

BIO-ACOUSTICS OF THE GRAY WHALE (Eschrichtius robustus)

By

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ABSTRACT

Gray whales (Eschrichtius robustus), while engaged in underwater signalling, circumvent noise in the acoustical channel by the structure and timing of their calls. Data yielding this conclusion were collected during an acoustical study on gray whales and their habitats (1981-1984). Sonographic analyses of tape recordings were used to quantify the acoustical repertoire, the ambient noise characteristics of the area, and the relationship between the animals' calls and the environment. The acoustical responses of whales to artificially increased levels of noise were documented during playback experimentation in Mexico. Nine sound parameters were inspected and compared between control and experimental conditions: calling rates, call types, frequency range of signals (Hz), emphasized frequencies (Hz), received levels of sounds (dB re 1 μ Pa), call duration (sec), percentage of calls exhibiting frequency modulation, number of pulses per series, and repetition rates of signals. The observed surface behavior of gray whales in response to noise (i.e., dive durations, movements and abundance) was also investigated. Analyses yielded: a description of gray whale call types; a characterization of the acoustical habitats occupied by this species, including a list of sources contributing to the ambient noise and a profile of the propagation characteristics of the study area; a determination of the relationship between whale calls and their habitats; and the acoustical capabilities and strategies of whales in response to noise. The plasticity observed in the overall behavior of this whale is of adaptive significance when considering the dynamic nature of noise in the environment. Typically, the multiple

strategies employed by the whales when faced with various noise situations enable them to minimize the detrimental effect that noise has on their underwater signalling. Gray whale responses varied with the sound source and may also differ relative to the geographical range and/or general behavior of the animal. It is concluded that ambient noise (both natural and man-made) has a profound effect on the behavior of this coastal species and that acoustical calling is modified to optimize signal transmission and reception.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vii
LIST OF FIGURES	ix
ACKNOWLEDGEMENTS	xiii
GENERAL INTRODUCTION	1
GENERAL MATERIALS AND METHODS	4
Study Area(s)	5
Research Equipment - Gray Whale Sound Production	5
Research Equipment - Ambient Noise.	10
Research Equipment - Playback Experimentation	10
CHAPTER I - SOUND PRODUCTION, AMBIENT LEVELS AND THE RELATIONSHIP OF WHALE SIGNALS TO THEIR ACOUSTICAL HABITATS	14
INTRODUCTION	15
MATERIALS AND METHODS	23
Analysis Procedures - Gray Whale Sound Production	23
Analysis Procedures - Ambient Noise	24
Analysis Procedures - Relationship Between Whale Calls and Ambient Noise	25
RESULTS	27
Types of Sounds Produced	27
Laguna San Ignacio (Mexico)	27
St. Lawrence Island (Alaska)	45
Washington State Waters	48
Integration of Regional Data Bases/Published Information . .	55

TABLE OF CONTENTS, CONTINUED

	Page
Ambient Noise	60
Laguna San Ignacio (Mexico).	60
St. Lawrence Island (Alaska)	80
Washington State Waters	91
Comparisons of Ambient Noise Throughout Range	96
Relationship Between Gray Whale Signals and Ambient Noise	99
DISCUSSION	109
CHAPTER 2 - RESPONSES OF GRAY WHALES TO INCREASED LEVELS OF TEMPORARY (SHORT-TERM) NOISE	122
INTRODUCTION	123
MATERIALS AND METHODS	126
1983 Experimental Design	126
1983 Analysis of Gray Whale Sound Behavior	130
1983 Analysis of Observed Surface Behavior	132
RESULTS	134
1983 Calling Rates	134
1983 Call Types	135
1983 Call Structure	138
1983 Observed Surface Behavior	141
DISCUSSION	151
CHAPTER 3 - RESPONSES OF GRAY WHALES TO INCREASED LEVELS OF CONTINUOUS (LONG-TERM) NOISE	157
INTRODUCTION	158

TABLE OF CONTENTS, CONTINUED

Page

MATERIALS AND METHODS	161
1984 Experimental Design	161
1984 Observed Surface Behavior - Tracking Experiments	162
1984 Distribution and Abundance - Transect Experiments	163
1984 Analysis of Gray Whale Sound Behavior	169
1984 Analysis of Tracking Experiments	170
1984 Analysis of Transect Experiments	171
RESULTS	172
1984 Calling Rates	172
1983/1984 Comparisons of Calling Rates	172
1984 Call Types	175
1984 Call Structure	175
1983/1984 Comparisons of Call Structure	180
1984 Observed Surface Behavior - Tracking Experiments	184
1984 Observed Surface Behavior - Transect Experiments	214
Seasonal Comparisons (Abundance/Distribution/Movements)	214
Between-Season Comparisons (Abundance of Whales)	230
DISCUSSION	239
GENERAL SUMMARY/CONCLUSIONS	253
REFERENCES	258
APPENDIX A	A-1
APPENDIX B	B-1
APPENDIX C	C-1

LIST OF TABLES

	Page
TABLE I. A Summary of Published Data on Sounds Produced by the Gray Whale (1967-1978)	19
TABLE II. A Classification of Sounds Produced by the Gray Whale in Laguna San Ignacio, Mexico	28
TABLE III. Sounds Produced by the Gray Whale Throughout Its Range Based on Acoustical Studies in Laguna San Ignacio and Published Accounts.	56
TABLE IV. Comparisons of Gray Whale Sounds Throughout Its Range. . .	59
TABLE V. Estimated Levels (dB re 1 μ Pa) and Their Associated Frequencies (Hz) for Biological Ambient Noise Stations #1-32 in Laguna San Ignacio, Mexico.	65
TABLE VI. Biological Organisms Potentially Responsible for the High Levels of Ambient Noise in Laguna San Ignacio, Mexico. . .	68
TABLE VII. Comparisons of Ambient Noise Profiles Throughout the Range of the Gray Whale	97
TABLE VIII. 1983 Calling Rates of Gray Whales in Laguna San Ignacio, Mexico	136
TABLE IX. 1983 Call Types Produced by Gray Whales in Laguna San Ignacio, Mexico.	137
TABLE X. 1983 Structural Changes in the Calls of Gray Whales Occupying Laguna San Ignacio, Mexico	140
TABLE XI. Average Dive Times (sec) of Gray Whales During Various Experimental Conditions during the 1983 Season in Laguna San Ignacio, Mexico	146
TABLE XII. 1984 Calling Rates of Gray Whales in Laguna San Ignacio, Mexico	173
TABLE XIII. Comparisons of the 1983 and 1984 Calling Rates of Gray Whales Occupying Laguna San Ignacio, Mexico. . . .	176
TABLE XIV. 1984 Call Types Produced by Gray Whales in Laguna San Ignacio, Mexico	177
TABLE XV. 1984 Structural Changes in the Calls of Gray Whales Occupying Laguna San Ignacio, Mexico	179

LIST OF TABLES, CONTINUED

	Page
TABLE XVI. 1983 and 1984 Comparisons of Structural Changes in the Calls of Gray Whales in Laguna San Ignacio, Mexico	181
TABLE XVII. Average Dive Times (sec) of Gray Whales Exposed to Various Experimental Conditions During the 1984 Season in Laguna San Ignacio, Mexico.	189
TABLE XVIII. 1983/1984 Comparisons of Average Dive Times of Gray Whales in Laguna San Ignacio, Mexico.	191
TABLE XIX. 1984 Trackline Data of Gray Whales Occurring in Laguna San Ignacio, Mexico	215
TABLE XX. Counts of Whales Occupying Laguna San Ignacio on or about 1 February and 2 March for the Years 1978-1982 (From Jones and Swartz, 1984).	233

	LIST OF FIGURES	Page
Figure 1.	Study Area -- Laguna San Ignacio, Baja California Sur, Mexico	7
Figure 2.	Bottom-mounted Transducer in Laguna San Ignacio, Mexico. .	12
Figure 3.	The Migration Route of the Gray Whale (<i>Eschrichtius robustus</i>).	17
Figure 4.	Spectrograph of a Gray Whale S1 Series	30
Figure 5.	Spectrograph of Two S1 Series Depicting Frequency Modulation	32
Figure 6.	Spectrograph of a Gray Whale S2 Signal	34
Figure 7.	Spectrograph of a Gray Whale S3 Signal	37
Figure 8.	Spectrograph of a Gray Whale S4 Signal	39
Figure 9.	Spectrograph of a Gray Whale S5 Signal (bubble blast). . .	41
Figure 10.	Spectrograph of a Gray Whale S6 Signal (sub-surface exhalation)	44
Figure 11.	Recording Locations of Gray Whales off St. Lawrence Island, Bering Sea, Alaska, Summer 1982.	47
Figure 12.	Spectrograph of a Sub-surface Exhalation (N6) Produced by a Surfacing Gray Whale off St. Lawrence Island, Alaska	50
Figure 13.	Study Area -- Coastal Waters of Washington State	52
Figure 14.	Recording Locations of Gray Whales in Washington State Waters	54
Figure 15.	Locations of Biological Ambient Noise Stations in Laguna San Ignacio, Mexico	62
Figure 16.	Spectra of Typical Biological Ambient Noise Levels in Laguna San Ignacio, Mexico.	64
Figure 17.	Knudsen Sea State Curves	67
Figure 18.	Spectra of Typical Large Vessel (25-35 m in length) Noise Encountered in Laguna San Ignacio, Mexico.	75

LIST OF FIGURES, CONTINUED

	Page
Figure 19. Spectra of a 20-hp Mercury Outboard Engine Operating at (a - d) a) idle, b) quarter throttle, c) half throttle, and d) three-quarter throttle	77/79
Figure 20. Locations of Ambient Noise Stations off St. Lawrence Island, Alaska	82
Figure 21. Average Levels (dB re 1 μ Pa) of Ambient Noise Stations 1 and 2, St. Lawrence Island, Alaska	84
Figure 22. Average Level (dB re 1 μ Pa) of Ambient Noise at Station 3, St. Lawrence Island, Alaska (influenced by ship noise)	86
Figure 23. Average Levels (dB re 1 μ Pa) of Ambient Noise at Stations 4 and 5, St. Lawrence Island, Alaska (influenced by surf noise)	88
Figure 24. Average Levels (dB re 1 μ Pa) of Ambient Noise at Stations 6-12 (Southeast Cape), St. Lawrence Island, Alaska	90
Figure 25. Noise Spectra of a 7-m Boston Whaler Operating off Southeast Cape, St. Lawrence Island, Alaska.	93
Figure 26. Spectra of Ambient Noise off La Push, Washington (coastal waters)	95
Figure 27. Composite Spectrograph of a Gray Whale Pulse Series (S1), Outboard Engine Noise and Biological Ambient Noise in Laguna San Ignacio, Mexico	101
Figure 28. Spectrograph of a Gray Whale Pulse Series (S1) and Outboard Engine Noise.	104
Figure 29. Relationships of Gray Whale Sound Frequencies and Levels to Ambient Noise	106
Figure 30. Spectrograph of a Bottlenose Dolphin Whistle and Biological Ambient Noise in Laguna San Ignacio, Mexico	108
Figure 31. Immediate Study Area off Rocky Point Defined During Tracking Experiments in Laguna San Ignacio, Mexico	129
Figure 32. 1983 Frequency Distribution of Gray Whale Dive Durations.	143
Figure 33. 1983 Frequency Distribution of Cow/calf Pairs and Single Whale Dive Times in Laguna San Ignacio, Mexico	145

LIST OF FIGURES, CONTINUED

	Page
Figure 34. Example of Line Display Depicting Behavior of Gray Whales and Environmental Effects During Tracking Experiments. . .	149
Figure 35. 1984 Vessel Survey Transect Route of Entire Lagoon System	165
Figure 36. 1984 Modified Transect Route -- Laguna San Ignacio, Mexico	168
Figure 37. 1984 Frequency Distribution of Dive Durations of Gray Whales Occupying Laguna San Ignacio, Mexico.	186
Figure 38. 1984 Frequency Distribution of Cow/calf Pairs and Single Whale Dive Durations in Laguna San Ignacio, Mexico	188
Figure 39. 1983/1984 Frequency Distribution Comparisons of Dive Times on All Whales Occurring in Laguna San Ignacio, Mexico	193
Figure 40. 1983/1984 Frequency Distribution Comparisons of Dive Durations on Cow/calf pairs in Laguna San Ignacio, Mexico	195
Figure 41. 1983/1984 Frequency Distribution Comparisons of Dive Durations on Single Whales in Laguna San Ignacio, Mexico	197
Figure 42. Percentage of Time Spent Tracking Whales Per Experimental Condition	200
Figure 43. Trackline of Whale During Control Periods	202
Figure 44. Trackline of Whale in Presence of Real Sources	204
Figure 45. Trackline of Whale During Outboard Engine Playback Periods.	206
Figure 46. Trackline of Whale During Oil-drilling Playback Periods. .	209
Figure 47. Trackline of Whale During Killer Whale Playback Periods (no progressive movement through area)	211
Figure 48. Trackline of Whale During Killer Whale Playback Periods (depicting increased distance offshore).	213
Figure 49. A Comparison of the Total Number of Whales Occupying the Waters Between Parmenter Point and Yucca Plant During Control and Experimental Conditions	218

LIST OF FIGURES, CONTINUED

	Page
Figure 50. A Comparison of the Number of Southbound Whales Occurring Between Rocky Point and Parmenter Point During Control and Experimental Periods	221
Figure 51. A Comparison of the Number of Northbound Whales Occurring Between Rocky Point and Parmenter Point During Control and Experimental Periods	224
Figure 52. A Comparison of the Number of Southbound Whales Occurring Between Rocky Point and Yucca Plant During Control and Experimental Periods	226
Figure 53. A Comparison of the Number of Northbound Whales Occurring Between Rocky Point and Yucca Plant During Control and Experimental Periods	228
Figure 54. A Comparison of the Number of Milling Whales Observed Between Parmenter Point and Yucca Plant During Control and Experimental Periods	232
Figure 55. Abundance of Gray Whales Occurring in Laguna San Ignacio, Mexico, for the Years 1978-1982 and 1984	236
Figure 56. Abundance of Single Whales (A) and Cow/calf Pairs (B) A and B Occurring in Laguna San Ignacio, Mexico, for the Years 1978-1982 and 1984	238

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GENERAL INTRODUCTION

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There is general agreement among scientists that the acoustical sense of marine mammals, especially that of the cetaceans, constitutes their most important sensory process. Although the sea provides a good medium for sound propagation and reception, communication channels within the aquatic environment are usually noisy. Thus, aquatic animals, dependent on acoustical signalling for spacing, attracting or alerting functions must overcome or be able to circumvent this noise in some way to remain effective. A reduction in acoustical transmission and/or its reception can adversely affect the reproduction or even the survival of a given species that is dependent on such a sensory process. In terrestrial studies, many features of animal signals have been shown to minimize the detrimental effect of noise on communication (Konishi, 1970; McGeorge, 1979). To date, quantitative studies addressing cetaceans and the effect of noise on their acoustic signals have not been attempted.

My hypothesis in undertaking this study was that the gray whale, while engaged in underwater signalling, circumvents noise in the acoustical channel by the structure and timing of its calls. To test this hypothesis it was necessary to 1) categorize the types of calls produced by the gray whale, 2) characterize the acoustical habitats occupied by this whale, and 3) determine the relationship between gray whale signals and ambient noise. With the descriptive information available (Chapter 1), experimental playback procedures were initiated to test the hypothesis. The acoustical responses, as well as the observed surface responses, of gray whales were quantified and compared between control and experimental

playback sessions. Gray whale responses to the projection of simulated noise sources are addressed in Chapter 2 (short-term playback experiments) and Chapter 3 (long-term playback experiments). A General Summary follows the final Chapter and describes the overall results and significant findings of the research.

GENERAL MATERIALS AND METHODS

GENERAL MATERIALS AND METHODS

Study Area(s)

Laguna San Ignacio, Baja California Sur, Mexico, located along the Pacific Coast of Baja California approximately 680 km south of San Diego, California, is one of the major calving areas for gray whales (Fig. 1). Laguna San Ignacio was a nearly "ideal" location for the work. A dense concentration of whales occurs in a small area, ensuring a large sample size. It is a focal point of tourism, allowing monitoring of gray whale phonations and ambient noise on days with and without vessel activity. Areas within the lagoon are relatively undisturbed, ensuring minimum interference with the proposed playback experiments. This lagoon has also been the site of long-term investigations on the gray whale (Swartz and Cummings, 1978; Swartz and Jones, 1980, 1981; Jones and Swartz, 1984). In addition to the primary research conducted in Mexico, recordings of gray whale sounds and ambient noise were also collected in the Bering Sea (Alaska) and on the migration route (Washington State).

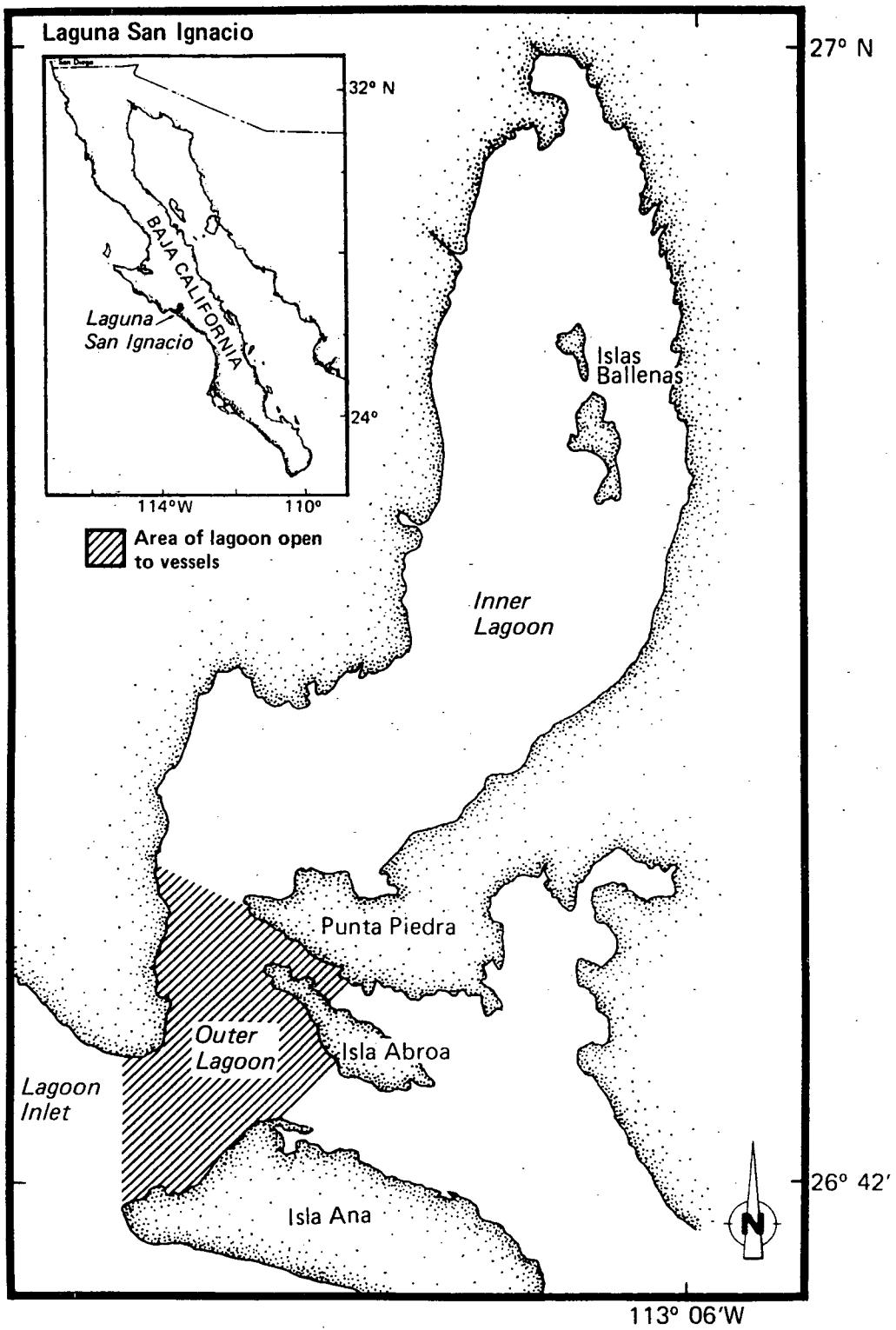
Research Equipment - Gray Whale Sound Production

In 1981 (8-25 March) at Laguna San Ignacio, a KSP (HS-107/222) hydrophone^{1/} was connected through a 2-dB step attenuator to a Nakamichi 550 cassette tape recorder. Maxell UD-90 tape was selected due to its low noise characteristics. Calibrated frequency response was 40 Hz to 19 kHz $\pm$ 3 dB. Recordings were collected from a 4.3-m inflatable boat. Bearings using three landmarks (Weems and Plath hand-held bearing compass) were taken during each session to determine location. In all sampling

^{1/}

Use of trade names does not imply endorsement by author.

Figure 1. Study Area -- Laguna San Ignacio, Baja California Sur, Mexico.



procedures, the hydrophone was placed at mid-water depth. Gain and attenuator settings as well as pertinent environmental and behavioral data were recorded on a narrative channel. The simultaneous narrative included: 1) time of day, 2) tide conditions, 3) sea state, 4) estimated distance of whales from recording platform, 5) behavior, 6) group composition, and 7) total number of whales within visual range. Signals produced by bottlenose dolphins (Tursiops truncatus) were also recorded incidentally during these sessions.

Between the years 1982 and 1984 (12 Feb - 2 March 1982, 31 Jan - 25 Feb 1983 and 26 Jan to 7 March 1984) at Laguna San Ignacio, a Nagra IV-SJS, reel-to-reel tape recorder was coupled with the KSP hydrophone and attenuator used in the 1981 experiments. Ampex 456 audio tape was selected. This calibrated system provided an effective response of 25 Hz to 10 kHz $\pm$ 2 dB at 9.5 cm/sec and 25 Hz to 20 kHz $\pm$ 2 dB at 19 cm/sec. Recordings were made at both speeds to determine whether gray whale signals extended above 10 kHz. Calibration tones were included in each recording.

Beginning in 1982, a bottom-mounted hydrophone system was used to record whale sounds. The hydrophone was suspended from the bottom by a float set at 3 meters. Water depth was 8 meters. The associated cable was weighted down and extended 25 meters following the bottom contour of the lagoon terminating at the shore-based station at Punta Piedra (= Rocky Point). This system provided certain advantages when compared to the floating platform used during the 1981 experiments. The bottom-mounted design provided 1) a reduction in system noise (less drift noise from recording vessel causing hydrophone acceleration); 2) less chance of platform interfering with whales' normal behavior; 3) an

elevated observation platform to document behavior and interactions of whales; and, 4) a 24-hour recording and monitoring system. Simultaneous narratives, similar to the 1981 data collected, accompanied each recording.

Recordings were also collected from the 4.3-m inflatable boat at various locations in the lagoon. This portable system ensured overall documentation of the acoustical behavior of gray whales throughout the lagoon area. An LC-32 hydrophone was connected through an U.S. Navy-built amplifier which in turn was connected to a Nakamichi 550 tape recorder. The frequency response of this portable system ranged from 40 Hz to 19 kHz $\pm$ 3 dB.

In the Bering Sea, research was conducted from the NOAA ships R/V MILLER FREEMAN and R/V DISCOVERER during the periods 7-26 July, 1982 and 12-27 September, 1982, respectively. A small skiff (7-m Boston Whaler) deployed from the support vessel served as the recording platform. Whales were first located visually and the skiff was then moved toward them. The outboard engines were shut down, and the hydrophone lowered to mid-water depth, determined by fathometer readings. The calibrated system consisted of a Nagra IV-SJS reel-to-reel tape recorder, Ampex 456 magnetic tape, a KSP Industries hydrophone (Model HS-107/222), coupled to an in-line preamplifier and attenuator, identical to that used in Mexico. Recording locations were determined by radar from the support vessel. A simultaneous narrative accompanied all recordings.

Attempts also were made to record gray whales within Washington State waters. A 4.3-m inflatable boat was used as the recording platform. The research equipment, approach to the whales, and subsequent hydrophone drop and narratives, was similar to the methods employed during the 1982 Bering Sea investigations.

Research Equipment - Ambient Noise Measurements

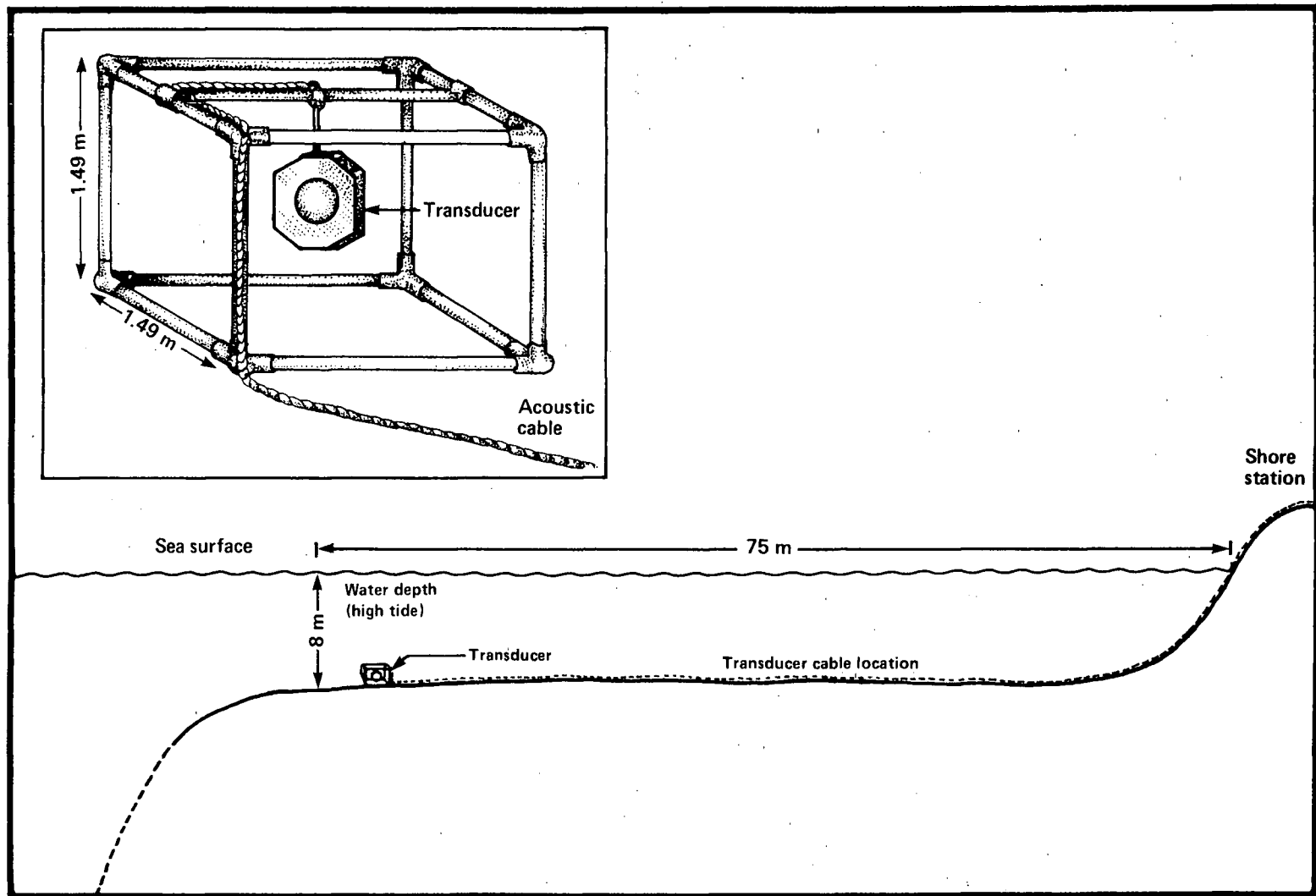
Ambient noise measurements were collected using the same acoustical equipment and recording platforms as those described when collecting gray whale sound information. Ambient recordings took place either concurrently with attempts to record whales and/or independently. A narrative was included on each tape collected. Sessions were terminated when environmental interference caused excessive noise: for example, 1) Beaufort 2 conditions or greater occurred; 2) the effect of tide caused hydrophone acceleration (= movement of hydrophone causing low-frequency noise); and 3) vessels/skiffs entered the area.

Sound spectra of large vessels were recorded at known distances from the port or starboard beam aspect when these vessels were underway and at anchor. Underwater sounds from small skiffs powered by outboard engines were also recorded as they operated at various speeds and idles. In Mexico, these non-biological, man-made sources were collected from both the floating recording platform as well as from the shore-based station.

Research Equipment - Playback Experimentation

During the 1983 and 1984 playback investigations, a Lubell Acoustic Transducer (Model 98) was bottom-mounted at a distance of 75 m off the farthest promontory available near the Rocky Point shore-based station (Fig. 2). To ensure proper depth, bottom placement and equipment safety, the transducer was affixed to a 1.5-m by 1.5-m square of PVC pipe. Several holes were drilled into this pipe, allowing water to enter into this structure as it was being submerged. A diver was used to guide the transducer cage (in an upright position) to the lagoon bottom. Once the structure was in contact with the bottom, the diver placed four

Figure 2. Bottom-mounted Transducer in Laguna San Ignacio, Mexico.



sand-filled burlap sacks over each lower leg of the cage to secure its location. This anchorage system ensured that no movement of the equipment took place against the strong tidal currents. The measured depth at high tide of this transducer was 8 meters; within the depth specifications required by the manufacturer of this transducer. An average tidal range of 3 meters was documented in Laguna San Ignacio. The associated transducer cable was weighted down at 5-6 m intervals. This cable ran from the cage, along the bottom contour of the lagoon, to the shore-based station at Rocky Point. The design of the cage and cable anchorage system was necessary to ensure that a whale could not become entangled in the acoustical equipment.

The shore-based equipment consisted of an Acoustics Systems, Inc., Transmitter (Model TS 107). This transmitter was driven by a 12-volt deep-cycle marine battery. Rotation and re-charging of batteries was necessary each day to ensure full power to the system. A Briggs and Stratton (40-watt) generator was built for recharging purposes. The level of projected sounds could be controlled by the use of the gain control on the transmitter, spanning the range of 40 to 150 dB re $1 \mu\text{Pa}$. The projected level varied with frequency. This transmitter was also equipped with a built-in calibration and/or test tone. This test tone swept from 15 kHz to 400 Hz and had a duration of 40 seconds. The input terminals of the transmitter were connected to a Nakamichi 550 cassette tape recorder. The overall frequency response of this system was 40 Hz to 19 kHz $\pm$ 2 dB. This equipment enabled the projection of pre-recorded, selected sounds to be played back underwater.

CHAPTER 1

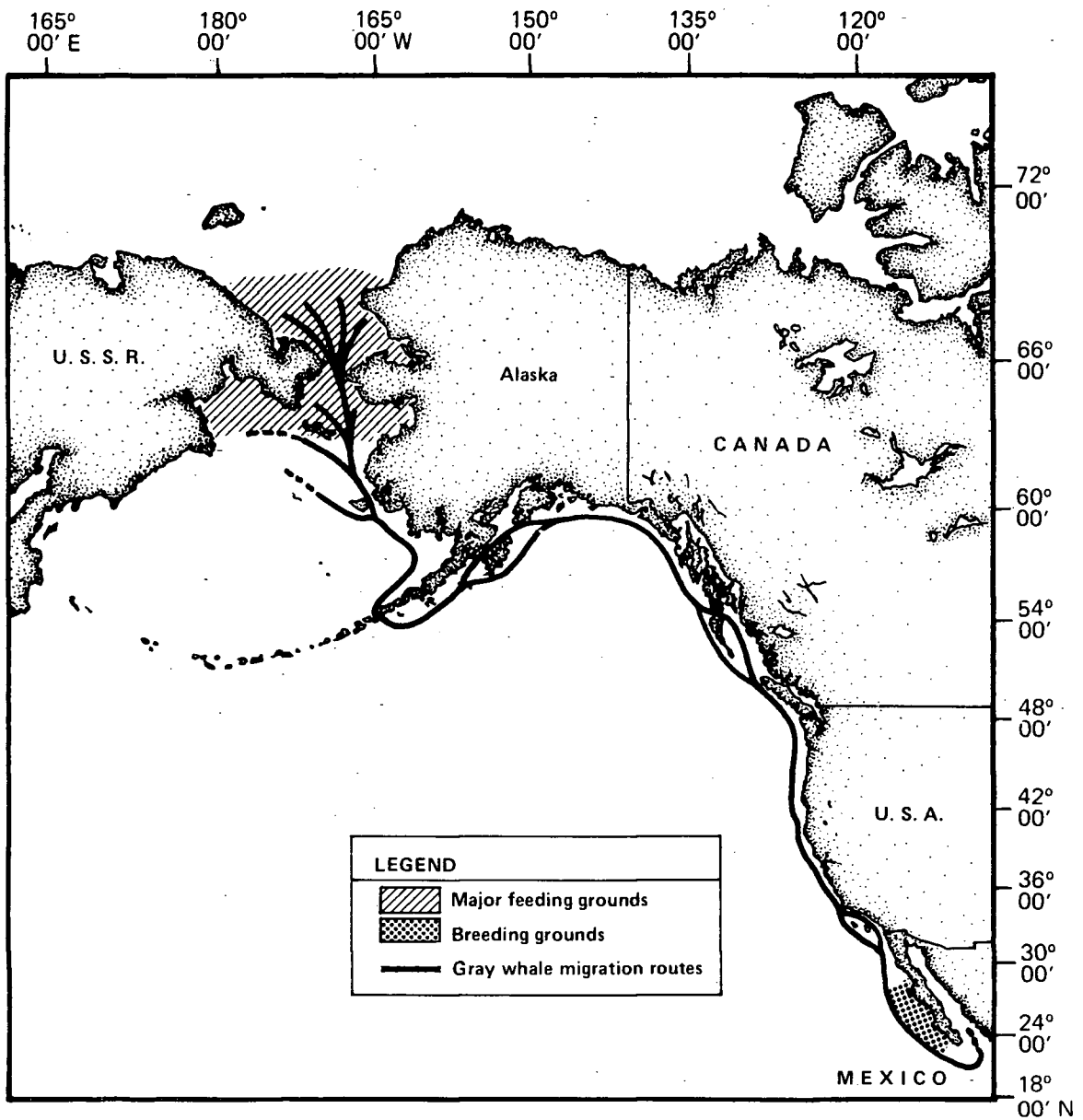
SOUND PRODUCTION, AMBIENT NOISE LEVELS, AND THE
RELATIONSHIP OF WHALE SIGNALS TO THEIR ACOUSTICAL HABITATS.

INTRODUCTION

The gray whale, Eschrichtius robustus (Lilljeborg, 1861), is the sole member of the family Eschrichtiidae (Suborder Mysticeti; Order Cetacea). Two stocks of gray whales occur in the North Pacific: the "Californian" or eastern stock, which breeds along the western coast of North America, and the "Korean" or western stock, which apparently breeds off the coast of eastern Asia (Rice and Wolman, 1971). Although severely depleted in the early 1900s by commercial whaling, the eastern stock has recovered to nearly its pre-exploitation level of 18,500 animals (Reilly et al., 1983). Unfortunately, the western stock has not had a similar recovery rate and is currently considered to be possibly extinct (Rice and Wolman, 1971) and/or at critically low levels (Brownell and Chun, 1977; Blokhin et al., 1985). The gray whale formerly occurred in the North Atlantic, as evidenced by subfossil remains and scanty whaling records, and is considered extinct in that area (Mead and Mitchell, 1984).

Most mysticete whales undertake annual migrations from their feeding locations in high latitudes of both hemispheres, to their breeding locations in more temperate and tropical waters. The gray whale is no exception and undertakes the longest known migration of any mammal, ranging from the Bering and Chukchi Seas to the waters of Baja California, Mexico (Rice and Wolman, 1971; Fig. 3). During this annual migration, 90% of the population passes within 3.2 km of the North American coastline (Reilly et al., 1983). Because of its coastal habitat, numerous studies have been accomplished on this species. These studies have primarily focused on estimates of population levels (Reilly et al., 1983; Rugh, 1984; Breiwick, York and Bouchet, 1985; Breiwick and Dahlheim, 1986); feeding habits (Oliver et al.,

Figure 3. The Migration Route of the Gray Whale (Eschrichtius robustus).
Modified from Reilly et al., 1983.



1983, 1984; Nerini, 1984); studies on the abundance and distribution within breeding lagoons (Bryant et al., 1984; Jones and Swartz, 1984); and distribution and migration (Braham, 1984; Herzing and Mate, 1984; Miller et al., 1985).

Despite the numerous contributions to the scientific literature on gray whales, little has pertained to their sound production behavior. Prior to 1967, only anecdotal information on the sounds produced by gray whales occurred in the literature. Aldrich (1889) reported that devilfish (gray whales) were known to "sing" on their northern feeding grounds. Tomilin (1957) reported that Soviet whalers operating in the Bering and Chukchi Seas detected "low-pitched roars" produced by gray whales. Eberhardt and Evans (1962), recording in Laguna Ojo de Liebre, noted "croaker-like grunts" and "low-frequency rumbles" which they ascribed to gray whales. Wenz (1964), in collaboration with Asa-Dorian, reported having detected "clicks" from migrating gray whales. Painter (1963) tentatively identified a low "grunting" sound recorded in the coastal lagoons of Mexico as having been produced by gray whales. Recordings made by Rasmussen and Head (1965) in Laguna Ojo de Liebre and off San Diego, California contained no signals attributable to this species. However, recordings they made in the presence of gray whales off Todos Santos Bay, Baja California Norte, Mexico included a "series of intense sounds" they likened to sound produced by hammering against the hull of a wooden ship. Hubbs (1966) obtained no recordings of gray whale sounds during work around solitary individuals and cow/calf pairs in Laguna San Ignacio. Between 1967 and 1978, various other researchers attempted to record sounds produced by the gray whale (Table I).

In reviewing the literature, it became apparent that the acoustical

Table 1
A Summary of Published Data on Sounds Produced by the Gray Whale (1967-1978)

Reference	Study area	Sound type	Frequency range (Hz)	Peak energy (Hz)	Duration (sec)	Pulses/burst	Pulse rate	Pulse duration (sec)	Comments in text
Asa-Dorian and Perkins, 1967	In Laguna Ojo de Liebre, Laguna Guerrero Negro, and off San Diego, California	Pulses Moans Whistles	70-3000 <2000 <2000	400-800		5-22	—	—	Pulses may be used in echolocation
Cummings et al., 1968	Off San Diego, California	Moans Blow sounds Bubble-type Knocks	20-200 15-175 15-305 Up to 350	— — — —	1.54 1.00 0.70	—	—	—	Soniferous day and night Assumed sounds were communicative
Poulter, 1968	In Laguna Ojo de Liebre	Grunts Rumbles Cries Rasps Pulses Chirps Clicks Bong	Up to 12,000 Up to 12,000 Up to 12,000 Up to 12,000	— — — —	1.00 2.0-5.0	—	5-18/sec 8/sec	—	Bong was unusual and may be alert signal
Fish et al., 1974	(a) In captivity and during open-water release	Growl or moan Pulse train Grunt Blowhole rumble Clicks	100-200,1500 100-10000,1400 200-400,1600 2000-6000 2000-6000	100-200,1500 100-10000,1400 200-400,1600 3400-4000 3500-4000	1.00 2.00 0.20 0.001-0.002 <0.002	8-14	14/sec 9-36/sec 8-40/sec	—	
	(b) In Wickaninnish Bay, Vancouver Island	Click trains	2000-6000	3500-4000	<0.002	1-96	8-40/sec		
Ray and Schevill, 1974	In captivity	Noisy pulsation				—		—	Noisy pulsation heard during feeding
Norris et al., 1977	In Bahía Magdalena	Pulses Clicks Grunts	100-20000		<1.00 0.25	—	2/sec	—	
Swartz and Cummings, 1978	In Laguna San Ignacio	Knocks Pulses Snorts Slamming Bubble bursts Squeaking moan	200-1500 66-600 50-2000 Up to 1400 700-1200	350 and 800 400 — 400-1200	4.00 0.20 1.00 0.30 4.00 0.60	1-11	— ~35/sec	0.10	

behavior of gray whales was not definitively documented and that additional long-term investigations could benefit our understanding of sound production by the gray whale.

To test the stated hypothesis of this study, it was also necessary to profile the acoustical habitats occupied by these whales. There has been an increasing awareness that ambient noise and its potential effect on marine mammals can no longer be ignored in the study of underwater bio-acoustics. Ambient noise is defined as "the contribution of all background oceanic noise resulting from either natural means and/or introduced sources" (Urlick, 1967). Ambient noise therefore may consist of 1) sounds produced from a wide variety of biological organisms such as invertebrates, fish and marine mammals; 2) sounds associated with the physical properties related to ocean dynamics (Beaufort state, surf noise, weather, tidal currents, etc.); and 3) sounds introduced by man, such as vessel noise, aircraft noise, and noise related to industrial activities. A profile of ambient noise typically contains a statement of frequencies emphasized, as well as the associated levels at these frequencies. The ambient level is the intensity, in decibels, of this ambient background measured with a nondirectional hydrophone and referred to the intensity of a plane wave having a root mean square (rms) pressure of one micropascal ($1 \mu\text{Pa}$).

The sea furnishes a superior medium for sound propagation and reception, with sound waves travelling at 1500 m/sec, a value four times that of the speed of sound in air (Urlick, 1967). Conversely, the sea can also represent a very dynamic environment for a travelling sound wave. A signal propagating through the aquatic medium can become delayed, distorted, enhanced and/or weakened. Propagation pathways can differ greatly depending upon the

physical characteristics of the area. Distinct differences in ambient levels and frequencies also exist regionally, depending upon the composition of sound-producing marine life, the physical properties of the area, and the relative amount of human activities. Within a specific area, daily and/or seasonal changes can occur, reflecting the constant state of flux of ambient noise.

Extensive literature is available defining and identifying ambient noise in the world's oceans (Heindsman et al., 1955; Wilkenshaw, 1960; Wenz, 1961, 1962; Ezrow, 1962; Calderon, 1964; Green and Buck, 1964; Arase and Arase, 1966). In most cases, however, detailed measurements have not been made for a specific area. Rather, the information for a particular region may be extrapolated from other areas with similar oceanic characteristics and then modelled for the area in question. Since it was critical to this project to define, profile, and understand the acoustical environments occupied by gray whales, it was necessary to collect on-site measurements of ambient noise rather than rely on extrapolated information.

In addition to collecting information on ambient noise levels in various parts of the gray whale's range, factors that could potentially influence a travelling sound wave were investigated as well. These included depth, temperature, salinity, and bottom substrate. To obtain precise information on propagation pathways in Laguna San Ignacio, a series of propagation experiments was conducted. These experiments provided a greater insight into the acoustical habitats of the whales and also added a critical element needed during the playback experimentation discussed in Chapters 2 and 3.

Communication between individuals can be accomplished in a variety of ways. For those species inhabiting the aquatic environment (e.g.,

cetaceans), certain restrictions are inherent on the use of different signalling methods. Vision appears to be well developed in those cetacean species studied (Breathnach, 1960; Kellogg and Rice, 1966; Caldwell and Caldwell, 1972). However, underwater vision is usually restricted to short distances. Chemical signals diffuse slowly and dissipate quickly, which could negate their use over long distances. In addition, the reduced and/or non-existent olfactory tracts in cetaceans imply little or no dependence on this sensory mechanism (Jansen and Jansen, 1953; Caldwell and Caldwell, 1972). Taking into account the advantages that a travelling sound wave has in the ocean environment, it appears that signalling and responding through the use of sound are by far the most effective means of exchanging information over a long distance in the aquatic environment.

To determine if ambient noise has the potential of interfering with or masking the signals produced by an acoustically-dependent animal, the sound repertoire of that species, as well as the characteristics of its acoustical habitats, must be investigated and quantified. The relationship between the animals' calls and their environment can then be defined. This Chapter documents the types of calls produced by the gray whale and profiles the ambient noise conditions encountered by this species. The relationship of gray whale signals to ambient noise is inspected to determine if the main sources of channel noise could affect the underwater signals produced by the gray whale.

MATERIALS AND METHODS

Analysis Procedures - Gray Whale Sound Production

Each underwater recording (magnetic tape) collected was edited and the pertinent information transferred to a written record. The edit sheet contained tape identification number, time and date of recording, tape count, type of sound emitted, subjective appraisal of the signal level (minimum, moderate, high), and general comments which included all pertinent behavioral or environmental data.

Sound types were initially categorized aurally. These categories were then visually inspected and verified through analysis on a Kay Elemetrics Corporation Sona-Graph (Model 7029A). Since onomatopoeic terms denote different things to people, I elected to use a numbering system to categorize gray whale sounds. Each distinct sound type was numbered. A letter was placed prior to the number to indicate the area in which this sound was recorded and documented. For example, an S1 signal (southern range signal) would be designated as an N1 signal on the northern range and/or an M1 signal if produced during the migration.

During analyses, sounds of high quality, without interference of man-made noise, were selected, which provided better resolution and accuracy during quantification. The analyses of these high signal-to-noise calls resulted in the major conclusions drawn regarding sound categorization of gray whale signals.

Since only one omni-directional hydrophone was used, it was not possible to obtain source levels of gray whale calls. However, received levels were computed and subsequently used to profile this parameter of gray whale signals. Hydrophone sensitivity, amplifier gain relative to attenuator

settings and calibration tones recorded on tape during field collections were used to compute these received levels. A Nicolet Scientific Corporation FFT Computing Spectrum Analyzer, Model 446 was used to compute pressure levels. Displays for these spectra were made on an X-Y plotter. The results were then digitized using a plastic overlay designed by the author. The overlay format represented frequency values on the x-axis with dB levels (re 1 μ Pa) on the y-axis.

Analysis Procedures - Ambient Noise

To calculate biological ambient noise levels, one-third octave average sound pressure levels were computed using a Spectral Dynamics 345 Spectrum Analyzer set for 0-20 kHz bandpass and either 32 or 64 linear averages. The reported average sound pressure levels were calculated by averaging as many linear averages as possible from a single biological station. Using this method, the reported levels for the stations represent a range of actual sampling times equivalent to a flat weighted average sound pressure meter sampling from 1.28 to 14.0 sec.

One-third octave levels for large vessels were calculated using a single output of 64 linear averages from a Spectral Dynamics 345 Spectrum Analyzer set at a 20 kHz bandpass. These data were not range corrected; thus, they represent levels received at the hydrophone. The outboard engine one-third octave levels were sampled using a General Radio 1995-9008 equipped with a 10 Hz to 80 kHz bandpass. The General Radio equipment was chosen for its high sampling rate which was needed during the analysis of the shorter-term signals produced by outboard engines. These levels were corrected assuming spherical spreading ($20 \log R$) to 1 yd. Although Laguna San Ignacio represents a shallow-water environment (< 30m), free-field

conditions (spherical spreading) were assumed during this phase of the research because of the close proximity of the outboard engines to the recording instrumentation.

During analysis of the Bering Sea and Washington State data, hydrophone sensitivity, amplifier gain relative to attenuator settings, and calibration tones recorded on tape during field collections were used to compute ambient levels. Average sound pressure levels were computed using a Nicolet Scientific Corporation FFT Spectrum Analyzer, Model 446. The high pass filter was set at 10 kHz, and recordings were averaged over three minutes. Displays of the calculated spectra for ambient sources were made on a X-Y plotter.

Analysis Procedures - Relationship Between Whale Calls and Ambient Noise

To determine the possible interference/masking effect of background noise on gray whale signals, several aspects of channel occupation were quantitatively examined.

Sounds produced by the gray whale were examined, with particular attention to emphasized frequency bands. The received levels of sound at these emphasized frequencies were noted as well. Variations within each call type were listed to determine if modifications occurred in call structure: e.g., 1) repetition rates of calls; 2) amount of frequency modulation; and 3) duration of signals. Gray whale signals produced on different parts of this species' range were compared to determine if these call modifications could provide a selective advantage in different habitats or behavioral contexts.

An inspection of the dominant frequencies and levels produced by natural background ambient conditions (e.g., biological organisms) was compared to the frequencies and levels emphasized by the gray whales.

In addition to the ambient noise profiles resulting from the biological component, an inspection of the frequencies and levels associated with different oceanic conditions was also reviewed. This was accomplished through my own field collections and a review of the appropriate literature. These data were compared to those collected on sound production by the gray whale.

Man-made noise sources were inspected as well, and the dominant frequencies and associated levels were listed. When signals produced by the gray whale occurred at the same time that a man-made event occurred, composite sonograms were made to illustrate the frequencies emphasized by both of these sources.

RESULTS

TYPES OF SOUNDS PRODUCED

Laguna San Ignacio (Mexico)

Based on 565 hrs of underwater recording, I have classified the sounds produced by the gray whale in Laguna San Ignacio into six distinct types (Table II). Field observations provided assurance that these signals were in fact produced by gray whales. Typically, signal strengths would increase as whales approached the hydrophone and decreased as whales moved away. In addition, the original recordings of a captive gray whale were obtained and compared to those calls collected in Mexico. And finally, recordings were collected in Laguna San Ignacio when whales were not present.

The most prevalent phonation (83% of all signals) recorded during the investigations was a pulsing sound which was termed S1 (Fig. 4). These transient pulses were broadband, with energy ranging from less than 100 Hz to 2 kHz, but usually having an emphasized band between 300 and 825 Hz. Although single pulses were recorded, typically S1 signals occurred in a series or burst, ranging from 2 to 30 with an average of 9.4 pulses per series. The durations of these series averaged 1.8 sec. Each pulse, however, was less than 0.05 sec long. Average pulse repetition rate was 5.9 per sec, with a range of 2.2 to 14.7 sec. Frequently, these pulse modulated sounds were also frequency modulated, as shown in Fig. 5. Pulses were often metallic sounding; however, this aural characteristic appeared to vary considerably. Received levels ranged from 90-160 dB re 1 μ Pa, with an average level calculated at 118 dB re 1 μ Pa.

The second sound type was termed an S2 signal (Fig. 6). In all cases, S2 signals were characterized by a rapid FM up/down sweep. A metallic

Table II. A Classification of Sounds Produced by the Gray Whale in Laguna San Ignacio, Mexico.*

Sound type	n	Frequency Range Low High	Energy Concentration Low High	Duration of Series	Number of Pulses Per Series	Pulses Per Second	Received Levels		
S1	1000	90 (120-1250)	1940 (1000-3000)	332 (100-1250)	824 (400-1600)	1.8 (0.3-4.6)	9.4 (2-30)	5.9 (2.2-14.7)	118 (90-160)
S2	100	250 (100-300)	300 (200-350)	250 (200-275)	300 (250-350)	0.3 (0.2-0.4)	---	---	102 (92-127)
S3	100	125 (80-200)	1250 (750-1800)	170 (125-625)	430 (300-750)	2.0 (1.0-4.0)	---	---**	94 (90-113)
S4	100	150 (125-200)	1570 (1500-1600)	225 (125-300)	600 (450-750)	0.9 (0.7-1.4)	---	---**	92 (88-108)
S5	100	130 (20-250)	840 (600-1500)	200 (20-250)	500 (300-750)	3.2 (1.8-4.5)	---	---	118 (97-124)
S6	100	250 (125-300)	850 (600-1000)	250 (125-300)	700 (300-800)	3.3 (1.2-3.6)	---	---	102 (96-113)

* Mean values are given and their associated ranges are shown in parentheses. All frequency values are given in Hz and time values in seconds. Received levels are shown in dB levels re 1 μ Pa.

** Pulse modulation occurring.

Figure 4. Spectrograph of a Gray Whale S1 Series.

4000

Series 1

Series 2

Frequency (Hz)

40

0

Time (sec)

4.8

30

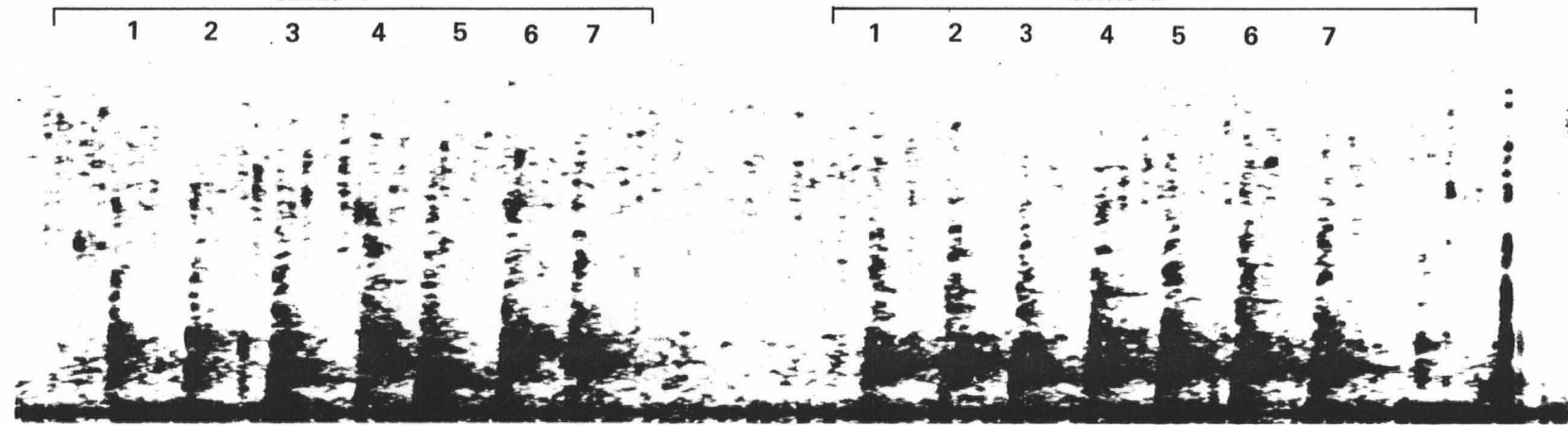


Figure 5. Spectrograph of Two S1 Series Depicting Frequency Modulation.

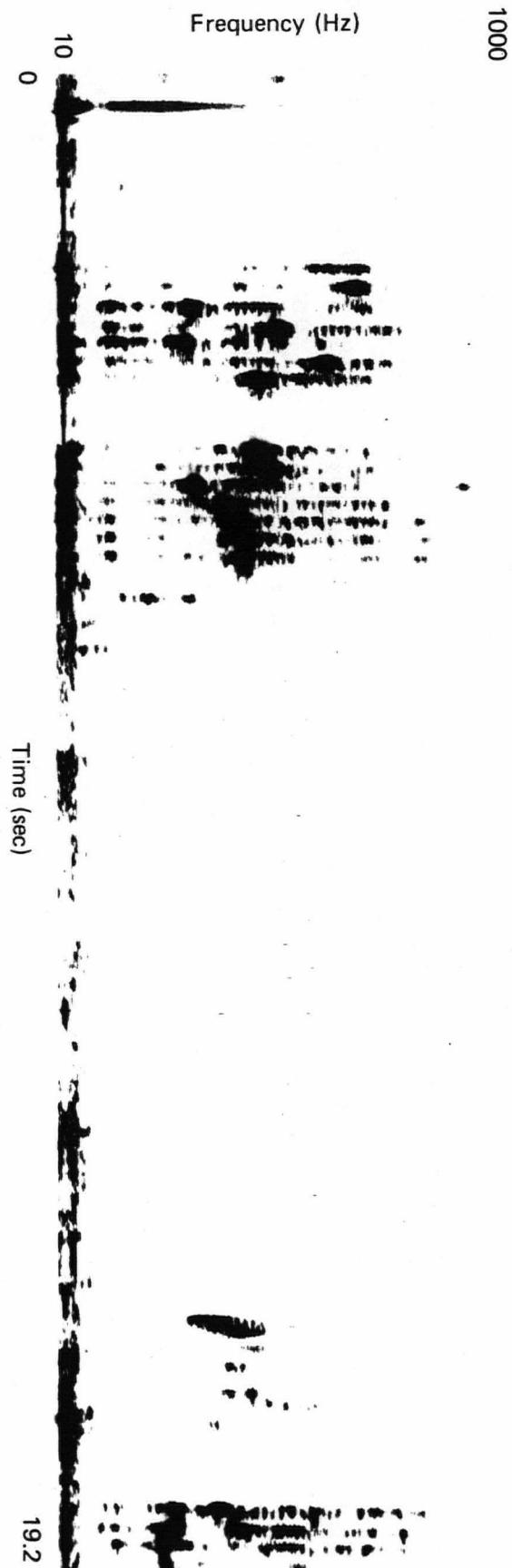
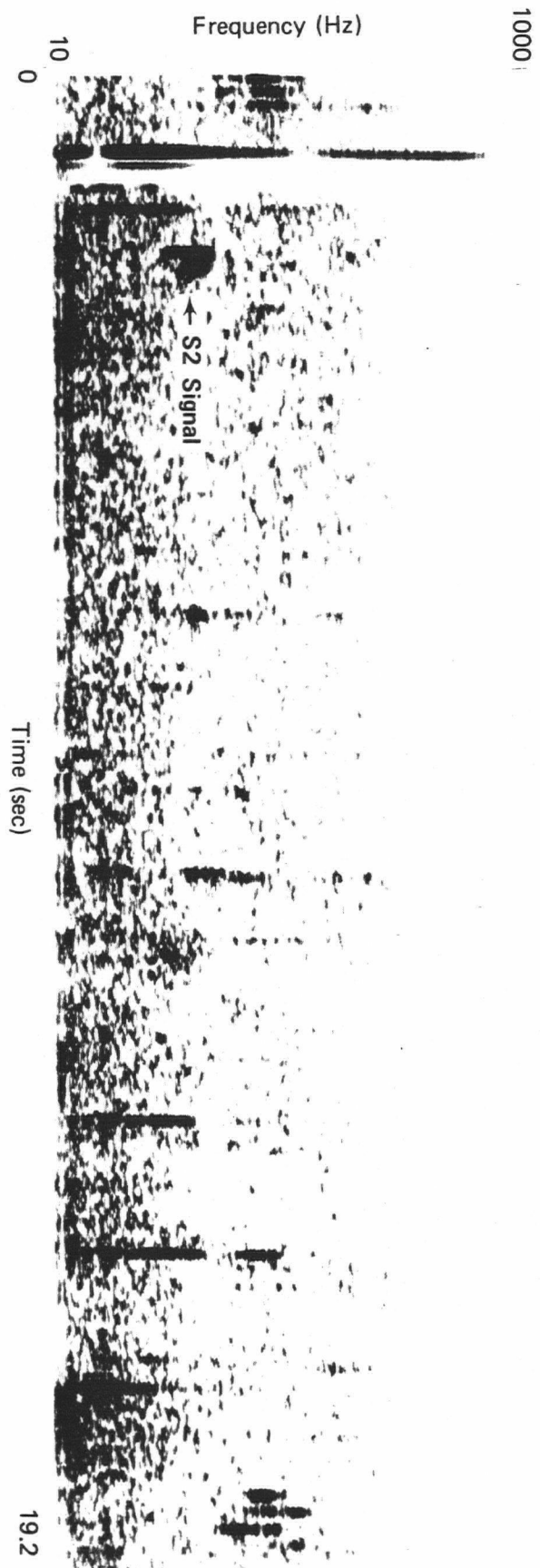


Figure 6. Spectrograph of a Gray Whale S2 Signal.



aural quality was prevalent in all S2 signals. A mean frequency range of 250 to 300 Hz was calculated with an average duration of 0.3 sec. Compared to a single S1 pulse, S2 signals had lower emphasized frequencies, were of longer duration, had less variation, and did not occur in a series. Five percent (5%) of the sample contained S2 signals. Received levels ranged from 92-127 dB re 1 μ Pa, with an average of 102 dB.

The third type of signal (S3) was characterized by its low frequency range (125 Hz to 1250 Hz) and long duration (1.0 to 4.0 sec). Energy was usually concentrated below 430 Hz. The spectrograph in Fig. 7 indicates that this signal is pulse modulated. S3 signals represented 7% of all calls recorded. Received levels were considerably lower as compared to the S1 and S2 signals and ranged from 90-113 dB re 1 μ Pa, with a mean of 94 dB. Some variability occurred within this signal, but to a lesser extent than that of the S1 signal.

S4 signals (Fig. 8) were typically of higher mean frequencies (150-1570 Hz) than S3 signals. Average energy was centered between 225 and 600 Hz. Average duration was short (< 1.0 sec). Five percent (5%) of the sample contained S4 signals. This sound type appeared to be pulse modulated as well. Little variation occurred in this signal. Received levels ranged from 88-108 dB re 1 μ Pa, with an average of 92 dB.

In Laguna San Ignacio, gray whales often release large amounts of air underwater. The released air rises to the surface where it develops into a large circular bubble mass. This behavior has been termed a "bubble blast" or "bubble burst" by previous investigators (Swartz and Cummings, 1978). The sound (S5) associated with bubble blasts is acoustically distinct and readily identifiable (Fig. 9). Mean frequency ranges were measured between 130 and 840 Hz, with most energy concentrated below 500 Hz. The average

Figure 7. Spectrograph of a Gray Whale S3 Signal.

2000

Frequency (Hz)

20

0

Time (sec)

9.6



Figure 8. Spectrograph of a Gray Whale S4 Signal.

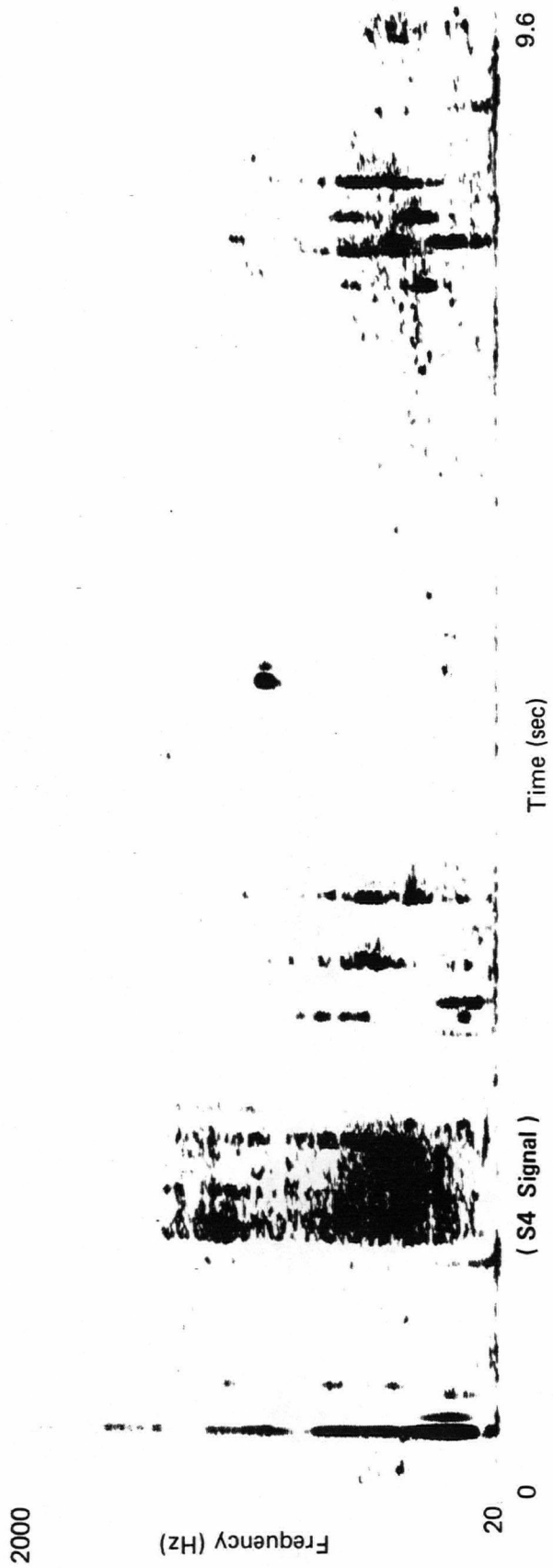


Figure 9. Spectrograph of a Gray Whale S5 Signal (bubble blast).

2000 |

Frequency (Hz)

20
0



Time (sec)

9.6

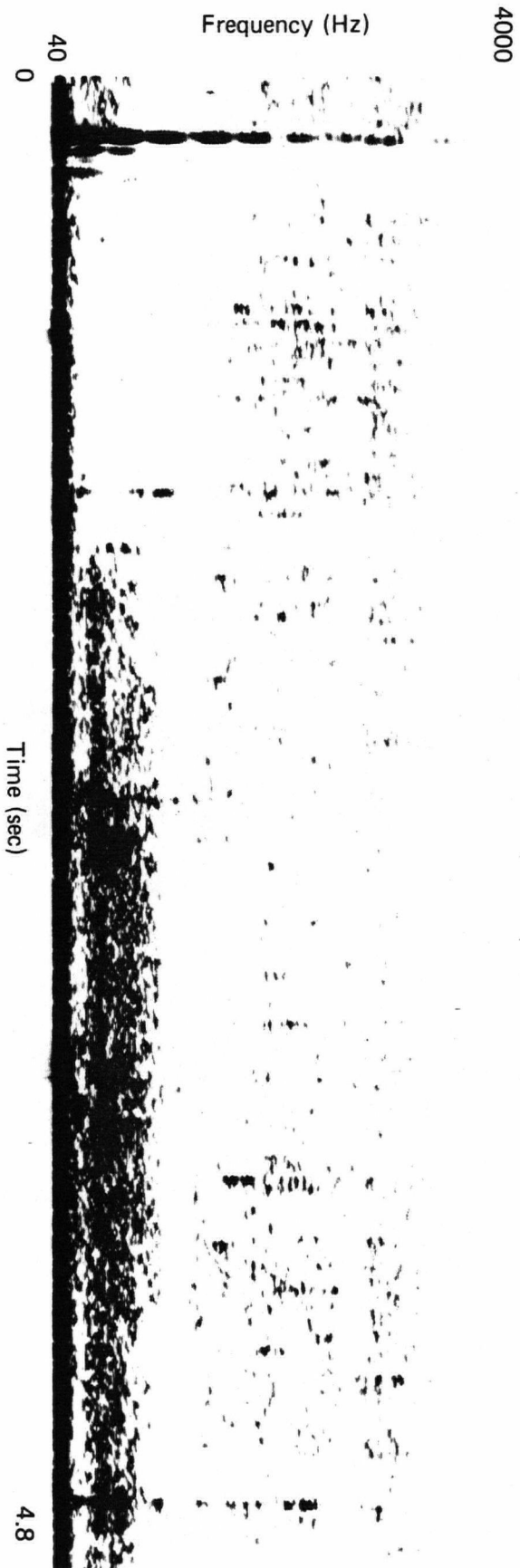
duration of this signal was variable, ranging from 1.8 to 4.5 sec. Bubble blasts could be heard underwater at estimated distances up to 2.5 km. A received level of 97-124 dB re 1 μ Pa was calculated, with a mean of 118 dB.

Frequently, gray whales also exhaled underwater trails of bubbles just prior to breaking the surface to breathe. Again, the sound (S6) was distinct aurally. Mean frequency ranges of the sub-surface exhalations were between 250 and 850 Hz, with major energy concentrated at frequencies less than 700 Hz (Fig. 10). Average duration was 3.3 sec. Levels received at the hydrophone ranged from 96-113 dB re 1 μ Pa, with an average of 102 dB.

The six major sound types were heard under a wide variety of behavioral activities. No attempt was made to correlate sound production and behavior, with the exception of the bubble blast and sub-surface exhalation.

To determine the periodicity of total sound production in the lagoon during February and March, the total number of sounds produced per hour was calculated for each month. In addition, the average number of whales occupying the lagoon each month was estimated. Out of 565 hours of recordings, 395 hours were recorded in February and 170 hours were recorded in March. In February, an average of 84 sounds were collected per hour. This value ranged from 62-128 sounds produced per hour. In March, total sound production per hour dropped to 38-86 sounds/hr, with an average of 50 sounds produced per hour. These monthly totals did not include the S5 or S6 signals. The abundance of whales calculated over a five-year period has been reported by Jones and Swartz (1984). Taking an average of their mid-February and March counts during the years 1978-1982 resulted in the following. The average number of whales occurring in the lagoon in February was 258 whales and in March 195 whales. If the total average number of

Figure 10. Spectrograph of a Gray Whale S6 Signal (sub-surface exhalation).



sounds produced per hour by month is divided by the average number of whales occupying the lagoon by month, the number of sounds produced per hour per whale is obtained (sounds/hr/whale). In February, 0.33 sounds/hr/whale was calculated. In March, 0.25 sounds/hr/whale was obtained.

In comparing the types of signals produced and periodicity of phonations over a 24-hour period, no differences in gray whale sound production were found ($t = 1.27$, $p > 0.05$). S1 signals dominated the vocal repertoire, and the level of sound activity remained the same.

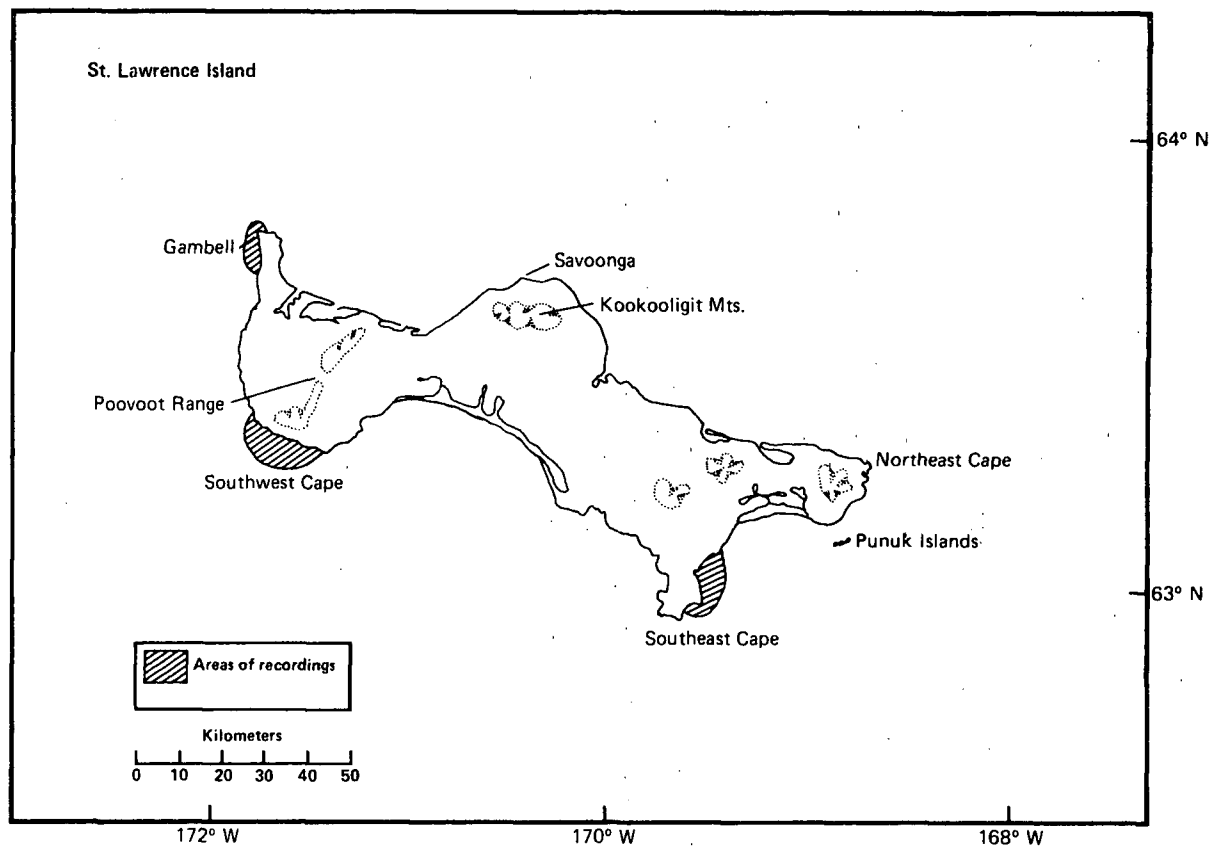
St. Lawrence Island (Alaska)

Despite considerable effort (40 hrs of recording), few signals were recorded in the presence of feeding gray whales. During July, 30 hours of recordings were collected; however, unfavorable weather in September limited collections to 10 hrs (Fig. 11).

Although at times the whales were in close proximity to the recording platform (< 10 m), the received levels of their sounds were considerably lower than the levels reported for Mexico. It is possible, however, that the signals actually recorded were not those of the whales within close range but represented sounds produced by distant whales. The low levels of these signals made spectral analyses impossible (signal-to-noise ratio = 0 dB). In editing these tapes, one can aurally distinguish gray whale signals; however, the resultant visual display could not distinguish the signal from the background noise caused by the pitch and roll of the recording platform and subsequent movement of the hydrophone.

A total of 53 sounds was recorded and aurally classified into four distinct call types: 1) broadband pulses produced in a series (N1 signal;

Figure 11. Recording Locations of Gray Whales off St. Lawrence Island, Bering Sea, Alaska, Summer 1982.



n = 14); 2) low frequency moans (N3 signal; n = 3); 3) grunt-like phonations (N4 signal; n = 6); and 4) sub-surface exhalations (N6 signal; n = 30).

The received level of the N6 signal was of sufficient strength for analysis.

This sound emphasized frequencies between 100 Hz and 1.0 kHz with energy concentrated below 600 Hz. Average duration was 4.2 sec (Fig. 12).

Received levels were comparable to those documented in Mexico, averaging 100 dB (re 1 μ Pa).

During 40 hours of recording, a total of 23 signals was documented (excluding sub-surface exhalations, n = 30). This reflects an hourly sound production rate of 0.58 signals/hr. If this value is then divided by the average number of whales occupying this area (approximately 100 animals, based on an visual estimate only), the resultant index of 0.006 sounds/hr/whale is obtained. Preliminary results indicate that sound activity is significantly reduced on the northern range as compared to sound production in Mexico. Due to the small sample size on the northern range, meaningful comparisons of sound periodicity over a 24-hour cycle could not be investigated.

Washington State Waters

Limited field work was accomplished in Washington waters. A total of 5 hours of recordings was collected from two locations within Washington State: 1) coastal waters (La Push, Washington; Fig. 13); and 2) inland waters (Langley, Whidbey Island, Puget Sound; Fig. 14). In coastal waters, three juvenile gray whales (approximately 10 m in length) were observed. One juvenile whale (less than 10 m) was observed during inland recordings at Langley. No sounds attributable to the gray whale were recorded during these sessions. At each location, it appeared that these juvenile whales

Figure 12. Spectrograph of a Sub-surface Exhalation (N6) Produced by a Surfacing Gray Whale off St. Lawrence Island, Alaska.

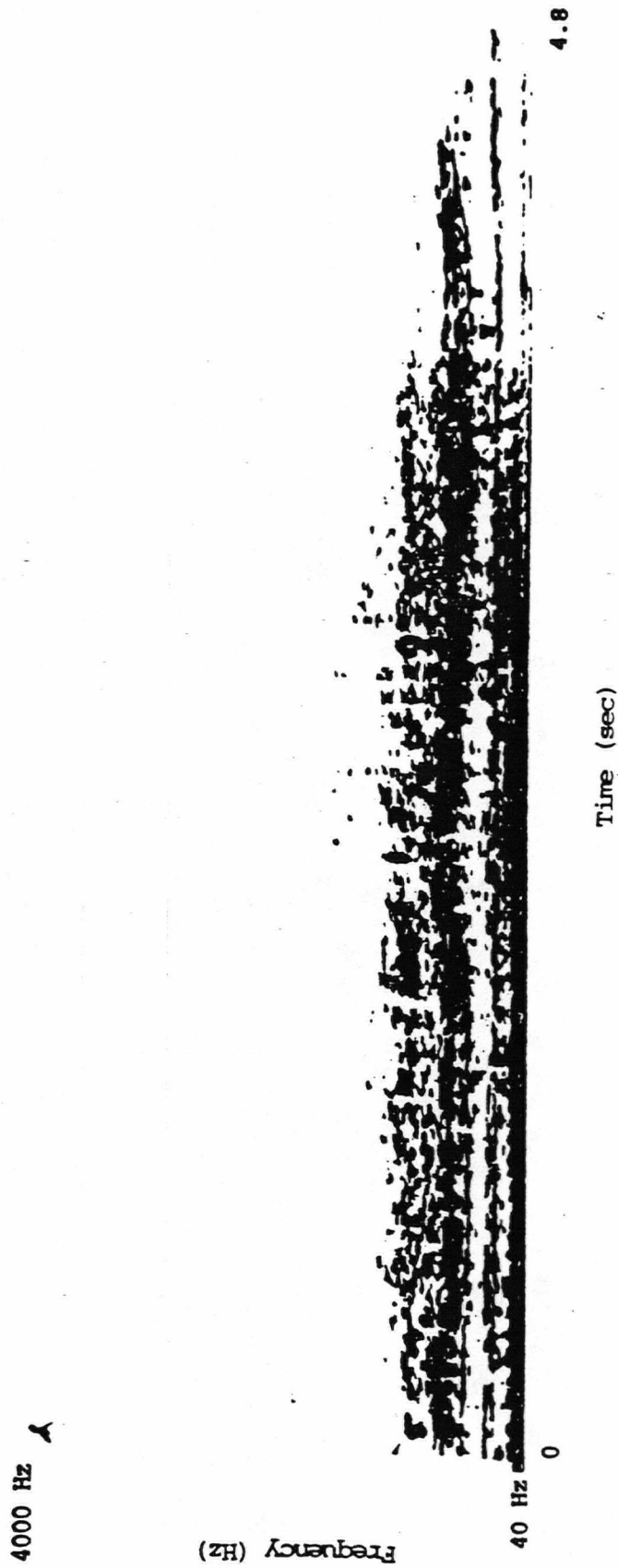


Figure 13. Study Area -- Coastal Waters of Washington State.

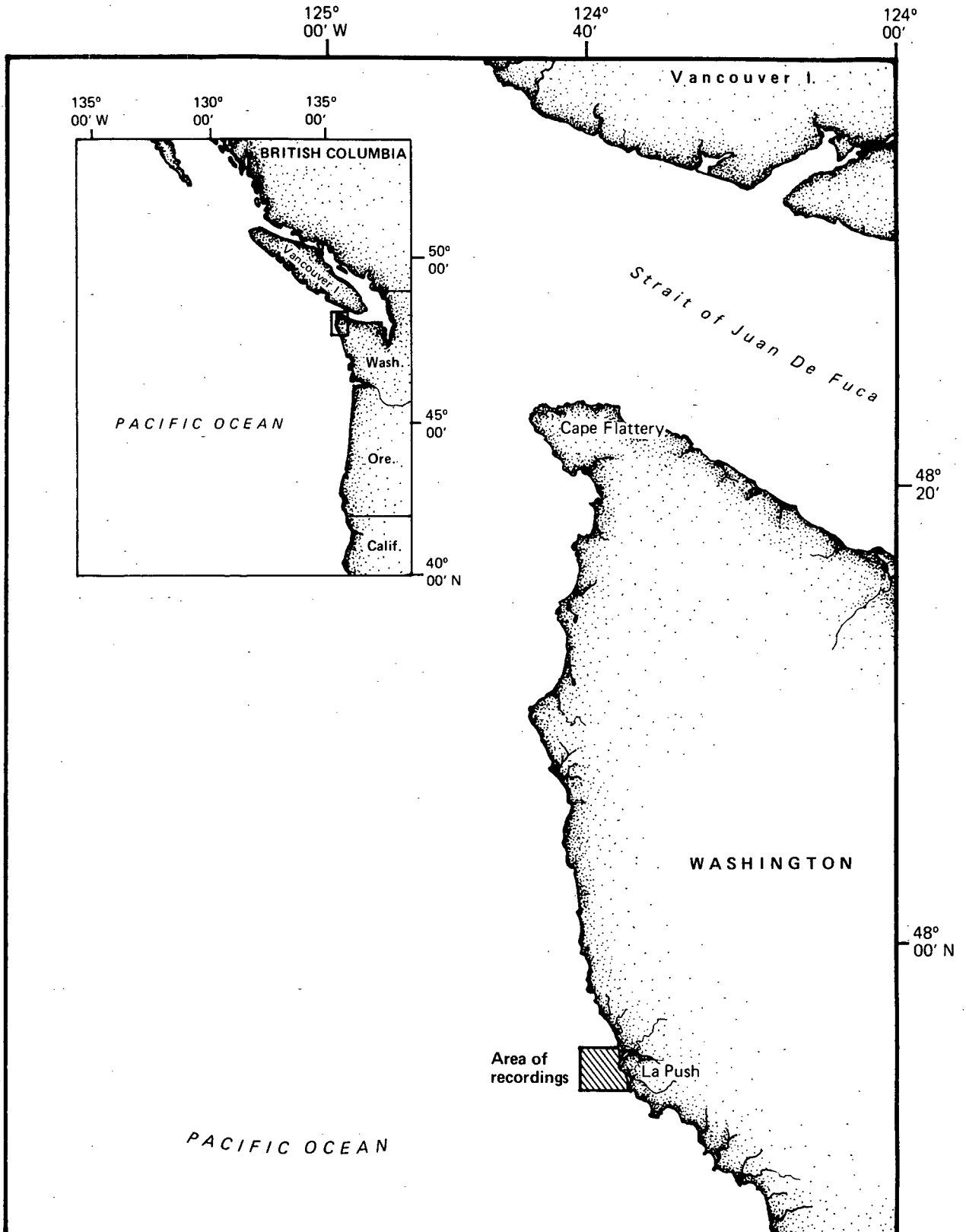
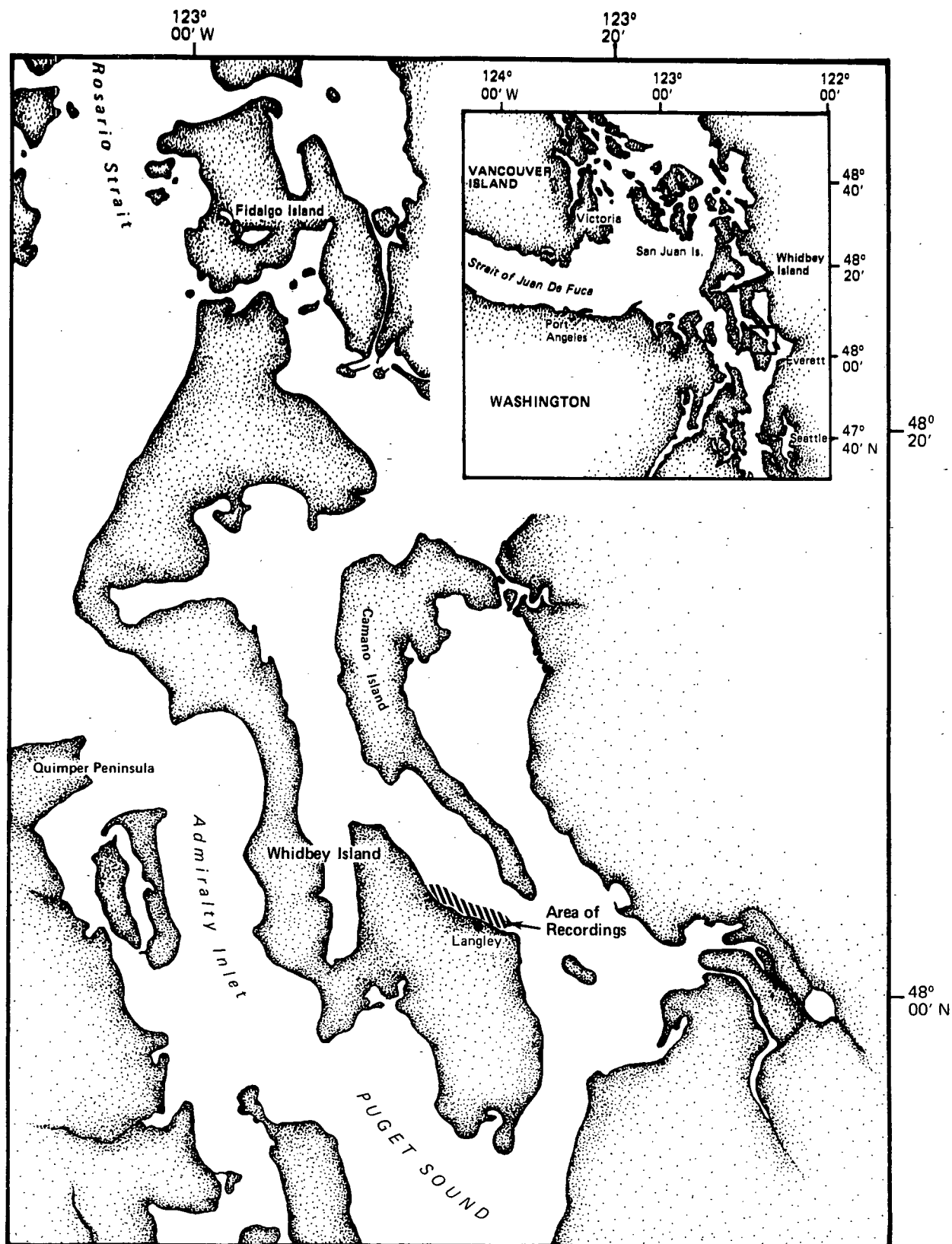


Figure 14. Recording Locations of Gray Whales in Washington State Waters.



were feeding, as evidenced by associated mud plumes and circling behavior (Moore and Ljungblad, 1984).

Integration of Regional Data Bases/Published Information

After comparing my spectrographs and recordings with those previously published and with the original tapes supplied by previous authors, a synthesis of all available data on calls produced by the gray whale was completed (Table III). Seven categories of sounds were established for the gray whale throughout its range.

Signals produced by the gray whale (S1 through S4) on its southern range emphasized the frequency ranges between 225-824 Hz. The received levels of these four southern call types varied, averaging 92-118 dB re 1 μ Pa. The S1 signal dominated the vocal repertoire of gray whales in Mexico. In addition, this sound also showed the most variation in call structure when compared to the S2, S3 and S4 signals. Variations within the S1 signal were observed in: the number of pulses per series (2-30); the repetition rates (2.2-14.7 pulses/sec); the amount of frequency modulation; the duration of the total signal (0.3-4.6 sec); and in the range of received sound levels (90-160 dB re 1 μ Pa). Little variation occurred within the S2, S3 and S4 call types. When comparing the recordings collected over a 24-hour period in Mexico, no significant changes occurred in call types and/or calling rates. The overall calling rates, of course, were significantly higher in Laguna San Ignacio than in other areas.

Comparisons of call structure from the northern and southern ranges revealed differences. On the northern range, as on the southern range, the N1 signal exhibited the most variation among signals and represented the most frequently used phonation. N1 signals were broadband, ranging

Table III. Sounds Produced by the Gray Whale Throughout Its Range Based on Acoustical Studies in Laguna San Ignacio and Published Accounts (only those accounts with sufficient data for comparison were included).

Sound type	Geographical area	Reference
S1*	S/N/M**	This Chapter; Asa-Dorian and Perkins, 1967 (pulses); Fish et al., 1974 (pulse trains); Swartz and Cummings, 1978 (knocks and pulses); Moore and Ljungblad, 1984 (knocks); Norris et al., 1977 (clack).
S2	S	This Chapter.
S3	S/N/M	This Chapter; Cummings et al., 1968 (moans); Fish et al., 1974 (growls or moans); Moore and Ljungblad, 1984 (moan).
S4	S/N/M	This Chapter; Fish et al., 1974 (grunt); Swartz and Cummings, 1978 (snort); Moore and Ljungblad, 1984 (grunt).
S5	S/M	This Chapter; Cummings et al., 1968 (bubble-type); Swartz and Cummings, 1978 (bubble bursts).
S6	S/N/M	This Chapter; Cummings et al., 1968 (blow sounds).
S7	S/M	Fish et al., 1974 (clicks and click train).

* An S1 signal produced on the northern range would be designated as an N1; the same type of signal produced during migration would be designated as M1.

** S, southern range; N, northern range; M, migration route.

from 200-4000 Hz, with most energy concentrated between 238-2584 Hz. Typically this signal contained 2-69 pulses per series ($\bar{x} = 12$), and was produced at a mean repetition rate of 7.14 pulses per second. Signal duration averaged 1.4 sec, with a range of 0.4 to 2.3 sec. Upon inspection of the N1 call type, no evidence was found of frequency modulation. The difficulties during analysis (poor signal to noise ratio) suggested that these northern signal strengths were low and approximated those of ambient conditions (estimated to be 65 dB re 1 μ Pa). A comparison between S1 and N1 signals revealed the following. N1 signals emphasized a broader and slightly higher frequency band than S1 signals. The repetition rates and number of pulses per series of N1 signals exhibited higher values; however, these northern signals were shorter in duration. The elaborate frequency modulation prevalent in the S1 signal did not occur in the N1 calls. Received levels of sound were considerably higher on the southern range.

In comparing the information available on the S3 type calls among the three areas of the gray whales' range, modifications were also noted in call structure. All "3-type" calls were pulse and frequency modulated. Collectively, these signals covered the frequencies of 20-1250 Hz, with the M3 call representing the narrowest range (20-200 Hz), N3 showing an intermediate value (102-578 Hz), and S3 exhibiting the widest range (125-1250 Hz). Energy concentrations within the S3 and N3 signal were similar. Call duration also varied among areas, with S3 signals showing the longest duration, followed by M3, and the shortest signal being the N3. Received levels were greatest in Mexico. Although Cummings et al. (1968) reported a value of 152 dB re 1 μ Pa for this signal off California, this value represented a source level; thus, valid comparisons could not be drawn.

The N4 signal exhibited a narrower range of frequencies than the S4 signal; however, the energy concentration of the S4 signal (225-600 Hz) included the 388 Hz mean value noted for N4 signals. N4 signals were considerably shorter in duration ($\bar{x} = 0.344$ sec) than S4 signals (0.944 sec). Received levels of these calls were higher on the southern range (92 dB vs 65 dB re 1 μ Pa). The tabulated data on these sound type comparisons are presented in Table IV.

Table IV. Comparisons of Gray Whale Sounds Throughout Its Range.

Sound Type	Frequency Range (Hz)	Energy Concentration (Hz)	Pulses Per Series	Pulses Per Second	Duration (sec)	Frequency Modulation Occurring	Amplitude Modulation Occurring	Received Levels dB re 1 μ Pa	Reference
S1	90-1940	332-824	9.4 (2-30)	5.9 (2.2-14.7)	1.8 (0.3-4.6)	Yes	Yes	118 (range)	Chapter 1
N1	200-4000	963 (238-2584)	12.0 (2-69)	7.1	1.4 (0.4-2.3)	No	Yes	65 (range)	Moore and Ljungblad, 1984; Ch.1
S3	125-1250	170-430	---	---	2.0 (1.0-4.0)	Yes	Yes	94 (range)	Chapter 1
N3	102-578	325	---	---	0.9	Yes	Yes	65 (range)	Moore and Ljungblad, 1984; Ch.1
M3	20-200	---	---	---	1.4	Yes	Yes	152*	Cummings et al., 1968
S4	150-1570	225-600	---	---	0.9 (0.7-1.4)	Yes	Yes	92	Chapter 1
N4	136-748	388	---	---	0.3 (0.2-0.5)	Yes	Yes	65	Moore and Ljungblad, 1984; Ch.1

* Represents source level of signal.

AMBIENT NOISE

Laguna San Ignacio (Mexico)

Biological ambient noise was recorded at 32 stations, 14 in the outer lagoon and 18 in the inner lagoon (Fig. 15). Although noise spectra varied among the stations, typically they followed the pattern depicted in Fig. 16. Levels were lowest below 2 kHz, increased to high levels between 2 and 5 kHz and then declined gradually through 20 kHz. The average ambient noise levels attributable to biological sources (excluding cetaceans) ranged from 94 to 110 dB re 1 μ Pa. The levels and associated octave-band frequencies for each of the 32 stations are listed in Table V.

An inspection of the synoptic ambient samples (24-hour recordings) from Rocky Point revealed no significant differences in levels or frequencies over a 24-hour period ($t = 1.17$, $p > 0.05$). Increase in sea states showed a corresponding increase in ambient levels. These spectra were compared to the standard open-ocean reference spectra developed by Knudsen (1948), which provide a standard for judging relative noisiness (Fig. 17). When the spectra of ambient noise obtained in Laguna San Ignacio are compared with this standard, the resultant conclusion is that ambient noise levels are extremely high in the lagoon habitat. The biological component of noise dominates the spectra. Numerous biological organisms were identified and deemed possibly responsible for the high levels of noise received (Table VI).

The only sources of anthropogenic noise occurring during these Mexican studies were vessel and skiff traffic. Data were collected on six large vessels (25-35 m in length) and 14 skiffs powered by outboard engines. The sources of noise radiating from these large vessels can be grouped into

Figure 15. Locations of Biological Ambient Noise Stations in Laguna San Ignacio, Mexico.

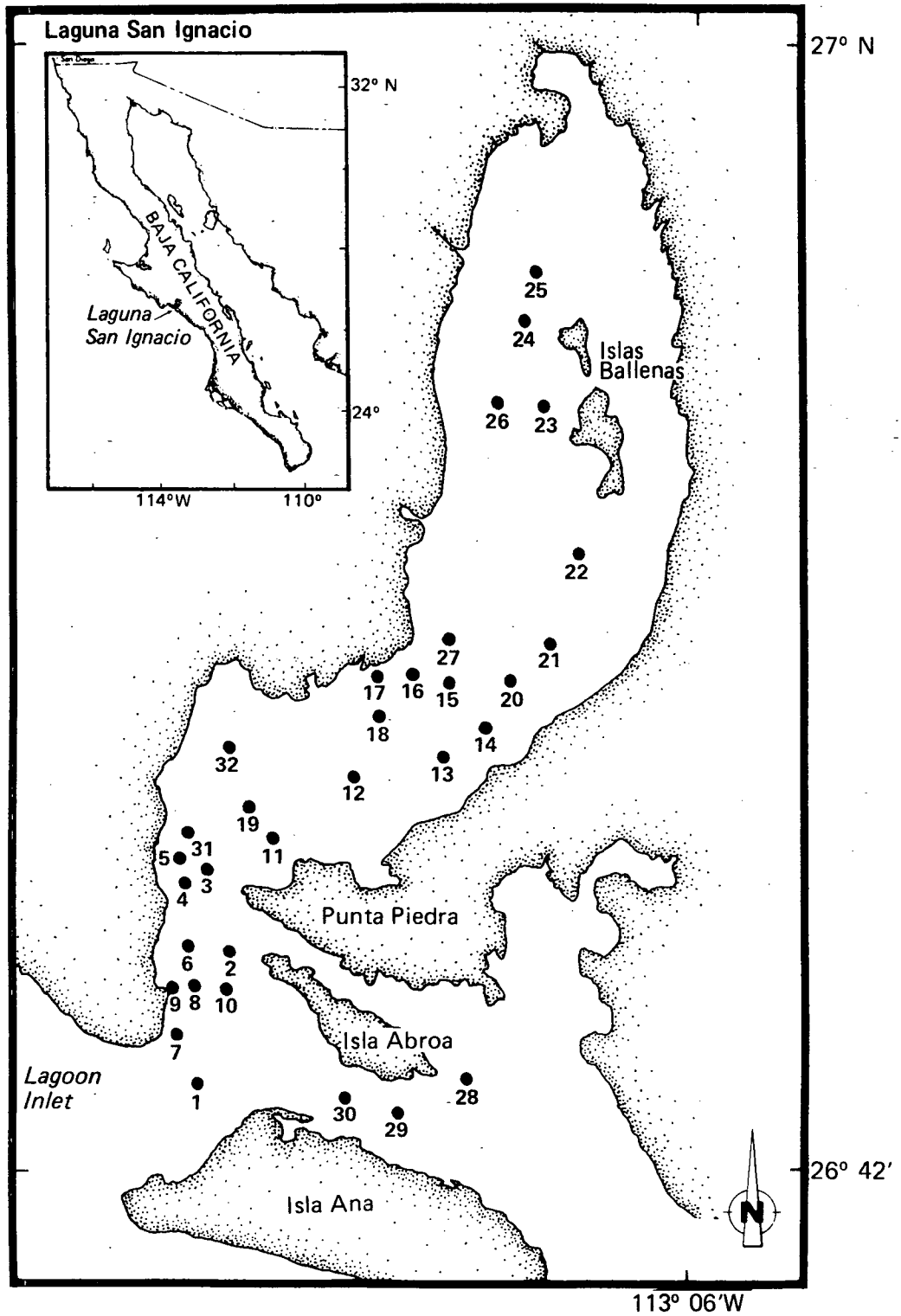


Figure 16. Spectra of Typical Biological Ambient Noise Levels in Laguna San Ignacio, Mexico.

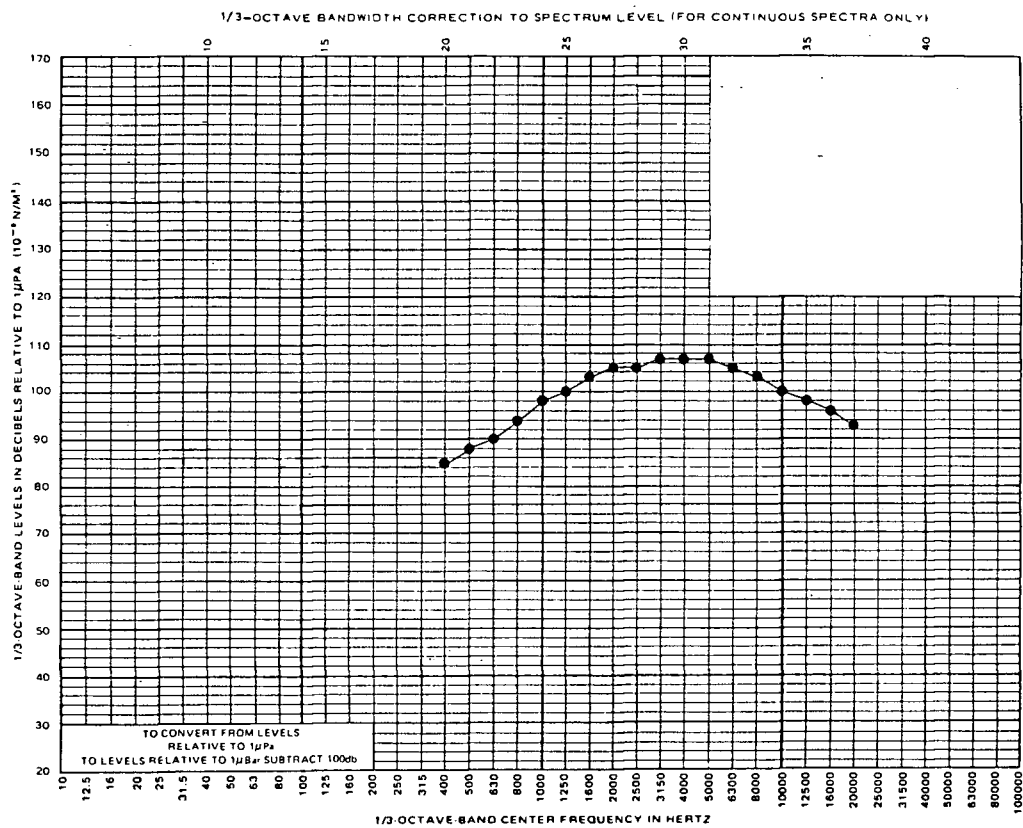


Table V. Estimated Levels (dB re 1 μ Pa) and Their Associated Frequencies (Hz) for Biological Ambient Noise Stations 1 - 32 in Laguna San Ignacio, Mexico

Biological Noise Station	Estimated Level (dB re 1 μ Pa)	Frequency (Hz)						
		1250	1600	2000	2500	3150	4000	5000
1 *	97						X	X
2	94						X	X
3	103					X	X	
4	107					X	X	X
5	98					X	X	X
6	109						X	X
7	97					X	X	X
8	94					X	X	X
9	99						X	
10	98						X	
11	105					X	X	X
12	102			X	X	X	X	
13	100			X	X	X	X	
14	103						X	
15	102			X				
16	105			X				
17	106			X				
18	104			X				
19	99			X				
20	96			X				
21	103			X	X		X	
22	102					X	X	
23	102				X	X		
24	106			X	X	X	X	
25	103			X				
26	110	X	X	X				
27	106			X	X		X	
28	105						X	
29	109						X	
30	108					X	X	X
31	99					X	X	X
32	95						X	

* For example, Station #1 had a maximum level of 97 dB in both the 4 and 5 kHz bands.

Figure 17. Knudsen Sea State Curves.

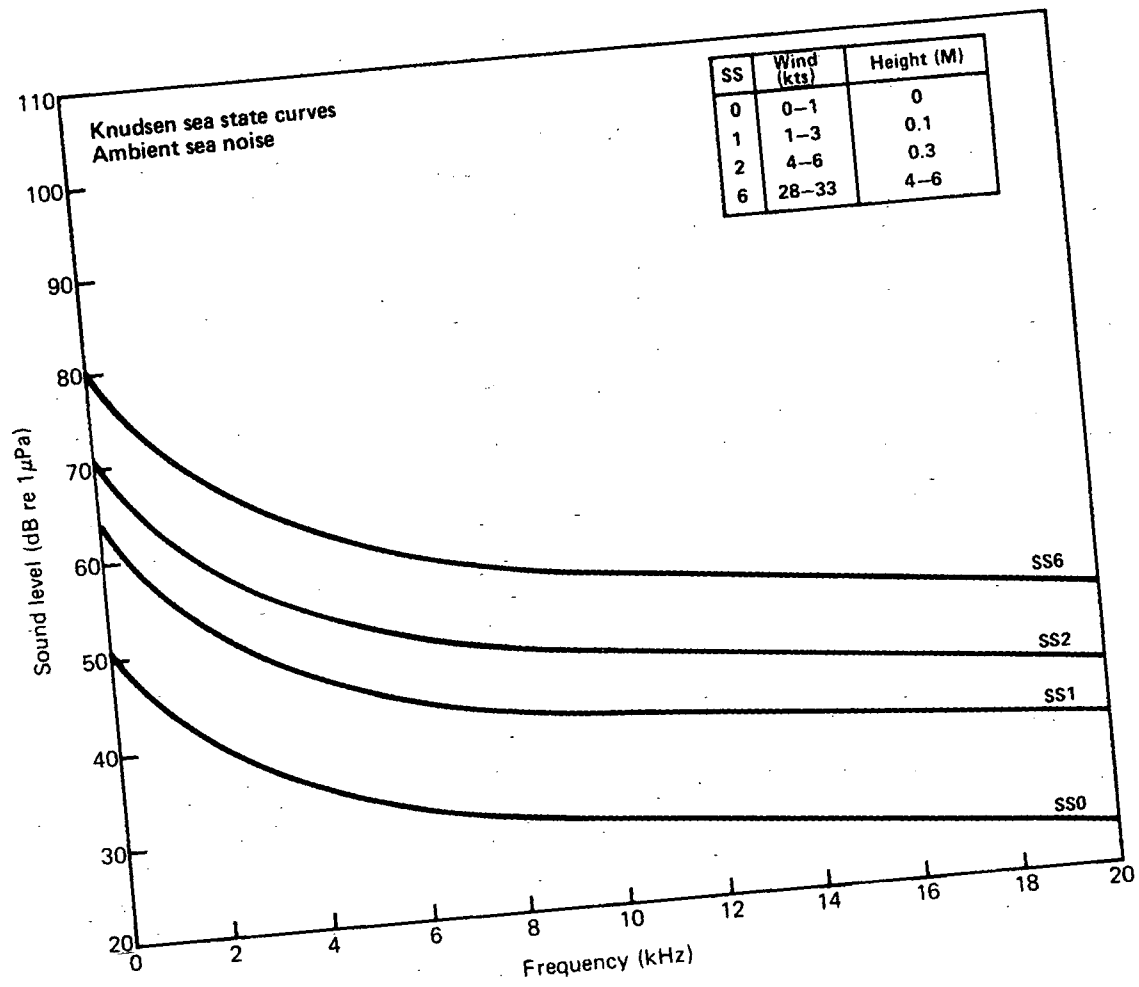


Table VI. Biological Organisms Potentially Responsible for the High-Levels of Ambient Noise in Laguna San Ignacio, Mexico
(scientific and common name listed).

FISH LIST FOR LAGUNA SAN IGNACIO, BAJA CALIFORNIA SUR, MEXICO

<u>Manta hamiltoni</u>	-	Pacific manta
<u>Mobula lucasana</u>	-	Smoothtail mobula
<u>Myliobatis californica</u>	-	Bat ray
<u>Urolophus halleri</u>	-	Round stingray
<u>Atherinopsis californiensis</u>	-	Jacksmelt
<u>Atherinops affinis</u>	-	Topsmelt
<u>Hippocampus ingens</u>	-	Pacific seahorse
<u>Scorpaena guttata</u>	-	Sculpin
<u>Stereolepis gigas</u>	-	Giant sea bass
<u>Mycteroperca xenarcha</u>	-	Broomtail grouper
<u>Mycteroperca jordani</u>	-	Gulf grouper
<u>Epinephelus analogus</u>	-	Spotted cabrilla
<u>Paralabrax maculatofasciatus</u>	-	Spotted sand bass
<u>Paralabrax sp.</u>	-	Grass bass
<u>Paralabrax nebulifer</u>	-	Barred sand bass
<u>Cynoscion xanthulus</u>	-	Orangemouth corvina
<u>Cynoscion parvipinnis</u>	-	Shortfin corvina
<u>Girella nigricans</u>	-	Opaleye
<u>Hypsypops rubicundus</u>	-	Garibaldi
<u>Mugil cephalus</u>	-	Striped mullet
<u>Paralichthys californicus</u>	-	California halibut
<u>Alopias vulpinus</u>	-	Common thresher
<u>Carcharodon carcharias</u>	-	White shark
<u>Sphyrna lewini</u>	-	Scalloped hammerhead
<u>Isurus oxyrinchus</u>	-	Bonita shark
<u>Triakis semifasciata</u>	-	Leopard shark
<u>Carcharhinus leucas</u>	-	Bull shark
<u>Rhinobatos productus</u>	-	Shovelnose guitarfish
<u>Cheilotrema saturnum</u>	-	Black croaker
<u>Halichoeres semicinctus</u>	-	Rock wrasse
<u>Sphoeroides annulatus</u>	-	Bullseye puffer
<u>Oxyjulis californica</u>	-	Senorita
<u>Pimelometopon pulchrum</u>	-	California sheephead
<u>Heterodontus francisci</u>	-	Horn shark
<u>Balistes polylepsis</u>	-	Finescale triggerfish
<u>Anisotremus davidsonii</u>	-	Sargo
<u>Calamus brachysomus</u>	-	Pacific porgy
<u>Epinephelus itajara</u>	-	Jewfish
<u>Rypticus sp.</u>	-	Soapfish
Rajidae Family	-	Skates
Pomadasyidae Family	-	Wavy line grunt
Chaetodontidae Family	-	Cortez angel

...continued

Table VI. Continued --

MARINE INVERTEBRATES OF LAGUNA SAN IGNACIO, BAJA CALIFORNIA SUR, MEXICO

<u>Haliotis fulgens</u>	-	Green abalone
<u>Haliotis corrugata</u>	-	Pink abalone
<u>Diodora digueti</u>	-	Keyhole limpet
<u>Collisella strigatella</u>	-	Limpet
<u>Calliostoma gemmulatum</u>	-	Gem top
<u>Calliostoma gardanum</u>		
<u>Calliostoma keenae</u>		
<u>Calliostoma rema</u>		
<u>Tegula aureotincta</u>	-	Gilded tegula
<u>Tegula fenebralis</u>	-	Black turban
<u>Tegula gallina</u>	-	Speckled tegula
<u>Turbo fluctuosus</u>	-	Speckled top
<u>Turbo funiculosus</u>		
<u>Astraea undosa</u>	-	Wavy top
<u>Homalopoma luridum</u>		
<u>Nerita scabricosta</u>		
<u>Theodoxus luteofaciatus</u>		
<u>Littoria fasciata</u>	-	Mangrove periwinkle
<u>Vermicularia pellucida eburnea</u>	-	Turret
<u>Cerithium stercusmuscarum</u>		
<u>Cerithidae californica</u>	-	California horn
<u>Cerithidae albonodosa</u>		
<u>Cerithidae mazatlanica</u>		
<u>Cerithidae montagnei</u>	-	Horn shell
<u>Epitonium tinctum</u>	-	Wentletrap
<u>Crepidula arenata</u>	-	Slipper
<u>Crepidula onyx</u>	-	Onyx slipper
<u>Crepidula excavata</u>	-	Excavated slipper
<u>Hipponix tumens</u>	-	Hoof shell
<u>Natica chemnitzii</u>	-	Moon shell
<u>Polinices uber</u>	-	White moon shell
<u>Polinices recluzianus</u>		
<u>Polinices altus</u>		
<u>Cassis centriquadrata</u>		
<u>Ficus ventricosa</u>	-	Fig shell
<u>Malea ringens</u>	-	Tun shell
<u>Muricanthus nigritus</u>	-	Black murex
<u>Eupleura muriciformis</u>		
<u>Ceratostoma monoceros</u>		
<u>Pteropupura festiva</u>	-	Festive murex
<u>Pteropupura erinaceoides</u>		
<u>Ocenebra foveolata</u>		
<u>Acanthina lugubris</u>	-	Unicorn
<u>Forreria belcheri</u>	-	Belcher's murex

Table VI. Continued --

MARINE INVERTEBRATES, CONTINUED

<u>Thais biserialis</u>	-	Dogwinkle
<u>Thais speciosa</u>		
<u>Macron aethiops</u>		
<u>Macron orcutti</u>	-	Smooth macron
<u>Anachis adelinae</u>	-	Adaline's pyrene
<u>Anachis coronata</u>	-	Crown pyrene
<u>Melongena patula</u>	-	Fossil?
<u>Nassarius tegula</u>	-	Mud Nassa
<u>Fusinus irregularis</u>	-	Spindle shell
<u>Oliva incrassata</u>	-	Shouldered olive
<u>Olivella beatica</u>	-	Olivella
<u>Cancellaria ventricosa</u>		
<u>Pseudomelatomia pincillata</u>	-	Turrid
<u>Terebra pedroana</u>	-	Pedro auger
<u>Terebra tiarella</u>	-	Auger
<u>Ophiodermella ophioderma</u>	-	Turrid
<u>Bulla gouldiana</u>	-	Gould's bubble
<u>Haminoea virescens</u>	-	Green bubble
<u>Melampus mousleye</u>	-	Salt marsh snail
<u>Arca pacifica</u>	-	Turkey wing
<u>Barbatia rostrata</u>	-	Arc
<u>Barbatia alternata</u>	-	Arc
<u>Barbatia reeveana</u>	-	Arc
<u>Andara tuberculosa</u>	-	Arc with nodes
<u>Andara grandis</u>	-	Massive arc
<u>Andara multicostata</u>	-	34 ribbed arc
<u>Arcopsis solida</u>	-	Small arc
<u>Lithophaga attenuata rogersi</u>	-	Boring mussel
<u>Modiolus capax</u>	-	Fat horse mussel
<u>Modiolus pseudotulipusk</u>	-	Mussel
<u>Pinna rugosa</u>	-	Pen, center groove
<u>Atrina tuberculosa</u>	-	Pen shell
<u>Isognomon recognitus</u>	-	Western tree oyster
<u>Ostrea columbiensis</u>	-	Columbian oyster
<u>Ostrea iridescens</u>	-	Brown metallic
<u>Pecten vogdesi</u>	-	Scallop
<u>Argopecten aequisulcatus</u>	-	Calico scallop
<u>Lyropecten subnodosus</u>	-	Lion's paw scallop
<u>Leptoplectin monoteris</u>	-	Kelp scallop
<u>Amonia peruviana</u>	-	Pearly jingle
<u>Cardita affinis</u>	-	Cardita
<u>Diplodonta subquadrata</u>		
<u>Felaniella sericata</u>		
<u>Chama pellucida</u>	-	Chama

Table VI. Continued --

MARINE INVERTEBRATES, CONTINUED

<u>Trachycardium panamense</u>	-	Cockle
<u>Papyridea aspera</u>	-	Thin cockle
<u>Laevicardium elatum</u>	-	Smooth cockle
<u>Laevicardium substriatum</u>	-	Egg cockle
<u>Trigoniocardia biangula</u>		
<u>Trigoniocardia granifera</u>		
<u>Ventricolaria fordii</u>		
<u>Tivela stultorum</u>	-	Pismo clam
<u>Amiantis callosa</u>	-	White amiantis
<u>Dosina dunkeri</u>	-	Dosina
<u>Dosina ponderosa</u>	-	Heavy dosina
<u>Megapitaria squalida</u>	-	Grey megapitaria
<u>Chione californiensis</u>	-	California chione
<u>Chione undatella</u>	-	Wavy chione
<u>Chione fructifraga</u>	-	Chione
<u>Chione gnidia</u>	-	Friiled chione
<u>Protothaca staminea</u>	-	Common littleneck
<u>Protothaca grata</u>	-	Littleneck
<u>Perticola californiensis</u>	-	Nesting clam
<u>Mactra californica</u>	-	California mactra
<u>Spisula hemphilli</u>	-	Dish clam
<u>Raeta undulata</u>	-	Thin, ridged
<u>Tellina bodegensis</u>	-	Bodega tellin
<u>Tellina simulans</u>	-	Red tellin
<u>Tellina ochracea</u>	-	Sulphur tellin
<u>Florimetus obesa</u>	-	Yellow interior
<u>Florimetus cognata</u>		
<u>Macoma identata</u>	-	Indented macoma
<u>Macoma secta</u>	-	Bent nose macoma
<u>Tellidora burneti</u>	-	Dorsal edge friiled
<u>Donax californicus</u>	-	Wedge clam
<u>Donax gouldii</u>	-	Bean clam
<u>Donax punctatostriatus</u>	-	Donax
<u>Heterodonax pacificus</u>	-	Heterodonax
<u>Sanguinolaria tellinoides</u>		
<u>Sanguinolaria nutallii</u>	-	Purple clam
<u>Semele desica</u>	-	Clipped semele
<u>Semele flavescens</u>	-	Yellow semele
<u>Tagelus californianus</u>	-	Jackknife
<u>Tagelus subteres</u>	-	Small jackknife
<u>Solen rosaceus</u>	-	Rosy razor
<u>Hiatella arctica</u>	-	Nesting clam ?
<u>Periploma planiusculum</u>	-	Spoon clam
<u>Thracia curta</u>	-	Short thracia
<u>Cryptomya californica</u>		
<u>Zirfaea pilsbryi</u>	-	Piddock
<u>Dentalium sp.</u>	-	Toothed shell

...continued

Table VI. Continued --

MARINE INVERTEBRATES, CONTINUED

<u>Panulirus interruptus</u>	-	California spiny lobster
<u>Alpheus sp.</u>	-	Snapping shrimp
<u>Hippolyte sp.</u>	-	Shrimp

MARINE MAMMALS

<u>Tursiops truncatus</u>	-	Bottlenose dolphin
<u>Zalophus californianus</u>	-	California sea lion

three major classes: machinery, propeller, and hydrodynamic noise. Due to the variation in hull construction and engine types, each vessel and/or skiff had its own sound signature, thus only representative samples are shown.

Noise from large vessels was broadband, ranging from 125 Hz to 20 kHz, with most energy concentrated below 10 kHz. Tonal peaks were typically observed below 1 kHz. Vessel noise was characterized by a continuous spectrum containing superimposed line components. Received levels of large vessels underway averaged 89 to 105 dB re 1 μ Pa (Fig. 18). Received levels from vessels at anchor were 10 to 20 dB below those from the same vessel underway (pump and generator noise prevalent only when vessels at anchor).

Fourteen skiffs (representing inflatables, wooden- and aluminum-hull craft) powered by five different models of outboard engines were recorded. Spectrum profiles were obtained for each model of engine. Overall noise levels were similar among models, but variations were prevalent in the sound signature of each engine. Noise levels and emphasized frequency bands also varied with the rpm of the engine. Source levels for a 20-hp Mercury outboard engine operating at idle, quarter throttle, half throttle, and three-quarter throttle are shown in Figs. 19a-d. The overall noise contributed by the outboard engine at idle is generally lower than that of the engine in gear. Estimated levels at idle occurred at frequencies below 1 kHz, with a noise level range of 92-117 dB re 1 μ Pa at 1 yd. Ranges of source levels (re 1 μ Pa) for speeds other than idle were quarter speed, 104-124 dB; half speed, 108-126 dB; and three-quarter speed, 108-134 dB. The levels reported for the three-quarter speed represent a 3-sec average sound pressure output. All other plots are 4-sec average sound pressure levels.

Figure 18. Spectra of Typical Large Vessel (25-35 m in length) Noise Encountered in Laguna San Ignacio, Mexico.

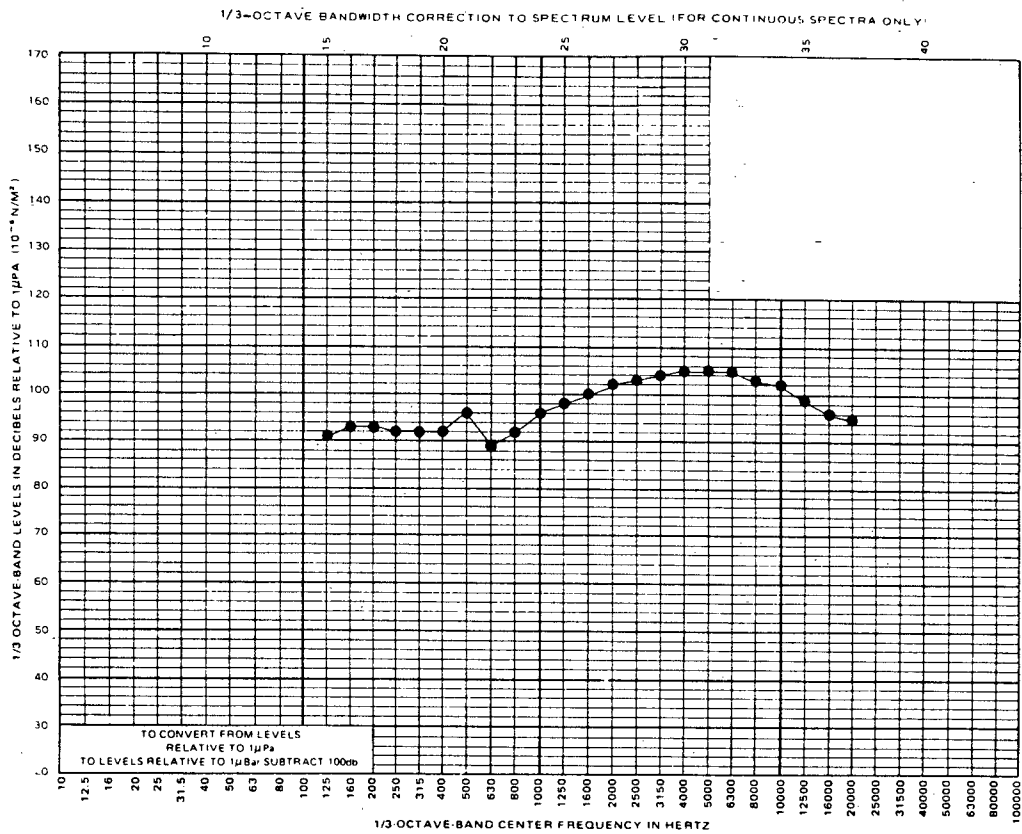
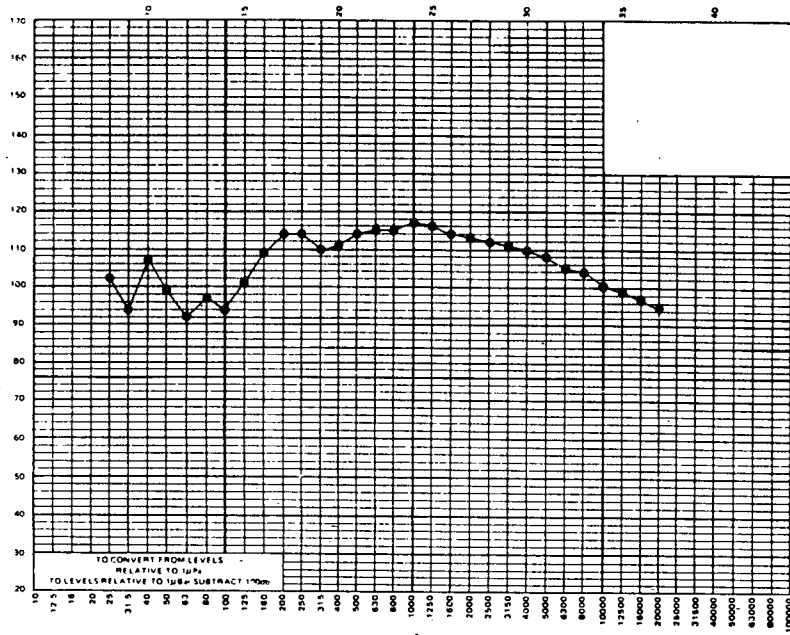


Figure 19. Spectra of a 20-hp Mercury Outboard Engine
(a - b) Operating at a) idle, and b) quarter throttle.

1/3-OCTAVE BANDWIDTH CORRECTION TO SPECTRUM LEVEL (FOR CONTINUOUS SPECTRA ONLY)

1/3-OCTAVE-BAND LEVELS IN DECIBELS RELATIVE
TO $1 \mu\text{PA}$ (10^{-6} N/M^2) AT 1 YD

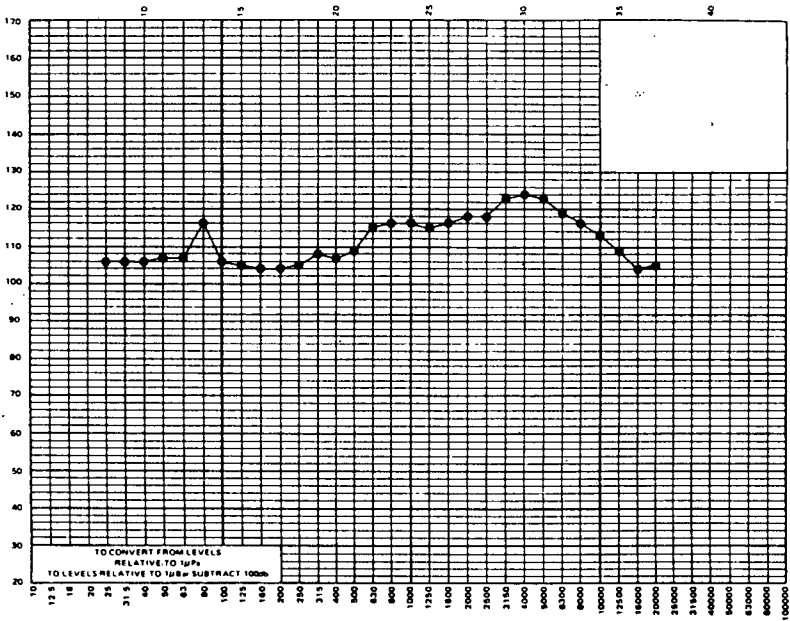


1/3-OCTAVE-BAND CENTER FREQUENCY IN HERTZ

A

1/3-OCTAVE BANDWIDTH CORRECTION TO SPECTRUM LEVEL (FOR CONTINUOUS SPECTRA ONLY)

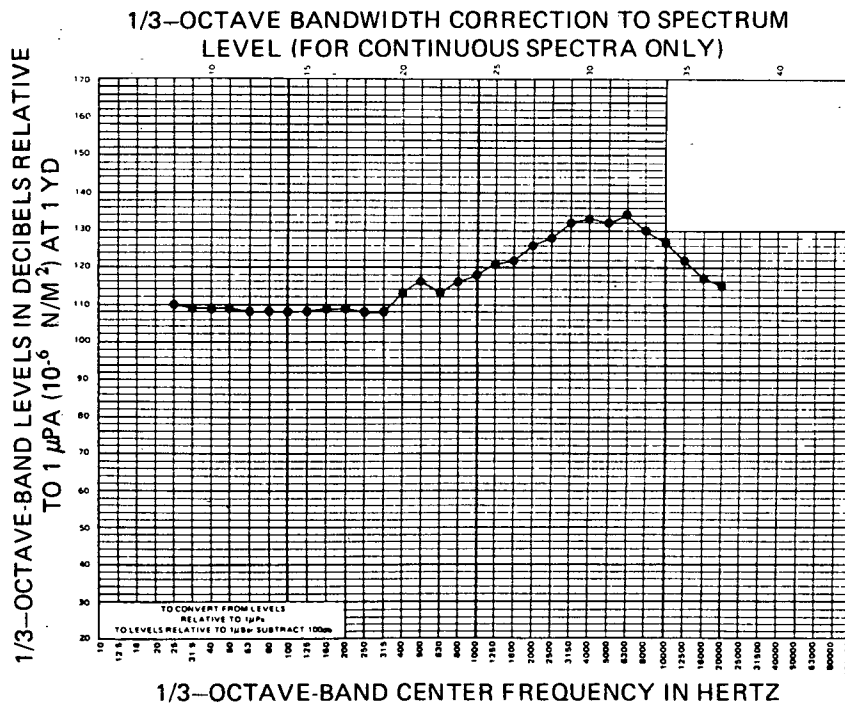
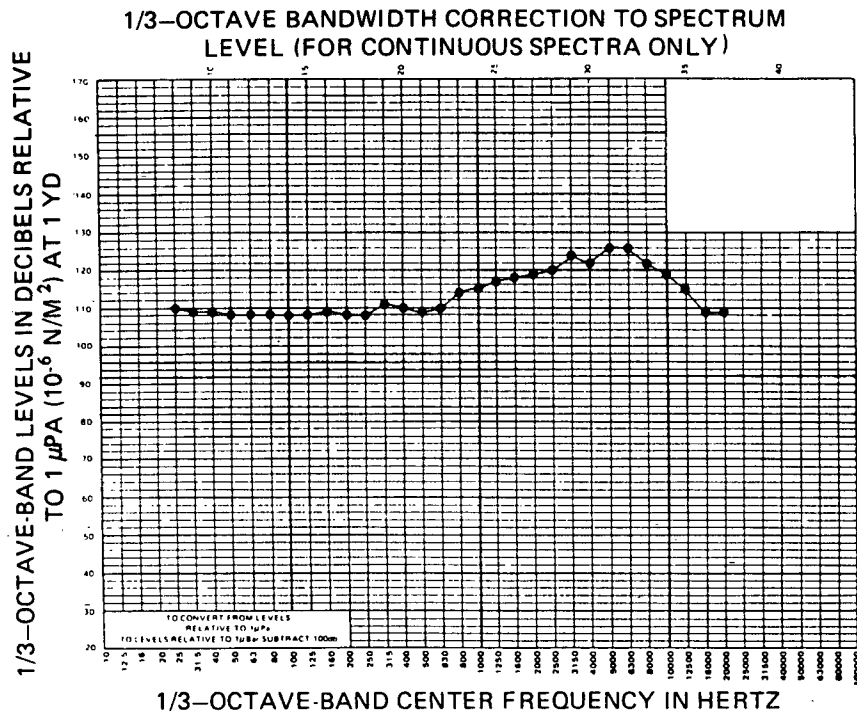
1/3-OCTAVE-BAND LEVELS IN DECIBELS RELATIVE
TO $1 \mu\text{PA}$ (10^{-6} N/M^2) AT 1 YD



1/3-OCTAVE-BAND CENTER FREQUENCY IN HERTZ

B

Figure 19. Spectra of a 20-hp Mercury Outboard Engine
(c - d) Operating at c) half throttle, and d) three
quarter throttle.



St. Lawrence Island (Alaska)

Recordings of ambient noise were made at twelve locations in July off St. Lawrence Island, five on the west side and seven off Southeast Cape (Fig. 20). The selection of these locations was based on the previous occupation in these waters by gray whales.

The levels of broadband ambient noise (dB re 1 μ Pa) at Stations 1 and 2 averaged 62 dB with most energy concentrated below 2 kHz (Fig. 21). An inspection of each station profile suggested little change above 10 kHz; therefore, the remaining profiles were analyzed between 0-10 kHz. The support vessel operated at a distance of 1.5 miles (speed = 3 knots). As a result, Station 3 (Fig. 22) was dominated by ship noise. Received levels ranged from 95-115 dB re 1 μ Pa at 20 Hz to 10 kHz. Stations 4 and 5 were located 0.5 miles and 1.5 miles off Gambell, respectively. Surf noise (one-meter surf break) dominated these two ambient stations (Fig. 23). A gradual increase in energy was noted with increasing frequencies. Bottom sediment consisted of gravel on the western side of the Island and beaches were steeply inclined. The ambient levels of Stations 4 and 5 were considerably higher than others due to surf noise (with the exception of Station 3, which was influenced by ship noise) and spectra ranged from 87-95 dB re 1 μ Pa. Recordings were made in water depths of 6.2-25.0 m.

Stations 6 through 12 were located off Southeast Cape. Although some variations were observed among stations, these ambient sound levels were 52-66 dB re 1 μ Pa (Fig. 24). Frequency profiles were essentially flat. Recordings were made in approximately 12.5 m (40 ft) and a coarse sand sediment dominated the bottom substrate.

The density and species composition of sound-producing marine life

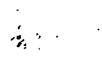


Figure 20. Locations of Ambient Noise Stations off St. Lawrence Island, Alaska.

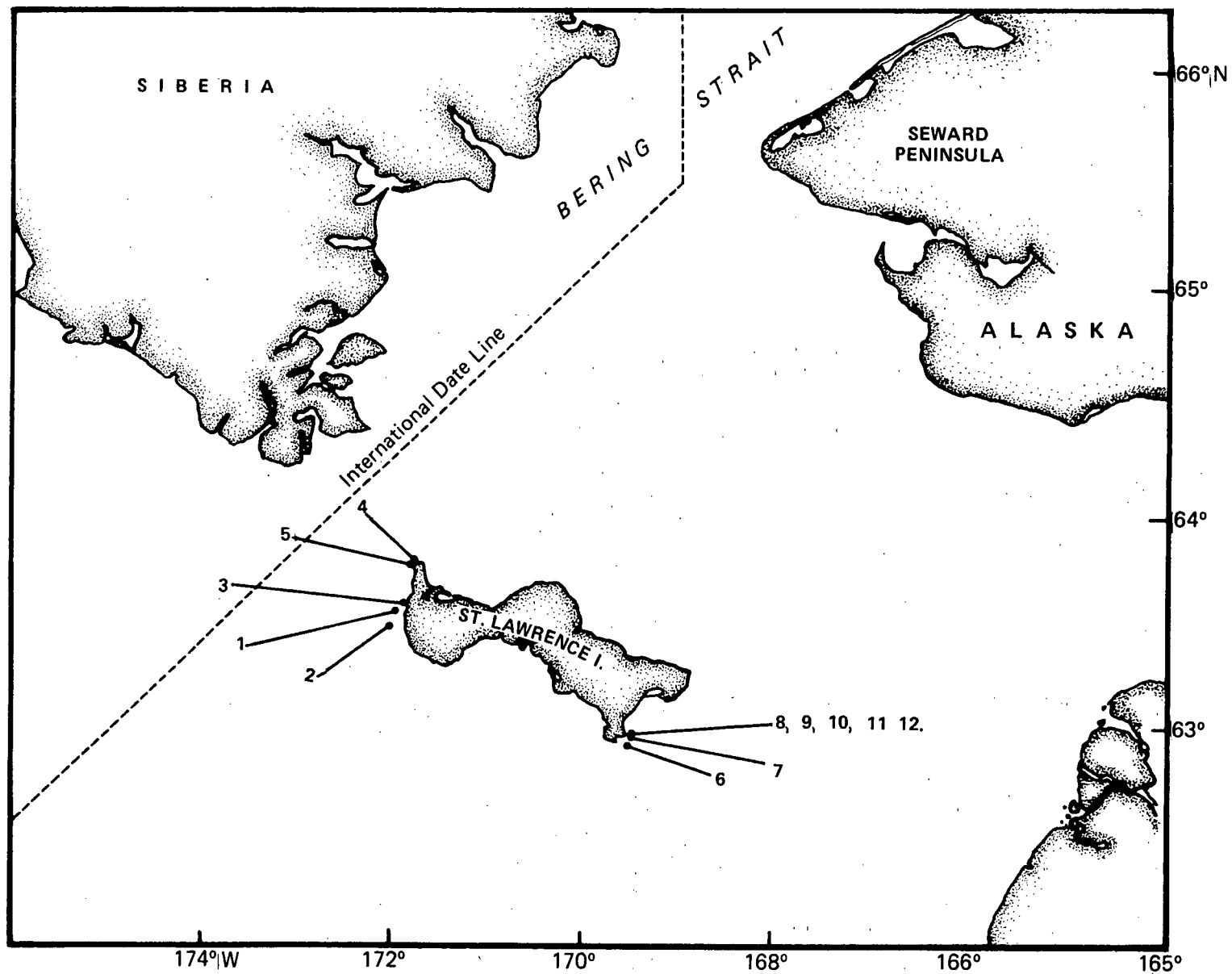


Figure 21. Average Levels (dB re 1 μ Pa) of Ambient Noise Stations 1 and 2, St. Lawrence Island, Alaska.

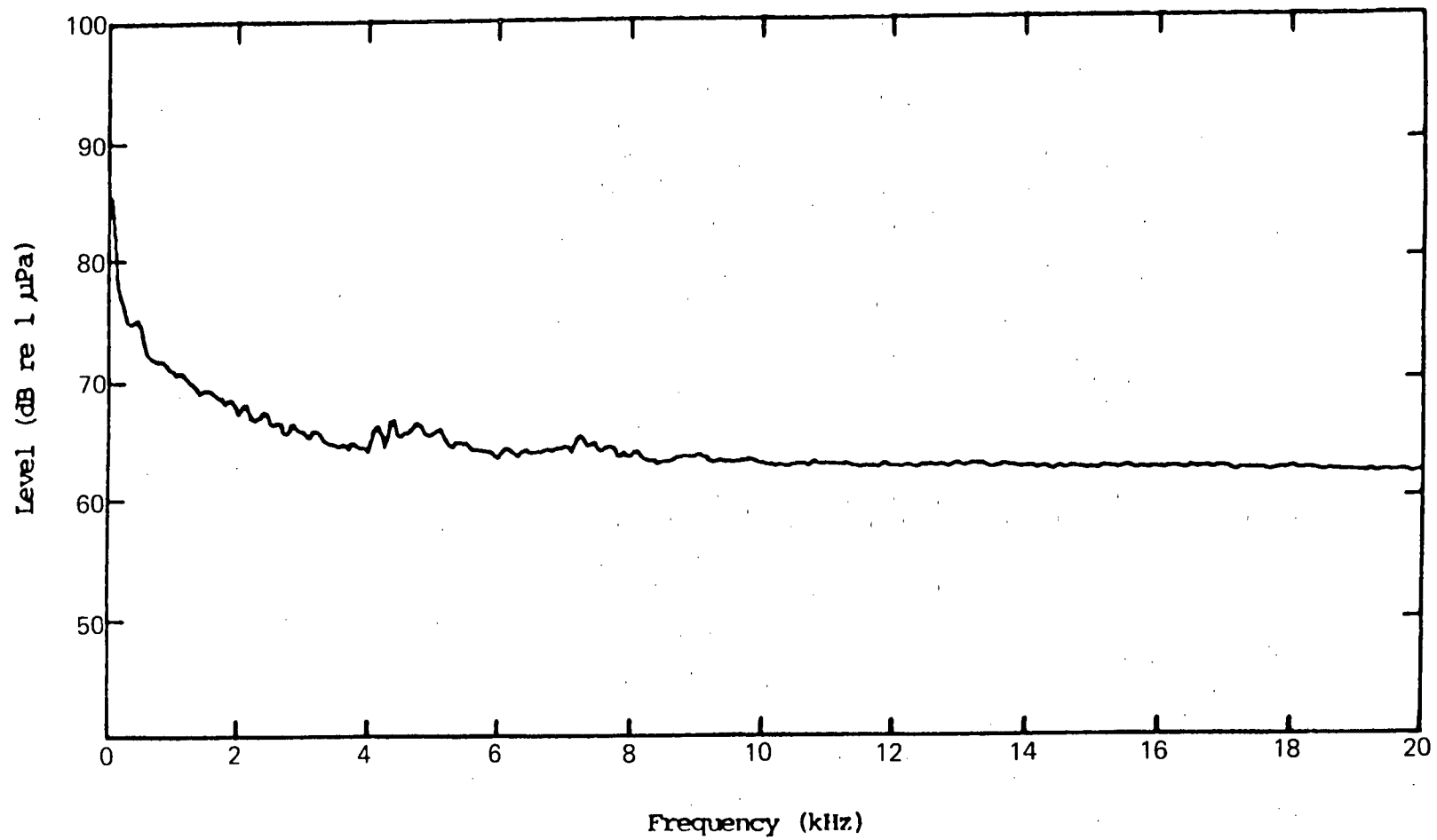


Figure 22. Average Level (dB re 1 μ Pa) of Ambient Noise at Station 3, St. Lawrence Island, Alaska (influenced by ship noise).

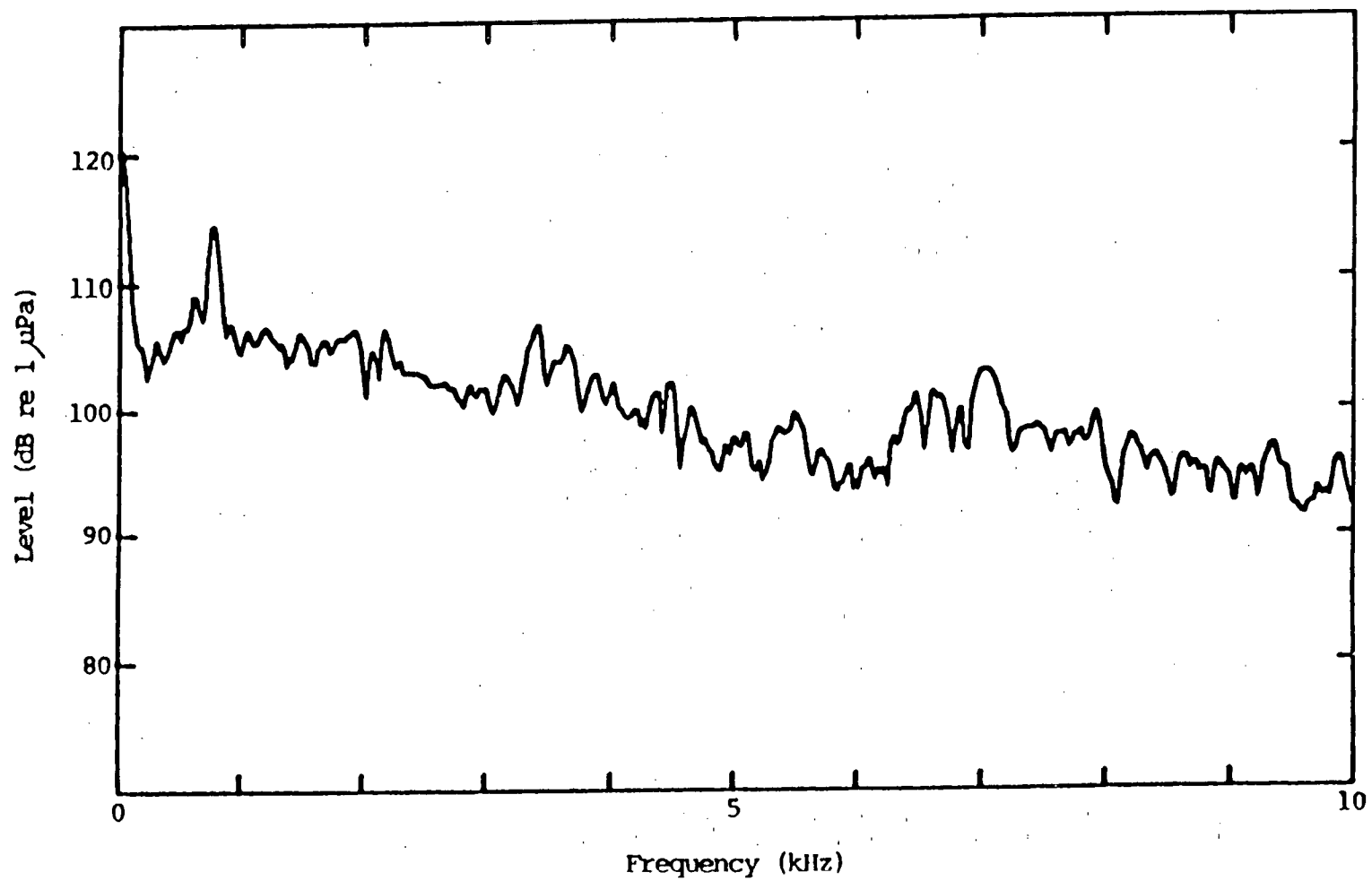


Figure 23. Average Levels (dB re 1 μ Pa) of Ambient Noise at Stations 4 and 5, St. Lawrence Island, Alaska (influenced by surf noise).

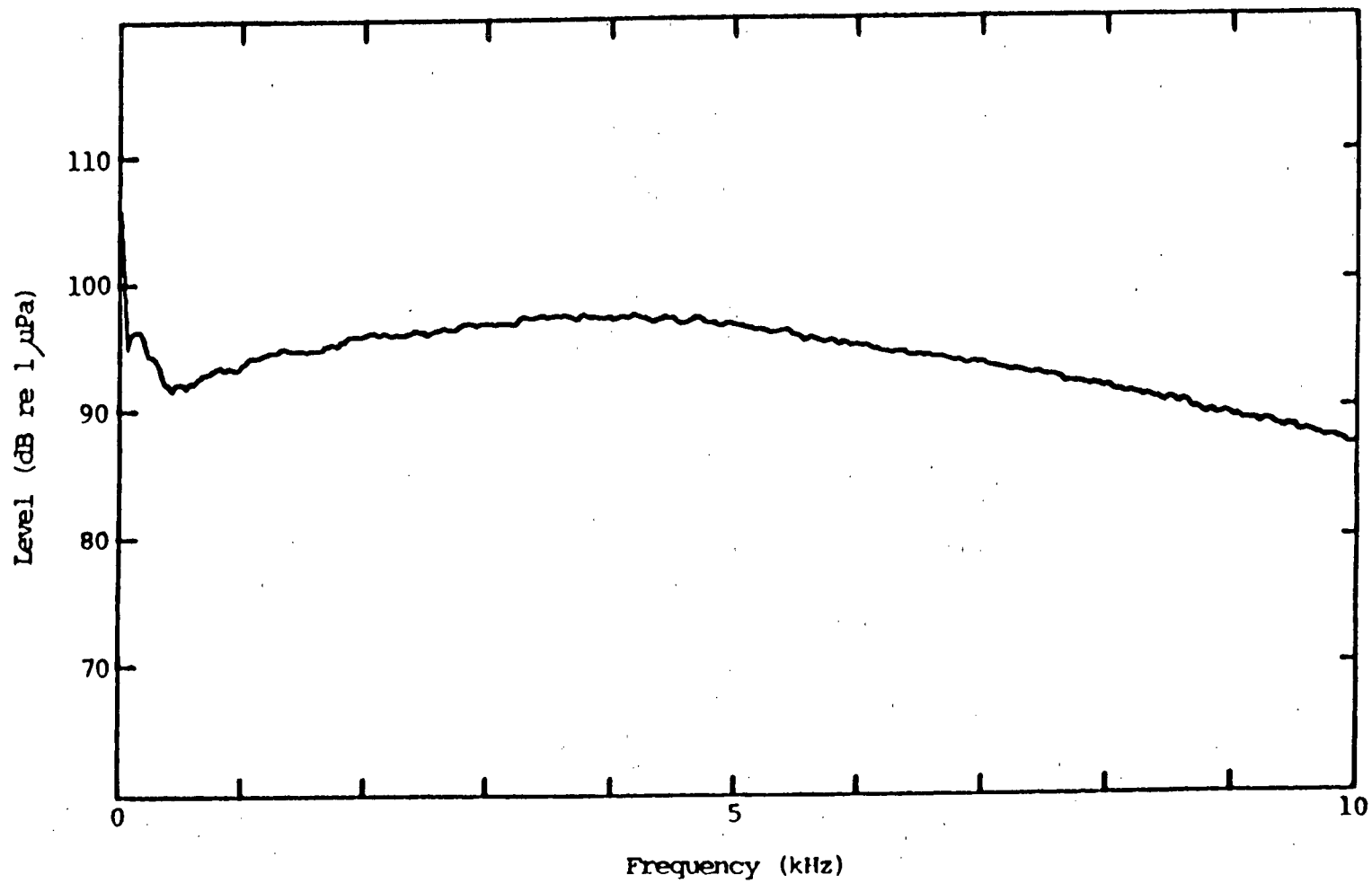
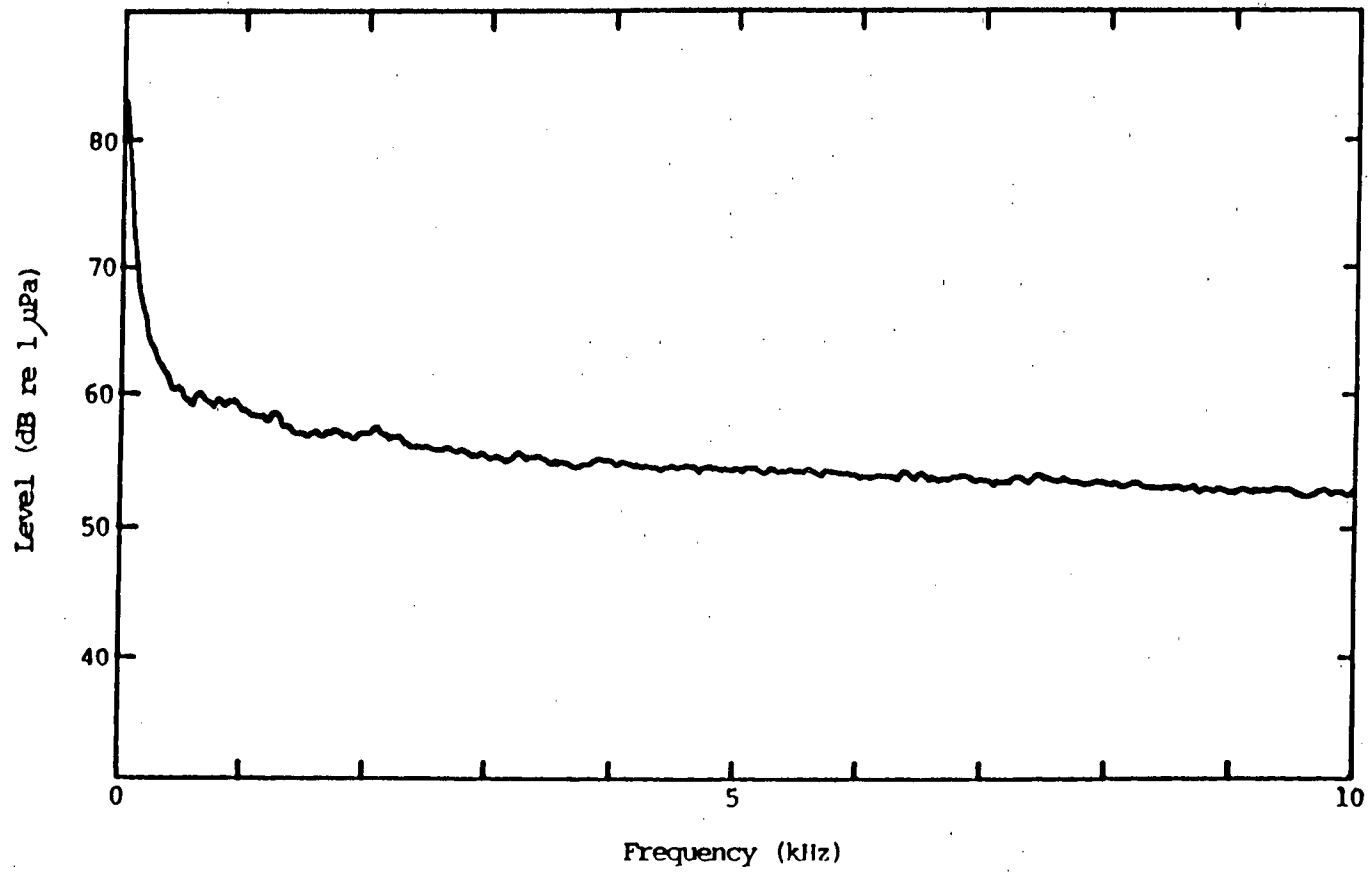


Figure 24. Average Levels (dB re 1 μ Pa) of Ambient Noise at Stations 6-12 (Southeast Cape), St. Lawrence Island, Alaska.



were significantly reduced in the Bering Sea as compared to Baja. Species prevalent in the area were identified by scientists from LGL Limited and are reported in Thomson et al., 1986.

In addition to the NOAA vessel, other non-biological sources were encountered and recorded. These included noise produced by five small launches powered by outboard engines. Each outboard engine exhibited its own sound signature and thus only one representative sample will be shown. The received levels ranged from 90-105 dB re 1 μ Pa and were broadband in frequency. Figure 25 depicts a sound spectrum of a 7-m Boston Whaler with two 90-hp Mercury outboard engines, operating at a distance of 1 mile at 1/4 throttle.

Washington State Waters

Ambient noise in the test area off La Push, Washington, was highly influenced by surf noise (Fig. 26). A 2.0-m surf break was observed during the recording sessions. The bottom contour sloped gently toward the beach with an associated sand substrate. Levels ranged from 78 to 89 dB re 1 μ Pa, with a concentration of energy observed at 81 dB. Limited recording time was spent collecting ambient noise in this area (less than 5 hours). Varying weather conditions will, of course, produce different levels and patterns of noise. No attempt was made to identify the biological organisms responsible for ambient noise and/or collect information on depth, temperature and salinity in Washington State waters.

Figure 25. Noise Spectra of a 7-m Boston Whaler Operating off Southeast Cape, St. Lawrence Island, Alaska.

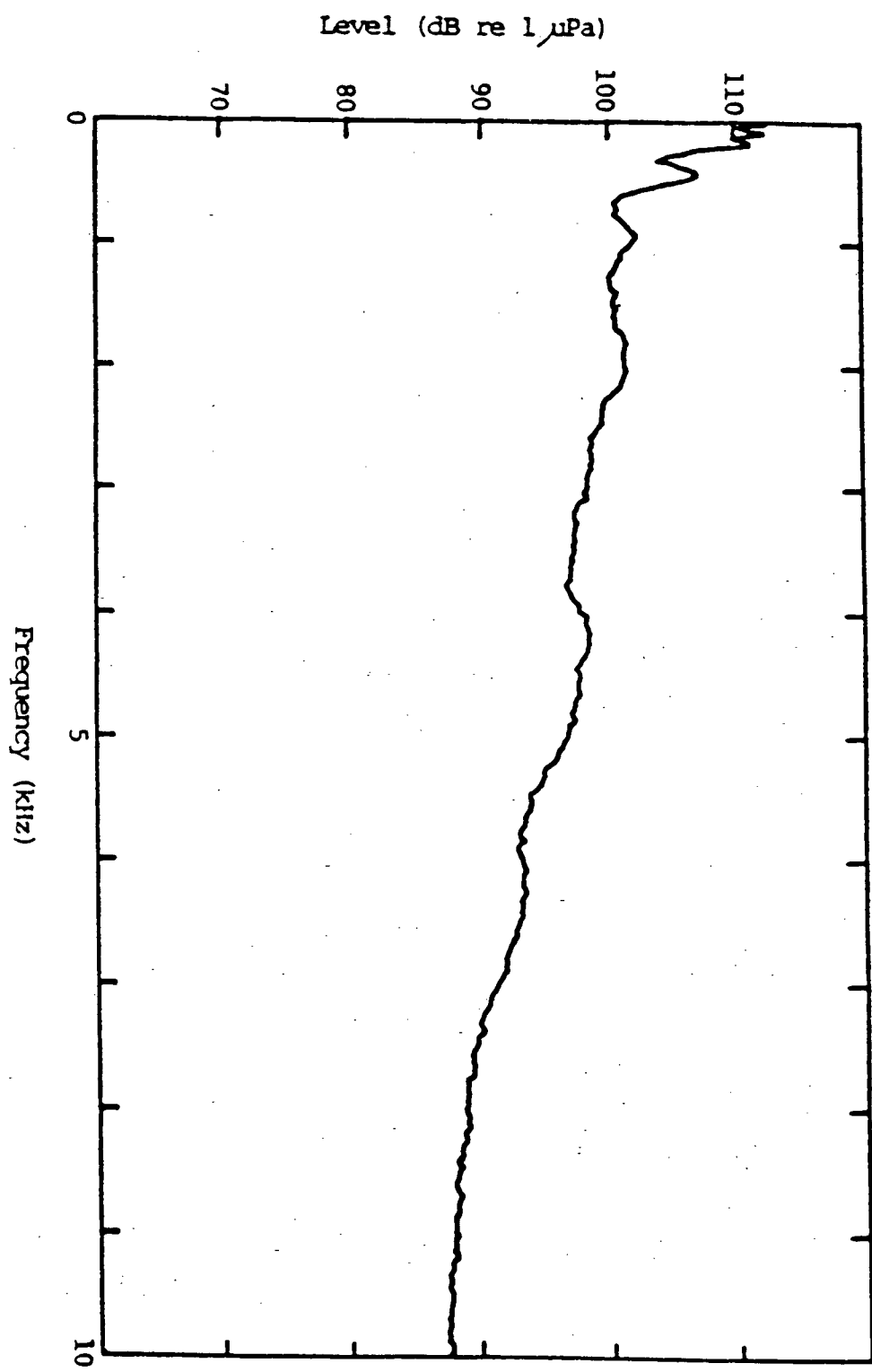
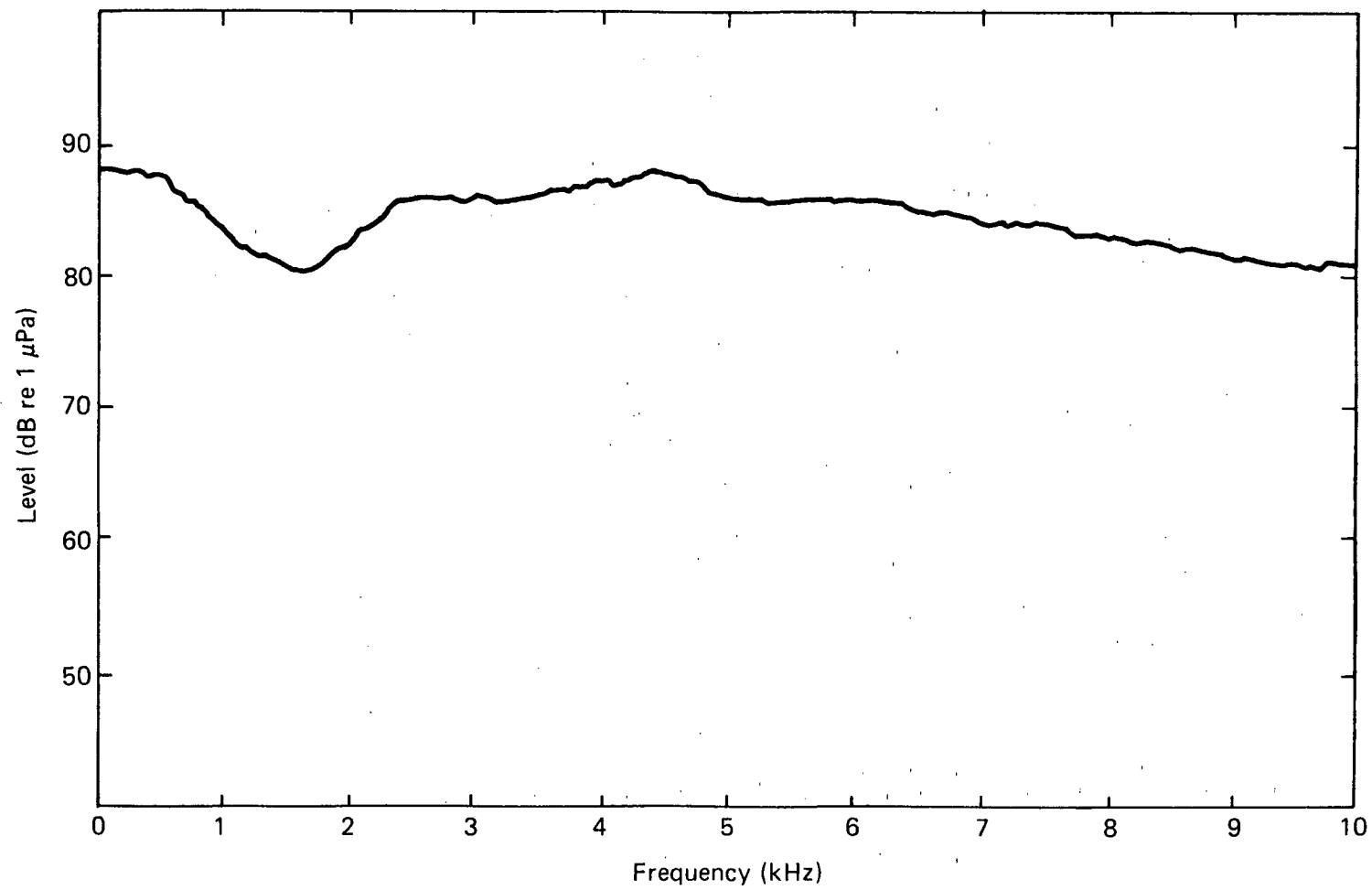


Figure 26. Spectra of Ambient Noise off La Push, Washington (coastal waters).



Comparisons of Ambient Noise Throughout Range

Noise spectra among the three major areas of the gray whales' range (breeding, feeding and migratory grounds) showed marked differences in emphasized frequencies and levels (Table VII). These various profiles resulted from differences in the abundance and composition of sound-producing marine life, oceanic conditions, and the amount of man's activities within the area. Recordings made in Laguna San Ignacio resulted in the highest levels of background noise (94-110 dB re 1 μ Pa) documented during these studies. Frequencies between 2-5 kHz were emphasized in these spectra due to the biological contribution of noise. Migratory values of biological ambient noise resulted in intermediate values with respect to sound level (87-99 dB re 1 μ Pa); however, frequencies emphasized (2-6.3 kHz) were similar to those obtained in Mexico (2-5 kHz). In the Bering Sea, the biological contribution to overall background noise was negligible.

During this investigation, ambient noise measurements were generally made when Beaufort 3 or less conditions prevailed. This method, of course, precluded the collections of precise on-site measurements with varying sea states. Predicted patterns were thus based on the extensive work by other authors. Of those articles reviewed, Knudsen et al. (1948) and Wenz (1962) provided what I believe to be the most comprehensive accounts with respect to ocean ambient noise profiles based on different physical events. In comparing the data collected during these investigations with this past literature, similar profiles were obtained for sea states 3 and below. However, due to the contribution from biological sources to the overall ambient noise in Mexico, the southern values reflect a somewhat higher

Table VII. Comparisons of Ambient Noise Profiles Throughout the Range of the Gray Whale.

SOUTHERN RANGE

	Received Levels (dB re 1 μ Pa)	Frequencies Emphasized	Source	Reference
Stations 1-32	94-110	2-5 kHz	Biological	This study
Man-Made	89-105	< 2.0 kHz	Large vessels	This study
Man-Made	92-134	< 2.0 kHz	Skiffs	This study

NORTHERN RANGE

Stations 6-12	52-66	< 1.0 kHz	Sea noise	This study
Man-Made	95-115	< 2.0 kHz	Ship noise	This study
Stations 1-2	$\bar{x}$ = 62	< 2.5 kHz	Sea noise	This study
Stations 4-5	87-95	< 2.5 kHz	Surf noise	This study
Man-Made	90-105	< 2.0 kHz	Boston Whaler	This study
Natural Ambient	$\bar{x}$ = 65	< 2.0 kHz	Sea noise	Moore et al. (1985)

MIGRATION

Washington State	78-89	< 2.5 kHz	Surf noise	This study
Central California	85	< 2.0 kHz	Distant shipping	Malme et al. (1984)
Central California	87-99	2.0-6.3 kHz	Biological	Malme et al. (1984)
Central California	90	6.3-16 kHz	Sea noise	Malme et al. (1984)

level than expected in the frequency range of 2-5 kHz. Conversely, the Bering Sea and California ambient noise data closely fit the model.

Introduced man-made sources typically were broadband, emphasized frequencies less than 2 kHz, had higher associated levels, and exhibited individual sound signatures. Similar overall profiles for man-made sources were documented independent of the area being investigated.

Propagation experimentation and factors potentially affecting a travelling wave (i.e., temperature, salinity and depth) were also investigated during these studies. Sound propagation in Laguna San Ignacio did not follow the cylindrical spreading law ($10 \log R$). Sound transmission was enhanced in the southerly direction (lower lagoon) and was reduced in the middle lagoon (northerly direction) due to the extensive sand bars causing shadow zones. As expected, major differences were noted in water temperatures and depths between the Alaska and Mexico. Salinity values, however, were similar between the two areas. Detailed results of these investigations are reported in Appendix A.

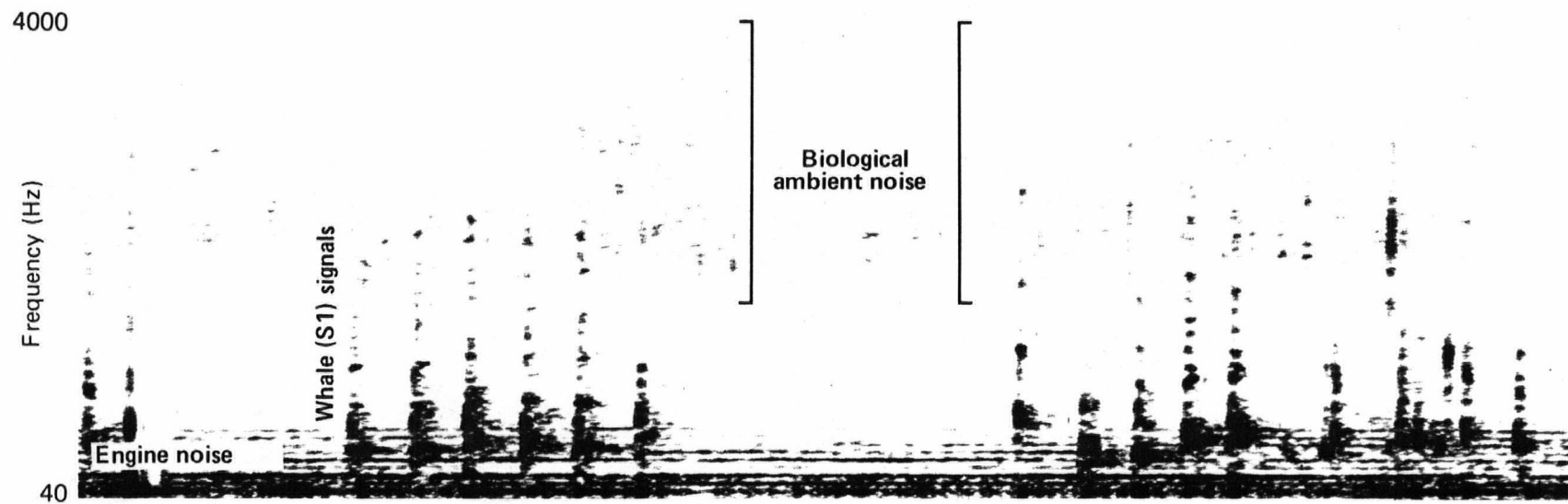
RELATIONSHIP BETWEEN GRAY WHALE SIGNALS AND AMBIENT NOISE

A composite spectrograph representing a gray whale S1 series, naturally occurring biological ambient noise and outboard engine noise, is shown in Fig. 27. Skiff noise predominates at frequencies below 500 Hz, with biological noise dominating the frequencies above 2 kHz. The major energy in the S1 signal is below 1 kHz. All gray whale sounds analyzed from this area emphasized the frequency bands below the main concentration of energy of the biological ambient noise. Similar findings resulted when comparing the emphasized frequencies of gray whale signals and the main concentration of biological ambient noise off California. No comparisons were made in the Bering Sea since the biological contribution to the overall ambient noise was negligible.

When emphasized frequencies of gray whale signals were compared to the sea noise models produced by Wenz (1962) and Knudsen et al. (1948), and from my own field collections, an interesting pattern emerged. Sea noise was broadband; however, frequencies between 200 and 2000 Hz did not typically contain the major energy of the profile. Wenz (1962) noise profiles are based on shallow water measurements, 7-10 kt wind and moderate shipping. Increasing wind conditions, with a corresponding increase in sea state, would increase the overall level of the profile; however, little change would occur in the frequencies emphasized.

A comparison of man-made noise and gray whale signals revealed a different pattern than those obtained during the comparisons between gray whale signals and naturally occurring sound sources. An inspection of frequencies of outboard engine noise and gray whale signals produced in Laguna San Ignacio indicated that similar acoustical channels were occupied

Figure 27. Composite Spectrograph of a Gray Whale Pulse Series (S1), Outboard Engine Noise and Biological Ambient Noise in Laguna San Ignacio, Mexico.



(Fig. 28). Based upon the profiles obtained from other man-made sources (e.g., oil, ship noise), and a review of profiles from other sources throughout the gray whale's range, overlapping frequencies are predicted between gray whale signals and these anthropogenic noise sources.

In addition to comparing the frequencies emphasized by different sources, ambient levels were compared to the received levels of gray whale sounds. On the southern range, gray whales typically produce high level signals. The levels of ambient noise in Laguna San Ignacio also reflect high levels. Off California, ambient levels were intermediate in value. In the Bering Sea, low level ambient conditions were documented. Similar results were obtained for signals produced by these whales for this area. Frequency and level comparisons are graphically represented in Fig. 29.

In addition to comparing the sounds of gray whales to ambient conditions in Laguna San Ignacio, I analyzed 50 signals produced by the bottlenose dolphin (Tursiops truncatus), the only other cetacean that occupies this lagoon area. This was done to determine the relationship of the dolphin signals to that of the high levels of natural occurring background noise (Fig. 30). In all cases, dolphin whistles occurred at frequencies above 7 kHz. The short duration whistles were frequency modulated, with the lowest frequency observed to rise when it encountered the ceiling of the biological ambient noise. Because dolphin signals were not treated in the same depth as those of the gray whale, these data should be interpreted with some caution.

Figure 28. Spectrograph of a Gray Whale Pulse Series (S1) and Outboard Engine Noise.

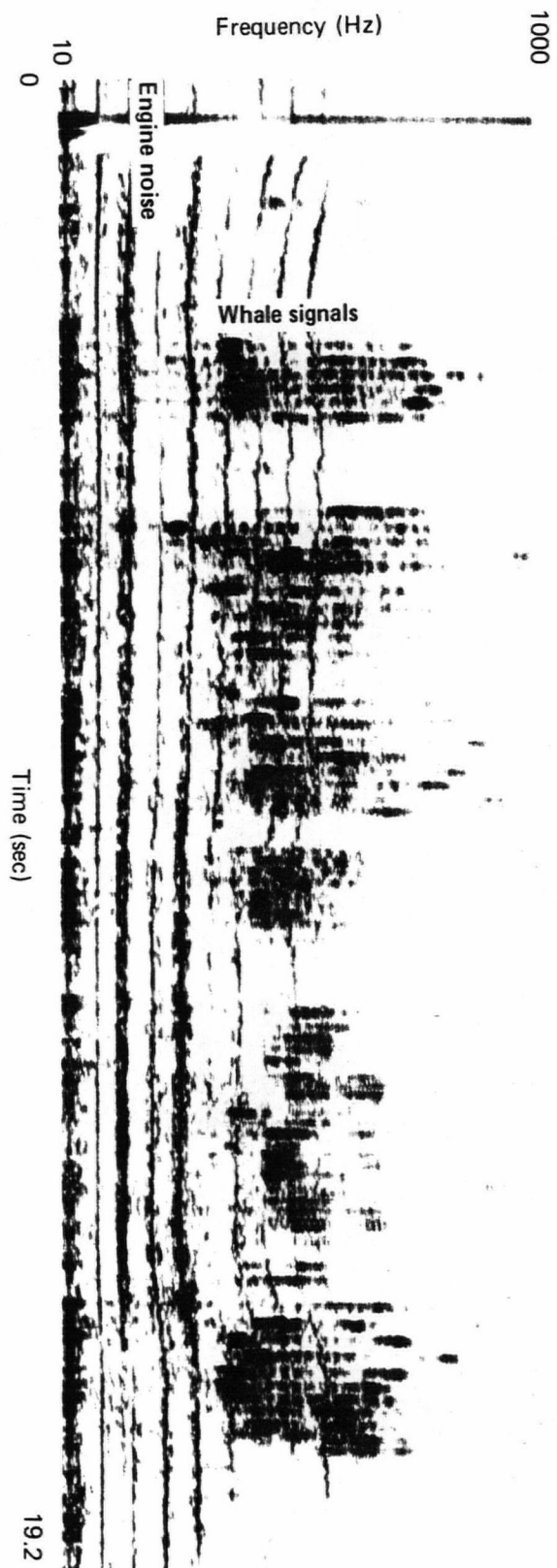


Figure 29. Relationships of Gray Whale Sound Frequencies and Levels to Ambient Noise.

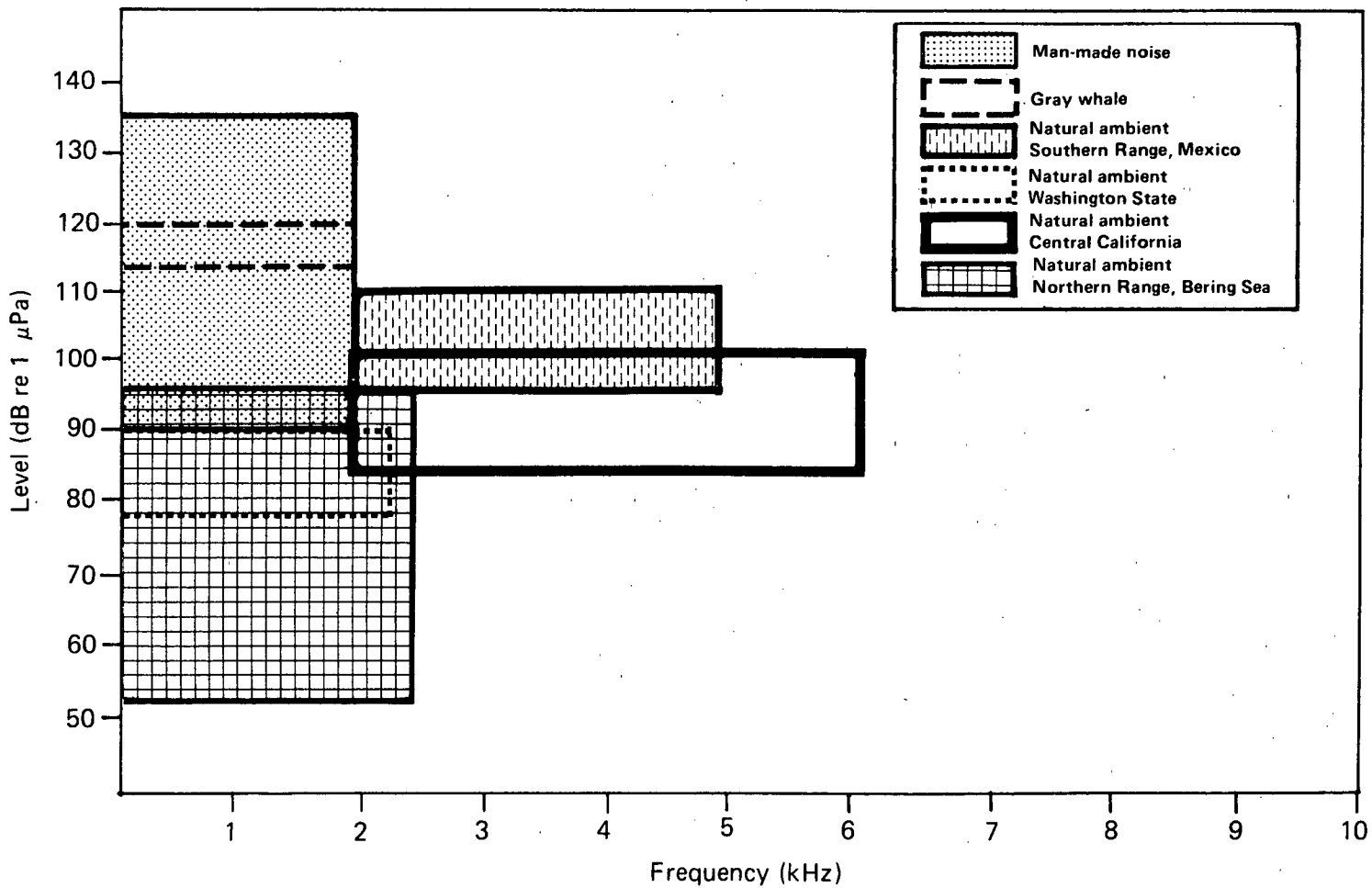
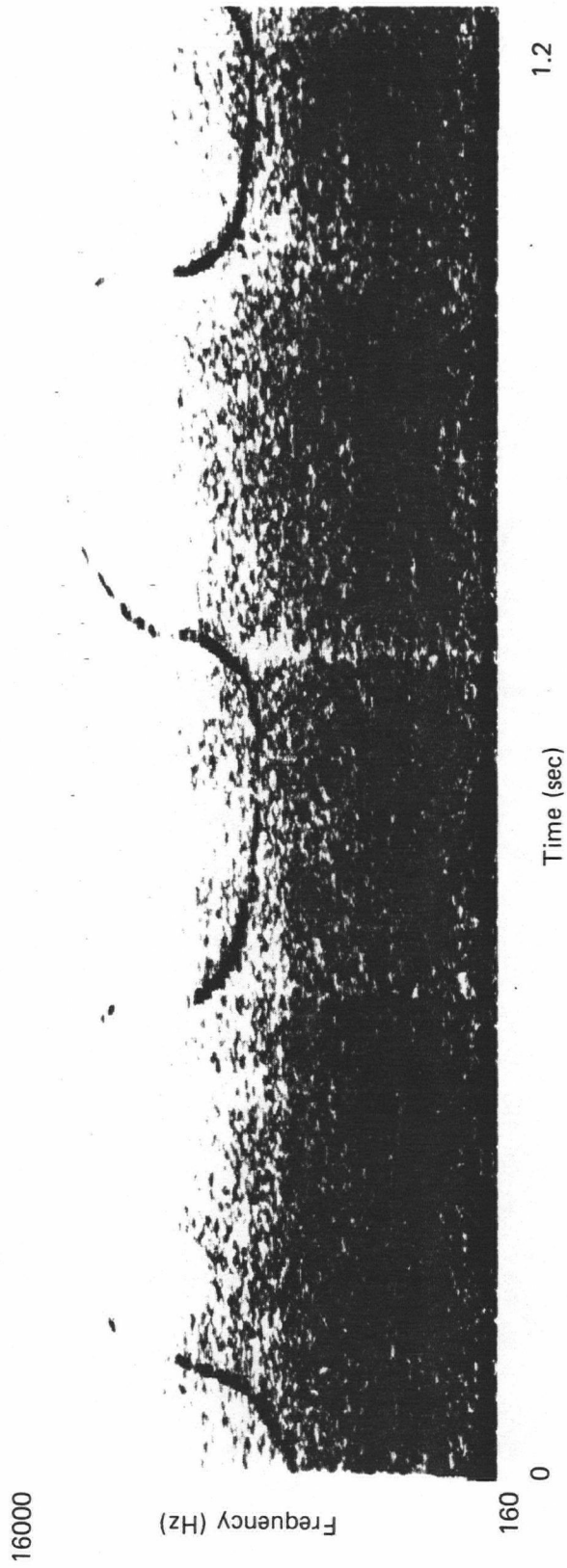


Figure 30. Spectrograph of a Bottlenose Dolphin Whistle and Biological Ambient Noise in Laguna San Ignacio, Mexico.



DISCUSSION

Gray whales were more soniferous on their southern range than expected from previously published accounts. Recent advances in technology and the amount of time spent in the field compared to previous investigators may account for this. Table III indicates that gray whales produce at least seven distinct sound types. The S7 call type was not recorded during the current investigations; however, there appears to be sufficient information (Fish et al., 1974) to warrant its categorization. Although variations did exist within sound categories, each category was sufficiently distinct to be classified independently. Variations in these call types may reflect individual differences or responses to different behavioral situations.

In addressing the overall acoustical activity of gray whales, hourly changes in sound periodicity and types of signals emitted by whales were inspected and compared. In Laguna San Ignacio, no obvious differences in periodicity or types of signals were detected over a 24-hr period. These results coincide with the observations of surface behavior of gray whales in this area presented by Swartz and Cummings (1978). These authors reported similar surface behavioral activities by gray whales over a 24-hr period. Although not significantly different, the slight decrease in the number of sounds produced per hour/animal in March did coincide with the departure of single, adult animals. These single whales represent the mating component of whales in Laguna San Ignacio and typically depart 30-45 days prior to the departure of the cow/calf pairs (Jones and Swartz, 1984).

With the exception of the S2 signal, all other sound types produced by the gray whale on the southern range have been documented on other areas of its range. Moore and Ljungblad (1984) recently published on gray whale sounds collected in the Bering Sea. Two hours of sounds of sufficient

level to permit analysis were reported on by these authors. Their results indicated three distinct sound types termed N1, N3, and N4, following the classification scheme designed for this study. The N1 signal dominated the vocal repertoire of feeding gray whales. A comparison of the results of these two northern studies (this study and Moore and Ljungblad, 1984) are similar and supportive. The only other available information on the acoustical behavior of feeding gray whales is noted in the Soviet literature (Bogoslovskaya, 1982). This author noted that single whales were usually silent; however, low-frequency sounds were occasionally exchanged between individuals. An adequate description of these sounds and the effort to obtain the recordings was not given in this report. Malme et al (1986) reported hearing no sounds attributable to gray whales in recent studies on feeding gray whales off St. Lawrence Island.

Since the initiation of this project, additional attempts have been made by various researchers to collect sounds from migrating gray whales along the coast of California. Recordings made during the southbound migration off central California (30-day effort in January 1983 and 30 days in January 1984) resulted in no sounds that could be attributed to migrating whales (Malme, pers. comm.)^{2/}. Three attempts have been made to collect sounds from northbound migrants, with the effort centered once again off the California coastline. Malme (pers. comm.)^{2/} reported hearing no gray whale sounds during a 30-day investigation off central California in March 1983. However, during work in Monterey Bay in March of 1983, a series of sounds

^{2/}

C. Malme, Bolt, Beranek and Newman, Cambridge, Massachusetts.
 Pers. Comm. to Dahlheim, July 1984.

were collected from gray whales (B. Würsig)^{3/}. This tape was reviewed by the author and was found to contain M1 signals. Detailed information regarding the number and/or behavioral aspects of the whales in the Monterey Bay region was not given. In April 1986, a two-week investigation took place off Piedras Blancas, California, during the northbound migration of cow/calf pairs. Sounds, reportedly produced by gray whales, were collected and are in the process of being analyzed (N. Cain, pers. comm.)^{4/}. The five hours of recordings made in the presence of juvenile whales and/or lone whales in Washington State waters during this study resulted in no sounds produced by the whales.

Based on the accounts with sufficient quantitative information, the most prevalent sound produced by the gray whale in Laguna San Ignacio, Mexico, and in the Bering Sea appears to be the S1 (N1) signal. The S1 call was also the most frequently heard signal recorded from the captive whale, "Gigi" (Fish et al., 1974). Cummings et al. (1968) reported that the M3 call dominated the vocal repertoire of southbound gray whales off southern California. Unfortunately, either due to the absence of gray whale signals during recording sessions and/or the lack of detailed information, it is impossible to conclude what type of sounds dominate the repertoire during the northbound phase of this whale's migration.

In comparing the results on the periodicity of sound production among the three major areas, which reflect three distinct behavioral modes of the animals (feeding, migrating, breeding/calving), the following preliminary

^{3/}

Würsig, Moss Landing Marine Laboratory, Moss Landing, California
Pers. Comm. to Dahlheim, March 1983.

^{4/}

N. Cain, UCSC, Santa Cruz, California. Pers. Comm. to Dahlheim,
May, 1986.

interpretation was made. When the northern range is compared with the other two areas, a significant reduction in acoustical signalling occurs on the feeding grounds. During the southbound migration, Cummings et al. (1968) reported a total of 231 sounds produced over a 24-hour period, which represented 218 whales. This would give a value of 0.04 sounds/hr/whale. This migratory value on sound production suggests a slight increase in sound activity during the southbound migration off southern California, as compared to the Bering Sea (0.006 sounds/hour/whale). The term "sounds/hr/whale" assumes that each whale within a defined area contributes equally to the sound environment. Although it may be erroneous to make this assumption, this term does allow an estimate or average of sound production to be made incorporating whale density.

From the available data, it appears that sound production peaks on the whales' mating/calving grounds (rates of 0.33 for February and 0.25 for March) and possibly just prior to engaging in these activities (Southern California rates = 0.04 sounds/hr/whale). The annual concentrations of gray whales found within the coastal lagoons and adjacent waters of Mexico represent the peak of social activities for this species. Interactions among whales occur on a regular basis. Conversely, on the northern grounds, few social interactions occur. Whales are typically found either singly or in pairs (Bogoslovskaya et al., 1981, 1982, personal observations by the author). During migration, the average pod size is 2.3 (Reilly et al., 1983); however, pods of up to 15 animals have been observed during census work conducted by the National Marine Fisheries Service (unpub. data). On their breeding locations, acoustical signalling may be necessary to ensure successful matings or to maintain contact between mothers and their newborn calves. Conversely, during feeding and migrating, whales may not

need to interact and thus signalling may not be as important.

To obtain a greater understanding of the acoustical behavior of gray whales, the literature pertaining to sound production by other cetaceans was reviewed. Odontocete (toothed) whales are well known for their extensive variety of calls, covering a wide range of frequencies (Evans, 1967; Fish and Winn, 1969; Watkins and Schevill, 1977; Watkins, 1977; Ford and Fisher, 1982; Dahlheim and Awbrey, 1982). A communicative as well as echolocative function has been ascribed and documented by experimentation for these whales (Bastian et al., 1966; Au, 1980; Au et al., 1985). The sound repertoires of the mysticete whales usually emphasize lower frequencies, have less variability, and cover a narrower range of frequencies when compared to the sounds of odontocetes. To date, echolocation capabilities have not been documented in the baleen whales. The available data acquired on baleen whale sound production do suggest that these whales can produce a variety of calls (Winn and Perkins, 1976). The elaborate calls of the humpback whales (Megaptera novaeangliae) have been well documented (Payne and McVay, 1971; Winn et al., 1971). In addition, humpback whales have been shown to have marked seasonal differences in calling rates and types of signals produced between their breeding and feeding locations. Reports are also available on the sound behavior of other members of the family Balaenopteridae: minke whales, Balaenoptera acutorostrata (Beamish and Mitchell, 1973; Winn and Perkins, 1976); blue whales, Balaenoptera musculus (Cummings and Thompson, 1971); fin whales, Balaenoptera physalus (Schevill and Watkins, 1962; Thompson and Cummings, 1969; Watkins, 1981); and the Bryde's whale, Balaenoptera edeni (Thompson and Cummings, 1969). With the exception of the humpback whale, adequate data do not exist for valid comparisons between the sound activities of these whales for their

breeding/feeding locations. Whales of the family Balaenidae, the southern right whale (Balaena glacialis australis), northern right whale (Balaena glacialis), and the bowhead whale (Balaena mysticetus), also are capable of producing a variety of phonations (Schevill and Watkins, 1962; Cummings et al., 1972; Ljungblad et al., 1980, 1982; Clark, 1982). Marked seasonal differences have also been demonstrated in their calls.

When gray whale sounds are compared to those sounds produced by other mysticete whales, the results imply that gray whales, representing the sole member of the family Eschrichtiidae, may have more of a limited repertoire (7 call types) and frequency range in which to operate (40 Hz to 4 kHz). The predominant S1 signal produced by the gray whale differs greatly both aurally and structurally when compared to those sounds produced by other baleen whales. Although some variation was shown to exist within sound types between mating and feeding areas, marked seasonal differences in call types were not apparent in these preliminary investigations. One fact that does seem consistent among the suborder Mysticeti is that calling rates increase when these species occupy their breeding grounds, which suggests a dependence on acoustical signalling during social activities and/or the rearing of their young.

The high levels of biological ambient noise in Laguna San Ignacio are typical of coastal, shallow, warm-water lagoon environments (Johnson, 1943). This biological background noise is broadband in frequency, with frequency bands of 2-5 kHz emphasized. One-third octave band levels ranged from 94-110 dB re 1 μ Pa. The diversity and relative abundance of the invertebrates and fish (Table VI) occupying Laguna San Ignacio, are apparently the major contributors responsible for this high-level background noise. Sea noise, of course, also contributes.

Vessel and skiff traffic were the only sources of man-made noise encountered during these southern studies. These levels were higher than those reported for the naturally occurring ambient noise and emphasized different frequency bands (less than 2 kHz). The received levels of these sources reported do not truly represent the source levels of these vessels since the acoustical waves have undergone transmission losses and attenuation. Source levels would, of course, be greater than those received at some distance.

When compared to the ambient noise levels on the southern range, relatively low levels of noise were found in the waters off St. Lawrence Island (52-95 dB re 1 μ Pa). The noise spectra obtained for this northern area differed in their profiles (when compared to Mexico), emphasizing different frequency bands and levels. The contribution of noise resulting from the biological component on the northern range was negligible. Received levels and frequency profiles from man-made sources were similar when the two areas (northern vs southern range) were compared. Again, these man-made sources emphasized lower frequencies (less than 2 kHz).

The limited recordings accomplished on the migration route off Washington State suggest an intermediate value (78-89 dB re 1 μ Pa) of ambient noise occurring in this area. In recent studies off central California, Malme et al. (1984) reported ambient noise at 85 dB re 1 μ Pa at frequencies below 2 kHz. Between 2 and 6.3 kHz, levels increased from 87-99 dB and then gradually dropped off to 90 dB re 1 μ Pa at 16 kHz. Malme et al. (1984) reported that snapping shrimp were responsible for the high-level background noise obtained between 2 and 8 kHz, and that lower frequencies were influenced by ship traffic. It is unclear how these authors

concluded that snapping shrimp were the source of high-level noise, since no collections were made. Their results are similar to my findings in Laguna San Ignacio; however, the levels off central California are lower. Again, the Washington and Californian values reflect an intermediate value between the Bering Sea and Mexico.

Many factors influence sound transmission in the sea; however, temperature usually has the most profound effect (McLellan, 1965). Sound propagation in the two major study areas (Alaska and Mexico) would follow very different pathways and be considerably different based on these current preliminary investigations (Appendix A). One would expect temperature to be responsible for the reflections/refraction of sound sources in the Bering Sea, whereas in Mexico, the shallow water environment (sea surface and bottom) may be the primary cause of the numerous reflections observed.

Previous reports suggest that sound propagation pathways in shallow-water environments typically follow the cylindrical spreading law ($10 \log R$). The experimentation in Laguna San Ignacio has shown that this formula cannot be used to estimate the level reaching the whales during playback experiments (Appendix A). This is apparent in both the immediate study area as well as for areas north and south of the primary area. Sound propagation in the southerly direction (into lower lagoon) is apparently enhanced by the numerous reflections and refractions caused by the sea surface and bottom. Conversely, in the middle lagoon, sound sources were barely audible. The prevalent sand bars in this area caused sound shadow zones. These shadow zones were independent of height of tide.

The acoustical characterization of ambient noise made during this

study represents a small window of time. Since gray whales only occupy Laguna San Ignacio between January and April (Jones and Swartz, 1984), the ambient values obtained more than likely represent a valid representation of noise during these months. A change in species composition (invertebrates or fish) would produce a different profile for this area. Major changes in bottom topography caused by storms/hurricanes would alter propagation pathways. The ambient noise profiles collected in the Bering Sea and off the coast of Washington represent extremely small time frames in which to predict ambient patterns. However, the measurements reported here are valuable since they do represent accurate levels obtained during selected time frames when whales were present. Moore et al. (1985), during recent studies in the Bering Sea, reported ambient profiles similar to those documented during the present studies. Future investigations of ambient noise on the migration route and in the Bering Sea should replicate the in-depth work accomplished in Mexico.

The dynamic nature of ambient noise within and among areas is well documented in our world's oceans (Urlick, 1967; Clay and Medwin, 1977). The conclusions drawn from this investigation document major differences in the gray whale's acoustical environments throughout its range. As gray whales proceed south during their annual migration, ambient levels increase and differences occur in the frequencies emphasized. In addition, man's activities increase as well. Gray whales are thus exposed to a broad spectrum of noise in their preferred coastal habitat. An inspection of the sounds produced by this whale also documents changes in call structure dependent upon the area being occupied.

In Laguna San Ignacio, high levels of natural ambient noise prevail throughout the gray whale season (January to March), emphasizing the

frequency bands of 2-5 kHz. On the northern range, these natural ambient profiles are considerably lower and emphasize different frequency bands. When the sound characteristics of gray whale signals are compared between these two areas, the southern acoustical behavior of the gray whale can be summarized as follows: 1) increased overall rate of calling, 2) high values of received levels, 3) calls emphasize a narrower and overall lower frequency range, 4) the amount of frequency modulation within signals is increased, 5) fewer number of pulses are produced per series at a low repetition rate, and 6) calls exhibit a longer duration. Conversely, when northern signals are compared to southern signals, these northern calls exhibit: 1) a decrease in the overall rate of calling, 2) a lower received level, 3) wider and higher emphasized frequency bands, 4) less frequency modulation within signals, 5) a higher number of pulses produced per series with a corresponding higher repetition rate, and 6) shorter call duration.

When profiles of gray whale sounds are compared to the spectra obtained for natural ambient noise conditions, an interesting pattern emerges. All gray whale signals analyzed either occupied frequency bands below the main concentration of ambient noise (e.g., Laguna San Ignacio) or occupied different frequency bands than those emphasized by the natural ambient conditions (e.g., Bering Sea). In addition, while occupying high-level ambient habitats, gray whale call rates increased, the level of sound output was increased, calls were typically longer in duration, and the amount of frequency modulation within the signals was increased. These various call modifications may ensure the maximum transmission and reception of signals when high-levels of background noise characterize an area. When relatively low-level ambient habitats are occupied, less demands are

placed on a calling species. This appears to be the case in the Bering Sea where calls of gray whales emphasized an overall broader and higher frequency range, call rates decreased, received levels of sounds were lower, and shorter call duration and less frequency modulation occurred in their signals. In comparing the acoustical behavior of a species between areas, the behavior of that animal cannot be ignored when evaluating differences in call structure. Although the behavior of this whale varies greatly between the two extremes of its range, it is reasonable to assume that most signalling (independent of area) represents an important function for this species. Therefore a gray whale signal produced either on the feeding and/or breeding grounds should be so structured as to optimize its output to remain effective.

It seems logical to postulate that cetacean sounds would have evolved to minimize the detrimental effect of noise on signalling. Natural ambient noise profiles in our oceans have remained relatively constant and somewhat fixed through time. With the exception of a catastrophic event, major changes in the overall spectra for an area are more than likely slow to occur. Noise due to the interference from other sounds and noise inherent in the transmission process delimit an acoustic niche for each calling species (Simkin and Il'ichen, 1965). The results of comparisons made between gray whale signals throughout its range and varying natural ambient conditions indicate that these signals occupy different acoustical channels than those dominated by the naturally occurring ambient conditions. This relationship suggests that a varying acoustical niche may be utilized by the gray whale on different parts of its range, thus ensuring the maximum transmission and reception of signals.

Man-made sources, when compared to natural noise, typically emphasize

lower frequencies (less than 2 kHz), have a corresponding high level of output at these low frequencies, and represent transient and/or temporary sound sources. When gray whale signals were compared to these man-made noise sources, it was found that these sources typically occupied the same frequency bands as gray whale signals. These results imply a high potential of man-made noise sources to interfere with and/or mask the signals produced by gray whales.

To date, no quantitative attempts have been made to document the acoustical responses of whales to noise produced by man in the natural environment. Two studies, however, have been recently accomplished in captive environments with the bottlenose dolphin (Tursiops truncatus) and the beluga whale (Delphinapterus leucas), Au et al., 1974 and Au et al., 1985, respectively. These studies demonstrated that these two species of toothed whales were capable of shifting frequencies to circumvent noise in their acoustical channels. In Laguna San Ignacio, during these investigations, preliminary comparisons between sounds produced by T. truncatus and ambient noise conditions suggested that these dolphin signals were typically higher than those emphasized by the ambient noise. These results support the work conducted in captivity by Au et al., 1974.

To determine if gray whales can actively structure their calls in ways to maximize the transmission and reception of their signals in the presence of man-made noise and provide more insight into the relationship between gray whale sounds and natural noise, a quantitative study addressing the acoustical responses of these whales to increased levels of noise was warranted. Chapters 2 and 3 investigate the acoustical capabilities and possible strategies employed by these whales when faced with dynamic noise situations, including the potential masking of whale signals by the calls of conspecifics.

In addition, these Chapters inspect the other behavioral options available to this species when sound sources directly infiltrate its acoustical channels.

C H A P T E R 2

RESPONSES OF GRAY WHALES TO INCREASED LEVELS
OF TEMPORARY (SHORT-TERM) NOISE

INTRODUCTION

Studies on the effects of noise have been completed on a wide variety of terrestrial species (Saunders and Dooling, 1974; Lim and Melnick, 1975; Fletcher and Busnel, 1978; Holt, 1978; Nawrot, Cook and Hamm, 1978; Nielson, Burnham and Talley, 1978; Anonymous, 1979; Kluczek, 1979; Zielinski, 1979; Smiley and Wilbanks, 1980). In most cases, noise has been shown to have a negative effect on the species being investigated. Physical adverse effects such as ear damage, and non-auditory physical effects such as physiological stress involving hormone responses leading to lowering of disease resistance, increased vulnerability to environmental stress, and hormone imbalances which may adversely affect reproduction, have been demonstrated. In addition, noise has the added potential of interfering with and/or masking the acoustical signals of animals. A reduction in the acoustic transmission and/or its reception can adversely affect the reproductive cycle or even the survival of a given species that is dependent on such a sensory process. Calls that have survival functions (e.g., providing appropriate information relative to food, competitors, potential mates and predators) must overcome or circumvent this noise to remain effective.

In terrestrial studies, many features of animal signals have been shown to minimize the detrimental effect of noise on communication (Konishi, 1970). Studies addressing orthopterans (Otte, 1977); birds (Thorpe, 1961; Armstrong, 1963; Marler, 1977; Smith, 1977); and primates (Gautier and Gautier, 1977; Marler and Tenaza, 1977; Oppenheimer, 1977; McGeorge, 1979) have been conducted. A collective review of these studies suggests that these various taxa do minimize the effects of noise on their signalling

by 1) the relative timing of their signals, and 2) the structure of their calls. To date, quantitative studies on wild cetaceans and how these aquatic populations acoustically respond to noise are lacking.

The gray whale, due to its preferred coastal habitat, is exposed to a dynamic acoustical environment. As demonstrated in Chapter 1, gray whales may minimize the detrimental effect that natural ambient noise has on their signals by operating in an acoustical niche. Operating in an acoustical niche would represent an adaptive strategy on the part of these whales to overcome or circumvent the constant high levels of natural noise prevalent in their environments, thereby ensuring minimum interference and masking problems with the transmission and reception of their own signals. Man-made noise spectra (characterized by low-frequency profiles and high-level outputs) may, however, directly interfere with and/or mask the signals produced by the gray whale. In addition, when numerous whales are vocalizing, some level of acoustical competition may exist among conspecifics. With the limited repertoire of calls available to the gray whale, is this species capable of circumventing increased levels of noise, in similar acoustical channels, produced by man and/or its own conspecifics?

To determine how this species uses its acoustical signalling most efficiently, noise levels were artificially increased through a series of playback experiments. Recordings collected during control and experimental conditions were compared to determine if a significant difference occurred in the acoustical behavior of the gray whale in response to playback. Comparisons were also made between simulated vessel/skiff noise (playback experiments) and real noise sources (vessels present in area) to determine the feasibility of using playback techniques to assess the effect of noise on the acoustical systems of marine mammals. Since gray

whales potentially could seek out areas of low-sound energy when subjected to increased levels of noise (thus avoiding the need to modify their acoustical signals), observations were also collected on the observed surface behavior of these whales. This Chapter investigates the effect of increased levels of short-term (temporary, stationary) noise stimuli on the behavior of gray whales in Laguna San Ignacio, Baja California Sur, Mexico.

MATERIALS AND METHODS

1983 Experimental Design

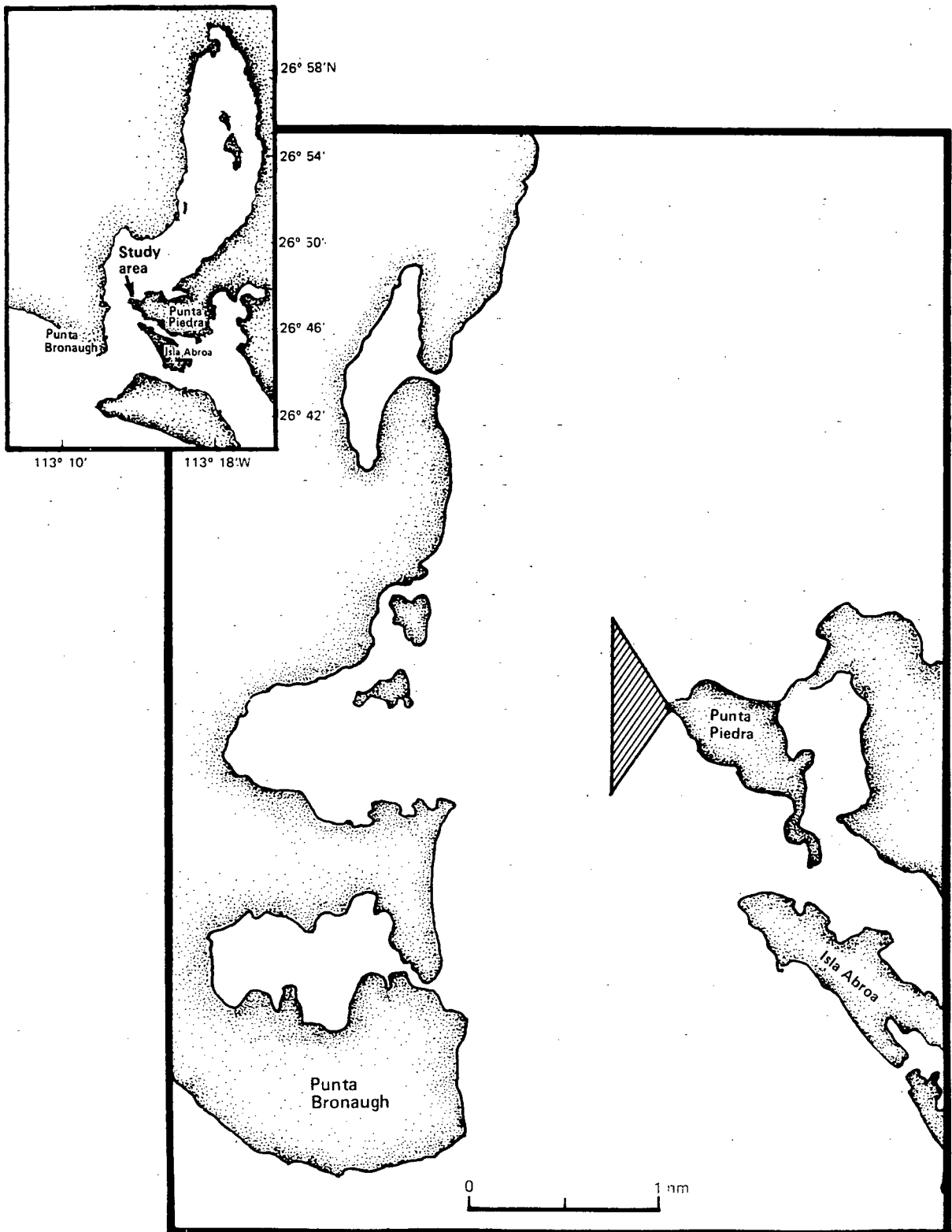
During playback sessions, the experimental design employed a pre-trial (= control), trial, and post-trial period. The duration of each session was 15 minutes. Sounds were projected back only during trial periods. The playback experiments included the projection of biological as well as non-biological sound sources. During biological sound playback periods, gray whale sounds (previously collected in Laguna San Ignacio) were projected back underwater. The biological playback schedule during this trial period consisted of one minute of playback, then one minute of silence, to prevent confusion during analysis. Thus for a 15-min interval, sounds were projected back for a total of eight minutes. Non-biological sound sources included: outboard engine noise (collected in Laguna San Ignacio, projected for 15 minutes) and test tones (calibration tone on acoustic amplifier, one tone produced every minute). Since these pre-recorded playback tapes already had undergone transmission losses (with the exception of the test tone) it was necessary to obtain a spectrum for each projected tape. Recordings of these playback tapes were made through the bottom-mounted hydrophone system to obtain an accurate spectra for each playback. All sound stimuli were projected at maximum levels which ensured[†] that whales within the immediate area (within 1/2 mile radius) were exposed to minimum sound levels of at least 130 dB re 1 μ Pa (determined by propagation experiments conducted - Appendix A). Playback experiments were terminated when 1) Beaufort conditions created noise interference and 2) noise from unplanned vessel and skiff traffic interfered with the experiments.

In addition to active playback periods, gray whale recordings were also

collected in the presence and absence of real man-made noise sources in the lagoon (e.g., vessel, skiff noise). The collection of gray whale sounds during the absence of vessel noise served as an additional control. Intra- and inter-experimental controls (e.g., pre-trials and absence of extraneous vessel sources) were compared to experimental conditions (playback trials and presence of vessels). Comparisons were also made between simulated outboard engine noise and real outboard noise to determine if the simulated noise source elicited similar responses by the whales. Post-trial periods were also compared among the various experiments.

Although the main focus of this study was to determine if a change in whale phonations would occur in the presence of noise (see following sections for parameters of sounds measured), the potential existed that a gray whale could possibly move out of the intensified sound area and seek an area of lower sound energy. This could negate the need for gray whales to alter their acoustical repertoire. For this reason, the observed surface behavior of the whales also became an important component of this study. To document the observed surface behavior of whales, two observers collected data on whale orientation and dive profiles when the whales passed through the immediate study area (defined by the visual range of observers - Fig. 31). Observers were positioned 100 m from each other at the Rocky Point shore-station and were involved in tracking different individuals. As each whale was located, the observer recorded the time the whale came to the surface and respired. At this time, the orientation (direction of heading) was noted as well. Only well-marked whales were selected to track (readily identifiable due to characteristic scars and/or color patterns), thus avoiding erroneous data on individual behavior. Observers were not aware of when playback,

Figure 31. Immediate Study Area off Rocky Point Defined During Tracking Experiments in Laguna San Ignacio, Mexico.



if any, took place. Observations were collected during both control and experimental conditions.

1983 Analysis of Gray Whale Sound Behavior

Each recording collected was edited and the information transferred to a written file. These edit sheets included: tape identification number, time, type of sound produced and a written log of all pertinent comments (e.g., sea state, tidal conditions, presence of vessels in area, and general behavior of whales). Once completed, the edit sheets were grouped by experiment. Five experimental groupings were defined:

- 1) Control periods - no intervention of man-made noise into the environment
- 2) Experiment A - real man-made sound sources prevalent in environment
- 3) Experiment B - simulation of outboard engine noise
- 4) Experiment C - simulation of gray whale sounds
- 5) Experiment D - projection of test tone

Within each experiment, data were further grouped for each test period (pre-trial, trial and post-trial). In the case of Experiment A, pre-trials did not always precede trials, since these experiments were conducted on an opportunistic basis when tour vessels were visiting the lagoon. This pre-trial, trial, post-trial approach allowed acoustical comparisons to be made between and within each experiment. For each experimental grouping, the following measurements were made on gray whale signals: a) total number of sounds produced, b) the types of calls produced, and c) structural changes within calls. Variables approximated a normal distribution, thus allowing statistical comparisons using parametric tests following Sokal and Rohlf (1969) and Zar (1974). Statistical tests were conducted with the use

of an IBM/XT computer using the Number Cruncher Statistical System (Version 4.2; Jerry L. Hintze).

Periodicity Change: The total number of whale sounds per experiment and per test period (pre-trial-post) were calculated by hand-scoring each signal produced (taken from edit sheet). The average number of sounds produced per 15-minute interval was then calculated. The resultant averages were compared for each test period and among experiments to determine if a significant difference occurred in sound periodicity when gray whales were exposed to different sound stimuli.

When addressing overall acoustical activity under different control/experimental conditions, whale density needed to be considered. During the projection of various sound stimuli, the zone of influence of potential acoustical interference exceeded the visual capabilities of the observers (outside immediate study area - Fig. 31). Thus no estimate could be made regarding the number of animals potentially impacted by increased noise levels. In addition, whales outside our visual range undoubtedly were contributing to the overall level of sound activity documented during these studies.

Call Types: To determine if gray whales switched call types in the presence of noise, data on the type of call produced were summarized from each edit sheet for each experimental condition described above. A percentage of a specific call type produced was then calculated, thereby illustrating the overall use of a specific call type for each event. These percentages were compared within and between each experiment.

Structural Changes: The following six sound parameters were investigated: overall frequency range of signal (Hz); emphasized frequencies of signal (Hz); received levels (dB re 1 μ Pa); percentage of signals

showing frequency modulation; duration (sec); and number of pulses produced per series. Overall frequency ranges, emphasized frequencies, duration, and number of pulses per series were calculated directly off the sonograms. Repetition rates were calculated based upon the average duration of the call and the average number of pulses produced per series. In the case of frequency modulation, the presence and/or absence of frequency modulation within the signal was noted for each phonation. A percentage was then calculated for the number of calls exhibiting frequency modulation within each experiment. To determine the received level of the call, average sound pressure levels were computed using a Nicolet Scientific Corporation FFT Spectrum Analyzer, Model 446. Displays of calculated spectra were made on an x/y plotter and an average received level was calculated for each sound for all experiments.

A matrix was established listing the average values calculated for each of the six acoustical variables under varying conditions. Statistical comparisons were made to determine if significant changes occurred in the call structure of gray whale signals between control and experimental conditions.

1983 Analysis of Observed Surface Behavior

Data collected on the observed surface behavior of gray whales during different experimental conditions were organized into proper dates and times and by experiment. Data were then screened for obvious errors. Erroneous entries and dive data with less than three entries were dropped from the data base. Each whale tracked and its associated respirations were numbered chronologically. Average dive times per whale, as well as overall average dive time for all whales, were calculated. Data on an individual whale's respiration were then categorized into respective time

intervals to obtain a frequency distribution of observed dive times. Respiration rates of cow/calf pairs and single whales were compared to determine if significant differences occurred in their dive profiles. Mean respiration rates were then compared between control and experimental conditions to determine if a significant change in dive duration occurred. For each whale tracked, a line display was made. This allowed a graphic representation of a whale's trackline (= respiration pattern) to be inspected. Environmental data surrounding specific dive times were noted on these line displays.

In addition to the analyses on gray whale respiration rates, the orientation (direction of heading) of the whale was also inspected. Each whale's trackline was investigated and the direction of heading for each whale was investigated for each surface blow. A percentage was then calculated indicating the total number of directional changes that occurred within an individual whale's trackline. The number of directional changes per trackline was compared among experiments.

RESULTS

1983 Calling Rates

A significant increase in calling rates was documented when gray whales were exposed to increased levels of noise (= trial periods). Post-trial values, although lower than trial periods, were still somewhat inflated when compared to pre-trial control periods. An exception to the above occurred when gray whales were subjected to the test tone. During this trial period, all vocalizations ceased. The post-trial rate obtained was significantly lower than pre-trial values.

Overt differences in the calling rates of gray whales were documented dependent upon the sound stimuli present in the environment. The presentation of outboard engine noise resulted in the greatest number of sounds produced with $45.5 \pm \text{s.d. } 11.3$ sounds per 15-min interval. Real noise sources in the environment also caused whales to vocalize more ($41.9 \pm \text{s.d. } 10.9$ calls produced per 15-min interval); however, these rates were not as high as those documented in the presence of projected outboard engine noise ($45.5 \pm \text{s.d. } 11.3$). Significant differences were not found when calling rates were compared between real sources and outboard engine noise. Both outboard and real noise sources yielded higher calling rates than those produced by gray whales in the presence of their own sounds ($23.9 \pm \text{s.d. } 5.9$ sounds per 15-min interval). Although rates of calling varied per experiment, ranging from 23.9 to 45.5, all trial values were higher than control values (18.6 calls produced for the interval), with the exception of the test tone when all vocalizations ceased. The post-trial values indicated that baseline and/or control calling rates were reached at different times, once again depending upon the sound stimuli presented to the whales. Post-trial rates were highest for

real sources ($29.6 \pm \text{s. d. } 3.8$), followed by outboard engine noise ($24.9 \pm \text{s.d. } 4.3$), the gray whale signals ($19.8 \pm \text{s. d. } 3.1$), control values ($18.0 \pm \text{s. d. } 5.2$), and finally test tone values ($15.2 \pm \text{s.d. } 3.7$). Calling rates for each control/experimental condition are listed in Table VIII. Details on intra- and inter-experimental comparisons and associated statistics are included in Appendix B (1983 Calling Rates).

1983 Call Types

Table IX summarizes the results of the investigations conducted on call types. During control periods (which includes pre-trials), the S1 signal dominated the sound repertoire of the gray whale, representing 83% of all calls produced. Of the remaining call types, S2 signals occurred 5%, S3 signals occurred 7%, and S4 signals occurred 5%. During all trial periods, with the exception of Experiment D when all vocalizations ceased, and post-trial periods, the S1 signal continued to dominate the sound repertoire of the gray whale.

Table VIII. 1983 Calling Rates of Gray Whales in Laguna San Ignacio, Mexico (total number of sounds produced per 15-minute interval includes mean, standard deviations, and range in parentheses).*

	PRE-TRIAL	TRIAL	POST-TRIAL
CONTROL n = 10.5 hrs	18.8 $\pm$ s.d. 5.5 (8-26)	18.6 $\pm$ s.d. 4.9 (6-26)	18.0 $\pm$ s.d. 5.2 (10-26)
EXPERIMENT A Real Sources n = 10.5 hrs	17.3 $\pm$ s.d. 5.2 (9-27)	41.9 $\pm$ s.d. 10.9 (22-61)	29.6 $\pm$ s.d. 3.8 (23-37)
EXPERIMENT B Outboard Engine n = 10.5 hrs	19.7 $\pm$ s.d. 3.4 (15-26)	45.5 $\pm$ s.d. 11.3 (26-65)	24.9 $\pm$ s.d. 4.3 (17-32)
EXPERIMENT C Gray Whale n = 10.5 hrs	17.6 $\pm$ s.d. 4.4 (8-28)	23.9 $\pm$ s.d. 5.9 (14-36)	19.8 $\pm$ s.d. 3.1 (16-28)
EXPERIMENT D Test Tone n = 10.5 hrs	18.7 $\pm$ s.d. 4.7 (7-26)	0	15.2 $\pm$ s.d. 3.7 (9-23)

* Total number of hours for all experimentation was 52.5 hrs. Each block represents 3.5 hrs which would be divided by 15-min periods to represent an individual experiment thus 14 experiments were accomplished for each block.

Table IX. 1983 Call Types Produced by Gray Whales in Laguna San Ignacio, Mexico.

	PRE-TRIAL	TRIAL	POST-TRIAL
CONTROL	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%
EXPERIMENT A Real Sources	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%
EXPERIMENT B Outboard Engine	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%
EXPERIMENT C Gray Whale	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	S1 = 85% S2 = 5% S3 = 5% S4 = 5%
EXPERIMENT D Test Tone	S1 = 85% S2 = 5% S3 = 5% S4 = 5%	No sounds	S1 = 90% S2 = 3% S3 = 3% S4 = 4%

1983 Call Structure

To determine if structural changes occurred in the calls of gray whales during experimental testing, signal characteristics were compared among different events. Since the S1 signal dominated the acoustical repertoire under all conditions (Table IX), I elected to use this particular phonation when investigating structural changes. The following variables were measured and compared within and among experiments: frequency range of signal (Hz), emphasized frequencies of signal (Hz), received level of sounds (dB re $1 \mu\text{Pa}$), percentage of S1 signals exhibiting frequency modulation, duration (sec), and number of pulses produced per series. Call repetition rates (number of pulses/sec) were derived from the average duration of the signal and the average number of pulses produced per series. Three sounds per 15-minute interval for each experimental period were randomly selected and analyzed; thus $n = 42$ sounds for each experiment were examined.

When trial periods of Experiments A, B, and C (Experiment D excluded since all vocalizations ceased) were compared to pre-trial values, significant increases were noted in received levels, number of signals with frequency modulation, number of pulses produced per series, and repetition rate of signals. Changes were not detected among the three test periods for call duration, frequency range of signal, and in the major concentration of energy of the signal. When post-trial test periods for each experiment were compared to the trial periods, an overall decrease was noted in received levels, number of signals frequency modulated, number of pulses produced per series, and repetition rates of signal. However, when comparisons were made between post-trials and pre-trials for each experiment for the four acoustical variables, the post-trial values

were still somewhat higher than control values, but were shown to closely approximate pre-trial values for certain sound stimuli. An exception occurred when post-trial periods of test tones were compared to pre-trial periods.

In all cases, similar variables changed among experiments, however the values were different. The degree/amount of structural change within a call may be related to the type of sound stimuli present in the habitat. In all three trial experiments (A, B, and C), when compared to control periods, changes occurred in received levels, number of signals exhibiting frequency modulation, and the number of pulses produced per series. The presentation of outboard engine noise elicited the greatest received levels ($156.6 \pm \text{s.d. } 9.5 \text{ dB}$), followed by real sources ($148.8 \pm \text{s.d. } 9.8 \text{ dB}$), then gray whale sounds ($126.4 \pm \text{s.d. } 11.7$). The presentation of gray whale sounds resulted in the greatest number of signals showing frequency modulation (95.2%) followed by real sources (85.7%) and then outboard engine playback (83.3%). When gray whales were subjected to real sources, the number of pulses per series was highest at $24.6 \pm \text{s.d. } 8.0$, followed by outboard engine playback ($22.6 \pm \text{s.d. } 6.8$), and then gray whale sounds ($12.8 \pm \text{s.d. } 6.7$). No changes occurred in call duration, frequency range or emphasized frequencies. An inspection of the differences obtained during post-trial periods among the experiments suggests that pre-disturbance levels are reached at different times depending upon the type of sound stimuli causing the acoustical perturbation. Values associated with these structural changes are summarized in Table X. Statistical values obtained during these investigations are listed in Appendix B (1983 Call Structure).

Table X. 1983 Structural Changes in the Calls of Gray Whales Occupying Laguna San Ignacio, Mexico.*

	Frequency Range (Hz)	Emphasized Frequencies (Hz)	Received Levels (dB re 1 μ Pa)	Percent Frequency Modulation	Duration (sec)	Number Pulses/ Series	Pulse Repetition Rates **
CONTROL AND PRE-TRIAL	100-2000	300-825	117.6 $\pm$ 14.2 (90-156)	71.4	1.7 $\pm$ 0.8 (0.3-4.6)	9.4 $\pm$ 4.4 (2-30)	5.4
REAL SOURCES TRIAL	120-1800	280-700	148.8 $\pm$ 9.8 (131-170)	85.7	2.0 $\pm$ 1.1 (0.5-5.2)	24.6 $\pm$ 8.0 (14-48)	12.0
POST-TRIAL	120-1950	315-820	128.3 $\pm$ 6.6 (118-142)	78.6	2.0 $\pm$ 1.0 (0.4-5.2)	18.4 $\pm$ 8.4 (8-40)	9.2
OUTBOARD ENGINE TRIAL	150-2000	300-800	156.6 $\pm$ 9.5 (138-172)	83.3	2.0 $\pm$ 0.9 (0.5-5.0)	22.6 $\pm$ 6.8 (12-46)	11.3
POST-TRIAL	200-1800	350-780	121.5 $\pm$ 6.2 (102-132)	73.8	1.9 $\pm$ 0.9 (0.4-4.6)	13.2 $\pm$ 5.1 (7-36)	6.7
GRAY WHALES SOUNDS TRIAL	100-2000	300-790	126.4 $\pm$ 11.7 (104-153)	95.2	1.9 $\pm$ 0.9 (0.4-4.6)	12.8 $\pm$ 6.7 (4-32)	6.6
POST-TRIAL	125-1950	320-820	119.7 $\pm$ 6.6 (107-140)	73.8	1.9 $\pm$ 0.8 (0.4-4.2)	10.8 $\pm$ 5.0 (5-34)	5.4
TEST TONES TRIALS	0	0	0	0	0	0	0
POST-TRIALS	125-2000	300-800	115.4 $\pm$ 9.3 (94-132)	71.4	1.8 $\pm$ 0.8 (0.4-4.2)	9.6 $\pm$ 4.9 (3-22)	5.3

* For each experiment a n value of 42 sounds were analyzed.

** Derived from average call duration and the average number of pulses produced per series.

1983 Observed Surface Behavior

To determine if whales moved away from the sound source, thus negating the need for them to alter sound behavior, 101 individual whales were visually tracked by observers based at the Rocky Point shore-station. Average dive duration (amount of time spent underwater between two surface blows) of gray whales occupying Laguna San Ignacio in 1983 (exposed to a variety of experimental conditions) was $68 \pm \text{s.d. } 34.0 \text{ sec}$ ($n = 700 \text{ dives}$). A frequency distribution of these dive durations by 10-sec categories is represented in Fig 32. Out of the 101 whales tracked, 56 (439 dives) of these whales were females with accompanying calves (= cow/calf pairs). The average dive time of these cow/calf pairs (blow rates collected on adult female not calf) was $49.1 \pm \text{s.d. } 14.8 \text{ sec}$. This value was statistically different ($t = 5.96$, $p < 0.05$) from the average dive duration obtained for single whales at $98.2 \pm \text{s.d. } 59.3 \text{ sec}$ ($n = 45 \text{ whales for a total of } 261 \text{ dives}$). Figure 33 graphically demonstrates the differences between the respiration rates of these two whale groups. Since dive durations were statistically different between cow/calf pairs and single whales, these data could not be lumped when comparing control and experimental conditions. Unfortunately, this decreased the sample size per experiment.

When cow/calf pair and single whale dive times were compared among control, real vessel, outboard, and test tone trial periods, there were no significant differences in respiration rates (Anova, $df = 3$, $F = 0.86$, $p > 0.05$; Anova, $df = 3$, $F = 0.52$, $p > 0.05$, respectively). These rates are listed in Table XI. During the collection of post-trial respiration rates of Experiment A, B, and D, cow/calf pairs were somewhat harder to find (as indicated by the reduced numbers on dive data) and were harder to track (less predictable dive pattern; missed blows). During the post-trial

Figure 32. 1983 Frequency Distribution of Gray Whale Dive Durations.

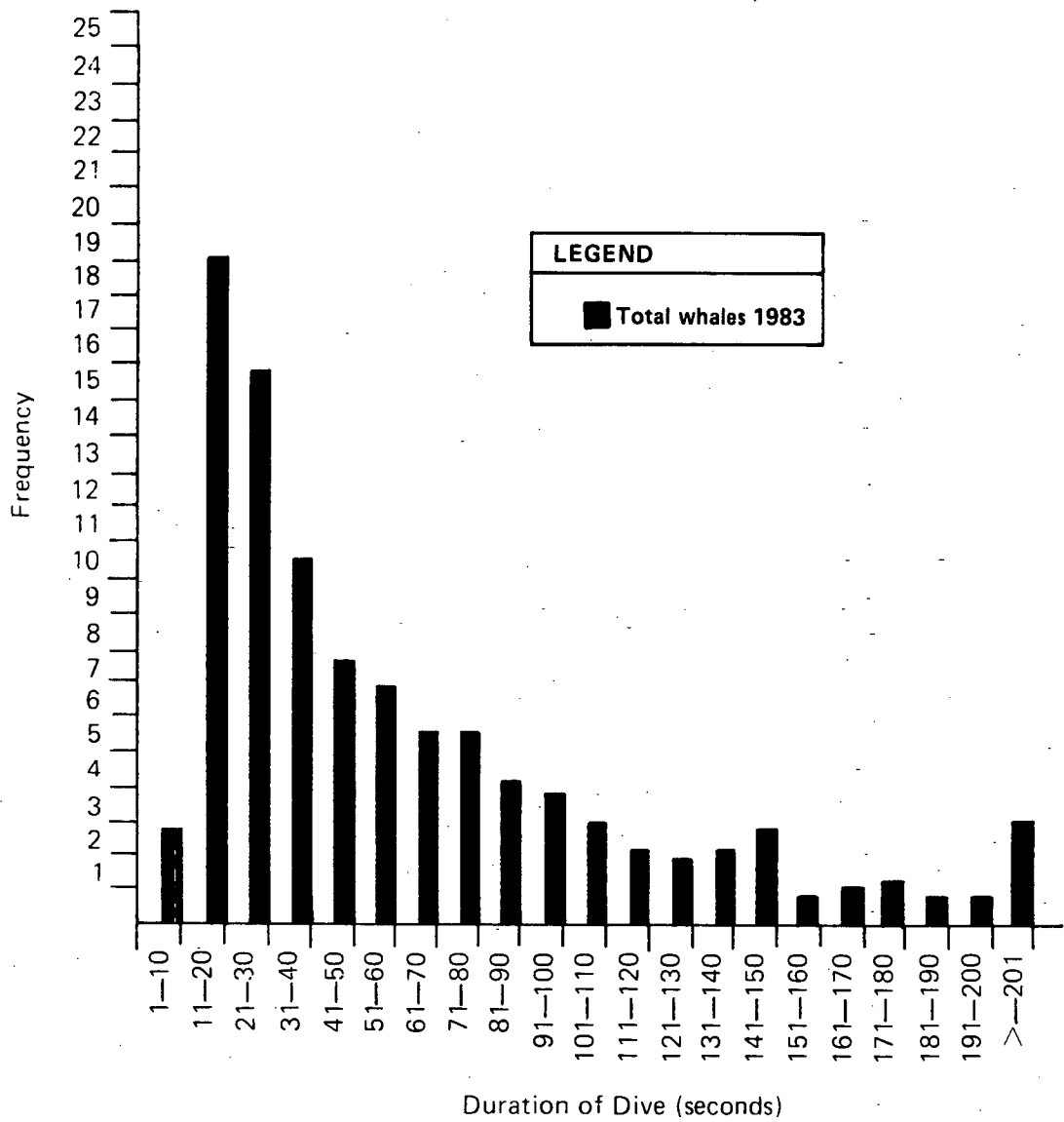


Figure 33. 1983 Frequency Distribution of Cow/calf Pairs and Single Whale Dive Times in Laguna San Ignacio, Mexico.

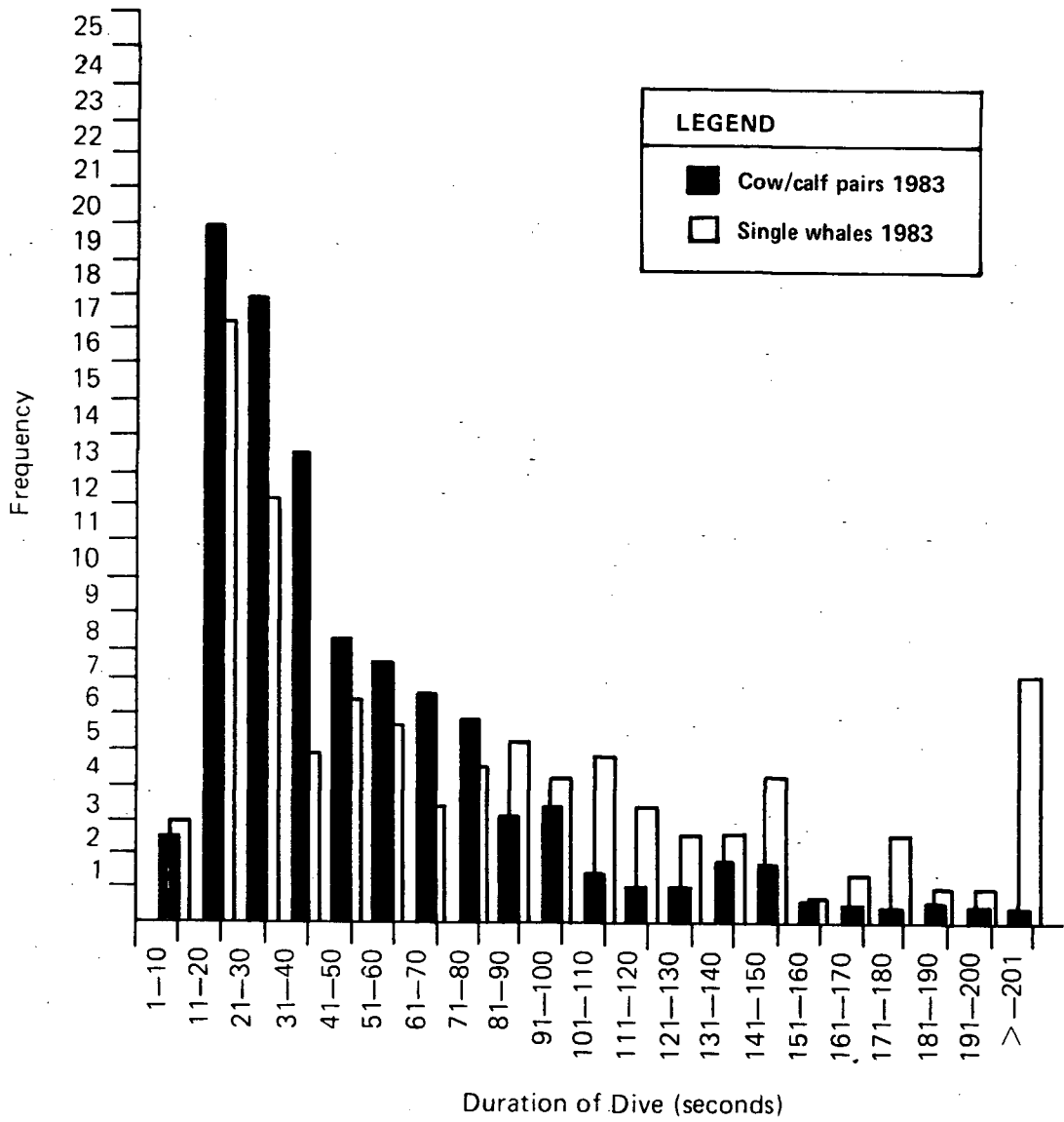


Table XI. Average Dive Times (sec) of Gray Whales During Various Experimental Conditions During the 1983 Season in Laguna San Ignacio, Mexico (includes mean, standard deviations and range in parentheses).

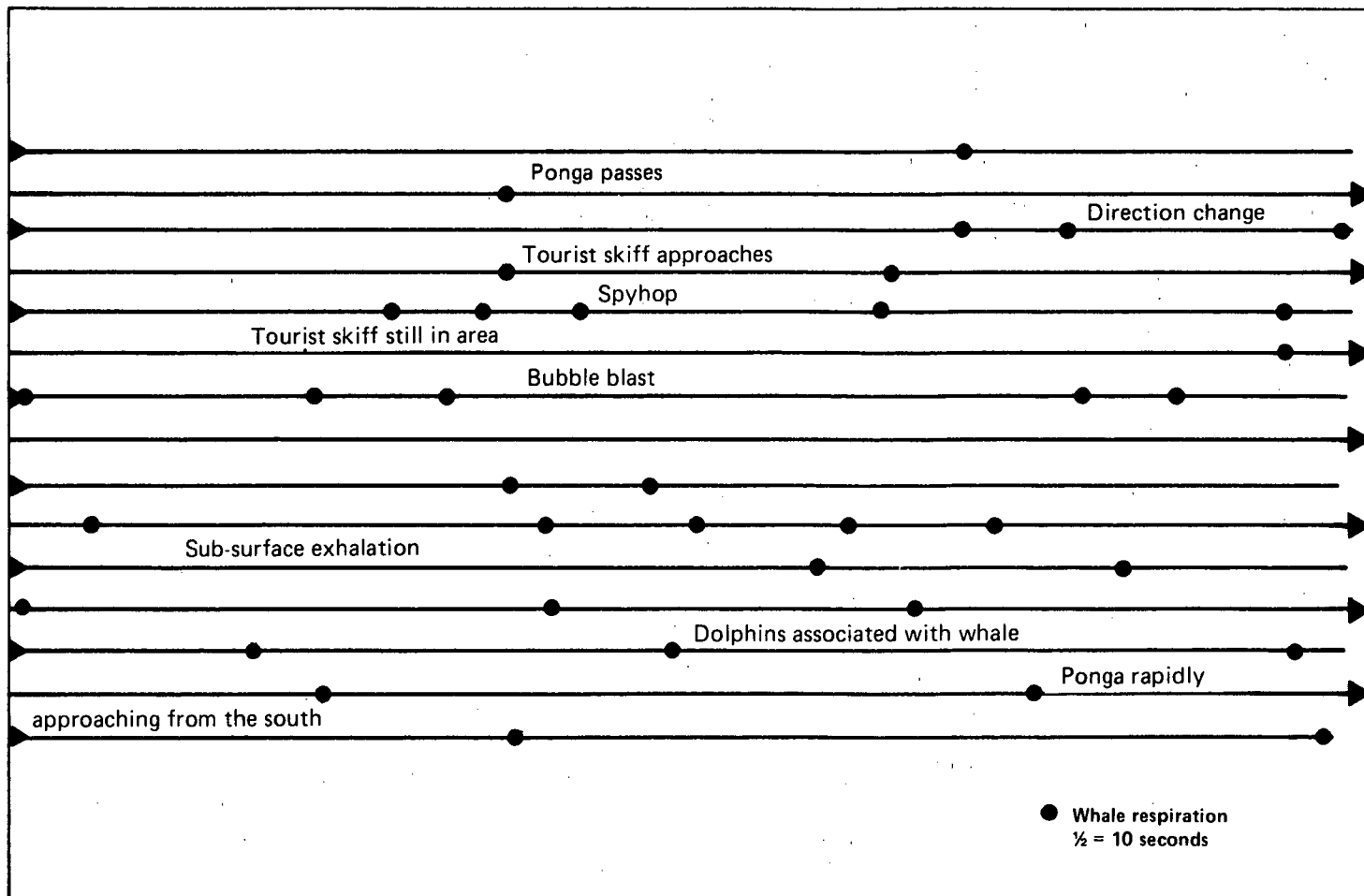
	SINGLE WHALES	COW/CALF PAIRS
CONTROL	$92.7 \pm \text{s.d. } 34.2$ (44-182) n = 87 dives	$52.0 \pm \text{s.d. } 16.2$ (31-89) n = 167 dives
EXPERIMENT A Real Sources	$82.3 \pm \text{s.d. } 31.5$ (49-136) n = 103 dives	$45.8 \pm \text{s.d. } 12.7$ (26-71) n = 149 dives
EXPERIMENT B Outboard Engine	$107.3 \pm \text{s.d. } 21.9$ (90-132) n = 22 dives	$54.1 \pm \text{s.d. } 10.6$ (38-70) n = 86 dives
EXPERIMENT D Test Tone	$95.5 \pm \text{s.d. } 67.0$ (27-221) n = 49 dives	$47.5 \pm \text{s.d. } 15.7$ (27-78) n = 37 dives

periods of Experiment D (test tone), typically cow/calf pairs could not be found. Similar trends were discovered when looking at post-trial periods (Experiment D) for single whales as well. Because of this, sample sizes were significantly reduced, thus comparisons among post-trial experiments were not attempted.

Although statistical differences in dive duration were not obtained when whales were exposed to increased levels of noise, an inspection of dive times greater than 150 sec ($n = 53$ dives) revealed the following. For each whale tracked that had a dive time greater than 150 sec, the associated line display was inspected (Fig. 34). An allowance of one minute on either side of an environmental event was given for a whale to react to the perturbation. A collective review of dive times greater than 150 sec indicated that 52% of these dives were associated with real sound sources in the environment and 43% were associated with playback experiments. The remaining 5% had no associated comments. Included in the percentage for playback experiments were 28 cases in which whales being tracked disappeared at the start of the playback session. When this occurred, observers watched for a total of three minutes and then ended that particular tracking session. These dive times were thus presumed to be greater than 150 secs.

Directional changes were also investigated during the 1983 season. During control periods, whales typically changed direction 46% of the time as they transited through the waters of the immediate study area. In the presence of real sources, an increase (69%) was noted in the number of directional changes made by the whales. Similar increases in directional changes were documented when whales were exposed to outboard engine playback (64%). The greatest number of directional changes occurred in the

Figure 34. Example of Line Display Depicting Behavior of Gray Whales and Environmental Effects During Tracking Experiments.



Line Display

presence of the test tone (87%).

Control periods were compared to experimental periods and yielded the following results. When control periods (46%) were compared to real sources (69%), a significant increase was noted in directional changes (Chi Square = 9.90, $p < 0.05$). Similar increases in the number of directional changes were detected when controls (46%) were compared to outboard playback (64%) (Chi Square = 5.83, $p < 0.05$) and test tone playback (87%) (Chi Square = 35.9, $p < 0.05$). When real sources (69%) were compared to outboard engine playback (64%), significant differences were not found (Chi Square = 0.35, $p > 0.05$). A significant difference was detected when real sources (69%) were compared to test tones (87%) (Chi Square = 8.42, $p < 0.50$) and outboard (64%) was compared to test tone (87%) (Chi Square = 13.08, $p < 0.50$). In each case, the test tone elicited the greatest number of directional changes.

The above data suggest that whales transiting through the immediate study area increased the number of directional changes in the presence of noise sources. Although the observers subjectively believed that whales were moving away from the station at certain times, overall movements toward and away from the sound source could not be quantified in the 1983 season. However, this season's work did provide the basis for detailed studies on whale movements for the 1984 season (Chapter 3).

DISCUSSION

Significant changes were documented in the acoustical signalling of gray whales when these whales were exposed to temporary, increased levels of noise in their environment. Typically, as noise levels were increased during trial periods (i.e., real sources, outboard engine playback, and projection of gray whale signals), a corresponding increase was documented in: 1) calling rates; 2) received level of the signals; 3) number of frequency-modulated signals; 4) number of pulses produced per series; and 5) repetition rates of signals. During the post-trial periods of these three experiments, the values associated with these five acoustical variables were shown to decrease with time and in some cases to approximate those values obtained during control periods.

Statistical differences were documented when the values obtained during trial and post-trial periods were compared among the experimental conditions. The combined results indicate that different sound stimuli dictate varying acoustical responses by gray whales. In the presence of real sources and the projection of outboard engine noise, similar changes were noted in calling rates and call structure for the two sound stimuli. Only the received level of the call was shown to be significantly higher in the presence of outboard engine noise. When comparing the post-trial periods between these two sound stimuli, significant differences were noted. Gray whales resumed baseline/control values for calling rates and call structure at a faster rate after exposure to simulated boat noise than to a real sound source present in the environment. Although the two vessel noise sources were somewhat similar in overall profiles, the ways in which these stimuli were presented were different. Outboard noise was presented as a rapid onset of sounds while real sources generally increased

gradually. This factor may be responsible for the different values obtained for received levels of calls, with a rapid onset of noise causing a higher value. A possible explanation for the different rates obtained during post-trial periods of these two sound sources could be that residual effects are still prevalent in the habitat with real sources (actual presence of boat) still emitting some noise, whereas during post-trials of outboard engine noise, the noise perturbation was completely terminated at the end of the trial period. Although some minor differences occurred when comparing the two sound sources, typically the two sources elicited similar changes in the acoustical behavior of whales. An inspection of the similarities obtained during these two trial experiments (real vs tape outboard) is of major importance. Apparently, gray whales respond in a similar acoustical manner to either real sources and/or simulated boat noise. These results suggest that playback techniques can be used to assess and monitor the acoustical behavior of gray whales to increased levels of noise.

Similar sound parameters changed when the calling rates and call structure were compared between the projection of gray whales (biological sounds) and the presence of non-biological sources (real and outboard). However, the degree/amount of change was not as great in the presence of gray whale sounds as that noted for vessel sources. One acoustical variable did show an unusually high rate of change when these experiments were compared. The number of signals exhibiting frequency modulation was highest (95.2%) during the projection of gray whale sounds.

The presentation of the test tone resulted in a radical departure when compared to other sound stimuli. When whales were exposed to this signal, all signalling ceased. During post-trial periods, gray whales typically

remained silent for approximately 10 minutes following exposure to this stimulus. When calling resumed, values associated with calling rates and call structure were somewhat lower than control values. When compared to the other three sound stimuli, this test tone signal was unique in several aspects. The signal covered a wide range of frequencies (15 kHz to 400 Hz), exhibited a transient nature, was projected on a random schedule, and did not normally occur in the lagoon environment.

Certain sound parameters did not change in the presence of the temporary noise: types of calls produced, frequency range of signal, emphasized frequency bands and call duration. Since the S1 signal typically dominates the acoustical repertoire and also shows the greatest amount of variation for all call types investigated, it may be advantageous for gray whales to modify this signal rather than switch to other signals. Possibly their only available option would be either to modify the predominant call type or move out of the area to ensure the maximum transmission and reception of their signals. Unfortunately the relevance of the call with respect to behavior is unknown. For example, it may be more beneficial in terms of circumventing noise to continue producing S1 signals; however, it may be irrelevant to change call types in terms of what the whale was doing and/or trying to convey in terms of communication. The fact that frequency shifting was not noted may reflect certain physical limitations regarding their anatomical structure and/or reflect responses to the rapid onset of short-term noise.

Significant differences in dive durations did not occur between control and experimental conditions. Statistical differences did, however, occur when dive times were compared between cow/calf pairs and single whales. The reduced cow/calf pair dive times and less variation in length

of dive could result from the adjustment made by cows to accommodate the limited breath-hold capabilities of their young calves. Overall, respiration was highly variable, ranging from 8 sec to 301 sec, with an average dive interval of $68 \pm \text{s.d. } 34$ sec. Although there was a tendency for longer dives to be associated with man-made events, this could not be demonstrated statistically. Possibly the small sample size (due to the breakdown needed) and the highly variable respiration rates masked this fact.

A total of 101 whales was tracked during the 1983 season. Although this data base is considerable smaller than that collected by Harvey and Mate (1984), overall dive profiles and their associated frequency distribution are similar. The average dive time calculated by Harvey and Mate (1984) for 3 single whales and 7 cow/calf pairs was $96 \pm \text{s. d. } 1.2$ secs, which represents a slightly longer dive duration than documented during these studies. Dive durations of cow/calf pairs were collected in March and April, thus these calves would be approximately 4-6 weeks older than those reflected in the current data base. Harvey and Mate's dive data represent respiration rates of gray whales collected under a wide variety of environmental conditions including exposure to man-made sources.

Directional changes occurred 46% of the time when observing whales under control situations. A significant increase in number of directional changes occurred in the presence of noise, with the test tone causing the greatest number of directional changes. Movements were subjectively noted to occur both toward and away from the sound source, depending upon the sound stimuli being projected. On several occasions, during the projection of outboard engine noise, whales were observed to overtly change direction and head directly (east) to the transducer location. In both cases, these whales dove directly over the transducer cage, lingered,

and then eventually swam away. This is of particular significance when one considers the "friendly/curious whale" behavior exhibited by gray whales in Laguna San Ignacio. Apparently, the whales interpreted the projected outboard engine noise as a real (= true) source. The attraction of curious whales to the transducer, as well as the similar acoustical results achieved between real sources and outboard playback, supports the use of playback techniques and experimentation for future studies of noise impact on cetaceans. The directional changes observed in 1983 and the reduced number of whales available for tracking during post-trial periods suggests that gray whales avoid the immediate study area (transducer site location) during exposure to increased levels of noise. The experimental design employed in 1983 did not measure the precise trackline (distance offshore or actual movement) and/or the amount of time in area of the whale relative to the transducer site. This may be an important consideration since the responses of whales may vary depending upon this relative distance to the sound source.

The combined results of these 1983 acoustical and observed behavioral investigations suggest that gray whales, when exposed to rapid onset of temporary noise, can modify their acoustical repertoire through call structure and timing. Several acoustical advantages for a calling species can be associated with these observed changes. If sounds are produced more often, there is certainly a greater chance of the signals being perceived. A similar result would occur if the level of sound production were increased. Frequency modulated signals have two advantages. These FM signals carry more information and travel farther distances (Wiley and Richards, 1978), thus enhancing the signal's transmission. A greater number of pulses per series and faster repetition rates would also

serve to enhance the signal. Under certain situations (i.e., test tone projection) a cessation of all vocalizations was documented. It may be that gray whales have a certain level of tolerance to various signals and/or how noise sources are presented to them. It may be more advantageous for a whale to move out of the ensonified area.

The experimental design employed during 1983 represented a projection of an intermittent/temporary, stationary sound source (except real sources). The onset of the sounds projected during trial periods was rapid, with no phasing in or out. When whales were in the immediate vicinity (within 1/2 mile range), the onset of sounds did not accurately represent a natural noise source encountered by a whale in the environment. Sound would typically increase/decrease gradually as whales moved by. Although valid, the resultant behavior may represent a startle response and thus may not adequately reflect the acoustical capabilities of the gray whale. Whales may conceivably respond differently to continuous, moving sound sources and/or exposure times. By employing different experimental methods, a greater understanding of the acoustical capabilities/strategies employed by gray whales can be obtained, lending more evidence in support and/or rejection of the proposed hypothesis.

C H A P T E R 3
RESPONSES OF GRAY WHALES TO INCREASED LEVELS
OF CONTINUOUS (LONG TERM) NOISE

INTRODUCTION

Ocean ambient noise is eminently characterized by variability (Urick, 1967). Much of this variability can be attributed to changes in the dominant sources of noise, such as sea state, amount of shipping, and/or composition/abundance of sound-producing marine organisms. The dominant sources of noise, prevalent in a specific environment, are responsible for the overall profile of noise with respect to emphasized frequencies and decibel levels.

Ambient noise can also be classified as an intermittent/transient or a constant source of noise in an environment. The contribution to the overall spectra can thus be regarded as short-term (e.g., temporary, seasonal) or long-term (prevalent over extended periods of time). The origin of these signals can also be mobile or stationary. The onset of the signals can be rapid (indicating a fast rise-time) and/or occur gradually over time (slow rise-times). Another source of variability arises out of the changing sound transmission conditions of the aquatic medium. When considering this dynamic aspect of noise, the potential exists that gray whales may respond in a variety of ways dependent upon the type and nature of the sound stimulus in the environment.

As demonstrated in Chapter 2, acoustical and observed surface behaviors of gray whales were documented to change when exposed to increased levels of short-term noise in Laguna San Ignacio. Responses varied with respect to the particular sound source present. These results suggested that the sound type, not the playback itself, was causative. The 1983 sound sources varied with respect to overall profiles; however, the presentation of most of these stimuli was similar across all experiments (i.e., rapid onset of short-duration sound sources). An exception occurred

when real sources were prevalent in the environment. The exposure of whales to these sources was gradual over time but still represented short-term exposure levels. When comparing the 1983 results between outboard engine playback periods and periods when real vessel noise occurred, differences were documented in the acoustical responses of the whales to these two sources. Could these differences reflect the whales' acoustical reaction to the rapid onset of short-term noise (i.e., outboard engine playback) vs their response to the gradual onset of short-term noise (real vessels in area)? At sea, when noise sources are encountered, typically this exposure is gradual over time. This allows the receiver adequate time to respond to and/or react to the source. Occasionally, in the case of certain signals, such as explosive charges (e.g., seismic blasts associated with oil exploration or natural sources such as isostatic rebound effects), the onset of sound is rapid and unpredictable. In these situations, adequate response time may not be given and the resultant behavior thus could be interpreted as a "startle response". Startle responses are, of course, valid and significant since they do represent an aspect of the whales' behavior; however, these responses may not fully represent the acoustical capabilities of the species being investigated. The possibility thus existed that the 1983 responses of gray whales (due to the experimental design employed) could have been described as startle responses.

To determine if gray whales employ different acoustical strategies or responses when exposure time to the source is increased, a study was conducted in 1984 to investigate behavioral responses of gray whales to the projection of gradual onset of long-term (sounds projected for six to eight hours at a time) noise sources in Laguna San Ignacio. It was hoped

that these investigations would provide a better understanding of the acoustical capabilities/strategies of the gray whale. This Chapter investigates the effect of long-term noise on gray whales and compares the acoustical and observed surface responses of whales between the 1983 and 1984 seasons.

MATERIALS AND METHODS

1984 Experimental Design

The experimental design employed control periods that were six to eight hours in duration. These control periods were defined as times without any intervention of man-made noise (either real sources or projected sounds). The playback experiments, conducted for six to eight hours at a time as well, included the projection of biological as well as non-biological sound sources. During biological playback, killer whale (Orcinus orca) sounds were projected. Since killer whales are known predators of gray whales (Dahlheim, 1981), it was assumed that this particular playback would result in an avoidance/aversive reaction on the part of the gray whales. This would allow documentation of the responses of gray whales to a known aversive stimulus, which could provide an important interpretive element to this study.

Two types of man-made noise sources were projected back underwater during these 1984 studies. These included outboard engine noise (same tape used during 1983) and oil-drilling sounds (collected in the Beaufort Sea). These two man-made sources dominated frequencies less than 2 kHz and thus potentially competed in the same frequency bands as signals produced by the gray whale. To verify that gray whales were not responding to the power generated/electrical energy produced by the transducer during playback experiments, the transducer was turned on for periods of up to eight hours, but no sounds were projected.

As in 1983, acoustical recordings were also made in the presence of real sources prevalent in the environment and compared between control periods and other experimental conditions. Experimental testing was

terminated when: 1) Beaufort conditions created noise interference, and 2) noise from unplanned vessel and skiff traffic interfered with experimentation.

1984 Observed Surface Behavior - Tracking Experiments

Based upon the experience gained in 1983, I decided that it was not only necessary to collect dive duration data on gray whales but also to collect precise data on the movements of the whales relative to the transducer site. The 1984 experimental design was modified from that of 1983 to allow for precise comparisons to be made of the surface activities of whales between control and experimental periods.

A four-member team was necessary to carry out this phase of the research. One member was positioned at a northerly station, designated as North Marker. The other member was stationed at a southerly station, termed South Marker. The distance between these two stations was 100 m. The boundaries defined for the study area during these tracking experiments were based upon the effective visual range of the observers, which ensured that the observers could accurately identify an individual whale. Each observer was equipped with a pair of Steiner binoculars. These binoculars had built-in compasses, allowing the observers to collect the bearing to an individual whale as it came to the surface to respire. The North and South observers gathered data on the same whale, which was coordinated through the use of hand-held CB radios. Only well-marked, easily identifiable whales were selected to track. A third team member (positioned at South Marker) was designated as a recorder for the primary observers and collected the following information on a data entry form designed for this purpose: identification of observer North, South and recorder; date; whale identification number (numbered consecutively);

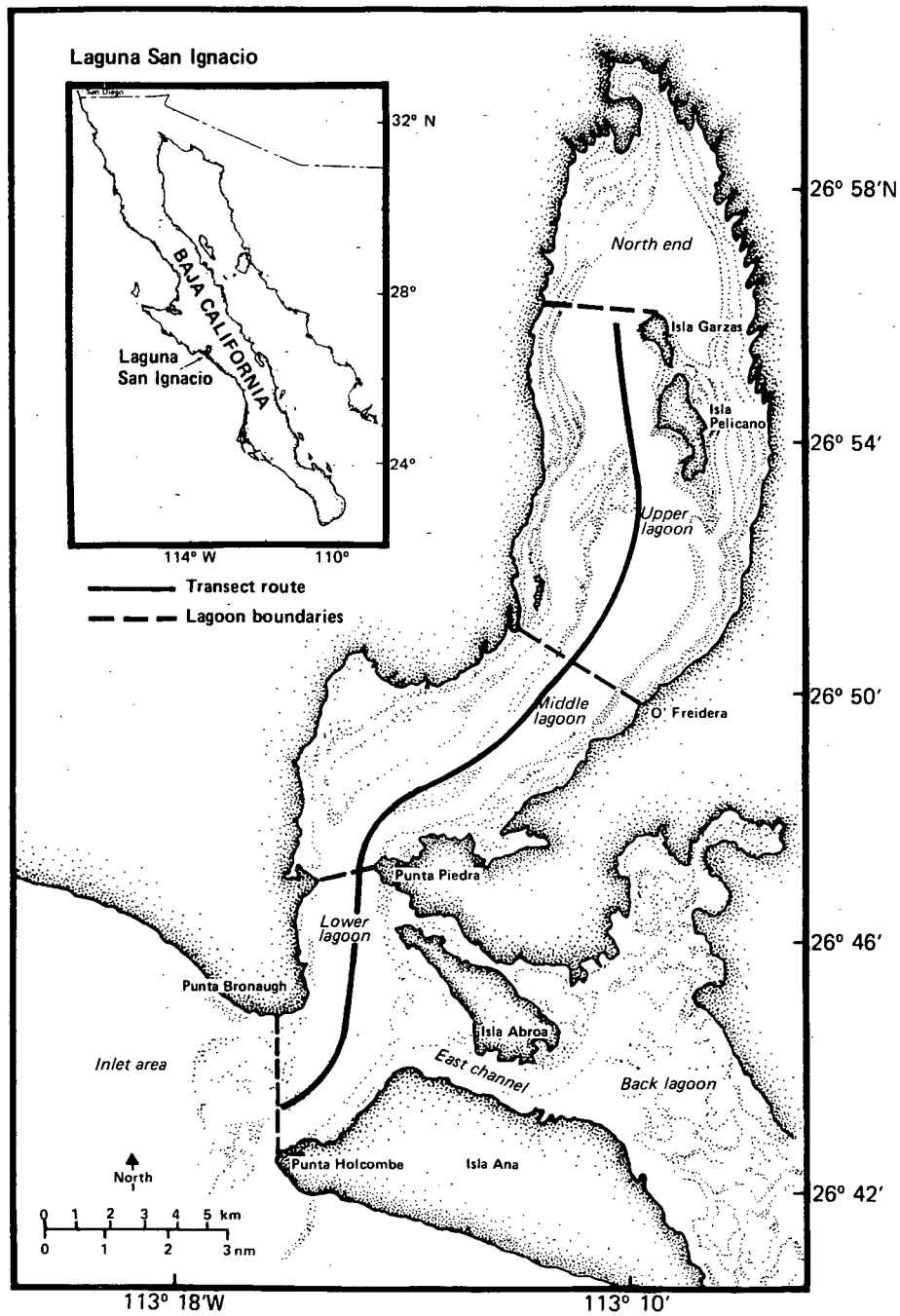
identification of whale grouping (e.g., cow/calf pair, singles); time of respiration; south and north bearing of each blow; environmental data to include information on weather, boats present and whale behavior. During these tracking experiments, the fourth team member was positioned near the shore-based playback equipment. The tracking team was not informed as to what, if any, type of playback was occurring, thus avoiding bias in sampling. An effort log was maintained by the observers noting the amount of time on station per day.

1984 Distribution/Abundance - Transect Experiments

To determine if a significant change occurred in the distribution and abundance of gray whales in the presence of increased levels of noise, vessel surveys were conducted during control and experimental conditions. The design of these surveys and the rationale employed followed those described by Jones and Swartz (1984), which represented a line transect methodology (Eberhardt, 1978).

Transects were conducted from a 4.3-m inflatable boat powered by a 20-hp outboard engine, travelling at a speed of 6 knots. This speed ensured that a whale (which usually travels at 2-4 kts) would not move ahead of the vessel and thus be double counted. A complete survey of the lagoon took approximately 3 hours and 20 minutes. Transects were conducted along an imaginary line drawn through mid-lagoon (Fig. 35) from the breaker line at the lagoon entrance, north to Isla Garzas (16 nmi). This mid-line survey track ensured that all whale inhabitable waters were properly censused (both shorelines were clearly visible). Whales in the "North End" of the upper lagoon (north of transect termination point) were censused from a 5-m bluff on the northern tip of Isla Garza following the procedures developed by Jones and Swartz (1984).

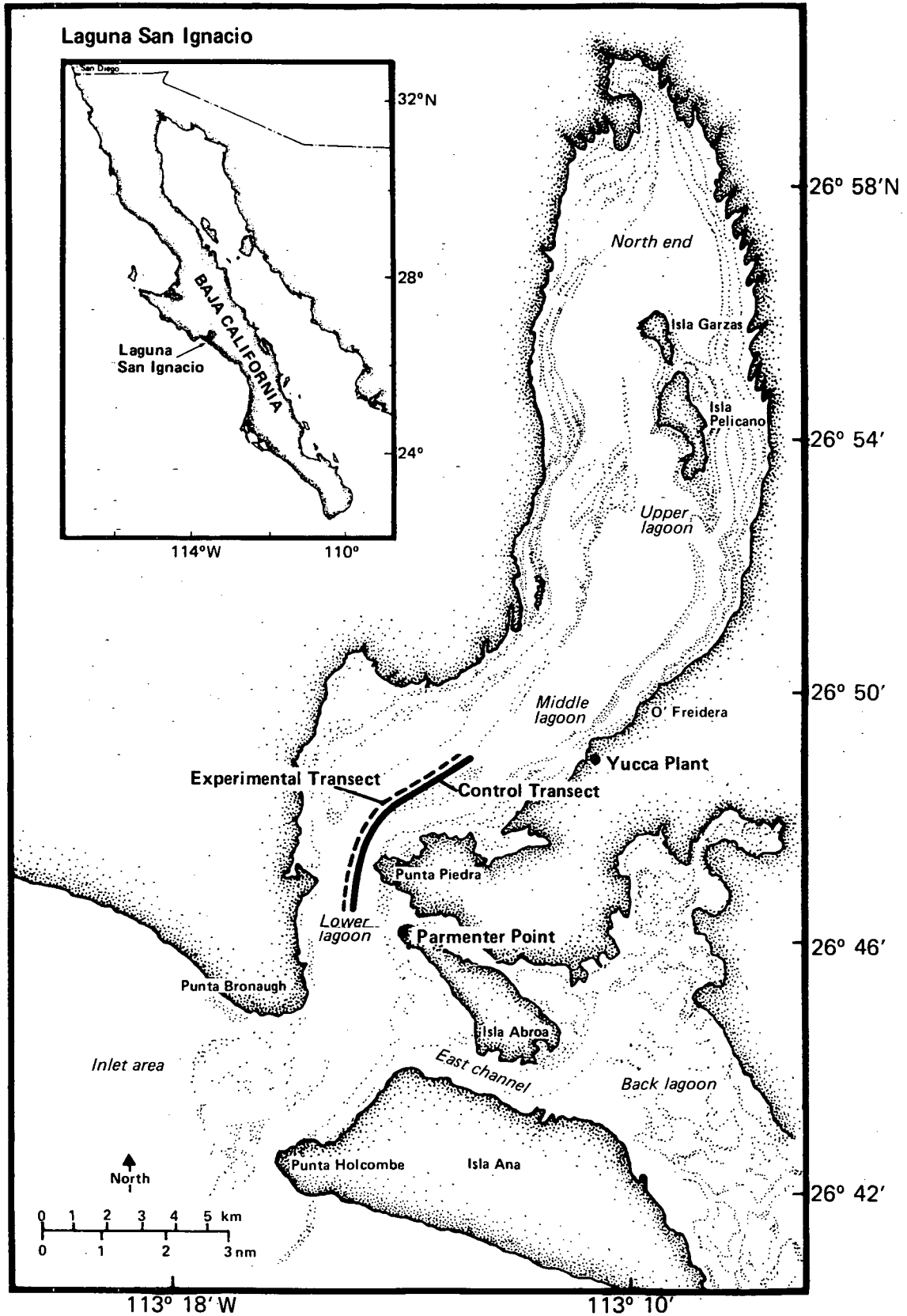
Figure 35. 1984 Vessel Survey Transect Route of Entire Lagoon System.
From Jones and Swartz, 1984.



The survey team included two primary observers (left and right positions) and a vessel operator. Positions were rotated to prevent observer anticipation. All whales observed were counted as they were approximately abeam of the vessel to eliminate any confusion factor when counting whales. All sightings were recorded on a hand-held tape recorder. For example: when a cow/calf pair was observed east of the transect line heading north in the lagoon, the sighting was noted as C/CNE. Cow/calf pairs were counted as a single unit. If three single whales, as a group, were observed heading South on the west side of the transect line, the notation would be 3SW. Whales were also noted as follows: DU = direction unknown (observer was not able to clearly see the whale) and ND = no direction (whale was milling). Abundance estimates were based entirely upon these sighting data. Whale distribution was determined by noting (on the cassette tape): starting time of transect; time each whale was observed; passage of landmarks; and end time of transect. Transects were terminated when wave and wind conditions obscured whale blows which lowered the overall probability of whale detection (Beaufort 3 conditions = winds 12-18 km/hr).

In addition to the full transects conducted, allowing comparisons of overall abundance between the 1984 season and the 5-year data base (1978-1982) collected by Jones and Swartz (1984), modified transects were also conducted. These modified transects (= partials) employed the same methods as the full census; however, the length of the transect line was shortened. Surveys were run between Parmenter Point and Yucca Plant (4 nautical miles - Fig. 36). These shorter surveys allowed transects to be conducted during control periods, as well as during playback periods. The vessel survey team would begin surveying at Parmenter Point and proceed north to Yucca Plant. During this period, no active playback took place

Figure 36. 1984 Modified Transect Route -- Laguna San Ignacio, Mexico.



(= control transect). The 4-mile transect took approximately 50 minutes to complete. As the northbound survey vessel passed the Rocky Point Station, the land-based observer would note the time of passage. An additional 35 minutes were given by the shore-based observer to allow adequate time for the survey vessel to reach the northbound limit (Yucca Plant) of the survey tract. Exactly 35 minutes after the vessel had been sighted abeam of Rocky Point and confirmation was obtained by radio that the vessel had reached Yucca Plant, sound playback was initiated. At this time the survey vessel began its southbound transect (= experimental transect), starting at Yucca Plant and proceeding south to Parmenter Point. Surveys were conducted at various tidal stages and times of the day to avoid the influence of these environmental factors. To avoid bias, the survey team was not informed as to what, if any, playback was occurring. This experimental design allowed comparisons to be made between control and experimental transects for the 1984 season.

1984 Analysis of Gray Whale Sound Behavior

The analyses procedure of the 1984 acoustical behavior followed the methods described for the 1983 acoustical analyses detailed in Chapter 2 (Materials and Methods section). Six experimental groupings were defined for the 1984 season.

- 1) Control - no intervention of real man-made noise into the environment
- 2) Experiment A - real man-made sounds prevalent in environment
- 3) Experiment B - simulation of outboard engine noise
- 4) Experiment C - simulation of oil-drilling noise

5) Experiment D - simulation of killer whale sounds

6) Experiment E - equipment on, no sounds projected

Since the 1984 design did not employ a pre-trial, trial and post-trial period, intra-experimental comparisons were not necessary. For each experimental and control condition the following sound parameters were inspected: Call periodicity, changes in call types and changes in call structure. The detailed procedures regarding the analyses and subsequent statistical comparisons of these sound parameters are described in Chapter 2 (Materials and Methods - Analyses of Gray Whale Sound Behavior).

1984 Analysis of Tracking Experiments

The 1984 analyses on the respiration rates of gray whales followed the same procedures as those described in 1983 (Analyses of Observed Surface Behavior - Chapter 2). The 1984 data were also compared to the dive durations collected in 1983.

In addition to the data collected on the dive durations of gray whales, detailed information was also available in 1984 on the movements (tracklines) of the whales as they passed through the study area. As each whale came to the surface to respire, two simultaneous bearings were taken from the North and South stations. Bearings collected were then converted into x and y distance values for each blow (= sighting) through triangulation. Data were screened for obvious errors and those bearings giving unrealistic distances and/or distance lines that did not intersect were deleted from the data base. A computer program was written which allowed conversion of these x/y coordinates. For each value obtained, a position (mark) was scored on a chart for each respiration/sighting. The series of sightings were then connected to illustrate the trackline of a

specific whale. Based upon these tracklines, calculations were then made to determine the average distance travelled offshore and to investigate the amount of time spent travelling vs milling by the whale. These data were compared between control and experimental periods.

Also available was the start and end time of each whale's trackline. These values allowed calculations of the amount of time spent in the area by the whale to be compared between experiments.

To obtain the amount of time spent tracking a whale under various conditions, an inspection of the effort log combined with the data entry form used during tracking experiments, was investigated. The percentage of time spent per experiment on a trackable whale as a reflection of the effort expended was thus obtained.

1984 Analysis of Transect Experiments

Sighting data stored on cassette tapes were transcribed to a written edit sheet. The edit sheets contained not only whale counts but also identified the time of passage of landmarks and start and end times of the transects. The information on these edit sheets was then transferred to a daily summary sheet. From each summary sheet, the abundance and distribution of whales per specific area could be determined. In addition to the abundance and distribution values, each sighting record noted the direction in which the whales were heading. The coding system employed during these surveys allowed an inspection of different directions and milling rates of the whales to be made among experiments. Seasonal comparisons were made between control and experimental transects examining abundance, distribution, direction, and milling. Between-season comparisons (1984 to 1978-1982) were only accomplished on abundance estimates.

RESULTS

1984 Calling Rates

Significant differences occurred between the calling rates obtained for each experimental test period (Anova, $df = 4$, $f = 257.3$, $p < 0.05$). Calling rates were highest when whales were exposed to real sources in the environment ($159.6 \pm \text{s.d. } 35.5$ sounds produced per hour). In the presence of outboard engine noise, these rates were $137.9 \pm \text{s.d. } 24.7$ per hour. In both cases, vessel noise resulted in higher calling rates than control periods. Rates decreased dramatically from those collected during control periods in the presence of oil-drilling sounds ($14.9 \pm \text{s.d. } 7.4/\text{hr}$) and the projection of killer whale sounds (all calling ceased). These results suggest that the amount of calling is dependent upon the type of sound source present in the environment. Table XII summarizes the rates of calling for each experiment. The statistics and detailed comparisons of these investigations are listed in Appendix C (1984 Calling Rates).

1983/1984 Comparisons of Calling Rates

Significant differences occurred in the calling rates of gray whales dependent upon the signal presentation and/or duration of the perturbation. Calling rates for 1983 were based upon the number of calls produced per 15-min interval. For the purposes of these comparisons, the 1983 rates were adjusted to represent the number of calls produced per hour. The calling rates of gray whales for the 1983 control periods (Chapter 2) averaged $73.6 \pm \text{s.d. } 19.2$ and those obtained in 1984 control periods were $81.4 \pm \text{s.d. } 16.6$. When compared, these control values were not significantly different ($t = 1.45$; $p > 0.05$). Calling rates produced by gray whales in the presence of real noise sources between 1983

Table XII. 1984 Calling Rates of Gray Whales in Laguna San Ignacio, Mexico (total number of sounds produced per hour includes mean, standard deviations and average range in parentheses).

CALLING RATES (number of calls produced per hour)	
CONTROL n = 40 hrs	81.4 $\pm$ s.d. 16.6 (32-106)
EXPERIMENT A Real Sources n = 40 hrs	159.6 $\pm$ s.d. 35.5 (90-246)
EXPERIMENT B Outboard Engine n = 40 hrs	137.9 $\pm$ s.d. 24.7 (100-200)
EXPERIMENT C Oil-Drilling Sounds n = 40 hrs	14.9 $\pm$ s.d. 7.4 (3-32)
EXPERIMENT D Killer Whale Sounds n = 40 hrs	No sounds produced
EXPERIMENT E Equipment on, no sounds projected n = 40 hrs	78.5 $\pm$ s.d. 17.0 (38-108)

167.7 $\pm$ s.d. 43.6) and 1984 (159.6 $\pm$ s.d. 35.5) were also similar ($t = 0.68$; $p > 0.05$). The presence of real sources for both years caused an elevation in calling rates when compared to control periods.

When the call rates of gray whales were compared between the two years in the presence of outboard engine noise, significant differences were detected ($t = 4.56$; $p < 0.05$). The 1983 calling rate of 182.0 $\pm$ s.d. 45.2 was significantly higher than the 1984 calling rate of 137.9 $\pm$ s.d. 24.7. Although the same tape was used during the 1983 and 1984 seasons, the presentation and duration of this stimulus varied between the years. In 1983 this sound stimulus was presented as a rapid onset of short-term noise, whereas in 1984 this vessel stimulus was phased in over time and was presented for longer durations. The results of these comparisons suggest that a higher rate of calling occurs when gray whales are exposed to short-term, rapid onset of noise. For both years, however, a higher rate of calling was documented in the presence of outboard engine noise when these trial values were compared to control periods.

An inspection of the projected sound stimuli that varied between the 1983 and 1984 field seasons (gray whale sounds and test tones in 1983 and oil-drilling and killer whale playbacks in 1984) yielded the following results.

In the presence of increased gray whale phonations, a call rate of 95.6 $\pm$ s.d. 23.6 calls per hour was established. When compared to the control values obtained in 1983 and 1984, an increase in calling rates was documented in the presence of their own signals. This rate was, however, lower than the calling rates obtained in the presence of vessel noise projected in 1983 and 1984 for both real source and outboard engine playback.

The projection of oil-drilling sounds reduced the total number of calls produced per hour. In the presence of this noise stimulus, gray whales produced an averaged of $14.9 \pm \text{s.d. } 7.4$ sounds per hour. This rate was significantly lower than those obtained for control periods, vessel noise, and gray whale signals. The most dramatic effect on calling rates was observed to occur in the presence of test tones and killer whale playback periods. These two sources caused gray whales to terminate all calling. Table XIII lists the calling rates obtained for the 1983 and 1984 seasons.

1984 Call Types

In 1984, as in 1983, the S1 signal dominated the vocal repertoire of the gray whale during control periods, representing 85% of the calls produced. Of the remaining call types, S2 signals occurred 5%, S3 signals occurred 5%, and S4 signals occurred 5%. During all 1984 experimental periods, with the exception of killer whale playback when all calling ceased, the S1 signal remained dominant in the sound repertoire of the gray whale. Table XIV summarizes the results of these 1984 investigations on call types.

1984 Call Structure

Exposure of gray whales to real sources, outboard engine noise, and oil-drilling sounds resulted in marked differences in gray whale call structure (increased values) when compared to control periods and test periods of Experiment E (equipment on, no sounds projected). Overall, similar acoustical variables and rates of change occurred when these three sound sources were compared. These results imply that similar mechanisms are employed by gray whales independent of the type

Table XIII. Comparisons of 1983 and 1984 Calling Rates of Gray Whales occupying Laguna San Ignacio, Mexico (mean and standard deviations). *

	1983 Season **	1984 Season
CONTROL	73.6 $\pm$ s.d. 19.2 n = 3.5 hrs	81.4 $\pm$ s.d. 16.6 n = 40 hrs
REAL SOURCES	167.6 $\pm$ s.d. 43.6 n = 3.5 hrs	159.6 $\pm$ s.d. 35.5 n = 40 hrs
OUTBOARD ENGINE	182.0 $\pm$ s.d. 45.2 n = 3.5 hrs	137.9 $\pm$ s.d. 24.7 n = 40 hrs
GRAY WHALE SOUNDS	95.6 $\pm$ s.d. 23.6 n = 3.5 hrs	No testing
OIL-DRILLING	No testing	14.9 $\pm$ s.d. 7.4 n = 40 hrs
TEST TONE	Ceased all calling n = 3.5 hrs	No testing
KILLER WHALE	No testing	Ceased all calling n = 40 hrs

* 1983 values multiplied by 4 to represent call rate per hour.

** Represents rates obtained during trial periods.

Table XIV. 1984 Call Types Produced by the Gray Whale in Laguna San Ignacio, Mexico.

	PERCENTAGE OF CALL TYPES PRODUCED			
	S1 SIGNAL	S2 SIGNAL	S3 SIGNAL	S4 SIGNAL
CONTROL	85%	5%	5%	5%
EXPERIMENT A REAL SOURCES	85%	5%	5%	5%
EXPERIMENT B OUTBOARD ENGINE	85%	5%	5%	5%
EXPERIMENT C OIL DRILLING	97%	1%	1%	1%
EXPERIMENT D KILLER WHALE	0	0	0	0
EXPERIMENT D EQ.ON - NO SOUNDS PROJECTED	85%	5%	5%	5%

of sound source present in the environment. The 1984 values obtained for call structure are listed in Table XV.

The presence of real sounds and the projection of outboard engine noise elicited similar structural changes in the gray whale's S1 signal. Received levels, compared between these two experiments, showed comparable values (real sources = $148.5 \pm \text{s.d. } 12.2$ and outboard = $150.2 \pm \text{s.d. } 12.8$) and were not significantly different ($t = 0.8$, $p > 0.05$). The number of signals exhibiting frequency modulation was also similar (real sources = 90% and outboard engine playback = 86.2%) (Chi Square = 0.37; $p > 0.05$). As expected from previous comparisons, a significant difference in call duration was not found (real sources = $2.0 \pm \text{s.d. } 1.0$ and outboard playback = $2.0 \pm \text{s.d. } 0.8$) ($t = 0.07$; $p > 0.05$). An inspection of the number of pulses produced per series also yielded similar values (real sources = $25.4 \pm \text{s.d. } 8.5$ and outboard = $23.1 \pm \text{s.d. } 6.9$) ($t = 1.8$; $p > 0.05$). When comparing these two sound stimuli, repetition rates, although slightly higher in the presence of real sources (12.7 per sec), were close to the value calculated in the presence of outboard engine noise (11.5 per sec). The overall frequency range of the signal and the emphasized frequency bands were also similar between these two experiments.

When comparing real and/or outboard engine noise against the structural values obtained in the presence of oil-drilling sounds, the majority of comparisons suggested that similar changes were occurring among the three experiments. One acoustical variable, however, was significantly different among these testing periods. When the received level of the call was compared between the presence of real sources ($148.5 \pm \text{s.d. } 12.2$) and oil-drilling sounds ($143.1 \pm \text{s.d. } 9.4$), significant differences were obtained ($t = 3.1$; $p < 0.05$). This was also the case

Table XV. 1984 Structural Changes in the Calls of Gray Whales Occupying Laguna San Ignacio, Mexico.

	Frequency Range (Hz)	Emphasized Frequencies (Hz)	Received Levels (dB re 1 μ Pa)	Percent Frequency Modulation	Duration (sec)	Number Pulses/ Series	Pulse Repetition Rates *
CONTROL n = 80 sounds	100-2000	350-850	120.3 $\pm$ 17.6 (86-168)	68.7	1.9 $\pm$ 0.8 (0.3-4.6)	9.9 $\pm$ 4.0 (2-30)	5.2
REAL SOURCES n = 80 sounds	150-1800	300-800	148.5 $\pm$ 12.2 (124-180)	90.0	2.0 $\pm$ 1.0 (0.5-5.3)	25.4 $\pm$ 8.5 (14-52)	12.7
OUTBOARD ENGINE n = 80 sounds	120-1900	320-860	150.2 $\pm$ 12.8 (120-180)	86.2	2.0 $\pm$ 0.8 (0.4-5.0)	23.1 $\pm$ 6.9 (12-50)	11.5
OIL DRILLING n = 80 sounds	110-2000	310-850	143.1 $\pm$ 9.4 (129-178)	92.5	1.8 $\pm$ 0.9 (0.4-5.2)	25.4 $\pm$ 7.4 (10-48)	14.1
KILLER WHALE	0	0	0	0	0	0	0
EQUIPMENT ON - NO SOUNDS n = 80 sounds	140-1800	340-860	119.6 $\pm$ 14.3 (92-160)	66.2	1.9 $\pm$ 0.8 (0.4-4.2)	9.3 $\pm$ 5.4 (2-32)	4.9

* Derived from average call duration and the average number of pulses produced per series.

when the received levels of the call were compared between outboard engine noise ($150.2 \pm \text{s.d. } 12.8$) and oil-drilling noise ($143.1 \pm \text{s.d. } 9.4$) ($t = 3.9$; $p < 0.05$). Received levels were significantly higher in the presence of vessel noise (real and outboard engine) than those obtained in the presence of oil-drilling sounds. The statistical values obtained for the other acoustical variables tested during these comparisons are given below. Real vs oil-drilling comparisons: frequency modulation (Chi Square = 0.15, $p > 0.05$); duration ($t = 1.05$; $p > 0.05$); number of pulses per series ($t = 0.009$; $p > 0.05$); and repetition rates 12.7 vs 14.1. Outboard vs oil-drilling comparisons: frequency modulation (Chi Square = 1.45; $p > 0.05$); duration ($t = 1.23$; $p > 0.05$); number of pulses per series ($t = 1.96$; $p = 0.05$); and repetition rates 11.5 vs 14.1. The frequency range of the signal and the emphasized frequency bands were similar for all three experiments.

During the projection of killer whale sounds, all gray whale vocalizations ceased; thus, structural comparisons among experiments could not be completed. Detailed comparisons and resultant statistics are given in Appendix C (1984 Call Structure).

1983/1984 Comparisons of Call Structure

The combined results of the 1983/84 seasons documented a measurable difference in received levels of calls, amount of frequency modulation within signals, number of pulses produced per series, and repetition rates of signals in the presence of increased noise. Frequency range, emphasized frequency bands and call duration was not altered in the presence of noise. Table XVI lists the values obtained for the 1983 and 1984 comparisons of call structure.

Table XVI. 1983 and 1984 Comparisons of Structural Changes in the Calls of Gray Whales in Laguna San Ignacio, Mexico (mean values and standard deviations).*

	Frequency Range (Hz)	Emphasized Frequencies (Hz)	Received Levels (dB re 1 μ Pa)	Percent Frequency Modulation	Duration (sec)	Number Pulses/ Series	Pulse Repetition Rates **
CONTROL							
1983	100-2000	300-825	117.6 $\pm$ 14.2	71.4	1.7 $\pm$ 0.8	9.4 $\pm$ 4.4	5.4
1984	100-2000	300-850	120.3 $\pm$ 17.6	68.7	1.9 $\pm$ 0.8	9.9 $\pm$ 4.0	5.2
EXPERIMENT E							
1984	140-1800	340-860	119.6 $\pm$ 14.3	66.2	1.9 $\pm$ 0.8	9.3 $\pm$ 5.4	4.9
REAL SOURCES							
1983	120-1800	280-700	148.8 $\pm$ 9.8	85.7	2.0 $\pm$ 1.1	24.6 $\pm$ 8.0	12.0
1984	150-1800	300-800	148.5 $\pm$ 12.2	90.0	2.0 $\pm$ 1.0	25.4 $\pm$ 8.5	12.7
OUTBOARD ENGINE							
1983	150-2000	300-800	156.6 $\pm$ 9.5	83.3	2.0 $\pm$ 0.9	22.6 $\pm$ 6.8	11.3
1984	120-1900	320-860	150.2 $\pm$ 12.8	86.2	2.0 $\pm$ 0.8	23.1 $\pm$ 6.9	11.5
GRAY WHALE							
1983	100-2000	300-790	126.4 $\pm$ 11.7	95.2	1.9 $\pm$ 0.9	12.8 $\pm$ 6.7	6.6
OIL DRILLING							
1984	110-2000	310-850	143.1 $\pm$ 9.4	92.5	1.8 $\pm$ 0.9	25.4 $\pm$ 7.4	14.1
TEST TONE***							
1983	0	0	0	0	0	0	0
KILLER WHALE***							
1984	0	0	0	0	0	0	0

* Sample size for 1983 = 42 sounds analyzed and in 1984 80 sounds per experiment were analyzed.

** Derived from average call duration and the average number of pulses produced per series.

*** All signalling ceased in the presence of this sound stimulus.

When control periods were compared between 1983 and 1984, the following results were obtained. The received level of the call was similar for both years (1983 = $117.6 \pm \text{s.d. } 14.2$ and 1984 = $120.3 \pm \text{s.d. } 17.6$) ($t = 0.8$; $p > 0.05$). The number of signals that were frequency modulated was also similar between the 1983 (71.4%) and 1984 seasons (68.7%) (Chi Square = 0.06; $p > 0.05$). The number of pulses produced per series for control 1983 was $9.4 \pm \text{s.d. } 4.4$, and $9.9 \pm \text{s.d. } 4.0$ for the 1984 season. These values were also similar ($t = 0.6$; $p > 0.05$). Comparable repetition rates were derived for both the 1983 and 1984 seasons (5.4 and 5.2 pulses per sec, respectively). The similarities obtained for control periods of both 1983 and 1984 are suggestive of an optimal/preferred call rate and call structure for gray whales occupying Laguna San Ignacio.

Real sources and their effect on call structure were compared between the 1983 and 1984 seasons and significant differences in call structure could not be obtained. The received level of the call in 1983 was $148.8 \pm \text{s.d. } 9.8$ and $148.8 \pm \text{s.d. } 12.2$ in 1984. These values were not statistically different ($t = 0.09$; $p > 0.05$). In 1983, 85.7% of the signals were frequency modulated. When this value was compared to the 90% obtained in 1984, once again significant differences were not detected (Chi Square = 0.5; $p > 0.05$). An inspection of the number of pulses produced per series was also similar between the two years (1983 = $24.6 \pm \text{s.d. } 8.0$ and 1984 = $25.4 \pm \text{s.d. } 8.5$) ($t = 0.5$; $p > 0.05$). Calculated repetition rates were 12.0 for 1983 and 12.7 for 1984.

A comparison of the structural changes occurring in the S1 signal in the presence of outboard engine noise between 1983 and 1984 yielded the following results. The 1983 received level was $156.6 \pm \text{s.d. } 9.5$. This value was statistically higher than that obtained in 1984 ($150.2 \pm \text{s.d. }$

12.8) ($t = 2.85$; $p < 0.05$). Similar values were obtained for the remaining acoustical variables in the presence of outboard engine noise and are summarized below. Frequency modulation in 1983 equals 83.3% vs 86.2% in 1984 (Chi Square = 0.14; $p > 0.05$); number of pulses produced per series, 1983 = $22.6 \pm \text{s.d. } 6.8$ and 1984 = $23.1 \pm \text{s.d. } 6.9$ ($t = 0.4$; $p > 0.05$); and repetition rates for 1983 were 11.3 per sec vs 11.5 per sec for 1984. Overall the presence of outboard engine noise elicited similar responses for the 1983 and 1984 seasons. The differences obtained in the received levels of the call between the two seasons could be due to differences in signal presentation and/or duration.

An inspection of the structural changes observed in the presence of increased gray whale phonations (1983) and oil-drilling playback periods (1984) also documented changes in received levels, number of signals showing frequency modulation, number of pulses produced per series, and repetition rates of calls. The values obtained in the presence of gray whale signals, although modified from controls, did not typically match the higher rates obtained during the presence of vessel noise and/or oil-drilling sounds. However, the number of signals exhibiting frequency modulation was 95.2% in the presence of their own signals, a value significantly higher than other test periods.

1984 Observed Surface Behavior - Tracking Experiments

Average dive duration of whales during the 1984 season (when exposed to a variety of experimental conditions) was $92.5 \pm \text{s.d. } 58.1$ sec ($n = 1287$ dives). A frequency distribution of these dive times by 10-sec categories is represented in Figure 37. Of the 128 whales tracked, 61 (768 dives) were cow/calf pairs. The average dive time of these cow/calf pairs (blow rate collected on adult female) was $70.9 \pm \text{s.d. } 30.7$ sec. This dive duration was statistically different ($t = 4.57$; $p < 0.05$) from the average dive duration obtained for single whales at $107.7 \pm \text{s.d. } 55.5$ sec ($n = 67$ whales, total dives = 519). Figure 38 graphically represents the frequency distribution of dives for cow/calf pairs and single whales.

When cow/calf pair and single whale dive times were compared among control, real sources, outboard engine playback, and oil-drilling playback periods, significant difference in dive durations could not be established among the events (ANOVA, $df = 3$, $F = 0.92$; $p > 0.05$; ANOVA, $df = 4$, $F = 0.76$, $p > 0.05$, respectively). Valid comparisons could not be accomplished during killer whale playbacks since cow/calf pairs did not enter the area. The dive durations calculated for both groups of whales during control and experimental conditions are listed in Table XVII.

When the dive durations of gray whales were compared between the 1983 and 1984 seasons, significant differences in these rates were obtained. In 1983, the overall dive duration of all whales exposed to a variety of environmental conditions was $68.0 \pm \text{s.d. } 34.0$ sec. In 1984, this rate increased to $92.5 \pm \text{s.d. } 58.1$ sec. Dive durations in 1984 were significantly longer than those observed in the 1983 season ($t = 3.7$; $p < 0.05$). To determine if cow/calf pairs and/or single whales were responsible for these observed differences, comparisons were

Figure 37. 1984 Frequency Distribution of Dive Durations of Gray Whales Occupying Laguna San Ignacio, Mexico.

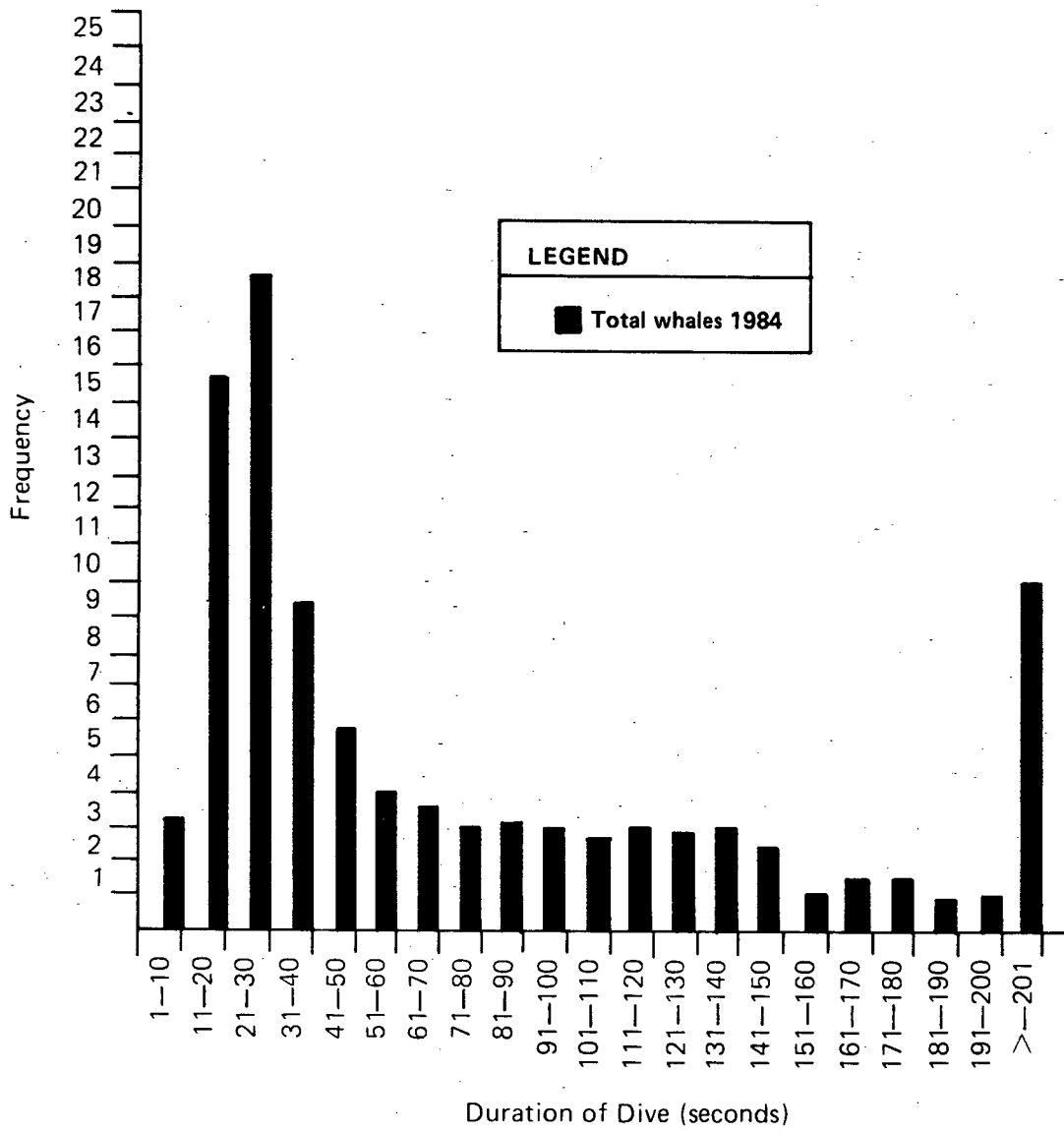


Figure 38. 1984 Frequency Distribution of Cow/calf Pairs and Single Whale Dive Durations in Laguna San Ignacio, Mexico.

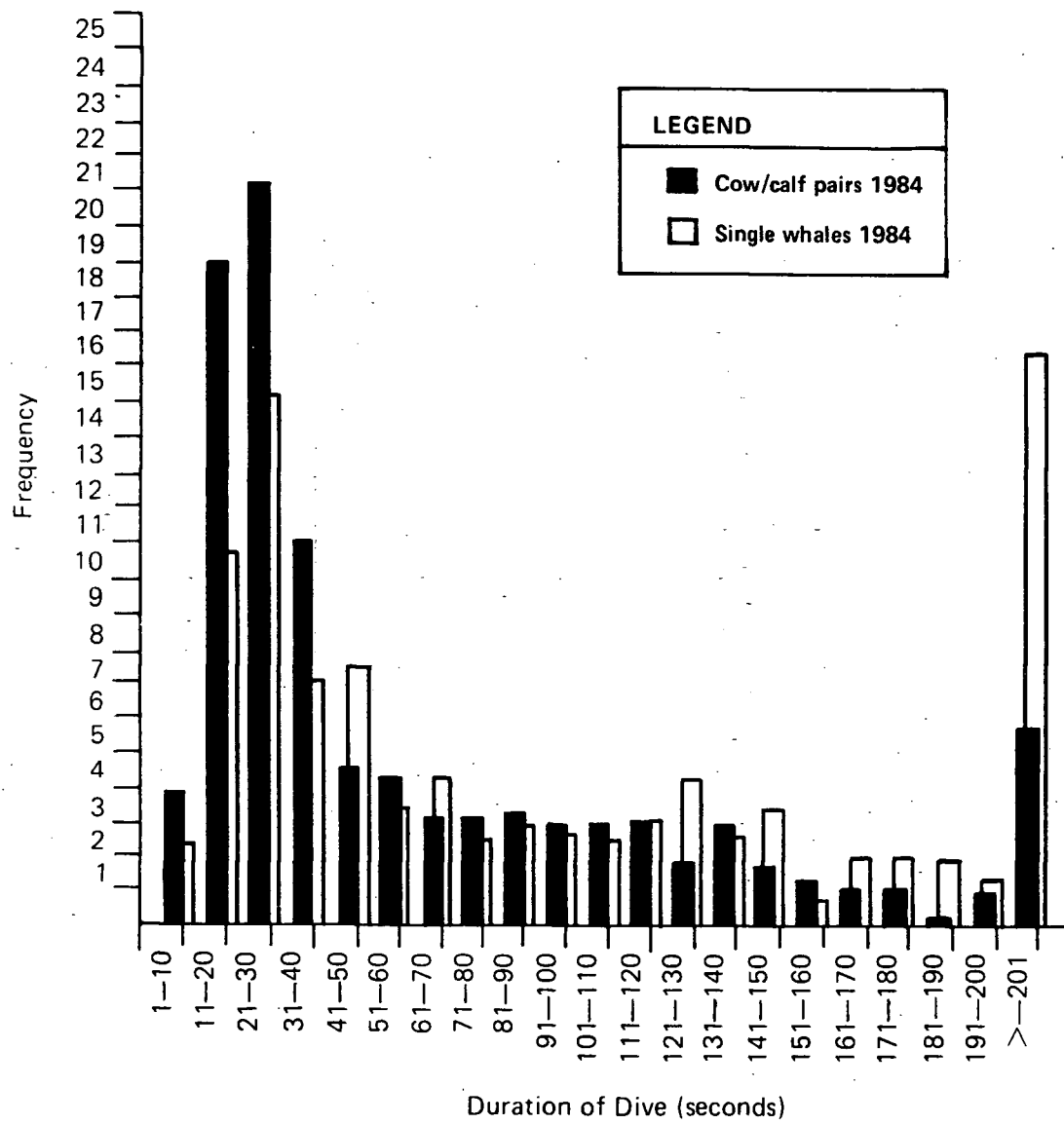


Table XVII. Average Dive Times (sec) of Gray Whales Exposed to Various Experimental Conditions During the 1984 Season in Laguna San Ignacio, Mexico (includes mean and standard deviations).

	SINGLE WHALES	COW/CALF PAIRS
CONTROL AND EXPERIMENT E	120.1 $\pm$ s.d. 32.7 n = 188 dives	67.1 $\pm$ s.d. 14.8 n = 278 dives
EXPERIMENT A Real Sources	125.8 $\pm$ s.d. 28.6 n = 127 dives	59.4 $\pm$ s.d. 21.3 n = 369 dives
EXPERIMENT B Outboard Engine	94.3 $\pm$ s.d. 46.7 n = 56 dives	83.8 $\pm$ s.d. 16.2 n = 33 dives
EXPERIMENT C Oil Drilling	81.0 $\pm$ s.d. 42.6 n = 86 dives	72.9 $\pm$ s.d. 12.4 n = 88 dives
EXPERIMENT D Killer Whale	113.2 $\pm$ s.d. 30.1 n = 62 dives	Pairs not present

made by whale group between the two seasons. When the dive durations of cow/calf pairs collected in 1983 ($49.1 \pm \text{s.d. } 14.8 \text{ sec}$) were compared to the dive times collected in 1984 ($70.9 \pm \text{s.d. } 30.7 \text{ sec}$), a significant difference was obtained ($t = 4.8$; $p < 0.05$). The dive times of cow/calf pairs in the 1984 season were significantly longer than those noted in 1983. When comparing the rates of single whales between the 1983 ($98.2 \pm \text{s.d. } 59.3 \text{ sec}$) and 1984 seasons ($107.7 \pm \text{s.d. } 55.5 \text{ sec}$), significant differences were not detectable ($t = 0.86$; $p > 0.05$). Similar dive durations were obtained for single whales between the two seasons. Table XVIII summarizes the values obtained and these data are graphically illustrated in Figures 39, 40 and 41.

Shore-based observers experienced days when they spent a considerable amount of time tracking whales in the immediate study area. Conversely, on some days, a considerable amount of effort was expended, but the number of whales actually tracked was low. As suggested by an inspection of the sample sizes in Table XVII, fewer whales were tracked for certain experimental conditions. Since each observer noted the time spent on effort each day and also had a record of the time spent tracking a whale, an estimate of the effort expended per day and per experiment and the percentage of time spent on a trackable whale could thus be quantified.

During control periods, observers spent 53% of the time tracking whales in the immediate study area. In the presence of real sources, this value was 46%. During the projection of outboard engine noise, this value decreased, and observers spent 38% of the time on trackable whales. A dramatic reduction in the number of available whales for tracking occurred during the playback of oil-drilling sounds and killer whale sounds. During the projection of oil-drilling sounds, only 9% of the

Table XVIII. 1983/1984 Comparisons of Average Dive Times of Gray Whales in Laguna San Ignacio, Mexico (mean and standard deviations).

	1983 Season	1984 Season
ALL WHALES	68.0 $\pm$ s.d. 34.0 n = 700 dives	92.5 $\pm$ s.d. 58.1 n = 1287 dives
SINGLE WHALES	98.2 $\pm$ s.d. 59.3 n = 261 dives	107.7 $\pm$ s.d. 55.5 n = 519 dives
COW/CALF PAIRS	49.1 $\pm$ s.d. 14.8 n = 439 dives	70.9 $\pm$ s.d. 30.7 n = 768 dives

Figure 39. 1983/1984 Frequency Distribution Comparisons of Dive Times on All Whales Occurring in Laguna San Ignacio, Mexico.

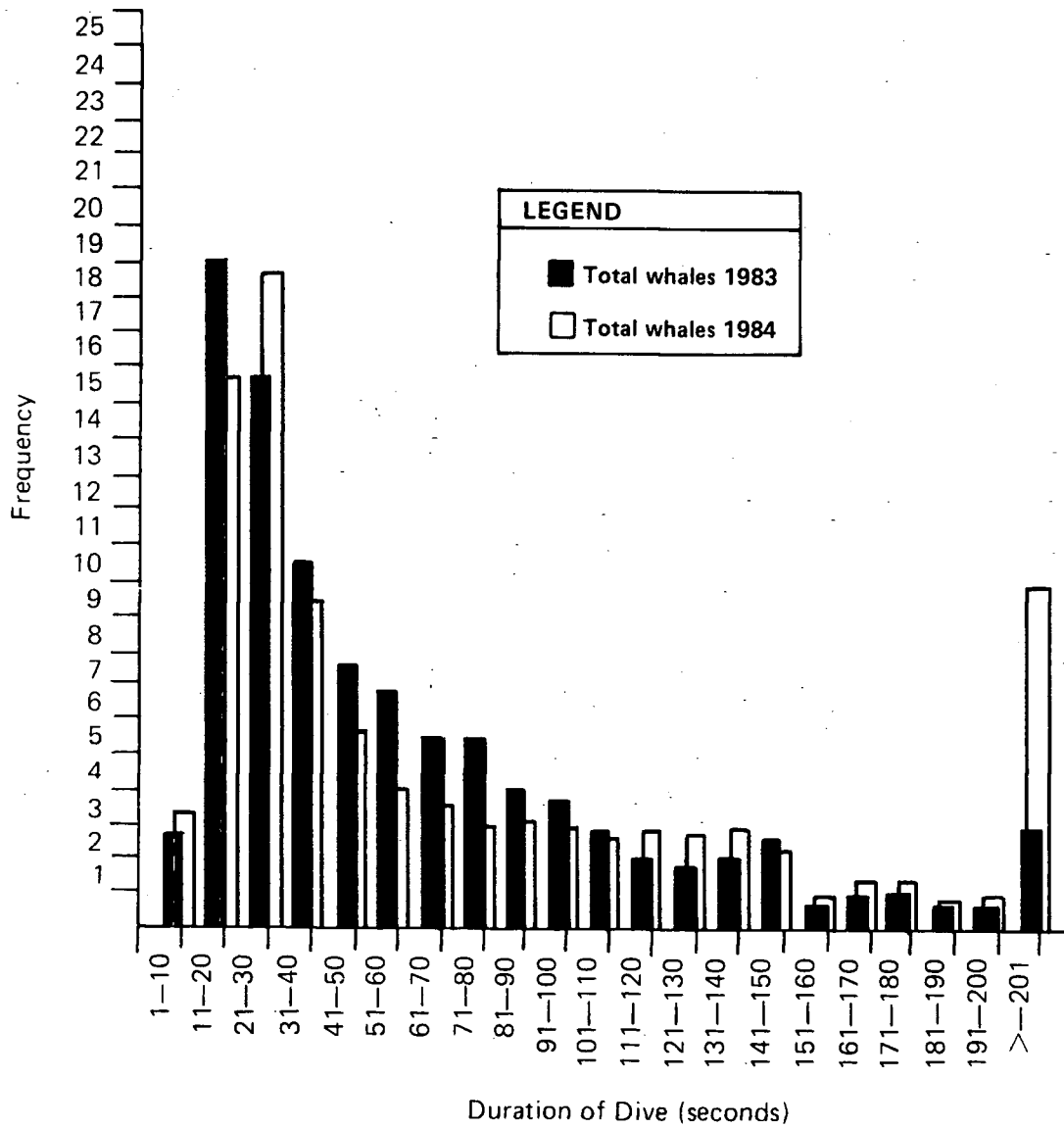


Figure 40. 1983/1984 Frequency Distribution Comparisons of Dive Durations of Cow/calf Pairs in Laguna San Ignacio, Mexico.

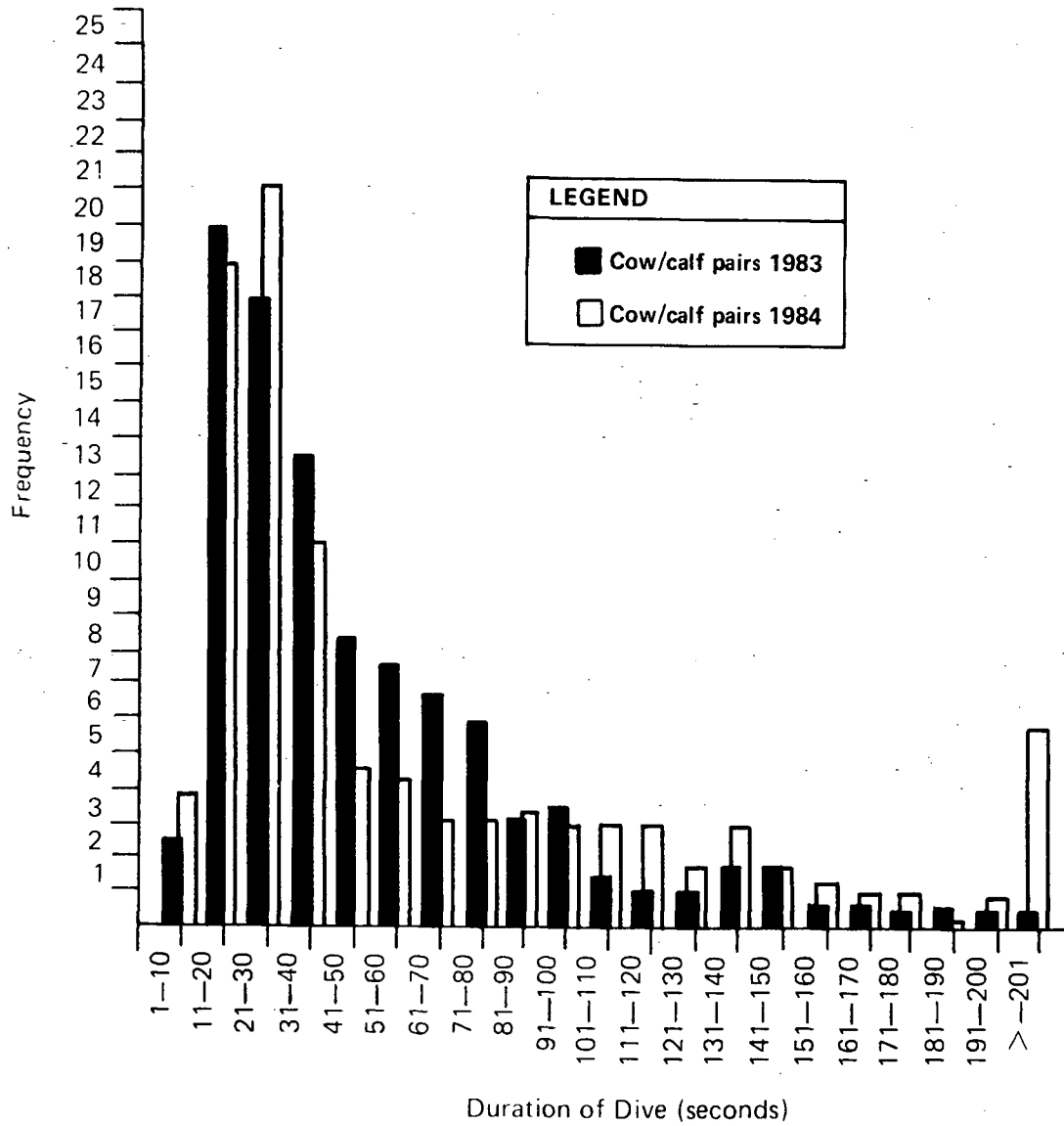
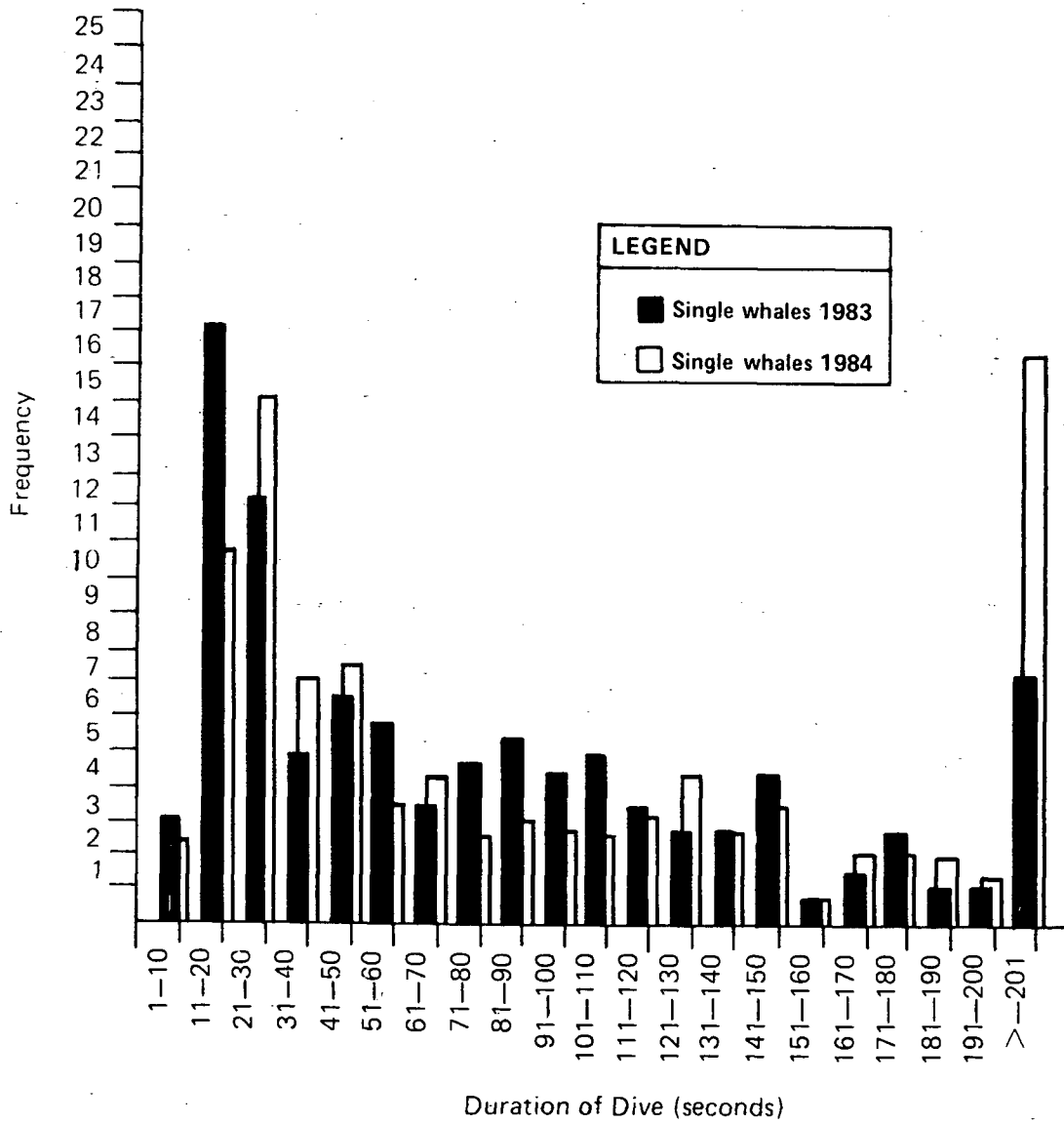


Figure 41. 1983/1984 Frequency Distribution Comparisons of Dive Durations on Single Whales in Laguna San Ignacio, Mexico.



time was spent tracking whales. During the playback of killer whale sounds, only 7% of the time was spent tracking whales. A breakdown by the number and types of whales, as well as the time spent per experiment tracking whales, is shown in Figure 42.

During control periods, whales typically were observed to travel directly through the study area with little evidence of milling taking place. The trackline depicted in Figure 43 demonstrates a typical movement pattern by a whale past the Rocky Point shore-station during control periods. The average perpendicular distance calculated offshore exhibited by these whales was $230.4 \pm \text{s.d. } 69.4$ meters. On the average, observers spent $6.4 \pm \text{s.d. } 4.0$ minutes observing each whale.

With real sources prevalent in the environment, whales once again showed a fairly direct trackline through the study area (Fig. 44). The average perpendicular distance travelled offshore was $243.9 \pm \text{s.d. } 70.9$ meters, which was not significantly different from control periods ($t = 0.86$; $p > 0.05$). The average time spent tracking a whale was $11.0 \pm \text{s.d. } 9.5$ minutes, a value similar to that obtained during control periods ($t = 0.42$; $p > 0.05$).

During the projection of outboard engine noise, the majority of whales were observed to transit directly through the study area; however, occasionally whales headed directly to the transducer site and were apparently attracted to the projected sounds (Fig. 45). The average perpendicular distance offshore was $261.5 \pm \text{s.d. } 92.0$ meters. This value was found to be similar to that obtained during control periods ($230.4 \pm \text{s.d. } 69.4$ meters) ($t = 0.39$; $p > 0.05$). During outboard engine playback, observers spent an average of 13.2 ± 9.6 minutes/whale, a value similar to that observed during control periods ($t = 1.78$; $p > 0.05$).

Figure 42. Percentage of Time Spent Tracking Whales Per Experimental Condition.

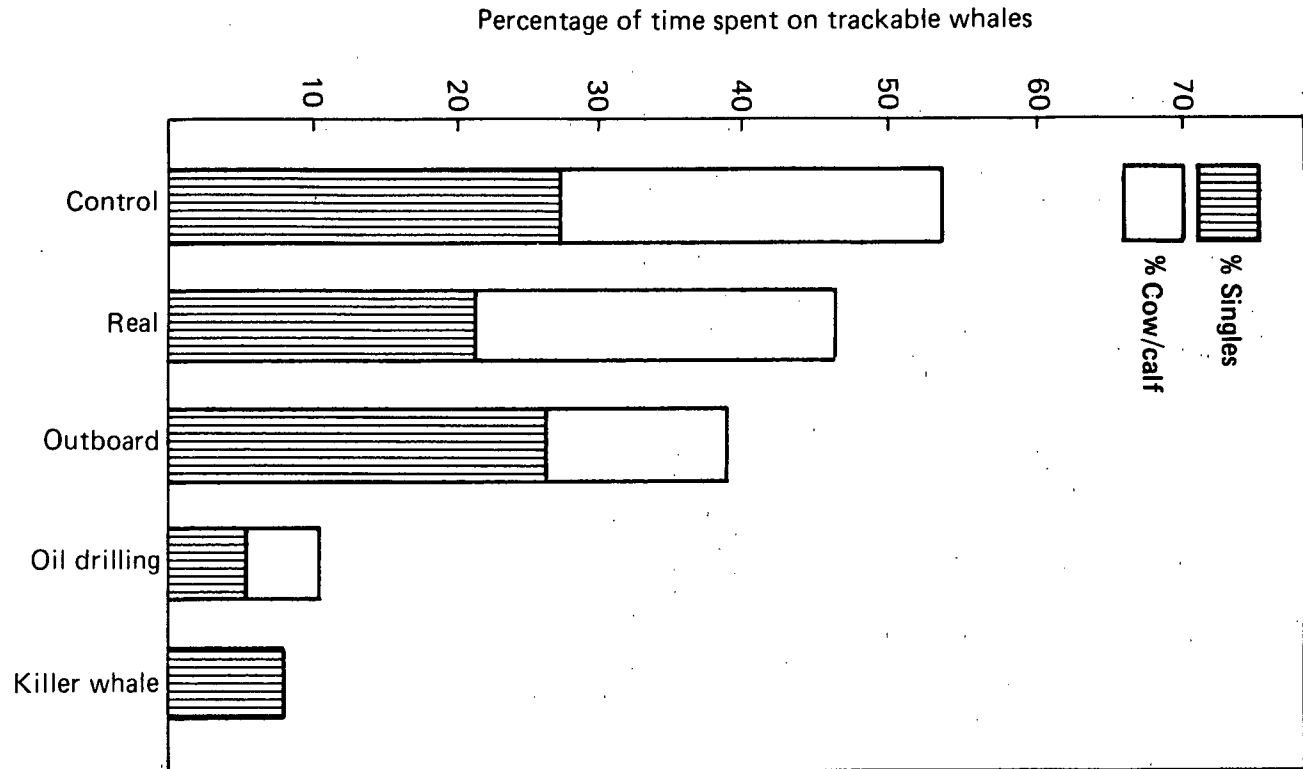


Figure 43. Trackline of Whale During Control Periods.
Whale movement right to left.

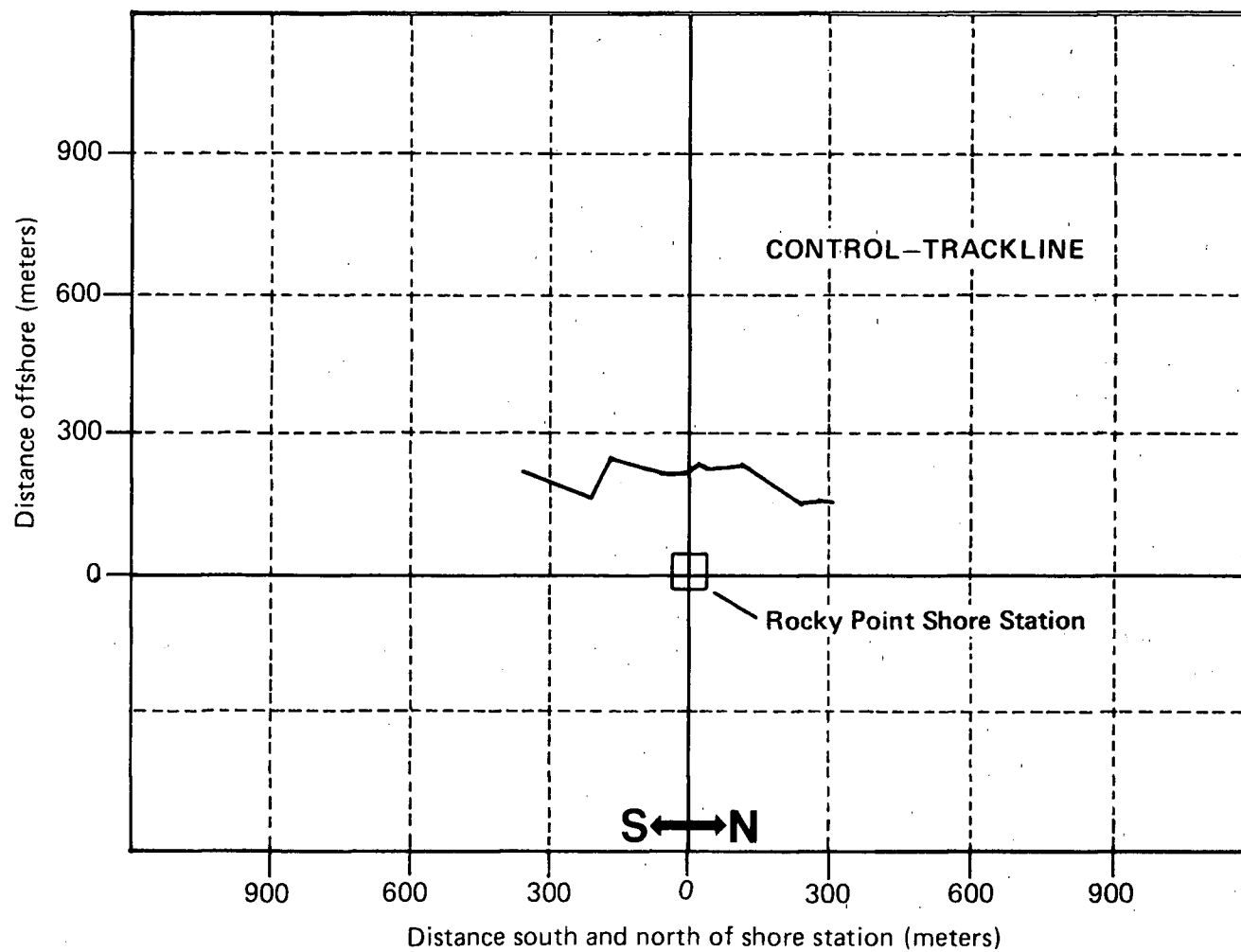


Figure 44. Trackline of Whale in the Presence of Real Sources.
Whale movement right to left.

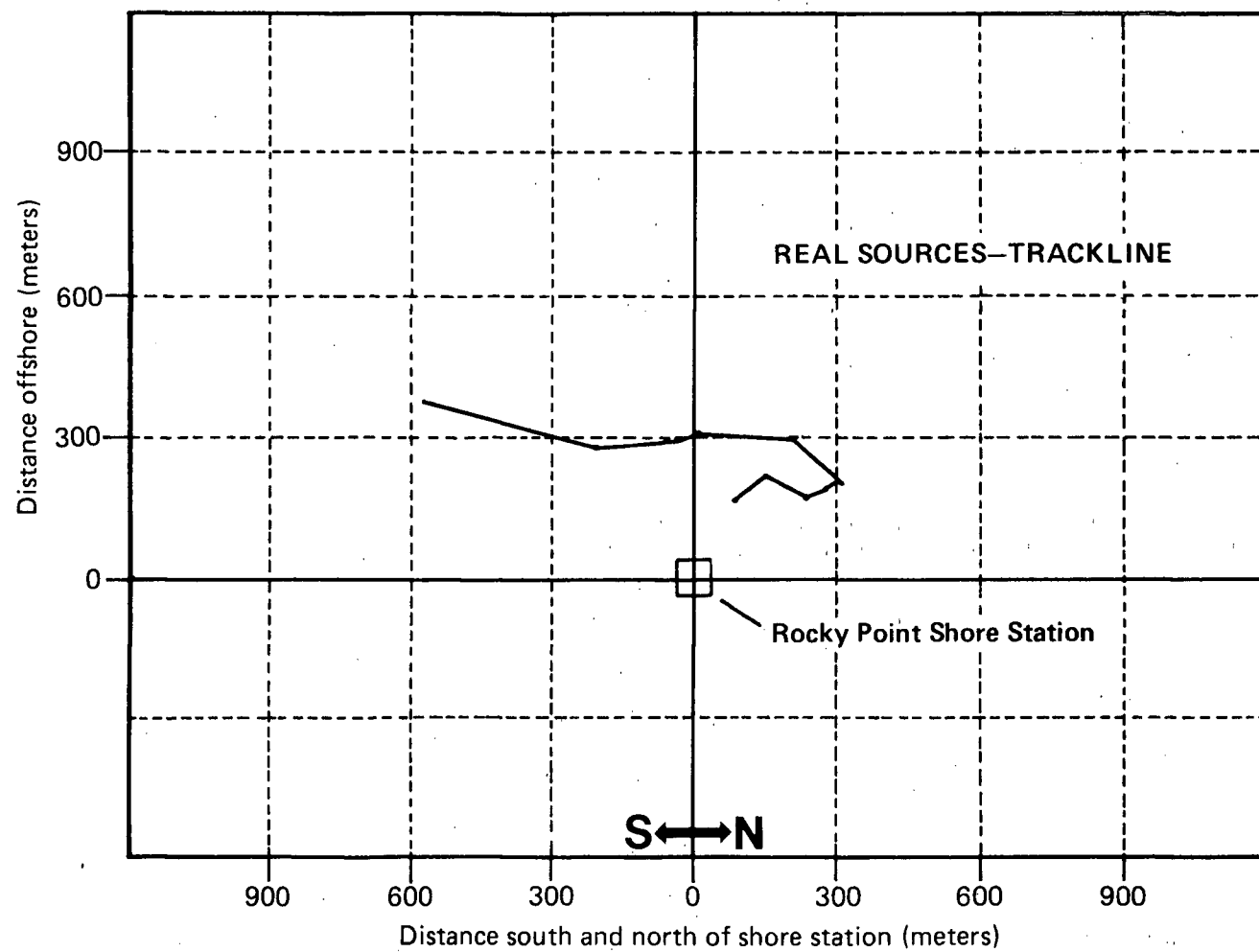
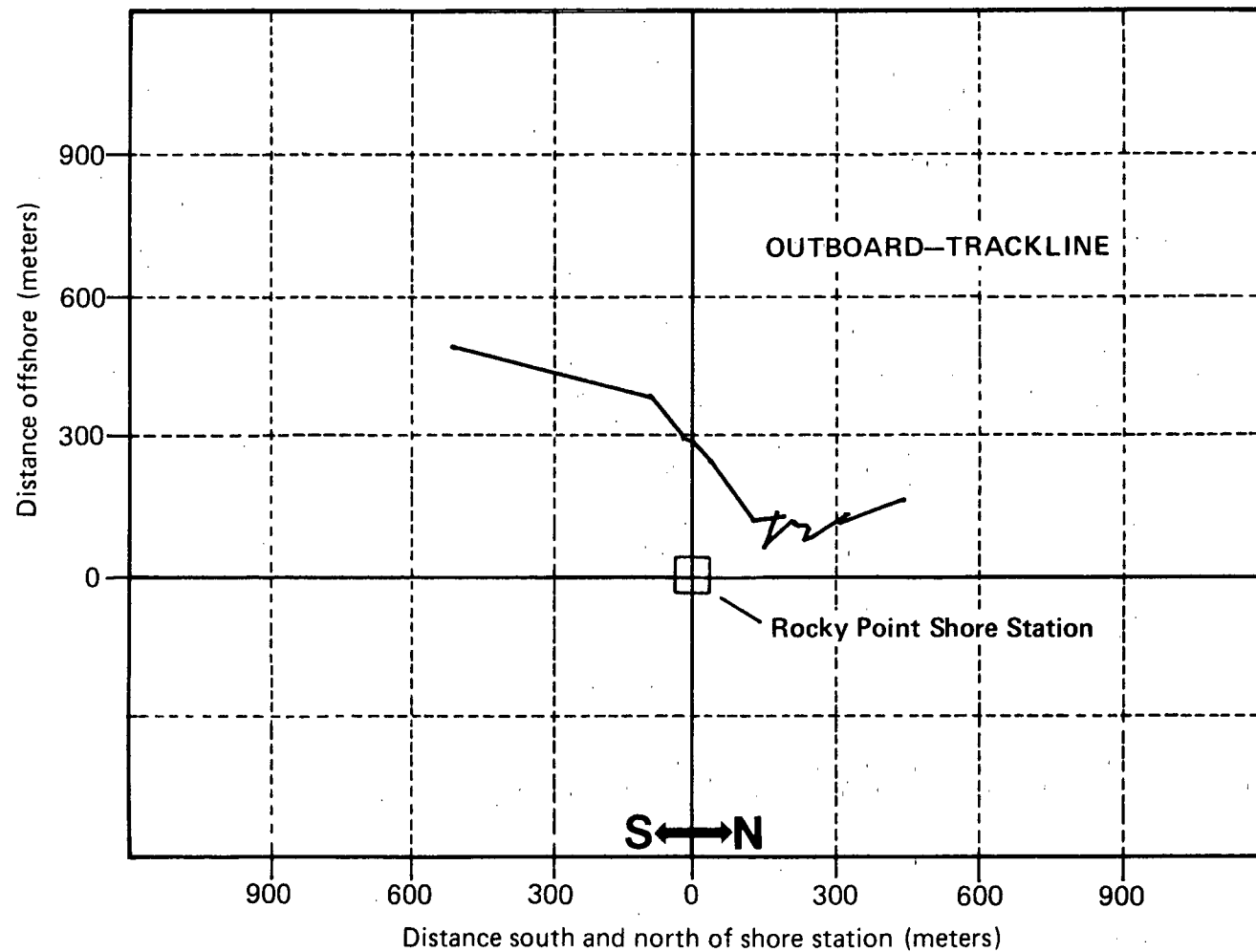


Figure 45. Trackline of Whale During Outboard Engine Playback Periods.
Whale movement right to left.



During oil-drilling playback periods, an increase was noted in the number of whales milling (64%) in the area vs travelling (36%) through the area (Fig. 46). The average offshore distance travelled by these whales was $238.7 \pm \text{s.d. } 108.7$ meters. When distances were compared between this experimental condition and control periods ($230.4 \pm \text{s.d. } 69.4$ meters), a significant difference was not detected ($t = 0.2$; $p > 0.05$). An average of $13.6 \pm \text{s.d. } 10.1$ minutes/whale was spent by observers tracking whales during the presence of oil-drilling sounds. This value was similar to control periods ($t = 1.48$; $p > 0.05$).

During killer whale playback periods, overt changes were documented in the movements of whales. Eighty-six percent (86%) of the whales tracked were observed to mill in the area. Typically a progressive movement through the study area was not documented (Fig. 47). Of those whales observed to travel through the area, the average offshore distance maintained by these whales in the presence of killer whale sounds was $335.1 \pm \text{s.d. } 72.5$ meters (Fig. 48). This offshore distance was significantly different than that obtained during control periods ($t = 3.21$; $p < 0.05$). Since whales were positioning themselves in one location for long periods of time and/or the fact that whales farther offshore took a longer time to transit through the study area (greater distances involved), the average time spent tracking a whale increased to $36.0 \pm \text{s.d. } 14.7$ minutes. When this value was compared to control periods, a significant difference was noted to occur ($t = 2.3$; $p < 0.05$).

A comparison of the various tracklines obtained during these experiments yielded the following results. Significant differences were not detected between control and vessel noise (real and outboard engine) in the distance travelled offshore, amount of time spent by the whale in

Figure 46. Trackline of Whale During Oil-drilling Playback Periods.
Whale movement left to right.

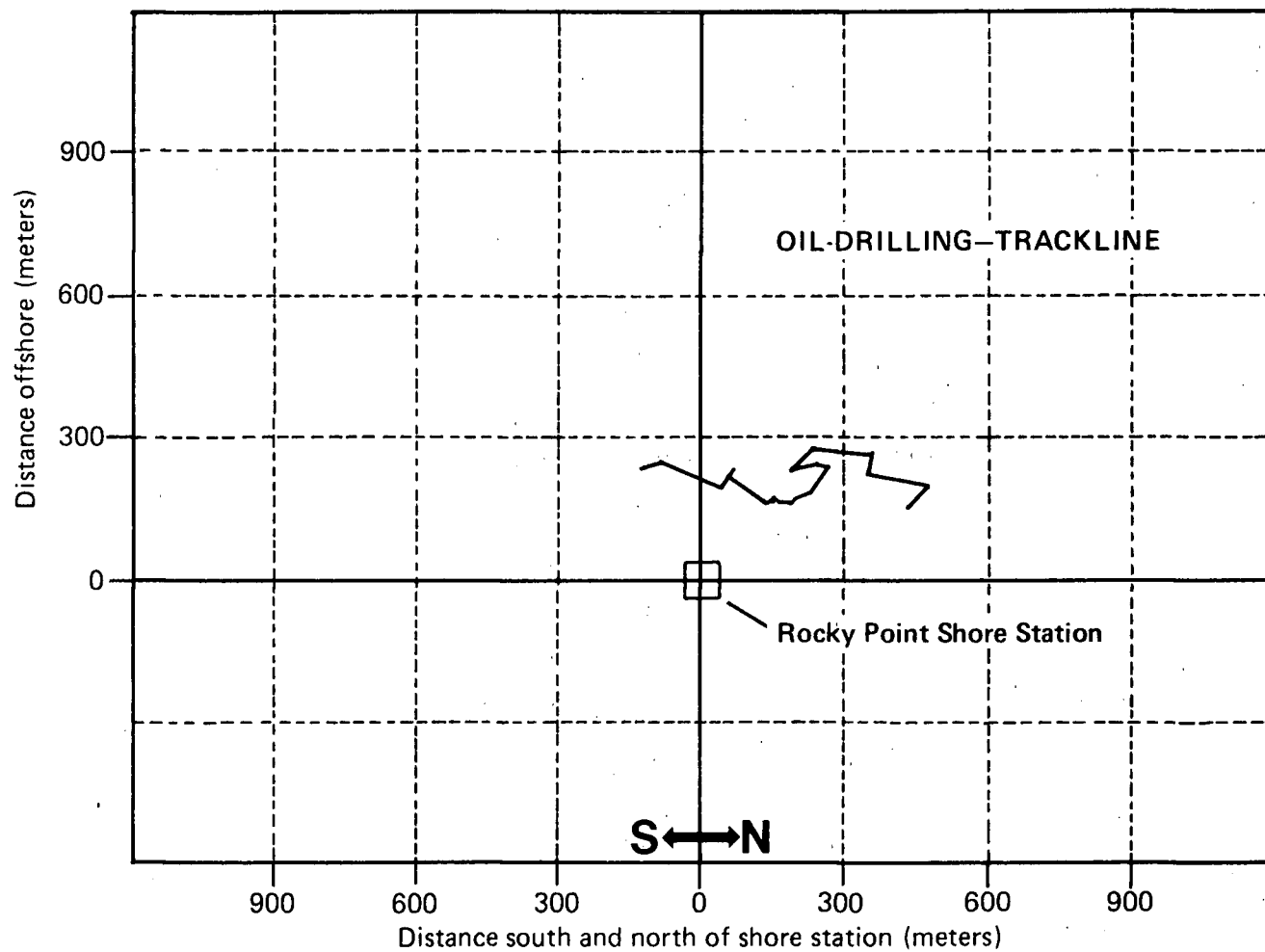


Figure 47. Trackline of Whale During Killer Whale Playback Periods (no progressive movement through area).

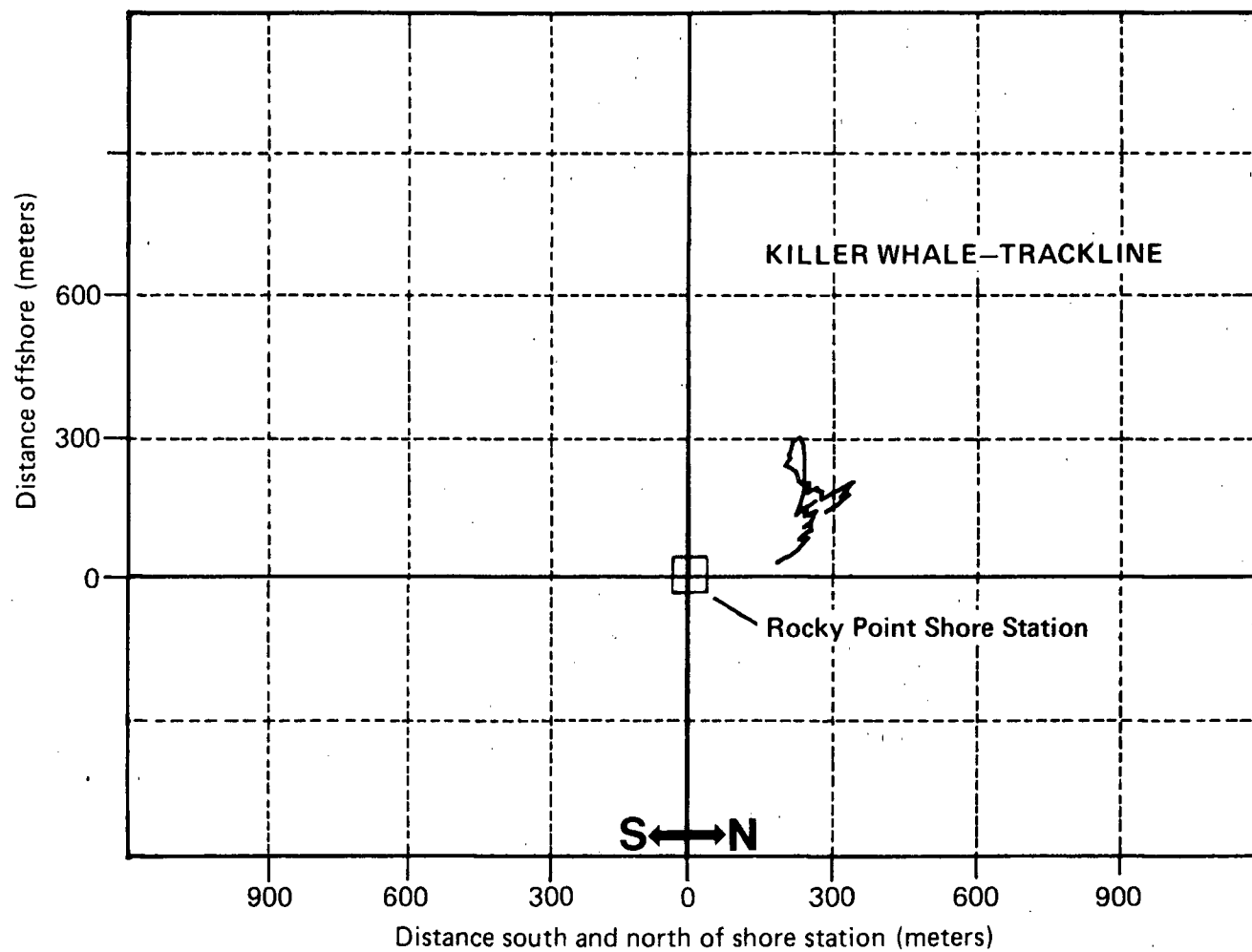
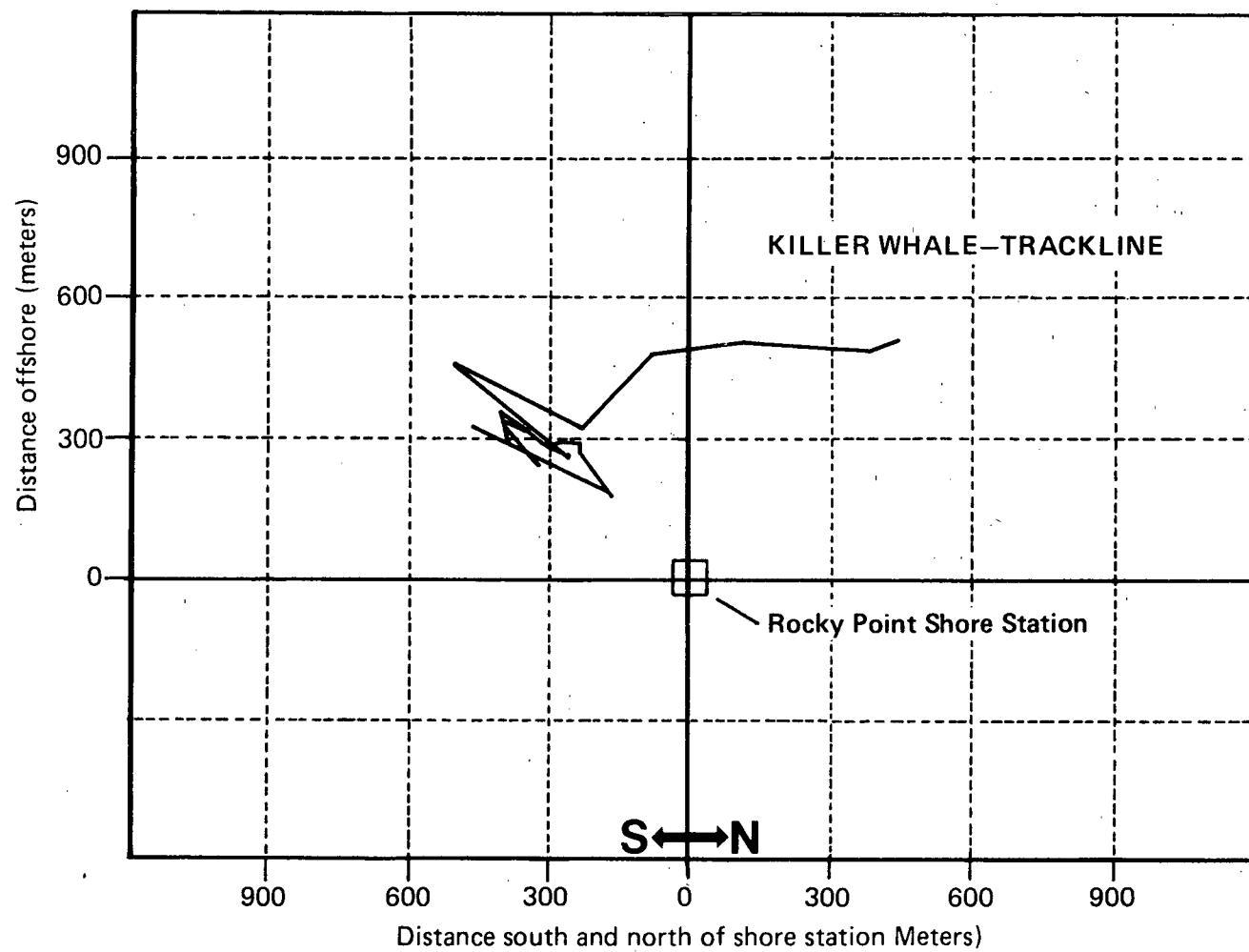


Figure 48. Trackline of Whale During Killer Whale Playback Periods (depicting increased distance offshore). Whale movement left to right.



the study area, and/or in the percentage of whales travelling vs milling. Oil-drilling playback periods did not elicit a change in the distance travelled offshore or in the amount of time a whale spent in the area. However, an appreciable increase in the number of whales observed to mill in the study area in the presence of oil-drilling sounds was documented.

Killer whale playback caused the greatest change to occur and, when compared to the other three experimental periods and the control periods, a significant increase was documented in: 1) distance travelled offshore, 2) amount of time spent in the area, and 3) number of milling whales. The values calculated for these tracking experiments are listed in Table XIX.

1984 Observed Surface Behavior - Transect Experiments

Seasonal Comparisons (Abundance/Distribution/Movements)

Four pair transects were completed during the 1984 season. Oil-drilling sounds were projected back on 6 February and 9 February 1984, and killer whale sounds were projected during the surveys conducted on 13 February and 20 February 1984. In addition to investigating the abundance and distribution of whales between control and experimental transects, the direction and milling rates of the whales were also compared between the paired transects.

A comparison of the total number of whales between control and experimental conditions inhabiting the waters of Parmenter Point to Yucca Plant resulted in a significant reduction of whales occurring in the area during experimental transects. On 6 February 1984, during control surveys, 73 whales were counted in these waters. During experimental periods, the number of whales occupying these waters decreased to 58. When

Table XIX. 1984 Trackline Data on Gray Whales Occurring in Laguna San Ignacio, Mexico
(Mean and standard deviations).

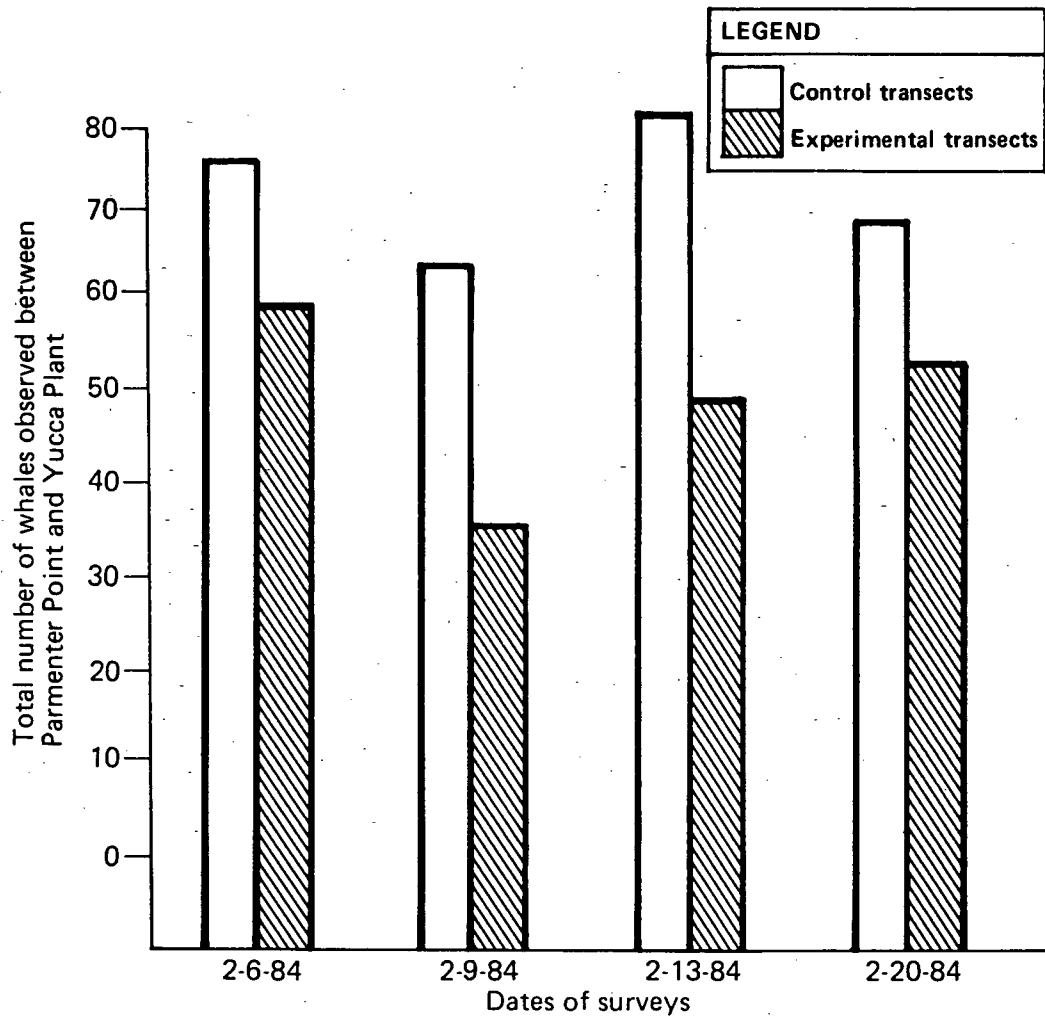
	Average Perpendicular Distance Offshore (m)	Amount of Tracking Time (minutes)	Percentage of Whales Travelling	Percentage of Whales Milling
CONTROL n = 466 dives	230.4 $\pm$ 69.4	6.4 $\pm$ 4.0	92.0	8.0
REAL SOURCES n = 496 dives	243.9 $\pm$ 70.9	11.0 $\pm$ 9.5	91.0	9.0
OUTBOARD ENGINE n = 89 dives	261.5 $\pm$ 92.0	13.2 $\pm$ 9.6	90.0	10.0
OIL DRILLING n = 174 dives	238.7 $\pm$ 108.7	13.6 $\pm$ 10.1	36.0	64.0
KILLER WHALE n = 62 dives	335.1 $\pm$ 72.5	36.0 $\pm$ 14.7	14.0	86.0

compared, a significant difference was obtained (Chi Square = 4.3; $p < 0.05$), with fewer whales occurring during experimental periods. On 9 February 1984, 63 whales occupied the area during control periods. In the presence of oil-drilling sounds, the count dropped to 36 whales. Experimental values were significantly lower than those obtained during control periods (Chi Square = 13.5; $p < 0.05$).

On 13 February 1984, 80 whales were observed during control surveys and 49 whales were counted during the experimental transect. Once again, a significant decrease in the number of whales occurring in the area was documented during playback periods (Chi Square = 19.6; $p < 0.05$). On 20 February 1984, a similar trend was documented. During controls, 67 whales were present. In the presence of killer whale sounds, this value dropped to 52 whales. A significant decrease occurred during experimental conditions (Chi Square = 4.06; $p < 0.05$). These data are graphically shown in Figure 49. The results from these comparisons document a decrease in the total number of whales occupying the waters of Parmenter Point to Yucca Plant, which indicates a shift in overall distribution by the whales in the presence of noise.

Assuming whales were potentially disturbed by increased levels of noise in the area, a movement away from the sound source would be expected. The analyses on whale abundance accomplished above indicate that this was indeed the case. An inspection of the direction of heading of the whales should then support these results. For example, if whales were located between Parmenter Point and Rocky Point (south of station), a southerly movement by the whales would 1) provide the best means of avoiding the sound source and 2) prevent the whale from being exposed to a higher source level of sound. Conversely, if whales were occupying the

Figure 49. A Comparison of the Total Number of Whales Occupying the Waters Between Parmenter Point and Yucca Plant During Control and Experimental Conditions.

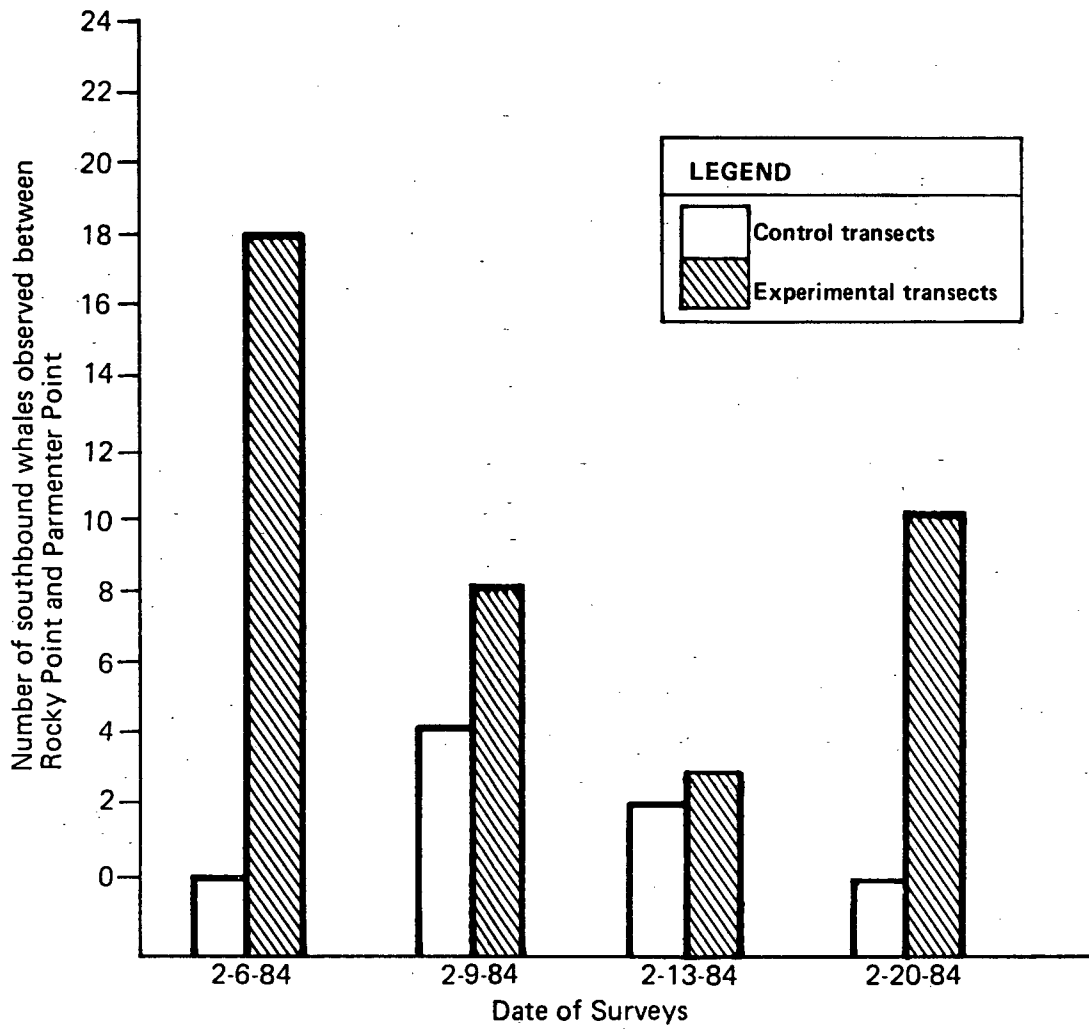


waters between Rocky Point and Yucca Plant (north of station), one would expect a greater number of northbound whales to be counted during the experimental periods (movement away from source). Data collected on the direction of whales during vessel surveys were compared between control and experimental events to verify this fact.

In the presence of oil-drilling sounds (6 and 9 February - data pooled due to small sample sizes collected per experiment), a significant increase occurred in the number of southbound whales counted between the Rocky Point and Parmenter Point area (Chi Square = 17.2; $p < 0.05$). During control periods, four whales were noted as heading south. During experimental surveys, this was increased to 26 whales. A similar pattern was observed during the projection of killer whale sounds. During control periods (13 and 20 February) two whales were noted as southbound, whereas during playback periods, the number of southbound whales increased to 13. A significant increase in the number of southbound whales (Fig. 50) occurred during this experimental playback period as well (Chi Square = 7.2; $p < 0.05$).

An inspection of the number of northbound whales between Rocky Point and Parmenter Point was also accomplished. One would expect that fewer northbound whales would be observed during the experimental surveys, if whales were avoiding the sound stimuli. Statistical comparisons supported this assumption. On 6 and 9 February (oil-drilling playback) 14 whales were noted as northbound during control periods. During experimental surveys, only one whale was observed northbound. A significant difference was, of course, obtained when these values were compared (Chi Square = 10.3; $p < 0.05$). The surveys conducted on 13 and 20 February (killer whale playback) also documented that fewer northbound

Figure 50. A Comparison of the Number of Southbound Whales Occurring Between Rocky Point and Parmenter Point During Control and Experimental Periods.



whales occurred during experimental conditions (14 whales counted during control and eight during experimental phase of transect - Fig. 51). However, when these values were compared, a significant difference could not be obtained (Chi Square = 1.27; $p > 0.05$).

Similar comparisons were accomplished on the number of southbound and northbound whales occurring between Rocky Point and Yucca Plant. If whales were avoiding the immediate study area, fewer southbound whales would be expected during playback periods. Conversely, a greater number of northbound whales should occur. On 6 and 9 February, 24 whales were observed southbound during control periods. During experimental transects, this number was 21. Although fewer whales were observed heading south during the experimental transect, this value was not significantly different than that obtained during control transects (Chi Square = 0.11; $p > 0.05$). When the paired transects conducted on 13 and 20 February were compared (control counts were 40 southbound whales vs 13 southbound whales during experimental transects), a significant difference was obtained (Chi Square = 17.3; $p < 0.05$), with fewer southbound whales observed during experimental conditions (Fig. 52).

An examination of the number of northbound whales between Rocky Point and Yucca Plant suggested that more whales headed north during playback periods (Fig. 53). On 6 and 9 February, 15 whales were northbound during control periods vs 33 counted during experimental transects. When compared, these values were found to be significantly different (Chi Square = 7.9; $p < 0.05$). On 13 and 20 February, nine northbound whales were observed during control surveys. This number increased to 37 during experimental conditions. A greater number of northbound whales was documented during experimental conditions in

Figure 51. A Comparison of the Number of Northbound Whales Occurring Between Rocky Point and Parmenter Point During Control and Experimental Periods.

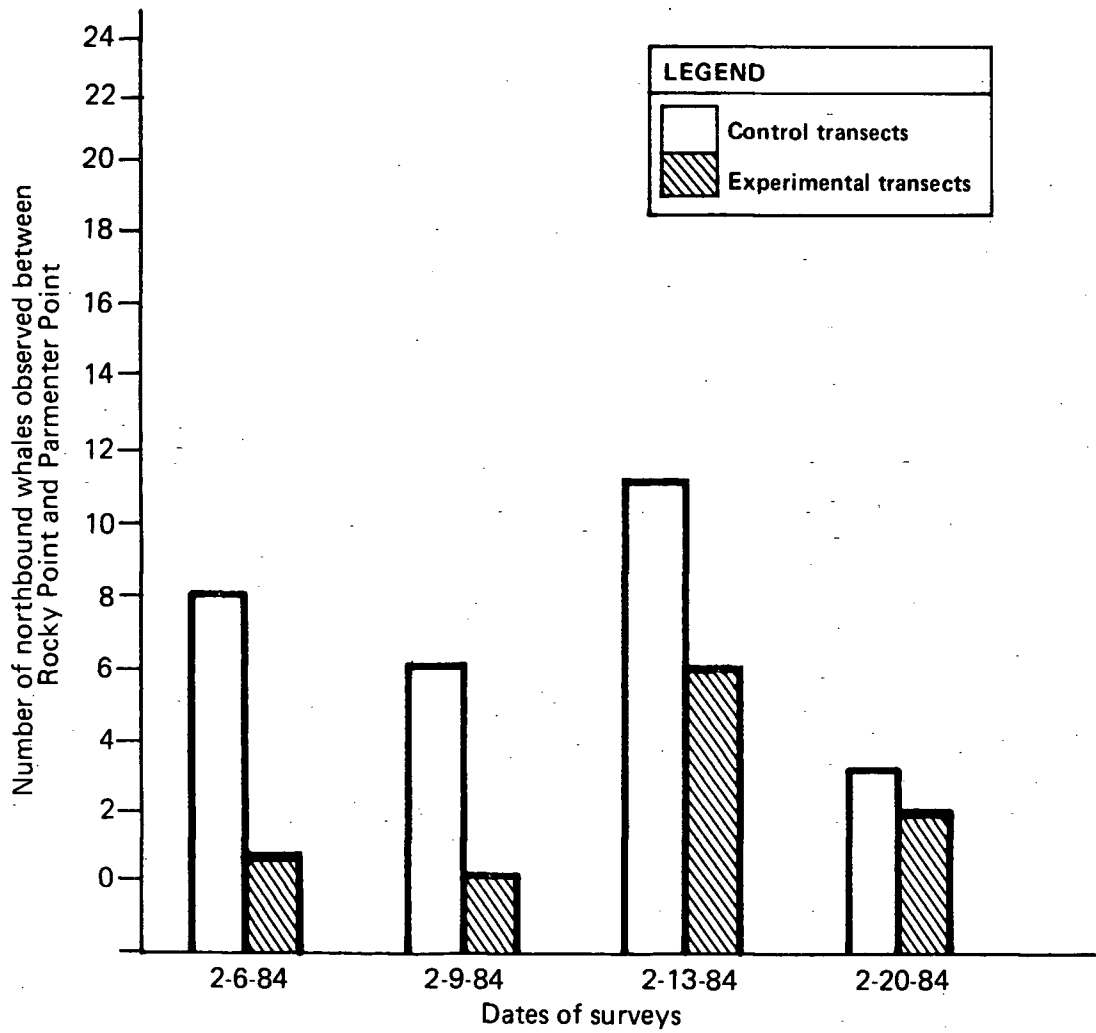


Figure 52. A Comparison of the Number of Southbound Whales Occurring Between Rocky Point and Yucca Plant During Control and Experimental Periods.

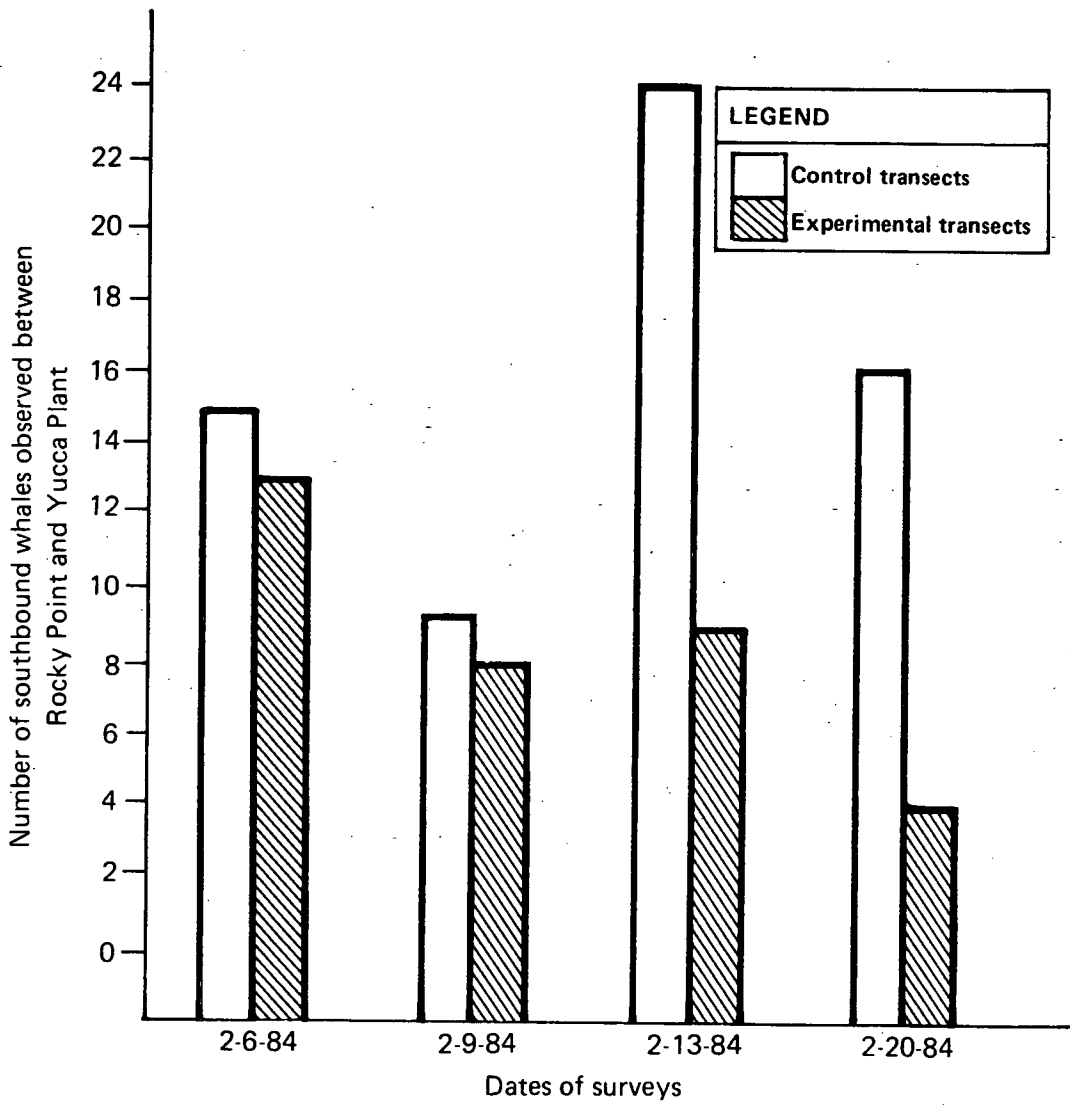
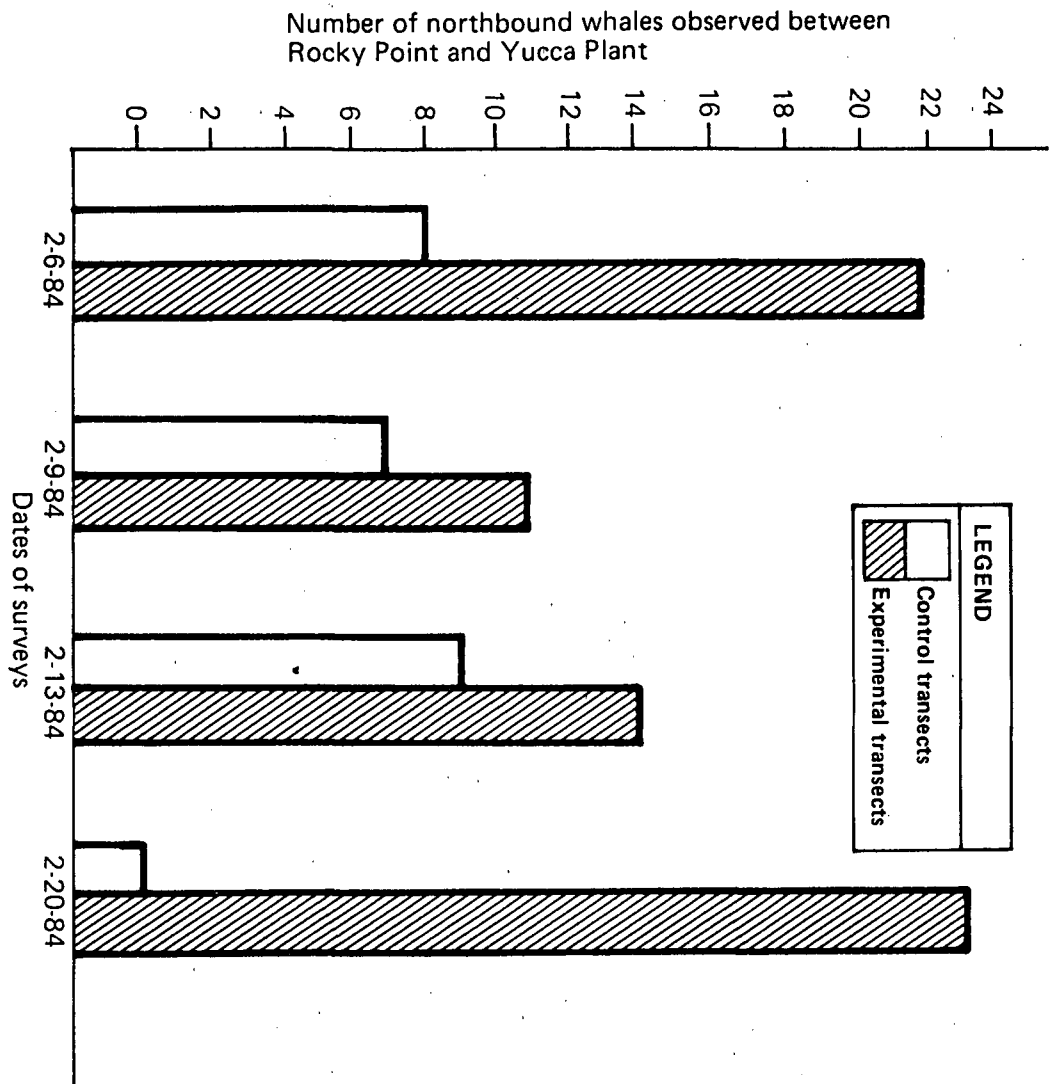


Figure 53. A Comparison of the Number of Northbound Whales Occurring Between Rocky Point and Yucca Plant During Control and Experimental Periods.



the presence of killer whale playbacks (Chi Square = 20.5; $p < 0.05$).

On 6 February 1984 (during control conditions), a total of 73 whales was noted to occur between Parmenter Point and Yucca Plant. Of these, eight were observed either heading north or south in the waters between Rocky Point and Parmenter Point. Examining the total number of southbound vs northbound whales between Rocky Point and Yucca Plant yielded a value of 23 whales. Thus, for the whole area only 42% (31 vs 73) of the whales could be accounted for either actively moving south or north. This suggested that the additional 42 whales must have been scored as either milling (No Direction = N.D.) or Direction Unknown (D.U.). Conversely, an examination of the total number of whales occurring through the whole area on 6 February during experimental transects gave a value of 58. Of these, 93% ($n = 54$) could be accounted for when comparing the total number of north vs southbound whales for the two areas (Rocky Point to Parmenter Point = 19 whales and Rocky Point to Yucca Plant = 35 whales). These data suggested that a greater number of whales was actively moving during experimental conditions. To confirm this, comparisons were made between control and experimental conditions comparing the number of milling whales (scored as N.D.).

On 6 February, considering the whole area (Parmenter Point to Yucca Plant), 28 whales were observed milling during control transects. This value declined during experimental testing to 17 whales. When compared, significant differences were obtained (Chi Square = 2.86; $p < 0.05$), with fewer whales milling during experimental conditions. On 9 February, 31 whales were noted as milling during control periods vs 13 during experimental transects. Once again, fewer whales were observed to mill in the presence of increased levels of noise (Chi Square = 8.42; $p < 0.05$).

Similar trends resulted when comparisons were completed for the experiments conducted on 13 and 20 February. On 13 February, 35 whales were scored as milling during control surveys. During experimental surveys, only 18 whales milled, a value significantly lower than that obtained during control surveys (Chi Square = 6.57; $p < 0.05$). On 20 February, 37 whales milled during control transects and 23 whales were observed exhibiting this behavior during experimental periods (Fig. 54). When compared, a significant decrease in milling rates occurred during experimental conditions (Chi Square = 4.02; $p < 0.05$).

The results obtained for the paired transects documents 1) an overall reduction in the number of whales occurring in the area during playback periods, 2) active movement away from the sound source, 3) change in distribution, and 4) decrease in milling rates.

Between-Season Comparisons -- Abundance of Whales

Two full transects were completed on 1 February 1984 (prior to any playback) and on 2 March 1984 (after numerous playbacks had occurred). The total number of whales counted for each transect was compared to the five-year data base collected by Jones and Swartz (1984).

Descriptive statistics (means, standard deviations, 95% confidence intervals) were calculated for the counts of whales collected on or about 1 February for the 5-year data base. Separate computations were completed for 1) all whales, 2) cow/calf pairs and 3) single whales. Similar statistics were calculated on or about 2 March for the 5-year data base as well. These calculations are summarized in Table XX.

The counts obtained during the acoustical investigations (1 February and 2 March 1984 - full transects) were compared to the 95% confidence

Figure 54. A Comparison of the Number of Milling Whales Observed Between Parmenter Point and Yucca Plant During Control and Experimental Periods.

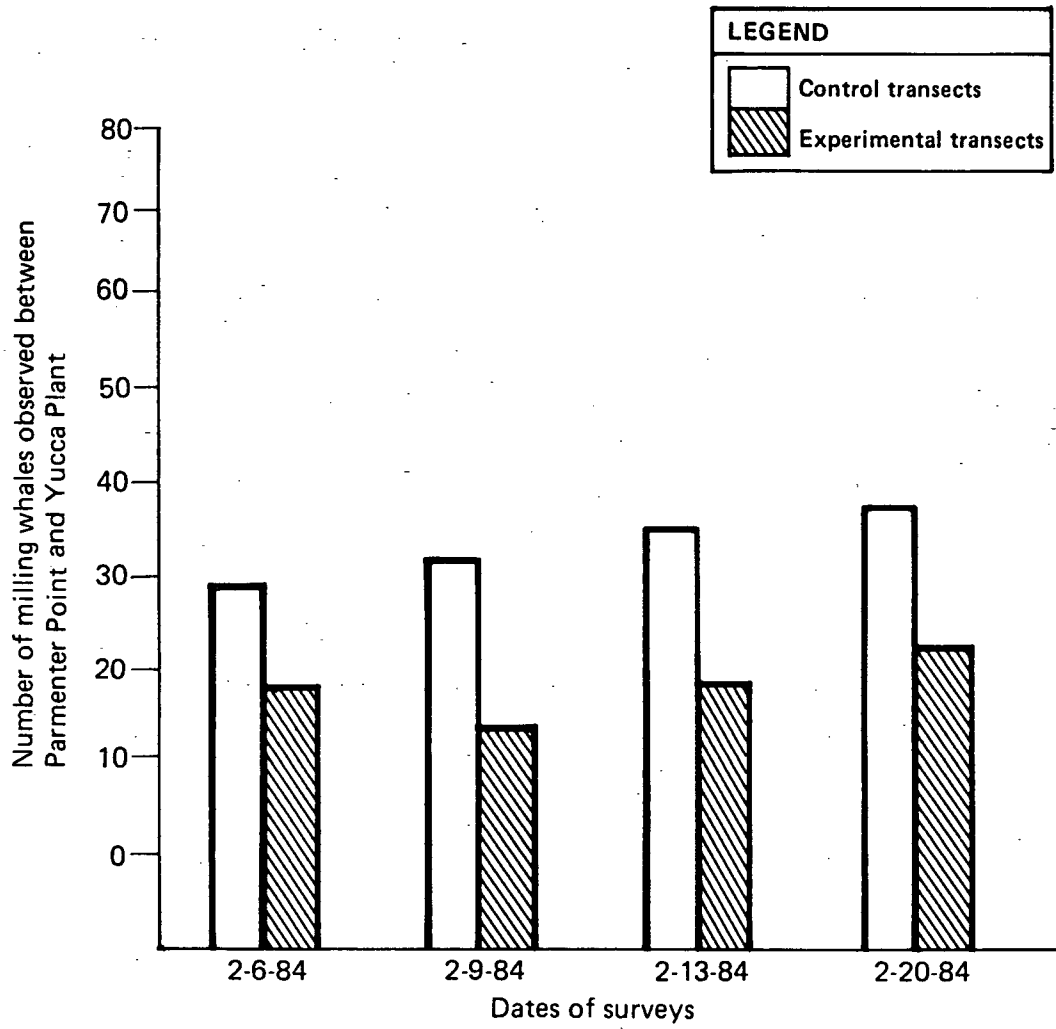


Table XX. Counts of Whales Occupying Laguna San Ignacio on or About 1 February and 2 March for the Years 1978-1982 (from Jones and Swartz, 1984).

	ALL WHALES	SINGLE WHALES	COW/CALF PAIRS
1 FEBRUARY			
1978	290	228	62
1979	159	95	64
1980	215	108	107
1981	292	198	94
1982	179	104	75
Mean and Standard Deviation	227.0 $\pm$ 61.7	146.6 $\pm$ 61.7	80.4 $\pm$ 19.5
95% Confidence Interval	169.1 - 284.9	88.7 - 204.5	62.1 - 98.7
2 MARCH			
1978	131	37	94
1979	310	209	101
1980	231	69	162
1981	193	11	182
1982	267	63	204
Mean and Standard Deviation	226.4 $\pm$ 68.6	77.8 $\pm$ 76.8	148.6 $\pm$ 49.0
95% Confidence Interval	162.0 - 290.8	5.6 - 150.0	102.7 - 194.5

intervals calculated for the years 1978 to 1982.

The 1 February 1984 count of all whales was 169. When compared to the confidence interval obtained for the 5-year data base (169.1-284.9), a significant difference in abundance of whales could not be detected. When the 1984 February count of single whales was compared with the confidence interval obtained for 1978-1982 (88.7-204.5), the 123 single whales observed in 1984 fell within the 5-year limits of the confidence interval. The number of cow/calf pairs counted on 1 February 1984 was 46. This value was found to be significantly lower than the 5-year average (62.1-98.7).

On 2 March 1984, a total of 43 whales was observed occupying Laguna San Ignacio. This value was significantly lower than the average derived from the 5-year data base (162.0-290.8). When single whale counts for 1984 (19 whales) were compared to the 5-year confidence interval (5.6-150.0), the 1984 count fell within the limits of testing. Single whale counts were not significantly different from the 5-year mean. Conversely, when the 2 March 1984 cow/calf pair count of 24 was compared to the 5-year data base (102.7-194.5), a major reduction in the number of cow/calf pairs occupying the lagoon in 1984 was documented. The overall results of these abundance comparisons suggested that although single whales were somewhat on the low side, the counts of these whales were not statistically different from previous years. The cow/calf pair count in 1984 was, however, significantly reduced when compared to previous years (Figs. 55, 56A and 56B).

Figure 55. Abundance of Gray Whales Occurring in Laguna San Ignacio, Mexico, for the Years 1978-1982 and 1984.

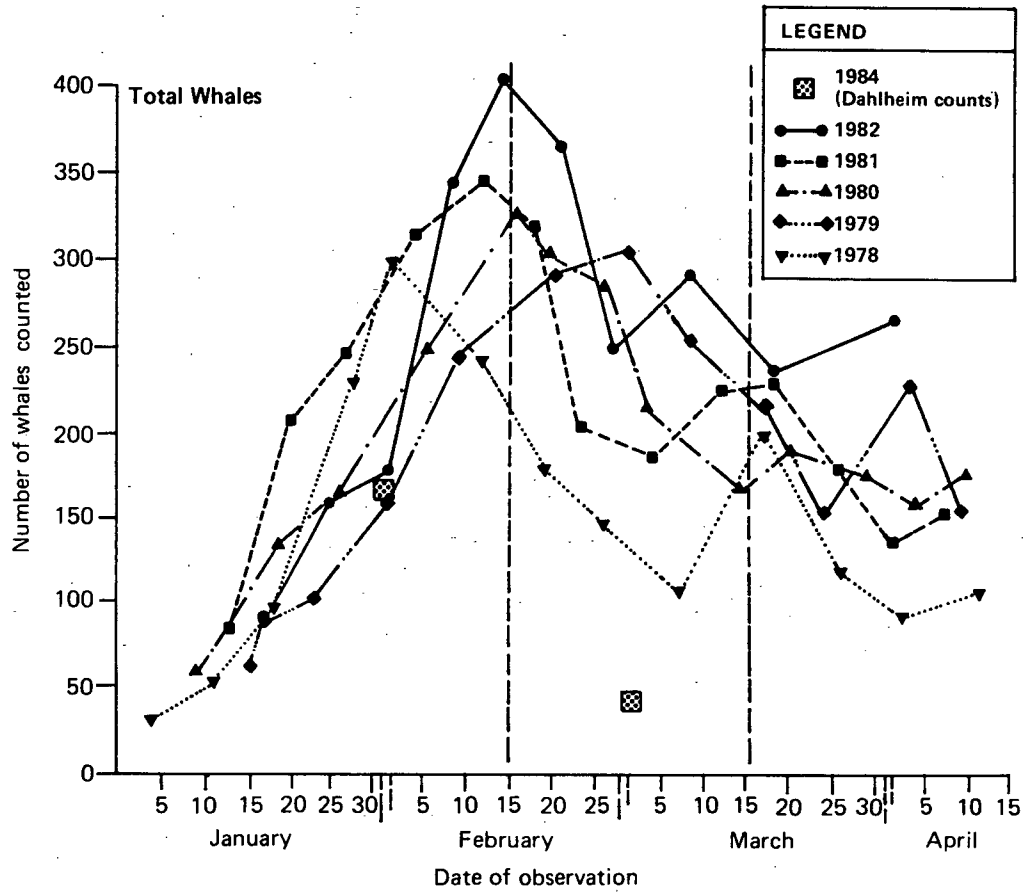
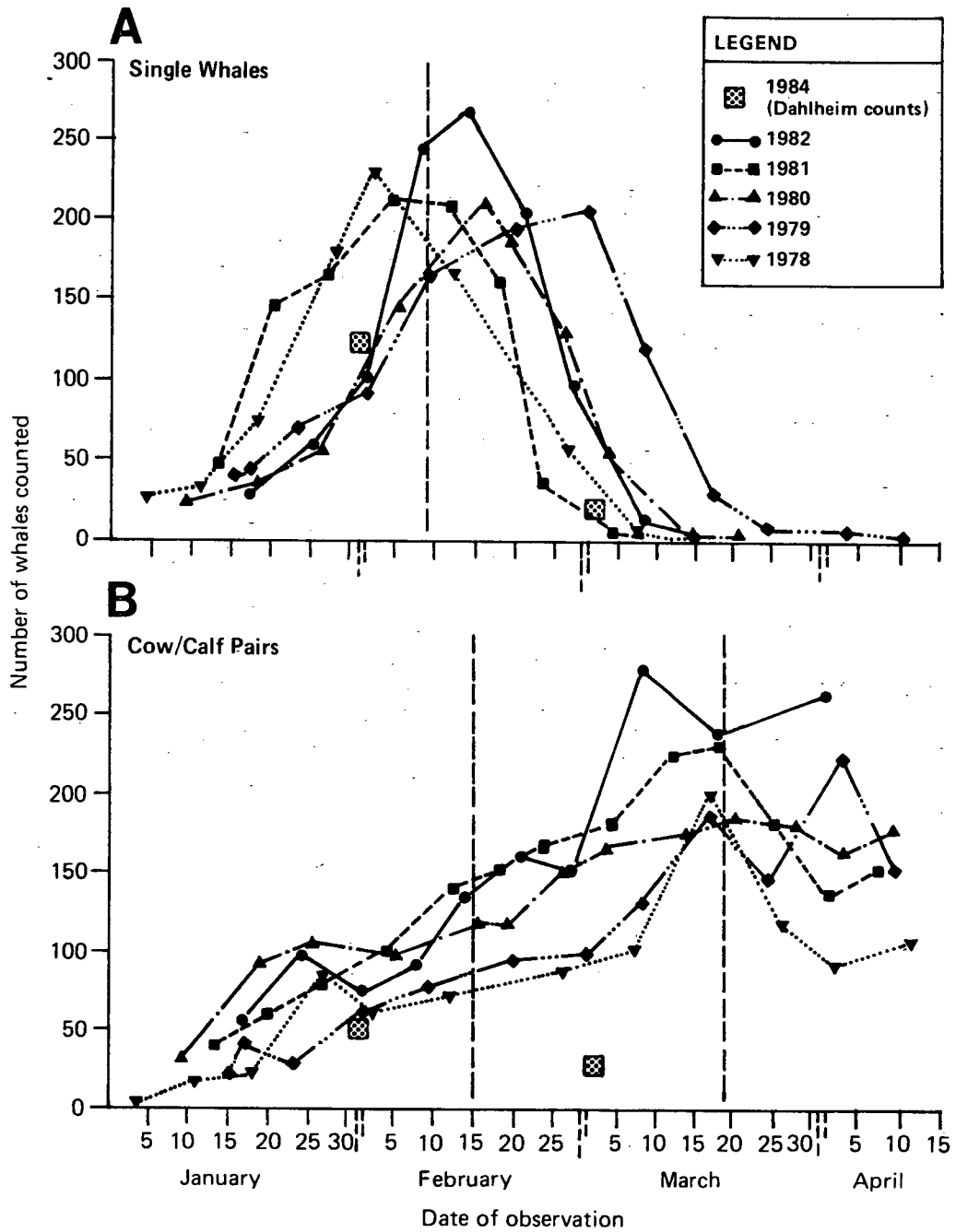


Figure 56. Abundance of Single Whales (A) and Cow/calf Pairs (B) Occurring in Laguna San Ignacio, Mexico, for the Years 1978-1982 and 1984.



DISCUSSION

The acoustical repertoire of gray whales occupying Laguna San Ignacio was significantly modified as noise levels were increased in their environment. During the 1983 and 1984 field seasons, gray whales were subjected to a variety of acoustical stimuli. These noise sources varied with respect to 1) emphasized frequencies and decibel levels; 2) the way in which the sound stimulus was presented (rapid vs gradual onset); 3) exposure periods (short vs long-term); 4) the biological vs non-biological origin of the source; and 5) their regular occurrence in the lagoon habitat vs novel stimuli for the particular area. Although distinctly different from one another, the overall effect of these noise stimuli on the acoustical behavior of the gray whale was similar for all experiments in that the same acoustical variables were observed to change during experimental test periods. As noise levels purposely were increased, associated changes were documented in: 1) calling rates; 2) levels at which signals were produced; 3) percentage of signals exhibiting frequency modulation; 4) number of pulses produced per series; and 5) average repetition rates of calls.

As described in Chapter 2, these modifications in the acoustical behavior of the gray whale during periods of increased levels of noise would serve to enhance signal transmission and reception. The fact that five of the nine acoustical variables measured were observed to change in the presence of noise implies a degree of flexibility in the acoustical behavior of the whales and a capability of circumventing a variety of ambient conditions. This acoustical flexibility may be required to cope with the dynamic ambient conditions encountered in coastal habitats. In addition, if other forms of communication are of

limited use in the aquatic environment (e.g., visual and/or chemoreception) then sufficient plasticity in the dominant sensory mechanism would be required.

The comparisons of the amount of change observed among experiments between the two seasons provided additional information and valuable insight into the acoustical capabilities and strategies of these whales when exposed to various sound stimuli present in their environments. For example, when comparing the acoustical responses of gray whales to outboard engine noise projected during the 1983 and 1984 studies, calling rates and received levels of signals were significantly higher in 1983. The 1983 results also documented significant differences among various experiments in gray whale calling rates and call structure. Conversely, in 1984, comparisons of experiments did not yield significant differences in these acoustical variables. These collective results imply that gray whales vary their call behavior dependent upon 1) type of signal present; 2) duration of signal; and 3) presentation of signal. If we assume that the 1983 acoustical responses to the projection of the rapid onset of short-term noise could be labeled as a startled response, then the following conclusion could be drawn when comparing the 1983 and 1984 seasons. When startled, gray whales will actively modify their acoustical behavior. The types of changes observed are similar to those reported for the gradual onset of sounds; however, significant differences are apparent in the degree of change observed within the particular acoustical variable. A higher degree of change is documented during startle responses. Of particular interest is the fact that the 1983 acoustical responses did adequately reflect this species' acoustical capabilities and provided additional information on the range of their capabilities.

The novel stimuli (sound types that do not occur typically in the lagoon habitat) projected during these studies (test tones, oil-drilling and killer whale sounds) did, however, result in a radical departure in the acoustical behavior of the gray whale. In the presence of oil-drilling sounds (although similar changes were observed to occur in call structure as described under vessel responses), overall calling rates were significantly reduced. The projection of test tones and killer whale sounds had the most profound effect on the acoustical behavior of this species. In the presence of these two sources, all calling ceased. A preliminary interpretation of these results would predict that a significant reduction in calling and/or a complete cessation of calling would be detrimental for an acoustically dependent animal. However, a further examination and detailed interpretation of these results suggested that in some situations signal reduction could be beneficial.

The benefits of the prey (= gray whales) remaining silent in the presence of predatory (= killer whale) sounds are obvious. If gray whales transit undetected through an area occupied by these predators, then certainly this acoustical strategy provides a selective advantage to the prey. This silent behavior by gray whales, while actually being pursued by killer whales in the Bering Sea, has also been reported by Ljungblad and Moore (1983). When confronted with unknown sound sources (e.g., test tones), possibly the best strategy is to remain silent. When reviewing the responses of this species to oil-drilling sounds projected in Laguna San Ignacio, other factors were considered. Due to the extensive range of gray whales and the fact that their preferred habitat has exposed

them to a wide variety of industrially-related sources, prior exposure to oil-drilling sounds was assumed. However, this stimulus was novel in that gray whales do not typically encounter this type of noise in their calving locations. Calling rates were reduced significantly in the presence of this signal; however, when they did call, signals were modified to ensure adequate transmission. This reduction in calling rate in the presence of oil-drilling sounds may represent an additional strategy in the random timing of the projected signal. Call reduction would, of course, provide certain benefits in temporary situations. However, if prolonged, call reduction could have a deleterious effect on an acoustically-dependent animal.

The overall results obtained during the 1983 and 1984 field seasons in Laguna San Ignacio also provided additional insight into the relationship between gray whale signals and their natural ambient environments. When comparing signals produced by the gray whale between the northern and southern range, significant differences in calling rates and call structure were obtained (Chapter 1). When the natural ambient conditions of the northern and southern range were compared (Chapter 1), overt differences were also documented. Laguna San Ignacio is characterized by high-levels of biological noise, whereas the Bering Sea represents a low-level ambient environment. If, for example, these two areas are treated as a control (= Bering Sea) and experimental (= Laguna San Ignacio) habitat, then responses of gray whales to different natural ambient conditions can be evaluated. When making comparisons of this nature, certainly the overall behavior of the animal must be considered. However, if we assume that effective sound communication would evolve independently

of the behavioral significance of the call, we would then predict that these calls would be structured to optimize their transmission and reception independent of behavioral requirements.

When treated in this manner, valid comparisons can be made between sound structures and calling rates between the two areas. When these data were compared to those obtained during the 1983 and 1984 investigations in Laguna San Ignacio, an important and interesting pattern emerged. Collectively, when exposed to high-level noise situations (i.e., natural ambient conditions on calving grounds and/or experimental conditions), similar acoustical variables were changed. All of these changes would benefit the caller through sound enhancement. Two additional variables were also modified when comparing call structure between the Bering Sea and Mexico. Call duration, although not documented to change in the presence of temporary noise sources (experimental), was significantly longer on the southern range vs the northern range. Certainly, increasing call duration while inhabiting high-ambient environments would be beneficial to the caller. An inspection of the frequency ranges emphasized by these whales also varied between the northern and southern range, with broader ranges observed on the northern grounds. This suggests that the high-level ambient conditions in Laguna San Ignacio, emphasizing the frequency bands of 2-5 kHz, may have affected and/or limited the frequency output of signals produced by the gray whale. These data imply additional flexibility in the acoustical behavior of the gray whale and suggest that these whales may employ different strategies when exposed to constant vs temporary high-level noise situations. When attempting behavioral comparisons, all environmental factors should be considered and stated. For example, the high repetition rates and number of pulses produced per

series collected during the northern research by Moore and Ljungblad (1984) may have resulted from the effect of aircraft noise on the whales. The combined results documented during these studies support the acoustical niche hypothesis and demonstrate that environmental noise (either natural and/or man-made) directly influences and shapes the acoustical behavior of this coastal species.

A study of the effect of noise on wildlife would not be complete unless a brief discussion on sound reception (hearing sensitivities) and sound-producing mechanisms was included. Unfortunately, little quantitative information is available on the auditory sensitivities of the marine mammals. Audiograms have been published for a select group of Odontocetes which include: the bottlenose dolphin, Tursiops truncatus (Johnson, 1966); the harbor porpoise, Phocoena phocoena (Andersen, 1970); the killer whale, Orcinus orca (Hall and Johnson, 1971); and the Amazon River dolphin, Inia geoffrensis (Jacobs and Hall, 1972). In most cases, however, only single animals from each species were studied. Information pertaining to the hearing sensitivities of the mysticete whales is non-existent in the published literature.

Despite the fact that sufficient information is not available regarding hearing sensitivities in gray whales, certain assumptions can be made as to how and to what types of sounds are perceived by these whales. One can assume that gray whales hear sounds in the same frequency in which they produce sounds (100 to 2000 Hz). In most mammals studied, hearing range is typically broader than the vocalization range and we could assume that the gray whale is not an exception here. Actual sound-receiving mechanisms are not known in the baleen whales. In odontocetes, sound is apparently received through the fat-filled lower jaw and transmitted

to the internal ear. In mysticete whales, however, the lower jaw is solid. As demonstrated during these studies, gray whales were very capable of localizing underwater sound sources, as evidenced by their direct movements to the transducer location during outboard engine playback periods. This, of course, implies biaural and directional hearing. During the 1984 studies, an attempt was made to gather information on the hearing capabilities of gray whales. The primary objective of this work was to determine the feasibility of conducting hearing studies on a mysticete whale in its natural environment. The methodology employed holds some promise and the results of these preliminary investigations are reported in Dahlheim and Ljungblad, in prep.

Although little is known on the sound-producing mechanisms in mysticete whales, there is general agreement that the site of sound production in the baleen whales is the pharyngeal pouches. In odontocetes, it is generally accepted that sound is produced through the extensive nasal sacs, a feature non-existent in baleen whales. The data suggesting that baleen whales produce sounds through the pharyngeal pouches are derived from studies conducted on sei whales (Balaenoptera borealis) and fin whales (Balaenoptera physalus), both representatives of the Family Balaenopteridae (Benham, 1901; Schulte, 1916; Hosokawa, 1950). Unfortunately, these structures have not been examined in gray whales and it may not be valid to extrapolate anatomical features between different families of whales.

Although gray whales are capable of acoustically responding in a variety of ways, as demonstrated during these studies, there must be some physical (either anatomical and/or physiological) limitation regarding the nature and extent of these call modifications. In addition, there also

must be some level of sensitivity to particular sound sources due to the hearing sensitivities and/or past experience of these whales to the noise source. This level of tolerance/sensitivity may also vary with respect to 1) the individual; 2) group size; 3) age; 4) reproductive status; 5) behavior; and 6) part of the range occupied by this species.

In addition to changes in call behavior in response to noise, changes were also documented in other aspects of their behavior. An inspection of the dive durations collected on gray whales during the 1983 and 1984 seasons in Laguna San Ignacio demonstrates the wide range of diving capabilities of this species. In 1983, as well as in 1984, significant differences were detected between the dive durations of females with accompanying calves vs the single whale component of the population. Apparently, mothers with young adjust the length of their dive to accommodate their young calves, resulting in shorter dive times. The dive durations exhibited by these adult females may change over time (i.e., increase in duration) with maturation of the calf. Comparisons conducted on the dive durations of cow/calf pairs and single whales in Laguna San Ignacio between control and experimental conditions did not detect significant differences when these whales were exposed to increased levels of noise. During recent studies by Malme et al., 1983 and 1984 addressing surface responses of gray whales to industrial noise along this species' migration route and feeding grounds, the following results were obtained. Blow rates of gray whales were not significantly different off California when comparing undisturbed vs disturbed periods. During these California experimental periods a variety of industrial sounds was projected, including noise from drillships, semisubmersible drill rigs, drilling platforms, production platforms, helicopter noise and killer

whale sounds. Conversely, when conducting similar experiments in the Bering Sea, a significantly longer dive time was obtained in the presence of drillship playbacks. However, during the projection of air-gun sounds, detectable differences were not found in the dive durations of these northern whales (Malme et al., 1986).

The extent of the diving capabilities of the gray whale is shown when the dive behavior of this species is compared between different parts of its range. Würsig et al. (1983) reported an average dive duration of $190.8 \pm \text{s.d. } 76.2$ sec for feeding gray whales in the Bering Sea, a value significantly longer than that reported for other areas. During migration, Sumich (1983) noted an average dive length of 43.2 sec (0.72 breaths per min). When these data are compared to those collected on this species' southern range (this study; Harvey and Mate, 1984), marked differences are apparent. These differences may suggest that the overall behavior and/or habitat occupied by these whales dictates the dive profile. In any case, the wide range observed in the dive cycles of these whales is obvious upon inspection of these data. In addition to dive duration rates, several other parameters have been used by researchers to describe the dive cycle of the gray whale (e.g., blow interval, number of blows per surfacing, and duration of surfacing). The fact that the 1984 dive durations of cow/calf pairs collected in Laguna San Ignacio were significantly longer than those collected in 1983 is somewhat perplexing. Assuming cow/calf pairs would be more sensitive than single whales to changing environmental conditions, an observable change could be expected. Unfortunately, it is not clear if these longer 1984 dive times of cow/calf pairs were triggered by the presence of long-term noise sources projected into their environment in 1984 and/or resulted from other, inherent factors.

Additional data would be required to make a definitive statement and to determine the amount of variability of respiration rates between seasons.

When inspecting the 1984 tracklines of gray whales in Laguna San Ignacio, despite the wide variety of behaviors exhibited by this species on its calving grounds, certain behavioral trends were documented in the presence of noise. Increased levels of noise were shown to have a direct effect on the travelling vs milling rates of these whales. This increase in milling by whales in the immediate study area may have resulted due to the close proximity of the whales to the sound source. In this situation, whales may have become confused, thus stopping all progressive movement past the sound source. Although precise tracklines were not collected in 1983, the increase in the number of directional changes observed during experimental periods suggests changes in movements and supports the 1984 tracking results. During studies conducted off central California (Malme et al., 1983, 1984), milling rates of migrating gray whales were also observed to increase in the presence of industrial playbacks. Similar work was conducted by this author in the Bering Sea, but unfortunately the sample size collected by Malme et al. (1986) in the same area was limited and valid comparisons could not be made. In addition to the increase noted in milling rates of gray whales in the presence of killer whale sounds, those whales actually travelling through the study area were noted to increase their distance from the sound source. The distances dealt with during these tracking experiments were restricted due to the visual limitations of the observers and initially were not that great. Possibly this fact was responsible for not detecting significant differences in the offshore distances of these whales to various experimental conditions. The results of these tracking experiments

noted that whales were, in fact, reacting to the sound source by changing their behavior and/or avoiding the area. In 1983, during post-trial periods, a significant reduction was noted to occur in the number of whales occupying the immediate study area. During these post-trial periods, whales were scarce and those that were present had unpredictable dive times, making them harder to track. In 1984, the results obtained from the effort log also suggested that whales were avoiding the immediate study area during certain experimental periods.

Gray whale abundance and distribution were quantitatively examined during the transects conducted in 1984. These data supported the results obtained during the tracking experiments. The paired transects conducted in 1984 verified that whales were avoiding the immediate study area during oil-drilling and killer whale playback periods. During these playback periods, overall gray whale abundance in the study area decreased, reflecting a distributional change by these whales; directional changes were documented to occur during experimental transects, with an overall movement away from the sound source noted; and milling rates (outside the boundaries of the immediate study area) were observed to decrease. Milling rates obtained during these tracking and transect experiments were examined and yielded interesting results. During tracking, whales in the immediate area were observed to increase their milling rates during playback periods, whereas during transect surveys, whales outside the immediate study area exhibited a decrease in milling rates. Comparisons suggested that the distance of the whale relative to the source could be responsible for the different behavioral responses noted in these milling rates. These data may also be indicative of the hearing sensitivities/level of tolerance exhibited by these whales.

Between-season abundance comparisons (1978-1982 vs 1984) documented a significant reduction in the number of cow/calf pairs occupying Laguna San Ignacio in the 1984 season. The long-term playback experiments conducted during the 1984 season were shown to cause small scale and temporary changes in gray whale abundance, distribution and behavior. The effect of the long-term playbacks conducted in 1984 pertaining to the large scale impacts are not as clear. For example, the 1 February surveys, prior to any playback, demonstrated that the counts of cow/calf pairs were statistically lower than previous years, indicating that other factors may have been involved with respect to these low cow/calf pair counts. The 2 March count of cow/calf pairs, after repeated exposures to playback periods was, however, greatly reduced as compared to previous years. The zone of influence during the projection of the playback stimuli certainly extended beyond the artificial boundaries defined for the immediate study area. There is the possibility that whales outside the study area were also significantly affected; however, this does not seem reasonable when considering the transmission loss of these signals with range. In addition, other factors and their effects on whales must be considered. The amount of tour boat activity in Laguna San Ignacio has actually decreased over the years. Local traffic, with respect to fishing efforts of local people, has also decreased. In 1983, El Niño conditions prevailed along the Pacific coast. In 1984, residual effects of El Niño were still documented for the Eastern Pacific Ocean. It is unclear at present as to what effects, if any, El Niño conditions would have on gray whales. Although the Laguna San Ignacio data base represents six years of data, this time window may not be adequate to predict the long-term natural fluctuations in gray whale

populations in the lagoon. The advantages of conducting long-term studies on these long-lived cetaceans are obvious. Considering the potential effect of these various factors on gray whales, and especially the fact that cow/calf pair counts were already reduced prior to any playbacks, a cause/effect relationship between the low counts and long-term playback experiments conducted in 1984 cannot be established.

Due to the significant reduction of cow/calf pairs observed in Laguna San Ignacio during the 1984 season, a follow-up study addressing cow/calf pair abundance was considered necessary by the Marine Mammal Commission. In February and March of 1985, joint investigations were conducted to determine the overall abundance and distribution of whales in Laguna San Ignacio. The 1985 results are briefly addressed here due to their pertinence to this current study and are described in detail in Jones, Swartz and Dahlheim (1986). The transects conducted in 1985 (in the absence of acoustical work) documented an increase in the number of cow/calf pairs occupying the lagoon when compared to the 1984 season; however, this estimate was still 20% lower than the 5-year average.

The conclusions based upon these acoustical investigations on gray whales have shown that ambient noise, either natural and/or man-made, has a profound effect on the acoustical behavior of this species. The sound behavior of the gray whale, documented during these studies, was modified in the presence of increased levels of noise, which was shown to enhance sound transmission and reception. Whale responses varied with respect to noise based on exposure time, the way in which the signal was presented, and the type of stimuli present in the environment. The plasticity observed in gray whale behaviors, when exposed to increased levels of

noise, enables this species to cope successfully with dynamic noise situations that typically characterize its coastal habitats. The hypothesis that gray whales, while engaged in underwater signalling, circumvent noise in their acoustical channels by the structure and timing of their calls has been accepted based upon the overall results obtained during these investigations.

GENERAL SUMMARY/CONCLUSIONS

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The results of this study have significantly increased our knowledge of the acoustical behavior of the gray whale.

- 1) Gray whales produce at least seven distinct sound types.
Variations exist within sound categories; however, each call type is sufficiently distinct to be classified independently.
- 2) Sound activity increased on this species' mating/calving grounds with a corresponding increase observed in social activities.
- 3) Similar call types were produced throughout the range; however, call structure showed more variation on the southern range.
- 4) Distinct differences were noted in the gray whales' acoustical habitats with low levels of natural ambient noise associated with the northern range (Bering Sea). Conversely, on the southern range (Mexico), high levels of natural ambient noise prevailed. Intermediate values of ambient noise were documented for the migration route (Washington State).
- 5) Numerous fish and invertebrates were identified and deemed potentially responsible for the high-levels of natural ambient noise in Mexico. The biological contribution to ambient conditions was reduced on the migration route and on the feeding grounds.
- 6) Each respective vessel/outboard engine recorded exhibited its own sound signature. Profiles of man-made noise did not vary with range.

- 7) Salinity, temperature and depth values were inspected and compared between Mexico and Alaska. As expected, major differences were noted in water temperatures and depths with range. However, salinity values were similar between the two geographical areas.
- 8) Sound propagation in Laguna San Ignacio did not follow the cylindrical spreading law ($10 \log R$). Sound transmission was enhanced in the southerly direction (lower lagoon) and was reduced in the middle lagoon due to the extensive sand bars causing shadow zones.
- 9) All gray whale signals analyzed either occupied frequency bands below the main concentration of ambient noise (e.g., Laguna San Ignacio) or occupied different frequency bands than those emphasized by the natural ambient conditions (e.g., Bering Sea).
- 10) The relationship between gray whale signals and natural ambient noise indicates that a varying acoustical niche may be utilized by the gray whale on different parts of its range.
- 11) Man-made sources (e.g., ship noise, outboard engine noise, oil-drilling sounds, etc.) were shown to have a high potential of masking/interfering with whale signals.
- 12) In the presence of artificially-increased levels of noise in Laguna San Ignacio, significant changes were documented in gray whale calling rates and call structure.

- 13) Typically, as noise levels were increased, a corresponding increase was documented in: calling rates, received level of the signals, number of frequency-modulated signals, number of pulses produced per series, and repetition rates of signals.
- 14) In the presence of test tones and killer whale sounds, gray whales ceased all signalling.
- 15) Significant changes were also documented in the observed surface behavior of whales in response to increased levels of noise. Changes were documented in the number of whales occupying the immediate study area, overall distribution and movements.
- 16) Dive durations varied between cow/calf pairs and single whales with cow/calf pairs exhibiting shorter dive times. Increased levels of noise did not influence dive patterns of whales.
- 17) The level of response (degree of change) varied depending upon the sound source projected (e.g., outboard engine noise, test tones, gray whale sounds, killer whale sounds, oil-drilling sounds).
- 18) The way in which the stimulus was presented (rapid onset of sound vs gradual onset of sound) also dictated the level of response.
- 19) Although whale responses varied among experiments, similar acoustical variables were consistently changed.
- 20) Comparisons of gray whale responses between real sound sources present in the environment and artificially produced outboard engine noise resulted in similar findings. These data

support the use of playback techniques as an adequate method of experimentation in studies addressing noise effects on marine mammals.

- 21) The flexibility observed in gray whale behaviors, when exposed to increased levels of noise, enables this species to cope with most dynamic noise situations that characterize coastal habitats.
- 22) Combined results of this investigation lend substantial evidence for acceptance of the hypothesis: The gray whale, while engaged in underwater signalling, circumvents noise in the acoustical channel by the structure and timing of its calls.

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A P P E N D I X A

APPENDIX A

Propagation Experiments

To determine the propagation characteristics of the underwater environment of Laguna San Ignacio, an underwater transducer (Lubell Speaker Model 98, capable of producing a signal of known frequency and level) was positioned approximately 75 m off the farthest promontory available at Punta Piedra/Rocky Point. This transducer was affixed to a 1.5-m by 1.5-m square of PVC pipe. This PVC structure (cage) arose out of the need to 1) float the transducer and 2) protect it from possible damage by the whales. Several holes were drilled into this pipe, allowing water to enter into the cage as it was being submerged. A diver was used to guide the transducer cage (in an upright position) to the bottom. Several burlap sacks filled with sand were placed over the lower bars of the cage to secure it to the bottom of the lagoon (to prevent drift due to tidal currents). The depth of the transducer cage was approximately 8 meters, within the tolerance level required for the transducer. The associated cables were weighted down (to prevent entanglement problems with whales) and were run along the bottom of the lagoon to the shore-based station at Rocky Point. The shore-based equipment consisted of an Acoustic Systems Inc. Amplifier driven by a 12-volt, deep-cycle marine battery. A Briggs and Stratton generator was used to recharge the batteries, since extensive battery drain occurred during playback periods. The amplifier was equipped with a built-in calibration (test) tone, which swept from 20 kHz to 400 Hz over a 40-sec time frame. Maximum output levels ranged from 80-150 dB re 1 μ Pa, which varied with frequency. The built-in test tone was the signal used during the underwater propagation experiments.

Once the acoustical equipment was in place, a 4.3-m inflatable boat

was dispatched from the shore-based station. Two team members were located in the boat and were equipped with all the necessary equipment to collect recordings of the projected test tones. The calibrated recording system used consisted of a Nakamichi 550 tape recorder and an LC-32 hydrophone. The frequency response of this equipment ranged from 40 Hz to 19 kHz $\pm$ 3 dB. Communication between the shore-based personnel and the boat team was accomplished through hand-held CB walkie talkies. The boat team was requested to position its vessel at various distances and angles relative to the transducer site. Boat locations were determined by taking bearings from two locations (separated by 100 m) from the Rocky Point shoreline. An optical range finder was also used to estimate the distance of the vessel from the shoreline.

Once the boat was on station, the hydrophone was lowered at 1.6 m (5 foot) depth increments until the bottom was reached. Recordings of the test tone (being projected by the shore-based team) were made at each station at these 1.6 m depth increments. Pertinent additional data recorded during the acoustical experiments included: 1) wind speed and direction; 2) sea state; 3) tide conditions; 4) time of day; 5) bottom depth; and 6) presence/absence of whales. Propagation experiments were terminated when Beaufort 2 conditions or above occurred, current caused hydrophone acceleration, and/or vessel or skiff traffic interfered with experiments.

In addition to the test tones projected during propagation experiments in the immediate study area, sound sources used during the playback experiments (Chapters 4 and 5) were also projected back underwater to determine the received levels of these sources in areas outside the immediate study area. Recordings were conducted from the 4.3-m boat and

utilized the same equipment as described for the collection of the test tone data.

Average sound pressure levels were computed using a Nicolet Scientific Corporation FFT Computing Spectrum, Model 446. The bandpass filter was set for 0-20 kHz range and 128 linear averages. Permanent displays of sound pressure levels calculated were obtained by connecting an X-Y plotter to the Spectrum Analyzer. Sound profiles were made for each station and compared against each other to determine the acoustical differences in frequencies and levels among station locations. An overlay grid was designed by the author which allowed conversion of the analog signals into digitized data.

In addition to conducting the propagation experiments, those physical parameters that could potentially influence a propagating sound wave were investigated. Information was either collected or reviewed on depth profiles, bottom sediments, temperature, and salinity. These parameters were collected throughout the lagoon system. Data on depth profiles were provided by Jones and Swartz (1984), discerned from echograms made by a continuous-recording fathometer. Divers made visual observations of the lagoon floor and sampled bottom sediments. A Beckman Salinometer and thermometer was used to collect information on salinity and temperature. In the Bering Sea, temperature and salinity profiles were made using CTDs deployed from the NOAA vessels. Values were calculated by a NOAA officer and given to those scientists who requested the information. Unfortunately, the locations of these measurements did not coincide with the locations of the ambient noise stations, since the large ship was not able to enter the shallow water areas visited by the Boston Whaler.

Results

A total of 61 propagation measurements was made in the immediate area off Punta Piedra (designated as the study area), representing a total of 15 stations (Fig. A1). Each station location was numbered and each associated 1.6-m drop was given a letter designation. For example, Station 2a = 1.6-m hydrophone depth; Station 2b = same location (however, depth of hydrophone was 3.2 m). Station locations, hydrophone depths, and other pertinent information recorded during these measurements are listed in Table A-I. All measurements were made at high slack water during Beaufort 1 or 2 sea states.

A sound profile was made for each of the 61 measurements displaying frequency on the horizontal axis and sound level on the vertical axis. An example is shown for Station 1a (Fig. A2). Each profile was converted to digitized data using a plastic overlay grid designed for this purpose. The levels at intervals of 1 kHz measurements were collected and are listed in Table A-II. A comparison of the profiles among stations indicated that only minor fluctuations occurred in sound propagation pathways. Major areas of sound enhancement and/or cancellation were not observed in the immediate study area.

An inspection of the received levels of projected sources calculated for areas outside the immediate study area, however, did result in major acoustical anomalies (Fig. A3). Recordings of the projected signals and playback tapes to be used in Chapters 2 and 3 projected into the lower lagoon area ($n = 6$ stations) resulted in levels higher than expected for sound propagation following the cylindrical spreading law. Conversely, recordings made in the middle lagoon ($n = 7$ stations) of these projected sources resulted in received levels lower than expected for sound

Figure A.1 Locations of Propagation Stations in Laguna San Ignacio,
Mexico.

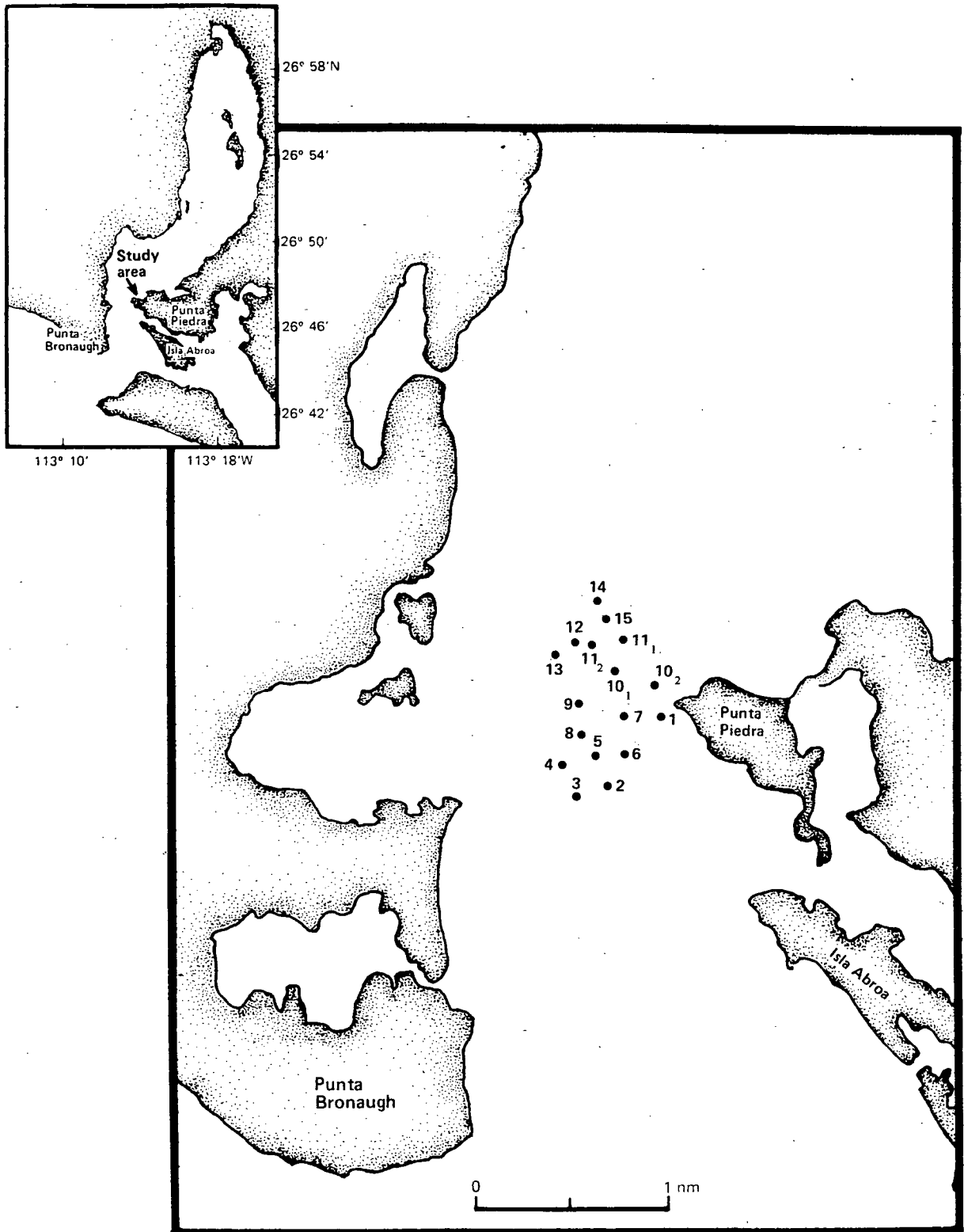


Table A-I. Angles and Measured Depths of Propagation Test Tone Stations in Laguna San Ignacio, Mexico

Station No.	Angle South Marker	Angle North Marker	Hydrophone Depth (ft)	Bottom Depth (ft)
1a	243	214	3	6
2a	222	212	5	22
2b	222	212	10	22
2c	222	212	15	22
2d	222	212	20	22
3a	218	214	5	25
3b	218	214	10	25
3c	218	214	15	25
3d	218	214	20	25
4a	234	224	5	23
4b	234	224	10	23
4c	234	224	15	23
4d	234	224	20	23
5a	233	225	5	22
5b	233	225	10	22
5c	233	225	15	22
5d	233	225	20	22
6a	240	222	5	18
6b	240	222	10	18
6c	240	222	15	18
7a	262	242	5	21
7b	262	242	10	21
7c	262	242	15	21
7d	262	242	20	21
8a	258	247	5	21
8b	258	247	10	21
8c	258	247	15	21
8d	258	247	20	21
9a	246	242	5	22
9b	246	242	10	22
9c	246	242	15	22
9d	246	242	20	22
10a1	276	255	5	21
10b1	276	255	10	21
10c1	276	255	15	21
10d1	276	255	20	21
10a2	289	253	5	8
11a1	283	279	5	21
11b1	283	279	10	21
11c1	283	279	15	21
11d1	283	279	20	21
11a2	286	272	5	26
11b2	286	272	10	26
11c2	286	272	15	26
11d2	286	272	20	26

... continued

Table A-I, Continued --

Station No.	Angle South Marker	Angle North Marker	Hydrophone Depth (ft)	Bottom Depth (ft)
12a	280	272	5	28
12b	280	272	10	28
12c	280	272	15	28
12d	280	272	20	28
13a	306	302	5	25
13b	306	302	10	25
13c	306	302	15	25
13d	306	302	20	25
14a	306	296	5	23
14b	306	296	10	23
14c	306	296	15	23
14d	306	296	20	23
15a	297	274	5	21
15b	297	274	10	21
15c	297	274	15	21
15d	297	274	20	21

Figure A.2 Sound Profile of the Received Test Tone at Station 1a
in Laguna San Ignacio, Mexico.

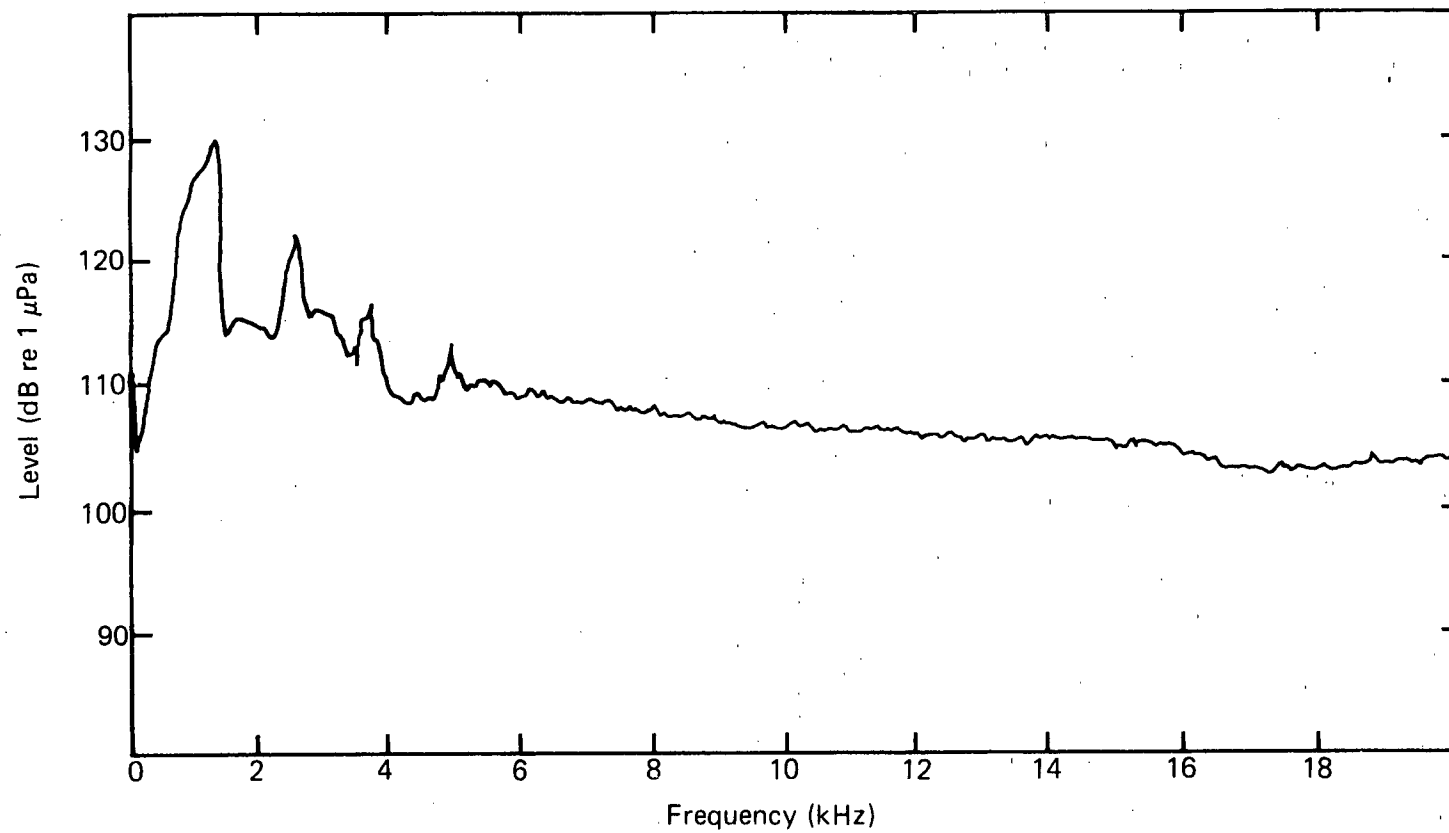


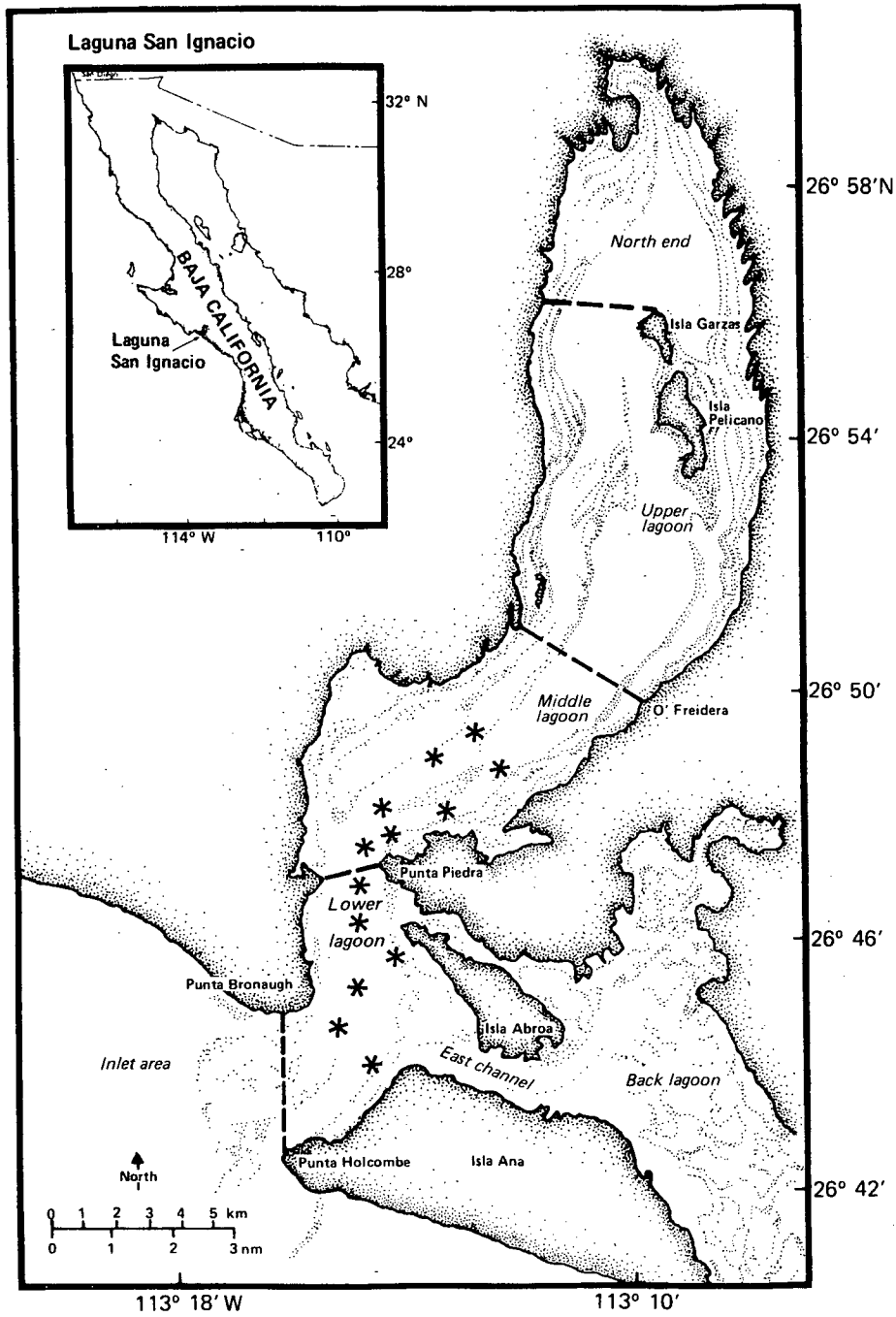
Table A-II. Digitized Data on Level (dB re 1 μ Pa) and Frequencies (kHz) of Test Tones Received at Stations 1a - 15d in Laguna San Ignacio, Mexico

Level at Station	F R E Q U E N C Y (kHz)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1a	118	104	105	100	101	99	98	97	96	96	96	96	96	96	96	95	94	94	94	94
2a	118	105	105	102	102	101	101	100	100	100	99	98	97	97	97	96	94	94	94	94
2b	118	106	108	102	103	101	101	100	100	100	99	98	98	97	97	96	94	94	94	94
2c	118	104	103	102	103	102	102	101	101	100	100	99	99	98	98	97	94	94	94	94
2d	118	103	103	102	102	101	101	102	100	100	100	99	98	98	98	97	94	94	94	94
3a	118	102	107	102	102	102	101	101	101	100	100	99	98	98	98	96	94	94	94	94
3b	118	102	106	102	102	102	101	101	101	100	100	100	99	99	98	98	97	94	94	94
3c	118	103	104	103	102	102	101	101	101	100	100	99	99	98	98	96	94	94	94	94
3d	118	104	106	103	103	102	102	101	101	100	100	99	98	98	98	96	94	94	94	94
4a	118	103	105	105	105	104	104	104	103	103	103	101	100	99	99	97	94	94	94	94
4b	118	103	107	104	104	103	103	103	102	102	101	100	100	100	99	97	94	94	94	94
4c	118	104	107	105	105	104	104	104	103	103	102	101	100	100	100	97	95	94	94	94
4d	118	105	109	106	106	105	104	104	104	106	105	103	102	102	101	100	95	94	94	94
5a	118	106	108	104	106	103	101	101	101	101	100	99	98	98	97	96	94	94	94	94
5b	118	106	108	105	105	104	102	102	102	101	100	99	98	98	97	96	94	94	94	94
5c	118	105	107	104	103	102	101	101	100	100	100	99	98	98	97	95	94	94	94	94
5d	118	105	107	104	105	103	102	102	101	101	101	100	100	99	98	96	95	94	94	94
6a	118	106	109	104	105	105	105	104	104	103	102	101	101	100	100	98	95	94	94	94
6b	118	105	111	107	107	106	105	105	105	104	103	103	102	101	101	100	95	94	94	94
6c	118	111	112	104	104	104	103	102	101	101	101	100	99	99	98	96	94	94	94	94
7a	118	107	112	108	110	105	104	104	104	107	103	100	99	100	98	98	95	94	94	94
7b	118	105	115	110	107	105	104	106	105	108	103	101	99	98	99	98	94	94	94	94
7c	118	106	108	107	107	106	105	106	102	103	102	100	100	100	98	97	94	94	94	94
7d	118	111	109	108	108	106	104	104	102	103	105	100	99	99	99	97	94	94	94	94
8a	118	103	108	104	105	104	102	103	102	102	101	100	99	98	97	97	96	94	94	94
8b	118	105	110	103	103	102	102	102	101	100	100	99	99	98	98	97	96	94	94	94
8c	118	105	110	104	104	103	102	102	101	100	100	99	98	98	98	97	94	94	94	94
8d	118	103	107	106	105	102	101	101	101	102	100	99	98	98	98	97	94	94	94	94
9a	116	102	104	103	103	102	102	101	100	100	100	99	98	98	98	96	94	94	94	94
9b	118	102	105	103	103	103	102	102	101	101	100	100	99	98	98	97	94	94	94	94
9c	118	102	107	102	103	102	101	101	100	101	100	99	98	98	97	96	94	94	94	94
9d	118	103	108	103	103	103	101	101	100	101	100	99	98	98	98	96	94	94	94	94

Table A-II. Continued --

Level at Station	F R E Q U E N C Y (kHz)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10a1	118	108	107	101	107	104	105	101	102	100	100	99	99	98	98	97	94	94	94	94
10b1	118	105	109	103	106	105	103	102	101	100	100	98	97	97	97	95	94	94	94	94
10c1	118	108	108	102	107	101	106	102	100	100	100	97	97	98	98	97	95	94	94	94
10d1	118	110	110	101	105	105	104	101	100	100	100	99	98	98	98	97	96	94	94	94
10a2	118	105	110	108	104	103	102	101	99	100	100	100	97	97	96	95	94	94	94	94
11a1	118	103	107	102	101	101	101	100	100	100	100	99	99	98	98	96	94	94	94	94
11b1	118	103	105	103	102	101	101	100	100	100	100	99	98	98	97	96	94	94	94	94
11c1	118	103	103	101	101	101	102	100	100	100	99	98	97	97	96	95	94	94	94	94
11d1	118	104	105	101	101	100	100	100	100	100	99	98	97	97	96	96	94	94	94	94
11a2	111	103	104	100	100	99	100	99	98	100	99	97	96	95	95	95	93	93	93	94
11b2	115	103	103	100	100	100	100	99	99	99	99	98	97	96	96	95	94	94	94	94
11c2	117	103	102	101	100	99	99	99	98	98	98	98	97	97	96	95	94	94	94	94
11d2	118	103	106	101	101	100	100	99	99	99	98	97	96	96	96	95	94	94	94	94
12a	113	100	104	102	101	101	101	100	100	100	100	99	98	98	97	96	94	94	94	94
12b	116	100	103	102	101	101	101	101	100	100	100	100	99	99	99	98	96	94	94	94
12c	115	100	103	100	100	100	100	100	100	100	100	99	98	98	97	96	94	94	94	94
12d	118	101	102	100	100	100	100	100	100	100	100	99	99	98	98	97	94	94	94	94
13a	115	100	103	102	102	101	101	101	101	100	99	99	98	98	97	96	94	94	94	94
13b	112	101	102	101	101	101	100	100	100	100	99	99	98	97	96	95	94	94	94	94
13c	117	103	103	102	102	101	101	101	101	100	100	100	100	99	98	96	94	94	94	94
13d	117	102	103	102	102	102	102	102	101	101	100	100	100	99	99	98	94	94	94	94
14a	118	102	104	102	102	102	103	100	100	99	99	98	97	96	96	95	94	94	94	94
14b	118	105	105	101	103	101	101	100	100	100	99	98	98	98	97	95	94	94	94	94
14c	118	105	104	101	101	101	100	100	100	99	99	98	97	96	96	95	94	94	94	94
14d	118	102	104	100	100	100	101	101	100	100	99	98	98	98	97	96	94	94	94	94
15a	118	105	104	100	106	104	106	102	100	100	99	98	97	97	96	95	94	94	94	94
15b	118	107	110	102	103	103	104	102	100	100	99	99	98	97	97	95	94	94	94	94
15c	118	105	107	101	102	101	101	101	99	99	98	97	96	96	96	95	94	94	94	94
15d	118	106	108	102	103	102	102	101	100	99	99	98	97	97	96	95	94	94	94	94

Figure A.3 Locations of Propagation Measurements Collected Outside of Immediate Study Area in Laguna San Ignacio, Mexico.



propagation following a cylindrical spreading law ($10 \log R$) as proposed for shallow-water environments.

Jones and Swartz (1984) divided the lagoon into five distinct areas based on lagoon bathymetry and sedimentology: the inlet, east channel, and the lower, middle, and upper lagoon (Fig. A4). For the purposes of this acoustical investigation, only the lower and middle areas of the lagoon are addressed. In the lower lagoon, a steep-walled channel cuts its way from the 3-km wide inlet to a constriction of 1.8-km wide at Punta Piedra, where it terminates. A maximum depth of 25.9 m was reported and represents the widest, relatively deep channel in the lagoon. The deepest regions of this channel are covered with poorly sorted, hard-packed, fine to coarse grained sand. West of Rocky Point, medium-grained sand ridges are interspersed with occasional rock outcroppings. Proceeding North, a system of three channels characterizes the middle lagoon. The channels range in depth from 7.6 to 21.3 meters. The sediments are poorly sorted, with fine to coarse grained sand with crushed shell and some rocky areas. Extensive sand bars support strands of eelgrass (Zostera marina); however, the channels are devoid of plant life. Depth profiles in Laguna San Ignacio are depicted in Fig. A5.

Temperature and salinity measurements were made at various locations and depths throughout the lagoon system (Fig. A6). Temperature values ranged from 17° to 19° C and salinity values averaged 32 ppt. A comparison of these values with depth indicated a homogenous, well-mixed water column.

In the Bering Sea, water temperatures varied with depth from 7.49°C on the surface to 0.10°C at 20 meters. A thermocline was prevalent at about 5 m and at 10 and 20 meters (Fig. A7). Salinity values ranged between 31.5 ppt to 32.0 ppt (Fig. A8). Major variations in salinity

Figure A.4 Major Geographical Divisions of Laguna San Ignacio, Mexico.
From Jones and Swartz, 1984.

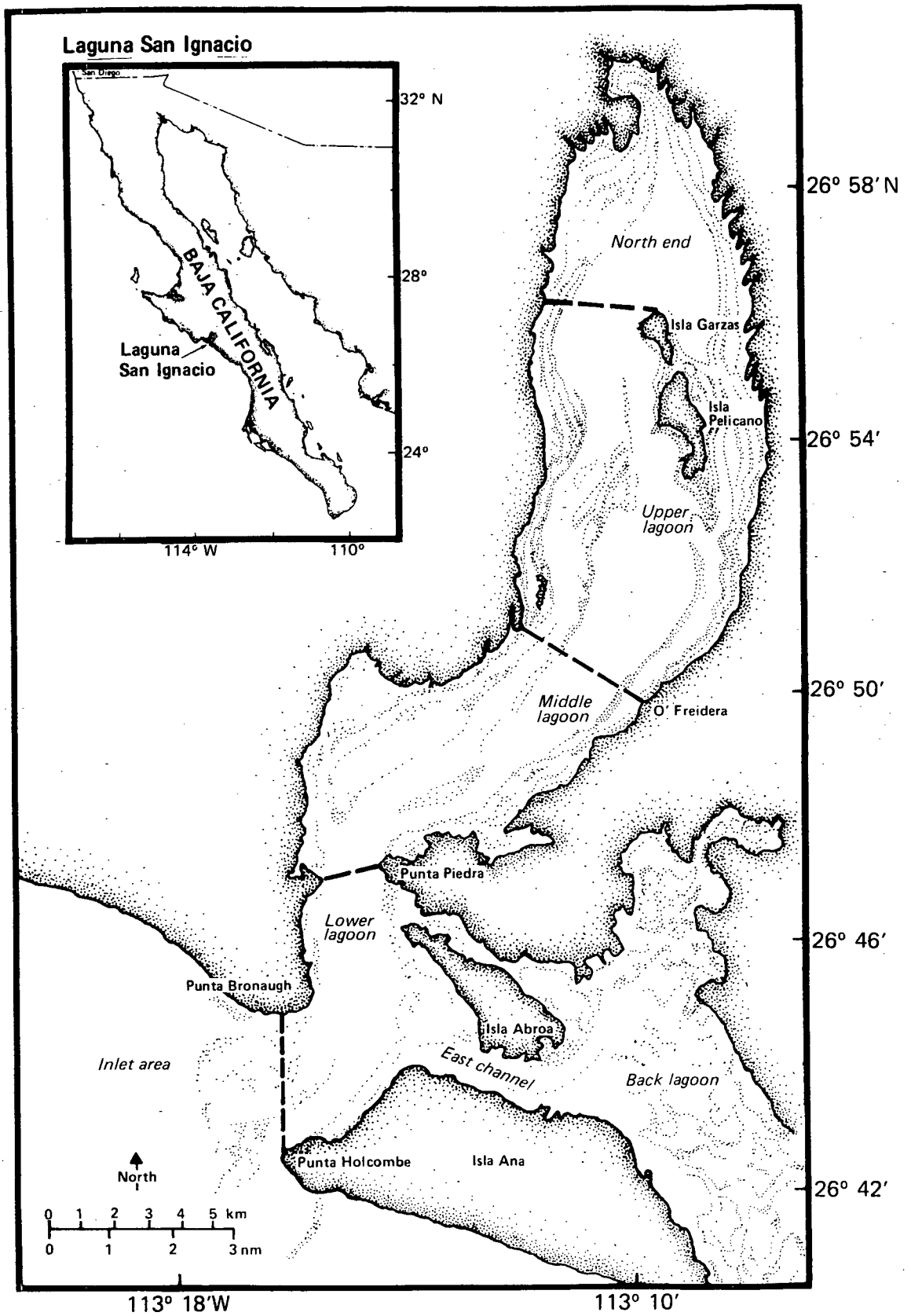


Figure A.5 Depth Profiles of Laguna San Ignacio Based on Echograms.
Soundings are in Feet and Vertical Exaggeration is 100x.
Horizontal Scale Approximate. From Jones and Swartz, 1984.

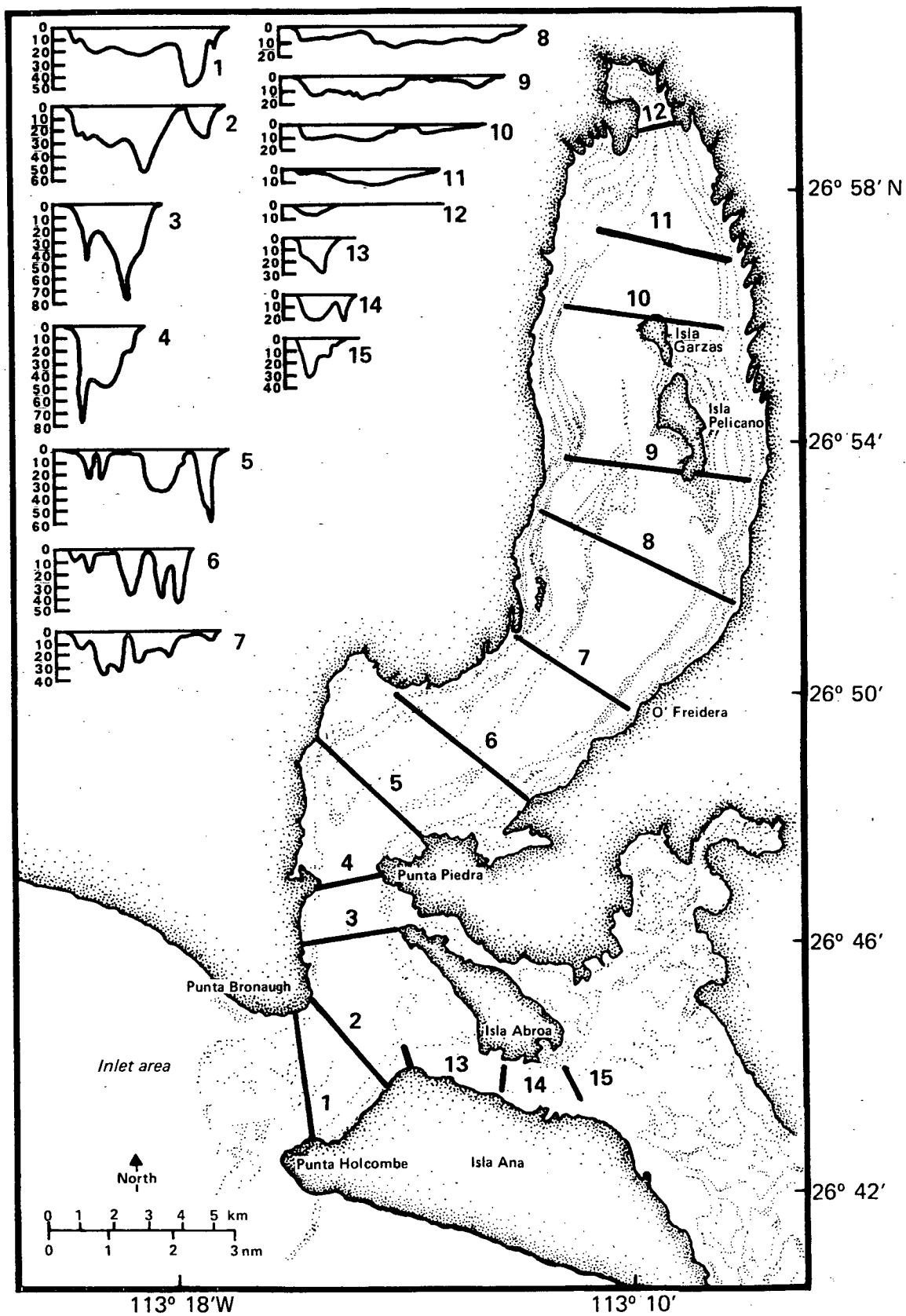


Figure A.6 Locations of Measurements of Temperature and Salinity
in Laguna San Ignacio, Mexico.

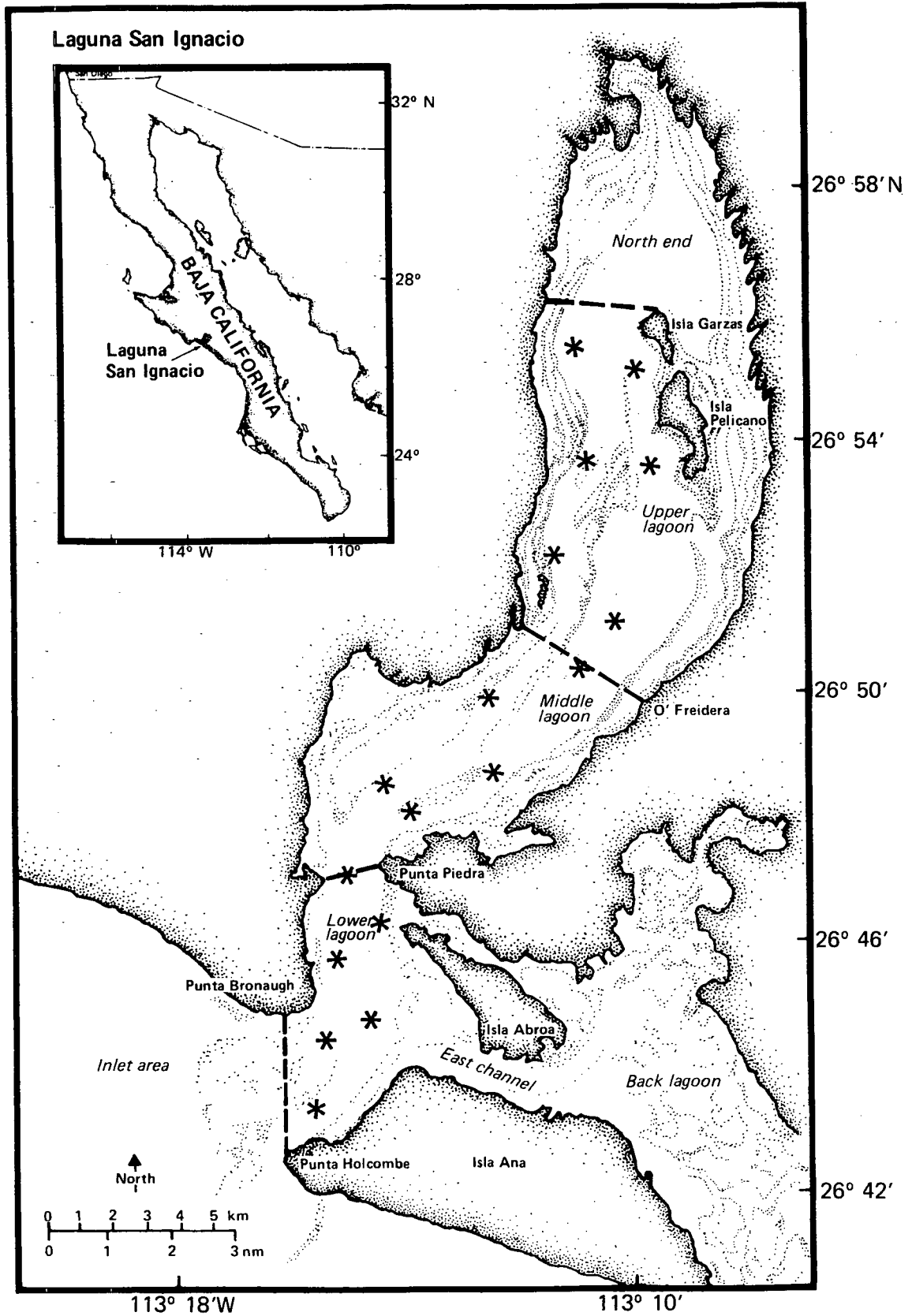


Figure A.7 Temperature vs Depth Profiles for Nine Stations off St. Lawrence Island, Alaska.

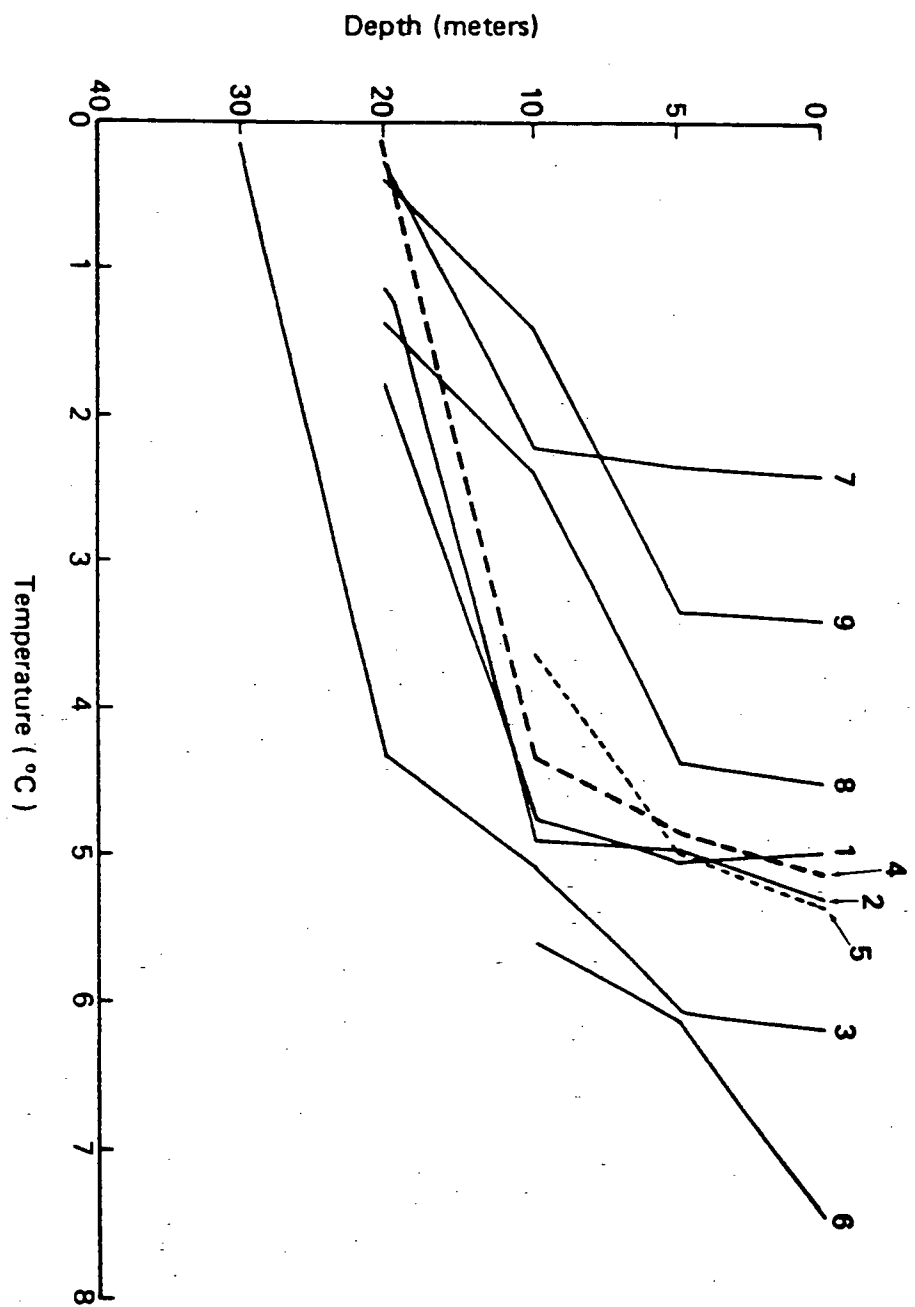
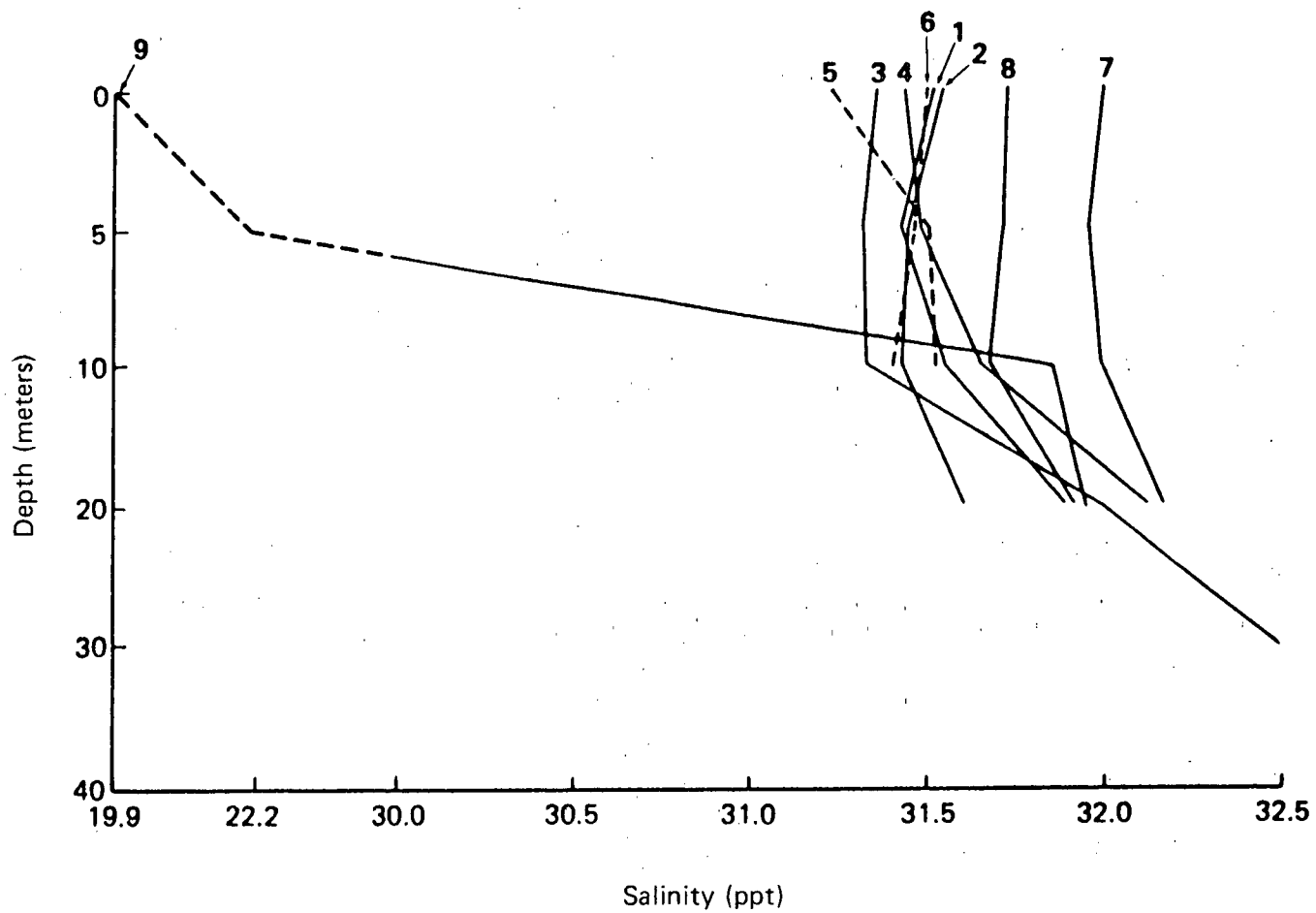


Figure A.8 Salinity vs Depth Profiles for Nine Stations off St. Lawrence Island, Alaska.



vs depth did not occur with the exception of Station 9, which was influenced by fresh water. The source of this fresh water is unknown. Locations of these measurements on temperature and salinity are listed in Table A-III.

Table A-III. Locations of Measurements Collected on Temperature and Salinity off St. Lawrence Island

Date	Time	Station	Latitude/ Longitude	Surface °C ppt	5 M °C ppt	10 M °C ppt	20 M °C ppt	30 M °C ppt	Bottom Depth(M)
7/11/82	1601	1	63° 24.5' N, 171° 51.2' W	5.06 31.54	5.13 31.46	4.80 31.56	1.79 31.90	-- --	32
7/11/82	2248	2	63° 33.8' N, 171° 53.8' W	5.30 31.55	5.00 31.48	4.96 31.45	1.14 31.61	-- --	30
7/12/82	2027	3	63° 54.4' N, 171° 57.9' W	6.23 31.38	6.10 31.33	5.15 31.34	4.36 32.08	0.69 32.51	37
7/13/82	1501	4	63° 37.3' N, 171° 52.1' W	5.18 31.45	4.96 31.50	4.40 31.67	0.10 32.14	-- --	26
7/14/82	1501	5	63° 46.4' N, 171° 48.5' W	5.32 31.25	5.02 31.52	3.60 31.64	-- --	-- --	23
7/15/82	1723	6	63° 45.1' N, 171° 28.3' W	7.49 31.53	6.19 31.50	5.63 31.42	-- --	-- --	20
7/16/82	1119	7	62° 59.5' N, 169° 27.7' W	2.48 32.04	2.41 31.97	2.26 32.01	0.57 32.09	-- --	23
7/20/82	0932	8	62° 59.0' N, 169° 28.4' W	4.58 31.76	4.40 31.74	2.40 31.67	1.41 31.92	-- --	22
7/21/82	1111	9	62° 59.5' N, 169° 28.0' W	3.49 19.90	3.48 22.27	1.46 31.86	0.89 31.91	-- --	22

A P P E N D I X B

APPENDIX B

1983 Calling RatesControl Periods

During control periods (defined as pre-trials and/or no intervention of man-made noise) gray whales produced an average of $18.4 \pm \text{s.d. } 4.8$ calls per 15-minute interval ($n = 24.5 \text{ hrs} = 98/15\text{-min intervals}$). Statistical differences were not detected when comparisons were made between periods with no intervention of man-made noise and pre-trial periods (Anova, $df = 4$, $F = 0.55$, $p > 0.05$). During trial and post-trial periods, the level of sound activity was observed to change when compared to control periods.

Experiment A - Real Sources

In the presence of real sound sources (trial periods Experiment A) gray whales produced an average of $41.9 \pm \text{s.d. } 10.9$ sounds per 15-minute interval ($n = 3.5 \text{ hrs} = 14/15\text{-min intervals}$). When this trial value was compared to pre-trial periods ($17.3 \pm \text{s.d. } 5.2$ sounds/15-min interval, $n = 3.5 \text{ hrs}$), a significant increase in calling rates was statistically documented in the presence of real sources ($t = 7.62$, $p < 0.05$). During post-trial periods, calling rates were shown to decrease with respect to trials with an average of $29.6 \pm \text{s.d. } 3.8$ calls produced for a 15-min interval ($n = 3.5 \text{ hrs}$). This post-trial rate was statistically lower than trial periods ($t = 3.89$, $p < 0.05$) but higher than pre-trial periods ($t = 7.32$, $p < 0.05$). A post-trial breakdown by 5-min intervals (but weighted for 15 minutes) indicated a gradual reduction in calling rates during this post-trial period. During the first five minutes an average of 36 sounds was produced. An average of 30 calls was produced during the second five minute category. During the final five minutes of the post-trial period, an average of 24 sounds was produced.

Experiment B - Outboard Engine Noise

During the projection of outboard engine noise (trial periods Experiment B), an increase in calling rates (when compared to control periods = $19.7 \pm \text{s.d. } 3.4$ calls produced/15 min interval) occurred with $45.5 \pm \text{s.d. } 11.3$ calls produced/15-min interval ($n = 3.5$ hrs). This trial rate was significantly higher than that documented during pre-trial periods ($t = 8.15$, $p < 0.05$). An inspection of the calling rates during post-trial periods for Experiment B showed a reduction in the average number of calls produced when compared to trials with an average of $24.9 \pm \text{s.d. } 4.3$ ($n = 3.5$ hrs) calls emitted for the 15-minute interval. Post-trial rates were statistically lower than trial periods and were significantly higher than pre-trial periods ($t = 6.35$, $p < 0.05$ and $t = 3.60$, $p < 0.05$, respectively). A breakdown of post-trial periods by five minute categories (weighted for 15 minutes) gave values of 30, 27, and 18 sounds produced for each 15-min interval. By the end of the post-trial period (last five minutes), calling rates had returned to pre-trial values.

Experiment C - Gray Whale Sounds

During Experiment C (trial periods with gray whale sounds being projected, $n = 3.5$ hrs), the rate of calling per 15-min interval averaged $23.9 \pm \text{s.d. } 5.9$ sounds produced for the 15-min interval. This trial value reflected a slight increase in calling rates over pre-trial periods ($17.6 \pm \text{s.d. } 4.4$ sounds produced). When these values were compared, a statistical difference was noted ($t = 3.06$, $p < 0.05$). An overall reduction in calling rates occurred during post-trial periods with 24 sounds produced in the first five minutes of the test period, 18 sounds for the second five minutes and 18 sounds for the last five minutes. These five-minute calling rates were, of course, weighted for a 15-min interval. An average call rate for

the overall 15 minute post-trial period was $19.8 \pm \text{s.d. } 3.1$ sounds produced. When this value was compared to trial periods, a significant reduction in calling rates was documented in post-trial periods ($t = 2.26$, $p < 0.05$). However, when comparisons were made between post and pre-trial periods, calling rates were not significantly different ($t = 1.37$, $p > 0.05$).

Experiment D - Test Tone Signals

During the projection of the test tone (trial periods Experiment D), a dramatic reduction in acoustical activity was documented when compared to pre-trial periods. In the presence of the test tone, all vocal activity ceased. An inspection of the post-trial periods associated with this particular experiment indicated that gray whales remained silent for at least 10 minutes following the acoustical perturbation. Sound activity was shown to increase during the last five minutes of this test period with $15.2 \pm \text{s.d. } 3.7$ calls produced (weighted for 15 minutes). This overall post-trial calling rate was significantly lower than pre-trial rates ($t = 2.16$, $p < 0.05$).

Comparisons of Calling Rates Among Trial Periods

A comparison of the calling rates among the various experiments yielded the following results. When trial periods of Experiment A (real sources, call rate equals $41.9 \pm \text{s.d. } 10.9$) and Experiment B (outboard engine playback, call rate equals $45.5 \pm \text{s.d. } 11.3$) were compared, no statistical differences in calling rates were detected ($t = 0.866$, $p > 0.05$). When calling rates were compared between trial periods of Experiment A (real sources = $41.9 \pm \text{s.d. } 10.9$) and Experiment C (gray whale sounds = $23.9 \pm \text{s.d. } 5.9$), significant differences occurred ($t = 5.41$, $p < 0.05$), with higher calling rates documented in the presence of real sources. The calling rates observed during trial periods of outboard engine playback

($45.5 \pm \text{s.d. } 11.3$) and gray whale sound playback ($23.9 \pm \text{s. d. } 5.9$) were also markedly different ($t = 6.3$, $p < 0.05$). Outboard engine noise elicited a higher calling rate than the projection of gray whale signals. Since all vocalizations ceased during the projection of the test tone, comparisons could not be made.

Comparisons of Calling Rates Among Post-trials Periods

Comparisons made during post-trial periods among the various experiments ($n = 3.5$ hrs for each experiment) resulted in distinct differences in calling rates for each comparison and are summarized as follows: real ($26.6 \pm \text{s.d. } 3.8$) vs outboard ($24.9 \pm \text{s. d. } 4.3$) ($t = 3.24$, $p < 0.05$); real ($29.6 \pm \text{s.d. } 3.8$) vs gray whale ($19.8 \pm \text{s.d. } 3.1$) ($t = 7.6$, $p < 0.05$); real ($29.6 \pm \text{s. d. } 3.8$) vs test tone ($15.2 \pm \text{s.d. } 3.7$) ($t = 10.3$, $p < 0.05$; and gray whale ($19.8 \pm \text{s. d. } 3.1$) vs test tone ($15.2 \pm \text{s. d. } 3.7$) ($t = 3.56$, $p < 0.05$). An analysis of variance applied to these post-trial rates also indicated statistical differences were occurring ($df = 4$, $F = 28.58$, $p < 0.05$).

1983 Call Structure

Control Periods

During control and pre-trial periods, the SI signal exhibited the following signal characteristics. Frequency range of the signal extended from 100 Hz to 2 kHz, with most energy concentrated in a band of 300 to 825 Hz. The average received level of this signal was $117.6 \pm \text{s. d. } 14.2$ dB re $1 \mu\text{Pa}$. Frequency modulation was noted to occur in 71.4% of the signals produced (30 signals out of 42). The average duration of this call was $1.7 \pm \text{s.d. } 0.8$ sec. Gray whales typically produced $9.4 \pm \text{s.d. } 4.4$ pulses per series. Calculations of number of pulses/series and the average call duration suggested an average pulse repetition rate of 5.4 per sec.

Experiment A - Real Sources

In the presence of real sound sources in the environment (trial experiments - Experiment A), the following structural changes occurred in the S1 signal. The received level of this signal averaged $148.8 \pm \text{s.d. } 9.8 \text{ dB}$ re $1 \mu\text{Pa}$. Received levels documented during these trial periods were significantly higher than those observed during control periods ($117.6 \pm \text{s.d. } 14.2 \text{ dB}$) ($t = 11.7$, $p < 0.05$). An increase was also noted in the number of S1 signals exhibiting frequency modulation during trial periods calculated at 85.7%. This value was significantly higher than the 71.4% value obtained during control periods (Chi square = 5.24, $p < 0.05$). Although there was a general tendency for signal duration to increase in the presence of real sources ($2.0 \pm \text{s.d. } 1.1 \text{ sec}$), this average value was not statistically different from control values ($1.7 \pm \text{s.d. } 0.8 \text{ sec}$) ($t = 1.44$, $p > 0.05$). The average number of pulses produced per series during trial periods was $24.6 \pm \text{s.d. } 8.0 \text{ pulses/series}$. The number of pulses/series produced during trial periods was significantly higher than that obtained during control periods ($9.4 \pm \text{s.d. } 4.4$) ($t = 10.7$, $p < 0.05$). The increase noted in the number of pulses produced per series and the fact that call duration had not significantly changed during trial periods indicated that pulse repetition rates also increased (average of 12 pulses/sec). A measurable change did not occur in the presence of real sources for overall frequency range of the signal (120-1800 Hz) and/or emphasized frequency range (280-700 Hz).

An analysis of the post-trial periods of Experiment A indicated that measurable differences were still prevalent in the S1 signal during this test period. The average received level was $128.3 \pm \text{s.d. } 6.6 \text{ dB}$ re $1 \mu\text{Pa}$. This post-trial received level was significantly higher than control levels

($117.6 \pm \text{s.d. } 14.2 \text{ dB}$) ($t = 4.42, p < 0.05$) but significantly lower when compared to trial periods ($148.8 \pm \text{s.d. } 9.8 \text{ dB}$) ($t = 11.2, p < 0.05$). An inspection of the number of signals that were frequency modulated during post-trial periods resulted in 78.6%. This post-trial percentage was not statistically different from that obtained during controls (71.4%) (Chi square = 1.02, $p > 0.05$) and/or trial periods (85.7%) (Chi square = 1.30, $p > 0.05$). During post-trial periods the number of pulses produced per series was $18.5 \pm \text{s.d. } 8.4$. The number of pulses/series was significantly lower in post-trial periods when compared to trial periods ($24.6 \pm \text{s.d. } 8.0$) ($t = 3.41, p < 0.05$). A comparison between pre ($9.4 \pm \text{s.d. } 4.4$) and post trial periods suggested that a significant difference also occurred in the number of pulses produced per series for these events as well ($t = 1.46, p < 0.05$) with higher values obtained during post-trial periods ($18.5 \pm \text{s.d. } 8.4$). Call duration ($2.0 \pm \text{s.d. } 1.0 \text{ sec}$) was not significantly different between post and trial periods ($2.0 \pm \text{s.d. } 1.1$) ($t = 0.227, p > 0.05$) and/or post and pre-trial periods ($1.7 \pm \text{s.d. } 0.8$) ($t = 1.25, p > 0.05$). No apparent differences were found in post-trial periods for overall frequency range (120-1950 Hz) and/or emphasized frequencies (315-820 Hz) of the signal. Similar values with respect to frequency ranges were obtained for all three test periods. Based upon the average number of pulses/series and the average call duration, an average repetition rate of 9.25 pulses/sec was calculated for post-trial periods. This value was somewhat lower than trial periods ($\bar{x} = 12$) but higher than control periods ($\bar{x} = 5.4$).

Experiment B - Outboard Engine Noise

During the projection of outboard engine noise (Experiment B trial periods), the following structural modifications were documented in the S1 signal. An increase was once again noted in received level of S1 signals

with a value of $156.6 \pm \text{s.d. } 9.5$ dB re $1 \mu\text{Pa}$. This trial value was significantly higher than the received level obtained during control periods ($117.6 \pm \text{s.d. } 14.2$) ($t = 11.7$, $p < 0.05$). The percentage of signals exhibiting frequency modulation was 83.3% during trial periods vs 71.4% obtained during control periods. These values were shown not be statistically different (Chi square = 3.36, $p > 0.05$), but were significant at the 0.06 level. Average call duration was $2.0 \pm \text{s.d. } 0.9$ sec during trial experiments. This value was not significantly different from that obtained during pre-trial periods ($1.7 \pm \text{s.d. } 0.8$ sec) ($t = 1.44$, $p > 0.05$). The number of pulses produced per series during trial periods was $22.6 \pm \text{s.d. } 6.8$. This value was markedly higher than the value obtained during control periods ($9.4 \pm \text{s.d. } 4.4$) ($t = 10.7$, $p < 0.05$). Repetition rates (calculated from the average number of pulses/series and average call duration) was 11.3/sec. Again no changes were observed to occur in frequency range (150-2000 Hz) and/or frequencies emphasized (300-800 Hz).

An inspection of the post-trial values (Experiment B) revealed that structural changes were still occurring in the S1 signal during this outboard test period. The average received level was $121.5 \pm \text{s.d. } 6.2$ dB compared to $117.6 \pm \text{s.d. } 14.2$ dB in control periods and $156.6 \pm \text{s.d. } 9.5$ dB in trial periods. Post-trial values were not significantly different than control levels ($t = 1.61$, $p > 0.05$) but were significantly lower than trial periods ($t = 20.0$, $p < 0.05$). During post-trial periods, the number of signals exhibiting frequency modulation was 73.8%. This post-trial value was not significantly different than pre-trial (71.4%) or trial periods (83.3%) (Chi square = 4.34, $p > 0.05$). The number of pulses produced per series during post-trial periods was $13.2 \pm \text{s.d. } 5.1$, which was significantly higher than pre-trials ($9.4 \pm \text{s.d. } 4.4$) ($t = 3.64$, $p <$

0.05) and significantly lower than trial periods ($22.6 \pm \text{s.d. } 6.8$) ($t = 7.09$, $p < 0.05$). Average call duration during post-trials was $1.9 \pm \text{s.d. } 0.9$ sec. Significant differences were not found when post-trial call duration was compared to pre-trial call duration ($1.7 \pm \text{s.d. } 0.8$ sec) ($t = 1.22$, $p > 0.05$) and/or trial periods ($2.0 \pm \text{s.d. } 0.9$ sec) ($t = 0.195$, $p > 0.05$). An average repetition rate during post-trials was 6.7/sec, somewhat lower than trial rates ($\bar{x} = 11.3$) but similar to pre-trial rates ($\bar{x} = 5.4$). Frequency range (200-1800 Hz) and emphasized frequencies (350-780 Hz) were similar in all three test periods.

Experiment C - Gray Whale Sounds

During trial periods when gray whale sounds were projected (Experiment C), structural changes in the S1 signal were once again documented. When compared to pre-trial ($117.6 \pm \text{s.d. } 14.2$), a significant increase ($t = 3.08$, $p < 0.05$) was noted in received levels, averaging $126.4 \pm \text{s.d. } 11.7$ dB re $1 \mu\text{Pa}$. The number of signals exhibiting frequency modulation was 95.2%, a value significantly higher than control signals (71.4%) (Chi square = 18.43, $p < 0.05$). The number of pulses/series was $12.8 \pm \text{s.d. } 6.7$, which was also significantly higher than control values of $9.4 \pm \text{s.d. } 4.4$ pulses/series ($t = 2.77$, $p < 0.05$). Once again, call duration of $1.9 \pm \text{s.d. } 0.9$ sec (trial periods) was not significantly different from controls ($1.7 \pm \text{s.d. } 0.8$ sec) ($t = 1.08$, $p > 0.05$). A repetition rate of 6.6 pulses/sec was calculated for trial periods, a value close to that obtained in control periods (5.4). No obvious differences occurred between control and trial periods with respect to overall frequency range (100-2000 Hz) or emphasized frequency bands of the signals (300-790 Hz).

During post-trial periods (Experiment C), received levels were noted

to be $119.7 \pm \text{s.d. } 6.6$ dB re $1 \mu\text{Pa}$. This post-trial average value was not significantly different from pre-trial values ($117.6 \pm \text{s.d. } 14.2$) ($t = 0.857$, $p > 0.05$) but was significantly lower ($t = 3.22$, $p < 0.05$) than trial periods ($126.4 \pm \text{s.d. } 11.7$ dB). Post-trial signals exhibiting frequency modulation were calculated at 73.8%. This value was not significantly different from control values of 71.4% (Chi square = 0.50, $p > 0.05$) but was significantly lower than the 95.2% obtained during trial periods (Chi square = 15.88, $p < 0.05$). During these post-trial periods the number of pulses/series was $10.8 \pm \text{s.d. } 5.0$. This average value when compared to pre-trial periods ($9.4 \pm \text{s.d. } 4.4$) was not statistically different ($t = 1.42$, $p > 0.05$). When the average number of pulses/series was compared between post and trial periods ($12.8 \pm \text{s.d. } 6.7$), once again significant differences could not be found ($t = 1.52$, $p > 0.05$). No significant difference could be detected in post-trial call duration ($1.9 \pm \text{s.d. } 0.8$ sec) between pre ($1.7 \pm \text{s.d. } 0.8$ sec) and post-trials ($t = 1.13$, $p > 0.05$) and post and trial periods ($1.9 \pm \text{s.d. } 0.9$ sec) ($t = 6.01$, $p > 0.05$). An average repetition rate during post-trials was 5.4 pulses/sec. All three test periods were similar with respect to repetition rates. The overall frequency range of the signal during post-trials was 125-1950 Hz and frequency bands of 320-820 Hz were emphasized. These frequency ranges were similar to those obtained during trial and pre-trial times.

Experiment D - Test Tone Signals

Since all vocalizations ceased during the projection of the test tone (Experiment D) structural comparisons, of course, could not be accomplished. An inspection of the post-trial periods of Experiment D did suggest that when gray whales began to vocalize once again

(approximately 10 minutes after the termination of the trial period) the structure of the S1 signal was similar to that described for control periods. The average received level of the signals during post-trials was $115.4 \pm \text{s.d. } 9.3$ dB re $1 \mu\text{Pa}$. When compared to the received values obtained during control periods ($117.6 \pm \text{s.d. } 14.2$ dB), a significant difference in call level did not occur ($t = 0.864$, $p > 0.05$). When the number of signals exhibiting frequency modulation were compared between pre- and post-trials, significant differences could not be documented. Control and post-trial values were both estimated at 71.4%. During post-trial periods, an average of $9.6 \pm \text{s.d. } 4.9$ pulses were produced per series. This value was not significantly different from the value of $9.4 \pm \text{s.d. } 4.4$ obtained during control periods ($t = 0.254$, $p > 0.05$). As in all other comparisons, call duration during post-trial periods ($1.8 \pm \text{s.d. } 0.8$ sec) was not significantly different from control periods (1.7 ± 0.8 sec) ($t = 0.357$, $p > 0.05$). Repetition rates calculated for post-trial periods were 5.3 pulses/sec, which were similar to the values obtained during pre-trial periods (5.4 pulses/sec). Overall frequency range of the signal was 125-2000 Hz and the frequency bands of 300-800 Hz were emphasized. No apparent frequency shift took place in these post-trial periods.

1983 Structural Comparisons of Calls

Received Level of Signals

Received levels of the S1 signals were significantly different between the trial periods of Experiment A (real sources = $148.8 \pm \text{s.d. } 9.8$ dB) and Experiment B (outboard playback = $156.6 \pm \text{s.d. } 9.5$ dB) at $t = 3.7$, $p < 0.05$. When comparing the trial experiments of real sources and gray whale playback ($126.4 \pm \text{s.d. } 11.7$ dB), once again significant differences were obtained ($t = 9.52$, $p < 0.05$). A comparison of the received levels of gray whale

calls between the projection of outboard engine noise ($156.6 \pm \text{s.d. } 9.5 \text{ dB}$) and gray whale signals ($126.4 \pm \text{s.d. } 11.7$) were shown to differ as well ($t = 13.0$, $p < 0.05$). The level of the received call was shown to vary depending upon the sound stimuli present in the environment.

When comparing the received levels of calls among the four experimental post-trial periods (including test tone post-trials), major differences were documented. These data are summarized as follows: Real ($128.3 \pm \text{s.d. } 6.6 \text{ dB}$) vs outboard ($121.5 \pm \text{s.d. } 6.2 \text{ dB}$) ($t = 4.8$, $p < 0.05$); real ($128.3 \pm \text{s.d. } 6.6 \text{ dB}$) vs gray whale playback ($119.7 \pm \text{s.d. } 6.6 \text{ dB}$) ($t = 5.96$, $p < 0.05$); real ($128.3 \pm \text{s.d. } 6.6 \text{ dB}$) vs test tone ($115.4 \pm \text{s.d. } 9.3 \text{ dB}$) ($t = 7.35$, $p < 0.05$); outboard ($121.5 \pm \text{s.d. } 6.2 \text{ dB}$) vs test tone ($115.4 \pm \text{s.d. } 9.3 \text{ dB}$) ($t = 3.55$, $p < 0.05$); and gray whale ($119.7 \pm \text{s.d. } 6.6$) vs test tone ($115.4 \pm \text{s.d. } 9.3$) ($t = 2.46$, $p < 0.05$). An exception occurred when post-trial periods were compared between outboard ($121.5 \pm \text{s.d. } 6.2$) and gray whale sounds ($119.7 \pm \text{s.d. } 6.6$). In this case significant differences could not be found ($t = 1.27$, $p > 0.05$). An inspection of the average levels received during these post-trial periods suggested that gray whales resume baseline/control levels at a faster rate when exposed to their own signals and/or the rapid onset of outboard engine noise. Post-trial levels were greatest following the presence of real sources in the environment ($128.3 \pm \text{s.d. } 6.6 \text{ dB}$), suggesting a slower recovery rate. After exposure to the test tone (although silent for 10 minutes), gray whale received levels ($115.4 \pm \text{s.d. } 9.3$) were similar to those obtained in control periods ($117.6 \pm \text{s.d. } 14.2 \text{ dB}$). The results of these analyses suggested that the post-exposure received levels of calls also varied with the type of sound stimuli that had been present in the environment.

Frequency Modulation Within Signals

When investigating the number of signals exhibiting frequency modulation during various trial periods, the analyses resulted in the following. When trial periods of real (85.7%) and outboard (83.3%) were compared, differences were not found (Chi square = 0.074, $p > 0.05$). However, when real (85.7%) and gray whale playback periods (95.2%) and outboard (83.3%) and gray whale playback periods (95.2%) were compared, statistical differences were noted (Chi square = 4.02, $p < 0.05$ and Chi square = 6.08, $p < 0.05$, respectively). In both cases, the number of signals exhibiting frequency modulation were highest during gray whale playback periods at 95.2%. An analysis of post-trials with respect to the number of signals that were frequency modulated suggested that the values obtained for the various experiments were not different (Chi square = 0.845, $p > 0.05$). The above post-trial comparisons suggest that the number of signals that are frequency modulated after exposure to increased noise levels is basically similar among various sound stimuli.

Call Duration

For all comparisons conducted on call duration, significant differences could not be found among the trial or post-trial periods among the various experiments. The statistical values calculated for these call duration values are listed as follows: 1) trial comparisons: real ($2.0 \pm \text{s.d. } 1.1$ sec) vs outboard ($2.0 \pm \text{s.d. } 0.9$ sec) ($t = 0.183$, $p > 0.05$); real ($2.0 \pm \text{s.d. } 1.1$ sec) vs gray whale ($1.9 \pm \text{s.d. } 0.9$ sec) ($t = 0.457$, $p > 0.05$); outboard ($2.0 \pm \text{s.d. } 0.9$) vs gray whale ($1.9 \pm \text{s.d. } 0.9$ sec) ($t = 0.30$, $p > 0.05$); and 2) post-trial comparisons: real ($2.0 \pm \text{s.d. } 1.0$ sec) vs outboard ($1.9 \pm \text{s.d. } 0.9$ sec) ($t = 0.127$, $p > 0.05$); real ($2.0 \pm \text{s.d. } 1.0$ sec) vs gray whale ($1.9 \pm \text{s.d. } 0.8$) ($t = 0.169$, $p > 0.05$); real ($2.0 \pm \text{s.d. } 1.0$

sec) vs test tone ($1.8 \pm \text{s.d. } 0.8$) ($t = 0.914$, $p > 0.05$); outboard ($1.9 \pm \text{s.d. } 0.9$) vs gray whale ($1.9 \pm \text{s.d. } 0.8$) ($t = 0.04$, $p > 0.05$); outboard ($1.9 \pm \text{s.d. } 0.9$) vs test tone ($1.8 \pm \text{s.d. } 0.8$) ($t = 0.858$, $p > 0.05$); and gray whale ($1.9 \pm \text{s.d. } 0.8$) vs test tone ($1.8 \pm \text{s.d. } 0.8 \text{ sec}$) ($t = 0.780$, $p > 0.05$). Call duration was similar for all experiments.

Number of Pulses Within Signals

A comparison of the number of pulses produced per series among different experiments yielded the following results. Statistical differences did not occur when the trial periods of real ($24.6 \pm \text{s.d. } 8.0$) and outboard playback ($22.6 \pm \text{s.d. } 6.8$) were compared ($t = 1.25$, $p > 0.05$). However, values obtained during the comparisons of trial periods between real ($24.6 \pm \text{s.d. } 8.0$) and gray whale playback ($12.8 \pm \text{s.d. } 6.7$) ($t = 7.26$, $p < 0.05$) and outboard ($22.6 \pm \text{s.d. } 6.8$) and gray whale ($12.8 \pm \text{s.d. } 6.7$) ($t = 6.56$, $p < 0.05$) were different. When an inspection of the number of pulses produced per series was made among various post-trial periods, statistical differences were found for each comparison as follows:

post-trial comparisons: real ($18.4 \pm \text{s.d. } 8.4$) vs outboard ($13.2 \pm \text{s.d. } 5.1$) ($t = 3.46$, $p < 0.05$); real ($18.4 \pm \text{s.d. } 8.4$) vs gray whale playback ($10.8 \pm \text{s.d. } 5.0$) ($t = 5.01$, $p < 0.05$); real ($18.4 \pm \text{s.d. } 8.4$) vs test tone ($9.6 \pm \text{s.d. } 4.9$) ($t = 5.84$, $p < 0.05$); outboard ($13.2 \pm \text{s.d. } 5.1$) vs gray whale ($10.8 \pm \text{s.d. } 5.0$) ($t = 2.10$, $p < 0.05$); and outboard ($13.2 \pm \text{s.d. } 5.1$) vs test tone ($9.6 \pm \text{s.d. } 4.4$) ($t = 3.22$, $p < 0.05$). An exception occurred when gray whale post-trials ($13.2 \pm \text{s.d. } 5.1$) were compared to test tone post-trials ($9.6 \pm \text{s.d. } 4.9$). These values were not significantly different ($t = 1.11$, $p > 0.05$). Again, the exposure to different sound stimuli resulted in different rates of decline during post-trial events.

Frequency Range and Frequencies Emphasized

No apparent differences were observed among experiments with respect to the overall frequency range of the signal and the frequencies emphasized in the signal.

C-1

A P P E N D I X C

APPENDIX C

1984 Calling Rates

In 1984, 40 hours were spent collecting the sounds of gray whales in the absence of any noise disturbance (= control periods). Under control conditions, gray whales produced an average of $81.4 \pm \text{s.d. } 16.6$ sounds/hour. When exposed to real sources in the environment (Experiment A; 40 hours), a change in calling rate was documented. Calling rates increased in the presence of real sources averaging $159.6 \pm \text{s.d. } 35.5/\text{hour}$, a value significantly higher than control periods ($t = 12.59$; $p < 0.05$). When gray whales were subjected to outboard engine noise (Experiment B; 40 hours), calling rates averaged $137.9 \pm \text{s.d. } 24.7$ sounds/hour. This experimental value reflected a significant increase in calling rates when compared to control values ($t = 11.9$; $p < 0.05$).

In the presence of oil-drilling sounds (Experiment C; 40 hours), a major decrease in sound activity was documented. An average call rate of $14.9 \pm \text{s.d. } 7.4$ sounds per hour was documented in the presence of this sound source. When compared to control values ($81.4 \pm \text{s.d. } 16.6$), a significant decrease in calling rates was noted during the projection of oil-drilling sounds ($t = 23.0$; $p < 0.05$). The projection of killer whale sounds (Experiment D; 40 hours) created a greater effect on the acoustical behavior of gray whales than the results obtained in the presence of oil-drilling sounds. When these predatory signals were projected, all vocalizations by gray whales ceased.

To verify that gray whales were not responding to the short click produced when the sound equipment was turned on, and/or the possible acoustical energy produced by the transducer, this equipment was fully

operated without projection of sounds (Experiment E; 40 hours).

Calling rates obtained during this experiment averaged $78.5 \pm \text{s.d. } 17.0$.

When these rates of calling were compared to control periods ($81.4 \pm \text{s.d. } 16.6$), a significant difference could not be obtained ($t = 0.77$; $p > 0.05$).

1984 Call Structure

Since the S1 signal continued to dominate the acoustical repertoire of the gray whale during the 1984 investigations, structural comparisons were once again conducted on this call type. As in 1983, six sound parameters were measured and compared among the experimental events: frequency range of signal (Hz); range of emphasized frequencies (Hz); received levels of sound (dB re $1 \mu\text{Pa}$); percentage of S1 signals exhibiting frequency modulation; duration (sec); and number of pulses produced per series. Call repetition rates (number/sec) were derived from the average duration and average number of pulses produced per series. Two sounds per hour for each experimental grouping were randomly selected and analyzed; thus a total of 80 sounds for each experimental condition were examined.

Control Periods

During control periods, the S1 signal exhibited the following signal characteristics. Frequency range of the signal extended from 100 Hz to 2000 Hz, with most energy concentrated in a band of 300 to 850 Hz. The average received level of this signal was $120.3 \pm \text{s.d. } 17.6$ dB re $1 \mu\text{Pa}$. An inspection of the number of signals showing frequency modulation was 68.7%. Average signal duration was $1.9 \pm \text{s.d. } 0.8$ sec. Gray whales typically produced $9.9 \pm \text{s.d. } 4.0$ pulses per series. The calculated average pulse repetition rate was 5.2 per sec. In the presence of increased noise levels, marked differences occurred in the structure

of the S1 signal when compared to control periods. These results are presented below.

Experiment A - Real Sources

In the presence of real sound sources (Experiment A), the following changes occurred in the S1 signal. The received level of this call was noted to increase and averaged $148.5 \pm \text{s.d. } 12.2$, a value significantly higher than that obtained during control periods ($120.3 \pm \text{s.d. } 17.6$) ($t = 11.7$; $p < 0.05$). The number of S1 signals exhibiting frequency modulation was 90%, compared to the 68.7% obtained during control periods. When compared, these two values were significantly different, with frequency modulation occurring more often in the presence of real sources (Chi Square = 12.6; $p < 0.05$). Call duration averaged $2.0 \pm \text{s.d. } 1.0$ sec during Experiment A and was not shown to differ from that of control periods ($1.9 \pm \text{s.d. } 0.8$) ($t = 0.89$; $p > 0.05$). An increase was noted to occur in the number of pulses produced per series, averaging $25.4 \pm \text{s.d. } 8.5$ pulses. This value was significantly higher ($t = 14.6$; $p < 0.05$) than that obtained during control periods ($9.9 \pm \text{s.d. } 4.0$). The derived repetition rate, based on average call duration and the average number of pulses per series, was 12.7 pulses/sec, a value significantly higher than that obtained during control periods (5.2 pulses per sec). A measurable change did not occur in the presence of real sources for overall frequency range of the signal (150-1800 Hz) and/or emphasized frequency bands of the signal (300-800 Hz).

Experiment B - Outboard Engine Noise

During the projection of outboard engine noise (Experiment B), a measurable change was noted in the received level of the call, averaging $150.2 \pm \text{s.d. } 12.8$ dB re $1 \mu\text{Pa}$. This value was significantly higher than

that obtained during control periods ($120.3 \pm \text{s.d. } 17.6$) ($t = 12.2$; $p < 0.05$). In the presence of outboard engine noise, the number of signals showing frequency modulation was 86.2%. When compared to control values of 68.7%, this experimental value was found to be statistically higher (Chi Square = 7.8; $p < 0.05$). During these experiments, average call duration was $2.0 \pm \text{s.d. } 0.8$ sec. When compared to controls ($1.9 \pm \text{s.d. } 0.8$), a significant difference in call duration was not detected ($t = 1.06$; $p > 0.05$). The number of pulses produced per series averaged $23.1 \pm \text{s.d. } 6.9$, a value significantly higher than that obtained during control periods ($9.9 \pm \text{s.d. } 4.0$) ($t = 14.6$; $p < 0.05$). The average repetition rate calculated for this experimental period was 11.5 pulses per sec, a considerable increase over that of 5.2 pulses per sec obtained during control periods. Once again, a detectable difference did not occur when experimental periods for frequency range of signal (120-1900 Hz) and/or emphasized frequency bands (320-860 Hz) were compared to control periods.

Experiment C - Oil-Drilling Sounds

During the projection of oil-drilling sounds (Experiment C), gray whale call structure was shown to differ from that described for control periods. Received levels averaged $143.1 \pm \text{s.d. } 9.4$ dB re $1 \mu\text{Pa}$. This value was significantly higher than control values ($120.3 \pm \text{s.d. } 17.6$) ($t = 10.2$; $p < 0.05$). The number of signals exhibiting frequency modulation was 92.5% vs the 68.7% obtained during control periods. Statistical differences were documented when these two values were compared (Chi Square = 16.5; $p < 0.05$). No apparent differences ($t = 0.2$; $p > 0.05$) were found when call duration was compared between experimental ($1.8 \pm \text{s.d. } 0.9$ sec) and control ($1.9 \pm \text{s.d. } 0.8$) periods.

The number of pulses produced per series averaged $25.4 \pm \text{s.d. } 7.4$, which reflected a significantly higher pulse rate than that noted during control periods ($9.9 \pm \text{s.d. } 4.0$) ($t = 16.2$; $p < 0.05$). The average repetition rate of the SI signal during the projection of oil-drilling sounds was 14.1 pulses produced per sec, a value markedly higher than control periods (5.2 pulses per sec). Frequency range of the signal (110-2000 Hz) and emphasized frequency bands (310-850 Hz) during exposure to oil-drilling sounds were similar to control periods.

Experiment D - Killer Whale Sounds

Since the projection of killer whale sounds resulted in a complete cessation of all gray whale vocalization, structural comparisons could not be accomplished for this experimental condition (Experiment D).

Experiment E - Equipment On; No Sounds Produced

To test whether gray whales were responding to the acoustical equipment used during these playback trials, comparisons of call structure between Experiment E (equipment on, no sounds produced) and control periods were accomplished. Significant differences could not be obtained for any of the acoustical variables measured, suggesting that the acoustical equipment itself had no effect on the behavior of gray whales. These comparisons are summarized below. Received levels (Experiment E) averaged $119.6 \pm \text{s.d. } 14.3$ vs control ($120.3 \pm \text{s.d. } 17.6$) periods ($t = 0.2$; $p > 0.05$); number of signals exhibiting frequency modulation during experimental periods (66.2%) vs control (68.7%) (Chi Square = .05; $p > 0.05$); call duration averaged $1.9 \pm \text{s.d. } 0.8$ during experimental testing and $1.9 \pm \text{s.d. } 0.8$ during control periods ($t = 0.04$; $p > 0.05$); number of pulses produced per series for experimental ($9.3 \pm \text{s.d. } 5.4$) vs $9.9 \pm \text{s.d. } 4.0$ for control periods ($t = 0.7$; $p > 0.05$); repetition rates of 4.9 per sec were calculated

for Experiment E and compared to the 5.2 per sec obtained during control periods, and were found to be similar. The overall frequency range of the signal was 140-1800 Hz and emphasized bands were 340-860 Hz during the test periods of Experiment E. No apparent shift occurred with respect to frequency values for experimental vs control periods.