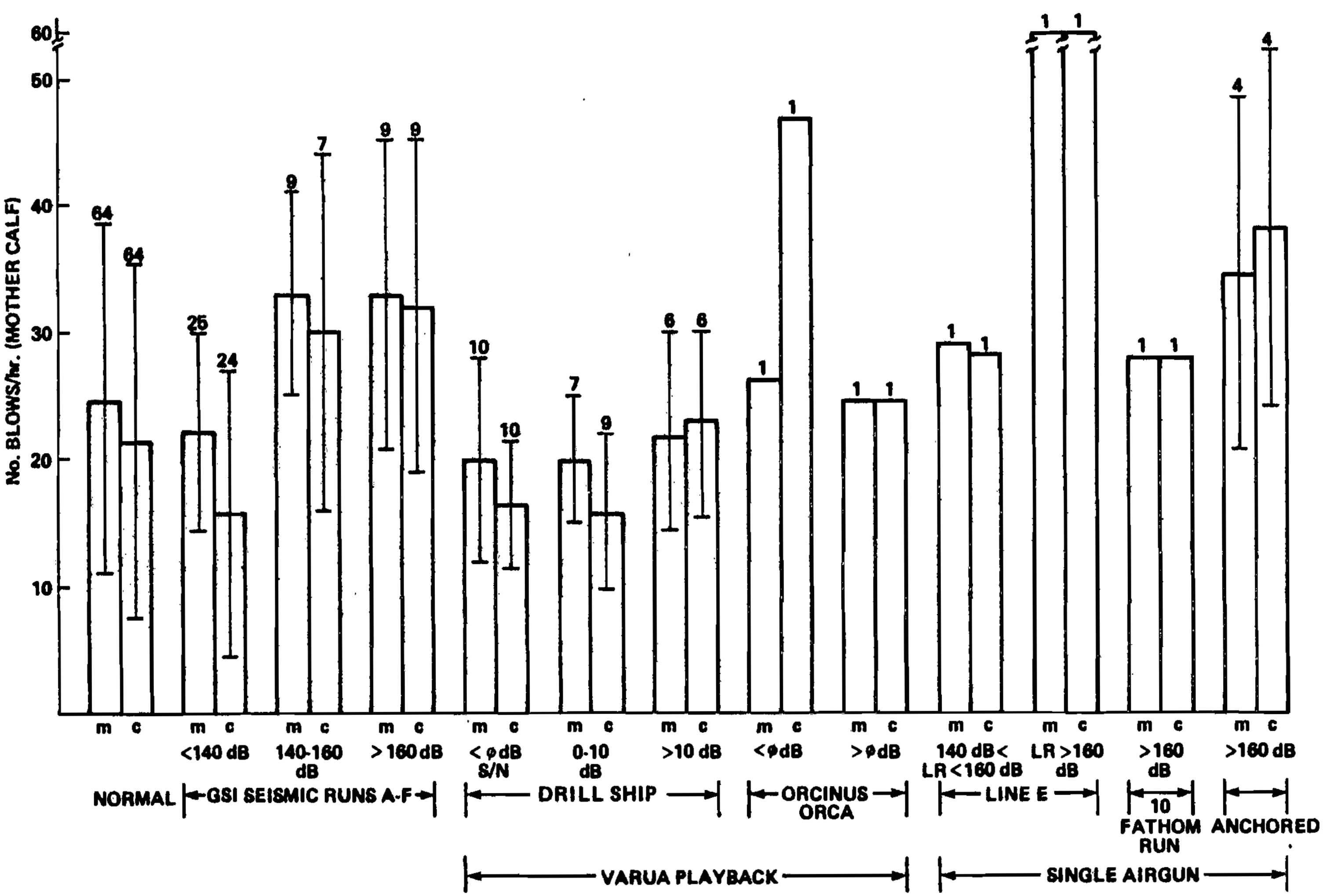


FIG. 7.3. THE MEAN BLOW RATE FOR MOTHER AND CALVES UNDER NORMAL CONDITIONS AND THOSE EXPOSED TO VARIOUS SOUND SOURCES (SOURCES DIVIDED ACCORDING TO RECEIVED LEVEL AND S/N RATIO): APRIL/MAY.

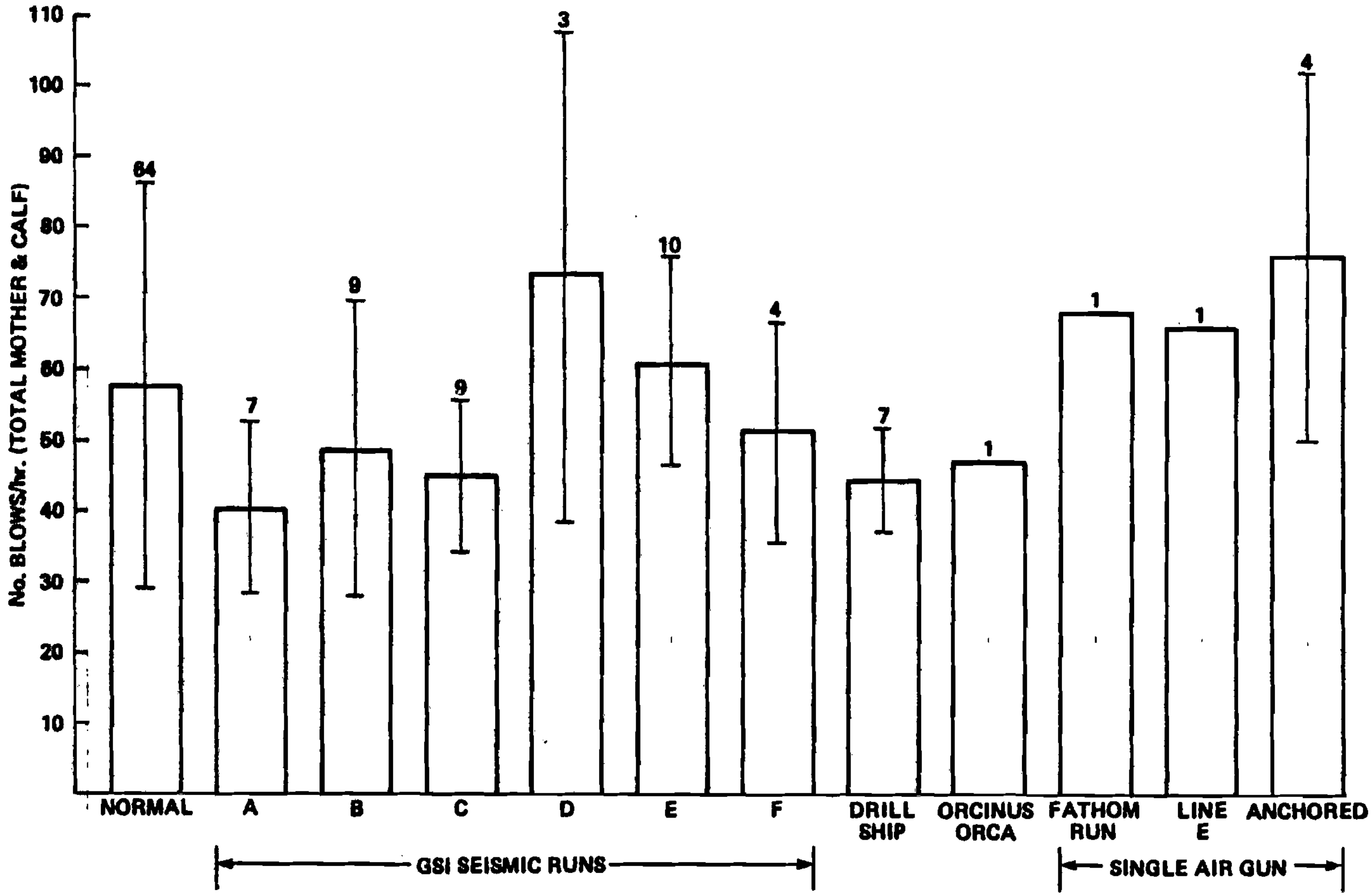


FIG. 7.4. MEAN BLOW RATES FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO VARIOUS SOUND SOURCES. (RATES COMPUTED BY DIVIDING ALL BLOWS SEEN FROM MOTHER/CALF PAIR BY THE TOTAL OBSERVATION TIME ON THAT PAIR): APRIL/MAY.

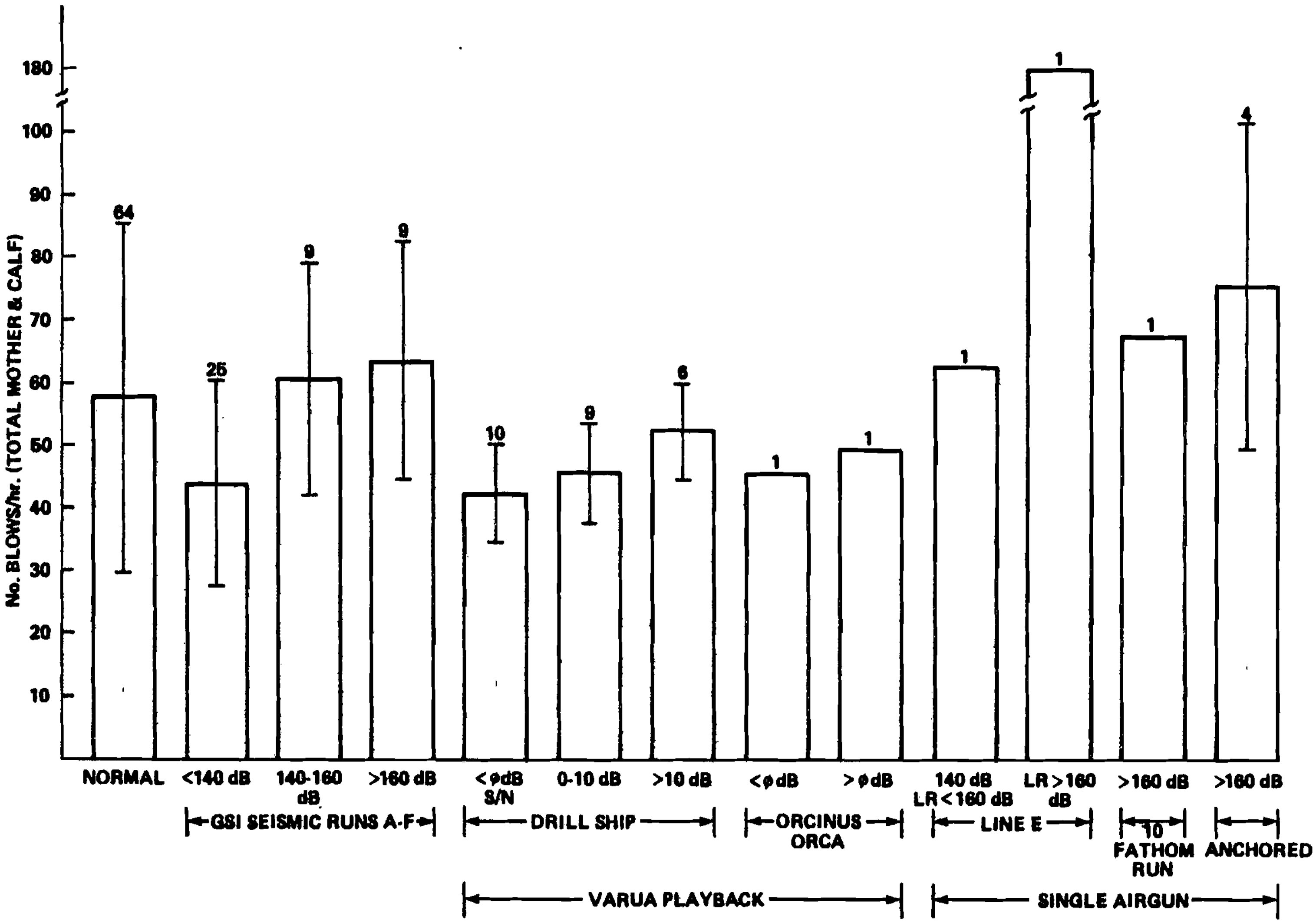


FIG. 7.5. THE MEAN BLOW RATE FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO VARIOUS SOUND SOURCES: APRIL/MAY. (SOURCES DIVIDED ACCORDING TO RECEIVED LEVEL AND S/N RATIO.)

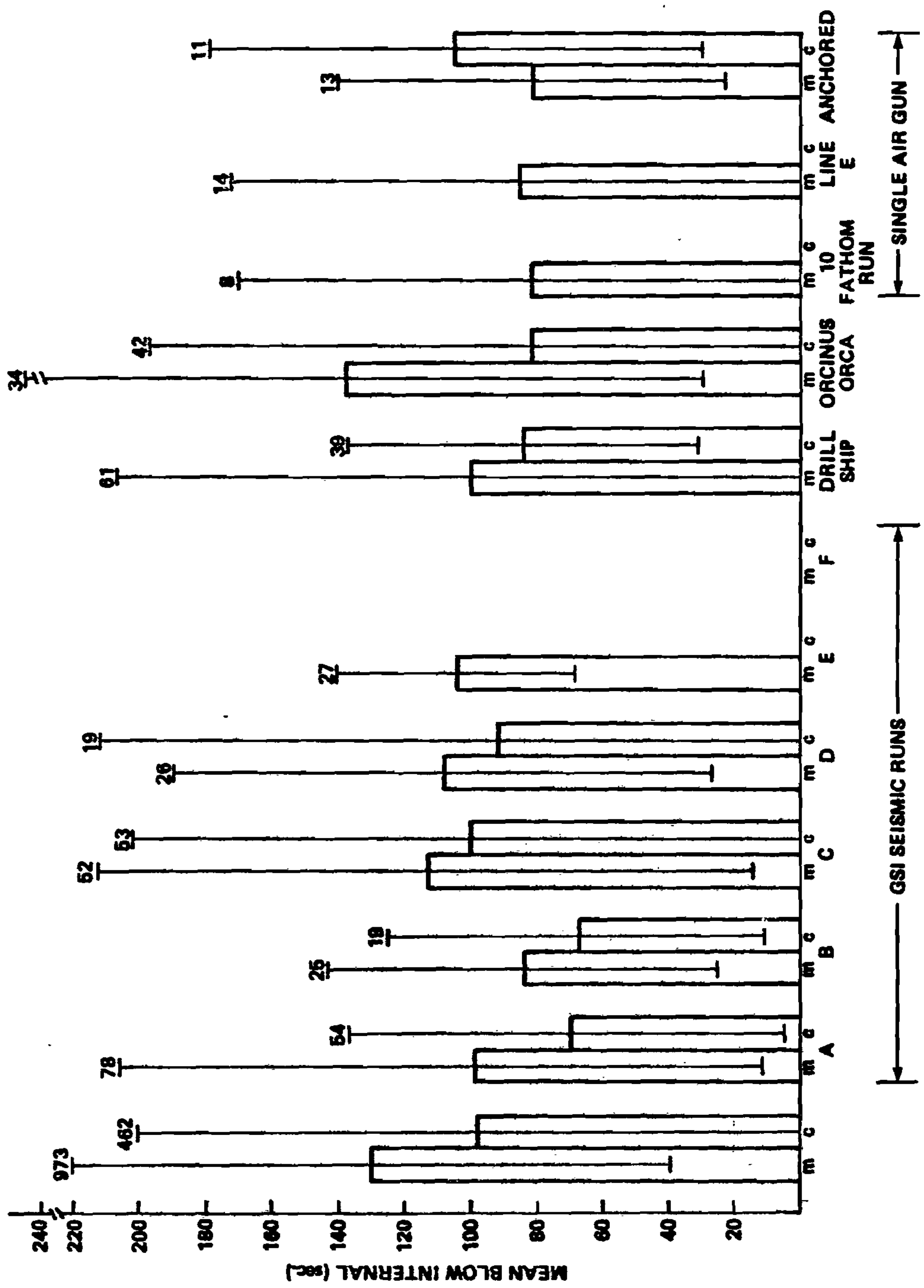


FIG. 7.6. MEAN BLOW INTERVALS FOR MOTHERS AND CALVES UNDER NORMAL CONDITIONS AND EXPOSED TO VARIOUS SOUND SOURCES: APRIL/MAY.

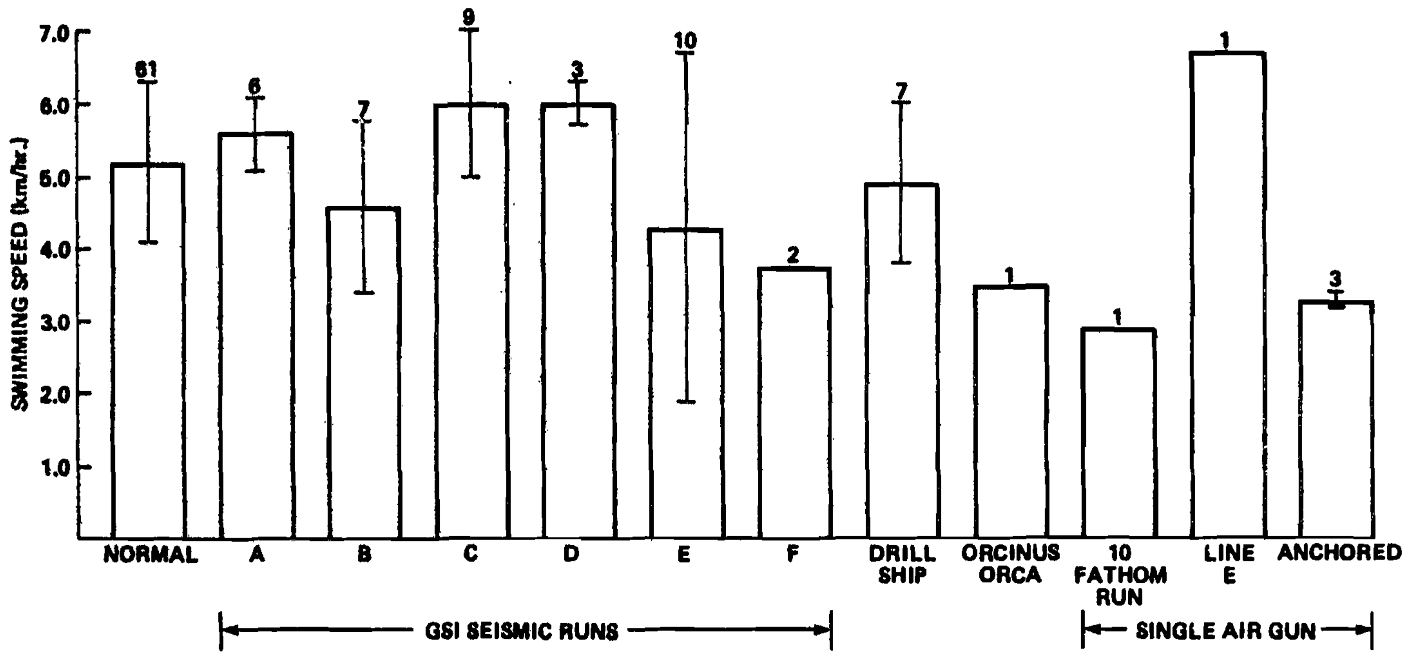


FIG. 7.7. THE MEAN SWIMMING SPEED FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO VARIOUS SOUND SOURCES: APRIL/MAY.

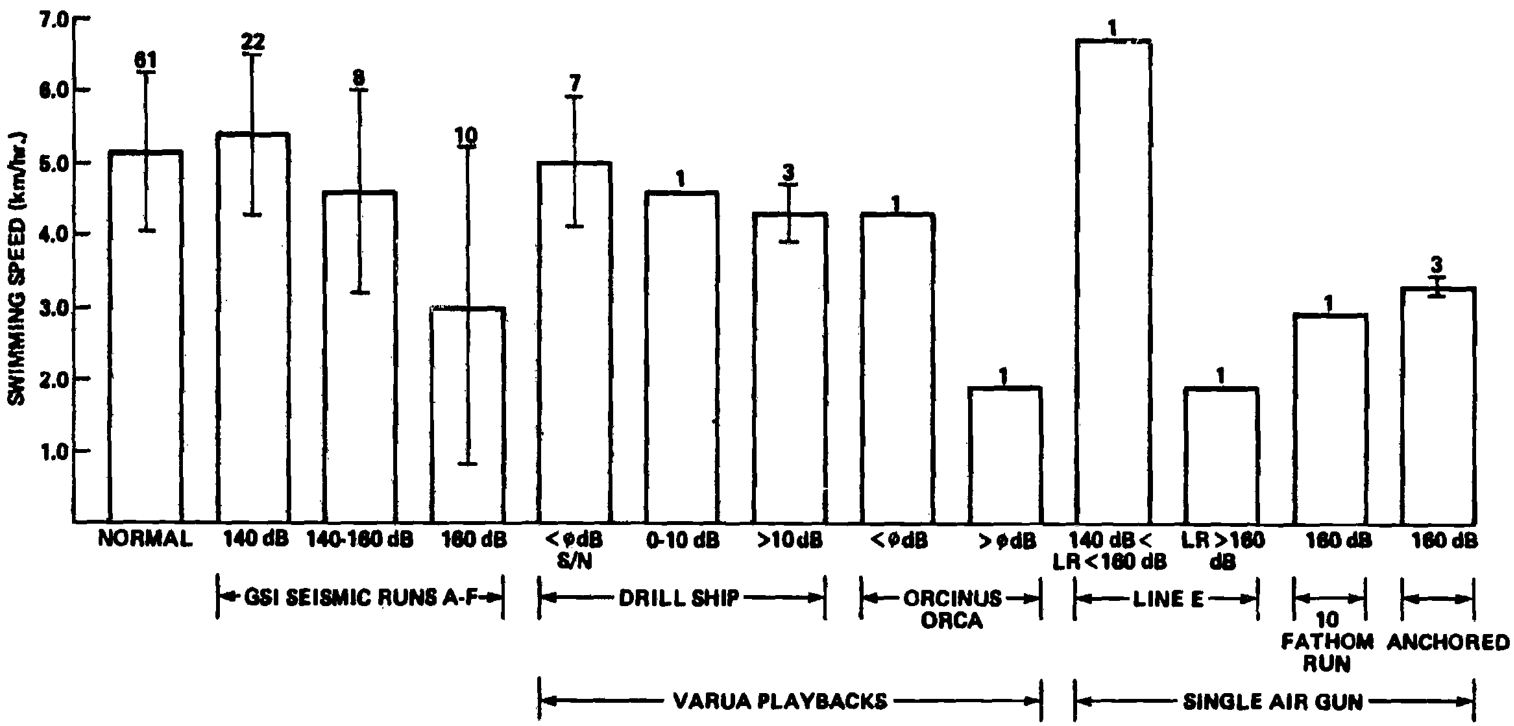


FIG. 7.8. THE MEAN SWIMMING SPEED FOR GROUPS UNDER NORMAL CONDITIONS AND GROUPS EXPOSED TO VARIOUS SOUND SOURCES (SORTED BY RECEIVED LEVEL AND S/N RATIO): APRIL/MAY.

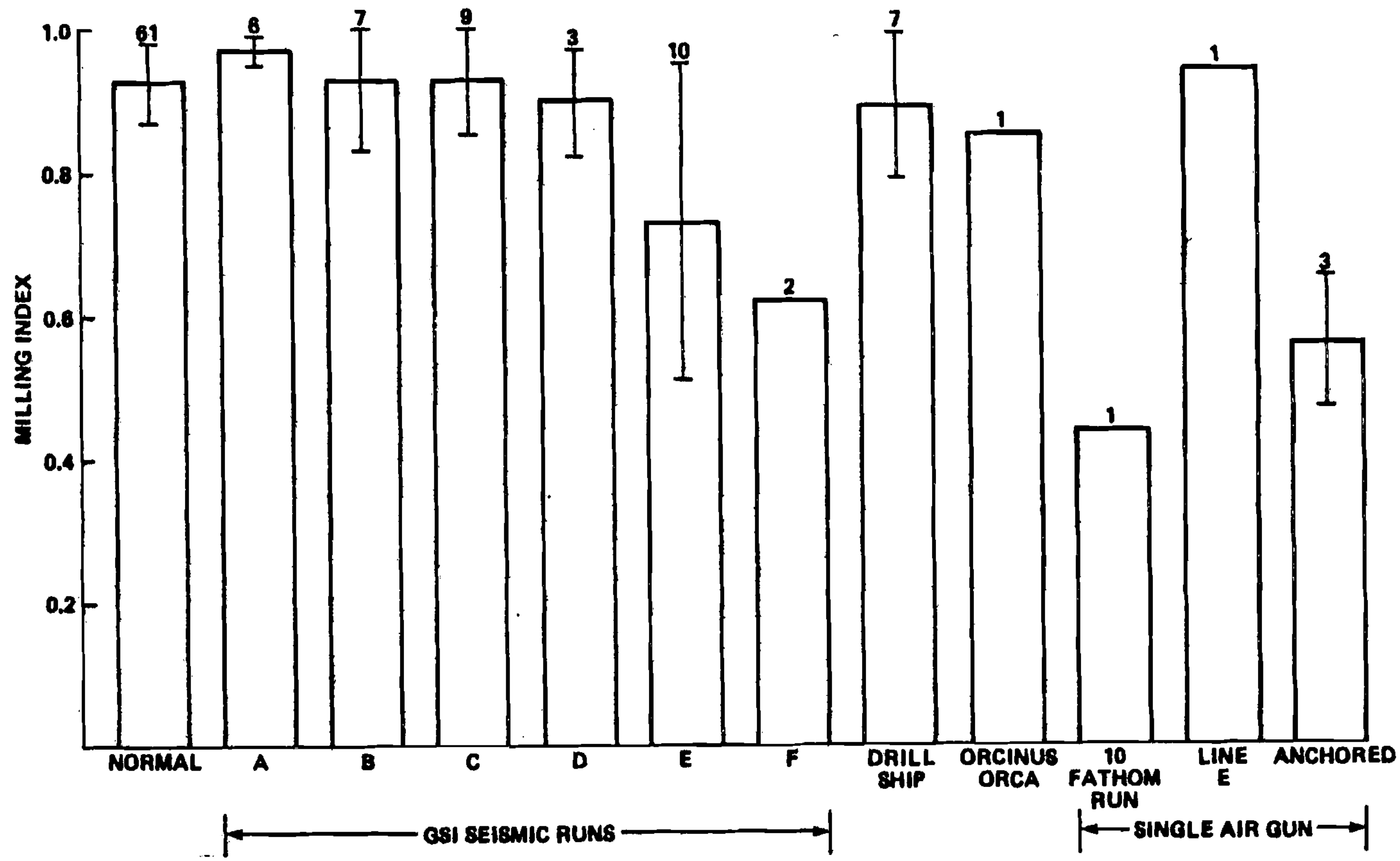


FIG. 7.9. MEAN MILLING INDEX FOR GROUPS UNDER NORMAL CONDITIONS AND EXPOSED TO VARIOUS SOUND SOURCES: APRIL/MAY.

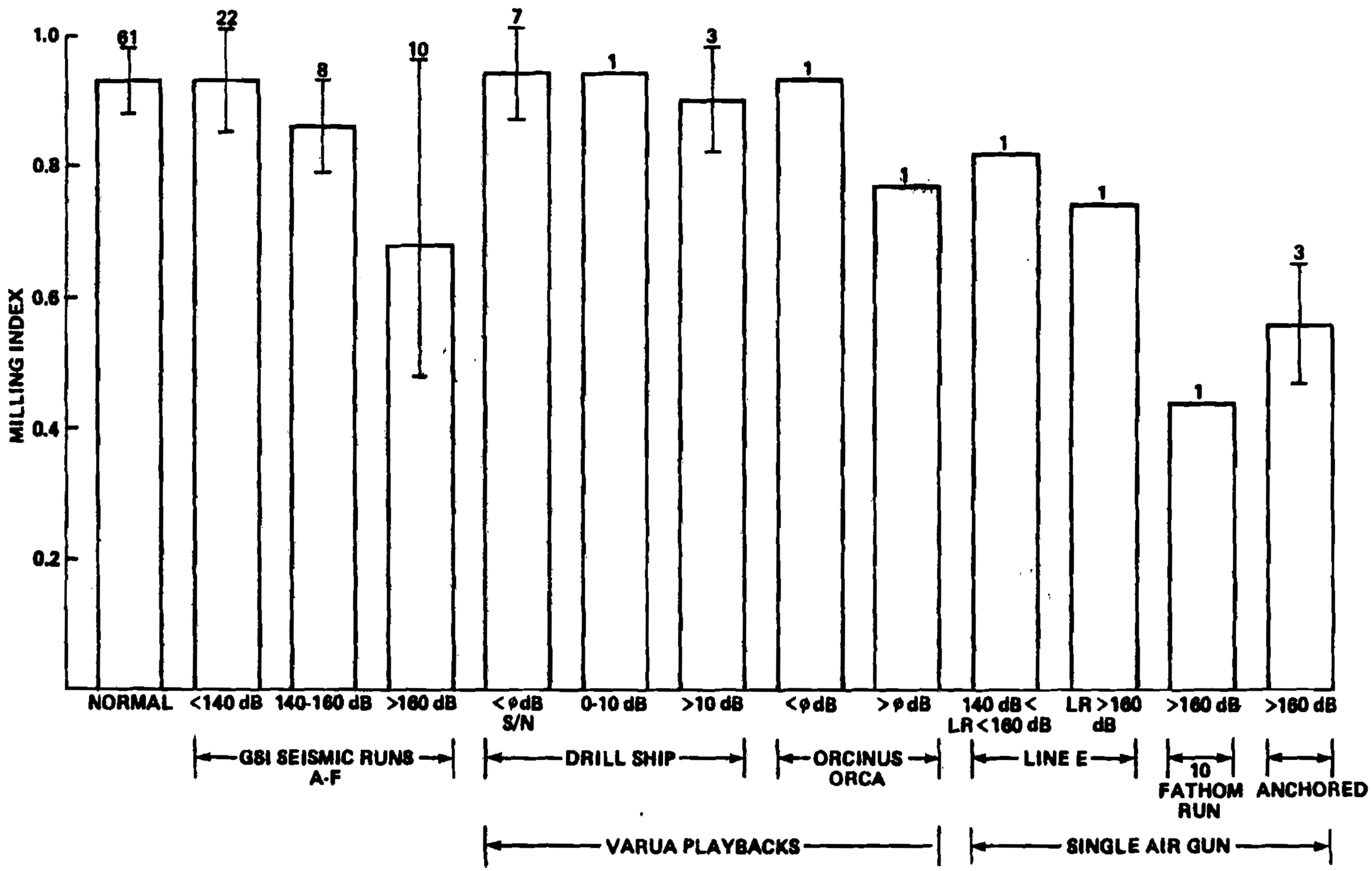


FIG. 7.10. MEAN MILLING INDEX FOR GROUPS UNDER NORMAL CONDITIONS EXPOSED TO VARIOUS SOUND SOURCES (SORTED BY RECEIVED LEVEL AND S/N RATIO): APRIL/MAY.

comparisons were performed using blow rates, milling indices, and speed indices.

The Kolmogorov-Smirnov test was used to test the significance of differences in the distributions of blow intervals recorded under potentially disturbed and undisturbed conditions. The G-test was used to test the goodness of fit of the behavioral scores under potentially disturbed and undisturbed conditions. An analysis of calf position relative to the mother in mother-calf pairs was performed using Chi-square testing.

7.4.1 Results of testing blow rate

There were no significant differences between blow rates recorded during any of the experimental conditions and normal conditions (NWU test). There were also no significant differences in blow rates recorded for groups observed prior to and during any of the experiments (WSR test). However, pairwise comparisons of blow rates during and after potentially disturbed conditions revealed significant decreases in blow rates in the post experimental condition. This result was true for mother blow rates (WSR $p < 0.01$, $n = 16$), calf blow rates (WSR $p < 0.01$, $n = 16$), and total blow rates (WSR $p < 0.01$, $n = 17$). Mother blow rates dropped from a mean of 29.7 blows/hr (Sd = 9.6) during the experiment to a mean of 16.8 blows/hr (Sd = 11.0) after the experiment. Calf blow rates dropped from a mean of 29.6 blows/hr (Sd = 14.1) during the experiments to a mean of 16.0 blows/hr (Sd = 10.3) after the experiment. Total blow rates dropped from a mean of 59.6 blows/hr (Sd = 22.5) during the experiment to a mean of 37.9 blows/hr (Sd = 21.1) after the experiment. These results are difficult to explain. The drop in blow rates for the post-experimental condition could be partially explained by the fact that four of the 16 groups under observation in the post-experimental period were over 1 km north of our northern-most observation site, making their blows more difficult to see. However, even if these four groups are not considered, blow rates drop significantly during the post experimental condition (see Appendix F for error analysis of respiration data).

7.4.2 Results of testing blow interval data

Results of the Kolmogorov-Smirnov test comparing blow interval data for normal and potentially disturbed conditions revealed no significant differences for the northward migration of mother/calf pairs.

7.4.3 Results of testing, milling index, and speed data

A significant difference was found in both the milling index (MWU $p < 0.01$, $t_s = 2.72$) between groups observed during the anchored air gun experiment and the normal condition. During the anchored air gun experiment, mothers and calves would always move south away from the source, before turning north and swimming inshore of it. It is important to note that in each of these three cases, the air gun was turned on when the whales were within 1 km and, therefore, were immediately exposed to a level > 160 dB. This dramatic response could therefore be considered a startle response.

Milling indices for groups observed prior to an experiment ($n = 13$, $\bar{\chi} = 0.94$, Sd = 0.05) were significantly higher (WSR $p < 0.05$) than milling indices for these same groups during an experiment ($\bar{\chi} = 0.80$, Sd = 0.16). Milling indices for groups observed after an experiment ($n = 9$, $\bar{\chi} = 0.93$, Sd = 0.10) were significantly higher (WSR $p < 0.01$) than milling indices for these same groups during an experiment ($\bar{\chi} = 0.70$, Sd = 0.19).

Speed indices for groups observed prior to an experiment ($n = 14$, $\bar{\chi} = 5.4$, Sd = 1.3) were significantly higher (WSR $p < 0.01$) than speed indices for these same groups during an experiment ($\bar{\chi}$ = 4.6, Sd = 1.4). Speed indices for groups observed after an experiment (n = 8, $\bar{\chi}$ = 5.8, Sd = 1.1) were significantly higher (WSR $p < 0.01$) than speed indices for these same groups during an experiment ($\bar{\chi}$ = 3.4, Sd = 1.2).

These results indicate that mothers and calves would slow their northward progress during potentially disturbed conditions by approximately 25%.

7.4.4 Results of the G-test

Surface Active Behaviors and Underwater Blows - Control vs Experimental

Because of the low number of surface active behaviors and underwater blows observed during experimental conditions, it is difficult to determine whether the behaviors resulted from the increased sound levels or whether they would have occurred normally. We need more observation time of whales under experimental conditions to determine, statistically, if the differences we observed were significant.

Whale Orientation and Milling

In the air gun array experiments, the whale groups exposed to received sound levels of > 160 dB from the air gun array almost invariably were seen to orient south, move east toward shore, and mill for varying lengths of time. Using the G-statistic (with Yates' correction) to compare the number of groups exposed to received sound levels > 160 dB and exhibiting these orientation changes with the control group data, we find the following:

1) Whale groups oriented themselves toward the south significantly more often under experimental conditions than under control conditions (G_{adj} = 23.964, df = 1, $p << 0.001$).

2) Whale groups moved east (away from the sound source) significantly more often under experimental conditions than under control conditions (G_{adj} = 22.096, df = 1, $p << 0.001$).

3) All of the groups (10 out of 10) observed during experimental conditions were seen to mill for varying lengths of time. During control conditions, 7 out of 127 groups were observed milling.

4) The percentage of groups oriented south, moving east, and milling decreased when the whales were exposed to lower received levels (140 to 160 dB).

The number of groups observed during the anchored air gun experiments was low (4). During these two experiments, the received sound levels were > 160 dB for all groups. All groups were observed oriented south, two of the four groups headed inshore (east) and three of the four were observed milling.

Under other experimental conditions, our sample size was too small to compare the number of groups oriented south, moving inshore, and milling under control and experimental conditions. It is of interest to note that the one whale group exposed to Orcinus orca playback turned toward shore and was observed milling when the S/N level was about 0 dB.

Splitting and Joining

In the air gun array experiments, groups of whales exposed to received sound levels of > 160 dB split significantly more often when compared to groups under control conditions (G_{adj} = 6.022, df = 1, $0.01 < p < 0.025$). The rate of group splitting when exposed to sound levels of 140 to 160 dB was practically the same for groups exposed to sound levels of 140 to 160 dB. Thus, the threshold received level for eliciting this response appears to be < 140 dB.

In the anchored single air gun and other experiments, we were not able to make meaningful comparisons between the splitting and joining rates under control and experimental conditions, because of the small numbers of groups observed.

7.4.5 Chi-square analysis

The chi-square test was used to determine if, under control and experimental conditions, there was a change in the position of the calf relative to the mother (either offshore or inshore) or if there was an observed change in the calf's position.

During undisturbed periods, calves were seen inshore of their mothers 306 times and offshore 136 times (n = 71 groups). Calves were observed to maintain their positions relative to their mothers on two consecutive surfacings on 108 occasions. They were observed to change positions, either offshore to inshore or inshore to offshore, 23 times (n = 32 groups). Because our numbers were very low for the single air gun experiments and the killer whale playback, we could compare undisturbed conditions only with the air gun array and Drill Ship playbacks.

Air Gun Array Experiments

During all air gun array runs, 22 calves were observed offshore of their mothers and 55 were observed inshore. There was no significant difference when compared to undisturbed periods ($\chi^2 = 0.1441$, $0.5 < p < 0.975$, n = 19 groups). Our sample size of calves that changed position during the air gun array runs was too low for statistical comparison. We did, however, observe a change in the position of calves on four occasions out of the 17 observations (n = 10 groups).

When we consider only air gun array runs D through F (3 nm - 0.5 nm), we observed 13 calves offshore and 32 inshore of their mothers. There was no significant difference when compared to undisturbed periods ($\chi^2 = 0.0737$, $0.5 < p < 0.975$), n = 10 groups). We did observe a change in mother/calf relative position on 3 occasions out of a total of 13 observations (n = 6 groups); this number of observations was too low for statistical comparison.

Drill Ship Playback

During the two Drill Ship playbacks on 29 April, we observed calves offshore of their mothers 14 times and inshore 31 times. There was no significant difference when compared to the undisturbed period ($\chi^2 = 0.4426$, $0.5 < p < 0.975$, n = 6 groups). Calves were seen to change position 5 times and to maintain their positions on two consecutive surfacings 16 times. Again, we found no significant difference when compared to the control period ($\chi^2 = 0.4426$, $0.5 < p < 0.975$, n = 4 groups).

7.5 "Bubble Cove" Behavior

When we examine the various behaviors presented in Tables 7.11 and 7.13, we see a wide discrepancy in the numbers of behaviors observed during control, "Bubble Cove," and experimental conditions. The number of vertical flukes, underwater blows, head-ups, spyhops, rolling, and group milling in the "Bubble Cove" area is extremely high, considering the small number of whale hours, when compared to control and experimental conditions.

We can see from Table 7.11 that all seven groups of whales in "Bubble Cove" were milling during these behavioral displays. (See a description of "Bubble Cove" activity in Sec. 4.1.) All whale groups exposed to > 160 dB received levels during the GSI air gun array runs and 3 of the 4 whales exposed to > 160 dB during the anchored single air gun experiment were also seen milling during the course of the experiments. However, "Bubble Cove" whales exhibited many more of the behaviors noted above. It was our impression that the whales in "Bubble Cove" were interacting with one another, because of the frequent body contact seen and because, during the longest behavioral observation in the area (26 April), we often observed synchrony in the surface active behaviors and underwater blows. As many as 3 adults were also observed in "Bubble Cove" oriented toward shore with waves breaking over them.

The milling behavior typically seen in other areas during experimental conditions was very different from that observed in "Bubble Cove." In other areas, very few surface active behaviors were associated with milling. When several groups were milling in the same areas, they did not appear to be interacting in any way. Instead, observers had the impression that the whales were disoriented and confused during experimental conditions (> 160 dB received levels). In contrast, our impression of "Bubble Cove" activity was that milling and associated behavior were site-specific and social and were not related to experimental tests. Indeed, as we stated in Sec. 4.1, Poole has observed similar behavior at his study site.

7.6 Discussion of April/May Findings

Although few of the results of statistical testing were significant, the trends are clear. Swimming speed and milling indices become more variable and decrease on the average during experimental conditions. Much of this variability can be explained by the variability in the movements of the air gun array vessel relative to the whales.

Specifically, of the ten groups that were exposed to $L_R >$ 160 dB during the air gun array runs, four were being overtaken from behind by the boat during the entire observation period; five were overtaken from behind and were passed by the boat, and one was approached and passed. None of the four that were being chased turned south, milled or moved inshore (milling index, $\bar{\chi} = 0.84$, Sd = 0.14; speed index, $\bar{\chi} = 4.9$, Sd = 2.1). All five of the groups that were overtaken from behind and were passed turned south and/or moved inshore within five min. after the vessel passed its CPA, then continued to mill and behave in a disoriented and confused manner (milling index, $\bar{\chi} = 0.54$, Sd = 0.34; speed index, $\bar{\chi} = 1.7$, Sd = 1.1). The one group that was approached head on and eventually passed turned south away from the boat when it was within one minute of its CPA. Again, this group milled and moved in close to shore (milling index = 0.75; speed index 1.8). These responses are probably related to the high level of directivity in the horizontal plane of the air gun array. As the array passed a group broadside, the group would experience a sudden increase in sound level on the order of 20 dB (see Fig. 5.13).

Another set of interesting observations was made during the 1.0 nm and 0.5 nm air gun array tests; on four occasions whales were observed moving into the surf zone and within the sound shadow of a nearshore rock or outcropping. In fact, on all four of these occasions, the groups were so far inshore that we could no longer reliably record their blows or obtain theodolite positions.

The distances between the air gun array vessel and a group when it showed a response that was obvious to observers were consistently on the order of 2 km. The distance at which these groups resumed normal migration ranged between 3.6 km and 4.5 km.

The results from the Drill Ship playback experiments are inconclusive. Milling and speed indices tend to decrease as S/N increases, a trend similar to the results for the air gun array tests.

Results from the anchored single air gun and 10 fathom single air gun tests are dramatic. In each of these experiments, a single group experienced the onset of air gun activity at an impulse level > 160 dB. In each case, the group immediately turned south and swam away from the source (see April/May track plots, Appendix C). Blow rates tended to increase during the single air gun exposures.

Results from the killer whale playback do not directly affect conclusions concerning industrial noise effects but do have implications concerning detection of a potentially dangerous signal. During the one playback of killer whale sounds, a single mother/calf pair was following the normal migratory path along the coast. When they came to within 900 m of the playback sound source, they slowed down almost immediately from a speed of 4.5 km/hr to 1.8 km/hr. At this range, the maximum one-third octave band (1 kHz) was at 0 dB S/N. Similar results for the January killer whale playbacks indicate that gray whales can detect killer whale sounds at the 0 dB S/N level. This response can serve as a point of comparison for detection level in future playback work using man-made noises. Since killer whales are a known predator on gray whales, there is certainly a selective advantage to having an auditory system with a low detection threshold for such signals. The expected detectability levels for man-made noises would therefore be no better than and probably higher than the level for killer whale sounds.

8. ACOUSTIC SCALING RELATIONSHIPS

8.1 Scaling Relationships Between Playback and Actual Sources

As shown previously in Table 3.1, a 1:1 relationship between the original industrial noise source and the playback sound level was not maintained. Thus, it is necessary to provide a means of scaling the results obtained from this study to predict the effects of the original or similar noise sources. This can be done by means of measured TL and S/N values.

Observed whale reactions which are determined to be relatable to absolute sound energy level can be scaled in distance by applying measured TL values at the site in question to estimated (or measured) source level values. Reactions which are the result of detection of a threatening or annoying sound in the presence of ambient noise can be scaled in terms of effective S/N ratio. Because of the variability of ambient noise levels and sound propagation conditions in shallow water regions where most oil and gas industry operations are located, on-site ambient noise and TL measurements should be made before scaling of the results of this study is attempted.

Of the five industrial noise stimuli used in this study, all produced behavior changes which were determined by data analysis. None produced behavior events which were recognized by the observers in the field - such as occurred for the orca playbacks. The stimuli and the analyzed behavior changes are:

Stimulus	Behavior
Drilling Platform	Change heading and slow down at 2 to 3 km, avoidance of source at 250 m
Drillship	Slow down at 1 to 2 km
Semisubmersible	Slow down at 1 to 2 km
Helicopter	Deflection of course at 2 km, avoidance of source at 250 m
Production Platform	Deflection of course at 0.5 km.

The two sounds producing the strongest reaction, drilling platform and helicopter, also had the greatest variation in amplitude-time characteristics. The Helicopter stimulus simulated flyby of a helicopter at random intervals from 10 sec to 2 min with a quiet (except for residual tape noise) interlude in between. The Drilling Platform stimulus contained sporadic impact sounds from pipe handling and sounds from a motor cycling on and off. They were potentially more annoying than the other stimuli which had considerably less variation in level and sound quality.

At this point, it is necessary to estimate what the range to the observed behavior changes would be for the original sound source. Since the TL characteristics and ambient noise conditions for the original source are not available (except for the drillship), we have assumed that the original sources are relocated to the test site. The TL relationship previously shown in Fig. 5.22 is used with the assumption that the source is at the VARUA position for the January field period. With these assumptions, Table 8.1 was developed which shows the relationship of the various response distances to the existing estimated sound level at the whales and the estimated S/N ratios. The estimated S/N ratios for both the effective signal bandwidth and the

TABLE 8.1. SCALING OF PLAYBACK RANGES TO ORIGINAL SOURCE RANGES FOR OBSERVED BEHAVIORS.

Stimulus	Behavior Range km	TL dB	Effective Bandwidth L_R dB//1µPa	Effective Bandwidth L_N dB//1µPa	Effective Bandwidth S/N dB	Max. 1/3 O.B. S/N dB	Playback Level (Table 3.1) ΔdB	Avail. TL dB	Orig. Source Range m
Drilling Platform	2.5	65	93	99	-6	-1		34	120
	0.25	40	118	99	19	25	31	9	-
Drillship	1.5	57	102	101	1	8	-9	66	2.7 km*
Semisubmersible	1.5	57	100	96	4	10	21	36	160
Helicopter	2.0	61	93	98	-5	-1		11	
	0.25	40	114	98	11	15	50	-10	150**
Production Platform	0.5	45	111	97	14	20	10	35	140

*Greene (1982, p. 323) reports the following L_R relationship for the region in the Eastern Beaufort Sea where the original drillship data were recorded

$$L_R = 122.9 - 1.52\,R - 10\log(R)\ \text{dB//1µPa} .$$

This relationship predicts that a received level of 102 dB will be obtained in the Beaufort Sea at a range of 7.8 km. The ambient noise level for this area was not reported, so a corresponding S/N estimate is not available.

**This value is the original altitude of the helicopter. The levels produced by the underwater projector at 100 m are comparable to the levels produced directly under the helicopter. Thus, direct overflight could be expected to produce the behavior observed. The horizontal transmission for the actual helicopter has a much higher TL than that of the underwater projector.

maximum 1/3 octave band are given. Examination of Table 8.1 discloses the following interesting relationships:

- The initial reaction to sound from the Drilling Platform and the Helicopter occurred at the most sensitive detection level of around 0 dB S/N for the highest 1/3 octave band level in the stimulus.
- The initial reaction to sound from the Drill Ship and Semisubmersible occurred at the detection level of 1 to 4 dB S/N for the total effective bandwidth of the signals.
- Avoidance behavior for the Drilling Platform, Helicopter, and possibly for the Production Platform occurred for S/N values of 11 to 19 dB for the effective signal bandwidths. This corresponded to signal levels of 111 to 118 dB//1μPa.

After scaling the playback stimuli response ranges to estimate the corresponding behavior ranges for the original sound sources, we can see that the Drill Ship remains the only source with a relatively large range of potential influence. For this source, the reaction observed was a reduction in swimming speed at detection range with no apparent avoidance reaction later.

8.2 Scaling single air gun and air gun array sources

Site-specific TL characteristics are also important in applying the results of this study to operation of air guns in other areas. In this case, absolute levels are of greater concern than S/N ratios. Figure 5.3 showed that for the array and air gun measured in this study, the average pulse pressures followed different propagation characteristics; hence, simulation of the array pulse pressure using a single air gun requires different range scaling factors for low pulse pressures than it does for high pulse pressures. The effect of water depth and bottom losses is also important. The bottom reflection loss contribution to TL is very significant for air gun sound propagation in shallow water.

A scaling relationship between array and single air gun effective pulse pressure can be developed by setting Eq. (6) and Eq. (7) equal to each other if range scaling is required or, if pressure scaling is required, Eq. (6) can be used to estimate the received pressure level from the array operating at a selected range and water depth. The required range for the single air gun to achieve the same pressure, for the same or different water depths, is then determined from Eq. (7). In other test areas with different bottom characteristics, appropriate modifications must be made to the propagation model to accommodate changes in the effective loss/bounce and possibly in the spreading loss term.

An example for various assumed ranges and bottom depths is shown in Table 8.2. We can see from this table that simulation of the array pressure using a single air gun is relatively easy for lower pressures and more distant ranges. However, simulation of the array for operation of the system near shore becomes more difficult if the pressure values above 170 dB are to be obtained. In this case, the air gun vessel must be within 400 m of the test region, depending on the depth in the area. At this distance, the effect of the presence of the relatively large vessel required is a factor that must be considered in evaluation of any observed whale behavior changes.

While consideration of effective pulse pressure scaling seems most appropriate for comparing the potential effects of air gun operation on nearby gray whales, we also examined other parameters for both array and single air gun signatures. An example of this comparison is shown in Table 8.3. The parameters considered here, in addition to effective pulse pressure level, $L_{\bar{p}}$, are the peak pressure level, $L_{\hat{p}}$; the pulse duration, T; the

TABLE 8.2. EXAMPLES OF SCALING AIR GUN EFFECTIVE PULSE PRESSURE VERSUS RANGE IN SOBERANES POINT AREA (4000-cu in. AIR GUN ARRAY AT 2000 psi TO 100-cu in. AIR GUN AT 4000 psi).

	Array (beam axis)		Air Gun		
L_P dB//1 μPa	Range km	d_s m	Range km	d_s m	Receiver d_r m
113	10	44	8	44	44
140	10	176	3.1	44	44
178.5	1	33	0.13	33	11
169	2	77	0.4	33	11

TABLE. 8.3. COMPARISON OF ARRAY AND SINGLE AIR GUN ACOUSTIC PARAMETERS.

Range (km)	$L_{\bar{p}}$ dB//1µPa	$L_{\hat{p}}$ dB//1µPa	T msec	fm Hz	L_{fm} dB//1µPa²/Hz
Array (Broadside)					
1.1	183	193	50	120	158
4.2	161	171	100	100	138
13.7	145	-	-	-	-
35.7	129	143	200	110	108
90.5	118	134	400	90	99
Single Airgun					
0.14	-	179	10	40	138
1.1	157	165	65	60	134

Key: $L_{\bar{p}}$ = Average pulse pressure level

$L_{\hat{p}}$ = Peak pulse pressure level

T =Pulse duration

f_m = Maximum spectrum level frequency

L_{fm} = Maximum spectrum level.

frequency at which the maximum pressure spectrum level occurred, f_m; and maximum pressure spectrum level, L_{fm}. Note, that at the closer ranges, the peak pressure level is about 10 dB higher than the average pulse pressure. At greater ranges, the difference between these pressures becomes larger and the pulse duration increases because of multipath propagation. The dominant frequency of the array is about an octave above that of the single air gun. This is probably a result of the design of the array which is intended to direct the low frequency output energy downward rather than in the horizontal plane where our measurements were made.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions are presented regarding the use of acoustic playback and air gun sources of sound and the gray whale behavioral response to those stimuli. Behavioral results are summarized for the southbound migrating population in January 1983 and for the mother/calf pair portion of the northbound migration during late April - early May 1983. Also included is a brief discussion regarding methods for mitigating acoustic source impact.

9.1.1 Acoustic playback and air gun sources

Playback Source

The playback tests demonstrated that gray whales have hearing thresholds below that of the prevailing ambient noise levels in the observation area. They were able to detect and respond to orca vocalizations at a range corresponding to an estimated S/N ratio of 0 dB for the loudest 1/3 octave band of the orca sound. This also was demonstrated for the drilling platform and helicopter stimuli where a heading deflection was detected at the 0 dB S/N level for the maximum 1/3 octave band.

An annoyance reaction was considered to have occurred because of an apparent avoidance of the source area out to ranges of about 250 m from the drilling platform and helicopter sounds. The sound levels at this range were about 111 to 118 dB//1μPa. Other industrial noise stimuli with smaller short-term fluctuation levels but with equal or somewhat louder sound levels did not produce a detectable annoyance reaction.

Scaling the playback stimuli levels to provide a range estimate at which similar behavior may be observed for the original sources showed that the observed behavioral responses would all occur at less than 200 m from the source. The only exception to this was the Drill Ship sound where, at an estimated range of 2.7 km, a predicted decrease in swimming speed would occur. Reservations must be made concerning the range estimate in this conclusion because of the lack of information on the farfield sound propagation characteristics for the Drilling Platform, Production Platform, Semisubmersible drill rig, and Helicopter original sound fields; and because of an 11 dB shortfall in the playback capability for the Drill Ship stimulus.

Air Gun Source

Average pulse pressure levels of 160 dB and higher produced clearly observable behavior changes in migrating gray whales subjected to impulsive sounds from the air gun array or the single air gun. This level corresponded to 170 dB peak pressure level. In the test area, these levels were produced by the single air gun at 1 km and by the array at 5 km.

Small sample sizes prevented definite quantification of response for average pulse pressure levels between 140 and 160 dB, but analysis showed that some behavioral changes did occur.

Sound propagation characteristics differed for the array and the single air gun source and were highly dependent on bottom loss components for shallow water transmission paths. Thus, pressure scaling relationships between sources must consider both range and operating depths.

9.1.2 Behavioral response of the January southbound gray whale population

During the January field season, while large numbers of track records were obtained for each of the six playback conditions, the only condition for which an obvious response was recognized under the double blind study conditions was the dramatic avoidance response of whales to the playback of orca sounds. In order to assess other possible responses to industrial sounds, a track deflection program was developed.

The measures used to assess possible responses were:

- Track Deflection (D_y) - the distance inshore or offshore of the sound source (VARUA)
- Speed - Cumulative speed of the whale group for a particular interval
- Compass Bearing - The compass bearing or course of the whale group for a particular interval
- VARUA Bearing - The angle between the course of the whale group and the course it would have had to take to directly approach the sound source or VARUA.

As Table 9.1 indicates, not only were significant differences found for each playback condition relative to an undisturbed control condition, but whales responded differently to different playback conditions.

Whales exposed to Orca, Drilling Platform, Helicopter, and Production Platform stimuli showed avoidance responses in which tracks deflected away from the source of the playback stimulus. Whales exposed to Orca, Drilling Platform, Drill Ship, Semisubmersible, and Helicopter stimuli slowed down in response to playback; this response may represent a cautious pattern of movement for whales in the presence of these sound sources.

TABLE 9.1. SUMMARY OF RESPONSES OF GRAY WHALES TO THE SIX PLAYBACK CONDITIONS USED IN THE JANUARY 1983 SOUTHBOUND MIGRATION FIELD SEASON.

	Acoustic Playback Condition					
Statistical Measure	**Production Platform**	**Drilling Platform**	**Drillship**	**Semi-Submersible**	**Helicopter**	**Orca**
Track Deflection (D_y)	Further offshore after CPA	One case of deflection at 0.5 km	One case of deflection at -4 km	NS onset ±2 km	Deflect offshore from source, shore at ±2, -1 km	Deflect away from source toward shore at +2, -1 km
Speed	NS	Slowed from 1 to 0 km and from -1 to -2 km from source	Slowed from +2 to -1 km from source	Slowed from +2 to -0.5 km and from -1 to -2 km from source	Slowed from ±0.5 to 0 km and from -0.5 to -1 km from source	Slowed +2 to +0.5 km from source
Compass Bearing	NS	Move offshore at 3 to 2 km	Less scatter in sample but no deflections	NS	NS	NS
VARUA Bearing	Deflect away from source from 0.5 km to 0 km	Deflect away from source +3 to +1 km	NS	NS	One case of deflection from -0.5 km to -1.0 km	Deflect at +2 to -2 km from source

Notes: (1) + or - notations represent grid lines as marked in Fig. 7.1.

(2) NS = Not Significant.

(3) All responses obtained were compared with a control condition of undisturbed whales with no boat present.

(4) Track deflection and speed differences assessed by Kolmogorov-Smirnov two sample test.

(5) Compass bearing and VARUA bearing assessed by Watson's U^2 sample test for circular samples.

9.1.3 Behavioral response of the mother/calf pairs during the northbound migration in April/May

The results presented in Sec. 7 for the April/May phase of the project strongly suggest that air gun noise affects the migratory behavior of gray whales under certain impulse level conditions. This effect is indicated by results showing that as the air gun noise level increases, mother/calf pairs swim at slower speeds, meander, move in toward shore, and turn away from the source. There is also some indication that blow rates increase during high levels of air gun activity. The results from the Drill Ship playback sounds are inclusive.

9.1.4 Mitigating acoustic source impact

Platforms, Drillships, and Helicopters

The behavioral observations for the playback stimuli suggest that only the loudest and most raucous industrial noise sources have an observable behavioral impact on migrating gray whales. The effective decoupling of elevated platforms from the water surface probably is very useful in reducing the amount of acoustic energy radiated into the water from this type of source. Helicopters are a very localized noise source because of the limited area through which they can radiate into the water. Thus, flight paths directed to minimize overflight of whales will also minimize the observed disturbing quality of helicopter noise. The loudest oil and gas industry sources, excluding seismic exploration sources, are probably drillships, dredges, tankers, and their icebreaking counterparts which are now being used in the arctic. Mitigation of noise from these sources is difficult. It can be achieved by design considerations in new construction, by modification of existing vessels, or by scheduling operations to have a minimal impact on migration periods. Since all of these alternatives are expensive, it is important to establish the noise levels at which significant behavioral changes occur in the impacted species so that unnecessary noise reduction efforts can be avoided.

Seismic Sources

The directionality of the seismic array can be utilized to reduce sound levels near shore by directing survey tracks primarily normal to the shoreline - if the data overlap requirements of the survey permit this type of grid pattern. Surveys in shallow water (less than 100 m) are benefited by high bottom reflection loss if nonducted propagation conditions exist. Seasonal changes in propagation conditions should be studied to determine if there is a maximum TL period. Cumulative effects of multiple seismic operations along a migration path are potentially disruptive in view of the observed impact in the test area. The timing of survey permits will help control this impact if they can be coordinated along the entire migration track.

9.2 Recommendations

Playback Studies

Future playback studies should attempt to simulate the louder oil and gas industry sources, such as drillships and dredges, with emphasis on more accurate reproduction of low frequency sounds. This is needed to determine the frequency/ sound level threshold for continuous sound which may result in the same type of avoidance behavior observed for air gun impulses at 160 dB and higher.

One area for improvement in the study design of these playback experiments is better matching of experimental and control conditions for time of day and stage within the season. For the industrial sound playbacks presented in this report, playbacks were performed on six consecutive days with little time for control observations. Thus, possible responses to playback had to be compared to undisturbed observations made both before and after the six day playback period. Furthermore, some playback conditions such as Orca were not presented at equal rates for different times of day.

In order to match samples better, it is proposed that any future playbacks of these stimuli be presented in three 3-day blocks with stimulus presentation set at fixed times of day. This playback schedule for six playback stimuli, labeled A, B, C, D, E, and F, is presented in Table 9.2. Each individual playback can be matched with a control observation at exactly the same time interval from an adjacent day. This study design minimizes potentially confounding diurnal effects or variability in responses due to stage of the migration season.

Air Gun Studies

The response to air gun noise pressure levels below 160 dB needs to be quantified. The number of samples available in the present study was too limited to establish response thresholds below 160 dB.

The propagation model for air gun noise in shallow water needs to be verified for ranges greater than 2 km. Most of the array data were obtained for offshore-onshore propagation where the model predictions tracked the data quite well. The model predicts high values of TL for propagation along shore in the water depths followed by the gray whale migration. Thus, the impact of nearshore seismic source operations should be quite localized.

TABLE 9.2. PROPOSED SCHEDULE FOR SIX EXPERIMENTAL PLAYBACK CONDITIONS WITH MATCHED CONTROLS.

		Block 1			Block 2			Block 3		
	Time of Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
	8		C			C			C	
	9		O			O			O	
AM	10	A	N	D	C	N	E	B	N	F
↑	11		T			T			T	
___	12		R			R			R	
↓	1	B	O	E	A	O	F	C	O	D
PM	2		L			L			L	
	3		↓			↓			↓	
	4	C		F	B		D	A		E
	5									
	6									

General

The findings of this study should be extended to other areas frequented by gray whales to insure that the observed behaviors in response to acoustic stimuli are not site or circumstance specific. This can be done by developing a TL model for the area in question, predicting the effects of a seismic source and play-back source in that area, and then performing a study to determine if the same acoustic level-related behavioral changes are observed. Similarly, this type of research should be extended to other whale species to determine their behavioral responses to acoustic stimuli associated with industrial activities.

The addition of a fourth observer to both observation stations and possibly the addition of a third observation station to allow earlier observation of tracks in a pre-exposure condition are also recommended to facilitate the use of each track as its own control in the track deflection analysis.

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APPENDIX A

THE CALIFORNIA GRAY WHALE (Eschrictius robustus): A REVIEW OF THE LITERATURE ON MIGRATORY AND BEHAVIORAL CHARACTERISTICS

James E. Bird

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PREFACE

The California gray whale (Eschrichtius robustus) is a near-shore migratory species that travels approximately 19,300 km each winter and spring between the feeding grounds in the Bering and Chukchi Seas and the breeding/nursery lagoons of Baja California Sur. The gray whale has been protected by international convention since 1947. Estimates of the number of gray whales at that time were 4000 to 5000 individuals (Wolman and Rice, 1979). Today, the population of the California gray whale numbers 16,500 ± 2,900 individuals (Reilly, Rice, and Wolman, 1980). It is the most heavily studied baleen whale, numerous scientists having observed and recorded migrational information from the Unimak Pass in Alaska to the lagoons of Baja California.

During its travel, the gray whale is exposed to numerous man-made noise sources, including offshore petroleum drilling platforms and associated support vehicles in south central California, as well as aircraft and ocean vessels. Its migratory pathway leads the gray whale through other areas where offshore lease sales and oil production will someday take place. Because of this situation, it is imperative that we have a knowledge of the gray whale's natural history and the possible effects of introduced noise. To this end, we were required under Contract AA851-CT2-39 to conduct an extensive literature review on a number of topics in order to compare our own research results with those of others and to determine what effect this introduced noise will have. The following is a brief outline of the organization of this literature review.

In the first section, we discuss the normal behavior of gray whales - that which is presumably undisturbed by man-made noise and activity. We examine four major topics: (1) the migratory and associated behaviors from Unimak Pass, Alaska, to the United States/Mexico border and back again; (2) the summer and fall resident populations of gray whales along the coasts of the United States and Canada; (3) the respiratory characteristics of the gray whale, including information on blow intervals and dive times; and (4) sound production of the gray whale.

The second section is devoted to noise sources that could potentially affect baleen whales, including the gray whale. In comparison to the data on sound reception by baleen whales, there is a relatively large amount of data on various types of equipment used in offshore oil and gas exploration/development. However, when attempting to relate the possible effects of these noise sources on whales, one is confronted with very little hard data and much educated speculation.

The responses of baleen whales (excluding gray whales) to various acoustic stimuli are examined in Sec. 3. We have divided the stimuli as reported in the literature into five types: aircraft, vessel, surface and underwater explosion, sonar, and offshore oil and gas exploration/development. Much of this literature is found as information ancillary to reports and is therefore more qualitative than quantitative. However, as stated in our proposal, we feel that it is useful to have a record of observations of this type in order to compare them to our own findings and to try and determine any trends that exist in noise sources and disturbance response by baleen whales.

In Sec. 4 of our review, we examine the response of gray whales to six types of acoustic stimuli: aircraft, vessel, underwater explosion, near-shore construction activity, killer whale (Orcinus orca) playbacks, and offshore oil and gas exploration/development activities. The rationale of Sec. 3 applies to this section. However, the database on the responses of gray whales to acoustic stimuli is even smaller than the data base that has been established for other baleen whales.

In several cases, specific acoustic data presented by various authors relating to characteristics of sound sources and the environment of baleen whales, including the gray whale, have been summarized here. These data have been extracted from documents which have been referenced in each case, and no attempt has been made to justify or critique the results presented by each author.

In our conclusion, we attempt to draw on the various areas of our literature search to determine the impact of man-made noise sources on gray whales. We identify gaps that exist in the literature on both normal and presumably disturbed behavior and discuss how our recent study has filled in some of those gaps.

A.1 UNDISTURBED BEHAVIOR OF GRAY WHALES

A.1.1 Gray Whale Migration

The California gray whale makes a yearly migration from the feeding areas in the Bering, Chukchi, and Beaufort Seas to the calving lagoons in Baja California and then returns to the northern waters. Much of the migration is coastal and has been the focus of much study (e.g., Rice and Wolman, 1971, Herzing and Mate, 1981, Rugh and Braham, 1979).

The discussion in this section is organized into the southward migration and the northward migration. For the southward, we start at Unimak Pass, Alaska and follow the path of the whales to the United States/Mexico border. We start the northward migration off Southern California and follow it to Unimak Pass. We concentrate on the area between Unimak Pass and the United States/Mexico border, because a vast majority of the research on gray whales has been done between these two locations.

Southward Migration

From information on 316 gray whales that were taken for scientific study from 1959 to 1969 off the California coast, Rice and Wolman (1971) determined that the order of the southbound migration is as follows: (1) females with near-term fetuses, (2) adult females recently ovulated, (3) immature females and adult males, and (4) immature males.

The most thorough study of gray whales leaving the Bering Sea was conducted by Rugh and Braham (1979) at Cape Sarichef, Unimak Pass, from 20 November to 9 December 1977. Using their sighting data, they estimated that 15,099 ± 2,341 gray whales came through Unimak Pass on the southward migration. This figure was calculated by taking actual counts, adding sightings missed before and after the survey, and assuming no diurnal variation.

The authors noted that 29% of the whales observed from their land station on Cape Sarichef were more than 815 m offshore. This figure may reflect weather conditions, because during calm conditions, whales passed by very close to shore, and during high surf conditions, the whale distribution shifted seaward.

Using more recent data from both shorebased and aerial observations, Rugh (1981) reports that gray whales passing through Unimak Pass follow the eastern edge of the pass, with 92% of the whales within 1.4 km of shore. Rugh and Braham (1979) go on to report that yearling and small whales accounted for 73% of the whales passing within 50 m of shore. Medium to large whales accounted for 77% of the whales passing beyond 100 m from shore. The authors note that as the season progressed the size of the whales decreased: Yearlings and small whales were more common at the end of the season than were large whales. This observation supports Rice and Wolman's (1971) studies on the order of the southward migration.

Rugh and Braham (1979) further report that at the beginning of the migration, 2.2% of the whales were oriented other than south. This suggests that the lead animals, the pregnant females, were intent on getting south to the calving grounds, while the later migrants, the immature males and females and adult males, were more involved in social interactions, as these interactions increased with time. No evidence was found for a diurnal fluctuation in migration pattern based on regression analyses of time spent on the surface as a function of light and direction of travel as a function of decreasing light.

The southward migration through Unimak Pass occurs from late October to early January, with numbers of migrants passing through the last two weeks of November and the first three weeks of December (Rugh, 1981).

Rugh and Braham (1979), using the peak-count day past Cape Sarichef, Unimak Pass (23 November 1977) and the peak-count day past Point Loma (11 January 1978) determined that gray whales made this southward journey at an average speed of 4.3 km/hr (49 days, 5056 km coastal contour.)

Recent work by Braham (in press) shows that gray whales travel a coastal route through the Gulf of Alaska. Hall (1979) reports that gray whales closely follow the coast through the Gulf of Alaska, passing through both Hinchinbrook Entrance and Montague Strait (see also Braham, 1977; in press, discussed in the northward migration section).

Pike (1962) notes that southbound migrants passing Washington follow a coastal route and are more concentrated, passing by in a shorter period than those travelling north.

Darling (1977) has described the southward migration past Vancouver Island. He found that the whales pass by between late November and mid January, peaking in numbers during the last two weeks of December.

Herzing and Mate (1981, in press) studied the migration of gray whales past the Oregon coast in 1978 to 1981, from Yaquina Head Lighthouse (44° 41' N, 124° 05' W). The peak of the migration occurred during the first week of January, with a maximum rate of 29 whales per hr. Between 19 December and 23 January, 90% of the migrants passed by their observation site. They note that 80% of the groups containing 4 or more whales passed by in mid-season from late December to early January. Groups of 1 to 3 whales were regularly spaced throughout the southward migration. They suggest that this change in group size may be the result of age/sex and reproductive segregation (after Rice and Wolman, 1971). Larger groups of whales tended to migrate farther offshore than smaller groups; however, they note that this conclusion may be incorrect based on aerial surveys that showed "numerous" groups of 1 to 2 whales beyond 4.8 km, as well as a higher percentage of groups composed of 1 to 2 whales within the 3.2 to 4.8 km range than had been noted by shore observers. Herzing and Mate note that the distance offshore of migrating whales decreased as the migration shifted from south to phase A north (nonmother/calf whales). A majority of the whales observed on the southward migration passed between 1.6 to 3.2 km offshore, in water depths ranging from 40 to 60 m.

Herzing (personal communication, 1982) reports a mean speed of southward migrants of approximately 6 km/hr, with migrants tending to travel in a straight path without pause along the Oregon coast. The author reports that theodolite tracking techniques were used opportunistically and were most effective when the weather was clear and sea state was less than Beaufort 3. The observer's experience and consistency was also a factor in the effectiveness of the theodolite tracking. Herzing goes on to note that the spacing of migrating whales was such that groups and individuals were not confused during tracking.

Huber, Ainley, Bockelheide, Henderson, and Bainbridge (1981) note that the southbound migration past the Farallon Islands, California, begins in mid-December and lasts until the end of January. The usual peak is in late December-early January; however, in 1980, a slight peak occurred in the third week of January. In 1979, the migration reached its peak during the last week of December, with a high count of 45+ on 28 December. The mean number of whales per day was 14.9.

Rice and Wolman (1971) found that the mean passage dates for the five age/sex classes of whales off the central California coast (38° N Latitude) was: (1) females with near-term fetuses -- 31 December, (2) adult females recently ovulated -- 5 January;

(3) adult males -- 9 January, (4) immature females -- 11 January, and (5) immature males -- 15 January. Annual censuses of southbound migrants have been conducted from various shorebased stations near Monterey, California, from 1967 to 1968 (Reilly, Rice, and Wolman, 1980). On the basis of these observations, Rice and Wolman (1979) report that 95% of these migrants pass within 2 km of shore.

Sund and O'Connor (1974) report that, based on aerial observations carried out between Monterey Bay and Point Sur from 15 to 23 January 1973, of 149 whales seen (50 total observations), all were within 11.3 km of shore: 98% within 8 km, 96% within 4.8 km, and 94% within 1.6 km. Survey flights were flown at altitudes ranging from 150 to 900 m, and the area surveyed was up to 40.2 km from shore.

Sund and O'Connor further note that during the same aerial surveys, behavior presumed to be feeding was observed on two occasions.

Reilly et al. (1980) report that shorebased counts from areas near Monterey Bay resulted in an estimate of 16,500 ± 2,900 whales passing by. This population estimate takes into account observer bias in group size estimation and whales passing by out of sight of land. The authors also determined, using nighttime optical equipment, that there is no diurnal fluctuation in rate of travel.

Using data gathered from Yankee Point, California, during the 1967-68 and 1968-69 seasons, Rice and Wolman (1971) showed that the group composition of migrating whales changed as the season progressed. Early in the migration (12 to 31 December), most groups consist of one whale with almost no groups of more than six individuals. During the remainder of the season (13 January to 19 February), groups composed of two whales or more predominate. The authors note that during the middle part of the southward migration past Yankee Point (1 to 30 January), most of the large groups - i.e., greater than two whales - pass. A high count of 197 southbound whales passing Yankee Point was made on 7 January 1968.

Adams (1968) notes that the area south of Monterey provides excellent shorebased viewing of migrating whales, because there is relatively light boat traffic, compared to San Diego, and there are no islands to attract the whales away from their inshore route.

Dohl and his co-workers at the University of California Santa Cruz, during a three-year (1975 to 1978) study of the marine birds and marine mammals of the Southern California Bight area (latitudes 32° 03' N to 34° 30'N; longitudes 117° W to 121° W), found that the important areas of concentrations of gray whales were coastal promontaries seaward to 15 km, particularly near Pt. Conception, Pt. Dume, Pt. Vicente, Dana Pt., Pt. Loma, and Santa Catalina Island (Hill, 1981). During this work, 747 gray whales were observed 747 times. Of this number, 7% were estimated to be immature animals (Dohl, Norris, Guess, Bryant, and Honig, 1980). All immatures were observed during the winter quarter (January through March). The pod size of all observed gray whales was from 1 to 13 animals with a mean of 2.5 animals per pod. Animals separated by 0.46 km or less were deemed members of the same pod.

During December, a majority of the southbound migrants were sighted in offshore waters or around islands in the Bight area. Whales were seldom seen following a coastal corridor (UC Santa Cruz, 1980). The mean pod size of southbound migrants was 2.5 (Dohl et al, 1980). The greatest number of migrating gray whales was seen during the winter quarter. Only 23.8% of the sightings were made in the 9.6-km wide coastal corridor from Pt. Arguello to the Mexican border.

Dohl and his co-workers conclude that during the southward migration through the Southern California Bight area, gray whales follow a more offshore path than during the northward migration. They also report, "The data indicate that, as the total gray whale population increases, large numbers are to be found in offshore waters." (UC Santa Cruz, 1980b, p. 16.)

Four survey flights were flown from Monterey Bay to Pt. Arguello during December and January (Dohl et al, 1980). A total of 442 gray whales was observed. No whales were seen beyond 4.6 km from shore, and less than 3% were beyond 2.8 km from shore. During these surveys, however, the plane was flown along a route 1.85 km from shore, and it was estimated that the observers could effectively spot migrating gray whales only up to 2.8 km offshore of the survey path. During three flights flown from Pt. Arguello to Monterey Bay during the 2nd week of December and the 2nd and 4th weeks of January at a distance of 5 km from shore, no gray whales were seen.

Work is now underway by UC Santa Cruz personnel to characterize the marine mammals and seabirds off central and northern California. Dohl, Guess, Doman, and Helm (1982) report that the earliest sighting of gray whales has been November 6. The main body of southward migrating gray whales arrives off the central California coast in late December. The central California coast is defined as from latitudes 36° 30' to 34° 10' N. The majority of these migrants are within 3.7 km of shore, with 6% being 9.3 km or more offshore. During the last two years of characterizing the southward migration, a phenomenon of gray whales "stacking up" in the St. George Reef area (approximately 41° 40' N) has been observed. A pattern of heavy occupancy followed by complete vacancy was observed at approximately weekly intervals.

It was also learned that migrating gray whales appear to avoid coastal areas of high turbidity. This behavior was evident particularly after periods of run-off due to inland rainfall. No whales were seen in Monterey Bay and other areas along the central and northern coast during these conditions; however, whales were observed in the clear waters that bounded these turbid plumes.

During shipboard transects run off Point Loma, Rice and Wolman (1971) found that 59% of the whales passed offshore, out of sight of land. Leatherwood (1974), during aerial surveys off Southern California, also found that a high percentage of southbound gray whales passed offshore, out of sight of Point Loma. He notes that the whales apparently head for nearshore waters after passing the southernmost of the Channel Islands. Peak numbers of whales were seen during the first and second weeks of January.

Cummings, Thompson, and Cook (1968) report that the mean speed of nine lone migrants off San Diego was 10.2 km/hr, based on daytime and nighttime sound source tracks.

Sumich (1981, 1983) monitored 74 southbound migrants from a shore station on Point Loma, using theodolite tracking techniques. He found the mean speed of these whales to be 7.2 km/hr.

Wyrick (1954) reports that, based on a study of gray whales off Point Loma during 28 January to 2 February 1952, the average speed of passing migrants was approximately 8.5 km/hr, with a low of 4.4 km/hr and a high of 12.0 km/hr.

Dohl and Guess (1979) found that during aerial surveys flown from Point Conception to the California/Mexico border, up to 60% of the migrants were travelling beyond 8 km offshore. The authors note that since shorebased counts at Point Loma have not shown reduced numbers, the gray whale population must be increasing and may be moving to offshore migration routes. Surveys were flown up to 193 km from shore.

Northward Migration

The procession of northward migrants, based on data from Rice and Wolman (1971), is as follows: (1) newly pregnant females, (2) adult males, (3) anestrous females, (4) immature females, and (5) immature males. A sixth category, mothers with newborn calves, should be added, based on the work of Poole (1981, in press), Dohl and Guess (1979), and Herzig and Mate (1981, in press).

Leatherwood (1974) reports that peak numbers of northbound migrants pass the vicinity of Point Loma, CA, during the second and fourth weeks of March. He notes that a high percentage of migrants pass offshore, out of sight of Point Loma, presumably retracing their southward movement pattern of spreading out through the Channel Islands until reaching Point Conception, where they again begin to follow an inshore path. Leatherwood also determined the speed of three naturally marked whales on their northward migration off the coast of Southern California: (1) 11 to 13 April 1972, 129 km/49.5 hrs = 2.6 km/hr; (2) 27 to 29 March 1972, 128 km/44 hrs = 2.9 km/hr; (3) 27 to 28 April 1972, 64 km/23 hrs = 2.8 km/hr.

Poole (1981; in press) observed the northward migration from Pt. Piedras Blancas, CA (35° 40' N, 121° 17' W) during 1980 to 1982. His efforts were concentrated on a 1.6-km coastal observation window. Observers were 11 m above sea level and observations were conducted 10 hr/day (2 observers, 5 hrs each). Data were taken on the number of whales, position of the whales, behaviors, distance offshore at the nearest point to shore, time and angle of approach and departure, and environmental conditions.

His findings show that the northward migration occurs in two phases. The first phase consists of nonmother/calf pairs. Their numbers peak around 1 March. It was noted that these whales migrate from one point of land to the next, avoiding coastal bights and indentations. At Estero Bay, whales would be approximately 16 km offshore, while at points of land they would be from 400 to 3,200 m offshore. The second phase of the migration consisted of mother/calf pairs. During 1980, Poole and co-workers observed 228 mother/calf pairs with peak numbers of 71 pairs passing by Pt. Piedras Blancas between 19 April and 26 April. In 1981, 209 mother/calf pairs were observed, with peak numbers of 42 mother/calf pairs between 2 May and 9 May. (Two points should be mentioned here: (1) The totals 228 and 209 are based on observations during all weather conditions, whereas the peak figures, 71 and 42, are based on counts only during good observation conditions - i.e., when sighting distance was 0 to 4.8+ km as opposed to 0-1.6 km; and (2) the number of hours of observation varies from week to week depending on the weather conditions.)

During this second migratory phase, 99% and 96% of the mother/calf pairs seen in the 2 years were within 10 m to 200 m of shore. Poole speculates that the reasons for such a nearshore migratory path are because of food availability and perhaps also for protection from killer whales (<u>Orcinus orca</u>). In 1980, Poole observed five killer whales approaching two gray whales. The gray whales stayed submerged for 17 min., apparently exhaled underwater (not seen), and surfaced at the same position only after the killer whales left. When they surfaced, a visible exhalation was not observed. Poole (citing S. Swartz, personal communication) states that "kelp beds may offer a physical and an acoustical 'screen' for protection of gray whales against predators." (p. 15).

Mention should be made here of the evidence of feeding by gray whales on their northward migration. Nerini (in press) presents a table which gives published and unpublished accounts of gray whales feeding on their northward migration (excluding the northern Bering and Chukchi Seas). Nerini notes that gray whales, during their northward migration, feed on pelagic and benthic fauna in selected locations. Sumich (personal communication) is cited as estimating that over 50% of the sightings of feeding gray whales along the Oregon coast are at river mouths, and Jefferies (cited as personal communication) notes gray whales feeding at river mouths along the Washington coast. However, Nerini cautions that since most gray whale sightings are near river mouths, the feeding data are "confounded" by the sighting effort. Leatherwood (cited as personal communication) states that only one incident of feeding that was determined to be reliable was observed during 14 years of aerial and vessel surveys off northern Baja and the California coast. Wellington and Anderson (1978) report a small (6-m) gray whale feeding in kelp beds west of Santa Barbara in early April. This observation, they conclude, indicates "... that gray whales can display plasticity in their feeding behavior." (p. 292.) These data are based on 96km of shoreline surveyed.

Wilson and Behrens (1982) observed concurrent sexual behavior in three groups of gray whales near Pecho Rock, San Luis Obispo County, during the northward migration.

Baldridge (1974) observed mother/calf pairs off Monterey and vicinity during late March, April, and May. He notes that they were travelling very close to shore. He also states that nonmother/calf pairs follow a more direct route from approximately Point Pinos, Monterey County, toward Davenport, Santa Cruz County. Baldridge has also observed sexual behavior during both the northbound and southbound migration. In the five northbound observations of sexual behavior, all groups were composed of three whales. In the three southbound observations, two groups were composed of two whales each, and one was a group of three. All of these whales were located 1 km or less offshore.

Sund (1975) reports that groups of four and three whales each seen on separate days, appeared to be feeding off Monterey. He notes that the whales swam in a circle around and beneath a school of fish. One whale would leave the circle and surface in the circle with its mouth open.

During 1980, a high count of 39+ whales was observed from the Farallon Islands (Huber, Anley, Morrell, Boekelheide, and Henderson, 1980). Northbound migrants are usually observed from February to mid-March.

Manzer (1954), during pelagic fur seal research from Washington to Mexico, observed 31 gray whales travelling north between 26 February and 9 April. Observations took place from 35° 10' N to 43° 25' N. All were within 16.1 km of shore, but never closer than 2.4 km. Distances travelled offshore during the research were up to 161 km.

Houck (1962) observed what appeared to be mating off Arcata, Humbolt County, California, on 17 March 1958. The group consisted of a male and a large whale with a smaller one, this pair presumed to be a mother and calf.

Dohl and Guess (1981) and Dohl et al (1982), like Poole (1981), also report a two-phase migration for northbound gray whales, based on their survey area along the nothern California coast (Point St. George, Klamath River Mouth, off Big Lagoon north of Patricks Point, and the Farallon Islands). They note that the northbound migrants are closer to shore than southbound ones. The first peak occurs in the first week in March and consists of nonmother/calf pairs. Less than 2% of the first phase northward migrants are further than 9.3 km offshore. A headland-to-headland migration path was noted. A lesser peak, observed in late May, consisted of mostly mother/calf pairs. These mother/calf pairs were seen extremely close to shore, frequently within kelp beds or directly seaward of the breaker line.

Herzing and Mate (1981) and Herzing and Mate (in press) describe a two-phase migration for northbound whales passing the Oregon coast, as well. The first phase, composed of nonmother/calf pairs, peaked around mid-March, with 14/hr passing the authors' shorebased observation station at Yaquina Head lighthouse. The second phase lasted from mid-April until the end of May, reaching a peak in mid-May. It was composed mostly of mother/calf pairs. The authors note that the first phase of the northward migration was closer to shore than the southward migration. There was also a decrease in group size compared to that of the southward migration. During the second phase of the northbound migration, 90%+ of the whales were within 0.8 km of shore. Herzing (personal communication, 1982) notes that mothers and calves are often very difficult to track because they travel very close to shore, often stopping to linger around headlands. Mean speed for northbound migrants was approximately 5 km/hr, excluding mother/calf pairs.

Pike (1962) reports that many northbound migrants off the Washington coast pass close to shore and are often difficult to detect in the breaking surf. He notes that some stay in the same area for up to four hours, exhibiting a variety of behaviors, including playing, mating, and feeding. Wilke and Fiscus (1961) report that on 24 April 200+ gray whales were observed 8 to 24 km off the Washington coast between 47° 40' N, 124° 29' W and 47° 54' N, 124° 39' W. The authors note that some were feeding and some were resting. The buildup to and decline of this peak was more gradual than that of the southward peak. Newman (1976) observed sexual behavior between two male gray whales 100 m off the coast at La Pugh, Clallam County, Washington, on 19 March 1975.

Hart (1977) reports that the peak of the northbound migration off southern Vancouver Island occurs in the first week of April, and the author gives data on group size, showing that 63% travel singly and 28% are in pairs. Most of the whales travel close to shore. Some breaching and "spyhopping" was observed. Sexual activity was observed only once, with copulation appearing to take place. Behavior, presumed to be feeding, was observed, with whales moving back and forth in the same area; however, no mud streaming was seen.

The northward migration past Vancouver Island has been described in great detail by Darling (1977). The first whales are seen in the latter half of February, with peak numbers passing by in the first two weeks of April. He notes that during the first two weeks in April, 70% of the whales sighted were travelling north. However, by the last two weeks in April, the numbers had reversed with 70+% of the whales presumably remaining in the area. (See a summary of the work by Darling and co-workers in Part B - Non-Migratory Observations of Gray Whales.) The gray whales pass Vancouver on the west side, some very near shore following the coastline, while others take a more direct headland to headland route. Depth contours may be an important cue for the migrating whales. This is Darling's conclusion. It is based on the knowledge of the area. However, until tested, it should be considered speculative in nature.

From aerial, shipboard, and landbased observations (including many unpublished observations from airplane pilots, fishermen, and pleasure craft owners) Braham (1977; in press) concludes that most gray whales follow a coastal migratory route through the Gulf of Alaska. Braham hypothesizes that the reason for this coastal migration may be food. If they do not feed (apparently) during their southbound migration and while they are in the breeding lagoons (see summary of feeding by Nerini, in press) then a near-shore track northward, in shallow water, would allow gray whales to feed at a minimum energy expenditure.

By March, the gray whales arrive in the northeast Gulf of Alaska and enter the Bering Sea through the Unimak Pass in early April. Hall, Harrison, Nelson, and Taber (1977) report that, according to aerial surveys in the northeast Gulf of Alaska from 7 April to 26 May, gray whales migrate from Cape St. Elias to the Unimak Pass within 400 m of shore and are not sighted more than 5 km from shore. Very few mothers and calves have been seen.

Hessing (in press), from research conducted in 1980, reports that gray whales passing through the Unimak Pass reach peak numbers from 21 April to 2 May. She notes that early in the season 46% of the whales sighted are more than 500 m from shore, whereas late in the season 90% are within 100 m of shore. Aerial surveys conducted in 1980 showed that no whales were further than 1.5 km from shore. During this study, smaller whales, assumed to be yearlings, were seen throughout, but their numbers rose in the last half of the census. The first mother/calf pair was sighted on 9 May and subsequent sightings of mother/calf pairs indicated that they were always within 150 m of shore. Hessing also reports possible feeding behavior on nine occasions. The whales were seen with their mouths open in a "head high" position.

A.1.2 Non-Migratory Observations of Gray Whales

Summer and fall occurrences of gray whales off Mexico, the United States, and Canada have been summarized by Patten and Samaras (1977). In their work, they term "unseasonable" any gray whales observed heading southward off British Columbia between late May and early September. There have been a number of such sightings, and these are presented in their review in tabular form. They identify three areas where populations seem to be resident throughout the year: the Gulf of California, off the Farallon Islands, and near Vancouver Island.

Dohl and his co-workers (Dohl et al, 1982) confirm a summering population off northern California. A summering population has been known to exist off Vancouver Island for a number of years (Hatler and Darling, 1974; Darling, 1977). Feeding behavior has been reported in the Vancouver Island population by Hatler and Darling (1974), Darling (1977), and Darling (in press). Murison, Murie, Morin, and Curiel (in press) have reported that the food source is most probably the mysid, Holmesimysis sculpta. A brief review of their findings is included below.

A.1.3 Surfacing and Diving Characteristics

Despite the many reports written on the California gray whale, there is a surprisingly small amount of information on respiratory rates.

Swartz and Jones (1978) report that the respiration rates for two "undisturbed" gray whales (boat stationary 100 m away) was 1.6 blows per min. and 1.7 blows per min., respectively. They note that these rates are representative of other gray whales in San Ignacio Lagoon.

Norris et al (1977), working in Magdalena Bay, report that the respiration rates for a mother and calf swimming slowly at the surface was 0.97 blows per min. and 1.47 blows per min., respectively. Data taken from a gray whale calf equipped with a telemetry tracking device showed that when it was quiescent, it spent 16 sec. per min. at the surface, and when it was swimming, the time at the surface fell to 3 sec. per min. At one point, the calf reached a recorded depth of 110 m ± 10 m after leaving Magdalena Bay.

Gard (1978) conducted aerial surveys of Scammon's and Guerrero Negro Lagoons and noted that for 25 groups of whales, including mothers, calves, and adults, the percentage of time spent at the surface vs percentage of time spent below the surface was 29.7% vs. 70.3%.

Mate and Harvey (1981) and Harvey and Mate (in press) radio-tagged 17 adult whales in San Ignacio Lagoon. Ten of the whales (three single adults -- two females and one unknown sex, and seven mothers with calves) were monitored for a total of 303.7 hrs, during which time 11,080 dives were recorded. The mean duration of the dives was 1.57 min. ±0.02 min. Ninety-five percent of the dives were under 6 min. in duration. The mean surface time (telemetry device antenna out of the water) was 4.4 sec. ±0.6 sec. Data taken from the 10 tagged whales show that they averaged 2.6% of the time at the surface. Their mean rate of surfacing was 35.6 ±0.08 surfacings per hr. Harvey and Mate found that the whales surfaced significantly more often during daytime than night (37.1 surfacings per hr compared to 30.3 surfacings per hr). When comparing resting whales to travelling whales, they found the former had long dive durations, very long surfacing durations, and low surfacing rates (surfacings per hr), while the travelling whales had short dives and surfacing durations, but high surfacing rates.

Using these data, the authors modeled three respiration patterns: (1) regular long -- regularly spaced dives greater than 1 min., (2) regular short -- regularly spaced dives less than 1 min., and (3) clumped -- a long dive (greater than 1 min.) followed by a series of 2 to 6 short dives. They note that the clumped dive pattern has been documented for migrating gray whales by a variety of workers; however, the two regular dive patterns have not been described before. The regular dive patterns occurred almost as frequently as the clumped dive pattern.

Sumich (1981, 1983) reports a respiratory rate of 0.72 breaths per min. for 74 whales passing Point Loma, CA, during the southward migration. The dive patterns of 11 individual gray whales could be divided into two distinct types: (1) approximately 67% of the dives were less than 1 min., and (2) most of the remaining dives were greater than 2 min. He found that the mean duration of short dives was significantly greater for seven whales swimming faster than the overall mean speed of 7.2 km/hr, than for four whales swimming at a slower rate than the mean. The faster swimming whales had a higher breathing rate than the slower whales, because the faster whales decreased the mean duration of their long dives.

Murison <u>et al</u> (in press) examined the respiratory and dive characteristics of a summer resident population of gray whales off Vancouver Island. During feeding behavior, they found that

53% of the observed dives were 20 sec. or less with a mean dive duration of 11.77 ± σ 3.75 sec. For dives longer than 20 sec. (47% of observed dives), they found a mean of 76.13 ± σ 42.35 sec.

A.1.4 Sound Production

Gray whale sound production has been the subject of a variety of reports over the years. In 1955 Asa-Dorian reported recording echolocation-type clicks from a gray whale off San Diego (Wenz, 1964). During the 1960's and 1970's, several researchers reported a number of sounds produced by gray whales under a variety of circumstances. These sounds include clicks arranged in pulse trains, moans, "bubble-type" sounds, and "rasps."

The following is a summary of the acoustic data collected. Whenever possible, the type of recording equipment, including response levels, is given. Also, the conditions under which the sounds were recorded are provided in detail. Two papers should be mentioned in the introduction to this section. Thompson, Winn, and Perkins (1979) provide a very good, brief review of the literature on the sounds produced by gray whales. Dahlheim, Fisher, and Schempp (in press) present a table showing all reported sounds of gray whales, including their acoustic characteristics.

Rasmussen and Head (1965) conducted studies off Point Loma, California from 22 December to 7 March 1965, to determine if gray whales use echolocation signals; and if they do, to evaluate them acoustically and discover under what conditions they are used. A stationary vessel was maneuvered so as to be in the path of migrating gray whales. Approximately 200 whales passed within the acoustic range of the deployed sonobuoys (frequency response ±3dB from 10 Hz-30 kHz) at distances ranging from less than

1000 m to as close as diving beneath the vessel. No sounds that could be attributed to gray whales were recorded during one test at Todos Santos Bay. A group of four whales was sighted at dusk moving toward a channel which separated the Todos Santos Islands and Punta Banda. The vessel was held stationary and a sonobuoy was deployed. The range estimate to the whales at this time was 600 m. A series of intense sounds was recorded, each sound with a duration of approximately 0.05 sec., with intervals between the sounds of one to fifteen sec. A spectrogram is presented; however, the frequency range is not labeled. The sounds could not definitely be attributed to the gray whales. The authors note, however, that the whales were passing "into a navigationally hazardous area," (p. 874). They speculate that the sounds may be echolocation signals, used only when the conditions warranted. The authors also conducted acoustic tests in Scammon's Lagoon. They note that from 30 to 40 whales (mothers and calves) passed within 200 m of the stationary vessel and deployed hydrophone. No sounds were recorded. They repeatedly attempted to record gray whale sounds in different locations in the lagoon, both in very shallow and in deep (750 m) water. Although they observed many whales displaying a variety of behaviors, including "spyhopping" and mating, no sounds were recorded.

Fish, Sumich, and Lingle (1974) recorded sounds from the captive gray whale "Gigi." Three types of sounds were recorded. A low-frequency sound was recorded on two occasions. The principal energy was in a band from 100-200 Hz, with a secondary peak at 1.5 kHz. The sound duration was 1 sec. The most common sound recorded was a pulsed signal, composed of about 8 to 14 pulses in a burst, lasting approximately 2 sec. The energy of this sound was in a frequency band from below 100 Hz to over 10 kHz, with several resonant peaks, the strongest being at 1.4 kHz. Short broadband grunts were also recorded on three occasions. These grunts had peak energy centered at 200-400 Hz and 1.6 kHz.

Recordings were made when Gigi was released on 13 March 1972. Shortly after she was released, a series of clicks was recorded. These clicks were recorded 6 sec. after most of the vessels in the area had shut off their engines to allow the authors to record. The clicks had a principal energy of 2 to 6 kHz centered at 3.4 to 4 kHz. The duration of the click train was between 1 and 2 msec. The number of clicks per train varied from 1 to 833, with a click repetition rate between 9.5 and 36.0 sec. All of these sounds were recorded with an Uher 4200 2-track tape recorder at a speed of 19 cm/second, connected to a Wilcoxon M-H90-A hydrophone with a frequency response of 40 Hz to 16 kHz ± 3dB.

Gray whale sounds were also recorded off the west coast of Vancouver Island during August 1973. Clicks were recorded with principal energy of 2 to 6 kHz centered at 3.5 to 4 kHz. The mean click duration was >2 msec. Clicks per train varied from 1 to 96. Repetition rates were between 8 to 40 sec. Click trains were recorded from a single gray whale feeding in 10 m of water approximately 1200 m from shore. During recording, the sea was calm and there was very little wind. Clicks were recorded 1 min. after a 3.58-min dive duration. The whale was 50 to 70 m away from the hydrophone. Click trains were also received from this whale after the first exhalation upon surfacing. Noise from a boat continued for 95 sec., starting 20 sec. after the surfacing click train was received. Another click train was recorded 50 sec. after the boat noise stopped and 50 sec. before the whale's next blow. At this time the whale was 80 to 100 m from the hydrophone. The received level of the clicks at this time was 5 to 7 dB below the received levels of the clicks recorded at 50 to 70 m distance.

Equipment used to record these whales consisted of a Sony model TC-126 tape recorder and an Interocean model 90A Bio-Acoustic underwater listening device with a frequency range of 100 Hz to 3 kHz. The authors note that the frequency range of these clicks is too low to locate individual food sources. "...They could be helpful for finding dense concentrations of organisms or for ranging off the bottom to feed or navigate." (p. 43). Clicks of this type have never been recorded by Naval Undersea Center (now NOSC) personnel during four seasons of acoustic work during gray whale migration.

Cummings, Thompson, and Cook (1968) recorded a total of 231 low-frequency sounds from southward migrating gray whales off San Diego, California, during January 1966 and 1967. Two stations were used: Point Loma, depth of water 32.0 m, and Point La Jolla, water depth 19.8 m. Of the 231 sounds recorded, 108 were visually correlated with passing whales. Distances from the hydrophone to the 108 sound sources were from 9.1 to 1189 m, with a mean of 424.3 m. Sounds were recorded during both daylight hours and at night, with 124 signals from 61+ whales recorded between 1800 and 0600 hrs and 107 signals from 157+ whales between 0600 and 1800 hrs. Eighty-seven percent of the sounds recorded were classified as moans, with a frequency range between 20 and 200 Hz. The mean duration of 155 of these signals was 1.54 sec. Sounds classified as "bubble-type" were recorded on 13 occasions. Frequencies ranged as high as 350 Hz. The mean range of the received sound pressure level corrected to 1-m range (source level) for all sounds recorded was 138 to 152 dB re 1 μPa at 1 m. The authors report an overall recording system response "essentially flat from 0.02 to 8 kHz."

Asa-Dorian and Perkins (1967) recorded pulsed sounds from three gray whales on 31 January, approximately 2 km off Point Loma, California. The authors observed the three whales in a kelp bed and positioned their vessel on the outer edge of the kelp, south of the whales. The whales were thrashing and circling around in the kelp bed. No sounds other than these were recorded. After 5 min. of listening, propeller sounds were heard, and a landing tank ship was noted to the stern of the research vessel, moving toward the whales. It passed by the whales and moved off rapidly, leaving a propeller wake between the research vessel and the whales. The whales separated, dove, and moved toward the research vessel. The whales came within 15.2 to 30.5 m of the vessel, and a series of from 7 to 20+ pulses were heard. These pulse series grew louder as the whales approached the vessel and weaker as the whales moved away. The pulse duration was between 1 to 1.5 msec. with 5 to 22 pulses in a train and 150 to 300 msec intervals between trains. The frequency range was 70 to 3000 Hz; however, most of the energy was from 400 to 800 Hz. The tanker propeller wake and the kelp bed set up underwater visual and acoustic interference, and the authors speculate that the whales were forced to use echolocation to extricate themselves. The equipment used was an AN/PQM-1A monitor and a Magnecord Model 728-A.

In 1955, Asa-Dorian reported the recording of a series of echolocation-type clicks from a gray whale off San Diego. The frequency range of these clicks was from 500 Hz to 3 kHz (Wenz, 1964). There has been much speculation as to whether these clicks were actually from a gray whale (Gales, 1966, Thompson et al, 1979). However, on the basis of the evidence of gray whale vocalizations reported here, it seems likely that Asa-Dorian's clicks were from gray whales.

Poulter (1968) reports that echolocation-type clicks were observed in the presence of gray whales in Scammon's Lagoon. The clicks, which were in groups of 3 to 5 separated by a few seconds, mostly occurred after low passes over the whales by a helicopter or other aircraft. He noted that the clicks were accompanied by a "bong" followed by a loud "rasp." These "bongs" and "rasps" were rarely heard except after the first low pass of a plane or helicopter. He goes on to note that if a helicopter made another low pass over the whales, the clicks would stop and not continue until the aircraft noise had almost ceased. He reports that the signals recorded may go up to 12 kHz. The equipment used to record these sounds was not described in detail, although it was noted that a high-frequency cut-off filter was used.

Norris, Goodman, Villa-Ramirez, and Hubbs (1977) recorded sharp clicks from two male calves which had been stranded at Puerto San Carlos, Magdalena Bay. After one of the calves had been released, a number of click-type sounds were recorded before this calf rejoined its mother. These clicks were unlike those reported by Fish et al. (1974) in that no long trains containing closely spaced clicks were noted. Instead, the signals were sporadic, with a maximum repetition rate of 2 per sec. More often than not, the clicks were recorded alone. Their duration was 0.25 sec., as compared to the 1 to 2 msec. reported by Fish et al. (1974), and they seemed much higher in intensity with a broader bandwidth. Some of the energy was perhaps above the flat response band of their instrumentation, which was 0.1 to 20 kHz.

Eberhardt and Evans (1962) recorded (frequency response ±3 dB from 0.01 to 30 kHz) sounds from gray whales while in the calving lagoons. During one encounter, two whales were active (action not specified) on the surface within 30 m from the hydrophone. Sounds recorded included "croaker-like grunts" and low-frequency "rumbles". The sound energy was well below 1 kHz, with a peak sound pressure level at 95 dB re 0.0002 microbars (121 dB//μPa). These same types of sounds were recorded on another occasion, and the authors observed that as the whales moved away from the hydrophone, the sounds decreased until no more were heard. Sound pressure levels in this case varied from 111 to 126 dB re 1 μPa. The frequency of the sounds recorded on these occasions was from the lower limit of the recording equipment, at 40 Hz to 700 Hz, with most of the energy concentrated in the 80-Hz to 300-Hz range. Mean duration of the clicks was 0.10 sec., occurring in groups of 4 to 6. In discussing the possibility of gray whale echolocation, the authors note that sounds of 700-Hz frequency have a wavelength in water of approximately 2.1 m, and they speculate that objects of less than 2.1 m would probably not be detectable to the whales. This could be the reason why gray whales sometimes collide with a sound-reflecting barrier erected in their path. The barrier consisted of a string of 0.05-m-diameter, 4.6-m-long aluminum tubes floated upright and anchored. To detect a 0.05-m-diameter tube, the authors calculate that a frequency of 20 kHz or more would be needed. Fleischer (1976) presents this same reasoning when discussing his interpretation of the non-echolocational ability of Mysticeti whales.

Dahlheim et al (in press) recorded six sound types from gray whales in San Ignacio Lagoon:

1) The most common sound was pulsed ranging in frequency from 100 Hz to approximately 2 kHz with the main energy concentrated in the 300- to 825-Hz range. The sounds were in series of 2 to 30, each pulse lasting approximately 0.05 sec., with a mean of 9.4 pulses per series. The mean series duration was 1.8 sec. and, the mean pulse repetition rate was 5.9 per sec.

2) A rapid FM up-down sweep with a mean frequency of between 250 and 300 Hz and a mean duration of 0.3 sec.

3) Frequency range of 125 Hz to 1.25 kHz with an energy concentration below 430 Hz. The duration of the sound was between 1 to 4 sec.

4) Frequency range between 150 Hz and 1.57 kHz with an energy concentration in the 225-Hz to 600-Hz range. The mean duration was less than 1.0 sec.

5) Bubble blasts or underwater blows with a frequency range of 130 Hz to 840 Hz with the principal energy below 500 Hz. The duration was 1.8 to 4.5 sec.

6) Blow just prior to surfacing (termed "sub-surface exhalations") with a frequency range of between 250 Hz to 850 Hz, principal energy at 700 Hz, and mean duration of 3.3 sec.

The authors present a table summarizing seven distinct sound types for gray whales throughout its range. The only sound type not heard was the clicks/clicktrains reported by Fish et al. (1974). It is noted that the vocalizations of gray whales are frequently below the sound level of the ambient (biological) sources in the lagoon. However, the frequency ranges of gray whale vocalizations overlapped the ranges of the nonbiological ambient (i.e., boats) in the lagoon. They hypothesize that the lower sound level of gray whales in relation to the biological ambient is possibly an adaptive strategy, insuring that their sounds would be receptive with a minimum of interference and masking.

A.2. SUMMARY OF NOISE SOURCES AND THEIR POTENTIAL EFFECTS ON MARINE MAMMALS

Davis (1981) reports on a meeting, which was attended by various representatives of oil companies, government officals, and scientists, to discuss the present state of knowledge on the effects of offshore oil exploration/production activities on Arctic marine mammals. Although these discussions were limited to Arctic mammals, their conclusions and recommendations can serve as a blueprint for all marine mammals, including gray whales. High priority was given to determining the areas and seasons of concentrations of marine mammals and why these animals use these areas. From our literature search and review of gray whale information, we know the various corridors of their southward and northward migrations and associated behaviors, including feeding, on the northward movement. We also know that there exist summering populations of gray whales.

The participants at the conference noted that studies which examine control/disturbance/control combined with normal behavioral observations are of high priority. Our recent field study on gray whales followed this recommendation. They also stated that: "Underwater noise is perhaps the most all-pervasive effect that will be associated with offshore hydrocarbon development." The cumulative effect of offshore development on marine mammals is unknown. It may be additive, compensatory, or synergistic, or some combination of the three. Because the long-term effects are not likely to be determined before exploration begins (which is the case), there is a need for long range studies of the biology and ecology of the target species before and concurrent with development. The conference participants concluded that without the monitoring of a species before and during exploration/development, it will be impossible to detect any harmful effects until major changes in population structure and dynamics have occurred (e.g., migratory pathways).

A.2.1 Sound Sources

In this section, we provide a brief review of the offshore oil and gas exploration/production activities that could affect the gray whale during migration. We have divided these potential disturbance sources into two parts: 1) production equipment and logistic support vehicles and 2) seismic operation. We will examine work done to determine the minimum detectable ranges of these noise sources by marine mammals, and finally, we will discuss the various possible physiological and behavioral affects of these noise sources on baleen whales.

A.2.1.1 Sound Levels From Production Equipment/Logistic Support Vehicles

Turl (1982) reports that the frequency range for offshore oil and gas drilling activities is in the range of 10 Hz to 10 kHz, with peak source levels between 130-180 dB re 1 μPa at 1 m. These figures are based on measurements of two drilling sites in Prudhoe Bay (Malme and Mlawski, 1979), construction sites in the Beaufort Sea (Ford, 1977, cited by Turl, 1982), logistic support for a construction site in the Beaufort Sea, and a semisubmersible platform in the North Atlantic (Kramer and Wing, 1976, cited by Turl, 1982). Urick (1967), as reported by Turl (1982, p. 12), notes that "Signal-to-noise (S/N) ratios may approach 80 to 100 dB above background noise levels."

Fraker and Richardson (1980) and Greene (1982) provide a very complete account of the various types of production structures and support craft that are likely to be used in offshore oil/gas production, as well as the sound levels associated with these sources of sound. Rather than rewrite their summaries, we refer the reader to pages 32 through 46 and pages 260 through 265, respectively, in their reports.

Schmidt (in Gales, 1982) reports on acoustic measurements of five production rigs. Acoustic data on the Arco Platform Holly show that the waterborne machinery noise was not above ambient levels. Measurements at the artificial island Rincon show that the major waterborne noise source was a salt water pump located on the west end of the dock area; however, this noise was largely masked by ambient noise. The noise levels from the semi-submersible Ocean Bounty, located 64.4 km off Homer, Alaska, were measured at distances of 15.2 m, 106.7 m, and 243.8 m. At a distance of 15.2 m noise levels rose approximately + 4 dB per octave to a 1/3-octave band level of 126 dB// μPa at a peak frequency of 80 Hz with a fall-off after the 80-Hz peak of approximately - 6 dB per octave. At 106.7 m, noise levels rose approximately + 5 dB per octave to a 1/3-octave band level of 118 dB//μPa at the 80-Hz peak with a fall-off after the peak of approximately -4 dB per octave. The overall level was lower at 106.7 m than at 15.2 m by 8 dB. At 243.8 m, the 80-Hz peak had a 1/3-octave band level of 116 dB//μPa and was still present but was more rounded. Schmidt determined that the noise levels of the Platform King Salmon, located off Kenai, Alaska, rose approximately + 17 dB per octave to a peak 1/3-octave band level of 136 dB at 40 Hz with a fall-off of approximately - 2 dB per octave to higher frequencies. The King Salmon is a quadripod type platform. For the Platform Spar, a tripod type, located 8 km north of the King Salmon, Schmidt notes: "There is now a peak at 20 Hz and, as in the King Salmon data, no indication of energy present below 12.5 Hz one-third octave band. The lower end slopes of the data ... are in the order of + 40 dB per octave. The data above 31.5 Hz may be visually separated into two bands above and below 630 Hz. There does not seem to be any pronounced change in analysis pattern with change in hydrophone depth." (p. D8).

Gales (1982) reports on the measured radiated noise levels of 18 platforms (see Tables I and II in the Gales report for a description of the platforms and their noise levels). He notes that in general, the noise measured at the 18 sites was characterized by a broadband spectrum combined with a number of spectral lines. All platforms measured showed noise components above ambient, especially for line spectrum components, and in some cases these components exceeded the sea state 6 curve by 45 dB. For platforms engaged in drilling or production, the maximum line components were generally at low frequencies from 4 to 8 Hz. The three sites that were judged the quietest were supplied with electrical power from shore by a cable.

The radiated noise of offshore platforms depends on a number of factors including "... size/shape of underwater surfaces, construction materials, structural configuration, structural bonding and damping, type of machinery and power, machinery balancing, machinery coupling to structure, machinery operating speeds, muffling of engine exhausts, etc." (p. 17). Water depth and bottom topography are also influencing factors of noise radiation. Gales presents a figure showing possible sound pathways from a hypothetical drilling platform.

Other sources of noise associated with outer continental shelf oil/gas exploration/development are:

1) Support vessels which are work/supply boats generally between 18.3 and 91.4 m in length, twin screw, and gas or diesel powered. "...(T)heir cavitating propellers produce high levels of broad band noise, covering a wide frequency range from infrasonic frequencies of the order of 10 hertz to ultrasonic frequencies well above 50 kilohertz." (p. 18). Machinery on board produces noise levels mainly less than 5 kHz.

2) Helicopters, which are the major means of personnel/equipment supply to offshore platforms. Gales notes that although much of the sound is reflected off the water's surface, a significant amount is propagated underwater. Gales presents a figure showing a ray-path diagram for helicopter noise. Gales states that "In general, the noise depends on the helicopter type, flight conditions and altitude, depth of measurement point, and distance from point immediately beneath the aircraft. Secondary factors ... (include) surface roughness, ocean sound speed profile, and absorption characteristics of the sea bottom." (p. 18-19).

A.2.1.2 Sound levels from seismic operations

Gales (1982) reports that seismic operations produce pulses of short duration (less than 1 sec.) with major energy content in the 5- to 500-Hz range. Maximum source levels are from 230-270 dB re 1 μPa at 1 m (Acoustical Society of America, 1980). Greene (1982) reports sound levels of 150 dB and 141 dB re 1 μPa for an active seismic vessel 8 km and 13 km away, respectively.

A.2.2 Detection Ranges of Offshore Production Activities by Baleen Whales

Turl (1982) calculates the minimum distances for which offshore exploration/development might be detected by large baleen whales. He assumes three hearing characteristics of these marine mammals: 1) underwater hearing in large whales is optimized, 2) the hearing band width is 1/3 octave, and 3) hearing is omnidirectional. His calculations are based on water depths that are greater than 100 fathoms (182.9 m). He states that for shallower water, his estimates are at best approximates of a "minimum detectable range." His estimates of minimum distances at which marine mammals might detect noise associated with oil and gas production operations range from 17.4 km for a 0.1-kHz, 15-Hz bandwidth signal having a source level of 150 dB re 1 μPa at 1 m (with an ambient level of 50 dB//1 μPa) to 174 km for a 25-Hz bandwidth signal at 1.0 kHz having a source level of 180 dB//1 μPa at 1 m under the same ambient background noise conditions.

Gales (1982) has calculated the noise detection capability of a generalized mysticete whale for three production platform types: 1) semisubmersible, 2) fixed production - quadripod, and 3) fixed production - tripod. Detailed specifications on these platforms are given. For each platform, two cases of noise propagation are presented: cylindrical spreading and spherical spreading. For each of these two propagation conditions, two "animal listening assumptions" are given: 1) good detection - 1/3 octave critical band and 2) conservative detection - 100 Hz critical band below 450 Hz, 1/3 octave band above 450 Hz. The calculated detection ranges are from a maximum of 5482 km (cylindrical spreading, low ambient, and good detection) to 38.8 m (spherical spreading, high ambient, and conservative detection). Sound propagation and ambient noise levels exert the greatest influence on calculated detection ranges. Gales cautions that these ranges are only initial guidelines. In practice, for good detection in a 1/3-octave critical band, it is more than likely that the expected maximum detection range for the three platforms would be somewhere between the following distance extremes: 0.4-183.3 km, 0.3-109.3 km, and 0.9-907.5 km under medium ambient noise conditions and "conservative" propagation (spherical spreading) and "optimal" propagation (cylindrical spreading), respectively.

Using the calculations given above, Gales presents the expected detection ranges of four species of whale (including the gray whale) for noise emitted from a semisubmersible drilling rig which was measured during operations. The source level of the rig was 138 dB re 1 μPa at 1 m at a frequency of 72 Hz. The detection range estimates for gray whales are 137.2 m and 20.1 km for spherical and cylindrical spreading assumptions, respectively. These estimates are for the Santa Barbara-Pt. Conception area of California. Gales believes that the actual detection range would fall somewhere in between these two values, probably closer to the spherical propagation case. An algorithm describing sound propagation loss at 4.5 dB per double distance, or 15 log range instead of spherical and cylindrical spreading, would give a calculated detection range of 823 m. Using the same calculation techniques, Gales estimates the detection range of the same semi-submersible platform by a gray whale in the Lower Cook Inlet of Alaska at 3.3 km.

A.2.3 Possible Effects of Sound on Marine Mammals

In this section, we discuss the possible physiological effects of sound on marine mammals. We refer the reader to Secs. 4 and 5 of this literature survey for behavioral observations of gray and other baleen whales in the presence or vicinity of offshore oil and gas exploration/production equipment and support vehicles.

Hill (1978) states that the effects of underwater shock waves on marine mammals can only be inferred from their effects on land mammals. The physical adaptations which marine mammals have undergone to enable them to dive (e.g., lungs, respiratory passages, outer and middle ear and accessory sinuses) may make them resistant to underwater shock waves, since these air-filled areas are sites of damage from shock waves in land mammals (see Norris, 1981). The thorax in marine mammals is less rigid than in land mammals and may not reduce the effects of the shock waves. The respiratory system of marine mammals, when compared to land mammals, shows an increase in supportive structure in the peripheral portions of the lungs (e.g., cartilage, collagen, smooth muscle, and elastic tissues). This increased supportive tissue is also present in the upper airway passages and indicates less vulnerability to shock waves. In land mammals, the severity of the effect of shock waves is directly proportional to body size.

Yelverton (1981) has calculated tentative "damage-risk criteria" for a number of land mammals exposed to various levels of impulse sound. As body weight increases, the sound level needed to cause damage also increases. For a 200-kilogram marine mammal (dolphin size), he states that injury would not be expected to occur for underwater impulses below 380 Pa-sec. However, for large marine mammals, the data presented showing weight vs impulse strength in relation to injury may be underestimated.

Gales (1982) identifies the following as possible auditory effects.

1) Excessive loudness - A sound level of 143 dB (calculated by assuming the mysticete hearing thresholds at low frequencies might be as sensitive as is that of the beluga [Delphinapterus leucas] at high frequencies [43 dB re 1μPa at 1 m] and adding 100 dB to this figure) might be uncomfortably loud to a mysticete whale. Platform noise measurements done for the Gales' report show that no levels were in excess of 136 dB re 1 μPa at 6.1 m and beyond.

2) Noise-induced hearing loss - In humans, hearing loss is caused by high sound levels over an extended period of time, with a continuous exposure generally more harmful than an intermittent one. Using his detection range calculations, Gales concludes that marine mammals might have a quiet zone that would be readily

available to them in order to escape from the noise. He cautions that this conclusion is based on data for which direct evidence is not now available, but goes on to say that the calculations provide a useful basis from which to begin to solve this problem.

3) Other physiological effects - Gales points out that human responses to noise range from startling to changes in heart rate and blood chemistry. Experimental work on laboratory animals has elicited some of these same responses. To speculate on the possibility of physiological changes in cetaceans is not justified at present on the basis of limited knowledge of noise-induced physiological effects on humans. Fletcher (1971) devotes much of his report to determining the effects of noise on laboratory animals. Effects observed were related to sexual function, blood chemistry, auditory function, signal masking, and heart rate. Many of the observed are stress-mediated and are "...possibl(y) associated with lowered resistance to disease, increased vulnerability to environmental disturbances, and endocrine imbalances which might in turn affect reproduction" (Geraci and St. Aubin, 1980, p. 3).

4) Masking of communication signals - Using calculations made on finback and humpback whales which produce signals of 20 Hz and 0.2 to 5 kHz, respectively, Gales concludes that: "It is possible that platform noise could produce masking of certain acoustic communication signals used by marine mammals, but such interference is not likely to be serious unless the receiving animal is very close to the platform, and the sending animal is much farther away." (p. 55). Norris (1981) discusses a possible middle ear reflex in cetaceans. The muscles to accomplish this reflex are present; although no experiments have shown that the reflex occurs in cetaceans, Norris suggests that it does occur. In other mammals, this reflex is used for brief impulse sounds, shutting down effective hearing and interrupting the use of the

animal's own sounds. If the middle ear reflex does exist in cetaceans, the author questions its effectiveness for prolonged sounds and/or long sustained increases in ambient noise level. It would also be difficult to determine how the cetacean would function if its use interrupted the animal's own sounds.

The middle ear structure in baleen whales suggests adaptations for low frequency hearing. The large, heavy typanic bulla is thought to oscillate against the periotic bone to enable baleen whales to hear. This hearing mechanism could function only for low frequencies. The excavated posterior jaws in toothed whales are thought to be related to high-frequency sound reception. In baleen whales, these excavated jaws have become filled with bone, presumably because they are no longer functional.

A.3. RESPONSES OF LARGE BALEEN WHALES (EXCLUDING GRAY WHALES) TO ACOUSTIC STIMULI

The literature on marine mammals contains a variety of reports concerning their responses to various forms of acoustic stimuli. Most of the reports are anecdotal in nature, giving one or two examples of whales reacting (or not reacting) to a sound source. Many contain very little detailed information on the acoustic characteristics of the sound source, only to say "During aerial observations...," or "The vessel approached to within..." One of the few exceptions is the information obtained by the LGL study concerning the disturbance responses of the bowhead whale in the Eastern Beaufort Sea. This report is discussed in detail in the following sections.

We feel that for proper understanding and interpretation of our own data on the possible effects of acoustic stimuli associated with oil and gas development/exploration on the gray whale, it is vital to have a knowledge of what others have observed in the course of their studies of baleen whale species.

In this section, we examine the responses of the following species to various forms of acoustic stimuli: humpback (Megaptera novaeangliae), blue (Balaena musculus), fin (Balaena physalus), minke (Balaena acutorostrata), right (Eubalaena australis, Eubalaena glacialis), and bowhead (Balaena mysticetus). We have divided the section into five parts: aircraft, vessel, surface and underwater explosion, sonar, and offshore oil/gas operations (excluding helicopters, which are examined in the aircraft subsection).

Tables A-1 and A-2 provide a general summary of the findings of the primary sources of information in this literature review regarding the responses of large baleen whales to acoustic stimuli (aircraft and boats, respectively). These tables exclude responses of gray whales which are covered in Sec. A.4.

TABLE A-1. RESPONSES OF BALEEN WHALES EXCLUDING GRAY WHALES TO ACOUSTIC STIMULI - AIRCRAFT.

Species	Activity	Group Size	Group Composition	Type of Craft	Activity	Altitude (m)
B. acutorostrata	--	3	M/C + 1 adult	Grumman Turbo Goose	--	--
B. acutorostrata	--	--	--	Cessna 172	Circling	50-300
B. physalus	--	3	M/C + 1 adult	Grumman Turbo Goose	Flyover	--
B. physalus	--	--	--	--	Repeated flyover	"Low"
B. physalus	--	--	--	Cessna 172	Circling	50-300
B. physalus	--	--	--	--	--	--
Megaptera novaeangliae	--	--	--	--	--	"Low"
Megaptera novaeangliae	--	--	Various	--	--	--
Megaptera novaeangliae	--	--	Various	--	Census	--
Megaptera novaeangliae	--	--	--	--	Repeated flyover	"Low"
Megaptera novaeangliae	--	--	--	P-3	Observation	150-300
Megaptera novaeangliae	--	--	--	--	Circling	304; <152
Megaptera novaeangliae	--	--	--	Cessna 172	Circling	50-300
B. mysticetus	--	--	--	--	--	65; 130-300
B. mysticetus	--	--	--	--	--	150
B. mysticetus	--	--	--	Twin Otter	Flyover	90; 150
B. mysticetus	--	--	--	Twin Otter	Transect & circling	300
B. mysticetus	--	--	--	Twin Otter	Transect	300
B. mysticetus	--	--	--	Twin Otter	Circling	300
B. mysticetus	Skim feeding	--	--	Britten-Norman Islander	Dropping	457-305
B. mysticetus	Skim feeding	--	--	Britten-Norman Islander	"Holding steady"	305
B. mysticetus	--	--	--	Grumman Turbo Goose	Survey--South of Strait	60-350
B. mysticetus	--	2 cases	--	Grumman Turbo Goose	Survey--South of Strait	60-350
B. mysticetus	--	--	--	Sikorsky H52-A helicopter	--	152 & 226
Eubalena glacialis	--	--	--	Helio Courier - Cessna	Observation	300
Eubalena glacialis	--	--	--	Helio Courier - Cessna	Close inspection	100
Eubalena glacialis	--	--	--	Cessna 172	Circling	50-300

Speed (km/hr)	Position w/reference to whales	Response	Comments	Reference
--	--	Short shallow dives		Ljungblad et al., 1982
Slow	--	"Less disturbed"	Quiet craft at low engine power	Watkins & Schevill, 1979
--	--	Dive	Resurface after Flyover	Ljungblad et al., 1982
--	--	Long dive	No quantitative data	Calkins, in press
Slow	--	"Less disturbed"	Quiet craft at low engine power	Watkins & Schevill, 1979
--	downwind, off to side	"Less disturbed"	Craft position reduces disturbance caused by shadow	Watkins, 1981
--	--	No observed response	No quantitative data	Kaufman & Wood, 1981
--	--	Evasion, dispersal, coalesce around calf	Response relates to group size and composition	Herman & Forestell, 1977 Herman et al., 1980
--	--	"Defensive"--bubble blowing, tail lash, M protect C	--	Forestell & Herman, 1979
--	--	Long dive	No quantitative data	Calkins, in press
--	--	No observed response	Observation brief due to speed of aircraft	Friedl & Thompson, 1981
--	--	Dive; no observed response	Inconsistent response	Shallenberger, 1978
Slow	--	"Less disturbed"	Quiet craft at low engine power	Watkins & Schevill, 1979
--	--	No observed response; vigorous response	Inconsistent response	Everitt & Krogman, 1979
--	--	Sometimes dive	Inconsistent response	Reynaud & Davis, 1981
--	--	Dive; didn't often dive	No systematic data	Davis & Koski, 1980
--	--	No observable response	No systematic data	Davis & Koski, 1980
--	--	No observable response	--	Fraker & Richardson, 1980
--	--	Dive	--	Fraker & Richardson, 1980
--	--	Dive	Unable to correlate altitude w/amount of sound entering water	Fraker et al., 1981
--	--	No observable response	--	Fraker et al., 1981
222-296	--	No observable response	No quantitative data	Ljungblad et al., 1982
222-296	--	Elephant-like trumpeting	2 separate individuals	Ljungblad et al., 1982
--	--	Escape	No difference in response to two altitudes	Dahlheim, 1980
Slow	--	"Less disturbed"	Quiet craft at low engine power	Watkins & Schevill, 1976
Slow	--	"Less disturbed"	Quiet craft at low engine power	Watkins & Schevill, 1976
Slow	--	"Less disturbed"	Quiet craft at low engine power	Watkins & Schevill, 1979

TABLE A-2. RESPONSES OF BALEEN WHALES EXCLUDING GRAY WHALES TO ACOUSTIC STIMULI - BOATS.

Species	Activity	Group Size	Group Composition	Type of Craft	Activity	Distance (m)
B. acutorostrata	--	--	Subadults	--	--	--
B. acutorostrata	--	--	--	Outboard motorboat size & type unspecified	--	--
B. acutorostrata	--	--	--	--	Tagging (approaching)	--
B. acutorostrata	--	--	--	--	Survey	--
B. acutorostrata	Feeding	--	--	--	Tagging (approaching)	--
B. acutorostrata	--	256 cases	--	--	Approaching	--
B. physalus	--	2+	--	--	Pursuit	--
B. physalus	--	--	--	--	Pursuit & tagging	--
B. physalus	--	--	--	--	Tagging (approaching)	--
B. physalus	--	--	--	--	Survey (approaching)	--
B. physalus	--	--	--	Small; type unspecified	--	--
B. physalus	--	1	--	10.5 m with gas engine	Tagging	--
B. physalus	--	2	--	10.5 m with gas engine	Tagging (careful approach)	--
B. physalus	--	2	--	10.5 m with gas engine	Reverse engine	--
B. physalus	--	3	--	10.5 m with gas engine	Tagging (approaching)	--
Megaptera novaeangliae	--	--	--	Power boats, type unspecified	Approaching	--
Megaptera novaeangliae	--	--	--	--	--	--
Megaptera novaeangliae	--	--	--	--	Approaching	--
Megaptera novaeangliae	--	--	--	--	--	--
Megaptera novaeangliae	--	4	3 adults + 1 C	Large ships, type unspecified	--	--
Megaptera novaeangliae	--	2	M/C	--	--	2500
Megaptera novaeangliae	Feeding	200+ cases	--	40+ trawlers, type & size unspecified	Fishing	--
Megaptera novaeangliae	--	1	--	Various ships, fishing boats, pleasure craft	--	Various
Megaptera novaeangliae	--	--	--	Small, type unspecified	Rapidly approaching	--
Megaptera novaeangliae	Feeding	--	--	Small, type unspecified	Passing	6-10

Speed (km/hr)	Position w/reference to whales	Response	Comments	Reference
--	--	Seeking behavior	--	Larson, 1981
"Fast"	--	Surface swimming	--	Ohsumi, 1980
Unvarying	--	No observable response	Whales easy to approach	Hall, 1979
Not moving	--	Curiosity & approach	Whales respond to boat noise?	Hall & Johnson, 1978
--	--	No observable response	--	Horwood, 1981
--	--	Actively avoid, dive	--	Horwood, pers. comm., 1982
--	--	Shallow dive, increased dive & surface time	Data combines 2+ whales under one reading	McCarthy, 1948
--	--	Reduced surface time	Data bias--difficulty in reidentifying individual	Ray et al., 1978
Not moving	--	No observable response	Whales "unusually docile"	Hall, 1979
Unvarying	--	No observable response	Whales "unusually docile"	Hall & Johnson, 1978
--	"Close"	Approach boat	Whales go closer to small, quiet boat (no quantitative data)	Watkins, 1981a
10.5/slow/stop	--	Whale continues to swim near boat	--	Watkins, 1981b
18.	--	No observable response	No response to boat or tagging	Watkins, 1981b
--	--	Acceleration, long dive, disappear	--	Watkins, 1981b
20, then stop	--	Whales move away quickly	--	Watkins, 1981b
"Fast"	--	Active avoidance, change in respiration rate	--	Levenson, 1969
--	--	Distress, aggression	Hierarchy of behaviors measured in terms of respiration rates	Jurasz & Jurasz, 1977
--	--	Change in respiration rate, aerial displays, in-air vocalization	Boats, orca, other whales also stress-producing	Jurasz & Jurasz, 1980
--	--	Defensive	--	Forestell & Herman, 1979 Herman & Forestell, 1977 Herman et al., 1980
--	--	Aerial behavior	--	Herman & Baker, 1982
Abrupt change	--	Aerial behaviors in calf	Change in speed accompanied by sharp increase in dB level	Baker, Herman, Bays, and Bauer, 1982
--	"Near"	No observable response	Whales continuously feed	Brodie, 1981
Various	Various	No observable response	Site tenacity near shipping lanes	Mayo, 1982
--	--	Aerial behaviors	--	Cuccarese & Evans, 1981
--	--	No observable response	--	Cuccarese & Evans, 1981

TABLE A-2. (Cont.) RESPONSES OF BALEEN WHALES EXCLUDING GRAY WHALES TO ACOUSTIC STIMULI - BOATS.

Species	Activity	Group Size	Group Composition	Type of Craft	Activity	Distance (m)
Megaptera novaeangliae	--	--	--	Motorboat, size & type unspecified	Close approach	--
Megaptera novaeangliae	--	--	--	Motorboat, size & type unspecified	"Presence"	--
Megaptera novaeangliae	--	--	--	--	Tagging	--
Megaptera novaeangliae	--	--	--	--	Survey (approaching)	--
Megaptera novaeangliae	Feeding	--	--	9 m survey boat, type unspecified	Approaching	< 92 m
B. mysticetus	--	--	--	Tugboat, size & type unspecified	Passing by	--
B. mysticetus	--	--	--	Outboard motorboat, size & type unspecified	Pursuit	--
B. mysticetus	--	--	--	16.1 m w/2 diesel engines	Moving, idling	≤ 900 m
B. mysticetus	--	4	--	16.1 m w/2 diesel engines	Idling	--
B. mysticetus	--	4	--	16.1 m w/2 diesel engines	Approaching	≤ 1 km
B. mysticetus	--	15+	--	--	Approaching & passing by	800/<300/800+

Speed (km/hr)	Position w/reference to whales	Response	Comments	Reference
--	--	Aerial behaviors	--	Matkin & Matkin, 1981
--	--	No observable response	Behavior changes, unpredictable	Matkin & Matkin, 1981
Not moving	--	Curiosity & approach	Attracted by boat noise?	Hall, 1979
Unvarying	--	Unapproachable	--	Hall & Johnson, 1978
18.5-27.8 constant while near whales	--	Avoidance but continued feeding	--	Hall, 1982
--	--	No observable response	No quantitative data	Fraker, 1977
--	--	"Docile escape"	Reaction to surface noise > reaction to airborne noise	Braham et al., 1980
--	--	Orientations varied	Orientation related to distance from boat	Fraker et al., 1981
Not moving	--	Reduced surface time	--	Fraker et al., 1981
"Cruising"	--	Reduced surface time, active avoidance, dispersal, change in respiration rate	Aircraft-directed survey	Fraker et al., 1981
--	--	Avoidance, reorientation	Site tenacity despite disturbance	Fraker et al., 1981

A.3.1 Aircraft

Most of the reports reviewed below have noted the responses of baleen whales to aircraft incidental to other studies. As a result, in many cases the type of aircraft used or the altitude flown is not given. Reactions have included "defensive" responses, diving, and rapid swimming at the surface. In some cases, no response was observed, even at aircraft altitudes as low as 65 m. Some authors report that whales are not consistent in their responses, showing fright response at high altitudes and no observable response at low altitudes, depending in large part on the activity of the whales, environmental conditions, the sound source (type of aircraft), and time of year (Braham, Krogman, and Carroll, 1980). During discussions among a number of bowhead whale observers (Proceedings of the First Conference on the Biology of the Bowhead Whale, 1982), it was noted that whale responses to survey aircraft is extremely variable. The possible reasons for this variability were given as: whale behavior at time of observation, aircraft altitude, engine setting changes, type of aircraft and survey, weather conditions, and geographic location of the whales. There was general agreement that altitudes of between 457 m and 610 m did not cause disturbance and that possible disturbance occurred at variable rates at altitudes between 244 m and 457 m.

Among the most detailed observations of response to aircraft are those reported by Payne, Brazier, Dorsey, Perkins, Rowntree, and Titus (1981), Fraker and Richardson (1980), Davis and Koski (1980), Dahlheim (1980), and Fraker et al (1981). Most of these reports provide precise details as to the type of aircraft used, its altitude, engine speed, and apparent effect, if any, on nearby whales. While some of the reports note that the whales' reactions were inconsistent, behavioral responses, when they occurred, were frequently dramatic. See Table A.1 for a summary of the observations below.

Payne et al. (1981) report that the responses of southern right whales at Peninsula Valdes, Argentina, to a survey aircraft varied with the individual animal. Most survey/photographic flights were made in a Cessna 182 single-engine aircraft with high wing configuration, at altitudes of greater than 400 m when observers were looking for whales and at 65 to 165 m when photographing them. Fright reactions exhibited by the whales included rapid diving as the plane approached and rapid swimming at the surface, sometimes accompanied by defecation. However, less than 2% of the individuals were estimated to have shown fright response; most whales exhibited no change in behavior. When responses were observed, groups of whales showed less response than single whales.

This observed difference between the reactions of single animals and that of groups is also noted by Herman, Forestell, and Antinoja (1980). Disturbance response of humpback whales to aircraft seemed inversely related to group size. Large groups (size/composition unspecified) exhibited less defensive responses than single whales or small groups; and very large groups (size/composition unspecified) showed no observable response to aircraft. Herman and Forestell (1977) note that pods of humpbacks composed only of adults would make evasive maneuvers and disperse when subjected to aircraft disturbance. However, if a calf was present in the group, the adult whales would coalesce around the calf. In their Hawaiian Islands study area, Forestell and Herman (1979) have observed that the humpback whales exhibit various "defensive behaviors" in response to censusing aircraft. Behaviors deemed defensive include bubble blowing, protective maneuvers of a mother whale toward a calf, and tail movements described as threatening.

Inconsistent responses were reported in a number of cases, most particularly those in which specific data as to type of aircraft, altitude, engine speed, and flight course were not available.

Braham et al (1980) note that the reaction of bowhead whales to aircraft varies greatly. Their reaction depends in large part on the activity of the whales, environmental conditions, the sound source (type of aircraft), and time of year. Kaufman and Wood (1981), studying disturbance reactions and habitat usage of humpback whales in the waters off Maui, Hawaii, detected no effects from low-flying aircraft on the behavior of whales. No quantitative data are presented. Everitt and Krogman (1979) report that few bowhead whales reacted vigorously to an aircraft flying at altitudes between 130 and 300 m, and that on a few occasions, no observable reaction was noted to an aircraft flying at 65 m. Again, no information as to the type of aircraft or its speed is given. Shallenberger (1978) reports that humpbacks are not consistent in their response to aircraft. He notes that the whales will sometimes react to an aircraft circling at 304 m by diving. But at other times, no observable reaction occurs when the aircraft is circling at 152 m or less. No data are provided regarding the specific type of aircraft used.

During aerial surveys south of the Bering Strait, Ljungblad, Moore, Van Schoik, and Winchell (1982) observed no overall behavioral response by whales to the aircraft, a Grumman Turbo Goose flying at altitudes between 60 m to 350 m at speeds of 222 km/hr to 296 km/hr. While they were surveying north of the Strait, however, an apparent acoustic response to the aircraft was heard on two occasions. In both cases, individual bowheads made an "elephantlike trumpeting." The authors note that although this sound type had been heard in the fall, it had never been heard in the spring (altitude and airspeed of the aircraft are not given). Three finback whales in the southern Chukchi Sea (including one mother/calf pair) were observed to dive each time the survey aircraft approached them. Immediately after the plane had passed over them, the whales were resighted. Three minke whales south of Sledge Island (including one mother/calf pair) apparently responded to the aircraft by making short, shallow dives. In both incidents, the aircraft altitude and speed were not given.

During acoustic measurement of waterborne noise from gunfire by a surface vessel in waters north of Kahoolawe Island, Hawaii, accompanied by behavioral observations and plotting of humpback whales' locations from a P-3 aircraft, Friedl and Thompson (1981) noted that the whales did not seem to respond to the aircraft, which was flying at 150 to 300 m. The speed of the aircraft was not given; however, the authors note that their behavioral observation time was very brief, due to the speed of the aircraft.

Under certain circumstances, whales were observed to be relatively consistent in their reactions to nearby aircraft. Circling or repeated passes flown at low altitudes appeared to result in evasive behavior in several cases where specific data on type of aircraft, altitude, and/or engine speed were reported.

Fraker and Richardson (1980), using a Twin Otter aircraft to fly transects at 300 m, report no observable reaction in bowhead whales in the Beaufort Sea. When the whales were being circled for behavioral observation and photographic purposes, however, they would, in every case, respond to the aircraft by diving.

Davis and Koski (1980) report that during aerial surveys in Canadian Eastern Arctic waters, they found that bowhead whales would almost always dive when overflown by a Twin Otter aircraft at an altitude of 90 m. However, when the survey craft was at

150 m, the whales did not usually dive at the plane's first pass. When the whales were surveyed (by both line transects and circling) at an altitude of 300 m, they exhibited little or no observable response. Systematic data for these reactions are not available (Davis and Koski 1980, citing Koski unpublished report).

Calkins (in press) states that although he has no quantitative data on the subject, humpback whales, as well as finbacks and gray whales, avoid aircraft that are approaching them. He also reports that when these species are repeatedly exposed to low-flying approaching aircraft, they dive and remain submerged for periods of time longer than normal. Renaud and Davis (1981), citing M. Fraker, L.G.L. (unpublished data) state that bowhead whales sometimes dive when exposed to aircraft flying at 150 m.

Dahlheim (1980) reports on work conducted by the National Marine Mammal Laboratory on the bowhead whale during the spring and fall of 1978-79. The whales exhibited an escape reaction in 11% of 160 encounters with a Sikorsky H52-A helicopter, flying at 152 m and 228 m altitude. There was no significant difference in the whales' response to the two altitudes. Dahlheim goes on to point out that these results are preliminary and that further studies are needed to measure the effects of noise on bowhead whales.

Fraker, Green, and Würsig (1981) report that although no comprehensive experiments were conducted to see if aircraft altitude had an effect on bowhead whales during a BLM-funded study in the Eastern Beaufort Sea, they did observe and record instances in which apparent disturbance reactions were observed. The aircraft used to conduct bowhead whale observations was a Britten-Norman Islander (BN 2A-21), high wing configuration, with two piston-driven engines (Lycoming IO-540 series) and a low stall speed. They report that all apparent disturbance reactions occurred while the aircraft was at altitudes of 305 m or less. In one instance, as the aircraft was circling at 457 m above them, a group of whales was observed skim-feeding. When the aircraft dropped to 305 m, all the whales dove. In another case, however, skim-feeding whales were observed from an altitude of 305 m for approximately 30 min., and no observable reaction was noted. Fraker et al (1981) provide a list of apparent disturbances caused by the aircraft during their 1980 study season. They provide the following information about the aircraft: above, plus two engines, synchronous operation at 2200 rpm, 21-in. manifold pressure, blade rate expected to be 73.3 Hz. Spectral analyses are presented for the Islander overflying a sonobuoy at altitudes of 157 m, 305 m, 457 m, and 610 m. They report the received levels for the 70 Hz tone at different altitudes to be:

157 m	96.6 dB/1 μPa
305 m	93.9
457 m	92.4
610 m	97.0

These differences in the sound levels at various altitudes were not expected, and they could possibly be explained by 1) rapid change in aircraft range with Doppler changes in the signal frequency, and 2) the aircraft may not have flown directly over the sonobuoy in all cases. Because of this discrepancy in sound levels at various altitudes, the authors conclude that "...the differential responses of the whales to our aircraft at different altitudes cannot presently be related to differences in the amounts of sound entering the water." (p. 183). (For a complete summary of bowhead response to aircraft, see Fraker, Richardson, and Würsig, 1982.)

Watkins and Schevill (1979) conducted observations on the feeding behavior of four species of baleen whales: right, humpback, fin, and minke, in the waters off Cape Cod, Massachusetts. They report that the whales are less disturbed by relatively quiet aircraft flying at slow speeds and reduced engine power. Their observations were conducted in a Cessna 172 circling at an altitude of 50 m to 300 m. This report corroborates the findings reported in Watkins and Schevill (1976). The authors found that right whales off the Cape Cod coast were not disturbed by slow-flying, small, less noisy aircraft such as single-engine planes in the Helio Courier to Cessna class. The aircraft was flown at reduced power settings, at an altitude of 300 m, for overall behavioral observations. For close inspection and photography they flew at 100 m. Further, Watkins (1981a) reports that during aerial observations of finback whales, he found that positioning the aircraft off to the side and downwind of the target animals reduced disturbance from engine noise. He also found that finbacks reacted to the shadow of the aircraft and that flying so that the shadow remained a short distance from the whales avoided reaction to it.

Ljungblad, Thompson, and Moore (1982) report that during acoustic work on the bowhead whale in the vicinity of Point Barrow, east to Prudhoe and Camden Bays, Alaska, sonobuoys were dropped from an altitude of approximately 60 m. The aircraft would then circle the target whales at an altitude of 300 m to avoid disturbing the whales and to lessen the background noise picked up by the deployed sonobuoys.

A.3.2 Vessels

There are many reports in the literature of baleen whales reacting to the presence of boats. However, as in responses noted to aircraft, many of the reports do not include the acoustic characteristics of the vessel.

Reactions to vessels include defensive behavior, changes in respiratory activity, and movement pattern shifts, including escape behavior, movement toward the vessel, and orientation changes.

In some cases, whales did not react to the presence of vessels. In discussing the nonreaction of feeding humpback whales in Newfoundland waters to the presence of small vessel activity, Brodie (1981, p. 289) states: "The degree of marine mammal reaction to disturbance may be related to their need to be in a certain area at a particular time and this may be governed by their energetics." This statement may be applicable to many of the following reports.

Herman and co-workers are currently engaged in a multiyear study in Southeast Alaska to determine what effect, if any, vessel traffic has on the summering humpback whale population (see Marine Mammal Commission, 1980, Herman and Baker, 1982, Baker, Herman, Bays, and Bauer, 1982, and Baker, Herman, Bays, and Stifel, 1982). Concurrent with this study, Bolt Beranek and Newman Inc. has determined the acoustic environment of Glacier Bay and Frederick Sound/Stephens Passage (Malme, Miles, and McElroy, 1982, and Miles and Malme, 1983).

The Herman team analyzed humpback whales' responses to five categories of boat presence: 1) no boat/control; 2) obtrusive, in which the boat would either circle the whale or whales, or pass in front of or behind a whale, with engine speeds changed abruptly and frequently; 3) unobtrusive, in which a whale or group of whales was tracked with the boat keeping parallel to the target whales, and a steady engine speed maintained; 4) passbys, in which the boat would follow a straight-line path by the whale or whales without changing its course or speed; and 5) opportunistic passbys. Preliminary findings indicate that in a comparison of the categories of obtrusive vs no boat/control, the whales during obtrusive trials would show a decrease in mean time between blows (blow interval) and showed an increase in mean dive times, as compared to the control trials. A graded response was observed so that as the distance from the boat to the whales increased, the effects decreased. The behavior, size, and distance of the vessel contributed to its impact on the whales. They found that the low incidence of aerial behaviors (breaching, lobtailing, etc.) made such behaviors unreliable indicators of disturbance. They did note, however, a few instances of intense aerial activity which appeared to be the result of boat activity.

At Bartlett Cove, data were obtained on three "resident" adult whales and one calf. The responses of the adults to the presence of large ships was positively correlated with the incidence of aerial behavior. Herman and his co-workers note that one day, a mother/calf pair was observed heading north into the cove. No aerial behavior was noted. A vessel was approximately 2500 m away and reported that she was changing speed. This change was accompanied by a sharp rise (16 dB) in sound level. The calf breached three times and head slapped once within 20 sec. of the engine speed change. When the vessel was 2100 m away, she increased speed. This change resulted in an abrupt drop and then an increase in sound level (16-dB rise). This rise in sound level was immediately followed by the calf's breaching 11 times over a 3-min. period . Although the behavior of the calf could not be positively related to the rise in decibel level, the observation is, nevertheless, an interesting one when seen in light of the Herman team's research, which showed an increase in aerial behavior in adults in the presence of large ships.

Forestell and Herman (1979), Herman and Forestell (1977), and Herman et al (1980) found that the "defensive behavior" response described in the Aircraft section of this report also holds true for humpback whales' response to boats. However, no quantitative data are presented.

Herman (1979) speculates that the retreat of whales near Oahu, Hawaii, which began during World War II, may be the result of the war itself, increased boat traffic and construction activities, and possibly a decrease in whale sightings during the war because of military-related restrictions. This decrease in numbers may indicate an ability on the part of the whales to make an adaptive response by habitat shifts and local site alterations. Norris and Reeves (1977, p 65), concerning this tentative conclusion, state: "It should be cautioned that the apparent decline in numbers may relate to natural, long-term cycles, or to heavy whaling on the Aleutian grounds in the early 1960's."

Jurasz, Jurasz, and Streueller (1979) state that increased boat traffic, most importantly in Glacier Bay, has caused humpback whales to vacate this feeding area. This conclusion is now undergoing scientific assessment by research supported by the National Marine Fisheries Service, Seattle (see the previous two pages in this literature survey for a summary to date of the work by Herman and his co-workers and Bolt Beranek and Newman Inc. A hierarchy of behavioral displays by humpback whales toward various craft was observed by Jurasz and Jurasz (1977). These behaviors were classified as distress/aggression and were measured in terms of respiration rates and patterns. Jurasz and Jurasz (1980) characterized the "normal" respiratory rate of humpback whales in Southeast Alaska, and then compared this rate with whales subjected to the presence of vessels. They note that changes in respiration rate occurred when whales were approached by vessels and by killer whales (Orcinus orca). They classified this reaction as stress-related and observed that some aerial displays and in-air vocalizations that they could relate to vessels, interactions with killer whales, or other humpback whales were also indicative of stress (see also Jurasz and Palmer, 1981).

Hall (1979) in his assessment of the cetaceans of Prince William Sound, Alaska, reports on three species of baleen whales: minke, fin, and humpback. During tagging operations, he states, minke whales were relatively easy to approach if the engine speed of the vessel was not varied. He reports that finback whales, contrary to other reports, frequently paid little attention to an approaching vessel and were "unusually docile." He notes that both minke and humpback whales would show curiosity toward motionless vessels by approaching them, apparently responding to various ship noises. This behavior was widespread during June in Prince William Sound and would occasionally be carried on throughout the rest of the summer months. This decrease in curiosity could possibly be the result of whales' adapting to the presence of vessels as the season progressed. The author speculates that if this behavior is not site-specific to Prince William Sound but holds for other areas as well, then these species may approach drilling rigs and support vessels associated with OCS development, attracted by their surface-generated noise. Hall and Johnson (1978) found while surveying cetaceans in Prince William Sound that minke whales were not difficult to approach by boat if the engine speed was not varied during the approach. They found humpback whales frequently inapproachable, and finbacks easy to approach and very docile.

Matkin and Matkin (1981), during surveys of marine mammals in Prince William Sound, were unable to correlate specific behavioral changes of humpback whales in the vicinity of motorized recreational boats. They note that whales were not observed vacating an area during the presence of boats. They did observe aerial behaviors (breach, lobtail, or flipper slap) presumably caused by the close approach of a boat. However, in general, behavioral changes were not predictable. Lawton (1979, cited by Cuccarese and Evans, 1981) also observed aerial behavior in humpbacks in Southeastern Alaska, when small boats would approach rapidly. However, on two occasions he saw no change in feeding behavior when cruise vessels passed to within 8 to 10 m of the whales. Hall (1982), studying humpback whales in the Prince William Sound area, did observe behavioral changes when his 9-m survey boat approached whales within 92 m, at speeds of 18.5 to 27.8 km/hr. The whales would dive and either surface 92 to 552 m behind the boat or surface at right angles to their previous path. However, the whales continued to feed in the area. Hall notes that care was taken not to change engine speed when near the whales, a maneuver which other researchers (Hall and Johnson, 1978, Swartz and James, 1978, Hall, 1979) have shown to cause behavioral changes in humpbacks and other baleen whale species.

Mayo (1982) discusses "site tenacity" in the distribution of individual humpback whales in the waters off Cape Cod, Massachusetts. He states that one whale stayed in the same area - an area that was in the outbound Boston shipping channel - from April to June during its feeding season. This area was also adjacent to areas of high-level human activity, including intense fishing and whale-watching activity. Rice and Wolman (1981) state that the humpbacks which stay in the inshore waters during their feeding season show a strong site fidelity and that aggregation area dispersal occurs rarely, if at all.

Braham et al (1980, p. 17) state in discussing bowhead whales that "surface noises appear to cause more frequent fright reactions than noises originating in air." They report that a boat with a running outboard engine (unspecified size) will cause bowheads to leave an area. Bowhead whale reaction to being pursued is characterized as "docile escape."

Nishiwaki and Sasao (1977) relate the decline in the yearly catch of minke whales on the Yobiko, Japan, whaling grounds to an increase in boat traffic. However, Fraker and Richardson (1980, p. 65) note that "...they (Nishiwaki and Sasao) base their conclusions on changes in 'catch-per-unit-effort' resulting from different types and numbers of vessels fishing for different periods of time. Because so many variables changed during the period when their data were gathered, it is impossible to interpret their data."

Brodie (1981) observed the capelin fishery off Newfoundland, which inluded 40+ large trawlers. He notes that the surface noise generated by these trawlers was apparent to the human ear and speculates that the underwater sound must have been louder. He reports, however, that there were several hundred humpback whales feeding in the area and that many of them were near the fishing vessels. He notes that humpbacks often feed in the inshore waters around Newfoundland, concurrent with small boat activity. Four large whales (apparently humpbacks) were seen feeding near shipping lanes in Halifax harbor on 9 February 1981. A feeding minke was noted there the previous year.

During radio-tagging experiments on finback whales in the Gulf of St. Lawrence, Ray, Mitchell, Wartzok, Kozicki, and Maiefsk (1978) measured various respiration rates of whales before, during, and after tagging; the time spent at the surface was significantly longer before a chase than during or after tagging; and downtimes were significantly longer before a chase than during a chase. However there was no significant difference in downtimes before a chase and after tagging. They found no significant difference in the number of breaths per surfacing and the time spent at the surface when comparing during and after tagging periods. The authors note that their data may contain some bias because of difficulty in reidentifying the same individual. This would cause the number of blows per surfacing and the surface time to be overestimated and the downtimes to be underestimated. They also state that any resulting error would be small because of the tendency for the whales to behave synchronously.

Watkins (1981a) notes that during studies of finback whales in the waters off Cape Cod, Massachusetts, the whales would often make closer approaches to vessels that were smaller and quieter than they would to ones that were larger. No quantitative data are presented in this report. However, Watkins (1981b) gives a detailed description of fin whales' response to boats engaged in tagging operations in Alaskan waters. The boat used for the tagging operations was 10.5-m long with a gas powered engine. In one case, the boat was nearing three finbacks that had surfaced together. The boat approached at 20 km/hr and stopped without reversing propellers. The whales moved away quickly as the boat approached. In another case, the boat made a careful approach at 18 km/hr to two finbacks. One whale was tagged. Neither whale showed any observable reaction to the boat or to the tagging. However, when the propellers were put into reverse, the whales accelerated their speed, dove for approximately 10 min. (not an unusually long dive for finbacks), blew twice and dove, and were not found again that day. In another incident, the vessel approached a finback at 10 km/hr, reducing speed as the whale surfaced alongside the vessel. The boat slowed to a stop as the whale continued to swim slowly near the vessel.

Underwater recordings were made when the boat made sudden speed increases and sharp turns, and when it reversed propellers, showing loud underwater cavitation sounds which may contribute to "disturbed" behavior. Startle reactions were also noted when whales became aware of a drifting boat or even a hydrophone cable. Watkins (1981b, p. 597) concludes, "The whales' reaction to tagging, therefore, appeared to be related more to response to boats rapidly approaching and sudden underwater noises than to the implantation of the tag."

During minke whale tagging cruises in Antarctic waters, Horwood (1981) notes that minke whales that were feeding were usually easy to approach and did not pay any noticeable attention to the vessel. Horwood systematically looked at responses of minke whales to vessels and divided the responses into six behavioral categories: 1) approaches a stationary or slowly moving vessel; 2A) approaches a rapidly moving vessel; 2B) rides at the bow or stern; 3) actively avoids vessel; 4) shows no obvious reaction to vessel; and 5) dives. Horwood (personal communication, 1982) notes: "Searching speed was 10-12 knots, when a whale was sighted speed was increased to 15 knots, but as the school was approached the speed was cut so as not to disturb the whales if they were not already running. The cut speed would be near zero." The results of his observations are as follows:

Behavior Category	# Times Observed
1 or 2A/B	2
3	97
4	76
5	159
4-3[1]	165
5-3[2]	104

1) The whale would first show no obvious reaction to the vessel, followed by active avoidance.

2) The whale would dive and then actively avoid vessel.

Although Horwood (1981) concludes that there is little evidence for avoidance or attraction of minke whales to tagging vessels, his data do show that when considering nonhyphenated response categories, whales either dove or actively avoided an approaching vessel in 256 cases, but showed no obvious reaction to the vessel in only 76 cases. Horwood (personal communication, 1982) notes that "In the North Atlantic, minke whales are supposedly caught by the vessel stopping and attracting whales to the ship." This statement is echoed by Larson (1981) who states that "... minke whales, especially the younger ones, have been noted by some investigators to exhibit a seeking behavior in response to vessels..."

Ohsumi (1980) reports that in 1968 Japanese coastal whalers started using fast outboard motorboats in order to catch minke whales. He notes that they are frightened by the noise and try to avoid the boat by swimming at the surface, thus making themselves easier targets for the whalers. He also notes an increase in catch-per-unit-effort from 1968 to 1972 coinciding with the use of fast outboard motorboats. However, he states that it is difficult to make this correlation, since there is no information regarding specific effort rates for a single boat operating with and without an outboard motor.

Levenson (1969) reports that humpback whales in Bermuda waters would actively avoid the approaches of fast-moving powerboats. He notes that the whales would remain submerged for 3 to 5 min. and surface for 20 to 30 sec. He classified the normal respiratory pattern into short dives of 2 to 4 min, respiration characteristics and dive times, the number of respirations per surfacing, blow interval, short-period dives (shallow dives between respirations), and duration of sounding dives. He found that there was an increase in duration of shallow surface dives between blows and an increase in duration of surfacings between dives for whales which were being "hunted" or pursued by a vessel. The data presented are difficult to interpret because of lack of information on vessel speeds, possible variations in hunting techniques, and the fact that the data, at times, combine two or more whales under one heading.

Perhaps the most rigorous experiments conducted to determine the effects of vessels on whales are reported by LGL Ecological Research Associates as a result of two years of study of the undisturbed and disturbed behavior of bowhead whales in the Eastern Beaufort Sea. This study, currently sponsored by the Minerals Management Service (previously funded by the Bureau of Land Management), is now in its third year. Fraker, Green, and Würsig (1981) describe the responses of bowhead whales to the vessel IMPERIAL ADGO, a 16.1-m boat with two GM diesel 8-cylinder, 2-cycle engines capable of a speed of 40.7 km/hr (2100 rpm). There is a 2:1 reduction gear box and each propeller has three blades. Data were taken on 23, 24, 26, and 27 August. When looking at the orientations of whales equal to or less than (≤) 900 m from the vessel, they found that when the boat was moving, the orientation of the whales was significantly different from uniform. When the boat was idling, the difference was still statistically significant, although to a lesser degree. When comparing various engine conditions (i.e., off vs idling), they found that the greatest statistical difference in the whales' orientations occurred when comparing engine off to engine engaged. However, the other two engine conditions, off vs idling, and idling vs engaged, were also found to be statistically different in regard to whale orientations. They found that whale orientation was related to the distance from the boat. The question was asked "Were orientations of bowheads $\leq$ and >900 m from the boat similar?" When the engine was off, no significant difference was found. When the engine was idling, there was a tendency for the whales to orient away from the boat at $\leq$ 900 m; when the engine was engaged, the whales $\leq$ 900 m from the boat did orient away from the boat to a significant degree.

On 27 August 1981 an opportunity arose to conduct a vessel disturbance experiment on a group of four bowheads that were more or less stationary. The vessel IMPERIAL ADGO was directed by an aircraft, thus allowing aerial observations of predisturbance controls: boat engine off, distance from whales 3.7 km; disturbance: boat engines idling; disturbance: boat moving near whales; and postdisturbance: boat leaving whale area. The findings are briefly outlined below.

A) Control period - longer surface times, constant duration when compared to whales affected by boat.

B) Idling engine - reduced mean surface time from control.

C) Boat moving near whales (cruising speed) - mean surface time lower than B, with increased variability (near vs control).

D) When IMPERIAL ADGO was within 1 km, the whales' response was to avoid the vessel actively.

E) Postdisturbance, boat leaving whales - the mean surface time increased but remained more variable than pre-disturbance control.

F) Reduced surface time coincided with reduced number of blows per surfacing.

G) Whales spread out more when disturbed by boat - the mean estimated "distance to nearest neighbor" was 112 m for the control period, as compared to 562 m for all disturbance categories including postdisturbance.

Observations were also made on the response of approximately 15 bowheads that were apparently feeding in an area 18 km east of Allen Island. A vessel was first observed approximately 4.6 km from the whales headed toward it. Aerial observations of the vessel/whale interaction were made from an altitude of 610 m. No observable reaction was detected until the boat was within about 800 m. The whales, then oriented away from the boat, appeared to observers to attempt to outdistance the vessel. When the boat was within 300 m, all the whales dove. When the boat had passed the whale concentration by 800 m, the whales oriented themselves in a number of different directions. Statistical tests run on the various orientations showed significant differences in the whales' orientations before and after the boat passed through the group. Upon returning to the area three hours later, observers found that bowheads (presumed to be the same animals) were still in the area. The researchers found no evidence that bowhead whales leave an area after being presumably disturbed by a boat. (For a complete summary of bowhead reactions to boats, see Fraker, Richardson, and Wursig 1982.)

A.3.3 Surface and Underwater Explosions

Friedl and Thompson (1981) conducted acoustic measurements of waterborne noise from gunfire by a surface vessel in waters north of Kahoolawe Island, Hawaii, in 1980. Recordings were made from seven SSQ-57A sonobuoys deployed by a P-3 aircraft. They noted that humpback whale vocalizations were the dominant element in the ambient noise spectrum, with peak energies at 500 Hz. The broadband source level of the gun shots was calculated to be 175 dB re 1 μPa at 1 m. The mean of the seven best measurements of vocalization source levels for humpback whales, made by Naval Ocean System Center personnel in Hawaiian waters in 1975, was determined to be 186 dB re 1 μPa at 1 m (σ ±5 dB). Behavioral observations and the distribution pattern of humpbacks during gunshot sequences are presented. The authors conclude that "No standards exist to evaluate the effects of the noise on marine mammals and thus the task could not assess the impact of the exercise on marine mammals." However, a humpback whale vocalization was heard and recorded at 0851 just after a five-shot sequence. (Locational data provided in the paper were used to calculate that the whale was approximately 20 km from the gunshot.) The phonation was tonal at approximately 500 Hz.

Payne (1978) reports that while recording humpback whales near Bermuda, a naval ship was in the vicinity, experimentally insonifying the area. The frequency of the explosions produced by the naval ship was within the range of the humpback whale's song. The author notes that an analysis of a continuous series of humpback whale songs during and in the absence of explosive testing in the area showed no apparent differences in song structure or continuity.

A.3.4 Sonar

During surface whale observations off Mozambique, Rorvik (1980) saw a large Balaenopterid whale in approximately 2500 m of water. He notes that the whale appeared to be frightened by the vessel, moving away from it at the same speed as the vessel, approximately 18.5 km/hr. He speculates that the whale may have exhibited this fright response because of the ship's sonar.

McCarthy (1946) notes that a blue whale was observed swimming slowly about 400 m from the boat. When the Asdic (sonar) was turned on, the whale immediately increased its speed. The author states, however, that in most cases the Asdic did not seem to cause any observable change in the whales' behavior.

Horwood (personal communication, 1982) notes that sonar is not used during tagging operations on minke whales because "it scares the whales." He states, "It has been suggested that deep-diving-hiding whales (thus difficult to mark) could be made to swim on the surface by a blast from the sonar."

A.3.5 Offshore Oil/Gas Operations (Excluding Helicopters)

Fraker et al (1981), during two sets of survey flights in the latter part of July and first three weeks of August, found relatively large numbers of bowhead whales near an artificial island construction site in the Eastern Beaufort Sea. The construction site equipment included a large suction dredge, a barge camp, 2 to 4 tug boats, and 1 to 2 crew boats. The authors noted several whales close to the site, with the closest being approximately 800 m away. Twenty whales were sighted within 5 km of the artificial island, and 64 were within 10 km. The observers could not determine, due to the variable distribution of whales in the survey area, if the whales were avoiding or were attracted to the area, or whether the density of bowheads near the construction site was significantly different from other areas. The industrial sound environment was not established during the observations. The authors conclude that some whales appear to show tolerance of the boats, artificial island construction,and the sound associated with these. They add, however, "Whether the area is still as suitable for feeding or other purposes as it was before offshore development began is not known." (p. 184). Observations were made of bowhead whales as close as 4 km from an operating drillship. The authors noted "...no consistent indication of unusual behavior among whales observed within 20 km of drillship" (Richardson, Fraker, Würsig and Wells 1983, p. 5). (Note: That report, an extended abstract, provides a very good summary of the three years of work on bowhead whales in the Beaufort Sea.)

Fraker et al. (1982) found inconclusive evidence that bowhead whales change their respiratory characteristics during seismic exploration activities at distances between 6-20 km. In two experiments with single airguns at a 5 km and 3 km range, varied responses were noted. There was a significant decrease in the number of blows per surfacing and surface times during the 5 km test possibly associated with the onset of the experiment. Bowhead sound production was also significantly lower when compared with control periods during the 5 km test.

Ljungblad et al (1982) noted that during an aerial survey in the southern Chukchi Sea, a group of three finback whales (including a mother/calf pair) exhibited no apparent response to an active seismic vessel that was 45 km away.

Reeves and Ljungblad (1983) concluded that the onset of seismic operations may have caused a large group of bowhead whales to change their respiratory behavior and orientations, although they stress that their observations were qualitative, because of weather and fuel constraints. They conducted aerial observations of bowhead whales in the Alaskan Beaufort Sea, flying at 305 m during transits and approximately 450 m while circling, making behavioral observations. During one observation, 18 bowheads were observed in a 2- to 3-km radius. The whales were in groups of 1, 2 to 3, and 6 to 7 animals, each group separated by up to 1 km. The whales' surfacings were both synchronous and asynchronous, while their orientations were termed random. A seismic vessel (distance to whales not given) commenced operations during their observations. A complete change in the behavior of this large group was noted shortly after the vessel began firing. The whales formed one large group of 12 to 14 with 4 to 6 other singles within 1 km of the main group. Surfacings of the large group became almost synchronous. The whales stayed in very close contact with each other (some touching) while remaining at the surface. They were also oriented toward each other.

Reeves and Ljungblad (1983) also observed bowhead whales 9 km away from active seismic operations. The whales did not exhibit any discernable avoidance and they did not leave the area. Preliminary results showed that the mean surface time increased although there was no significant change in dive times or blow intervals. The authors note, however, that their results must be viewed with caution because of the possibility of unqualified variables entering into their results (e.g., annual variation in respiration characteristics).

Kapel (1979) reports that a total of 261 baleen whales were seen from support vessels that were stationed "at or near" three offshore oil drilling sites in Davis Strait, off the west coast of Greenland. The sighting included mostly minkes, finbacks, and humpbacks, with two blue whales and one bowhead sighted. Fraker et al (1981) note, however, that "Unfortunately, the observational procedures, proximity of the whales to the drill ships, and behavior of the whales were not reported." Also not reported was whether these vessels were stationary with engines off, idling, or moving. Kapel notes that overall distribution of whales observed in West Greenland waters is in good agreement with the 1952 catch data of the whaling ship SONJA KALIGTOQ and the distribution of Norwegian catches in 1924.

A.4. RESPONSES OF GRAY WHALES TO NOISE AND DISTURBANCE

It is surprising that for the amount of research carried out on gray whales and their proximity to land during migration, there is not much information in the literature on gray whale response to various sound sources. Perhaps the reason is that in the past much attention has been given to censusing the California stock and quantifying its recovery.

Reeves (1977) provides an excellent summary of the problems of gray whale harassment in the breeding lagoons. All of the disturbance accounts are anecdotal in nature. However, as stated elsewhere in this report, we feel it is important to have a firm understanding of response of whales to a variety of stimuli in order to assess our own data more effectively. Therefore, some of the studies that Reeves discusses have been reviewed, as well as other reports.

The most intensive study of the reactions of gray whales to disturbance has been reported by Swartz and Jones (1978) in their multiyear study on the gray whales of San Ignacio Lagoon. Their research is detailed in the following sections.

We have divided the acoustic stimuli into six types: aircraft, vessel, underwater explosion, near-shore construction activity, playback experiments, and offshore oil/gas operations (excluding helicopters).

Tables A-3 and A-4 summarize the findings from review of the major sources of information regarding responses of gray whales to acoustic stimuli. Table A-3 relates to aircraft-related responses and Table A-4 presents responses to boat-related stimuli.

TABLE A-3. RESPONSES OF GRAY WHALES (*Eschrictius robustus*) TO NOISE AND DISTURBANCE - AIRCRAFT.

Whale Activity	Group Size	Group Composition	Type of Craft	Activity	Altitude
—	—	—	—	Repeated flyover	"Low"
Swimming, belly-up	1	—	—	Approaching	—
—	2	M/C	Helicopter, size & type unspecified	Hovering	3-9-1
—	—	—	Helicopter, size & type unspecified	Herding whales to shallow water	3-9-1
—	—	—	Helicopter, size & type unspecified	Firing tranquilizer darts	—

Speed (km/hr)	Position w/reference to whales	Response	Comments	Reference
—	—	Long dive	See discussion, p.	Calkins, in press
—	—	Roll, dive	Whale accompanied by pilot whale which also dove	Leatherwood, 1974
—	—	M shield C	—	Walker, 1949
—	—	Aerial behaviors	—	Walker, 1949
—	—	Swim in tight circle, female long dive	—	Spencer, 1973

TABLE A-4. RESPONSES OF GRAY WHALES (Eschrictius robustus) TO NOISE AND DISTURBANCE - BOATS.

Whale Activity	Group Size	Group Composition	Type of Craft	Activity	Distance (m)
--	--	--	Small, type unspecified	"Heavy traffic"	--
Feeding	--	--	--	--	--
--	--	--	Large ships, type unspecified	--	"Near"
--	--	--	--	Survey	--
--	--	--	--	Survey	--
-	--	--	--	Whaling (pursuit)	--
Feeding	--	--	--	--	350-550
Feeding	--	--	--	--	< 550
Feeding	--	--	--	pursuit	--
--	--	--	Inflatables, small aluminum or wood skiffs	--	--
--	--	M/C (newborn)	Motorboat, size and type unspecified	Observation (approaching)	25
--	1	--	--	--	--
Mating, Spyhopping	--	--	Outboard motorboat, size & type unspecified	Whale watching (approaching)	30-40/10-15
Mating	2	--	Outboard motorboat, size & type unspecified	Whale watching (approaching)	2-3
--	--	--	--	Approaching	--
--	2	--	Skiff, size & type unspecified	Observation (approaching)	--
--	--	--	Skiff, size & type unspecified	Observation (approaching)	--
--	--	--	--	Whale watching	--
--	--	--	--	Whale watching (moving away)	--

Speed (km/hr)	Position w/reference to whales	Response	Comments	Reference
—	—	Site tenacity	—	Carl, 1968
—	—	Site tenacity	—	Hatler & Darling, 1974
—	—	"Potential tolerance"	—	Burns & Morrow, 1973
—	Ahead	Whale veers aside, then resumes course	Whales on southward migration	Wyrick, 1954
—	Behind	No observable reaction	Whales on southward migration	Wyrick, 1954
—	—	Surface without apparent blow. Lactating female dive time reduced.	No statistical tests for significance.	Zimoshko & Ivashin, 1980
— —	— —	Continue feeding but move away	—	Bogoslovskaya *et al.*, 1981
—	—	No observable reaction	—	Bogoslovskaya *et al.*, 1981
—	—	Stop feeding, leave area	—	Bogoslovskaya *et al.*, 1981
3.7-7.4/idle/engine off	—	Whales approach/stay near/terminate contact	Behavior occurs only in area of small boat traffic	Dahlheim *et al.*, 1981
—	—	Move away, mill	M=highly tolerant	Mills & Mills, 1979
engine off	—	Whale circles, then moves on	No machinery running on board	Eberhardt & Evans, 1962
—	—	"Uneasy"/move rapidly away & surface 100+ m distant	—	Kenyon, 1973
—	—	No response, then dive & leave area	Whale watching boats more disturbing than tugs and barges operating in area	Kenyon, 1973
—	—	Move away/avoidance decrease/avoidance increase as M/C arrive on ground	Seasonal change in response; whales become more active as boat activity increases	Swartz & Jones, 1978
—	—	Drop in respiration rate	—	Swartz & Jones, 1978
Moderate/idle/drifting	—	Avoidance/less avoidance/slight increase in avoidance	Whales least disturbed when approached at speeds close to their own	Swartz & Jones, 1978
Not moving	—	Approach & stay near/repeated curiosity by same individual/M/C attract others	Impact of curiosity on reproductive success unknown	Swartz & Jones, 1981
—	—	Whales attempt to follow	—	Swartz & Jones, 1979

A.4.1 Aircraft

There is very little detailed information on the effects of aircraft (re altitude and sound) on the gray whale. What is present in the literature is primarily of an anecdotal nature, and is incidental to other studies.

Walker (1949) reports on an early expedition led by C. Hubbs to San Ignacio Lagoon to study and photograph the gray whale. Aerial observations were made using a helicopter (model not specified). The helicopter was used to herd the whales into shallow water so that photographs could be taken more easily. The helicopter's altitude was below 7.6 m or 9.1 m, and sometimes as low as 3 to 4.6 m above the whales. When the helicopter was hovering over a mother and calf, it was noted, the mother would occasionally attempt to "shield" the calf with her body. After the helicopter hovered over the whales and herded them to shallow water, a distinct change in the whales' behavior was noted:

> Instead of swimming along in a placid manner, some of the Grays churned the water with flukes and fins until their wakes became swirling cauldrons of foam. Before such displays of angry power, the pilot invariably lifted the craft to a safe 25 or 30 feet.

Leatherwood (1974) notes that while conducting aerial surveys off Southern California in March 1973, he observed several gray whales with approximately 200 pilot whales (Globicephala melaena) along the west side of Catalina Island. One of the gray whales was lying belly-up in a group of twelve to fifteen pilot whales. One pilot whale was swimming over the gray whale. Leatherwood states: "Both whales were alarmed by the aircraft and sounded on our approach." (p. 50). The type of aircraft and its altitude were not given.

During physiological studies on gray whales in Laguna Ojade Liebre, Baja California, Mexico, Spencer (1973) flew in a helicopter to fire tranquilizer darts into gray whales. Although the type of helicopter and its altitude are not given, it is presumed that the altitude over the whales was quite low so that the darts could be placed successfully. Spencer notes that the presence of the helicopter caused the whales to turn in a tight circle. A female was observed attempting to stay beneath the surface and not to rise and blow under the helicopter.

A.4.2 Vessels

Many of the behavioral observations of gray whales in the presence of vessels are ancillary to the main topic of the given report. However, the work by Swartz and Jones (1978) is an exception.

Wyrick (1954) conducted a vessel survey of gray whales off the coast of San Diego during the southward migration. He notes that when the vessel came within 200 to 300 m ahead of a whale, the animal would veer either to the east or west until clear of the vessel, and then continue on its southerly course. He goes on to say that as long as the vessel stayed approximately 0.5 km away from the whale it was following, there was no observable change in the animal's behavior when compared to other whales under observation from greater distances. The size of the boat, its engine characteristics, and speed at the time of observation were not given.

Dahlheim, Schempp, Swartz, and Jones (1981) report that gray whales in San Ignacio Lagoon seek out small outboard motor vessels that are moving at speeds from 3.7 to 7.4 km/hr. The types of vessels sought out include inflatable Avons and Zodiacs and aluminum and wooden-hulled skiffs. They note that whales maintained their proximity to these boats for as long as three hours when engines were set at idle and that some of the whales would terminate boat contact when the engine was turned off.

These behaviors occurred only in areas where gray whales were repeatedly exposed to small vessel traffic. This behavior has been noted for the past four years (now five years) in San Ignacio Lagoon and more recently in Guerrero Negro Lagoon, as well.

During whaling operations in the vicinity of the Chukotka Peninsula, a gray whale feeding area, Zimoshko and Ivashin (1980) note that when grays are being chased, they appear at the surface without seeming to blow, although they do reveal their blowholes. The authors note that lactating female gray whales normally dive for 1.42 to 5.32 min. with a mean dive time of 2.7 min. When chased, the whales' dive times became slightly less, 1.0 to 4.97 min., with a mean of 2.28 min. Statistical methods were not employed to determine if the difference is significant.

At the entrance to Bukhta Provideniya on the feeding grounds, Bogoslovskaya, Votrogov, and Semenova (1981) observed gray whale reactions to ship traffic. They noted that if a vessel was at a 350 to 550 m distance from feeding whales, the animals would move away from the vessel, but continue feeding in the same general area. If the vessel was greater than 550 m from the whales, no observable reaction or avoidance could be detected. Whales being pursued would stop feeding and leave the area. It was not noted if the whales would return to the same area after pursuit.

Carl (1968) notes that presumably the same whales stayed in the same general area near Vancouver Island for several weeks during the summer of 1967, despite small boat traffic which was characterized as "fairly heavy." This is consistent with Hatler's and Darling's (1974) findings that a group of whales summer in the waters off Vancouver Island, presumably feeding.

Ichihara (1958), while on a whale-marking cruise north of Unimak Pass, Alaska, observed a 10.7-m gray whale near the vessel. The whale was bleeding from a back wound. Nevertheless, the whale appeared to swimming in a "...regular pattern as described by others, without fright at the noisy tons of engine of our boat." (p. 202).

Eberhardt and Evans (1962) observed a gray whale approach within 35 ft of their research vessel at a time when it was stationary with no machinery running. The whale circled the vessel and then moved on.

Kenyon (M.S. 1973) observed gray whales at Scammon's Lagoon during mid-February 1973, as part of a tourist cruise. Three outboard motor boats launched from a 27.4-m twin diesel cruise vessel were used to observe the whales. Kenyon notes that as one of the small outboard motor boats approached whales that were either moving slowly at the surface or engaged in surface behavior such as mating or "spyhopping," the whales would begin to show "uneasiness" when the boat was 30 to 40 m away. At a distance of 10 to 15 m, the whales would move rapidly away from the boat, either travelling near the surface, or diving, surfacing 100+ m away from the boat. He notes that on one occasion, an outboard motor boat approached very close to a mating pair of whales. The whales continued mating, apparently undisturbed by the approaching boat, until the boat was within 2 to 3 m, when they suddenly dove and left the area. Kenyon estimated that during his two-day visit to Scammon's Lagoon, the rate of disturbance was 10 whales per hr, with 16 boat hours of disturbance, or a total of 160 whales disturbed. He observed that whalewatching boats caused much more disturbance to the gray whales in Scammon's Lagoon than did the tugs and barges operating in deep channels, associated with salt mining activity.

Mills and Mills (1979) witnessed the birth of a gray whale in Estero de la Soledad. Because of poor viewing conditions, the observation boat was moved to within 25 m of the whales after the birth. The mother and newborn moved away from the boat, then slowed down and started to mill. At this point the whales were not followed, and the authors note: "The female exhibited a high tolerance to our continued noisy presence. In what must have been trying circumstances for her, not once did she display any hint of aggressive recognition of our presence." (p. 195)

Gard (1978) conducted a number of aerial censuses of gray whales on their breeding lagoons. He notes that his 1976 census data were not consistent with previous years' work. The number of whales in Scammon's Lagoon and Magdalena Bay decreased, while the number increased in Guerrero Negro and San Ignacio Lagoons. He notes that the number of small boats increased in San Ignacio Lagoon, as did the number of whales.

Caton (1888) observed gray whales on their southward migration as he travelled down the California coast in a steamer. He notes that, on occasion, whales would appear close to the vessel. However, the ship appeared to have no noticeable effect on the whales' behavior.

The most systematic and detailed study of gray whales' reaction to boat activity is the work by Swartz and Jones (1978). They have spent a number of seasons at San Ignacio Lagoon surveying the gray whale population and examining population demographics.

During observations at Rocky Point, it was determined that the mean activity level of gray whales was 0.089 on days with no boat activity in the lagoon and 0.106 on days when there was boat activity. This activity level was found by dividing the number of whales passing Rocky Point per hour by the number of whales in the lagoon. The authors found that this difference was statistically significant, being slightly greater during boat operation days.

Whales in the lagoon showed a seasonal change in their response to boats. During the early part of the season (January), whales were easily disturbed and moved away from an approaching boat. However, as the season progressed, whale avoidance behavior decreased. This decrease in avoidance was found to be highly significant. (Using chi square statistics, this test was applied only to data from 8 January to 8 March, before the arrival of cow/calf pairs.) After cow/calf arrival, avoidance behaviors increased, suggesting that the whales that had been present in the lagoon prior to March 8 had built up a tolerance to boat traffic and that the new arrivals, the cow/calf pairs, were responsible for this increase, not being accustomed to boat traffic.

During January, whales responded to the research skiff on 25 of 25 occasions, by moving to one side or diving when in its path. However, during March, in 25 encounters with whales, only 13 moved out of the way or dove. The authors also note that gray whales avoided Mexican fishing boats and large sport-fishing vessels that were underway in 25 out of 25 observations.

The approach speed of the boat was found to be a factor in the number of whales that showed avoidance behavior. Whales avoided the research skiff 76% of the time when they were approached at a moderate speed, but avoided the boat only 35% and 39% of time when the boat was idling and drifting, respectively. These avoidance percentages are somewhat biased by the seasonal changes in the whales' behavior. Whales showed the least amount of disturbance when approached at a speed close to (but not exceeding) their own. It was found that whales exhibited the least amount of disturbance (3 out of 25) when approached slowly from behind or alongside without abrupt changes in engine speed.

Avoidance response varied with the whales' behavior. Sleeping whales avoided the approaching skiff 77% of the time, resting whales 61%, whales in transit 31%, and courting whales 30%.

"Normal" and presumably "disturbed" respiratory data were also taken. Prior to a boat approach (greater than 100 m from the whales), one whale's blow rate was 1.6 per min. After the approach began, the blow rate dropped to 0.8 per min. A second whale showed a similar decrease in respiration rate: 1.7 to 0.7 blows per min. Both whales were observed for 10 min. prior to the approach. Changes in respiratory and swimming patterns occurred in all 27 approaches in which transiting whales were passed by or herded into shallower water. It is noted that the number of visitors to San Ignacio Lagoon increased by 30% over the previous season; however, this increased activity did not affect the whales' distribution or large-scale movements in and out of the lagoon.

Behavior characterized as "curious" or "friendly" has been observed by a number of authors (Gilmore, 1976, cited by Reeves, 1977; Swartz, 1977; Lindsay, 1978; Swartz and Jones 1978, 1980, 1981; Swartz and Cummings, 1978; Dahlheim et al, 1981). Curious behavior consists of whales approaching very close to whale-watching boats and sometimes staying for extended periods of time. Swartz and Jones (1981) report that during the 1980-81 season in San Ignacio Lagoon, 26 out of 28 tour vessels experienced these curious whale encounters. During the 1978-79 season, Swartz and Jones (1979) report four types of curious whale encounters not previously observed: 1) whales approaching stationary large sport-fishing boats and remaining for extended periods; 2) single whales and cow/calf pairs appearing to attract other whales that are passing by; 3) repeated curiosity behavior by the same identified whale over extended periods of time; and 4) whales attempting to follow skiffs that are in the process of breaking away from the encounter, sometimes at vessel speeds in excess of 11 km/hr. Swartz and Jones (1980) conclude that the impact of curious behavior and tourist activity on the reproductive success of gray whales in the lagoons is not known, and that additional observations and evaluation of data are needed.

A.4.3 Underwater Explosions

There are very few observations of the reactions of gray whales to underwater explosions. The two that are related here are both anecdotal in nature.

Wyrick (1954) observed that when 1/2-pound blocks of tetryl TNT were detonated underwater within 457 m of a gray whale on its southward migration, the whale was not seen again.

Fitch and Young (1948) report on seismic operations in the coastal waters of California. Two types of underwater explosive techniques were used: open shots in which 40 or 80 pounds of explosive were floated a few feet below the water's surface and jet shots, in which 20 pounds of explosive were buried under the ocean floor. They note: "...California gray whales (Rhachianects glaucous) observed in the region of a blast were seemingly unaffected and in fact were not frightened from the area." (p. 56).

A.4.4 Construction Activity and Orca Interaction

Morejohn (1968) observed a gray whale/killer whale encounter from a long pier at Moss Landing, California. A mother and calf, upon encounter with the killer whales, moved very close inshore, coming to the first pier, and circling near it two or three times. The whales were surfacing and blowing every 68 to 80 sec. Morejohn notes that this is a higher respiration rate than normal, possibly due to the increase in activity of avoiding the killer whales. The gray whales left the first pier and travelled north, still very close to shore, to a second pier. They then surfaced and blew every four to five min. Circling behavior was noted at the second pier, and the whales travelled parallel to this pier and continued north. This second pier was undergoing construction, with pile-driving and hammering concurrent with the whales' presence. Morejohn states that the respiratory pattern of the whales was not noticeably affected by these construction activities.

A.4.5 Playback Experiments with Gray Whales

Cummings and Thompson (1971) conducted playback experiments on southbound migrating gray whales off Pt. Loma, CA. The experiments took place from a boat "...moored in 30 m of water, 33 m seaward of an extensive kelp bed," (p.525). Gray whales normally passed through this area, staying close to shore but avoiding the kelp bed. Experiments were conducted in daylight hours between 0830 and 1630 hrs.

Playback experiments were started when whales were anywhere from 150 m to 450 m north of the boat and when the whales were not "encumbered" by small boat traffic. A total of 77 experiments were completed on 132 whales (group size 1 to 4). Playback sessions lasted from 30 to 100 min. and they "... were alternated so that successive contacts would not encounter the same situation." (p. 527) Three types of sounds were used: 1) killer whale "screams" in a natural sequence (behavior of recorded killer whales was not noted), 2) two simultaneous pure tones of 500 Hz and 2000 Hz each, and 3) random noise in the band from 500 Hz to 2000 Hz. The 500- and 2000-Hz frequencies were chosen because they"... resembled the major frequency components in most of the recorded killer whale 'screams'." (p. 526). Controls were the random noise and pure tones as well as a no-playback situation. The peak source levels of the killer whale "screams" and the control stimuli were nearly constant, i.e., 151 dB re 1 newton/m^2 at 1 m in the 1969 trials and 176 dB in the 1970 trials. The authors note: "... (W)e expected sound pressure levels of the projected sounds to reach the prevailing ambient sea noise level in the third-octave band at 500 Hz, at about 1100 to 1400 m." (p. 526).

Results showed that of 36 groups of whales exposed to killer whale "screams", 30 showed avoidance, 3 showed no avoidance, and 3 reactions were rated "questionable." Avoidance reactions included turning around and heading north, away from the sound source, heading offshore from the source if their previous path had been outside the source, and heading into the kelp bed. It took anywhere from 5 to 30 min. for these whales to continue on their southward migration. Of the 10 groups contacted with pure tones, 2 showed avoidance and 8 showed no avoidance. The same was true for the 10 groups contacted with random noise. The 21 groups to which no playbacks were done showed no avoidance.

Observers on board the playback boat noted some interesting changes in the "disturbed" whales' surfacing and respiration characteristics. These whales would barely expose their bodies at the surface and their blows were noticeably less well defined (in some cases invisible and almost inaudible to the human ear at close range) than those of "undisturbed" whales. The surfacing of "undisturbed" whales "... involved the simultaneous appearance of head and blow accompanied by a well-defined surface wake." (p. 528). It is also interesting to note that during six years of study, the authors have only observed three instances of "spyhopping" gray whales during migration. However, "spyhopping" was prevalent among the whales who entered the kelp bed after being exposed to killer whale "screams."

A.4.6 Offshore Oil and Gas Operations (excluding helicopters)

During aerial observations in the Chukchi Sea, Ljungblad et al (1982) observed a concentration of 36 gray whales, including 1 mother/calf pair, and 3 finback whales, also including 1 mother/calf pair, (approximate location 67 30'N, 168 30'W) within 68 km of an active seismic vessel (12 to 14 sec. between shots). The gray whales were in groups ranging from 2 to 12 individuals and most were feeding (mud plumes seen). No change in behavior was observed. Two sonobuoys were deployed, one near a group of 12 feeding gray whales and one near the seismic vessel. The source level of the pulses from the vessel was 246 dB re 1 μPa at 1 m (citing Gales, 1982). A spreading loss of 20 log r was used to calculate the received sound levels at the gray whales. The levels were determined to be 154 dB re 1 μPa and 149 dB re 1 μPa for the closest (36 km) and the furthest (68 km) gray whales. The mother/calf gray whale pair was at a distance of 42 km from the seismic vessel. The sound level at this pair was 154 dB re 1 μPa. The calf continued to nurse during their observations. The three finback whales were 55 km from the seismic vessel. Sound level at this trio was calculated to be 152 dB re 1 μPa The group was slowly swimming during the seismic operations.

A.5 LITERATURE REVIEW SUMMARY

The literature search presented in Appendix A was performed to characterize the normal migratory behavior of the gray whale and to determine if introduced sound from a variety of sources, including offshore oil and gas development, would have an observable effect on that behavior. Because of the limited data on behavioral reaction of gray whales to noise and disturbance, we have also included in this literature review information on the behavioral reaction of other baleen whale species.

We discovered that there is very little information on the migratory behavior of the gray whale with which to compare our behavioral observations under experimental conditions. Most of the literature on gray whale movements concerns migratory corridors and censusing with very little data on respiration rates and no information at all on rates of different types of behaviors. Because of this, our only database of presumably undisturbed behavior was our own field observations during the south and northbound migration.

The gray whale, because of its nearshore migratory route, is exposed to a variety of man-made sound sources, including offshore oil and gas operations. In order to determine if these man-made sounds have an effect on the normal migratory behavior of the gray whale, we examined the baleen whale literature and categorized the sound sources into the following types:

1. Aircraft,
2. Vessels,
3. Surface and underwater explosions,
4. Sonar,

5. Construction activity, and

6. Offshore oil and gas operations.

Because many of the observed responses of baleen whales to sound sources are reported as ancillary information to the main topic of the paper, acoustic information on the sound source is not given.

We have included nonoil and gas related sound stimuli as possible sources of gray whale disturbance because the literature on the acoustic effects of petroleum-related activities on whales is not extensive. Because of the limited amount of data on reactions of gray whales to noise and disturbance, the comments here are a result of our findings related to baleen whales in general.

The responses of whales to aircraft were highly variable. This variability was caused by the type of survey being done (transient or behavioral observation), altitude at which survey was flown, type of aircraft and position relating to the whales, and activity of the whales. At altitudes above 457 m (1500 ft), there was generally no visible response. However, below this altitude response varied. A summary of the literature on the response of whales to aircraft is presented in Tables A-1 and A-3.

In general, the responses of baleen whales to vessels were variable. We found that whales engaged in a specific activity, such as feeding, would continue that activity when a vessel was in the vicinity. However, if the vessel approached (usually within 100 m), the whales would usually move away or dive. Changes in respiration rate and surface active behavior, such as lobtailing, were noted concurrent with the close approach of a vessel, however responses showed great variability. Much of the literature indicates a startle response to vessels when there is a sudden change in engine speed. The whales would dive and move away from the source at a rapid rate of speed. Researchers have found that gray whales in the breeding lagoons seem least disturbed when they are approached at speeds near to their own. Gray whale attraction to idling outboard engines was also observed.

Because of the limited number of reported responses of whales to surface and underwater explosions, sonar, and construction activity, we refer the reader to those sections in Appendix A.

In order to assess the reaction of gray whales to natural sounds in their environment, we examined in detail the one Orcinus orca playback experiment with gray whales. There was a high degree of avoidance shown by the gray whales exposed to these sounds. Also noted was a change in the gray whale surfacing and respiration characteristics.

There are few quantitative observations of whales in the presence of offshore oil and gas operations. Most of the observations concern bowhead whales in the Eastern Beaufort Sea, a Minerals Management Service Project being conducted by LGL, Inc. In general, the evidence was inconclusive that the whales' respiratory characteristics were altered in the presence of ongoing seismic operations at distances of 6 to 20 km. Single airgun experiments at distances of 3 km and 5 km showed varying effects with whales exposed to the 5 km test showing a significant decrease in the number of blows per surfacing and surface times. These effects were possibly due to the onset of the experiment. Other researchers have observed reactions by bowhead whales to the onset of seismic operation, with whales clustering together and synchronizing their surfacings. These observed effects, however, are of a qualitative nature.

There are very few observations of gray whales in the presence of seismic operations. Gray whales at a distance of 36 km from an active seismic vessel, experiencing sound levels of 154 dB re 1μPa, showed no visible reaction.

Section A.2 summarizes the various sound sources from offshore oil and gas operations and discusses the theoretical detection ranges of these sounds by baleen whales and their possible auditory effects. Because there is little data on the auditory capabilities of baleen whales, much of the information regarding detection ranges of sounds and possible auditory effects of these sounds are speculative in nature.

Our study has provided base-line data on the normal migratory behavior of the gray whale and has quantified the effects of various sound sources associated with oil and gas exploration and production on this normal migratory behavior. Although more observations under control and experimental conditions are needed to begin to assess the long-term effects of offshore oil and gas production on gray whales, we have, in our study, added a significant amount of information to the present database.

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APPENDIX B

TRACK PLOTS AND CUMULATIVE FREQUENCY DISTRIBUTION PLOTS

B.1 TRACK PLOTS FOR THE SOUTHBOUND GRAY WHALE MIGRATION IN JANUARY 1983

Track plots are presented for control and experimental conditions during the January playback period (Figs. B.1 through B.11). Figure 1 provides overlapping plots of undisturbed whale Group WW/WW8 which was first tracked by North site and then handed off and tracked by Soberanes site. Section 6 discusses this group in particular. See Fig. 1.1 for site positions. The remaining plots indicate the paths taken by all groups during each presentation of the stimulus condition listed. Tracks start with the first sighting after the playback started and with the last sighting before the playback ended. The thick curved line near the bottom of the plot shows the location of the coast line. The coordinates of the plot are kilometers north along the x-axis and kilometers west along the y-axis. The origin is centered on the Soberanes observation site. The VARUA is indicated by a triangle at 1.0 km north and 1.4 km west, while the Lobos Rocks are indicated by two octagons at approximately 0.5 km north and 0.8 km west. These plots are presented in the following order of playback condition - Control No Boat Present, Control VARUA Present, Orca, Drilling Platform, Drill Ship, Semi-submersible, Helicopter, and Production Platform.

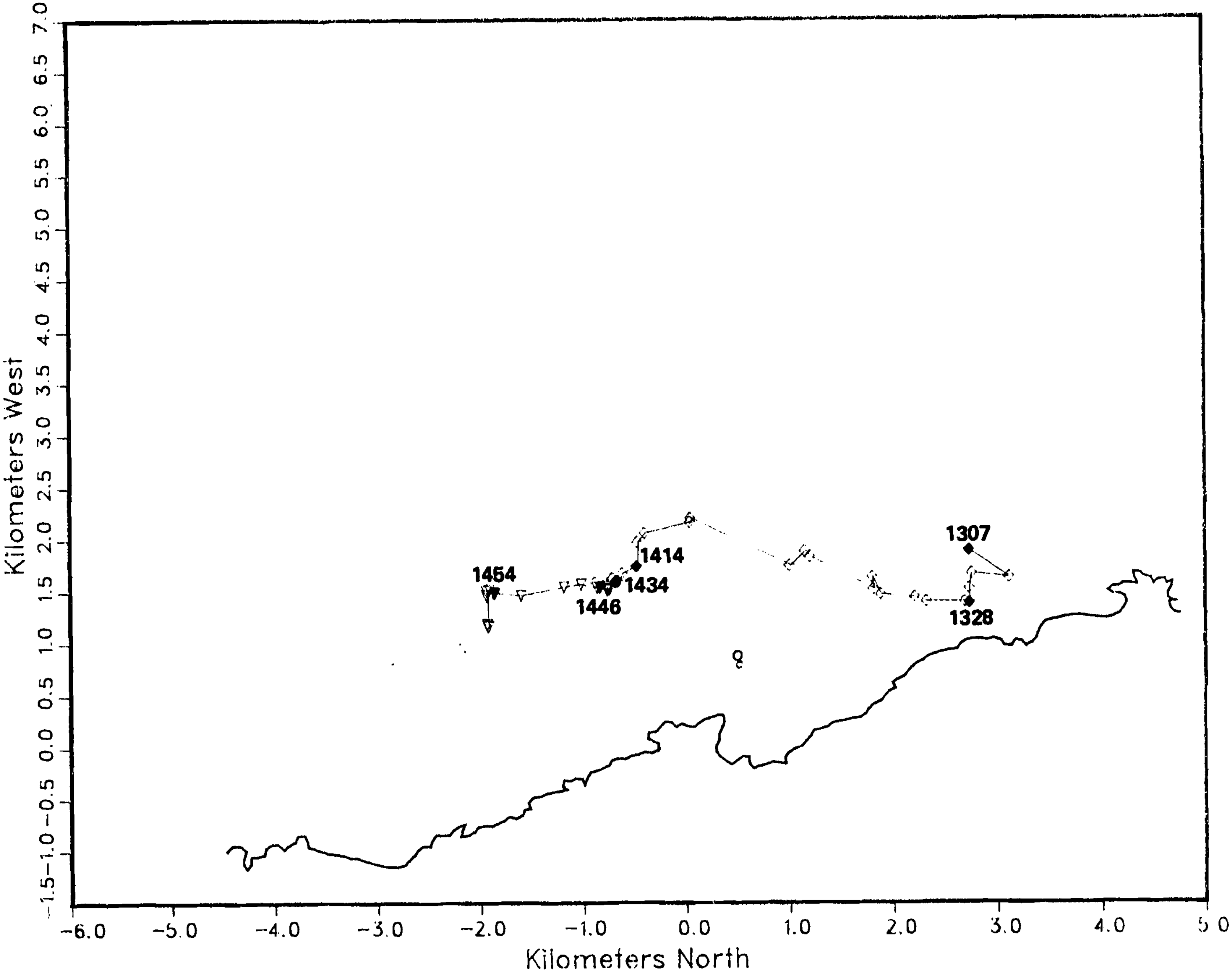


Fig. B.1. WHALE TRACKS WW & WW8, 15 JAN 83.

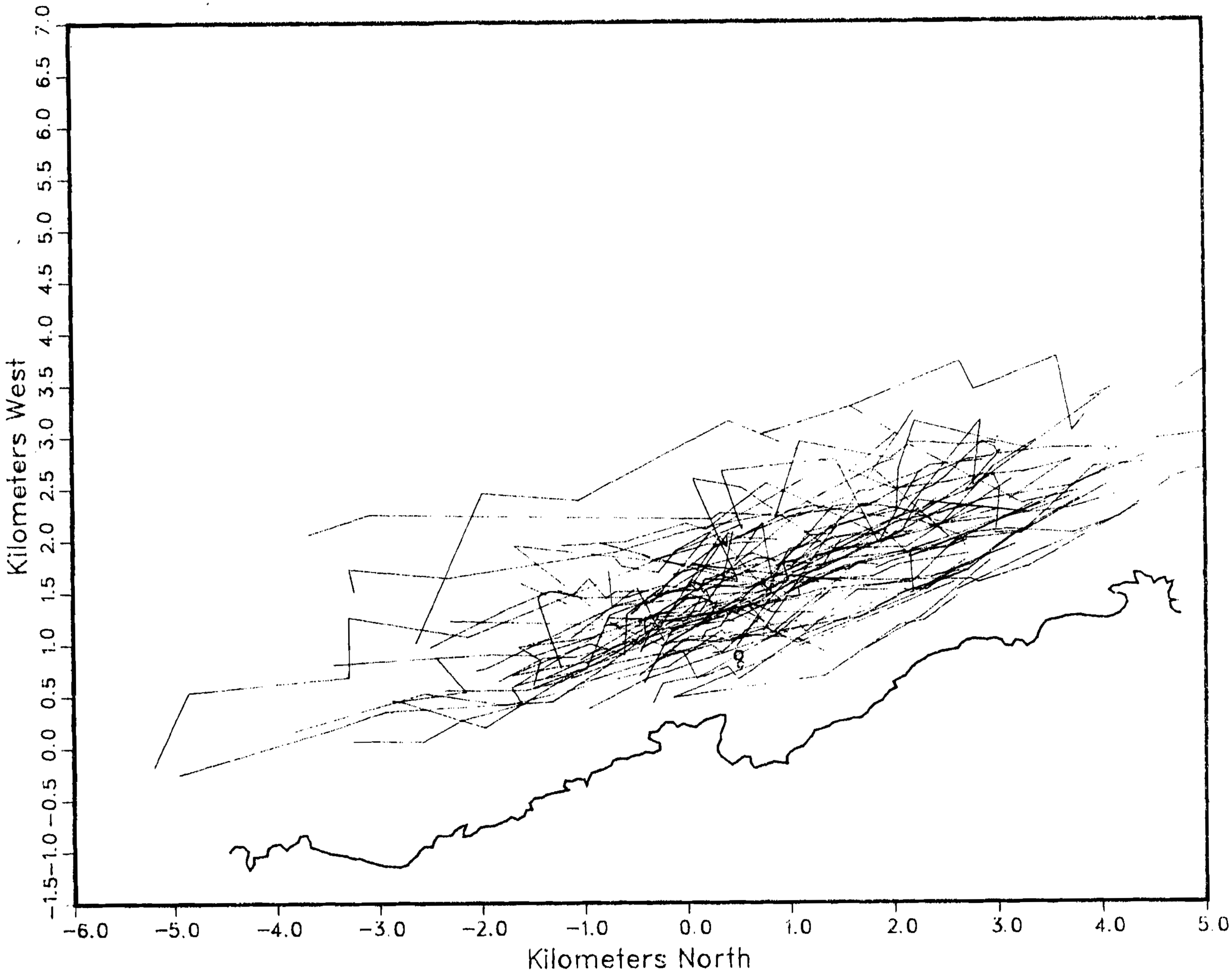


Fig. B.2. UNDISTURBED, NO SHIP PRESENT, 7-8 JAN 83.

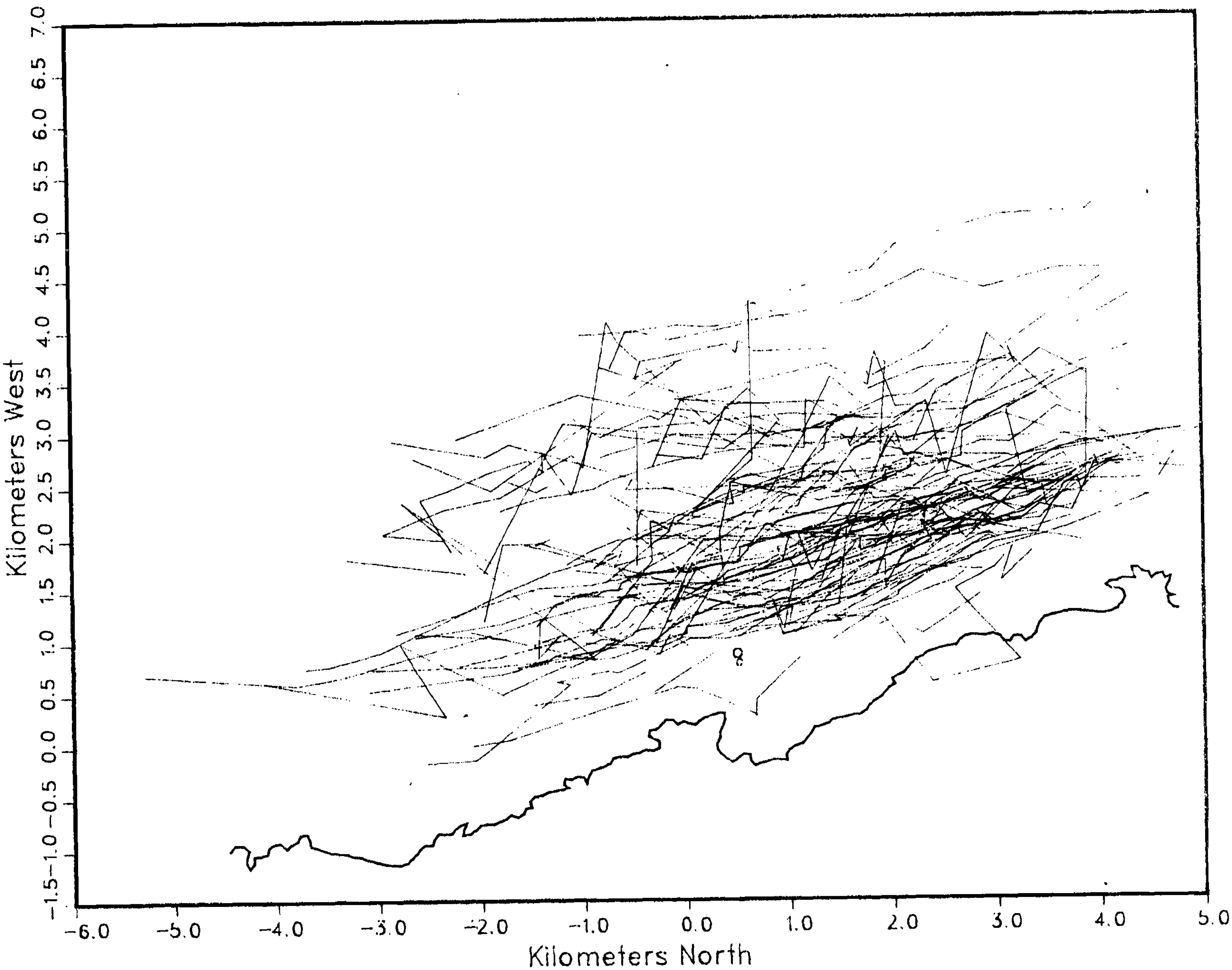


Fig. B.3. UNDISTURBED, NO SHIP PRESENT, 9-10 JAN 83.

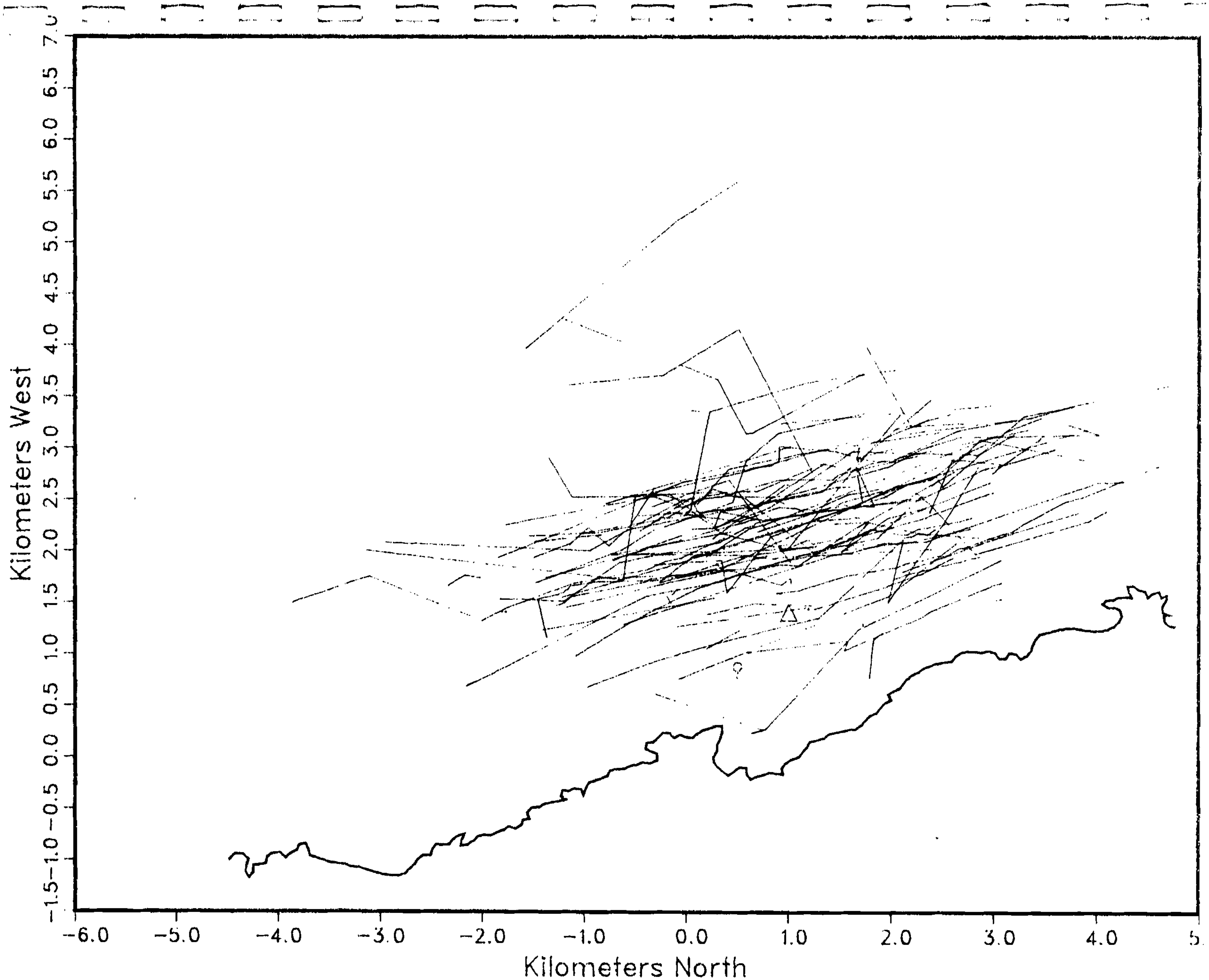


Fig. B.4. UNDISTURBED, NO BOAT PRESENT, 19-21 JAN 83.

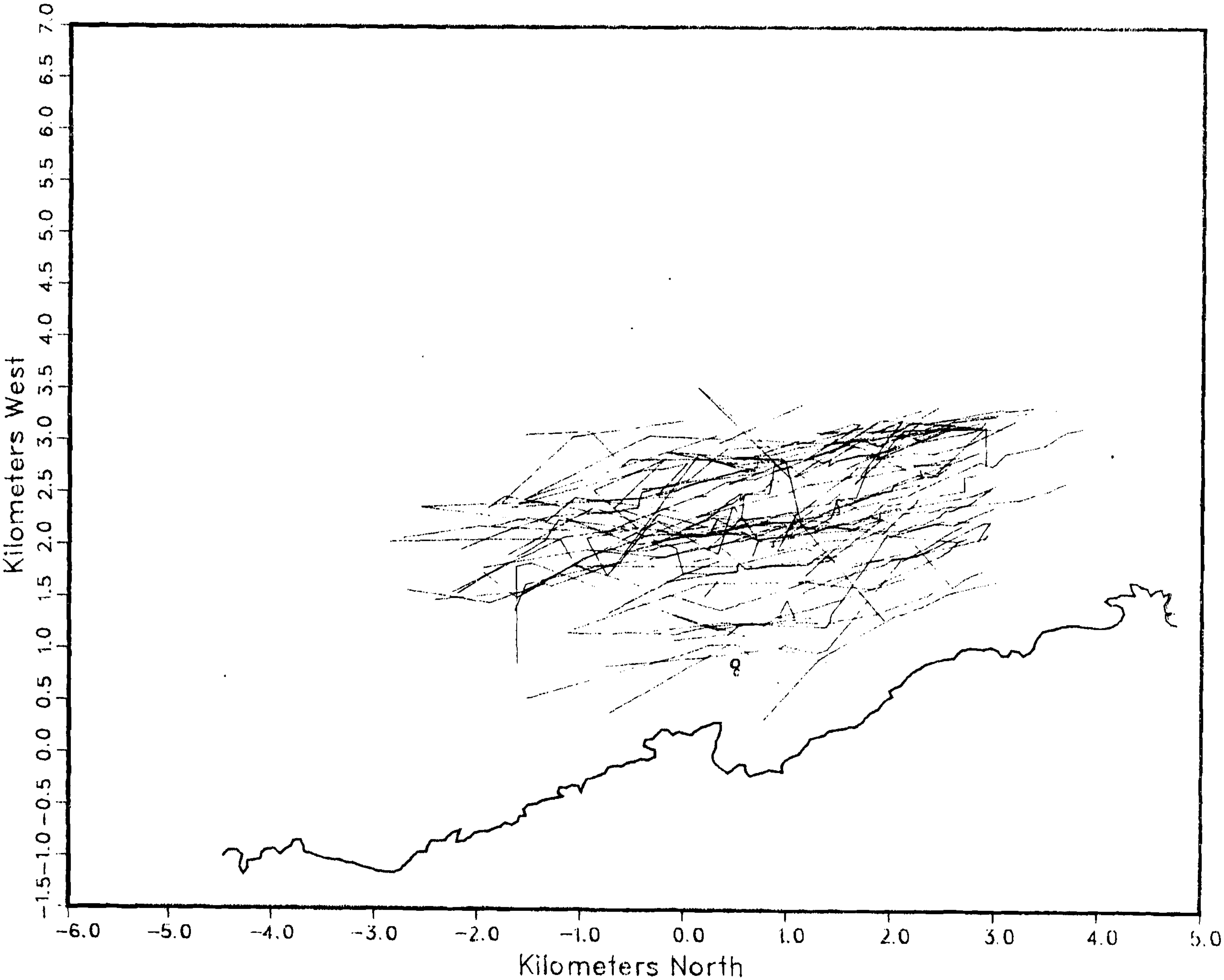


Fig. B.5. UNDISTURBED, VARUA ANCHORED.

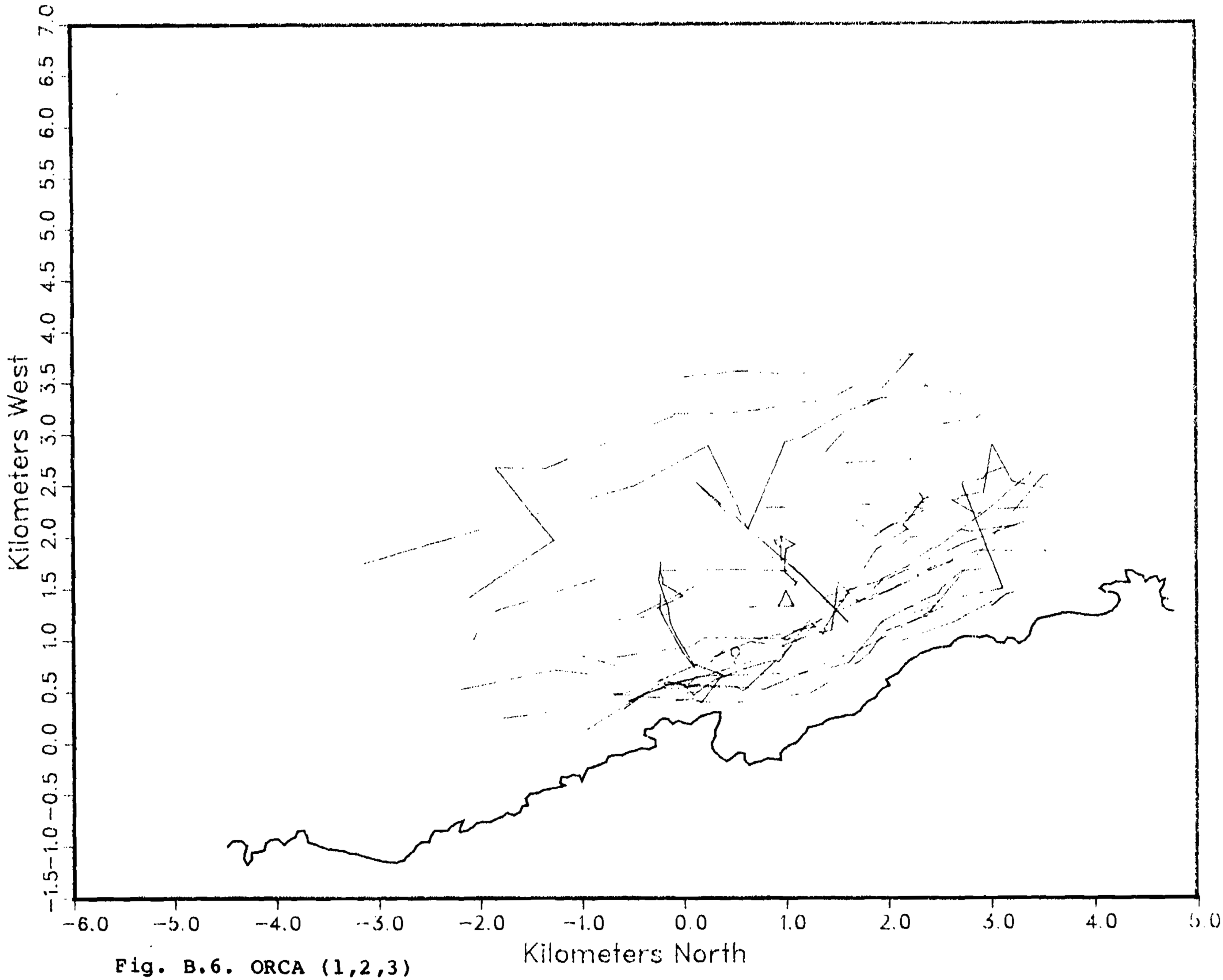


Fig. B.6. ORCA (1,2,3)

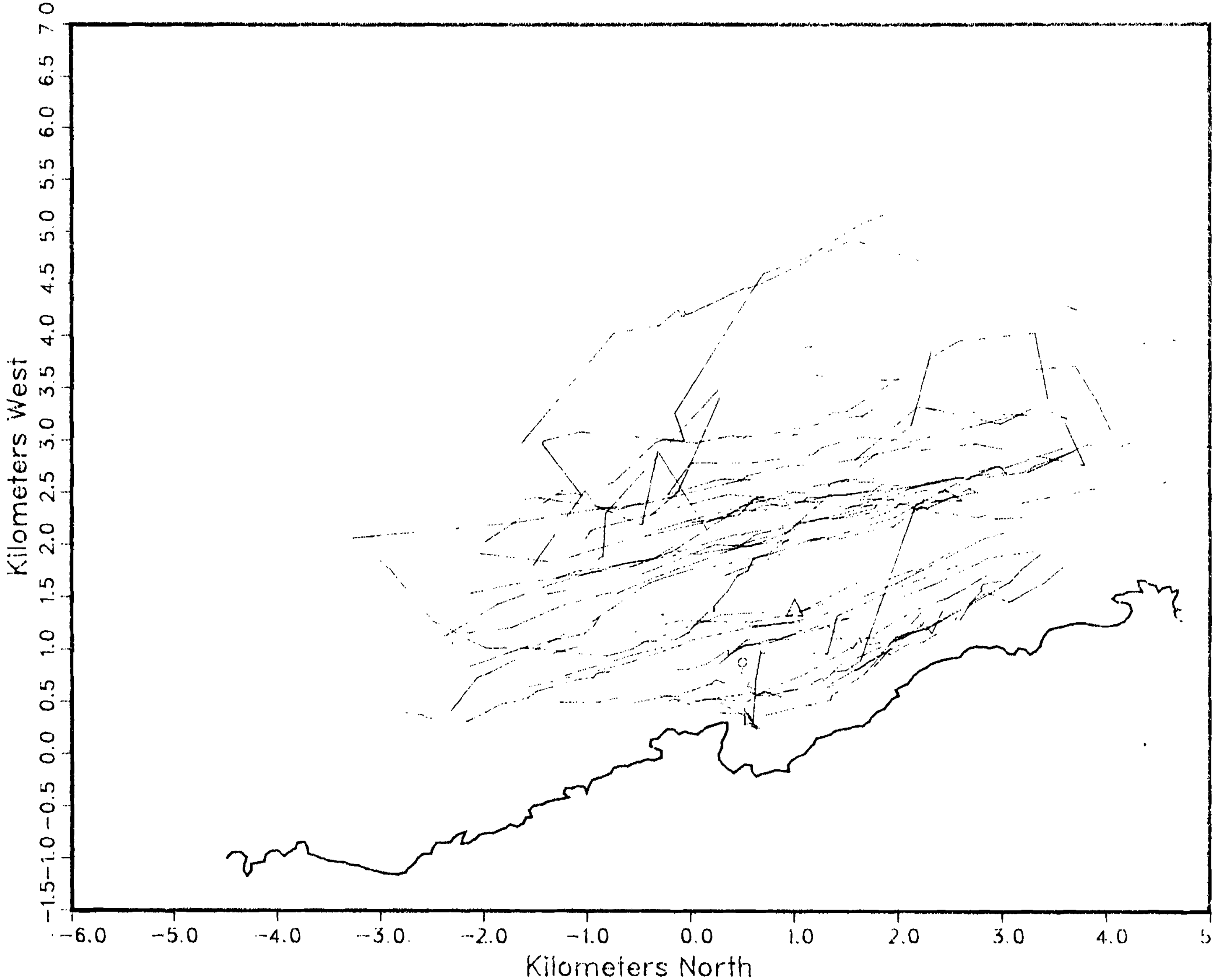


Fig. B.7. DRILLING PLATFORM (1,2,3)

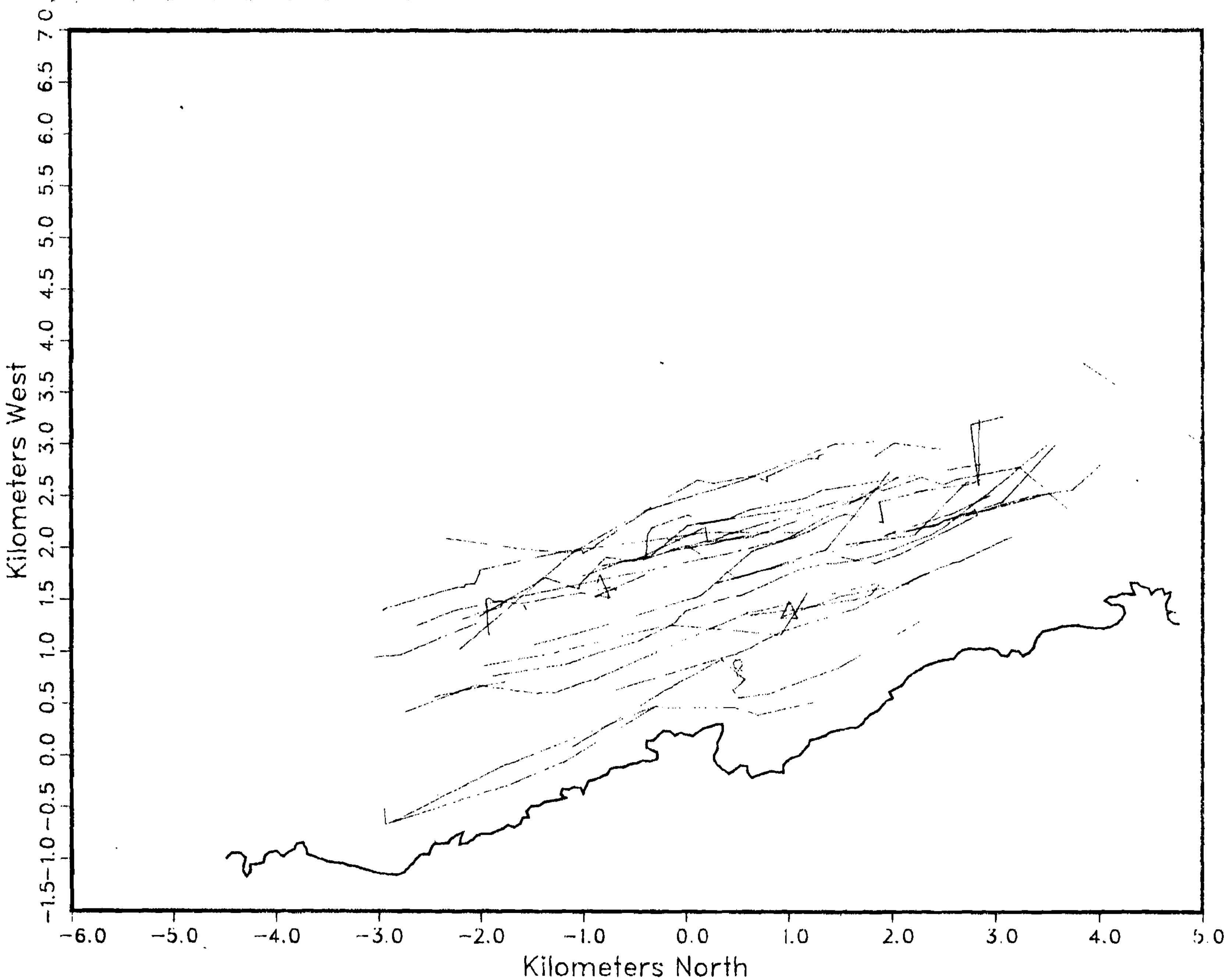


Fig. B.8. DRILLSHIP (1,2,3)

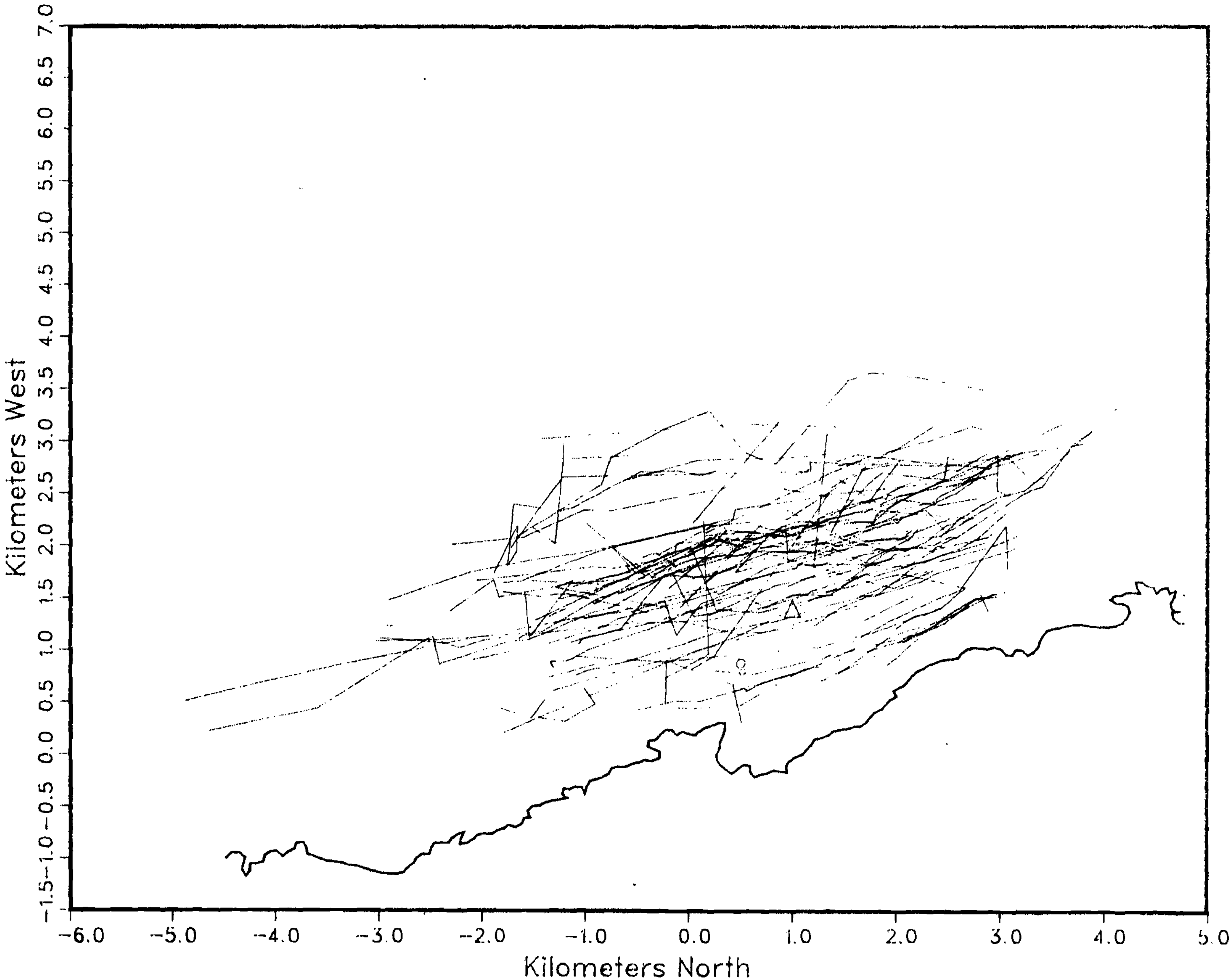


Fig. B.9. SEMISUBMERSIBLE (1,2,3)

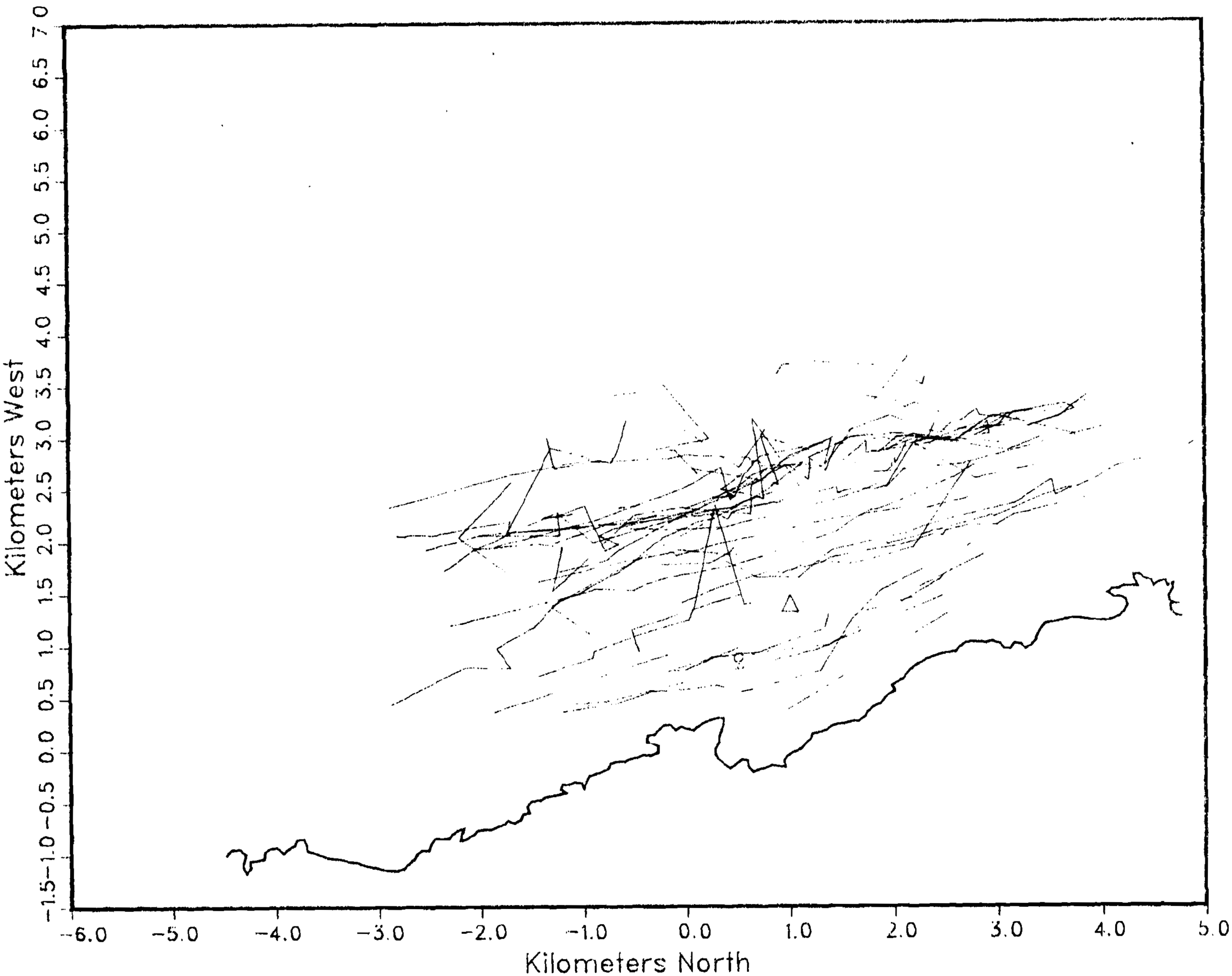


Fig. B.10. HELICOPTER (1,2,3)

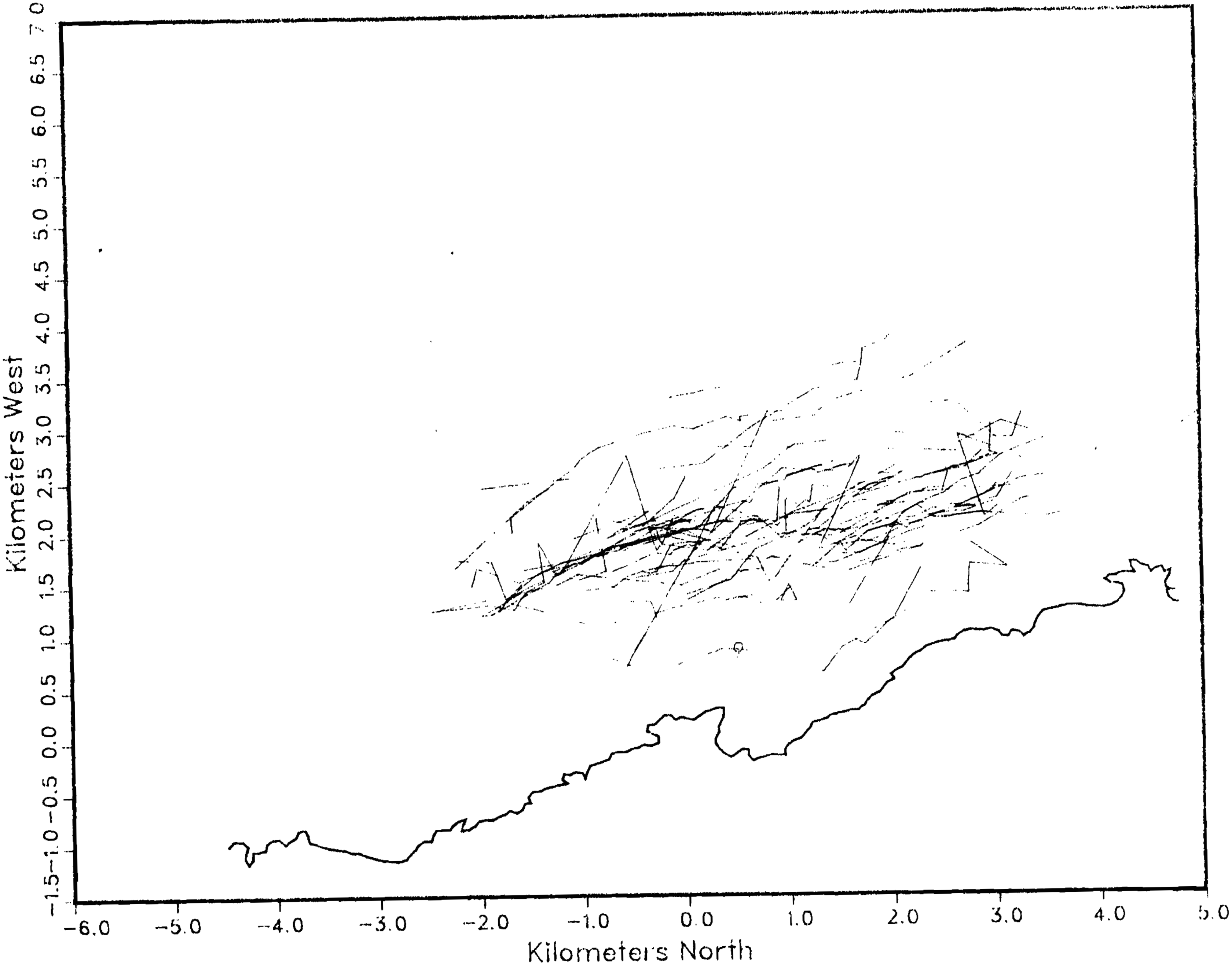
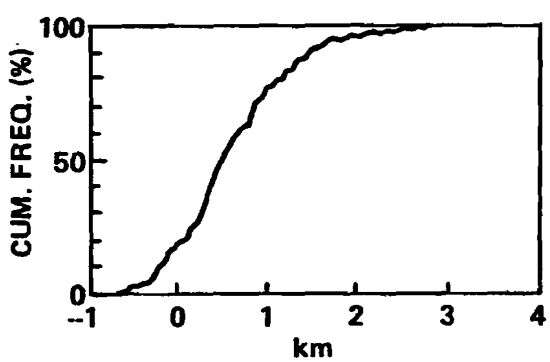


Fig. B.11. PRODUCTION PLATFORM (1,2,3)

B.2 CUMULATIVE FREQUENCY DISTRIBUTION PLOTS FOR THREE LINEAR TRACK DEFLECTION MEASURES IN JANUARY 1983.

Plots are presented of cumulative frequency distributions for each of three linear track deflection measures, D_y, Speed, and Milling Index for each of the six experimental conditions and for the two control conditions (Figs. 12-32). These plots are presented in the following order of Playback Conditions - Control No Boat Present, Orca, Drilling Platform, Drill Ship, Semi-submersible, Helicopter, and Production Platform. On the left edge of each page is listed the measure and the playback condition. Score D_y is labeled "D_y (grid crossings measured from VARUA)". The D_y plots show 11 cumulative frequency distributions on each page, one for each grid line crossed, starting with -4.0 = 4.0 km North of the VARUA and ending with 4.0 = 4.0 km South of the VARUA (see Fig. 7.1). The Shore and Milling Index plots show 10 cumulative frequency distributions on each page, one for each grid interval crossed. An easy way to compare the distributions of these measures between experimental and control conditions is to make transparent xeroxes of the control plots. These can then be used as overlays to compare distributions with the Experimental Plots.

Key for Figs. B.12 through B.32:



Track Deflection Parameter (e.g., D_y Speed, Milling Index) as Noted in Figure Title.

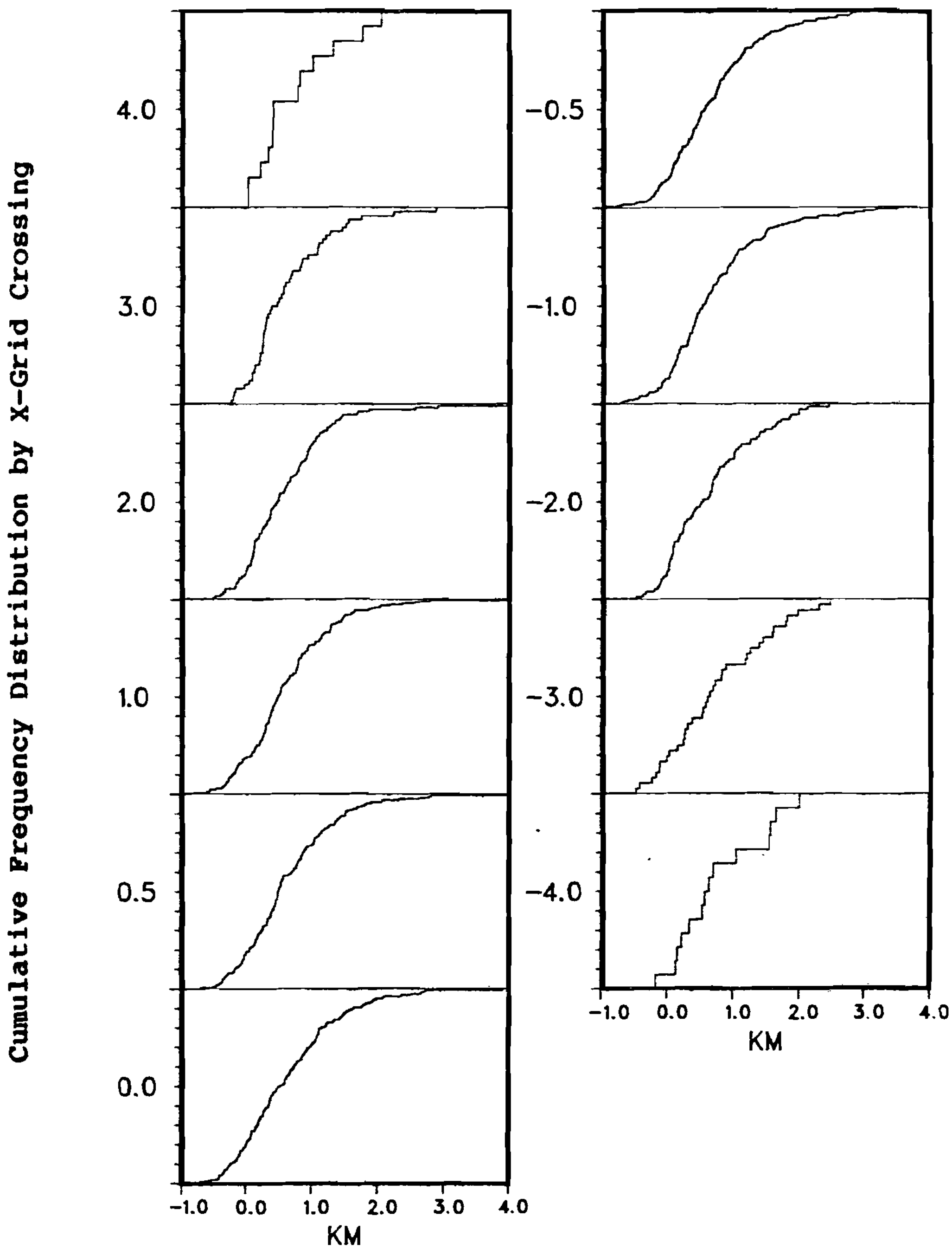


FIG. B.12. UNDISTURBED, NO BOAT PRESENT, 7-10 & 19-21 JAN 83. D_Y (GRID CROSSINGS MEASURED FROM VARUA).

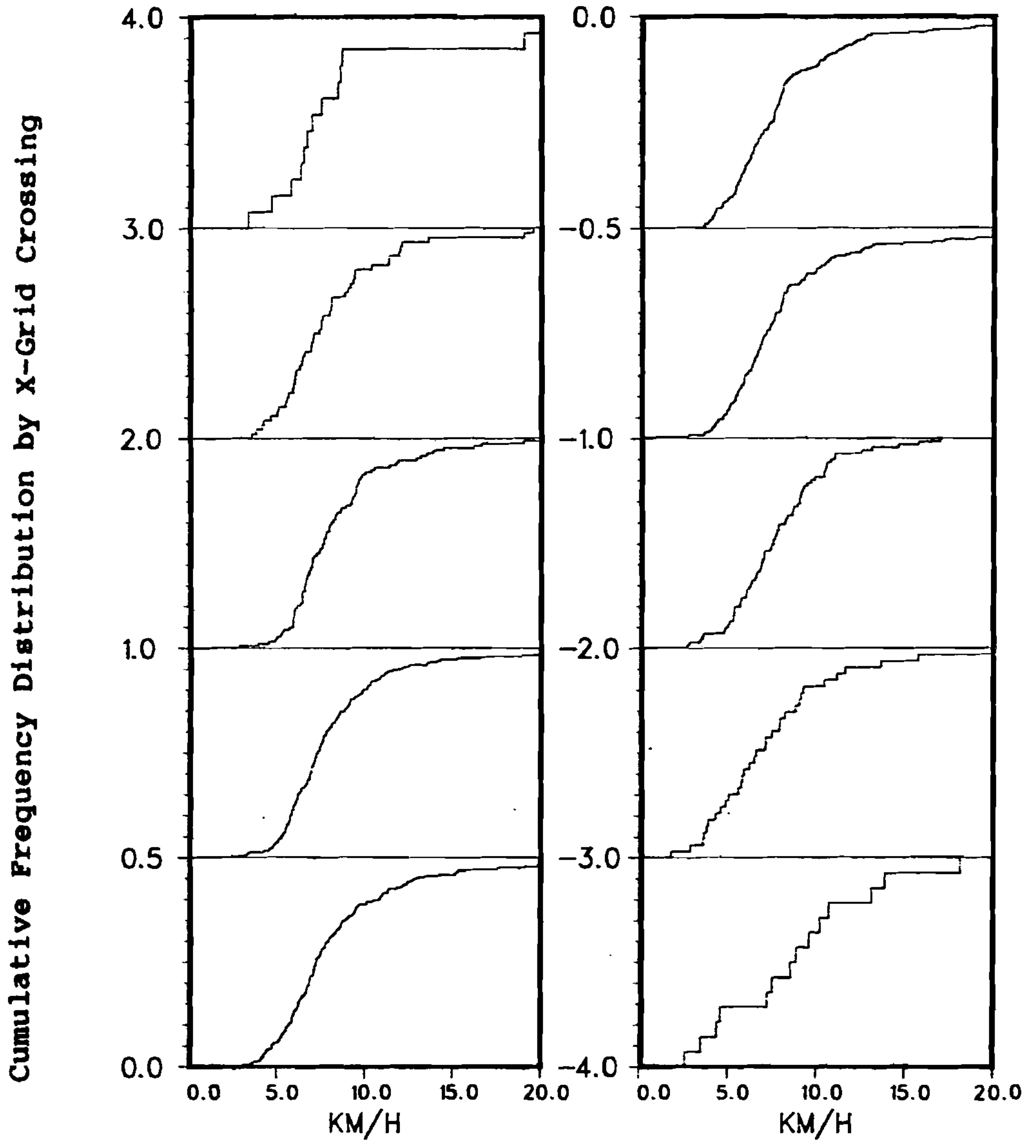


FIG. B.13. UNDISTURBED, NO BOAT PRESENT, 7-10 & 19-21 JAN 83. SPEED.

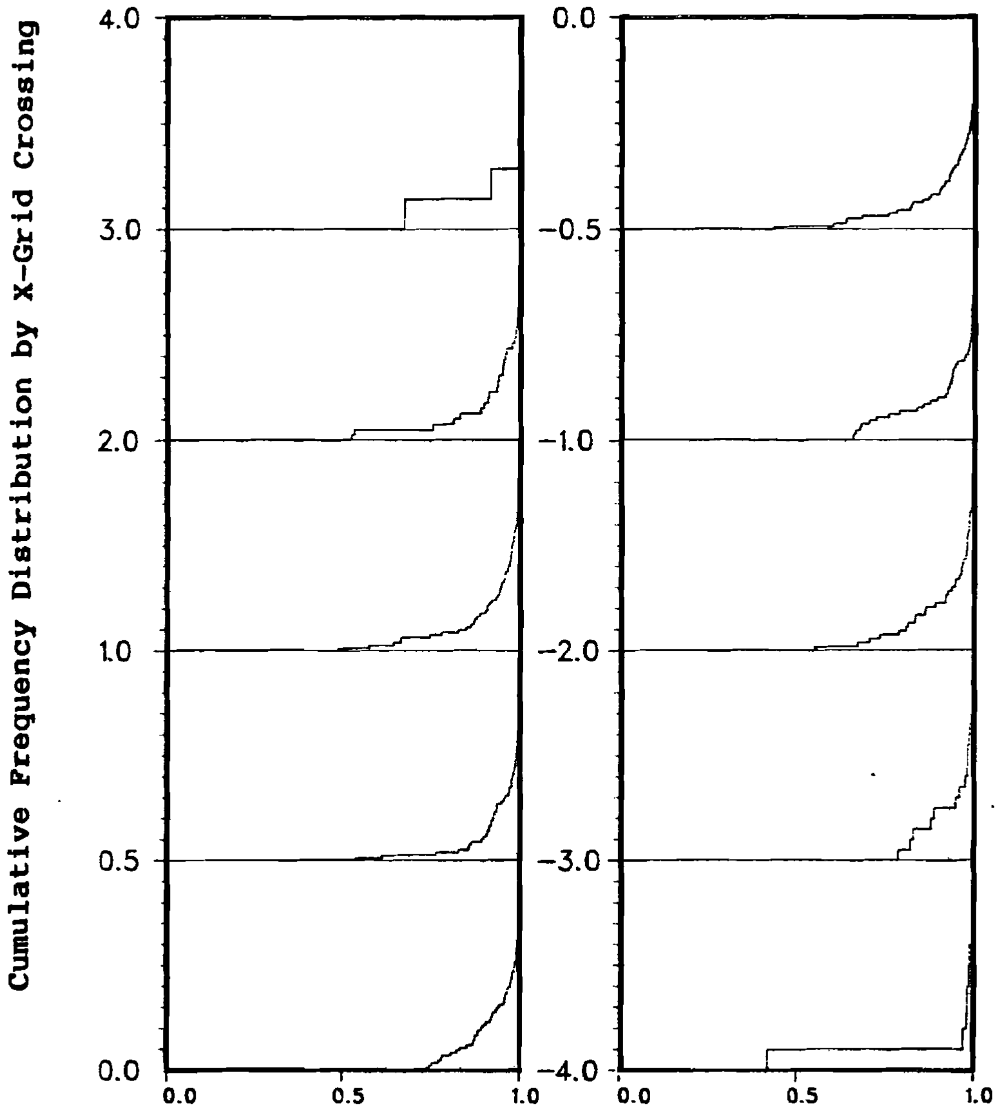


FIG. B.14. UNDISTURBED, NO BOAT PRESENT, 7-10 & 19-21 JAN 83. MILLING INDEX.

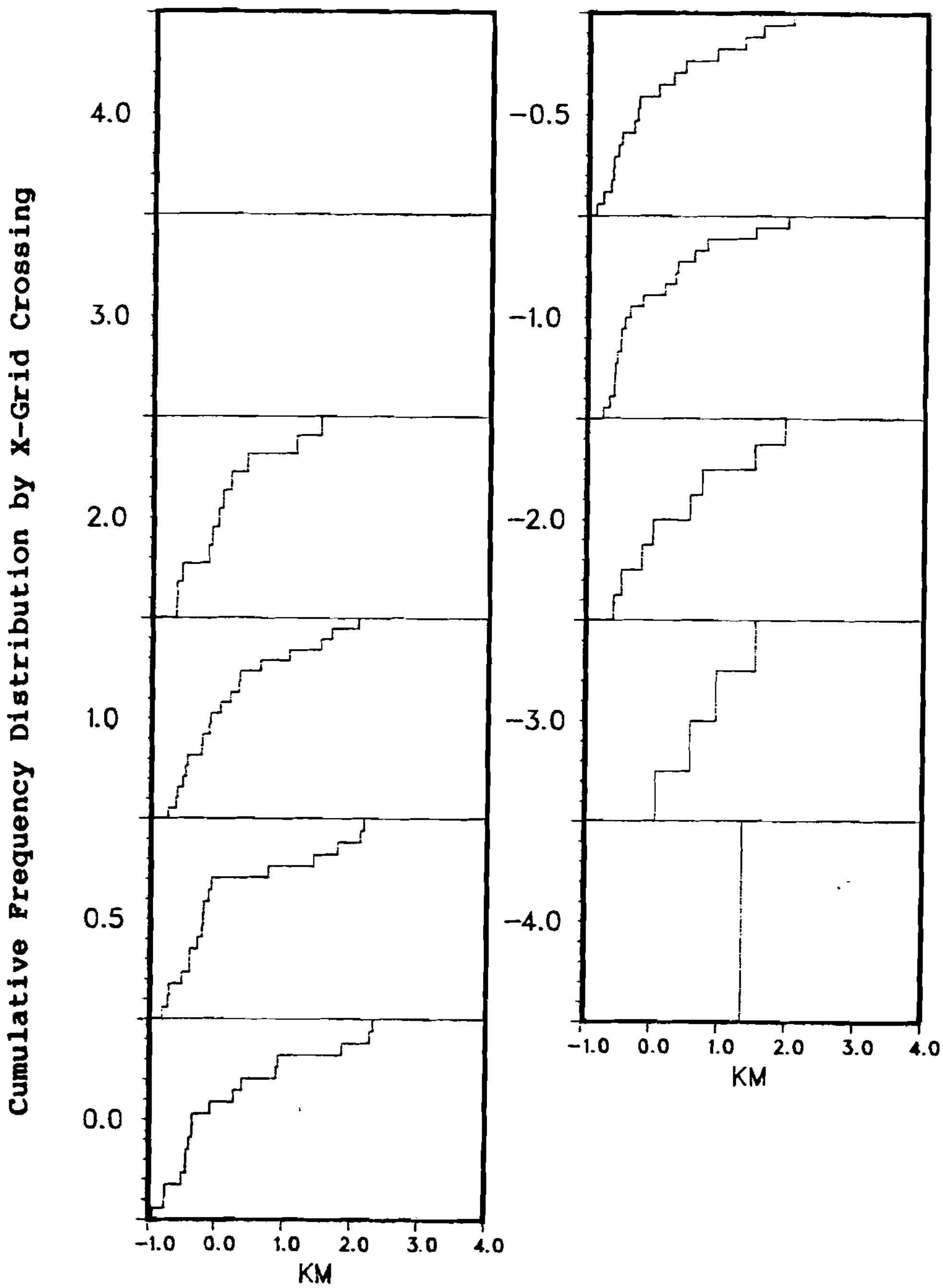


FIG. B.15. ORCA (1,2)
D_Y (GRID CROSSINGS MEASURED FROM VARUA).

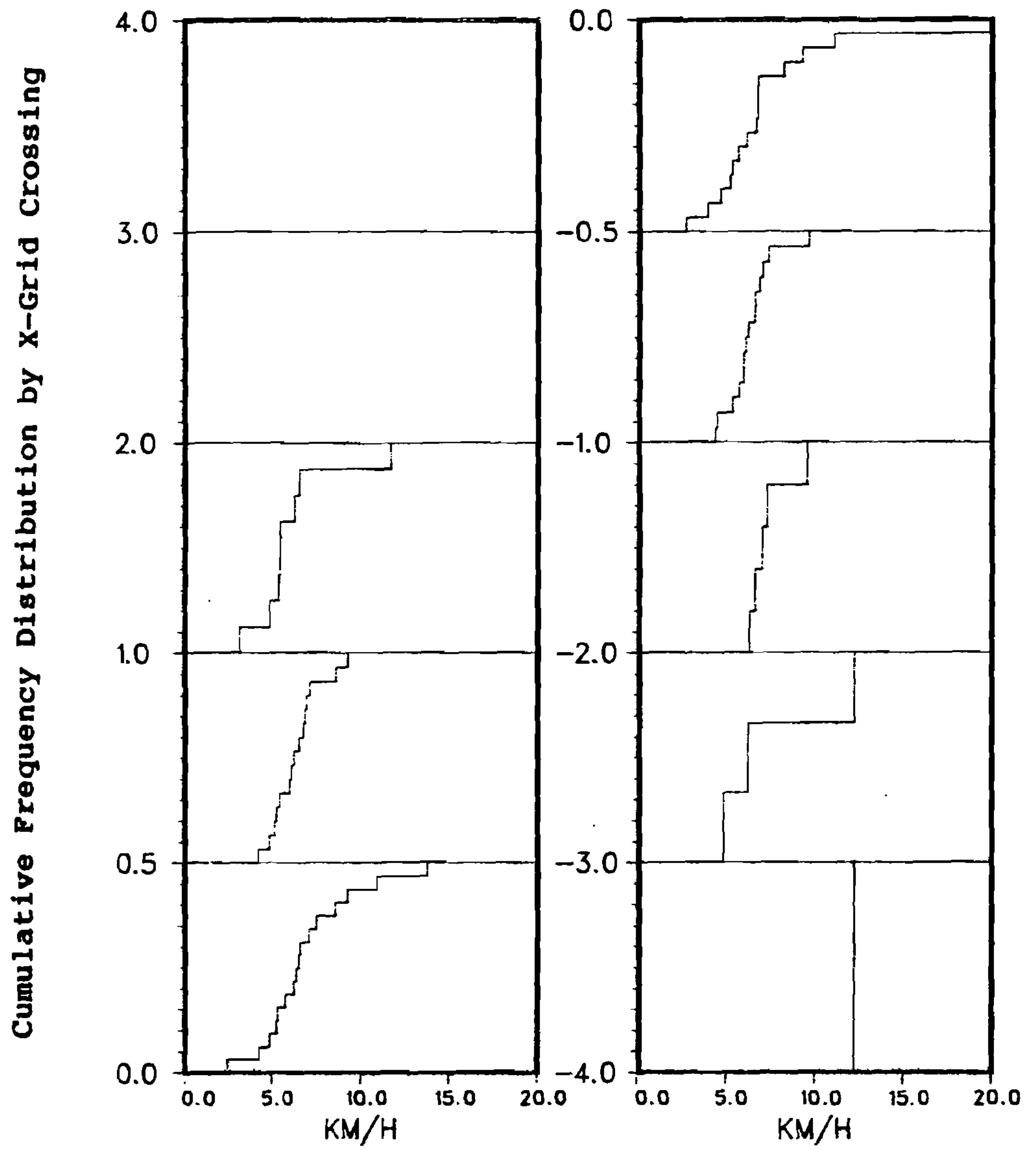


FIG. B.16. ORCA (1,2)
SPEED.

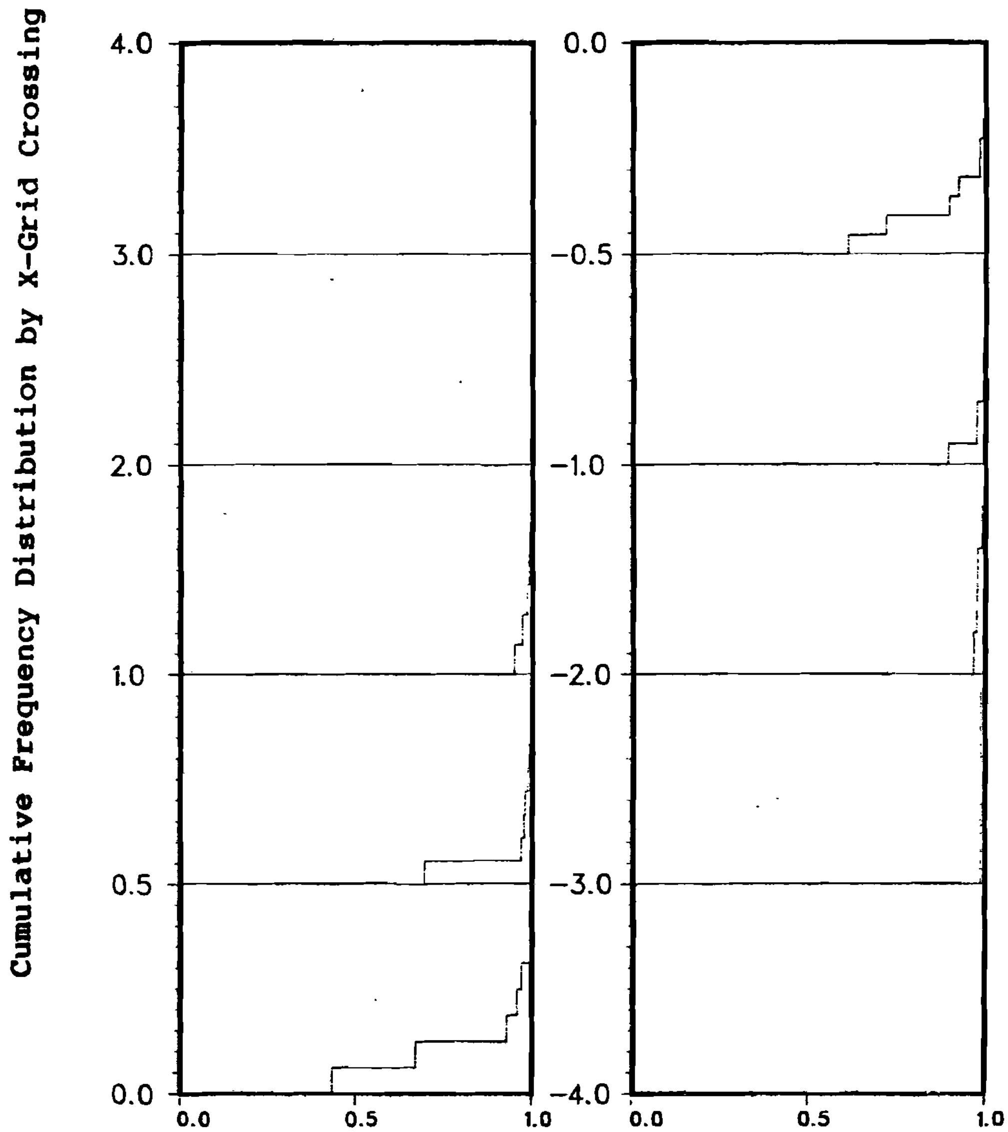


FIG. B.17. ORCA (1,2)
MILLING INDEX.

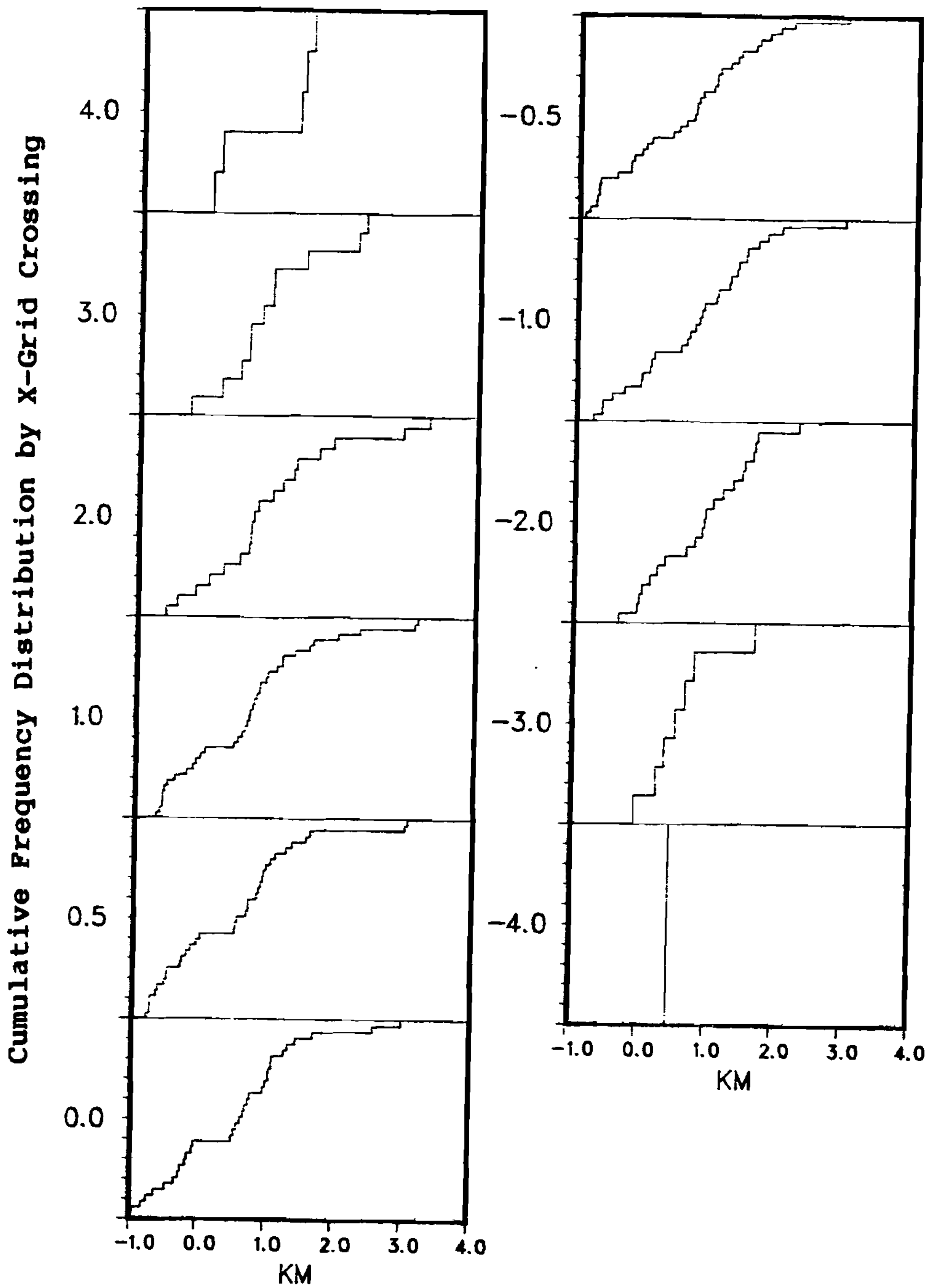


FIG. B.18. DRILLING PLATFORM (1,2,3)
D_Y (GRID CROSSINGS MEASURED FROM VARUA).

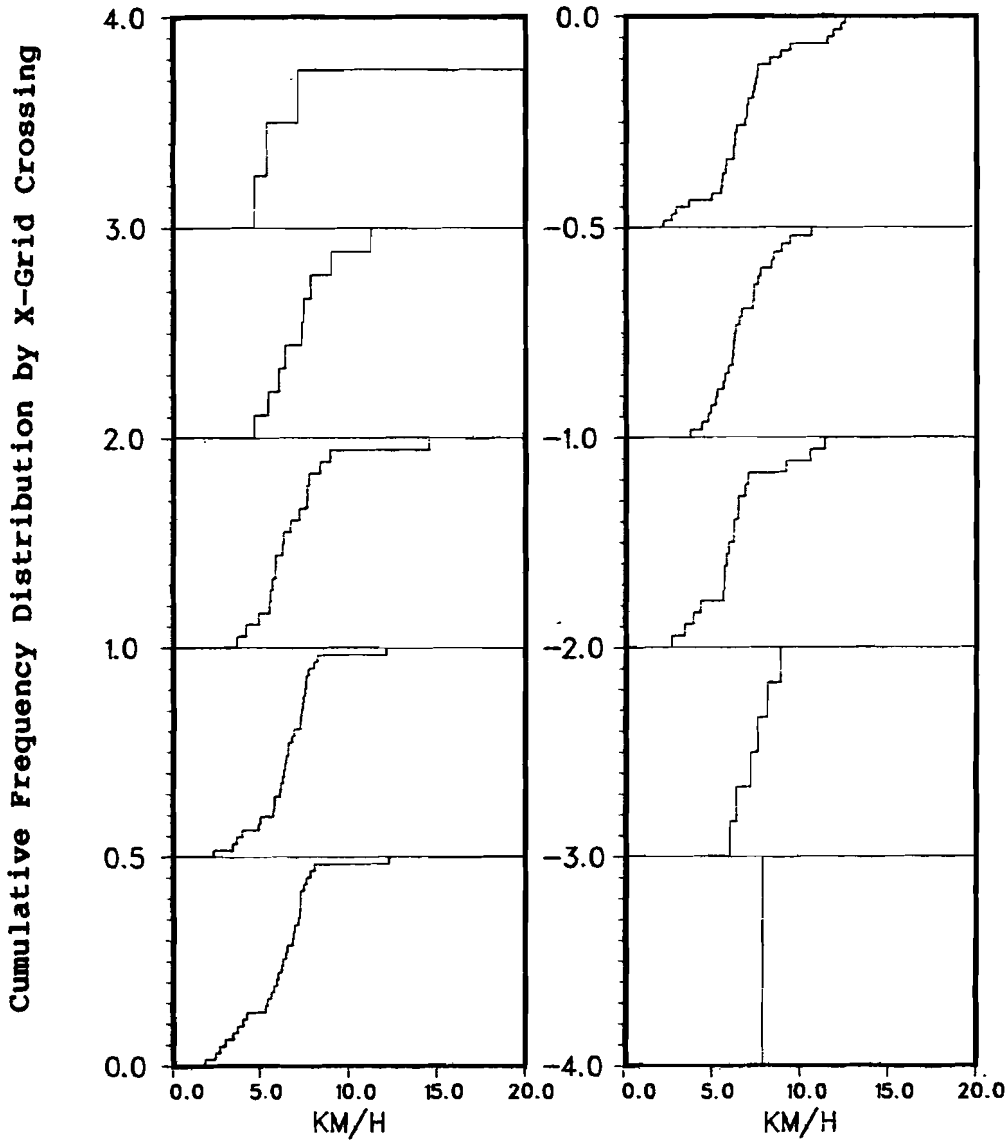


FIG. B.19. DRILLING PLATFORM (1,2,3) SPEED.

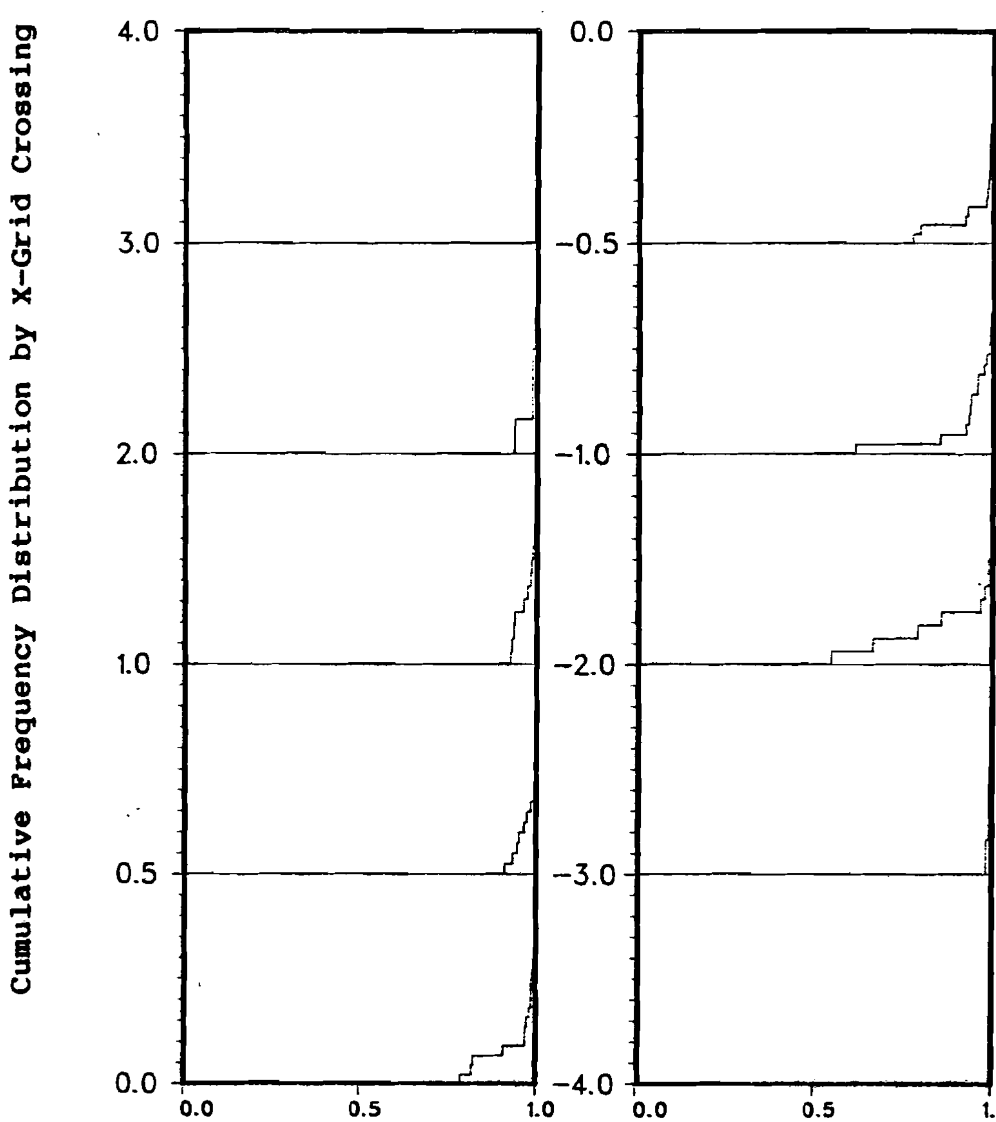


FIG. B.20. DRILLING PLATFORM (1,2,3) MILLING INDEX.

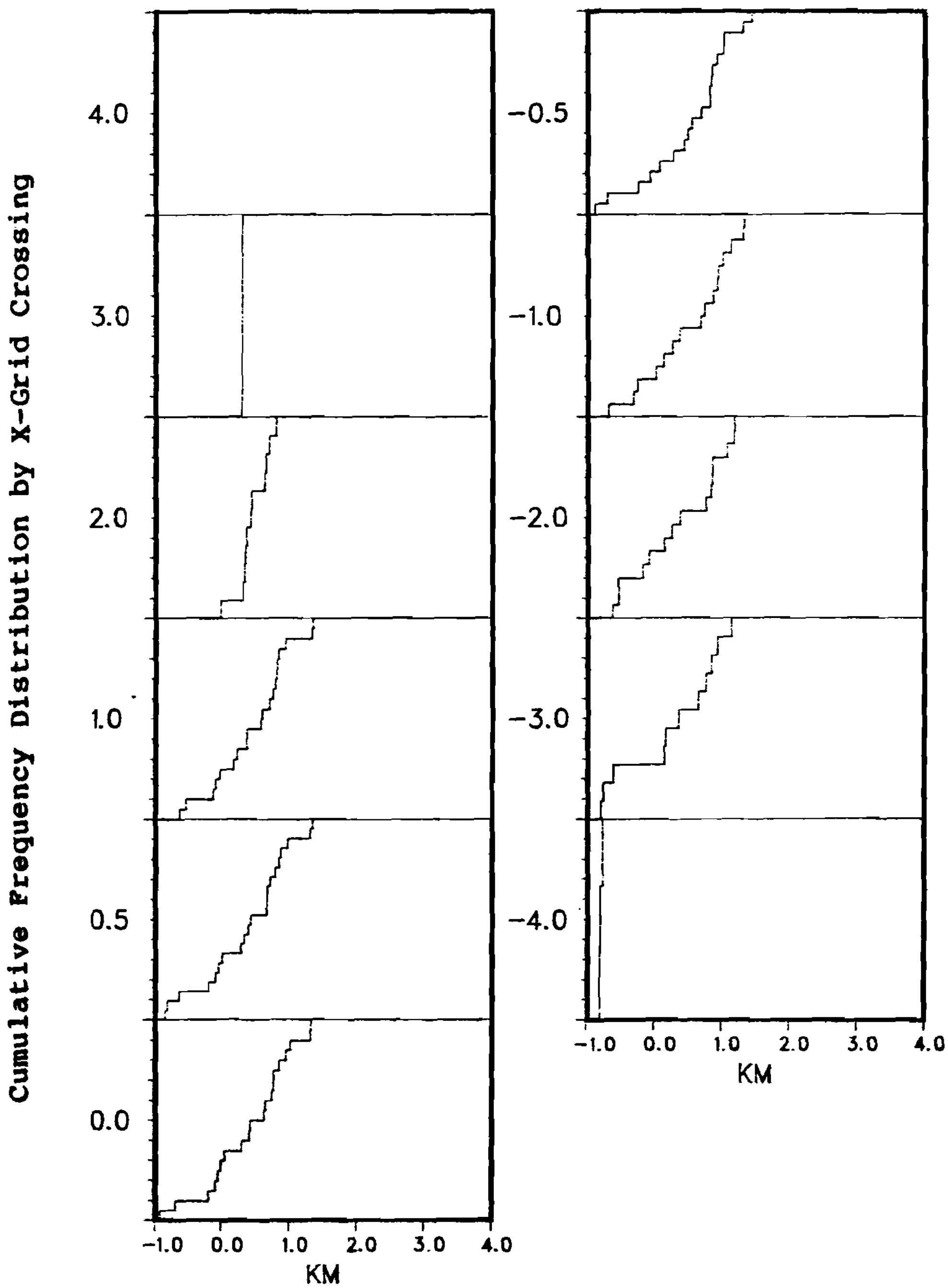


FIG. B.21. DRILLSHIP (1,2,3)
D_Y (GRID CROSSINGS MEASURED FROM VARUA).

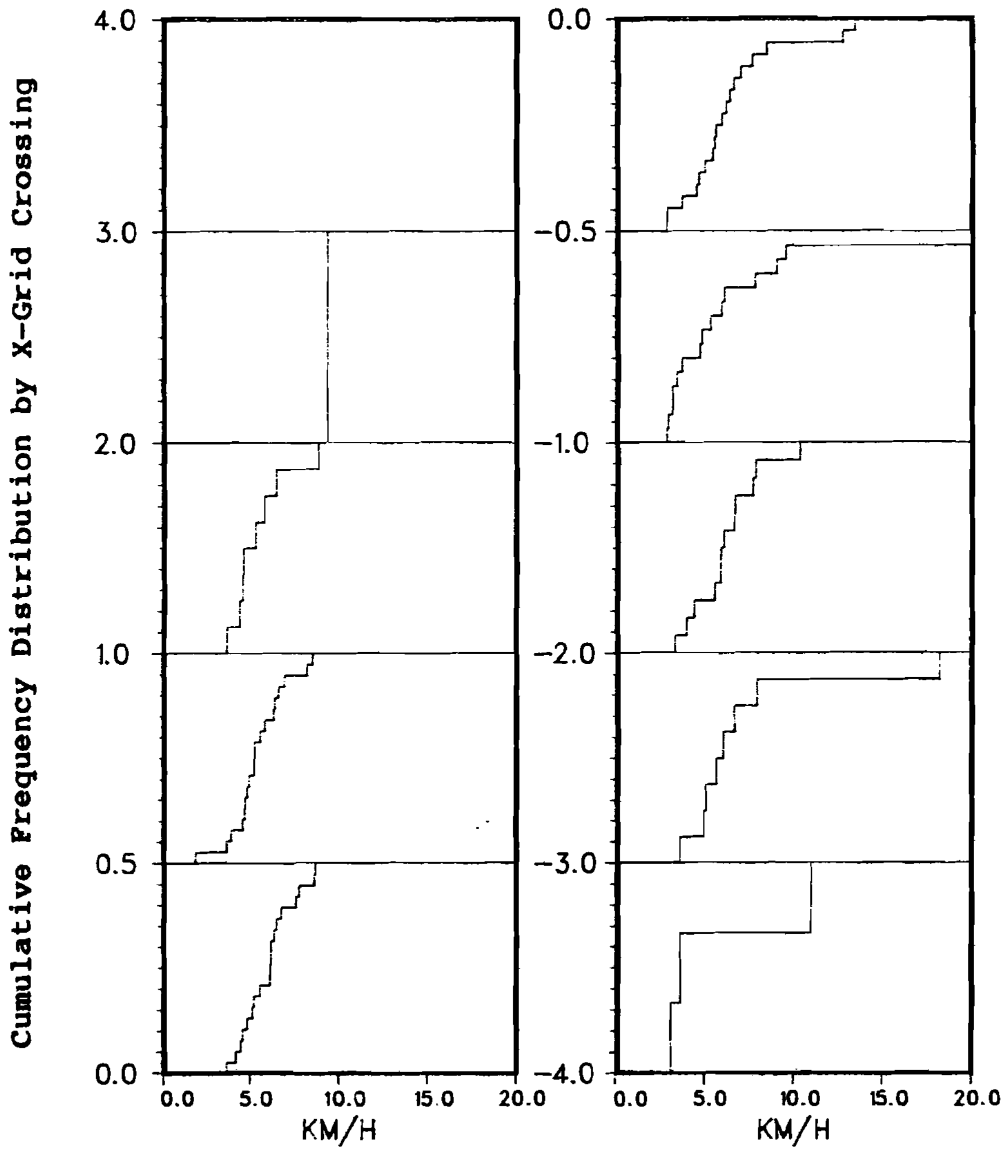


FIG. B.22. DRILLSHIP (1,2,3) SPEED.

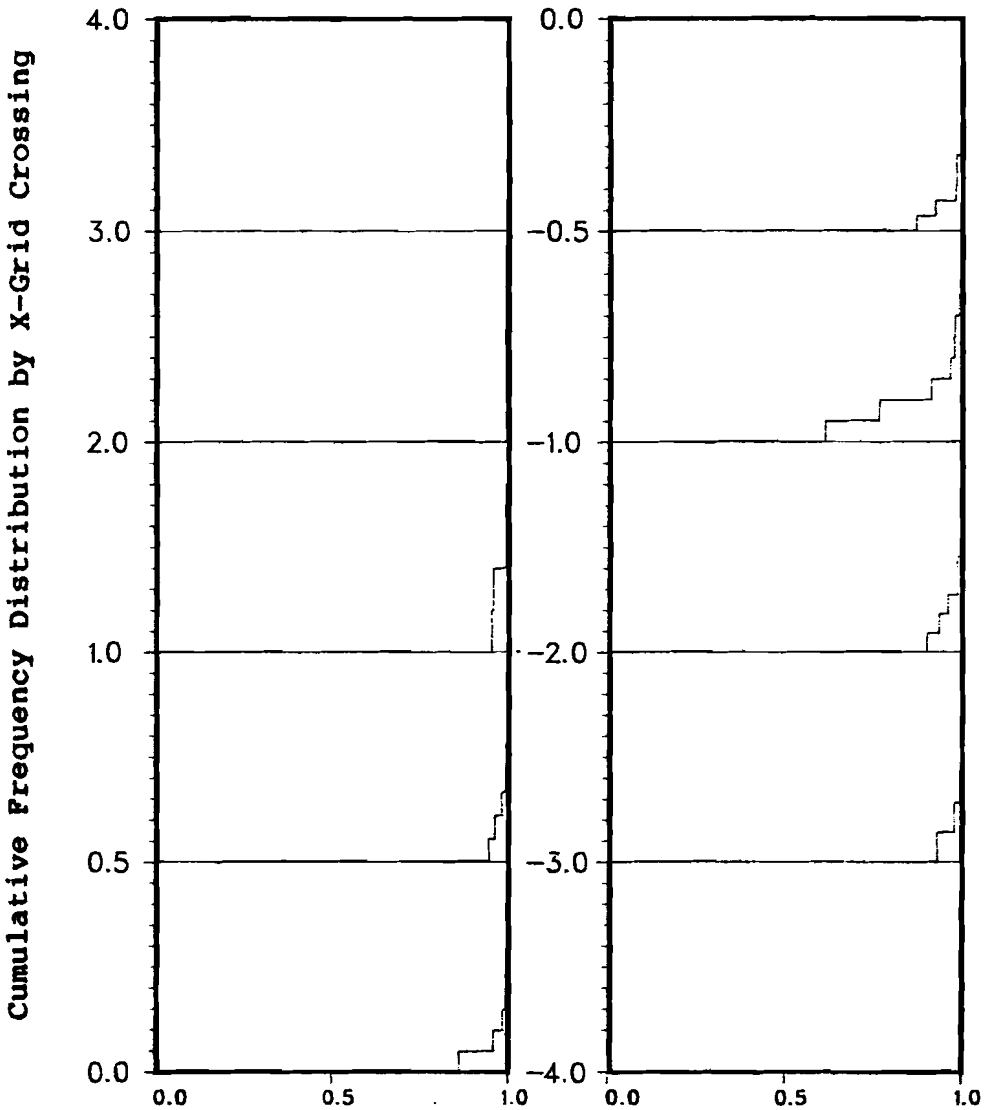


FIG. B.23. DRILLSHIP (1,2,3)
MILLING INDEX.

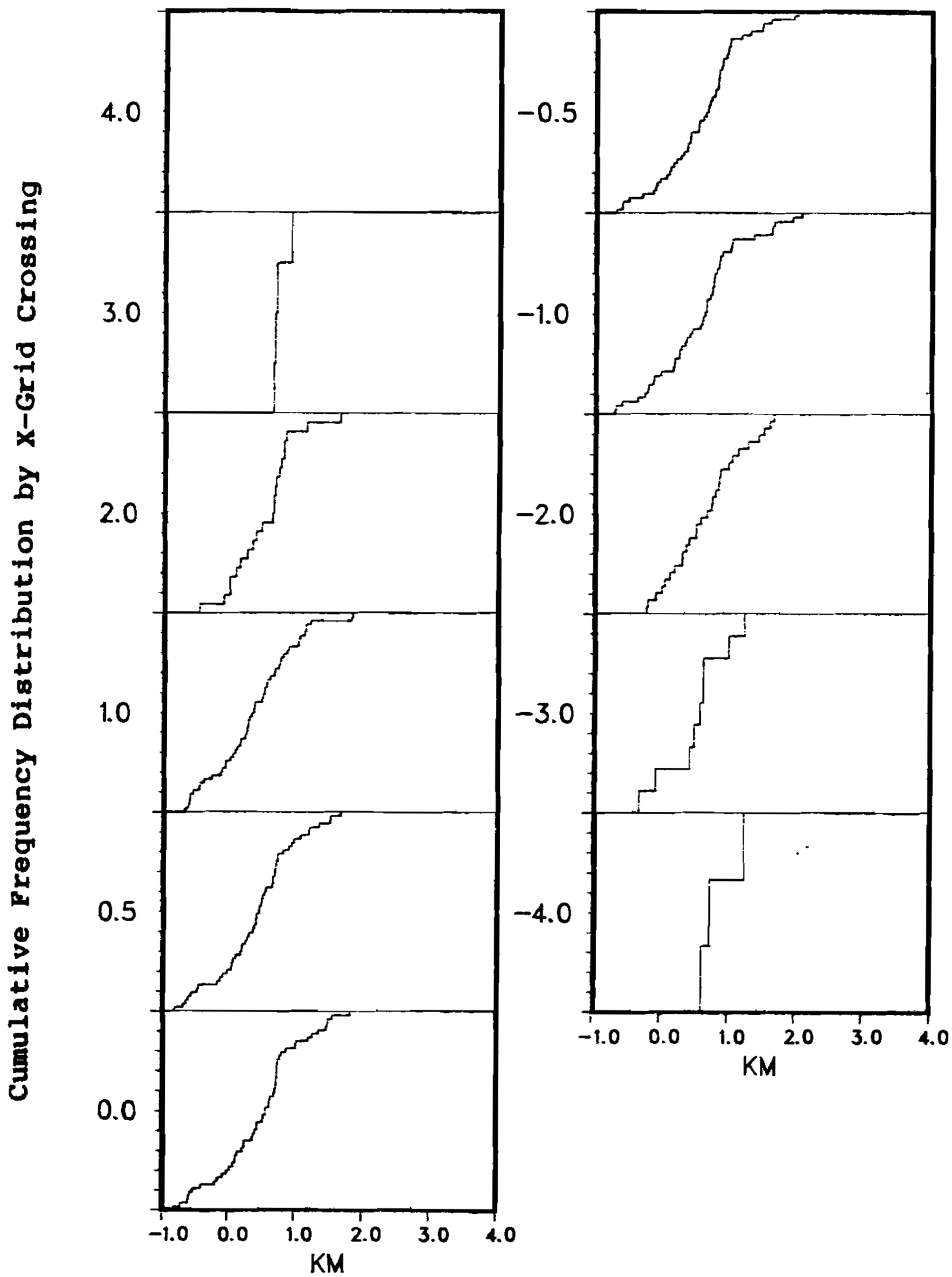


FIG. B.24. SEMISUBMERSIBLE (1,2,3)
D_Y (GRID CROSSINGS MEASURED FROM VARUA).

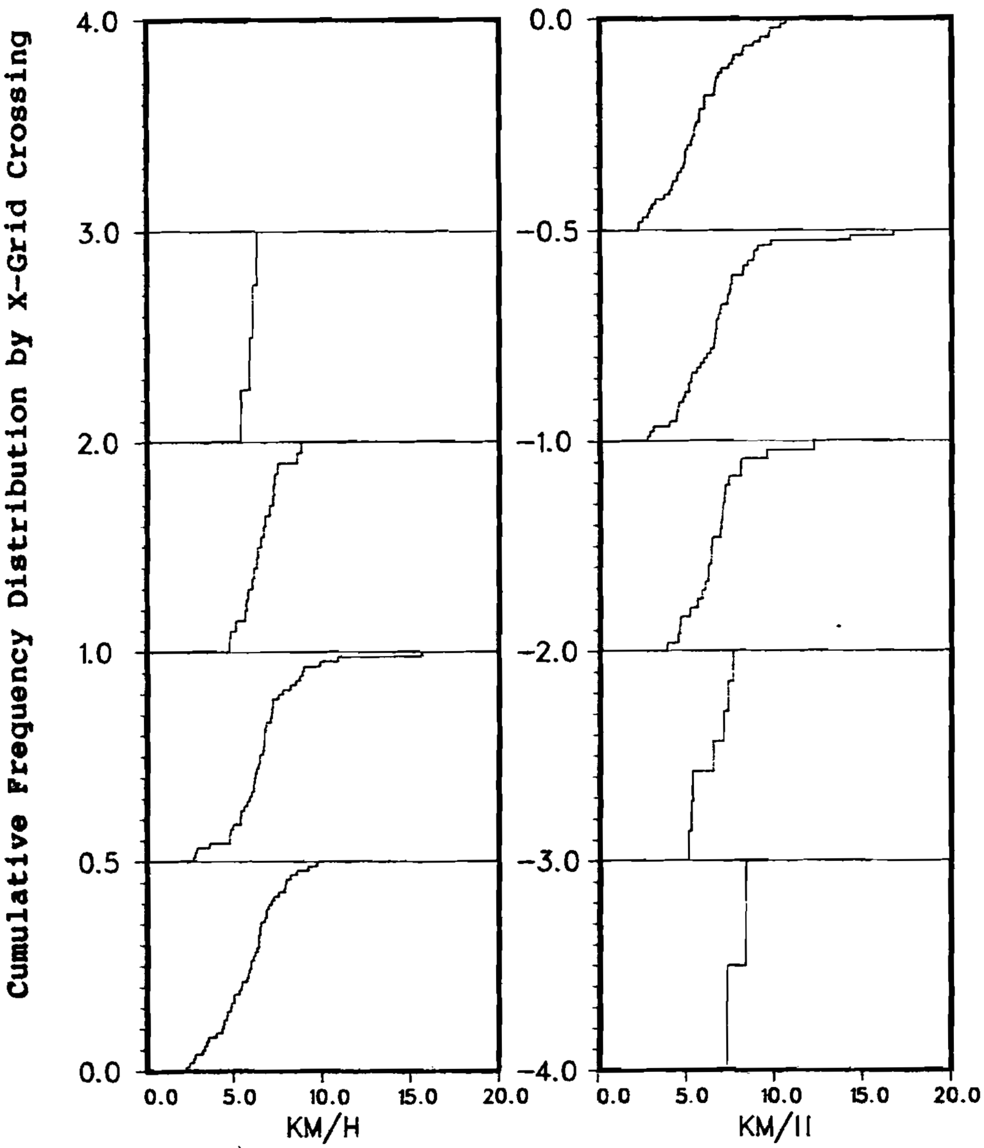


FIG. B.25. SEMISUBMERSIBLE (1,2,3) SPEED.

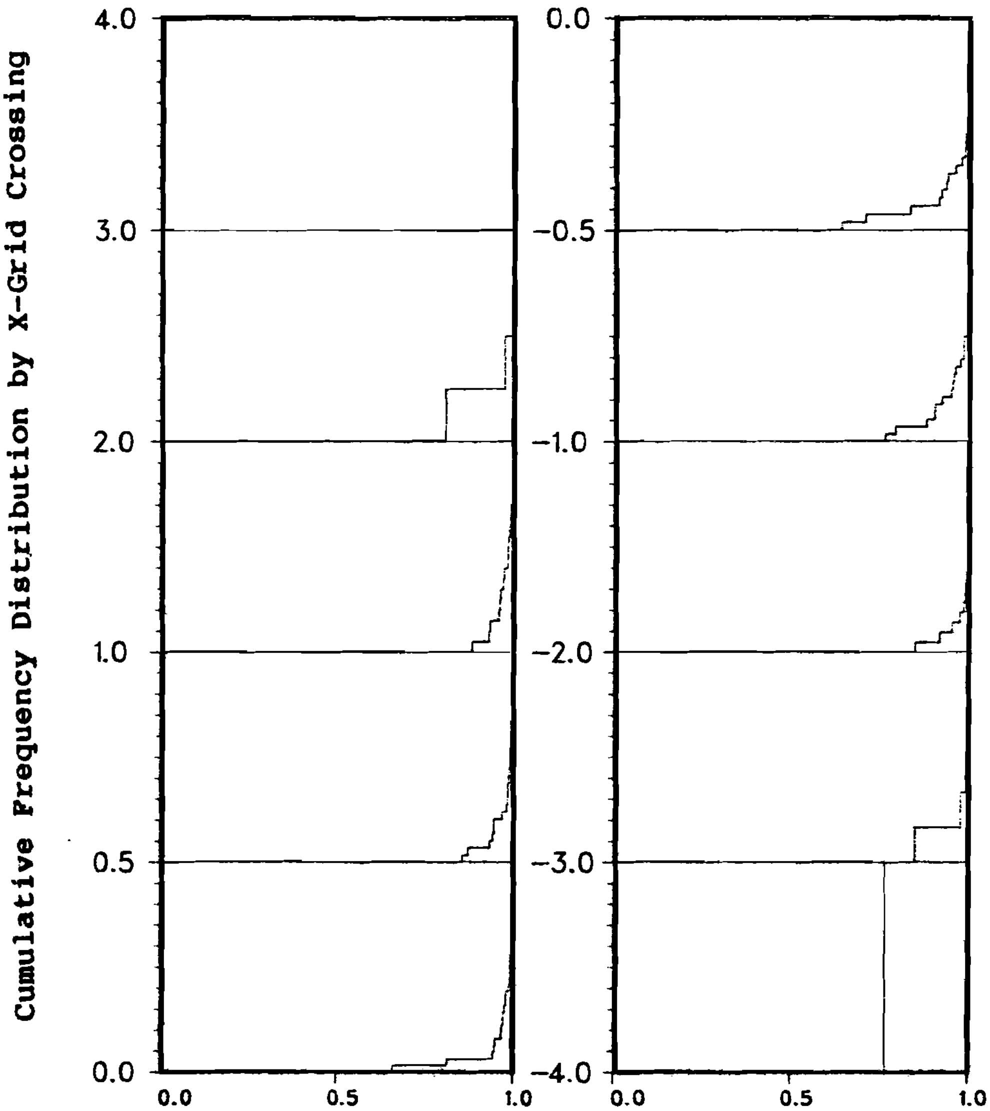


FIG. B.26. SEMISUBMERSIBLE (1,2,3) MILLING INDEX.

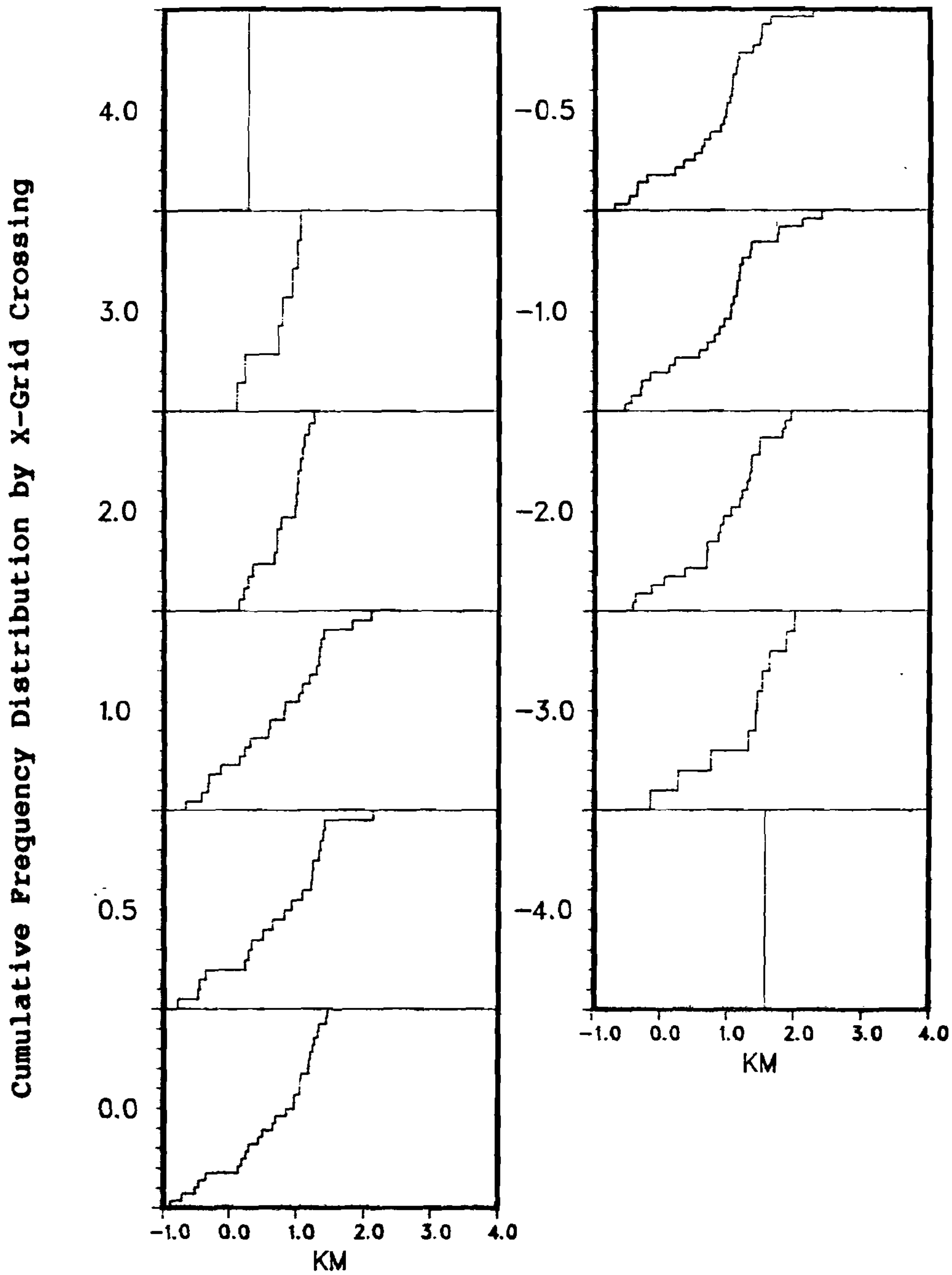


FIG. B.27. HELICOPTER (1,2,3)
D_Y (GRID CROSSINGS MEASURED FROM VARUA).

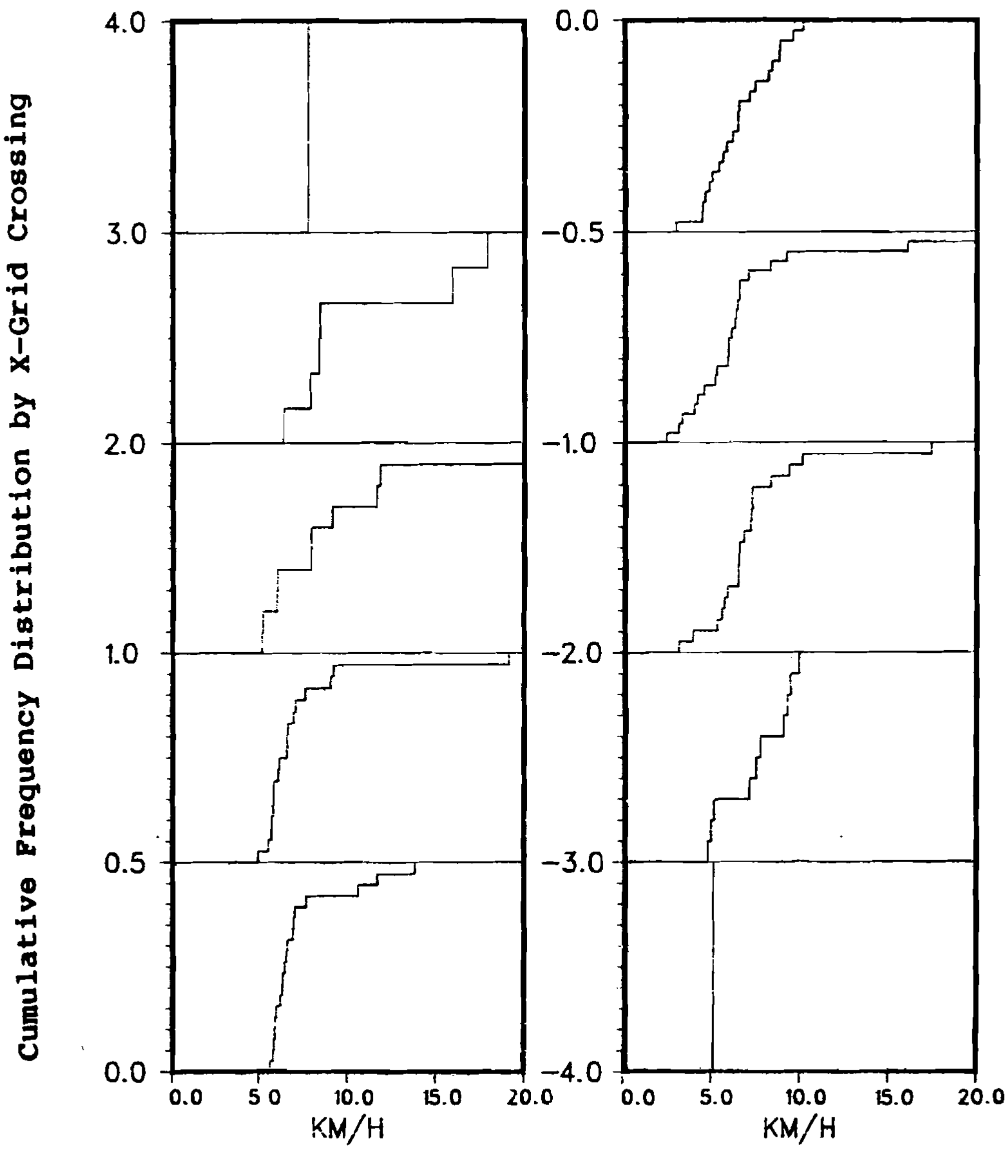


FIG. B.28. HELICOPTER (1,2,3) SPEED.

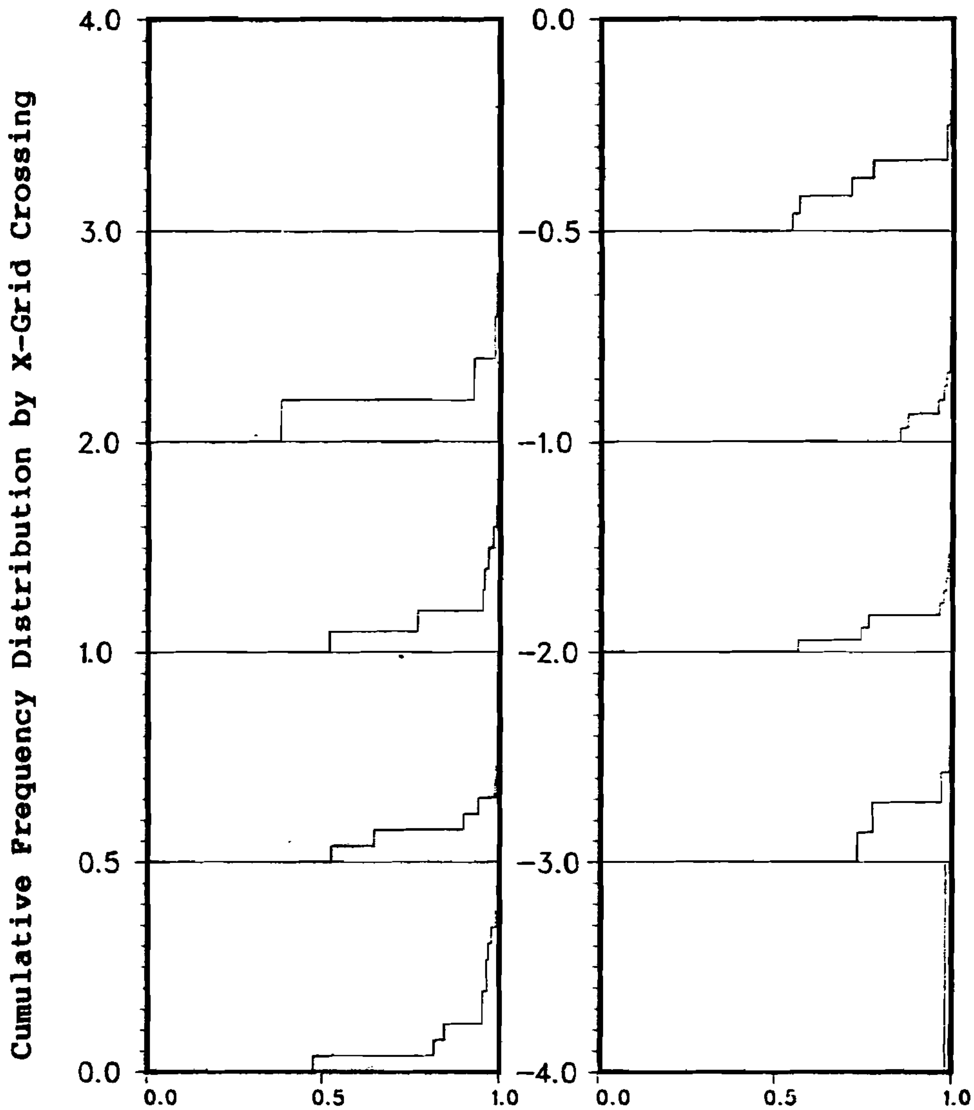


FIG. B.29. HELICOPTER (1,2,3)
MILLING INDEX.

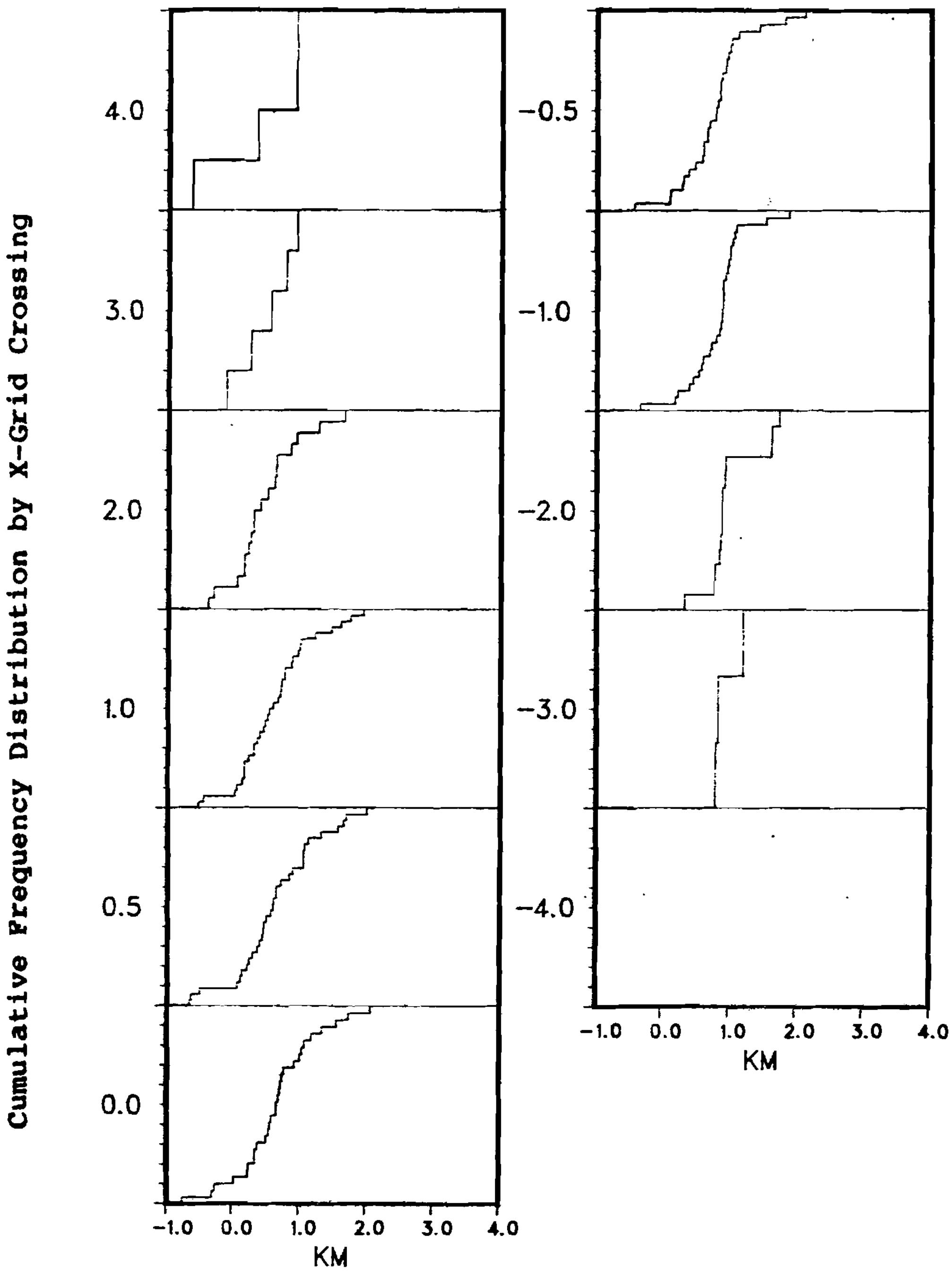


FIG. B.30. PRODUCTION PLATFORM (1,2,3)
D_Y (GRID CROSSINGS MEASURED FROM VARUA).

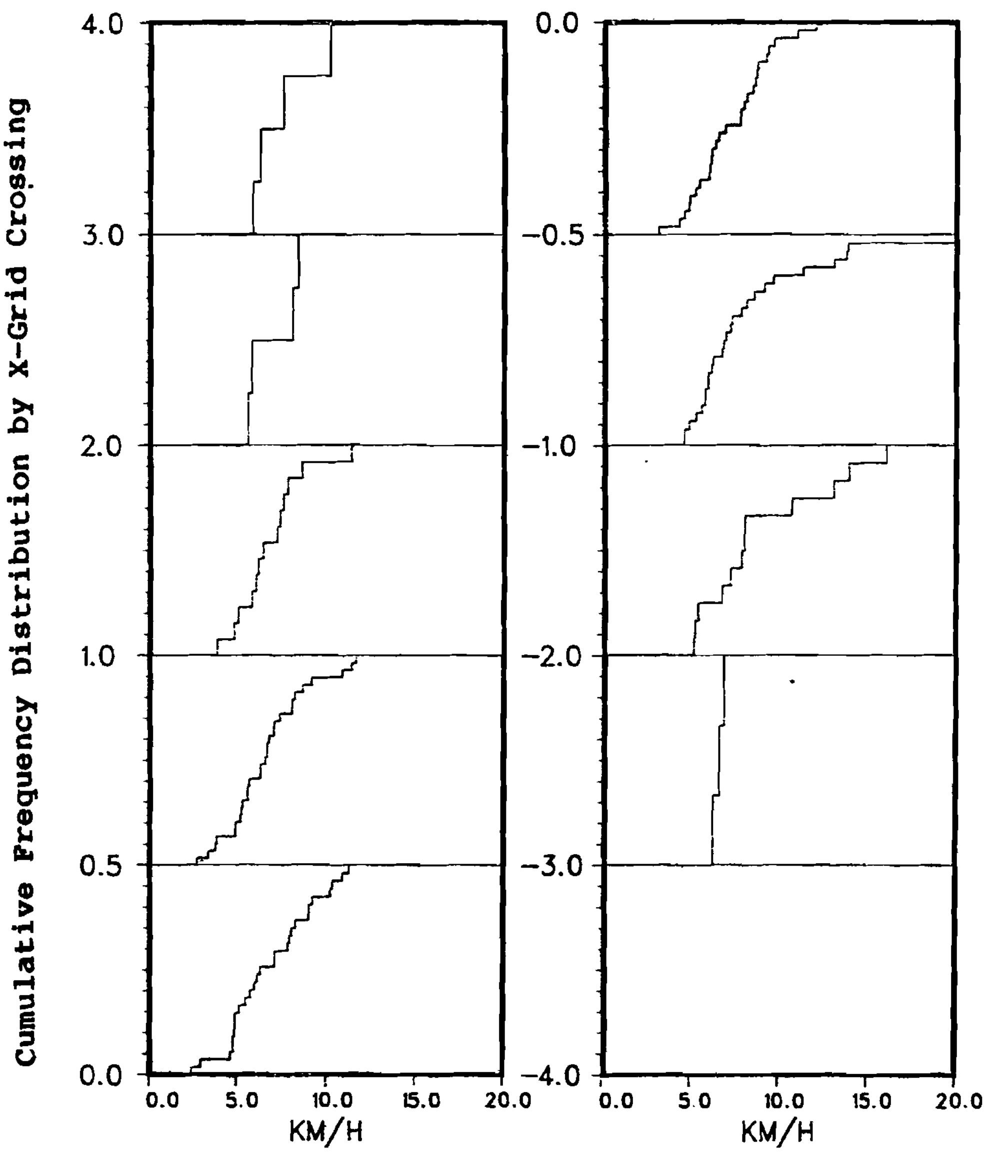


FIG. B.31. PRODUCTION PLATFORM (1,2,3)
SPEED.

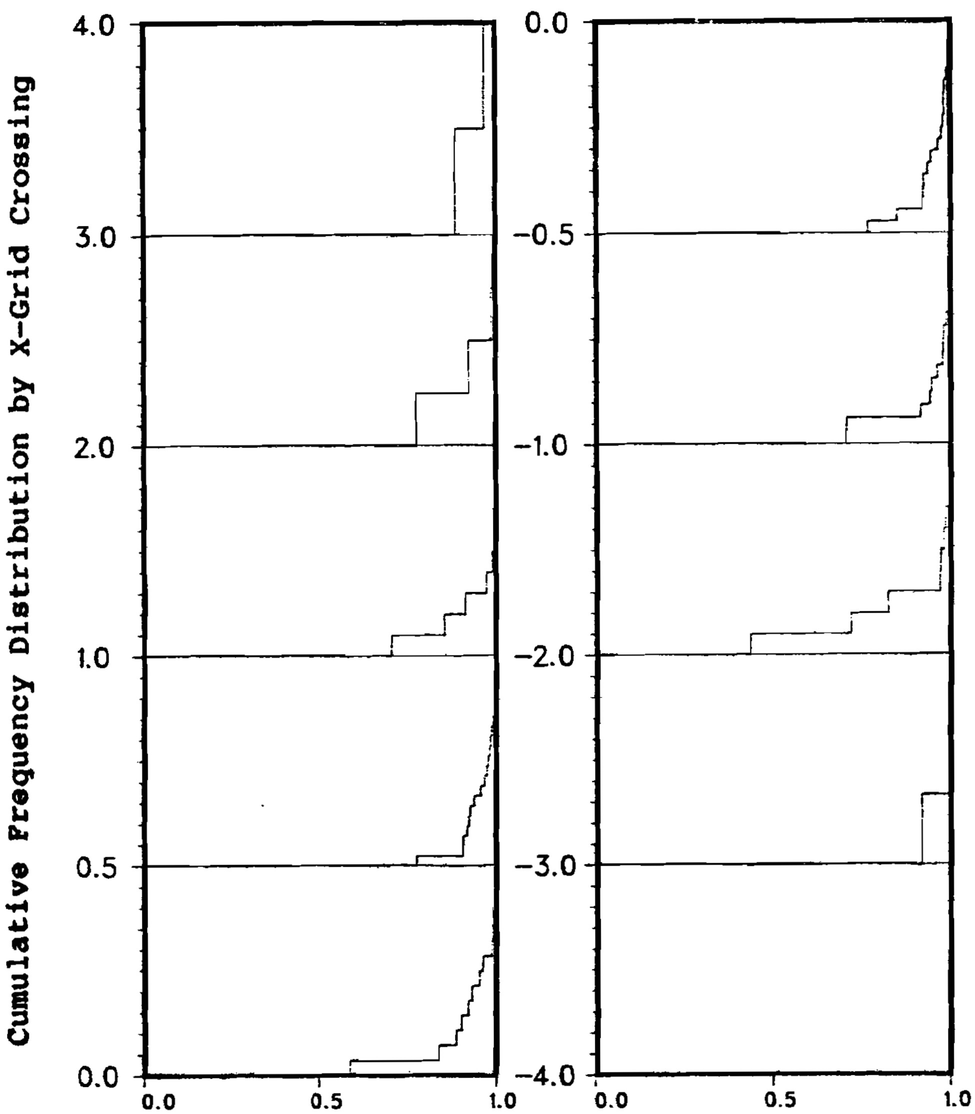


FIG. B.32. PRODUCTION PLATFORM (1,2,3)
MILLING INDEX.

APPENDIX C

TRACK PLOTS FOR THE MOTHER/CALF PORTION OF THE NORTHBOUND MIGRATION IN APRIL/MAY 1983

C.1 TRACK PLOTS FOR THE NORTHBOUND GRAY WHALE MIGRATION IN APRIL/MAY 1983

Figures C.1 through C.9 represent track plots for whale groups under control and experimental conditions for the gray whale mother/calf migration during April/May 1983. Comparing the plots with those for January (Appendix B), we see that they are much closer to shore, reinforcing the fact that mothers and calves follow a nearshore coastal migratory track.

Figures C.1 through C.3 are tracks of three whale groups under control or undisturbed condition. Group C in Fig. C.1 is two mother/calf pairs. Group A and Group B in Figs. C.2 and C.3 apply to single mother/calf pairs. All of the groups progressed northward in a normal manner. In Fig. C.1 at approximately -3400 (x-axis), Group C milled about at the south end of the Garrapata Beach for approximately 10 min. before continuing north. For a general description of the plotting format, see the introduction to Appendix B.

Figures C.4 through C.6 give track plots of whales during exposure to the GSI air gun array runs E2 and F (1 and 0.5 nm respectively) on 25 April. Each figure shows that the whale groups stalled and milled about for a varying period of time at some point during exposure. These periods coincide with high sound levels as the array vessel passed by the whale group. During these high levels of exposure, the groups were very close to shore (10 m off in some cases). Group J and Group O in Figs. C.4 and C.5 are both two mother/calf pairs. Group K in Fig. C.6 is a single mother/calf pair. In Fig. C.5, the vessel was travelling south; note, in particular, the grouping of northbound whale track data points south of Soberanes Point. This occurred as the vessel approached the whales. After the vessel passed by, the whales then proceeded to the north.

Figure C.7 shows the track plot of Group J, a single mother/calf pair, during the Killer Whale (orca) playback. The group traveled very close to shore, and a number of orientation changes were observed. Observers at north station noted that the mother and calf were very close together and that blows were synchronous.

Figure C.8 shows the track plot of Group O, a single mother/calf pair, during the Drill Ship playback. No observable behavior changes were noted.

Figure C.9 depicts the track plot of Group A, a single mother/calf pair, under the stationary air gun experiment and during pre- and post-experimental conditions. The asterisk (*) provides the location of the anchored single air gun vessel. The air gun was activated at 1308 when the group was directly off Soberanes Point (0,0 x-axis). The group immediately turned south. On the next two surfacings, the group was observed to be turning in various directions. The group then headed close in toward shore, rounding Soberanes Point and again in toward the shore, moving north the entire time (see detailed description in Sec. 6).

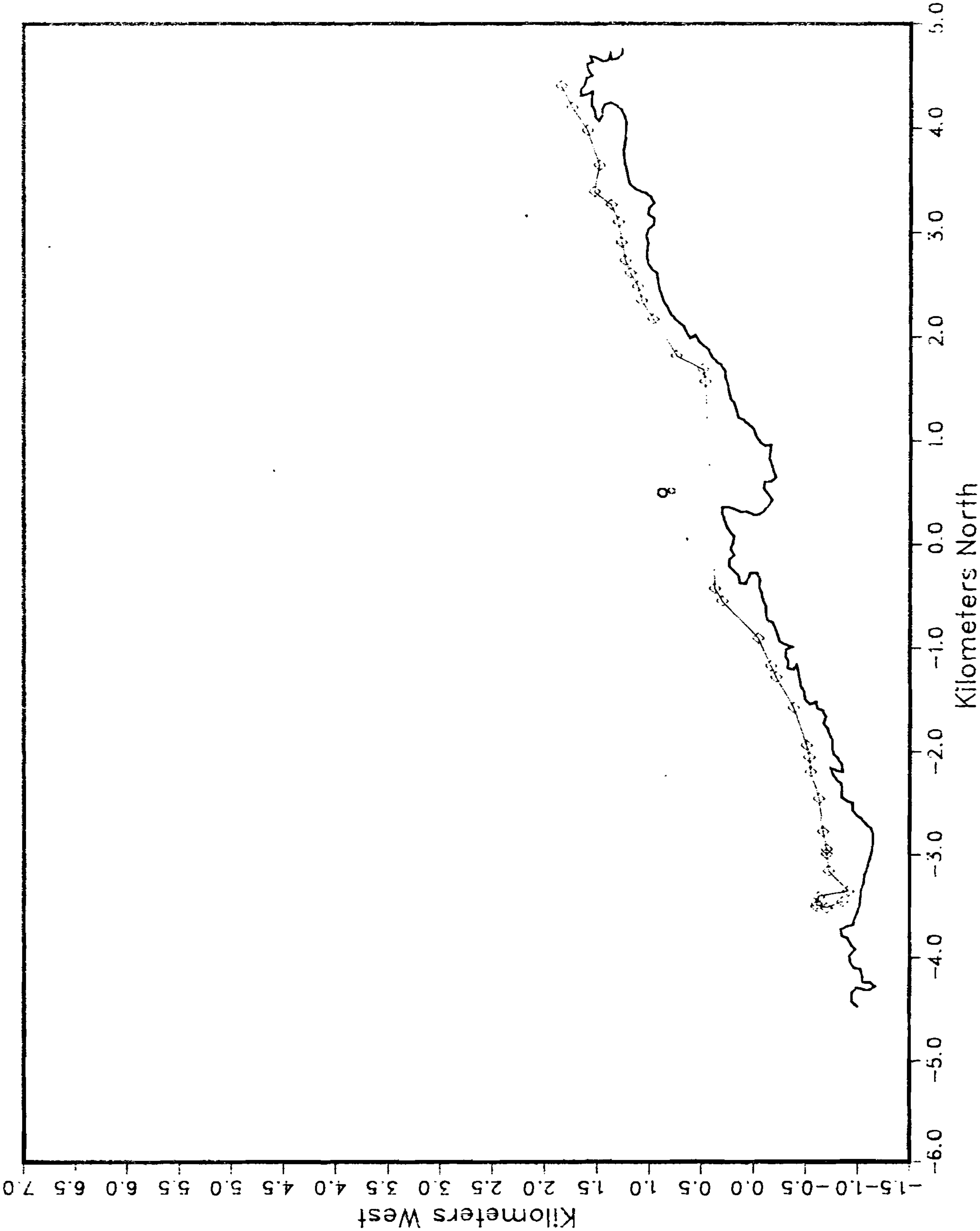


FIG. C.1. WHALE TRACK C, 20 APRIL 83.

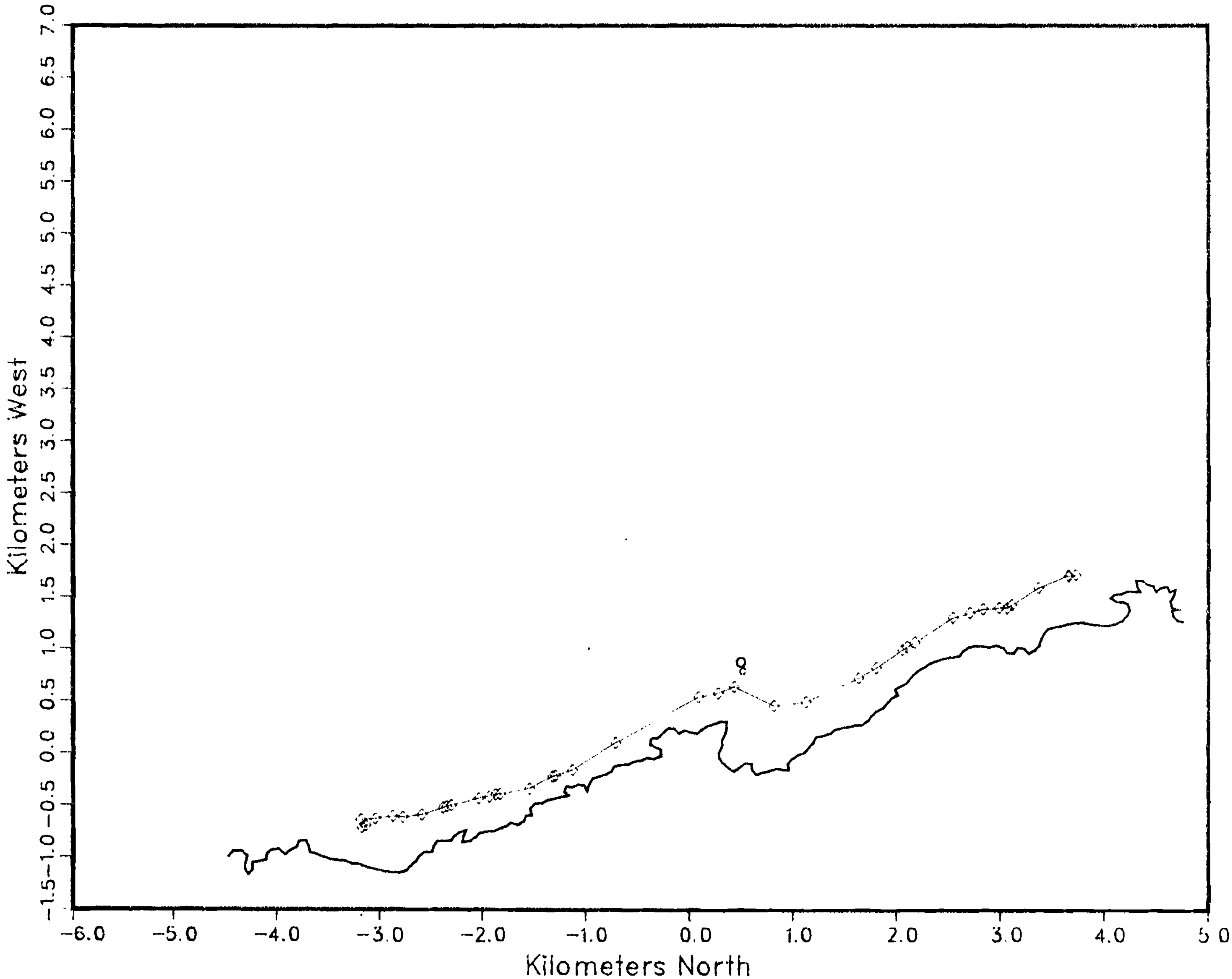


FIG. C.2. WHALE TRACK A, 22 APRIL 83.

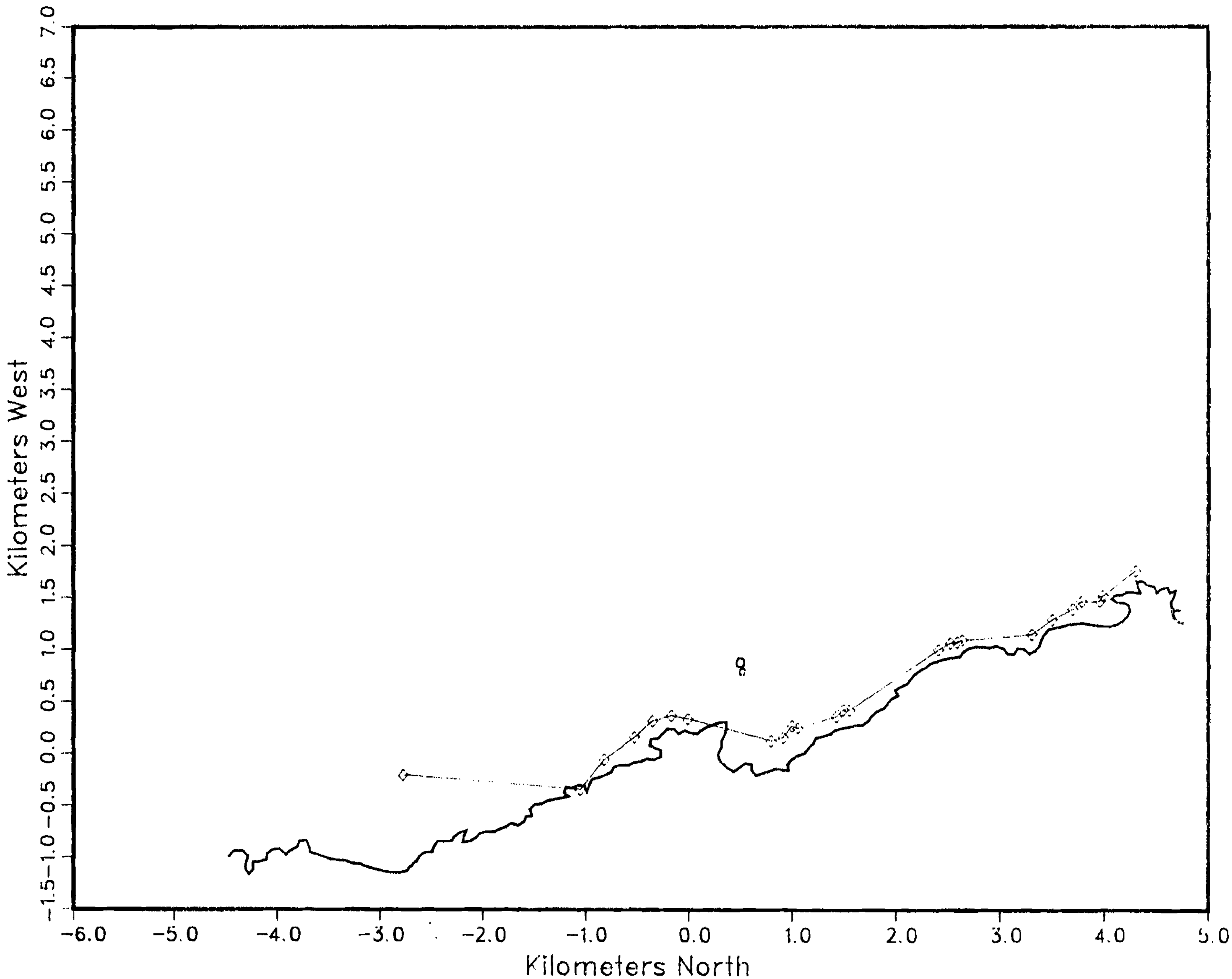


FIG. C.3. WHALE TRACK E, 2 MAY 83.

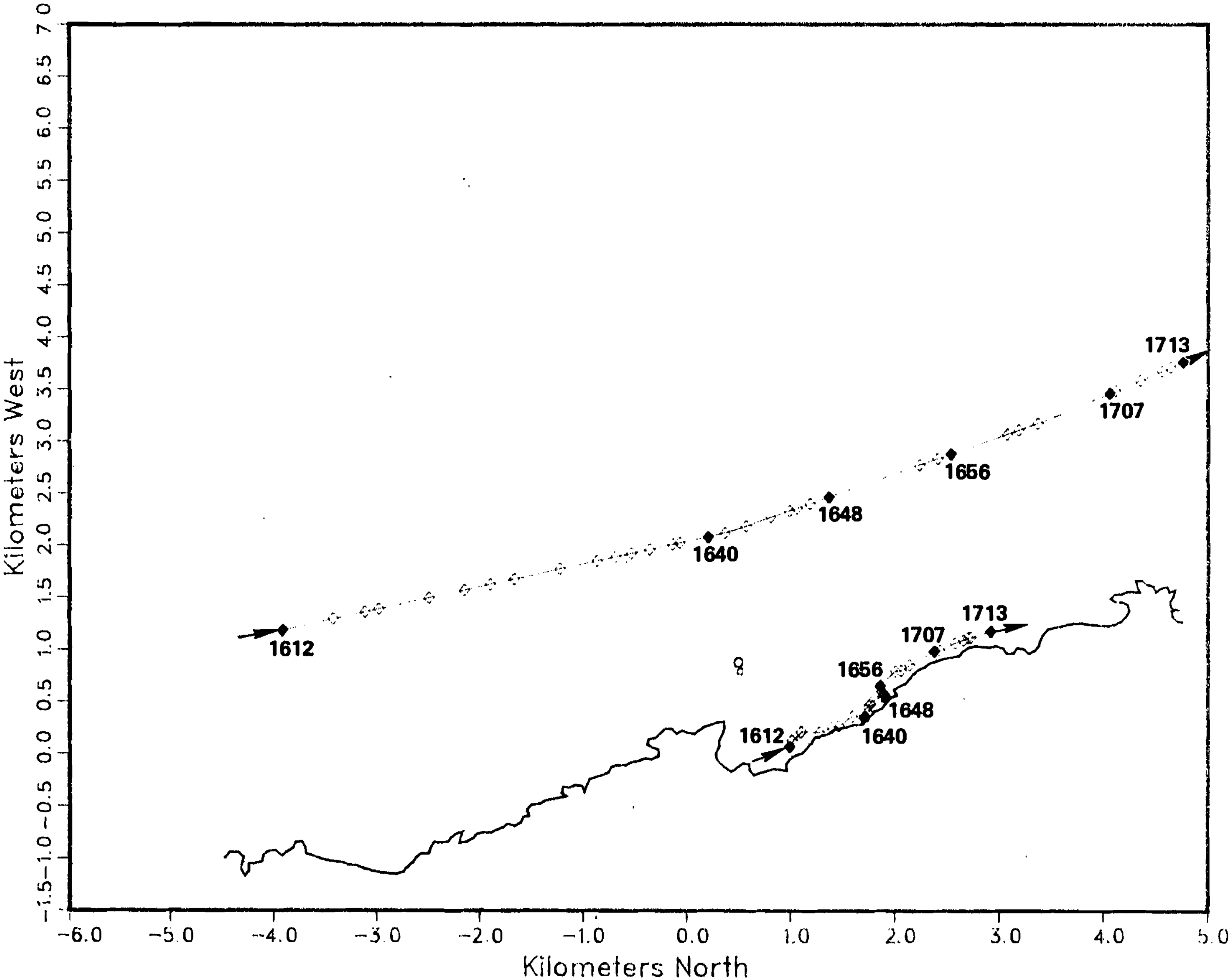


FIG. C.4. GSI TRACK E2, WHALE TRACK J, 25 APRIL 83.

(GROUP O)

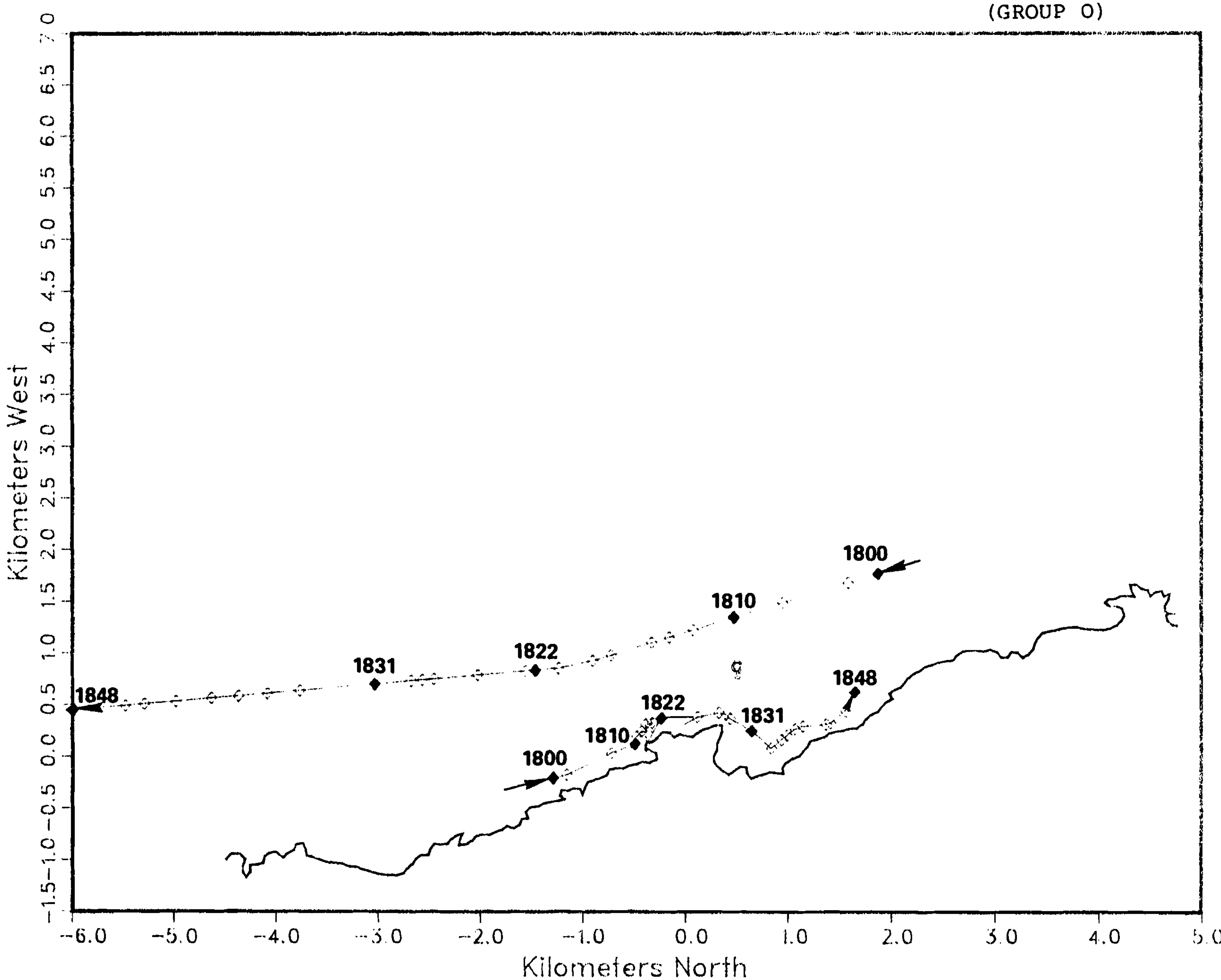


FIG. C.5. GSI TRACK F, 25 APRIL 83.

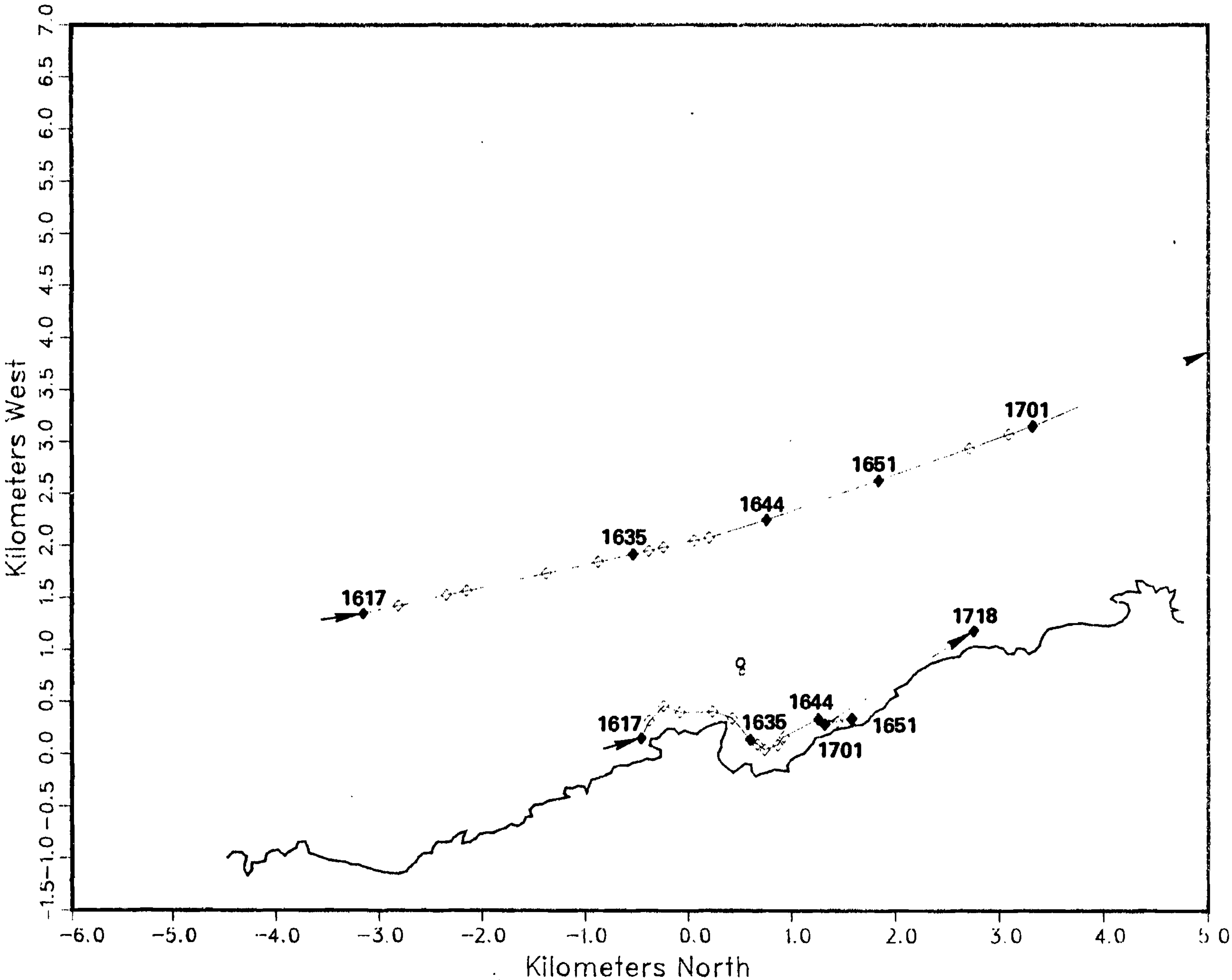


FIG. C.6. GSI TRACK E2, WHALE TRACK K, 25 APRIL 83.

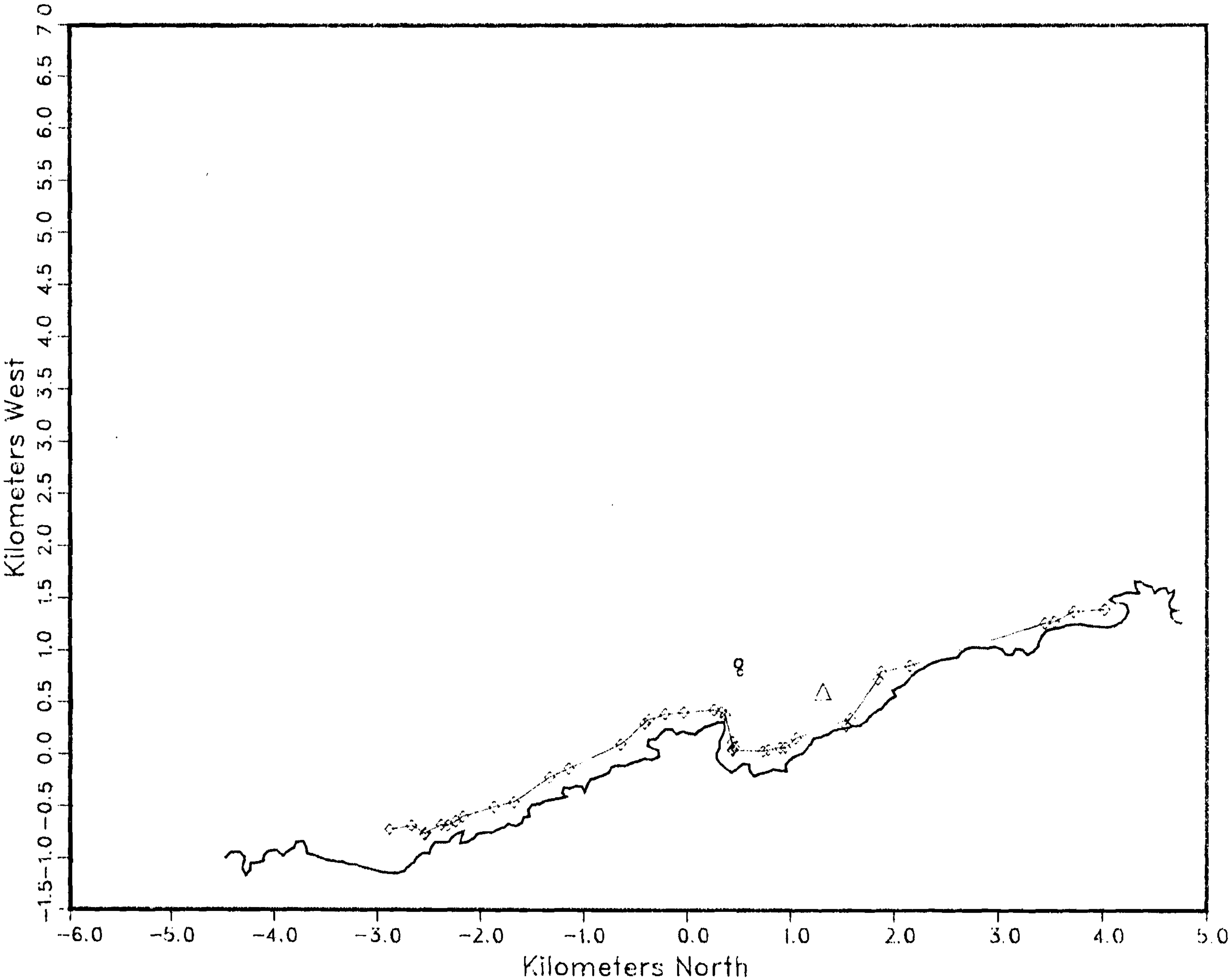


FIG. C.7. ORCA, WHALE TRACK J, 1 MAY 83.

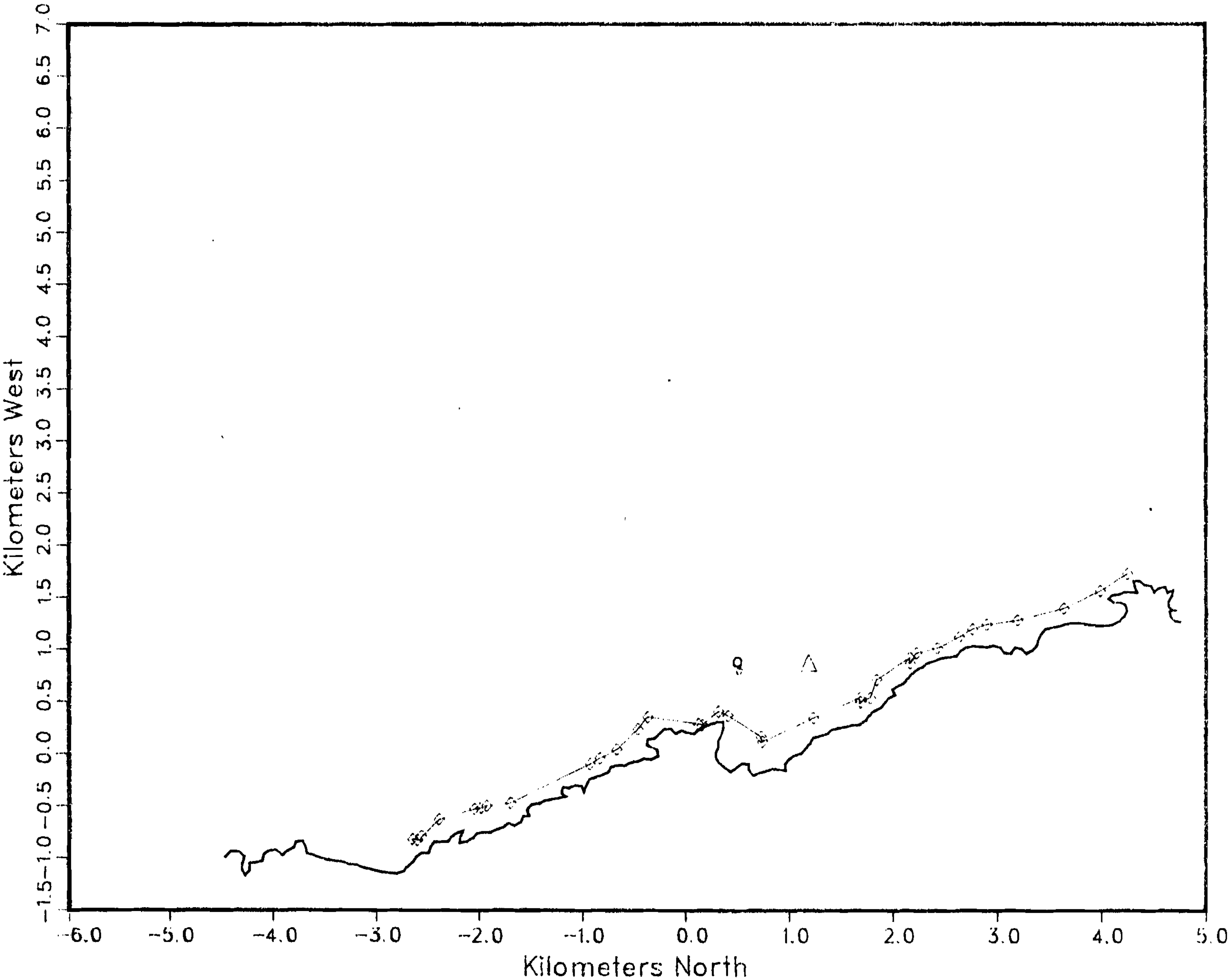


FIG. C.8. DRILLSHIP, WHALE TRACK 0, 29 APRIL 83.

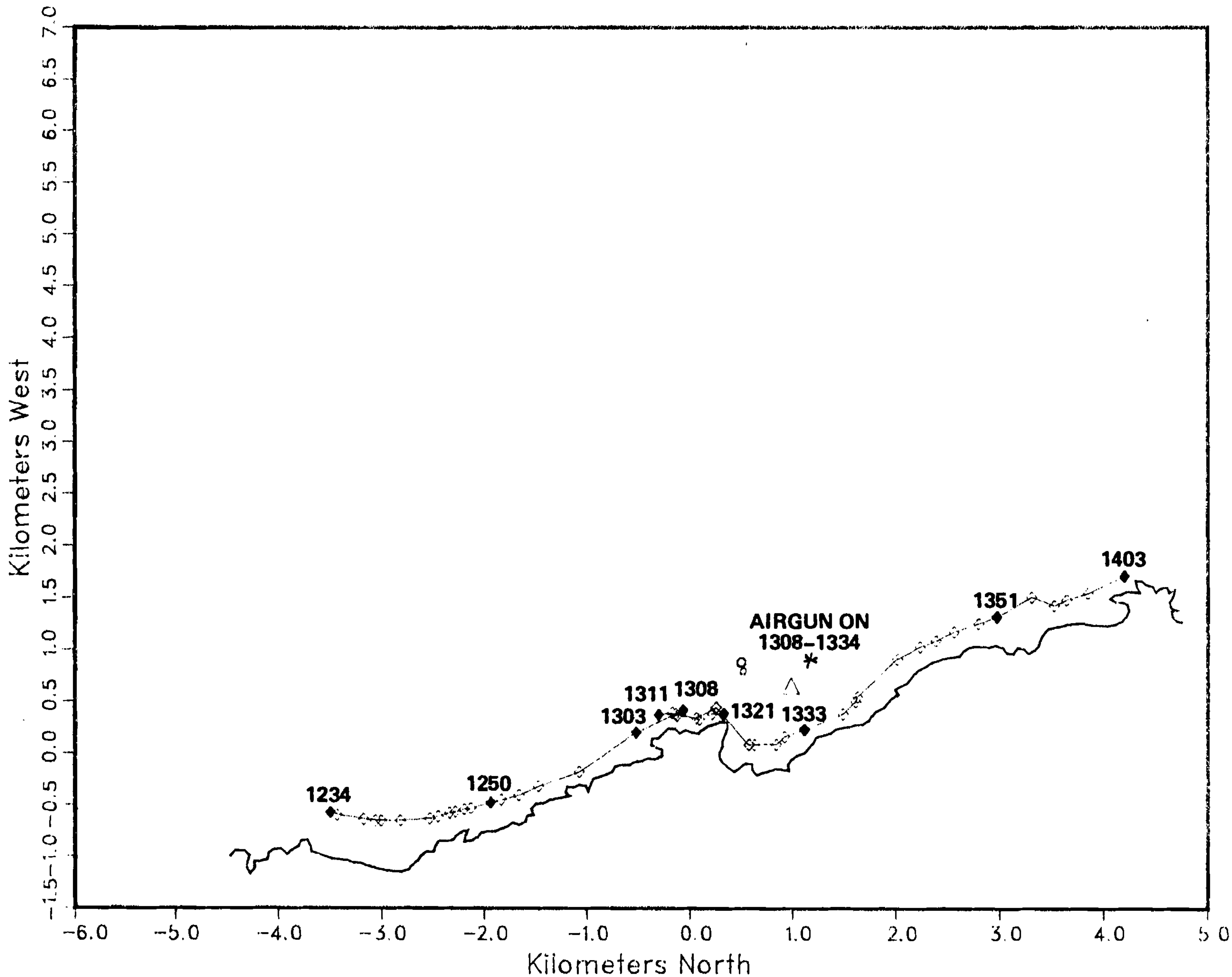


FIG. C.9. ANCHORED AIRGUN, WHALE TRACK A, 5 MAY 83.

APPENDIX D

PLAYBACK STIMULI SPECTRA

This appendix contains a set of narrowband and 1/3-octave band spectra for each of the playback stimuli used in the study. Spectra for both the original recording dub and the playback are included to permit comparison. The frequency fidelity for the projector system was not "Hi-Fi" in the sense of typical "dry" audio systems but was representative of the achievable response using readily available projectors with a crossover system to permit operation with a single power amplifier.

The J-13 projector was limited in low frequency response below 50 Hz. To achieve a significant increase in low frequency reproduction capability would require the use of specialized transducers such as the "Seahorse," which is a U.S. Navy test transducer weighing 1500 lbs, requiring a special handling crew and a large support vessel. Some improvement in output below 50 Hz could be achieved by using two J-13 projectors in close proximity. With the required high frequency projector, this assembly would be about 220 lbs - considerably less than the Seahorse projector.

A "crossover" notch was present in the playback response which depressed the playback signal 8 to 10 dB around 1 kHz, the region between the optimum response ranges of the J-13 and F-40 transducers. A corrective network will be used in future playback work with the projector system to boost the response in this region.

The response data for Drill Ship, Helicopter, Semi-submersible, Drilling Platform, Production Platform, and Killer Whale (Orcinus orca) vocalization are presented in Figs. D.1 through D.11. They are given as listed on the next page.

Figure	Source
D-1	Drill Ship, NB
D-2	Drill Ship, 1/3 oct.
D-3	Helicopter, NB
D-4	Helicopter, 1/3 oct.
D-5	Semisubmersible, NB
D-6	Semisubmersible, 1/3 oct.
D-7	Drilling Platform, NB
D-8	Drilling Platform, 1/3 oct.
D-9	Production Platform, NB
D-10	Production Platform, 1/3 oct.
D-11	Orca, 1/3 oct.

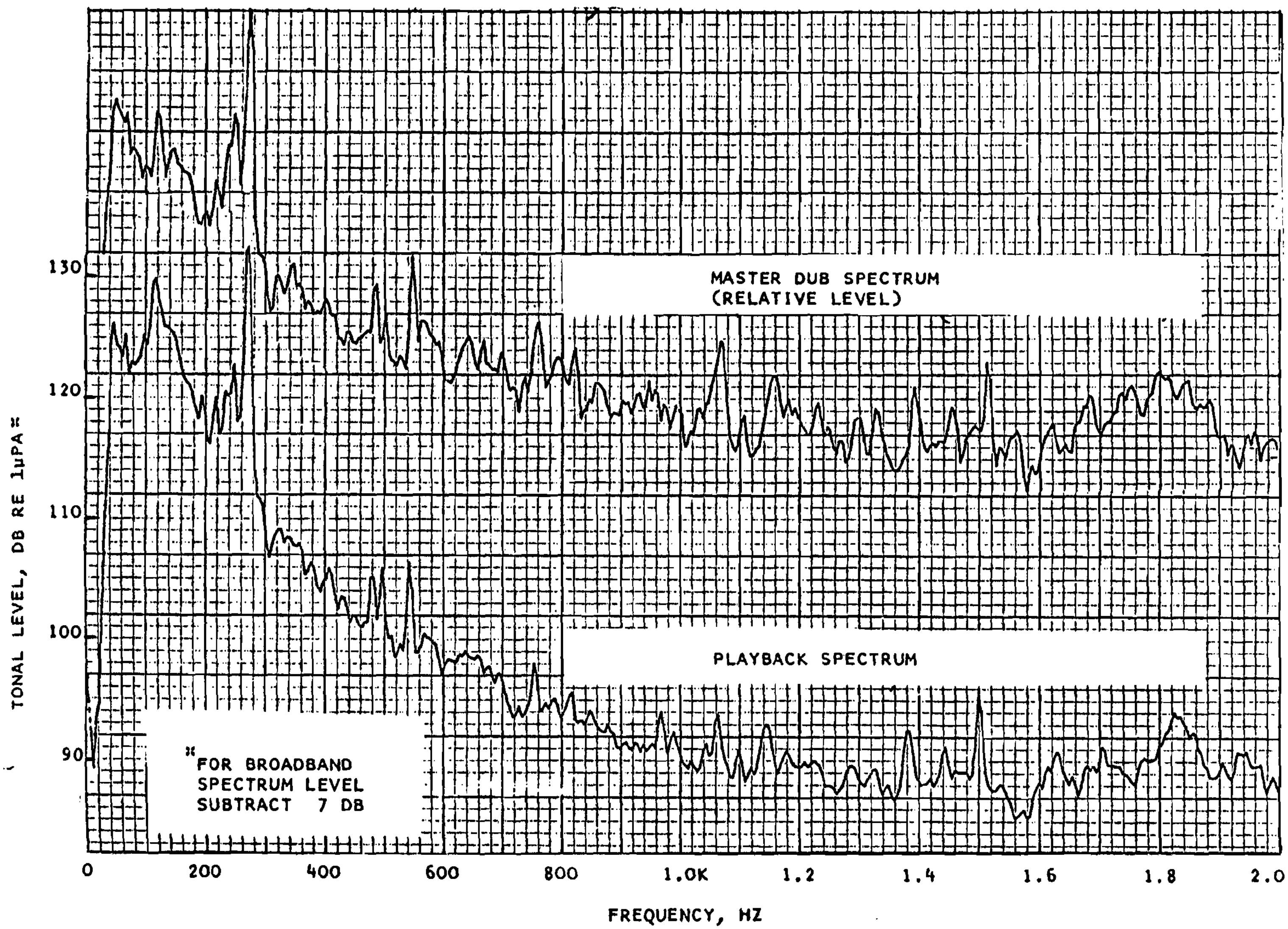


FIG. D.1. DRILLSHIP NARROWBAND SPECTRA.

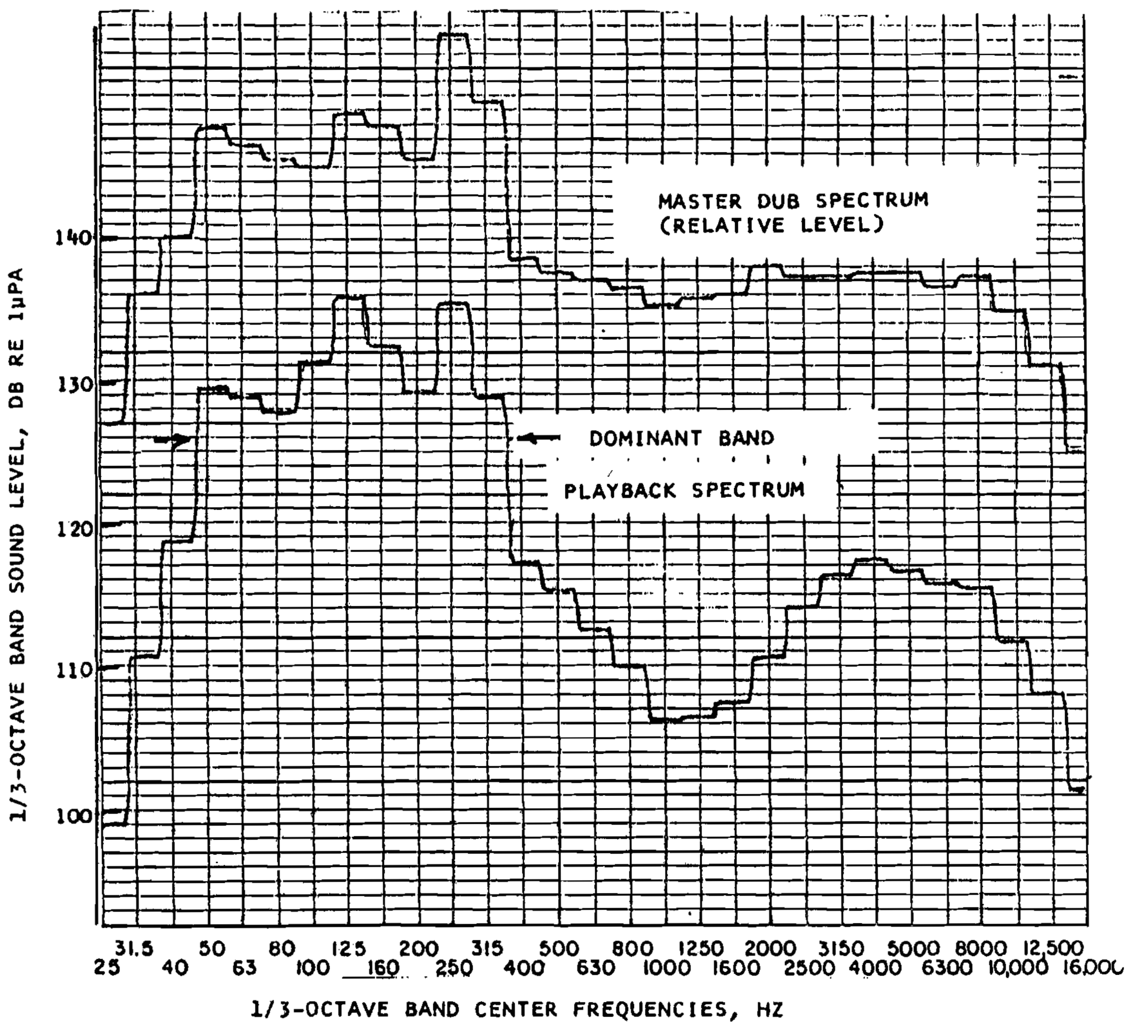


FIG. D.2. DRILLSHIP ONE-THIRD OCTAVE BAND SPECTRA.

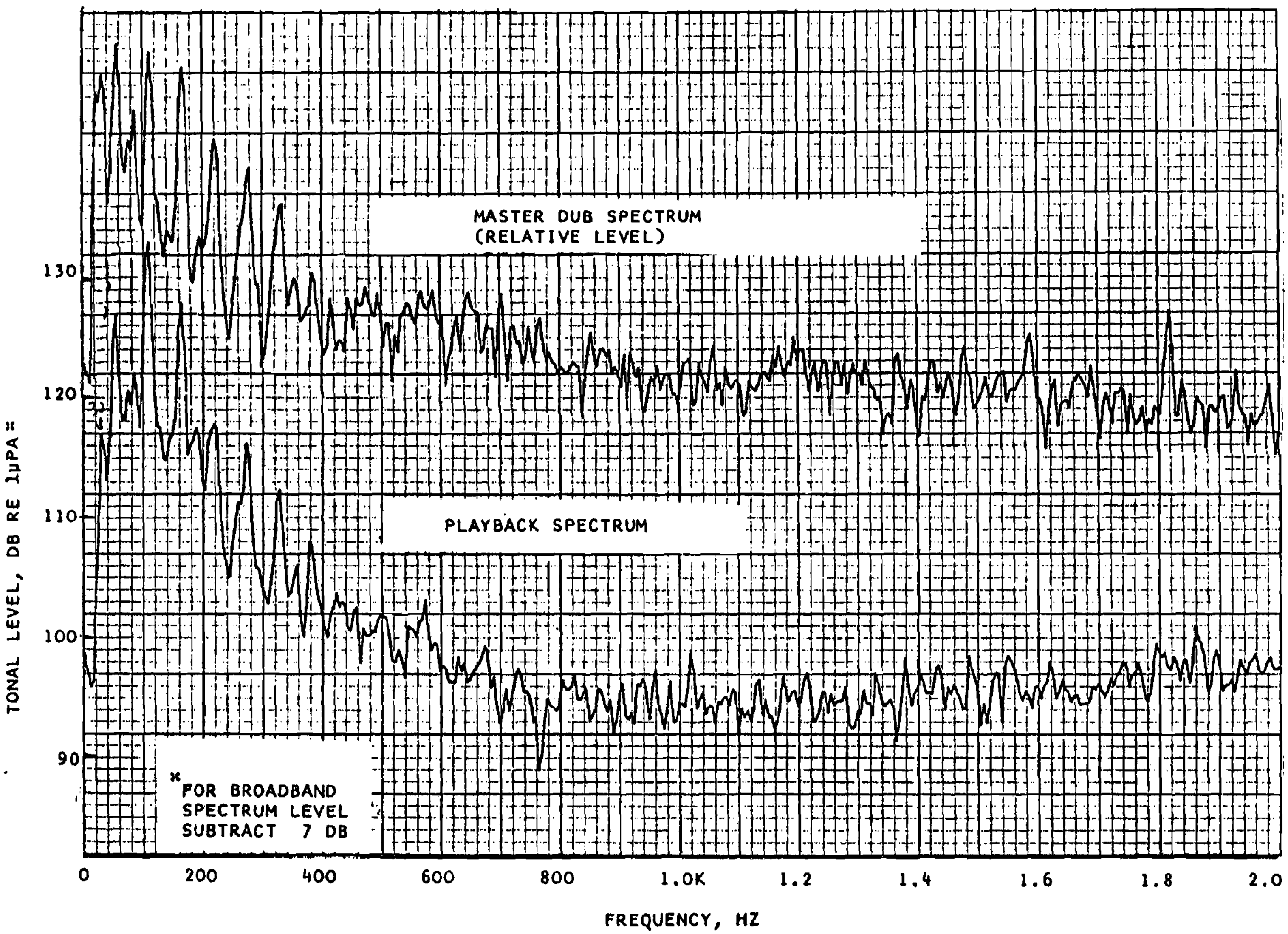


FIG. D.3. HELICOPTER NARROWBAND SPECTRA.

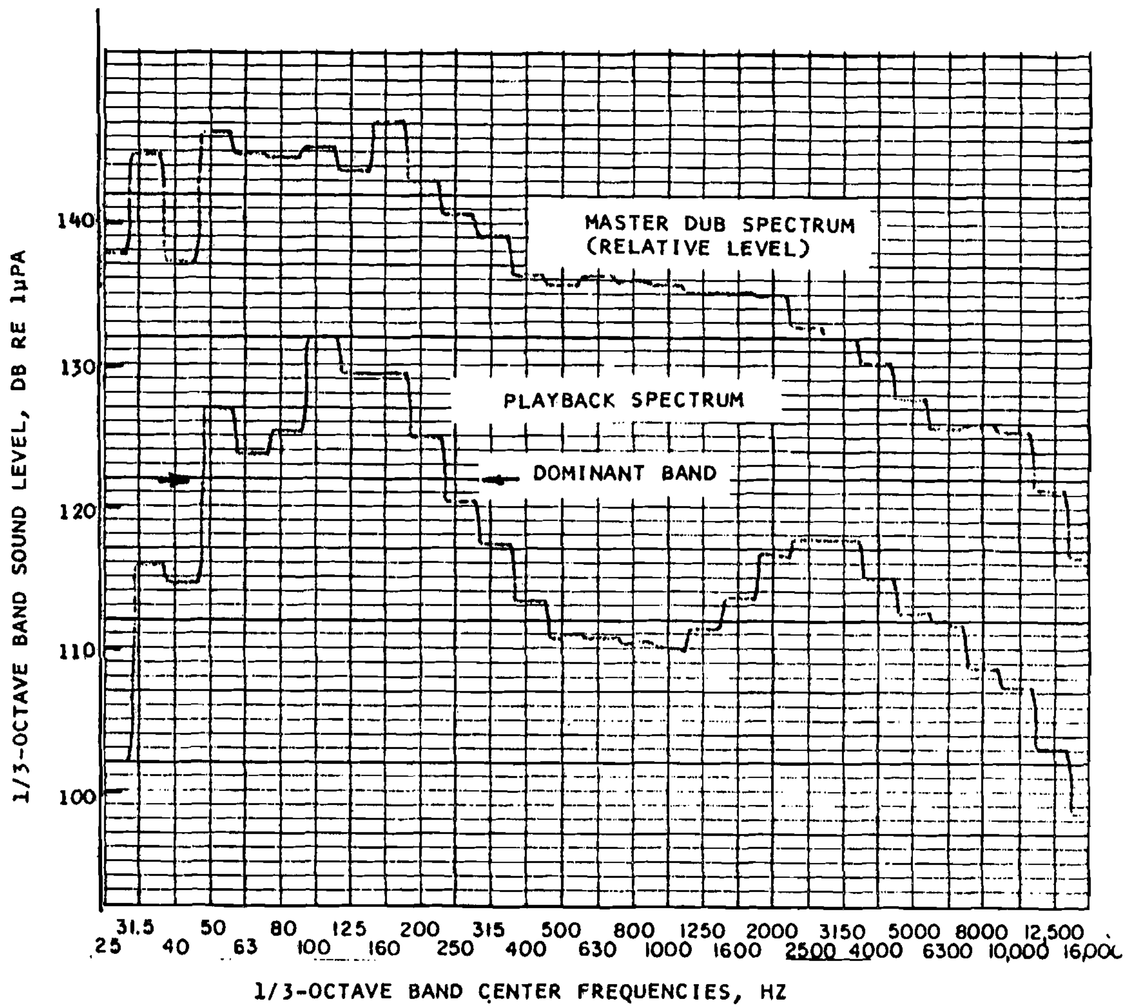


FIG. D.4. HELICOPTER ONE-THIRD OCTAVE BAND SPECTRA.

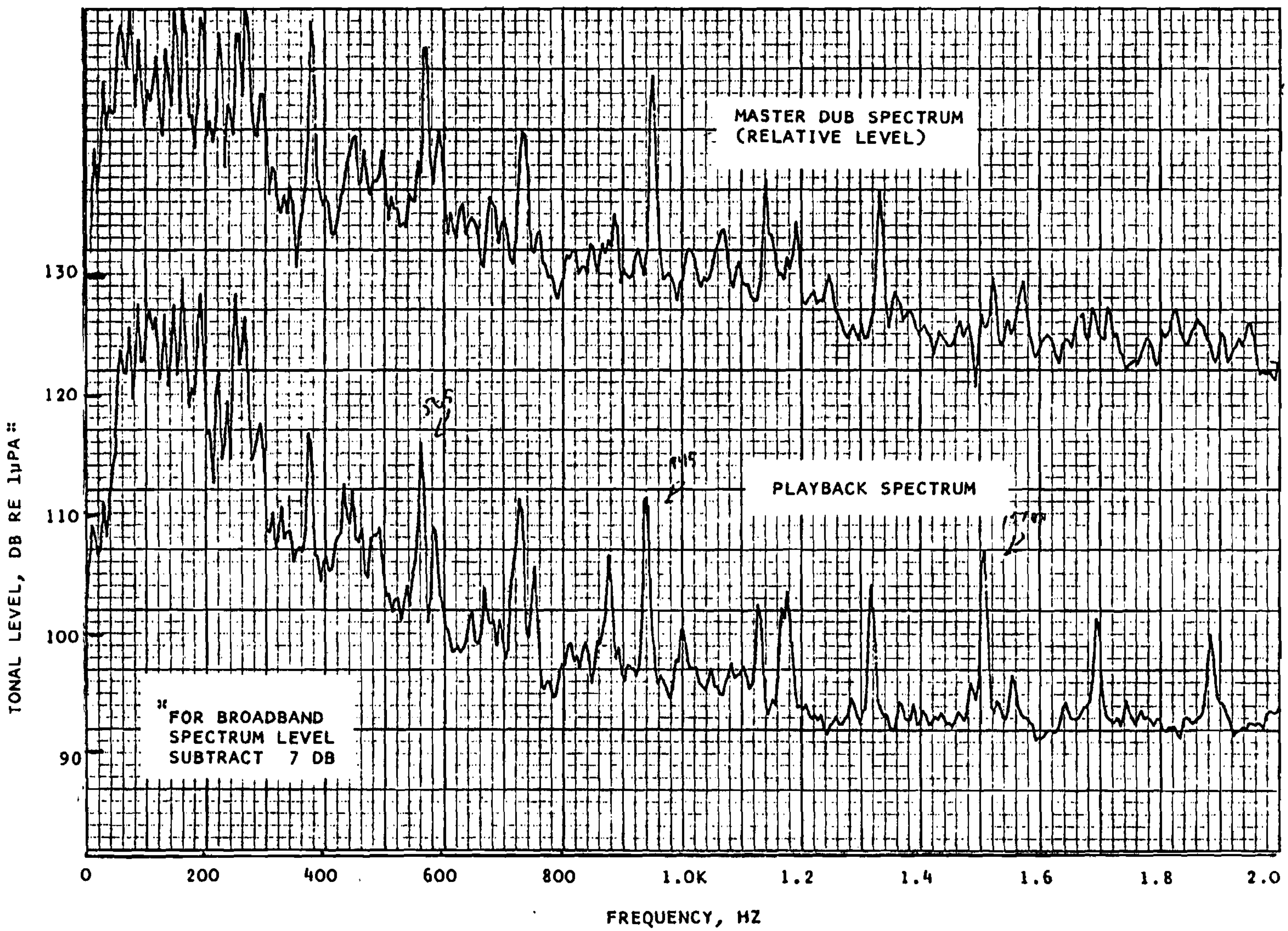


FIG. D.5. SEMI-SUBMERSIBLE NARROWBAND SPECTRA.

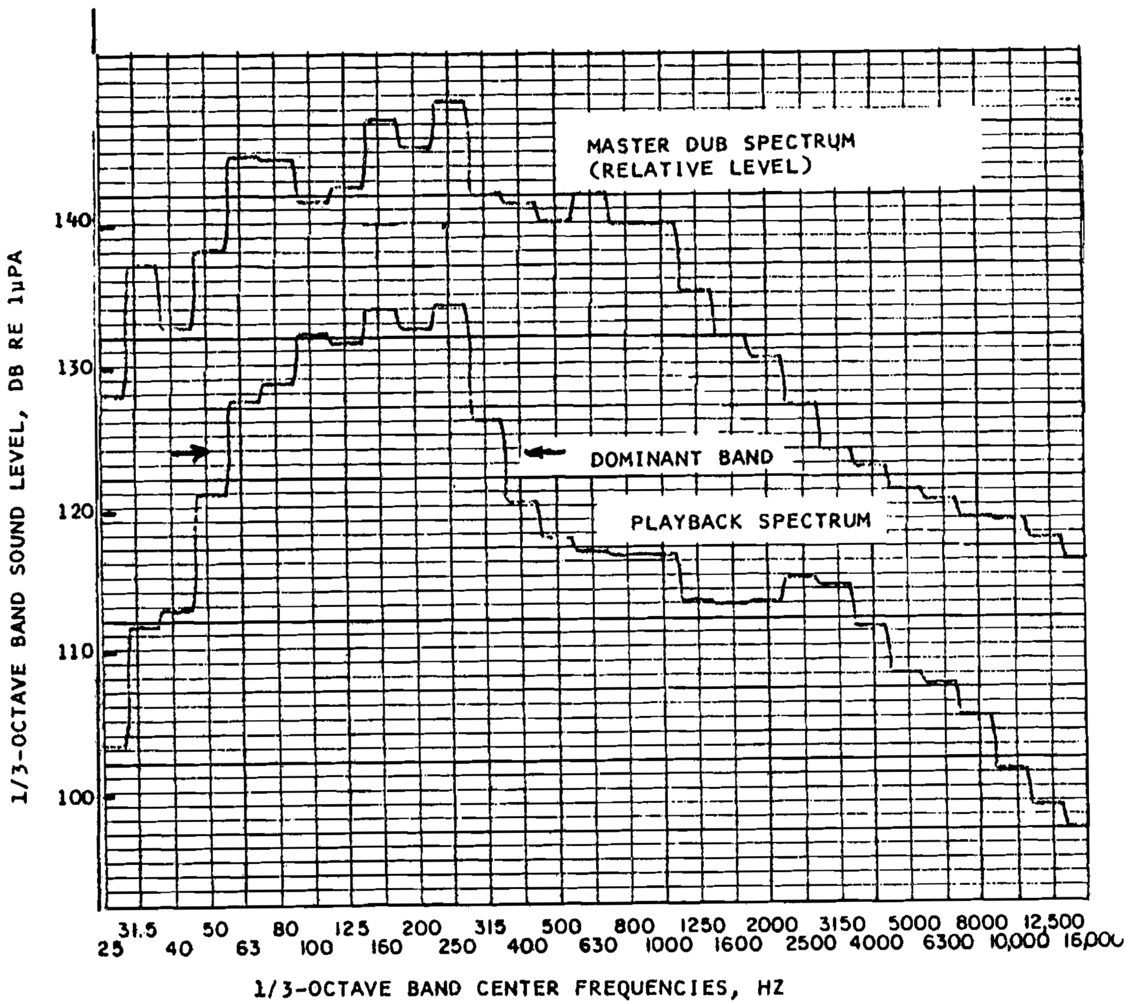


FIG. D.6. SEMI-SUBMERSIBLE ONE-THIRD OCTAVE BAND SPECTRA.

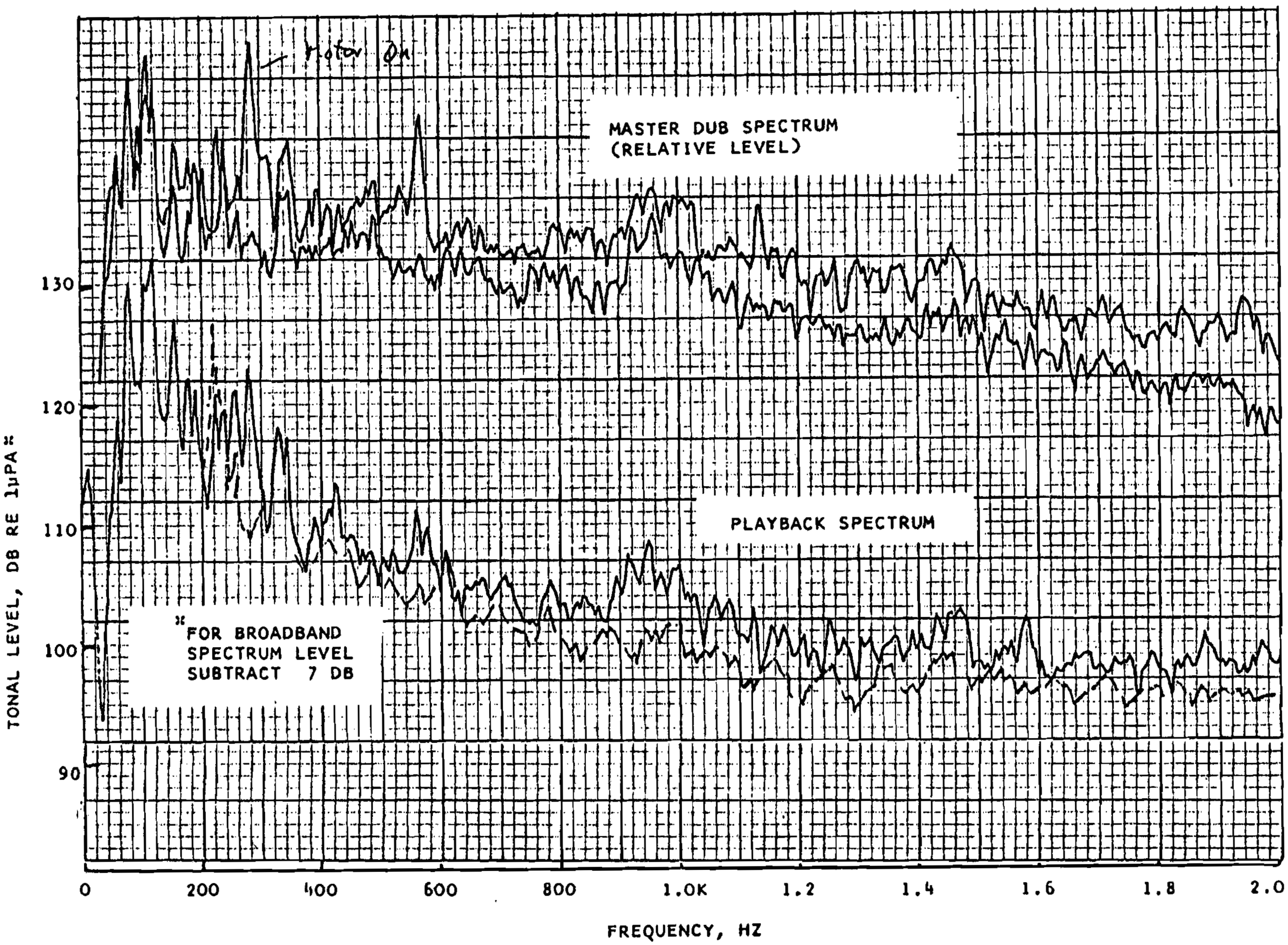


FIG. D.7. DRILLING PLATFORM NARROWBAND SPECTRA.

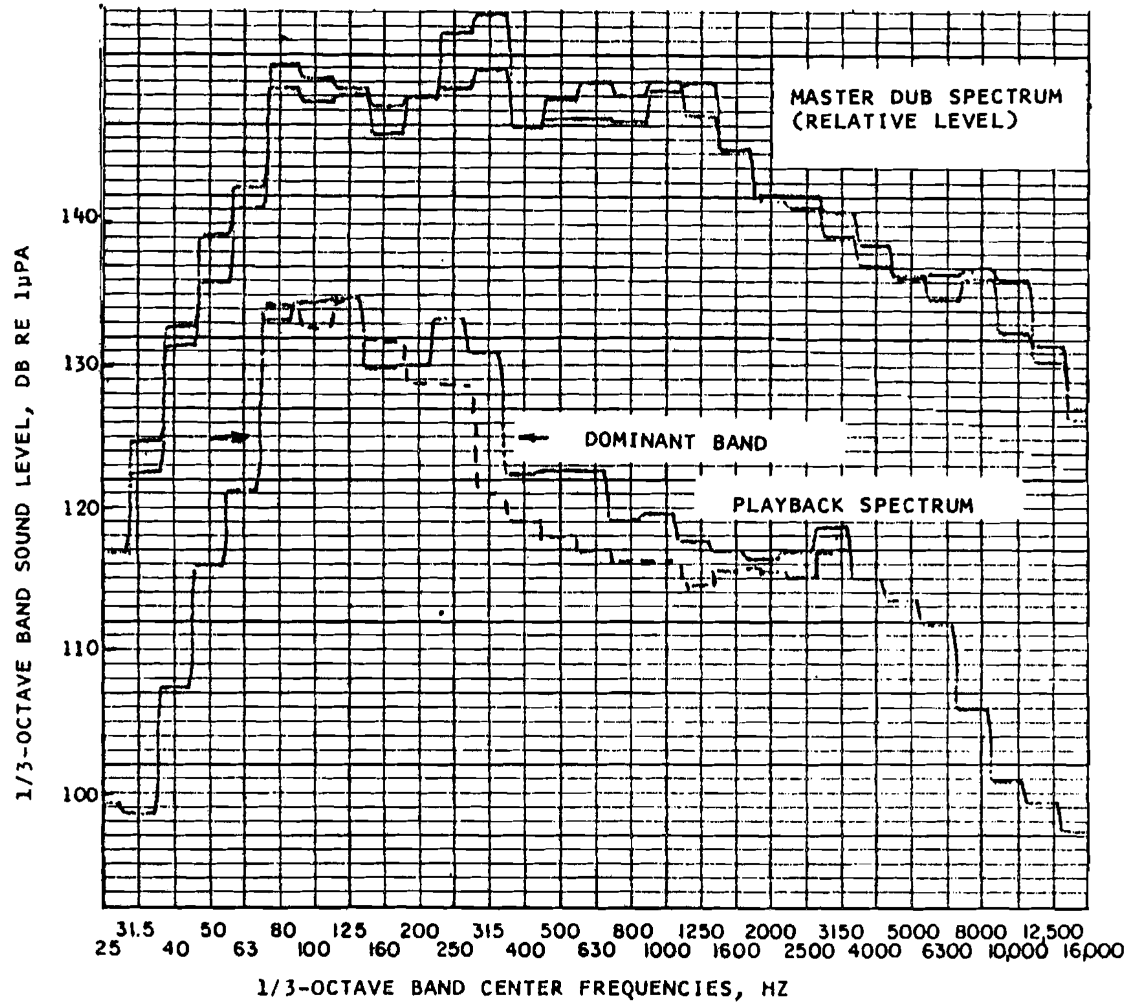


FIG. D.8. DRILLING PLATFORM ONE-THIRD OCTAVE BAND SPECTRA.

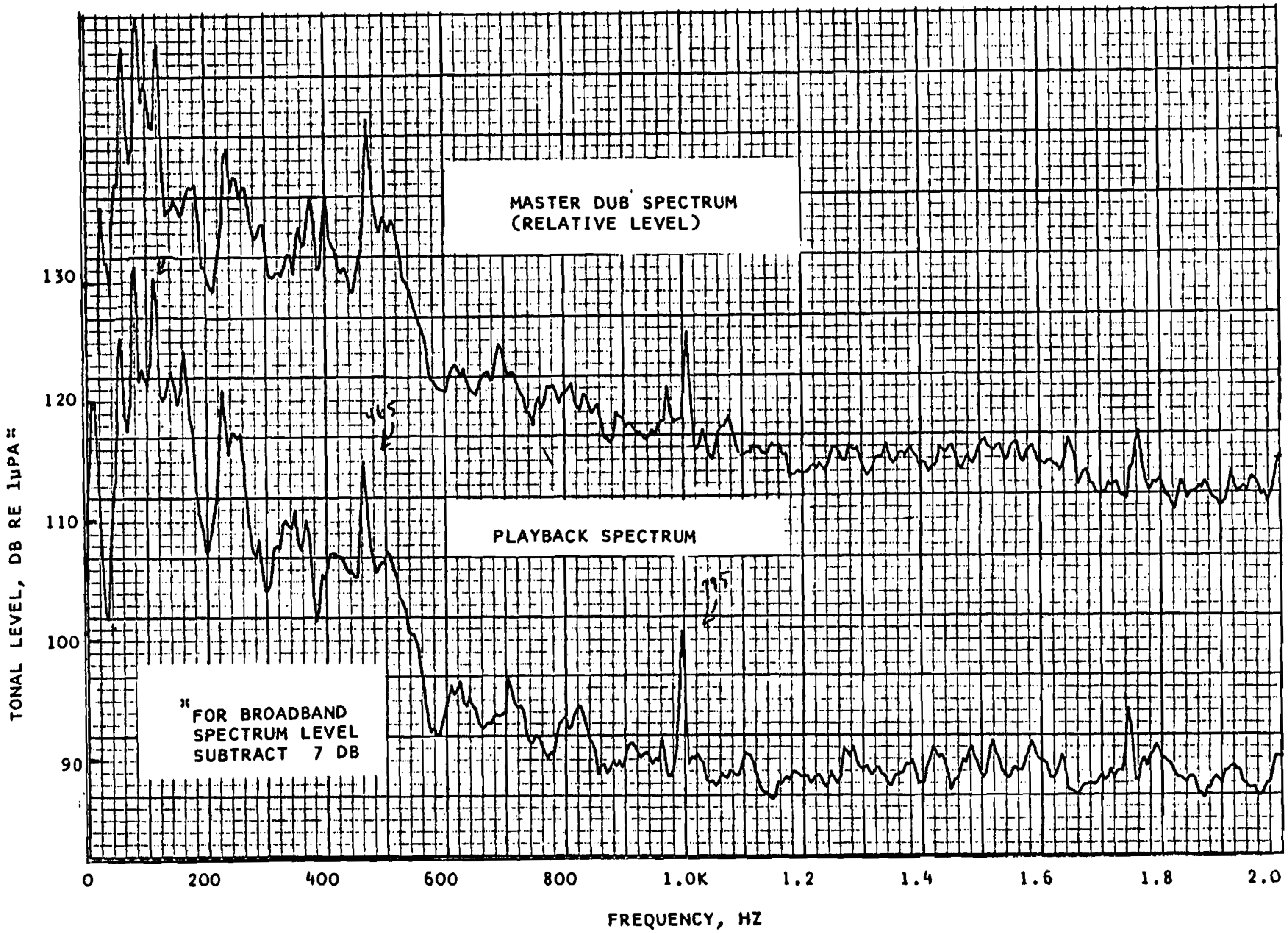


FIG. D.9. PRODUCTION PLATFORM NARROWBAND SPECTRA.

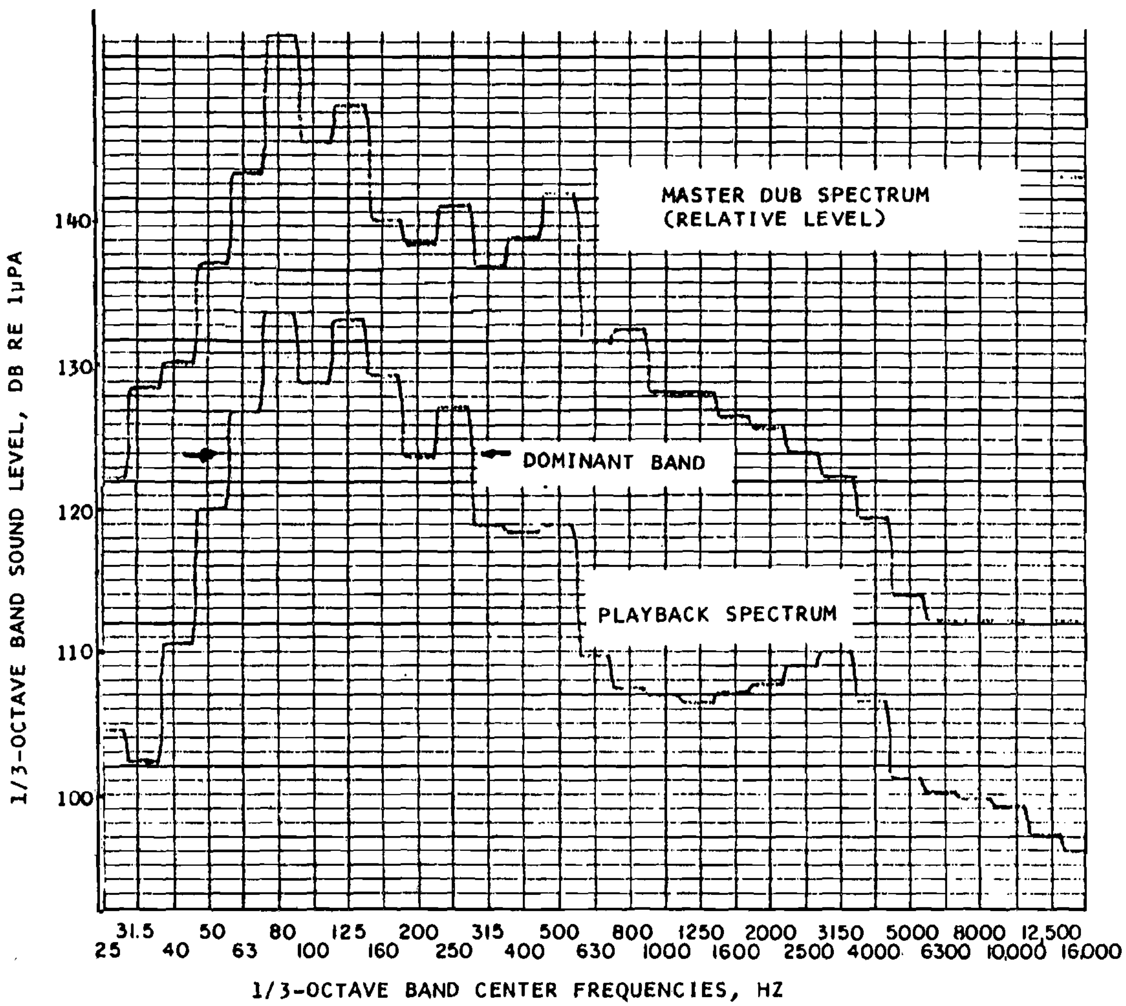


FIG. D.10. PRODUCTION PLATFORM ONE-THIRD OCTAVE BAND SPECTRA.

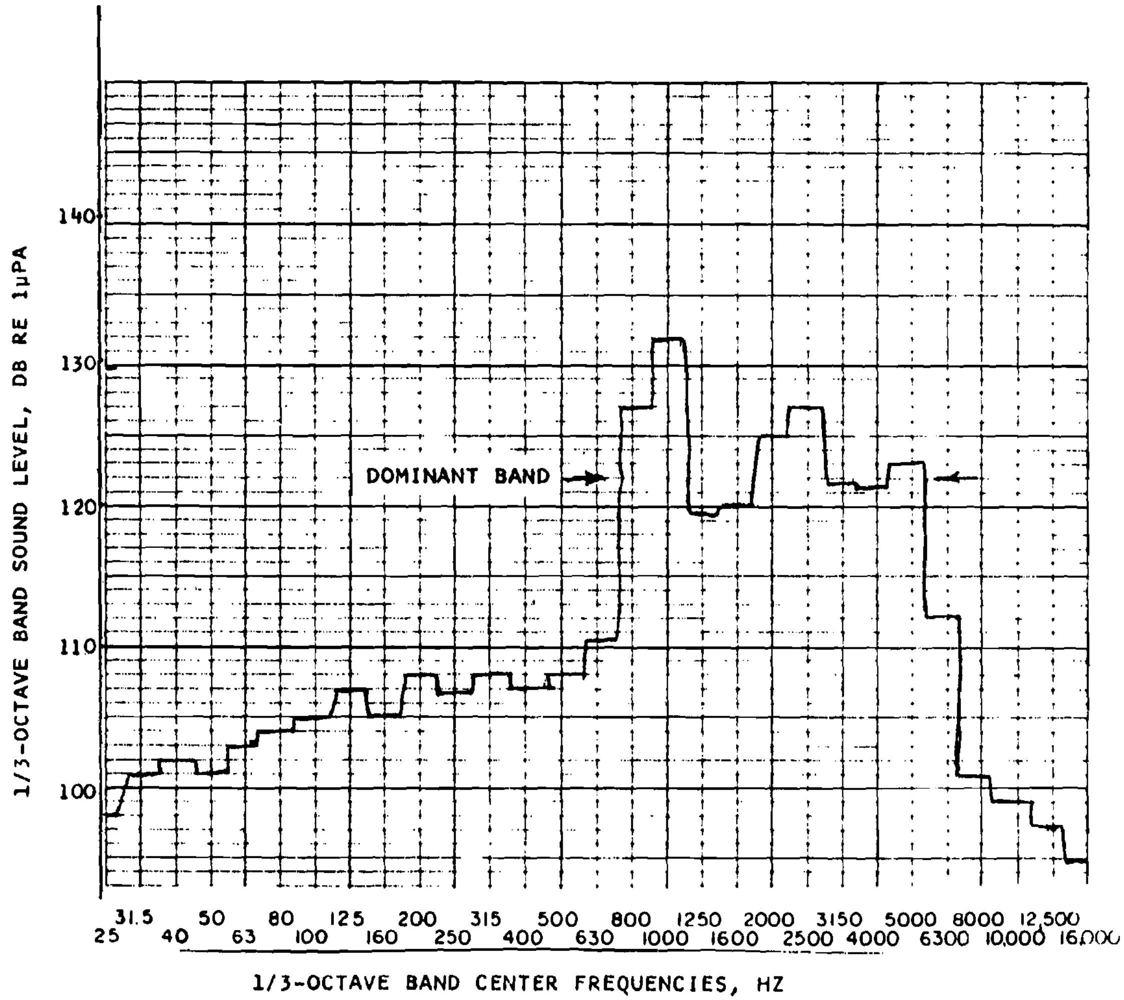


FIG. D.11. KILLER WHALE (Orcinus orca) VOCALIZATION (ONE-THIRD OCTAVE BAND SPECTRA.

APPENDIX E

ACOUSTIC MONITORING OF MIGRATING GRAY WHALE DENSITY

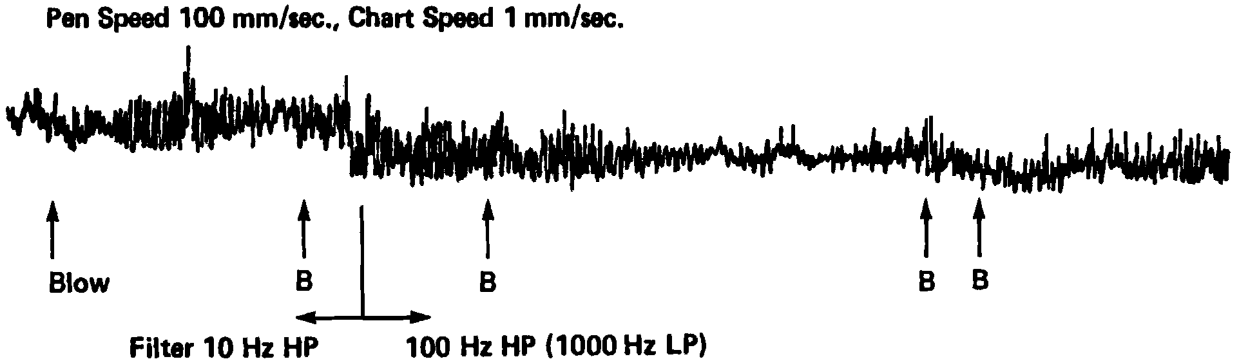
Because of the anticipation that VARUA would remain on station overnight during the performance of the playback study, we designed a simple experiment to attempt to learn more about the question of day/night effects on gray whale migration rates. This is of interest because of its potential impact on population estimates. Presently, an assumption is made that day and night migration rates are equal.

The experiment was designed to detect possible day/night migration rate differences by acoustically monitoring the gray whale in-air sounds as heard on the VARUA. The system used is shown in Fig. E.1. It consisted of a weather-proofed microphone mounted on an 8-ft mast connected to a tape-recording system. Concurrent frequency selective filtering was performed on the signal, and the resulting acoustic level was displayed as a function of time on a strip-chart recorder. A directional microphone was not used because of the difficulty in accommodating the rolling of the vessel and the limited vertical aspect angle of the sea surface.

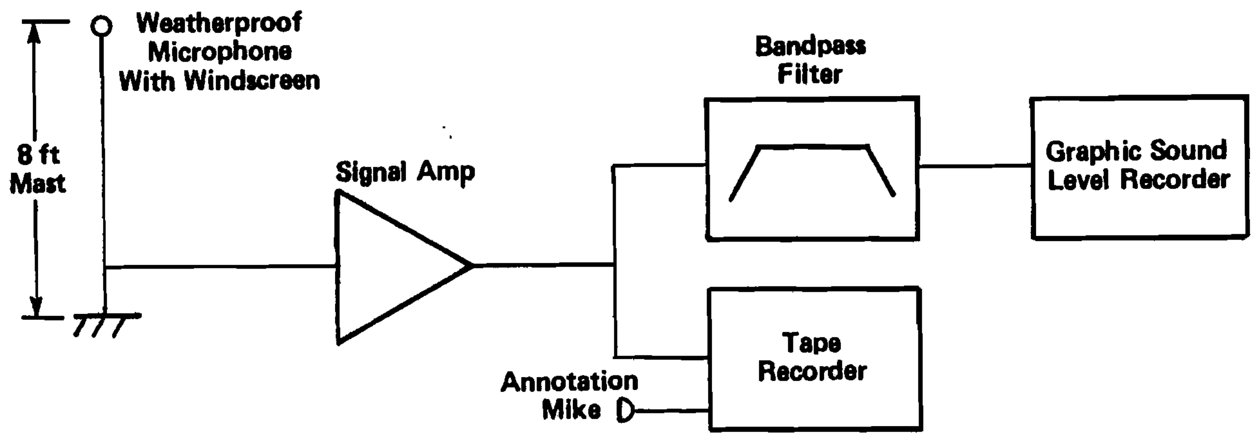
The experiment plan was based on acoustic observations made in southeast Alaskan waters of blow sounds of humpback whales. These sounds were found to be often audible over local ambient noise for a distance of a kilometer or more. Thus, we anticipated that the blow sounds of migrating gray whales would be similarly audible and could be monitored acoustically to obtain an estimate of the number of whales nearby. An observer on the VARUA would provide the means of correlating audible blows with the actual number of nearby whales. The blow sound time-amplitude envelope would be automatically recorded on a chart with its presumably distinctive pulse-shape providing a means of distinguishing blow records from ambient noise events.

Unfortunately, California coastal waters are not as sheltered as those in southeast Alaska and, as a result, we were not able to get satisfactory results from this experiment. As shown in the sample chart record in Fig. E.1, the generally high sea state produced high ambient noise levels on the VARUA due to wind noise and splash noise on the hull. While blow sounds are shown on the chart record, they are not uniquely distinguishable. Experimentation with different filter arrangements was performed, but because of the broad frequency content of the blow sound (10 to 1000 Hz), no optimum bandwidth was determined which was able to selectively reject ambient noise. We also were periodically visited by members of a nearby sea lion colony. The blow sounds of sea lions swimming nearby were found to be indistinguishable from those of gray whales.

For the reasons described above, it appears that acoustic monitoring of blow sounds to obtain an estimate of the number of nearby whales is not feasible under the generally prevailing sea conditions off the California coast. It may be possible to obtain acoustic data from shore using an appropriately directional microphone system. The recorded data we have obtained would be useful in the design of this experiment.



a. Example Chart Record



b. Sound Recording System

FIG. E.1. WHALE BLOW SOUND RECORDING.

APPENDIX F

ERROR ANALYSIS OF RESPIRATION RATE AND BLOW INTERVAL DATA, APRIL/MAY

For almost all groups observed in April/May, there was a period during which two stations were taking respiration data simultaneously. Typically, this period lasted less than 10 min. Groups were usually about 1 to 1.5 km from either of the two stations during these overlap periods since this "passing off" or "handing off" procedure occurred halfway between stations. Occasionally both stations would note that they felt confident that they were observing all respirations from either the mother, her calf, or both animals in the group.

In order to determine the reliability of the respiration data, a comparison was made between the respiration data collected by the two observation stations. Because of the difference in confidence level on the part of observers, two separate comparisons can be made; one using the data when the two stations were making simultaneous observations but were not confident that they were observing all blows, and another when both stations were confident that they were noting all blows. The first comparison affects the reliability of the behavioral measure called respiration rate, while the second comparison affects the reliability of the behavioral measure called blow interval. It must be stressed that this analysis of the respiration data is not a calibration of the accuracy of observations when groups were within 1 km of a station. Instead, it is a means of specifying where and the extent to which errors could occur during observations on groups further than about 1.5 km from the land-based observers.

All respiration data from periods when groups were simultaneously observed (April/May only) were compared. The procedure was simply to make comparisons of the timing of respiration events reported by two stations for an individual (mother or calf) or the group as a whole. The results of each comparison were scored in one of nine categories representing one of the possible pair combinations of blow mother (BM), blow calf (BC), blow unknown (B?), and blow not observed (--). A tally was made under BM if both stations recorded respiration times for the mother which differed by less than 6 sec. (We assume that our time notations are accurate to within 5 sec.) A tally was made under BC if both stations recorded respiration times for a calf which differed by less than 6 sec. A tally was made under B? if both stations recorded respiration times for an unspecific member of the group which differed by less than 6 sec. A tally was made under BC/BM if one station recorded a BC while the other recorded a BM. A tally was made under BM/B? if one station recorded a respiration for the mother in the group when the other station recorded a blow from an unspecific member of the group. A tally was made under BC/B? if one station recorded a respiration time for the calf when the other station recorded a respiration from an unspecific member of the group. A tally was made under either BM/--, BC/--, or B?/-- if one station recorded a respiration from the mother, calf, or unspecific member of the group when the other station did not record a respiration.

Table F.1 shows the scores resulting from comparing respiration times when two stations were making simultaneous observations but were not confident that they were noting all blows.

These results show that of the 1015 blows recorded during simultaneous observations on a group, 71% were seen by both stations and both stations concurred on the identity (BM, BC, or B?) only 50% of the time. There was greater agreement for mother blows than for calf blows. If one station recorded a mother blow (n = 526), the other station recorded a mother blow in 295 cases (56%), a calf or unspecific blow in 160 cases (41%), and no blow in 71 cases (13%). If one station recorded a calf blow (n = 428), the other station recorded a calf blow in 167 cases (39%),

TABLE F.1. TALLIES OF SCORES RESULTING FROM COMPARISON OF RESPIRATION DATA RECORDED SIMULTANEOUSLY FROM TWO SEPARATE OBSERVATION STATIONS WHEN BOTH STATIONS WERE NOT CONFIDENT THAT THEY WERE SEEING ALL BLOWS.

BM	BC	B?	BM/BC	BM/B?	BC/B?	BM/—	BC/—	B?/—	TOTAL
295	167	47	36	124	49	71	176	50	1015

a mother or unspecific blow in 85 cases (20%), and no blow in 176 cases (41%).

From this we conclude that when a station was not confident that it was seeing all the blows and the whales were greater than 1.5 km away from the observers, 30% of the blows on average would be missed. This high percentage is principally due to the distance between the stations and the whales. Since any two stations were 2.4 km apart, the minimum distance on average to a group would only be 1.2 km. There is no way to reduce the distance since as the group gets closer to one station, and hence easier to observe, it moves farther from the other station and becomes more difficult to observe. This point is further illustrated by the following result. Of the 71 cases when one station did not record a mother blow observed by the second station, 67 of these misses occurred when the station that missed the blow was greater than 2 km from the whales. Of the 176 cases when one station didn't record a calf blow, 89 occurred when that station was greater than 2 km from the whales. Thus, as would be expected, reliable respiration data are a function of sighting distance, and calf blows are much more difficult to observe than adult blows.

In terms of the effect of these inaccuracies on our calculations for blow rates, we can state that the above results represent worst case. When calculating rates, we used data from all observation sites so blows missed by one site but observed by another would be included in the calculations. Likewise, disagreements in blows would be decided in favor of the station closer to the group, and so these, too, would get included in the calculations. The worst error would occur if both stations missed a blow. A simplistic approach would estimate that 9% of the blows would be missed by both stations when whales were halfway between the two stations (30% x 30% = 9%). Thus, under worst case conditions, 9% of the blows would be missed. When only one station was observing (for example, when the most northern station was following the group as it proceeded up north), the percentage missed would increase to about 30% by 2.0 km. Therefore, the most reliable estimates of respiration rates should include only those periods when whales were within 2.0 km of a station. A single respiration rate calculated using the total number of blows from the group is the most accurate measure of respiration rate. Calf blow rates are subject to the greatest errors.

A second comparison was made using only the data collected when both stations were certain that they were seeing all blows from either the mother or calf and the observation period lasted at least 10 min. Table F.2 summarizes these results. Under these conditions, 95% of the observations agree. Out of the 68 mother blows, only 2 were missed. Of these two, one occurred when the group was greater than 2 km from one of the stations. The other error occurred because the group swam around and inshore of a large rock and so were not visible to one of the stations. Out of the 17 calf blows, three were missed; one was missed when the group went around the large rock and the other two were simply missed. The one disagreement, BM/BC, occurred when the group was greater than 2 km from the station which erroneously, we believe, identified the blow as a calf's.

Thus, 66 out of 68 (97%) of the possible mother blows and 14 out of 17 (82%) of the calf blows noted during periods of confidence lasting 10 minutes or longer were sighted by both stations. Since at least half of these sightings were at distances greater than 1.5 km, we would interpret this to indicate that observers were very accurate in their notations of mother respirations and less accurate in their notations of calf respirations. This would suggest that the blow interval data for mothers is not

TABLE F.2. TALLIES OF SCORES RESULTING FROM COMPARISON OF RESPIRATION DATA RECORDED SIMULTANEOUSLY FROM TWO SEPARATE OBSERVATION STATIONS WHEN BOTH STATION WERE CONFIDENT THAT THEY WERE SEEING ALL BLOWS AND THE PERIOD OF CONFIDENCE LASTED 10 MIN. OR LONGER.

BM	BC	BM/BC	BM/—	BC/—	TOTAL
66	14	1	2	3	86

confounded by missed blows. There is not enough data to make such a statement concerning calf blows. However, since we already know that calf blows are easily missed, we would not feel confident in placing much emphasis on this behavioral measure with respect to calves.

In summary, the respiration data were found to be subject to errors due to observers misidentifying the individual responsible for the blow or missing the respiration altogether. This was particularly true when whales were greater than 2 km from the observers. This would suggest that the respiration data used to calculate blow rates should be restricted to those periods when whales were within 2 km of a station. For this report, the best measure of blow rate is total blow rate.

The blow interval data for mothers appear to be quite reliable, while that for the calves are subject to greater errors due to the difficulty of observing calf blows.

APPENDIX G

THEODOLITE TRACKING SYSTEM ERROR ANALYSIS

The use of two transit stations during this project for tracking whale groups allows for the first time an empirical measurement of range errors in the transit technique. The measurement of horizontal angles for azimuth determination is little affected by refraction and is more precise than is required for reasonable accuracy of location. The measurement of vertical angles for range determination is, however, much more critical and is affected by refraction, curvature of the earth, tide, ocean waves, and swells. The distance from the transit station to a whale equals the altitude of the transit above sea level (corrected for tide) times the tangent of the vertical bearing angle (corrected for tide) times the tangent of the vertical bearing angle (corrected for curvature of the earth). The precision of range data is thus directly proportional to the altitude of the transit station for a given level of angular resolution of vertical bearings. As shown in the following calculations, the elevations of Soberanes and North sites, 75.7 and 63.4 m respectively, were high enough to allow range estimates at 5 km (the maximum range of our observations), to within ± 16 m for Soberanes site and ± 20 m for North site, given the 10 second precision of our vertical angle measurements (calculations ignore the trivial effect of earth's curvature for simplicity).

These calculations ignore possible sources of error due to refraction and ocean waves, however. In order to estimate these errors, a program was written to search through the January transit sighting data for sightings of the same group of whales or boat within 30 sec. The program then calculates an azimuthal position (x_{az}, y_{az}) by triangulating from the horizontal angles of

CALCULATION OF RANGE RESOLUTION

Soberanes Site

Altitude = 75.7 m range = 5000 m

tanα = arctan (66.05) = 89.1326° = 89° 07' 57.4"

for error of +10" α = 89° 08' 07.4" = 89.1354°

tanα = 66.262

range = 75.7 x 66.262 = 5016.1 m

for error of -10" α = 89° 07' 47.4" = 89.1298"

tanα = 65.839

range = 75.7 x 65.839 = 4984.037

North Site

Altitude = 63.4 m range = 5000 m

tanα = range/alt = 78.9

α = arctan (78.9) = 89.274° = 89° 16' 24.7"

for error of +10" α = 89° 16' 34.7" = 89.2763"

tanα = 79.167

range = 63.4 x 79.167 = 5019.2

for error of -10" α = 89° 16' 14.7" = 89.2708°

tanα = 78.564

range = 63.4 x 78.564 = 4980.95

the two stations. The range error of each station is calculated as the distance between the azimuthal position and the position calculated for each station using both vertical and horizontal angles.

Since groups of whales often were spread over 20 to 50 m (up to 100 m) and since groups travelling at a typical speed of 8 km/hr would travel 67 m in 30 sec, this analysis does not test the limits of precision for the transit analysis, but rather yields an indication of the resolution of observations of whale groups. Single observations may yield artificially high apparent errors. An overall regression analysis of error vs range, however, should separate out the typical space occupied by a whale group in 30 sec (the y-intercept of the regression) from the range dependent error inherent in our conversion of vertical bearing angle to range (the slope of the regression).

This error analysis program was run for all of the January data files and yielded 191 pairs of sightings of the same group or boat from different transit stations within 30 sec of each other. Of these 191 pairs, 12 yielded apparent errors of > 1.0 km and these are listed in Table G.1. Cases 2, 7, 10, and 11 all have a large error in data from one station but very small error (< 100 m) in data from the other. These probably represent cases of an error in the logging of vertical angle at one station (rate for this error = 4 errors/(191 pairs of sightings * 2 stations per pair) = 1%). Cases 3 and 4 have very large errors that arose when the two stations called two different boats or groups of whales by the same name through a misunderstanding (error rate = 2/191 * 2 = 0.5%). The other 6 cases are intermediate in error; while it is clearly impossible that two sightings of the same group within 30 sec could be spread over 1 km, the source of this error is not apparent. They may arise from less drastic errors in measuring or in copying down the vertical bearings erroneously from the

TABLE G.1. LIST OF ALL CASES OF APPARENT ERRORS OF > 1.0 km FROM ERROR ANALYSIS OF ALL JANUARY DATA FILES (OUT OF 191 PAIR SIGHTINGS).

Case	Date	Time	Identifier	Soberanes Error (km)	Soberanes Range (km)	North Error (km)	North Range (km)
1	7J	0820	B	2.892	3.309	0.294	1.224
2	7J	1110	T	1.540	2.312	0.010	1.445
3	10J	1147	X	11.883	10.582	10.371	8.442
4	12J	1303	BT5	14.160	19.808	14.359	20.763
5	12J	1320	V	1.262	2.392	1.298	1.055
6	12J	1653	VV	1.917	3.,965	0.455	2.884
7	13J	1058	S	0.074	2.587	1.552	2.407
8	13J	1152	AA	0.571	1.667	2.169	3.754
9	16J	1514	JJJJ1	1.397	2.584	0.459	1.446
10	16J	1614	ORCA	0.014	2.005	1.336	1.634
11	16J	1703	YYYY	0.021	0.742	1.737	1.823
12	20J	1402	SS	1.026	3.636	0.294	2.365

theodolite vernier. These errors tended to occur at the start of the field season or when things became very hectic such as during the orca attack on 16 January.

Figures G.1 and G.2 show the distribution of the error in sightings from Soberanes Site and North Site, respectively, as a function of range from the site to the whale. There appear to be two kinds of error presented here. The errors of > 200 m do not appear to show a range dependent pattern and probably result from observer error such as those listed in Table G.2, not error inherent in the transit measurement technique. The errors of < 200 m appear to increase systematically with increasing range and probably reflect error due to conversion of vertical bearing angles to range.

Results of a linear regression (BMDP6D, Dixon 1982) of the range dependent portion of the data yield the following equations:

		Residual mean square error
Soberanes:	Error = 0.75451 * X = 1.7306	0.50186
	Mean Error = 0.2689 ± 1.3610 std. dev.	
North:	Error = 0.72081 * X -1.4245	0.44410
	Mean Error = 0.2451 ± 1.2983 std. dev.	

These results are dominated by the large observer errors and tell us little of the errors inherent in the transit technique.

Results of a second linear regression analysis, limiting data in error to 150 m at Soberanes and 120 m at North site and range to 5.0 km, yield the following results:

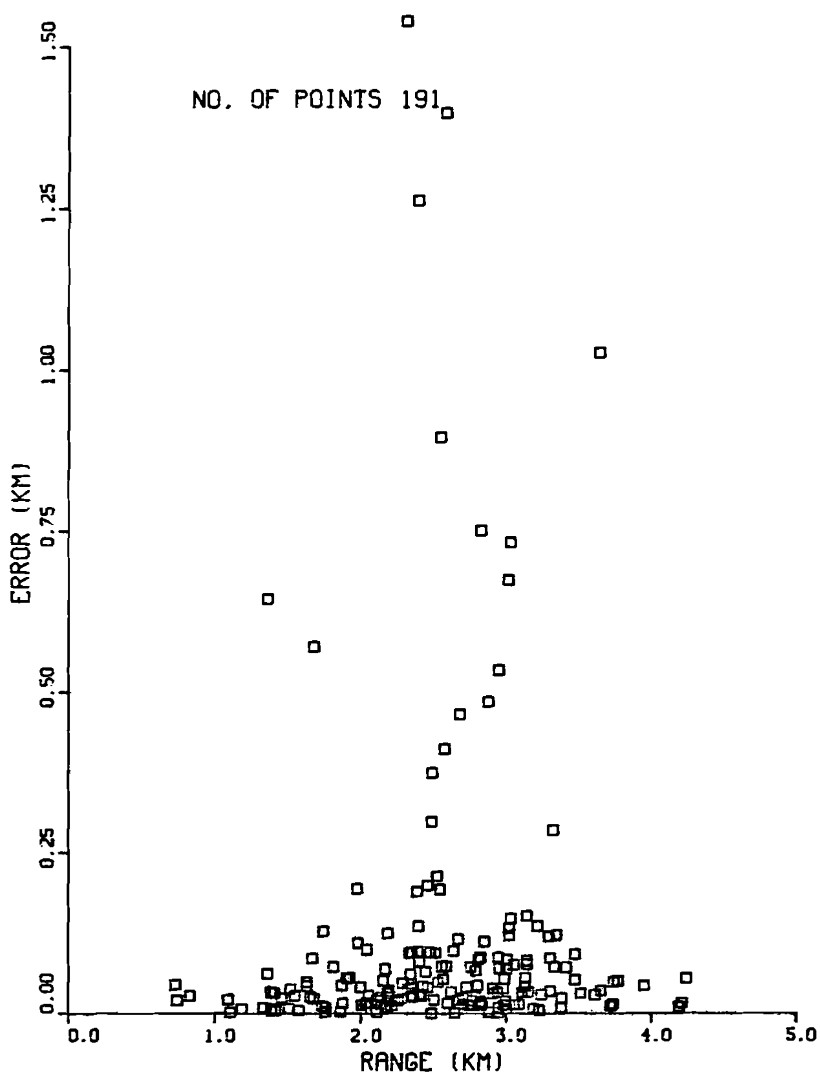


FIG. G.1. ERRORS IN RANGE FROM VERTICAL BEARINGS AT SOBERANES SITE AS A FUNCTION OF RANGE.

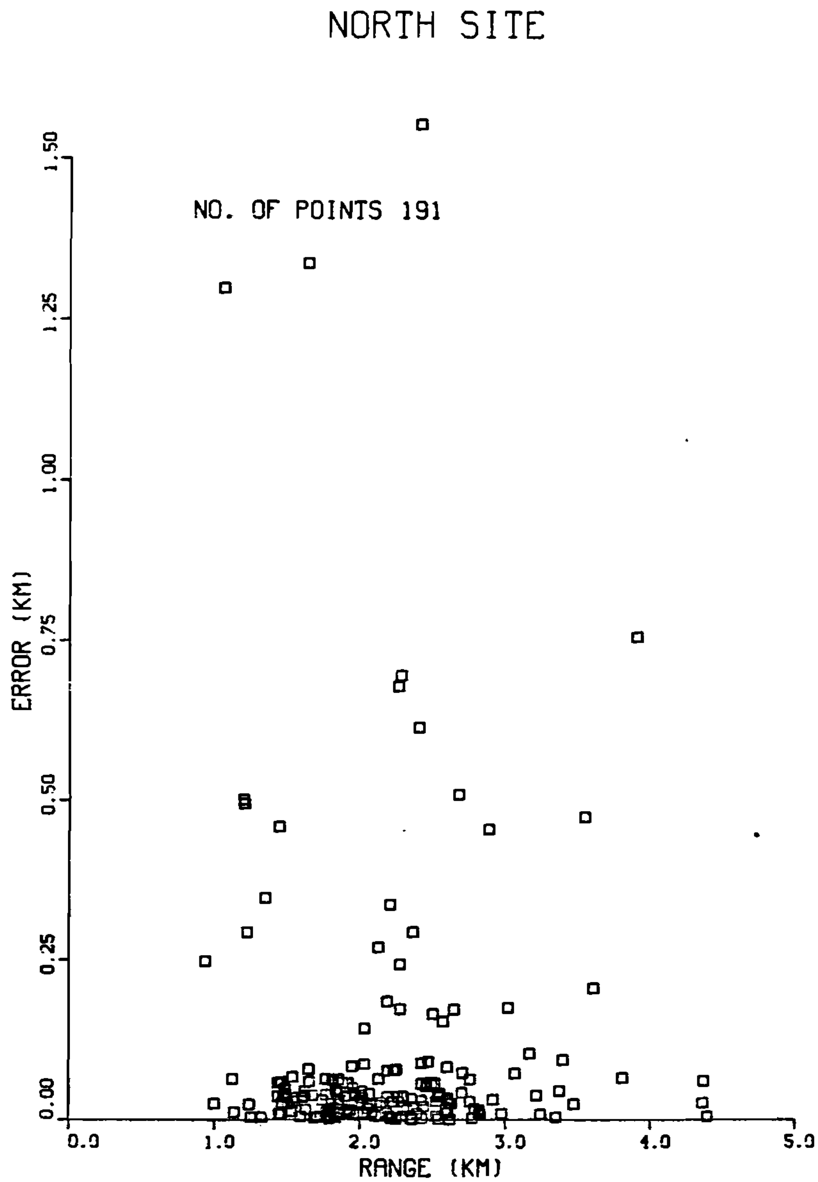


FIG. G.2. ERRORS IN RANGE FROM VERTICAL BEARINGS AT NORTH SITE AS A FUNCTION OF RANGE.

		Residual mean square error
Soberanes:	Error = 0.01014 * Range + 0.01753	0.00119
	Mean Error = 0.048 ± 0.44 std. dev.	
North:	Error = 0.00401 * Range + 0.02238	0.00057
	Mean Error = 0.0403 ± 0.0443 std. dev.	

This provides a better analysis of the errors inherent in our use of angles of depression to calculate range. The Y-intercept of 17 or 22 m in both cases indicates the typical difference in sightings of groups within 30 sec. This is easily within the expected limits described above. In addition to this result was a typical error of 4 to 10 m per km of range up to the 5 km limit of the analysis. Since there is little reason to expect that error will necessarily be strictly linearly proportional to range, a nonlinear regression analysis was also performed.

Results of a nonlinear regression analysis (BMDP3R, Dixon 1981) attempting to fit the range dependent portion of the data (Error S < 0.15, Error N < 0.12, Range S, Range N < 5.0) to an exponential function yielded a regression function of:

Soberanes: Error S = 0.023294 Range S $e^{0.211584}$
with a residual mean square error of 0.001

North Site: Error N = 0.0204986 Range N $e^{0.109008}$
with a residual mean square error of 0.000585

The residual mean square error for this nonlinear analysis is nearly identical to that for the linear regression for both stations. Thus, at least for ranges of up to 5.0 km, the simpler linear fit appears as good as an exponential one. The preceding analysis indicates that aside from observer error, our use of the transit technique yielded errors only 2 to 3 times as great as that predicted theoretically from the precision of our theodolites, ignoring errors from refraction or ocean waves.