AMBIENT, INDUSTRIAL AND BIOLOGICAL SOUNDS RECORDED IN THE NORTHERN BERING, EASTERN CHUKCHI AND ALASKAN BEAUFORT SEAS DURING THE SEASONAL MIGRATIONS OF THE BOWHEAD WHALE (*Balaena mysticetus*), 1979-1982

Sue E. Moore

SEACO, Incorporated

San Diego, California 92106

Donald K. Ljungblad

NOSC, Code 5141

San Diego, California 92152

David R. Schmidt

NOSC, Code 5134

San Diego, California 92152

Final Report: prepared for the Minerals Management Service, Alaska OCS Region, U.S. Department of Interior; prepared by SEACO, Incorporated, 2845 Nimitz Boulevard, San Diego, California 92106

AMBIENT, INDUSTRIAL AND BIOLOGICAL SOUNDS RECORDED IN THE NORTHERN BERING, EASTERN CHUKCHI AND ALASKAN BEAUFORT SEAS DURING THE SEASONAL MIGRATIONS OF THE BOWHEAD WHALE (Balaena mysticetus), 1979-1982

Sue E. Moore

SEACO, Incorporated

San Diego, California 92106

Donald K. Ljungblad

NOSC, Code 5141

San Diego, California 92152

David R. Schmidt

NOSC, Code 5134

San Diego, California 92152

1984

Final Report: prepared for the Minerals Management Service, Alaska OCS Region, U.S. Department of Interior; prepared by SEACO, Incorporated, 2845 Nimitz Boulevard, San Diego, California 92106

CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

We wish to acknowledge the professional assistance of many people who contributed to our safe and successful field seasons, and to the formulation of this report. At the Office of Aircraft Services (OAS), Department of Interior, Anchorage, AK we cite the persevering performance of the pilots, maintenance staff and administrative personnel. At the Minerals Management Service (i Of MS), we appreciate the support and advice of Cleve Cowles, Jerr y Imm , Jerome Montague and Tim Sullivan. Janet Clarke of SEA(XI, Inc. compiled and edited all figures, and John Bennett and Jim Keene, also of SEACO, Inc., reviewed, edited and provided helpful comments on this draft. Many thanks also to Susan Hogman and Rene' Hearne-Trevathan, Jeanne Cole and Mark Merker (SEACO, Inc.) for their dedicated typing. Funding for this work was provided by M MS via interagency agreement number 41-12-0001-29064, project BLM-AA851- 1A2-3, element OFGOV.

ABSTRACT

Magnetic-tape recordings made during the spring and fall bowhead whale migration (1979-1982) were analysed for ambient, industrial and biological sound content. Sound pressure levels measured off narrowband (500 Hz), spectrums of opportunistically recorded ambient noise ranged from 60 dB to 86 dB re 1µ Pa^2/Hz and were classified by year, region, and season. A logarithmic average of measured ambient noise level in the 500 Hz band ranged from 65 dB to 77 dB across all regions and with no significant difference ($p < 0.20$) between seasons. Narrowband ambient spectrum level recorded in the Canadian Beaufort Sea averaged 62 dB. The effect of local sea state, ice coverage and depth on measured ambient level was analysed via multiple regression, with sea state emerging as the dominate correlate in narrowband ($r = 0.783$) and broadband (0.853) analyses of a single-region sample. Industrial noise levels from aircraft, small and large vessels, seismic airguns and pipe driving sounds were measured off sound spectrums and classified by source. When corrected for distance, highest industrial noise levels were measured from seismic airguns followed by pipe driving, large vessels, small vessels, and aircraft. Time waveform analysis was performed on transient impulsive signals such as airgun shots and pipe driving bangs to correlate temporal analysis to spectrum levels. Biological sounds produced by bowhead, belukha and gray whales, and bearded seals were analysed via spectral and spectrographic techniques. A preliminary classification of seven bowhead and four gray whale call types based upon temporal and frequency (i.e. spectrographic) features is presented. A seasonal analysis of biological noise levels found spring to be the season with the highest such levels. These data were subsequently compared with those of similar studies, and recommendations made for future acoustic research including ambient noise and water column sound speed profile measurements, transmission loss modelling, measurement and modelling of the directivity pattern of active airgun arrays, correlation of sound production and behavior for biological sources, and tests of mysticete hearing capabilities.

INTRODUCTION

Each spring (April-3 une), bowhead whales (*Balaena mysticetus*) migrate northward from the Bering Sea through the eastern Chukchi Sea and across the U.S. Beaufort Sea to their summer feeding grounds in Canadian arctic waters. In the fall (August-October), the whales migrate westward through the Beaufort Sea, cross the Chukchi Sea and pass through the Bering Strait, as they return to their wintering grounds in the Bering Sea. Much of this migration passes through or near areas under, or proposed for, energy resource development. As part of its responsibilities under the Outer Continental Shelf Lands Act, National Environmental Policy Act , Endangered Species Act, Marine Mammal Protection Act and other legislation, the Minerals Management Service (MMS) has funded a study through the Naval Ocean Systems Center (NOSC) since 1979 to conduct aerial surveys in these regions (Ljungblad et al, 1980; L jungblad 198 l; Ljungblad 1982a and 1983). These surveys seek to determine the seasonal distribution, migratory pattern, relative abundance and habitats of endangered whales and other marine mammals such that sound decisions relative to leasing, exploration and development of the outer continental shelf can be made. Magnetic tape recordings have been made to monitor underwater sounds during the seasonal bowhead migration. The results of analyses of screened and selected recordings for ambient, industrial and biological sound content are the topic of this report.

The primary intent of most recordings was to collect sounds produced by bowhead whales. Sounds related to industrial activities were initially considered a source of interference while recording biological sounds. Later in these studies, industrial-related sound sources became the priority as concern for possible noise effects on bowheads became a major issue. Ambient or "background" noise was recorded opportunistically and in association with biological or industrial "target" sounds. Ambient noise sampled in this way is useful in a comparative format with other "target" sounds, but extreme caution should be exercised when interpreting the data beyond this framework because available data do not supply a sample base sufficient to analyse long term trends, as is usually done in ambient noise anal ysis. While it is important to establish a baseline ambient noise level against which to compare industrial and biological sound levels, it is impractical to collect an unbiased ambient noise sample while conducting a study designed to monitor endangered whale population demographics. The intent of the analyses presented herein was to summarize acoustic data collected between 1979 and 1982, and to provide baseline information for future comparisons.

METHODS

Study Regions

The overall survey area included the Bering Sea north of 63ºN latitude, the Chukchi Sea east of 169ºW longitude, and the Alaskan Beaufort Sea from Point Barrow to the U.S. - Canadian border offshore to 72ºN latitude. This area was divided into five regions for the purpose of data analyses and presentation (Figure 1). Archived sonobuoy recordings were identified by region and season to present a characterization and synthesis of acoustic data recorded between 1979 and 1982 in a comparative format.

Recoding System

During aerial surveys recordings were made via sonobuoys which are passive acoustic listening systems that contain a hydrophone, signal processing electronics and a VHF transmitter. The three types of sonobuoys used were AN/SSQ 4 1A, AN/SSQ 41B and AN/SSQ 57A. These units have frequency responses of 10 Hz to 6 kHz, 10 Hz to 20 kHz and 10 Hz to 20 kHz, respectively. The nominal frequency response and the frequency response envelope for 57A sonobuoys is presented in Figure 2. The 4113 and 57A sonobuoy units are functionally quite similar and are specified to have sensitivities f alling within the envelope presented. The 41A sonobuoy has a 'similar response envelope, but is equipped with an automatic gain control (AGC) feature, therefore, sound level can not be measured from spectra of recordings made with this type of sonobuoy. Additionally, some 57A sonobuoys are equipped with an optional 20 dB attenuator. This feature, when selected allows the 57A to record (relatively) louder sounds than the 41 B, without distortion.

Sonobuoys were dropped from the aircraft, and their descent slowed by a rotochute or parachute. Once in contact with the water, a salt-water activated battery energized the unit and the hydrophore dropped to a preset depth of 18.2 m. Sounds picked up by the hydrophore were amplified and transmitted to a Defense Electronics Instruments Model GPR-20 VHF broadband receiver aboard

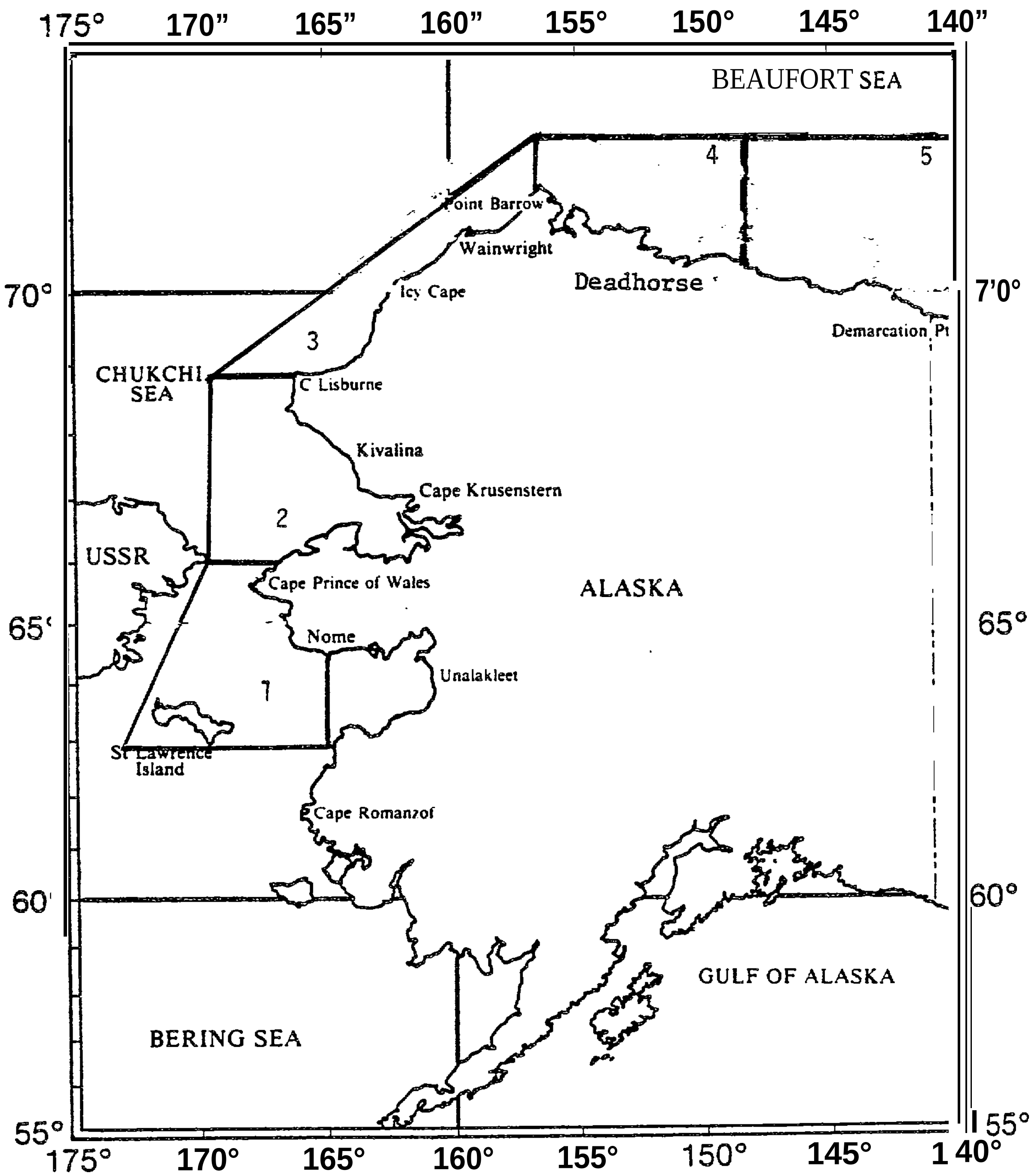


Figure 1. Five regions of the overall survey area:

Region 1: northern Bering Sea
Region 2: southeastern Chukchi Sea
Region 3: northeastern Chukchi Sea
Region 4: western Beaufort Sea
Region 5: eastern Beaufort Sea.

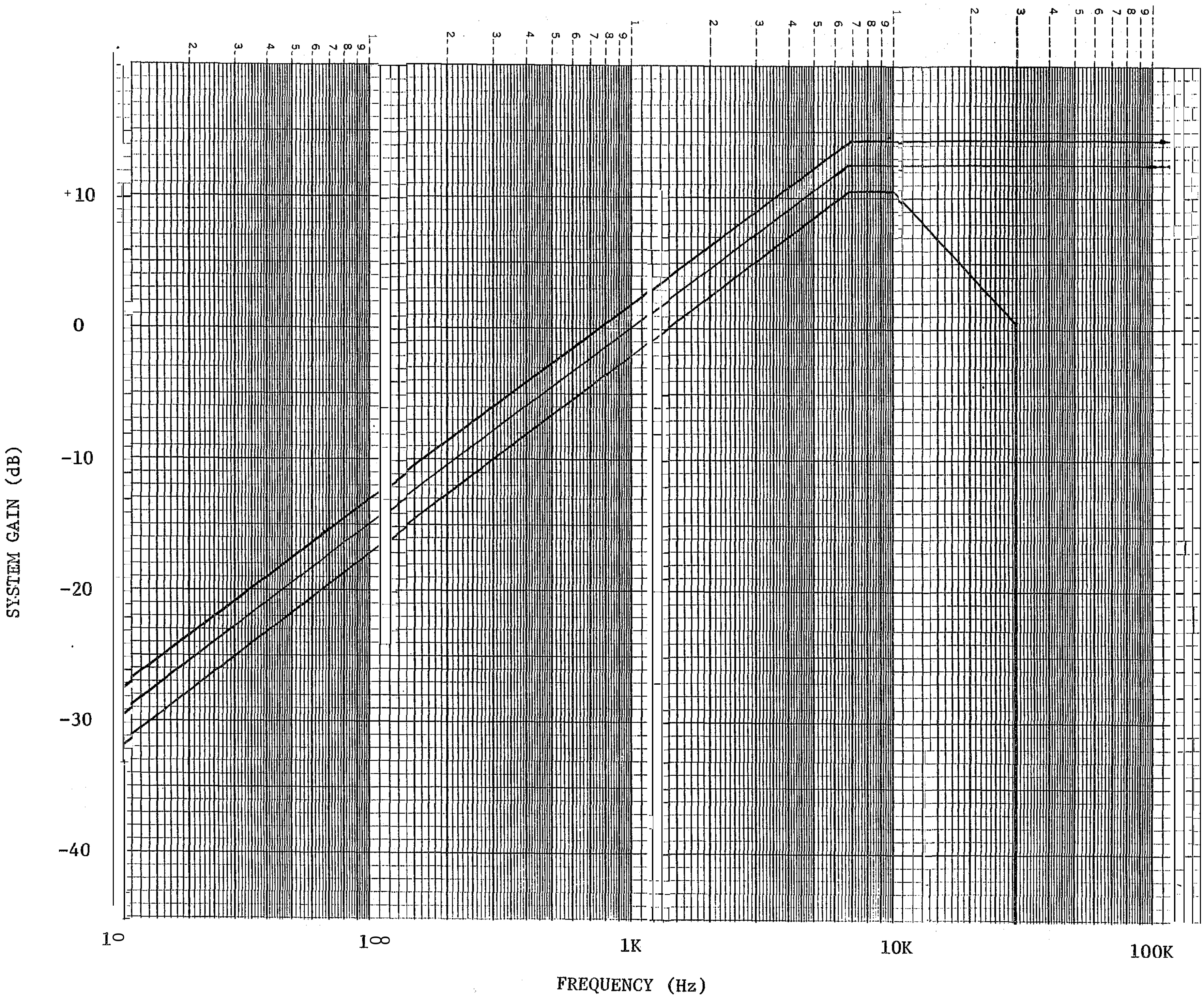


Figure 2. Frequency response envelope for AN/SSQ-57A sonobuoys, from Military Specification, Sonobuoy AN/SSQ-57A, MIL-S-81478B (AS). Scale plotted is relative to 1 kHz.

the aircraft. The receiver output was connected to a NAGRA IV-SJ tape recorder with a frequency response of 25 Hz to 10 kHz ± 1.5 dB at a recording speed of 9.5 cm/s. This recorder has two channels permitting simultaneous recording of waterborne sounds and verbal comments.

The sensitivity of the recording system using typical sonobuoys was examined in tests at the NOSC Transducer Calibration Facility (TRANSDEC) in 1981 and 1983. As a result, typical system frequency response curves were obtained so that recorded ambient, industrial and biological acoustic levels could be compared against the ± 2 dB manufacturing tolerance prescribed by military specification of all the sonobuoys used in this work. The test comparison verified that the sample buoys had frequency responses that met the military specifications of their design.

Data Screening

One hundred twenty-two archived acoustic tapes were aurally reviewed at recorded speed. Voice comments were transcribed off one track, and notations were made on the type and quality of data recorded on the second track. This information was summarized on data sheets and bound together as an acoustic tape index.

Tapes selected for analysis were those that contained information on sonobuoy type, drop location and recorder/sonobuoy attenuation settings. This information is vital to analysis and measurement of sound pressure level (i.e. as mentioned, recordings made with 41A sonobuoys were unsuitable for level measurement due to the ‘automatic gain control feature). Data was identified as ambient, industrial or biological and categorized by year, season and region. Because acoustic data was gathered only during the bowhead seasonal migration, all regions were not sampled during each season every year, nor was all industrial or biological activity sampled. Ambient noise samples were aurally chosen to exclude man-made and biological sounds as much as possible. As a result of this data screening, thirty--five tapes were selected for analysis of ambient noise content, fifteen tapes were found to contain identifiable industrial noise, and samples of biological sounds were identified on seven tapes.

Analysis System

Spectrum analysis were performed on recorded data to obtain measures of ambient, industrial and biological sound pressure levels. Spectrum level refers to a measure of the mean square sound pressure, in decibels (dB), in a 1 Hz wide frequency band relative to a reference level. The reference level is one microPascal (μPa). All sound levels presented here are in dB re 1 μ Pa^2/Hz [1].

The magnetic tape records were reproduced on a Nagra IV-SJ recorder. The reproduced data was analysed by a Spectral Dynamics SD-345 Spectroscope III analyser. The SD-345 is a 400 line Fast Fourier Transform (FFT) analyser with frequency analysis range from 1 Hz to 100 kHz. For ambient noise analysis, maximum frequency (i.e. full scale) values used in plotting were either 500 Hz or 5000 Hz. Hereafter, narrowband analysis refers to 500 Hz frequency analysis, and the 5000 Hz band is called the broadband analysis. For other analyses, maximum frequencies were chosen to be appropriate to the signal being analysed. The analysis bin width of the SD-345 is 1/400th of the maximum frequency (e.g., 1.25 Hz at 500 Hz and 12.5 Hz at 5000 Hz maximum frequencies, respectively).

The SD-345 was calibrated before each day's analysis by inserting a 1000 Hz signal at a level of 1 volt Root Mean Square (RMS) and setting the analyser scale to O dB for that signal level and frequency. All output levels were therefore referenced to 1 volt RMS at 1000 Hz.

The ambient noise and vessel noise spectra were signal-averaged. The number of averages varied due to artifacts and, in some cases, biological sounds that were present. Averages were taken until the profile was observed to have settled to a stable level. Sixteen averages generally produced this stable level in the averaged data, so at least this number of averages were taken where possible. In cases where artifacts were present, the section of the data to be averaged was selected so as to exclude these artifacts. In some cases, fewer averages had to be taken so as to exclude artifacts.

All samples were monitored with earphones. The earphone driving system had a 1/3 octave band equalizer in the circuit. This equalizer was set to approximate the inverse of the sonobuoy frequency response so as to present to the listener a close approximation of the sound in the water at the sonobuoy hydrophone. When necessary, the voice track was monitored to obtain gain changes, sonobuoy type and location, and other information.

---

1) A good summary of acoustic terminology appears in Ross (1976], p. 4-8.

Transient signals such as single event biological sounds and seismic airgun signals were analysed by means of the transient capture mode of the SD-345. These spectra, then, represent the frequency content and level of that single event, as opposed to signal-averaged profiles such as with the ambient or vessel data spectra. The duration of the captured signal depended on the full scale analysis frequency selected. For a maximum frequency of 500 Hz, the duration was 800 msec, while for a 1000 Hz maximum frequency, the duration was 400 msec. Other durations may be determined by scaling from these relationships given. Ten percent of the captured period contains data which occurred just prior to the captured transient..

The spectra were stored on floppy disks as uncorrected or ''raw'' data files to be later corrected and plotted. Information on the tape identification number and tape counter location of the signal on the tape were also entered in the file. Front panel settings of the SD-345 were stored on the disk automatically for future use when plotting data.

The raw data were put through a correction program in the NOSC microcomputer used to control the SD-345 analyser. Two frequency response corrections were made to the raw data file. One corrected for the frequency response of the sonobuoy so as to produce a flat response. The correction data used was based on the frequency response envelope of an AN/SSQ-57A sonobuoy as shown in Figure 2. The frequency response of the 41B sonobuoy falls within the range of the 57A sonobuoy so the same frequency correction was used for both. The second frequency response correction was for the recording system. Since the Nagra IV-SJ record/playback frequency response showed variations from a flat response, a correction was applied to modify these small variations (± 1 dB) to a flat response. Both the sonobuoy and recorder frequency corrections were referenced to 1000Hz.

The Nagra IV-SJ playback output level is 100 mv for a record meter indication of OdB. If a recording was made on the +20 setting of the main attenuator, which corresponds to a 0 dB record level of 10 mv, a gain of 20 dB would be realized upon playback. The playback isat unity gain with a recording setting of +40 on the main attenuator? so a correction was applied to the data by the correction program by subtracting (40 - x), where x is the main attenuator record setting, from the levels obtained from the SD-345 analyser spectrum output.

A correction to spectrum level was also made in the microcomputer correction program. This was of the form: level in analysis bin width minus 10 $\log_{10}$ (analysis bin width). The analysis bin width is read from the stored SD-345 data. As an example, for full scale analysis frequencies of 500 Hz, the analysis bin width was 1.25 Hz. The correction would therefore be -0.97 dB. A correction such as this assumes a constant level within the bin being corrected to a spectrum level. After the raw data were corrected, it was stored on floppy disks as a "corrected" file and subsequently used in plotting spectra.

All data were plotted using the plotting package associated with the microcomputer used to control the SD-345. The plotting package reads the SD-345 front panel data (stored as part of the data file) to set the frequency range, and reads analysed levels to set the plot level scaling. Multiple spectra may be plotted together with the same ordinate scaling. This was done in some cases to exhibit a source spectrum versus an ambient spectrum.

The plots were titled as to type of source (ambient, biologic, vessel) and year, season, and region of recording. Location coordinate data, sonobuoy type, date of recording, and miscellaneous pertinent information were entered into an information legend area located below the plot. Data below 15 Hz was not plotted so as to minimize low frequency artifacts and to avoid domination of the plotted data by high level low frequency signals.

General notes were hand written on the bottom of the plot page. These notes were on such topics as: (1) frequencies of major" signal components and harmonics, (2) on biological sounds, an aural characterization of the sound and (3) tape number and counter information. All plotted data were classified and filed by source, year, season, and region.

Sound pressure measurements were taken directly off the corrected spectrum plots. Lines were hand fitted to the narrowband plots to estimate the average level, and to the broadband plots to derive the high frequency roll off (- dB/octave = line slope) of the spectrum to 5 kHz.

Transient industrial noise sources such as airgun shots arid pipe driving sounds were analysed via time waveform signatures. These signatures were not corrected for frequency response of the sonobuoys or Nagra attenuation settings, therefore levels shown may not be the maximum levels present in the water. Time signatures are provided to demonstrate the temporal components of (relatively) loud industrial noise sources and are presented with spectral plots that do provide associated absolute spectrum levels.

A few spectrographic analyses also were performed on identifiable biological sounds. Spectrograms show the temporal variability of frequency within the sound being analysed. Unfiltered sounds were analysed using a real time Spectral Dynamics 350 D analyser with power averaging capability. The response of this system was flat from 50 Hz to 10 kHz over the recording spectrum.

RESULTS AND DISCUSSION

Ambient Noise

Ambient noise is background noise that does not have an identifiable source (Urick, 1967). Ambient noise sources include: tides and waves, naturally occurring seismic activity, oceanic turbulence, thermal noise, distant ship traffic and distant biological noise. In coastal waters, such as over continental shelves where most of our data was recorded, wind speed and its resultant sea state have been cited as the strongest factor in determining overall noise level between 10 Hz and 3 kHz (Urick, 1967). This relationship between wind speed and coastal water ambient. noise level has been documented both in open water and in partial ice cover conditions (Milne et al, 1967). Knudsen curves of ambient noise spectrums in variable sea states, and the averaged effects of shipping noise and wind speed on ambient noise levels are presented in Figure 3.

One hundred eighty ambient noise spectrum plots were obtained from ninety sample portions of tape. Each sample is represented by a narrowband (.500 Hz), and broadband (5000 Hz) plot. Sixty samples (120 plots), classif iable by region and season, were suitable for ambient level measurements (Table 1; refer to Figure 1 for region locations)..

Table 1. **Ambient noise samples by year, region and season. (60 Samples, 120 Plots)**

Season \ Region	1	Number Samples	2	Number Samples	3	Number Samples	4	Number Samples	5	Number samples
SPRING	-	-			1979	2	1979		7	- -
	1981	8	-	-						
							1982	6	-	-
FALL	-	-	-	-	-	-	-	-	1979	12
	-	-	-	-	-	-	-	-	1980	2
	-	-	-	-	-	-	-	-	1981	8
	-	-	-	-	-	-	1982	3	1982	12

Ambient samples that fell outside our region/season format were one (2 plots) from region 2 analysed from tape recorded in July 1981, and five (10

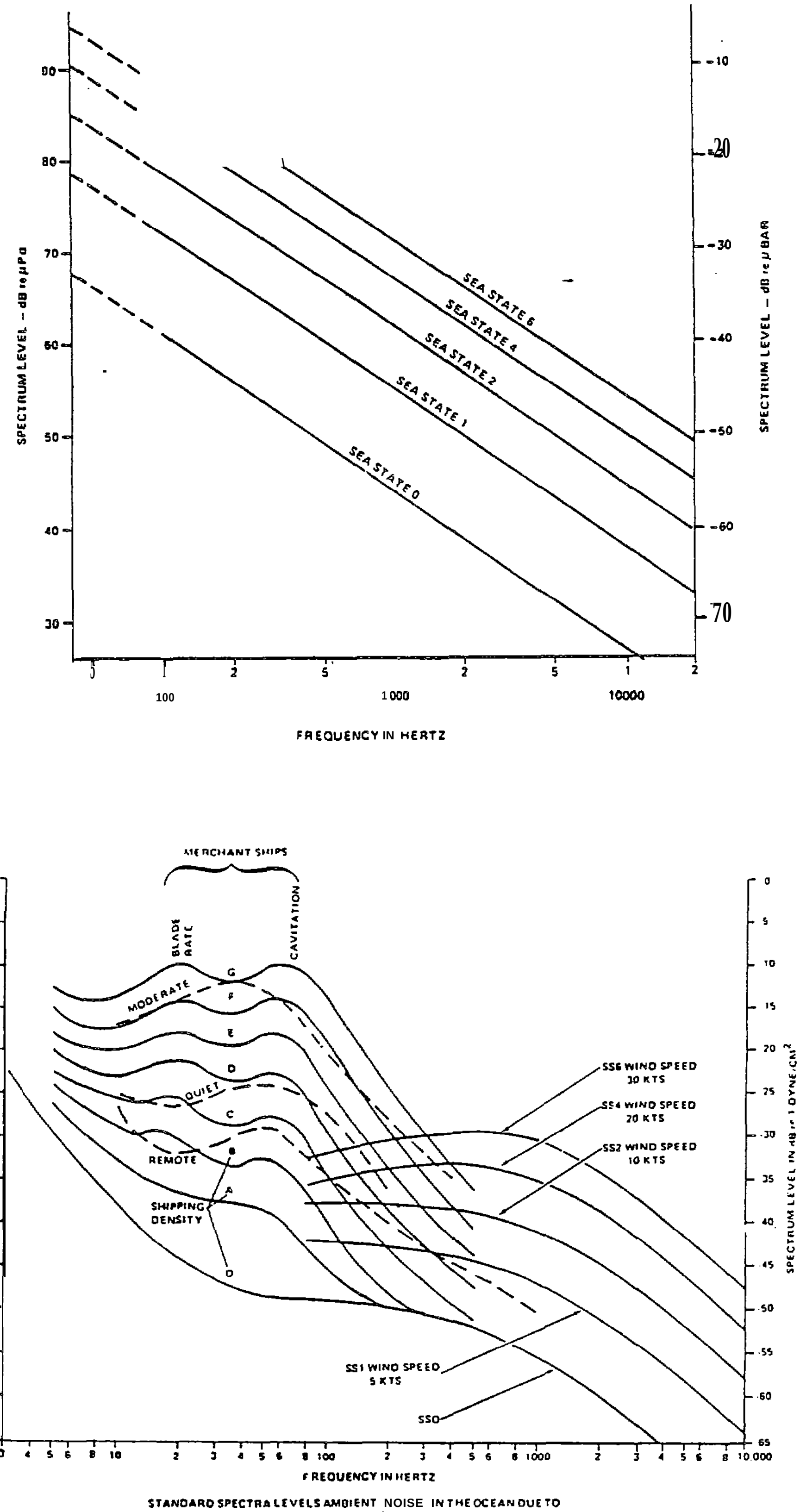


Figure 3. Knudsen curves of ambient noise spectra in variable sea states (after Urick, 1967), and averaged effects of shipping noise and wind speed on ambient noise levels (from NAVSEA 0905-LP-518-7010).

plots) from Canadian waters analysed from tapes recorded in 1980. These tapes were analysed for comparative purposes and are presented in the Summer: Region 2 and Examples from the Canadian Beufort Sea sections of this report. Three samples (6 plots) were made f rein tapes recorded using a 41A sonobuoy, to compare to data recorded at the same time and general location from 41B or 57A sonobuoys. Such comparisons were useful when unexpected anomalies were found in ambient data recorded using the 41 B or 57A units. As previously stated, spectrums resulting from analysis of recordings made with 41A sonobuoys could not be used to measure absolute level due to the sonobuoy's AGC feature. Though every attempt was made to avoid samples with industrial or biological sounds, twenty-one samples (42 plots) contained contamination from such sources and were excluded from ambient spectrum level measurements

Ambient analyses on additional tapes were not possible primarily due to: 1) numerous recordings over the years made with 41A sonobuoys, and 2) overriding contamination from biological or industrial sources. Recordings made in spring contained a wealth of biological sounds, such that ambient noise analysis on most tapes was all but impossible. Recordings made in fall often contained seismic airgun shots at approximately 15 sec intervals, thus ambient samples had to be averaged between sounds that were the intended subject of the recording. Noise from the survey aircraft also contaminated portions of many tapes.

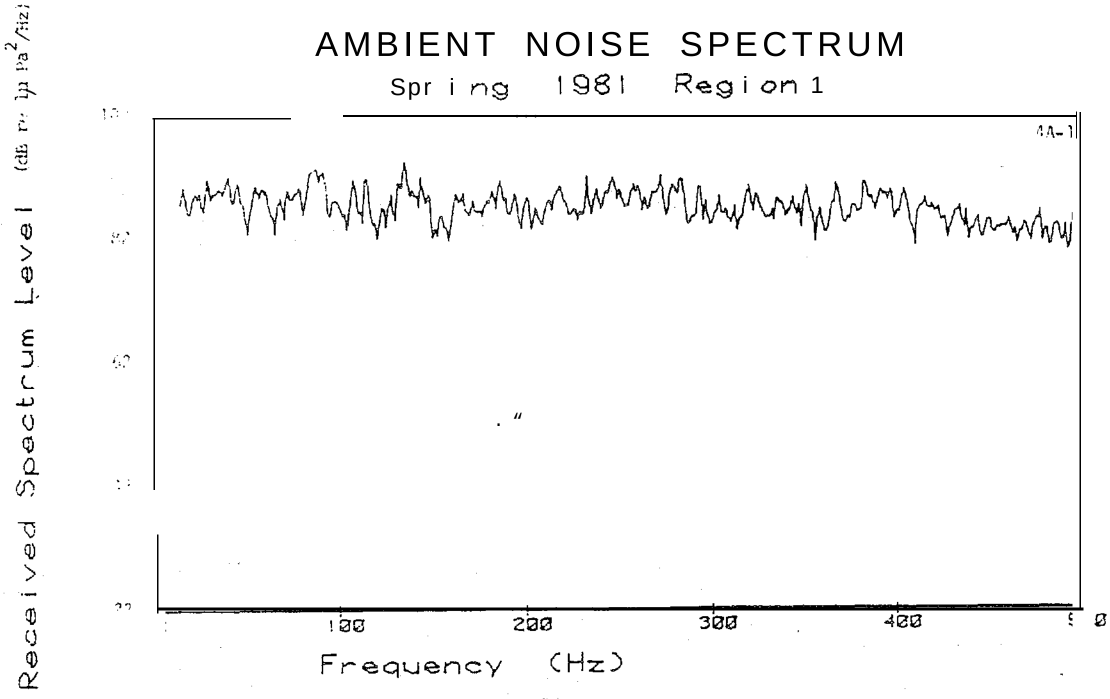
Spring: Regions 1, 3 and 4

Spring recordings made in regions 1 , 3 and 4 were analysed for ambient noise content. Measured spectrum levels and associated sea state, ice coverage and water depth for each sample are presented in Table 2. All analysed portions of tape were identified by tape number and tape count. A typical example of received ambient noise spectrum levels for each region and year is depicted in Figure 4.

Ambient spectrums were essentially flat to 500 Hz, with a roll off (- dB/octave) to 5000 Hz. Ambient spectrum levels in region 1 (example, Figure 4A) ranged from 72 dB to 86 d13 in the 500 Hz band. These levels decayed at -6.1 dB/octave to -11.8 dB/octave to a 58 dB to 32 dB level at 5000 Hz. Measured spectrum levels in region 3 (example, Figure 413) ranged from 60 dB to

Table 2. Measured ambient noise spectrum levels and associated sea state, ice coverage and water depth for samples recorded in spring, 1979-1982. (AU levels in dB re 1 $\mu Pa^2/Hz$).

Region		Tape No.	Tape Count	Location	SB	Average spectrum Level 15-500 Hz	Roll off (-dB/octave)	Spectrum Level at 5 kHz	Sea State	Ice Cover	Depth (m)
1 (N=8)	1981	644	16.9	6353.4 16730.1	4113	72	-11.8	32	2	0/10	35
		719	3.0	6430.6 16953.6	57A	76	-10.7	39	1	8/10	35
		719	0.5	6430.6 16953.6	57A	79	-9.5	49	1	8/10	35
		707	19.1	6426.3 16959.5	57A	76	-10.7	34	1	8/10	35
		707	2.8	6432.1 17022.0	57A	82	-9.5	57	1	8/10	40
		702	9.5	6428.7 17005.0	57A	86	-8.3	56	1	7/10	33
		702	3.1	6332.2 16814.8	57A	72	-6.1	57	0	9/10	29
		702	0.2	6332.2 16814.8	57A	76	-7.0	58	0	9/10	29.
3 (N=2)	1979	273	13.0	71 16.0 15701.9	57A	60	-4.8	42	1	7/10	42
		271	1.4	7121.4 15857.3	57A	70	-5.9	48	1	7/10	51
4 (N=13)	1979	393	14.5	7138.4 156 14.3	57A	78	-10.2	37	1	8/10	123
		393	8.7	7138.4 15614.3	57A	78	-12.5	35	1	8/10	123
		391	7.5	7129.6 15609.7	57A	62	-6.8	38	1	8/10	18
		391	3.4	7129.6 15609.7	57A	62	-5.6	39	1	8/10	18
		396	15.5	7129.6 15609.7	57A	67	-4.6	53	1	8/10	18
		396	8.5	7129.6 15609.7	57A	70	-4.6	51	1	8/10	18
		396	5.6	7129.6 15609.7	57A	70	-4.6	52	1	8/10	18
	1982	978	1.5	7134.8 15459.7	41B	72	-6.8	39	1	7/10	27
		979	22.7	7134.8 15459.7	41B	74	-10.2	37	1	7/10	27
		979	14.5	7133.3 15538.6	41B	67	-8.0	31	0	9/10	40
		979	7.9	71 32.8 15514.4	41B	67	-8.0	29	1	8/10	20
		979	2.5	7132.8 15514.4	41B	65	-10.2	32	1	8/10	20
		979	0.8	7132.8 15514.4	41B	61	-10.2	34	1	8/10	20



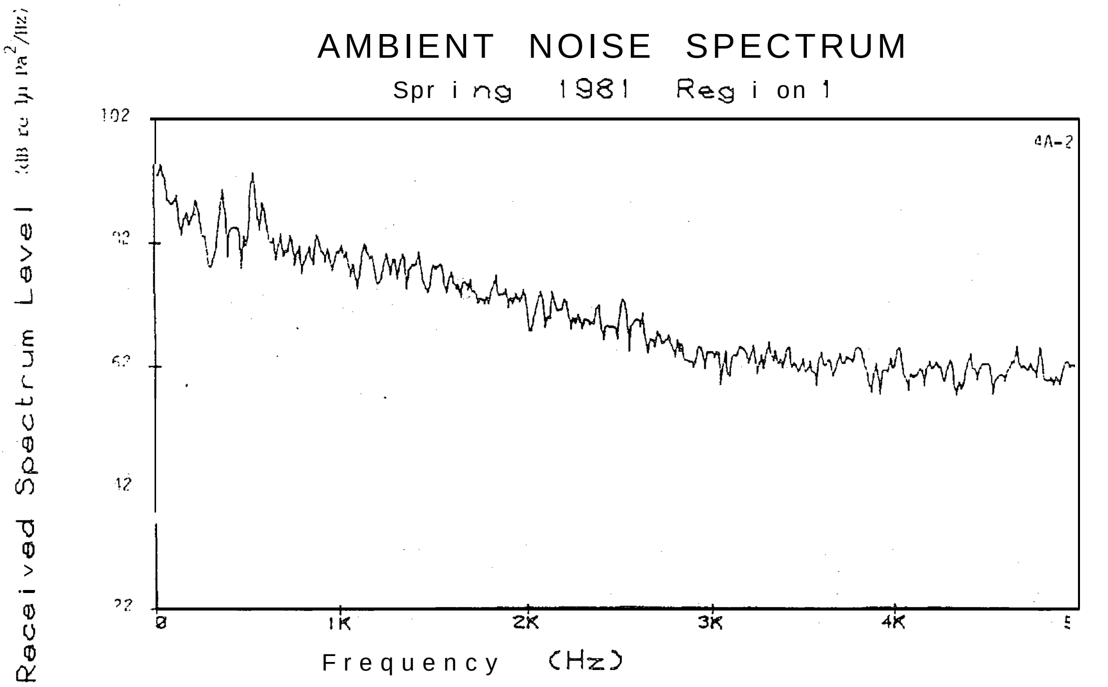
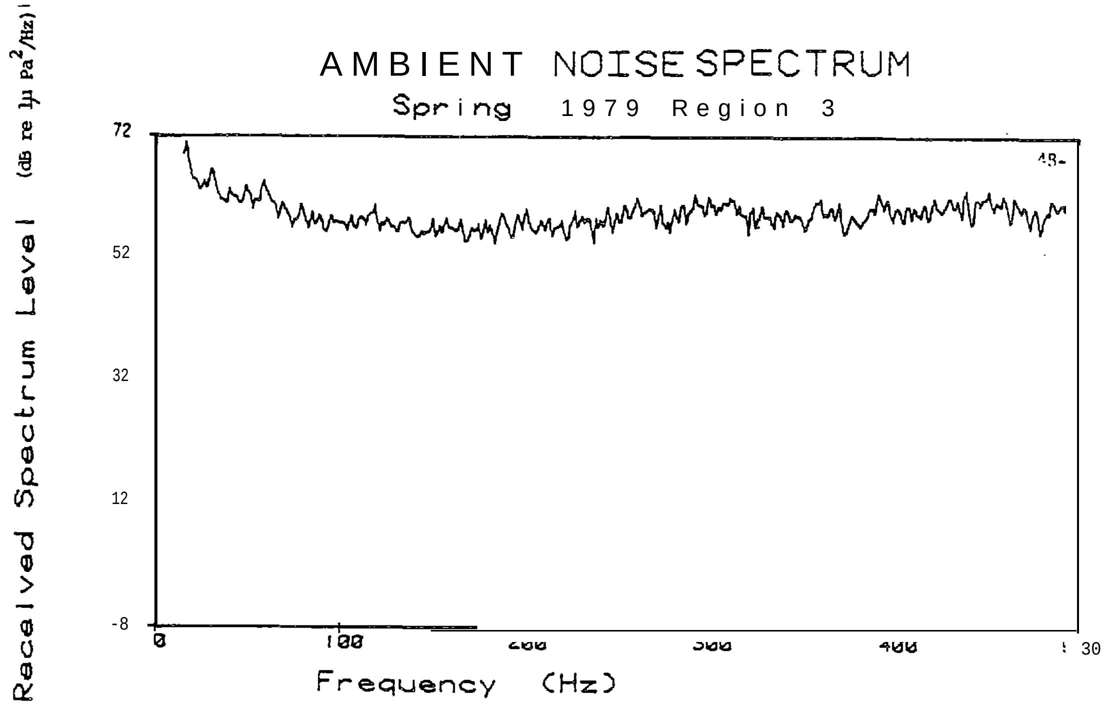
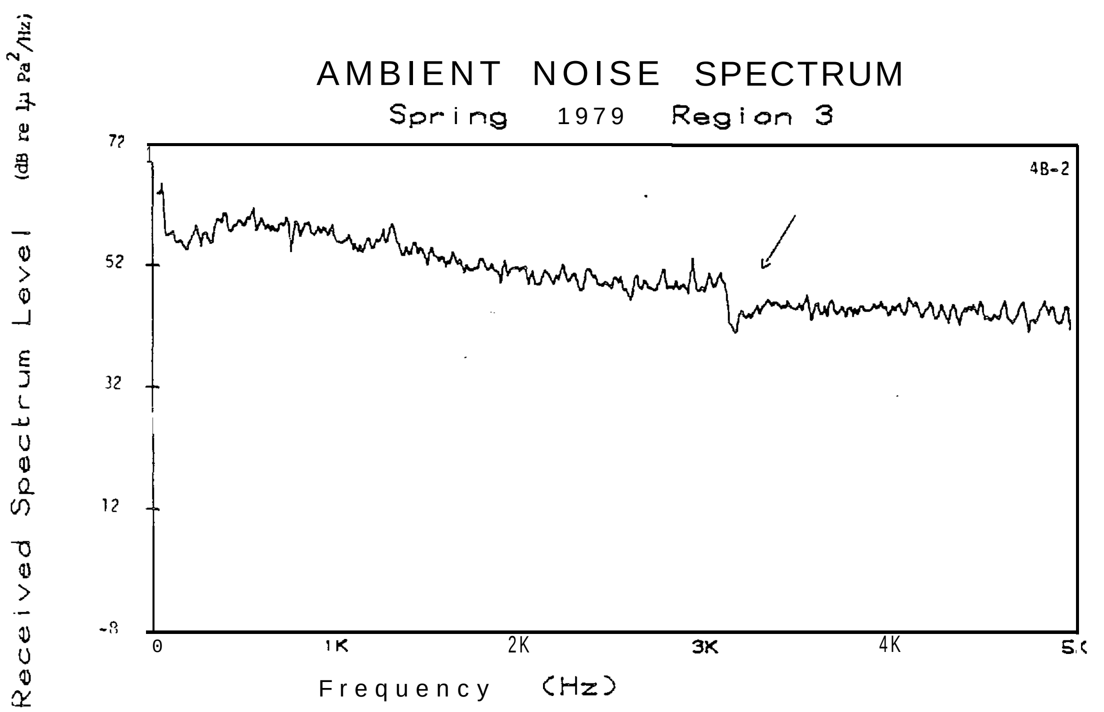


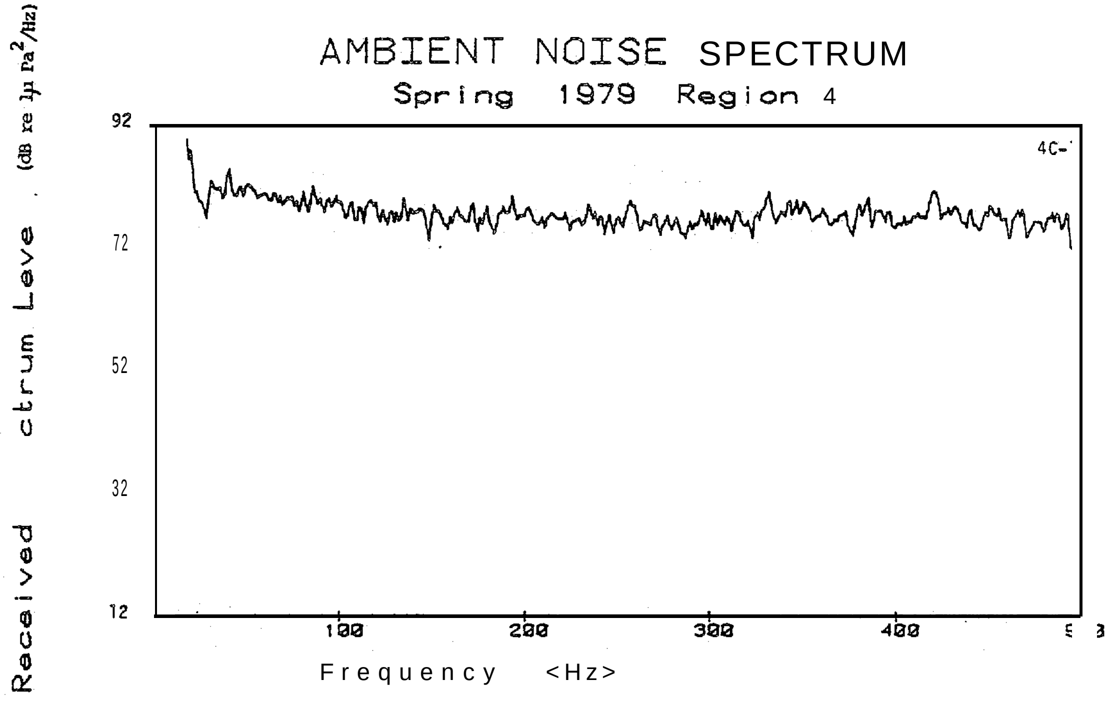
Figure 4. Received spectrum levels of ambient noise recorded in Region 1 (A), Region 3 (B) and 4 (C), in spring. Tape No./Tape count on plots identifies date source.

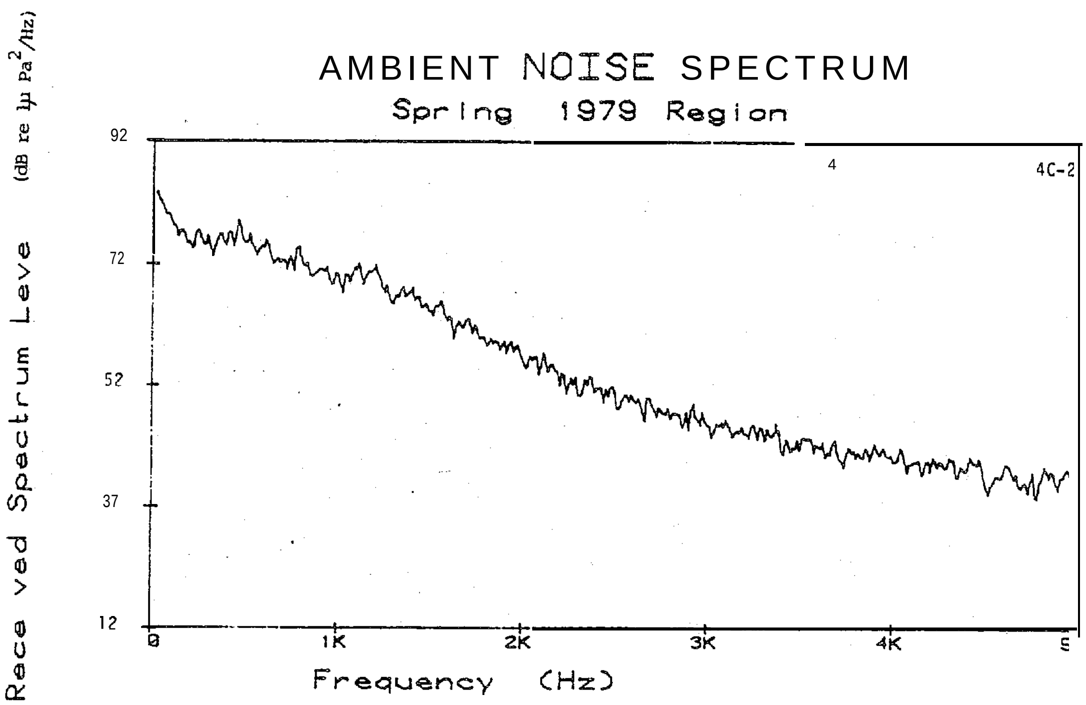




Date: 5/21/79
Location: 71 16. ON, 157 01.9W
57A SB 273/13.0

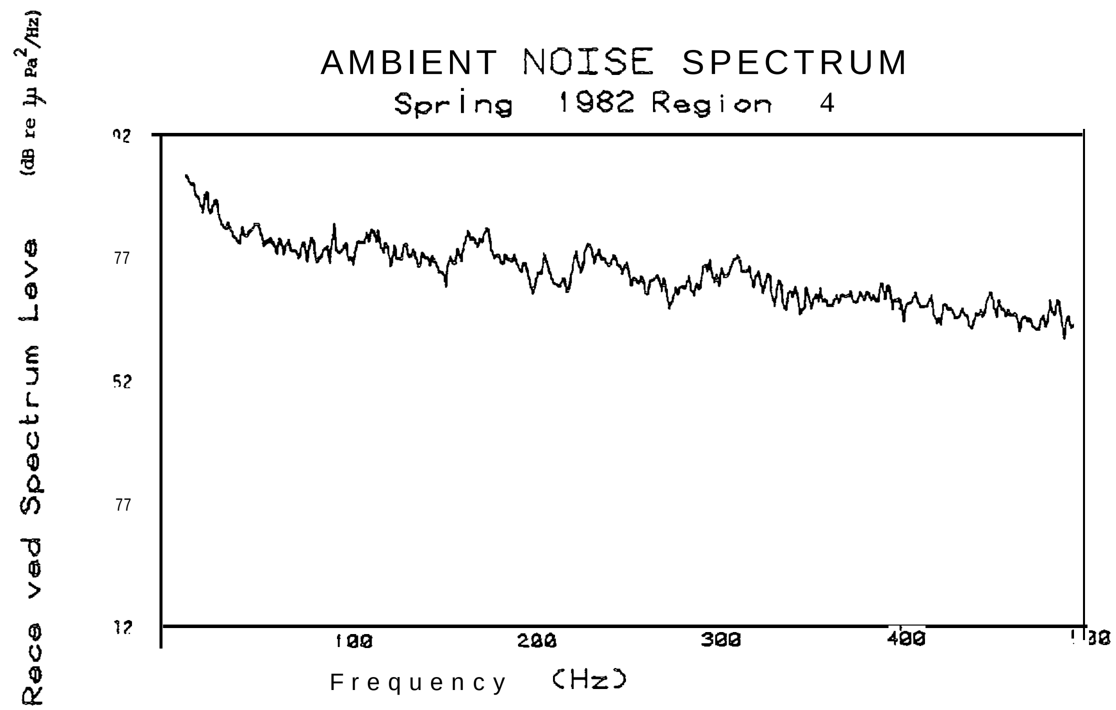
Figure 4 (cont). Ambient noise recorded in Region 3, in spring.





Date: 5/9/79
Location: 71 38.4N, 156 14.3W
57A SB 393/14.5

Figure 4 (cont). Ambient noise recorded in Region 4, in spring.



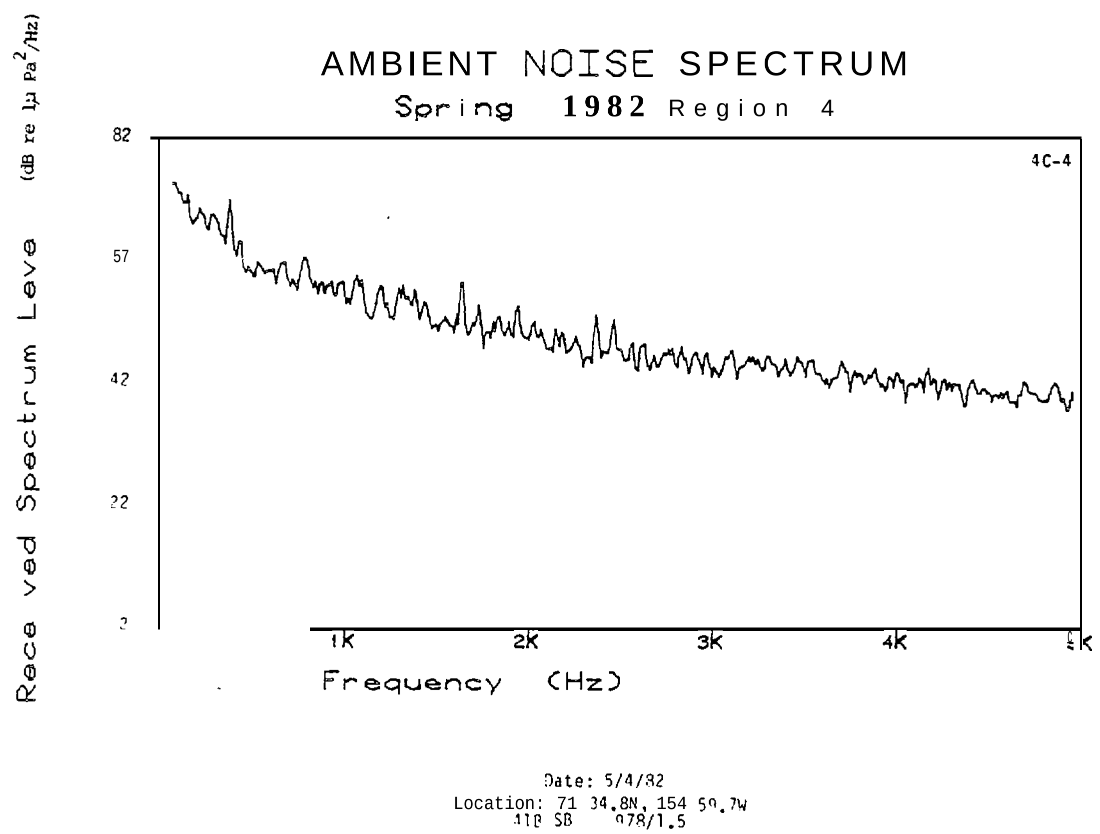


Figure 4 (cont). Ambient noise recorded in Region 4, in spring.

70 dB in the narrowband, with a decay of -4.8 dB/octave to -5.9 dB/octave to 48 dB to 42 dB at 5000 Hz. Region 4 (example, Figure 4C) had narrowband spectrum levels ranging from 61 dB to 78 dB with a slope range of -4.6 dB/octave to -12.5 dB/octave, and a 5000 Hz level between 53 dB and 29 dB. Ice coverage, sea state and depth were similar for recordings in the three regions. The comparatively shallow roll off in region 3's broadband spectra is unexplained, arid may simply be a function of small sample size. Similarly, the cause of the "step down" in spectrum 4B at about .3100 Hz is unknown. Such anomalies were riot uncommon in our data. Discussion of possible sources for such data variations is presented in the Ambient Noise Anomalies section of this report.

Fall: Regions 4 and 5

Fall recordings made in regions 4 and 5 were analysed for ambient noise content. Measured sound levels and associated physical parameters for each sample are presented in Table 3. A typical example of received ambient noise spectrum levels for each region and year is depicted in Figure 5.

As in spring samples, ambient spectrum level was nearly flat to 500 Hz, then decayed to 5000 Hz. Ambient spectrum levels in region 4 (example 5A) ranged from 64 dB to 67 dB across 500 Hz with a -8.5 dB/octave to -10.5 dB/octave decay to 37 dB to 32 dB at 5000 Hz. In region 5, (example 5B) measured ambient spectrum levels in the narrowband were 60 dB to 72 dB. The broadband roll off in region 5 was -5.4 dB/octave to -12.1 dB/octave, with a 54 dB to 26 dB level at 5000 HZ.

A seasonal logarithmic average of ambient spectrum noise level in each region was calculated by pooling data from all years (Table 4). There was no significant difference between averaged spring and fall levels ($t = 0.87$, $df = 3$, $p \leq 0.20$). Averaged ambient level over all regions and seasons ranged from approximately 65 dB to 77 dB in the narrowband, with a -5.3 dB to -9.5 dB decay to 47 dB to 34 dB at 5000 Hz. These averaged levels and approximate slopes to 5 kHz fall within. the range of values expected for shallow water ambient sea noise in the frequency bands analysed (Urick, 1967).

-raw **3.** Measured ambient noise spectrum levels and associated sea state, ice coverage and water depth for samples recorded in fall, 1979-1982. **(All levels in dB re 1 μ Pa^2/Hz)**

Region		Tape No.	Tape Count	Location	SB	Average spectrum Level 15-500 Hz	Roll Off (-dB/octave)	Spectrum Level at 5 kHz	Sea State	Ice Cover	Depth (m)
4 (N=3)	98.	995	19.6	7126.4 15214.7	41B	64	-8.5	34	3	0/10	183
		994	4.2	71 17.0 151” 08.0	41B	66	-9.6	37	1	0/10	55
		994	5.6	7120.0 15235.0	41B	67	-10.5	32	1	0/10	70
5 (N=34)	“979	253	6.3	7029.4 14715.5	57A	70	-5.4	49	1	8/10	22
		253	1.0	7029.4 14715.5	57A	72	-7.7	50	1	8/10	22
		270	3.0	7035.0 14742.7	57A	64	-7.7	41	1	9/10	24
		265	23.0	7023.7 14602.6	57A	6 2	-9.8	27	1	9/10	29
		265	7.4	7023.7 14602.6	57A	62	-9.8	26	1	9/10	29
		259	1.0	7022.7 14545.3	57A	60	-6.5	35	1	9/10	33
		266	18.0	7031.0 14615.0	57A	64	-7=7	38	2	8/10	37
		266	4.5	7038.1 14651.7	57A	65	-6.5	38	2	8/10	38
		262	21.6	7031.3 14713.2	57A	62	-6.5	39	2	8/10	27
		262	2.0	70 31.3 147 13.2	57A	64	-7.7	41	1	0/10	27
		264	5.3	6949.2 141 10.7	57A	71	-10.9	28	1	0/10	22
		264	2.7	6949.2 141 10.7	57A	70	-9.8	35	1	0/10	22
	90	546	0.3	7032.0 14659.5	41B	69	-6.5	46	2	2/10	33
		848	7.0	6950.0 14215.0	57A	70	-7.7	42	2	1/10	⁻20

Table 3 (cont'd). Measured ambient noise spectrum levels and associated sea state, ice coverage and water depth for samples recorded in fall, 1979 - 1982. (All levels in dB re 1 μ Pa^2/Hz)

Region		Tape No.	Tape Count	Location	SB	Average spectrum Level 15-500 Hz	Roll Off (-dB/octave	Spectrun Level at 5 kHz	Sea State	Ice Cover	Depth (m)
5 (cont'd.)	1981	705	10.0	7006.6 14153.7	41B	64	-7.7	39	1	1/10	29
		752	8.1	6950.5 14054.6	41B	67	-12.1	28	1	0/10	27
		752	1.5	6950.5 14054.6	41B	72	-12.1	24	1	0/10	27
		912	3.0	7002.0 14229.1	41B	64	-6.5	45	2	1/10	18
		828	1.5	7002.7 142 .31.4	41B	67	-6.5	51	2	1/10	18
		828	15.8	7022.6 14523.0	41B	64	-7.7	47	3	1/10	37
		758	6.0	7011.3 14309.8	41B	66	-6.5	47	3	1/10	18
		923	14.0	7018.4 14454.9	41B	72	-6.5	54	3	5/10	33
	1982	992	24.2	6959.7 1410.77	57A	64	-8.8	30	2	0/10	40
		990	22.6	7035.0 14018.0	57A	66	-8.8	26	6	0/10	842
		990	17.2	7126.1 1453601	41B	62	-8.2	32	3	3/10	2500
		990	12.7	6955.0 14006.0	57A	72	-6.5	47	1	3/10	54
		990	8.8	6941.9 14010.9	57A	67	-6.5	43	0	3/10	26
		988	19.5	7107.0 14546.0	57A	66	-5.4	43	2	7/10	1000
		988	7.2	7059.9 14323.1	41B	67	-6.5	40	2	7/10	1000
		988	0.5	6943.7 14032.2	41B	68	-8.8	38	0	2/10	26
		987	21.4	6943.7 14032.2	41B	67	-7.7	40	0	2/10	26
		987	13.9	7054.0 141 16.8	41B	69	-7.7	40	1	3/10	2000
		987	4.5	7055.6 14311.0	41B	67	-8.8	35	0	7/10	1200
		987	2.9	7010.0 14304.0	41B	66	-7.7	37	0	6/10	24

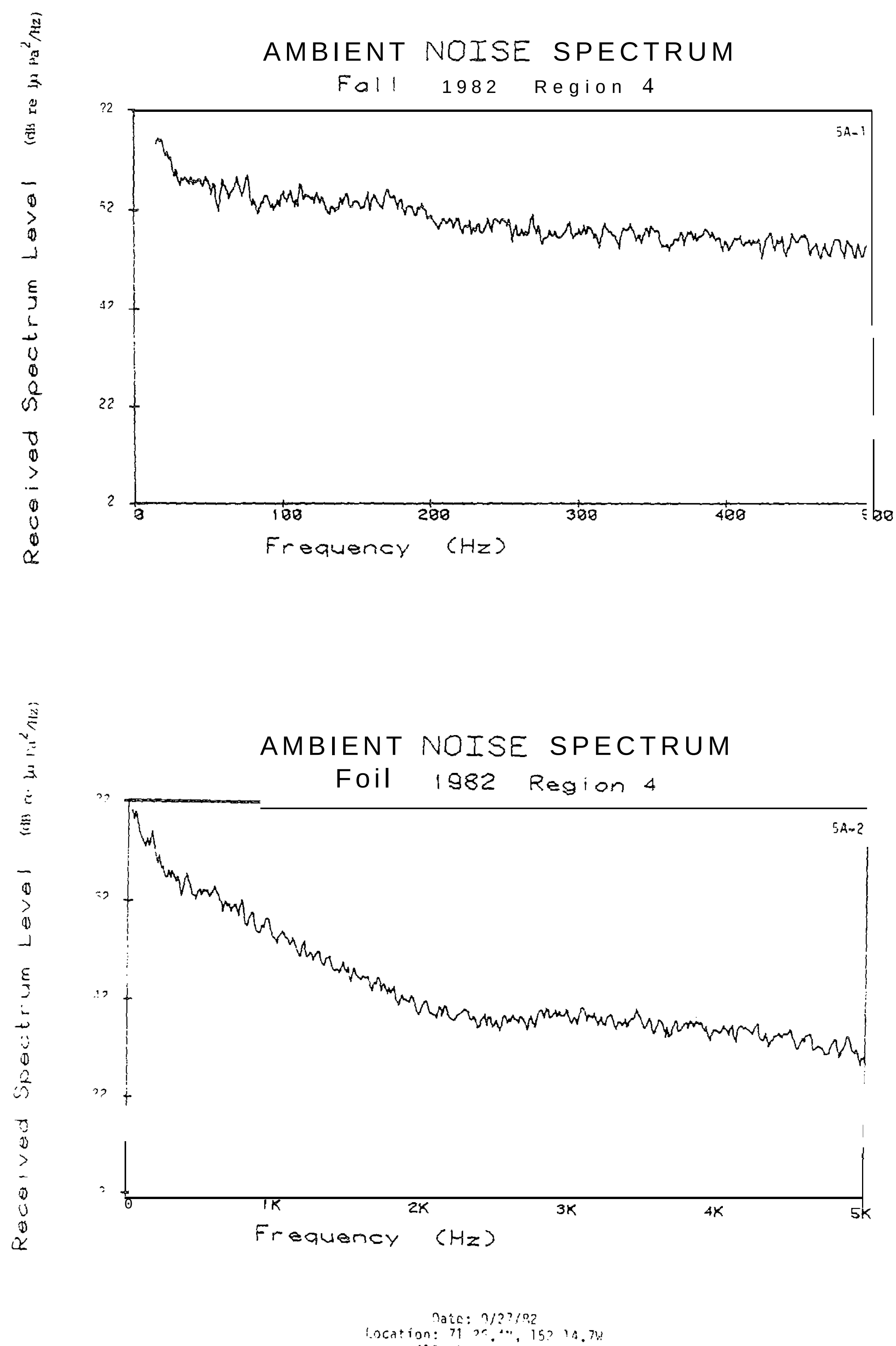
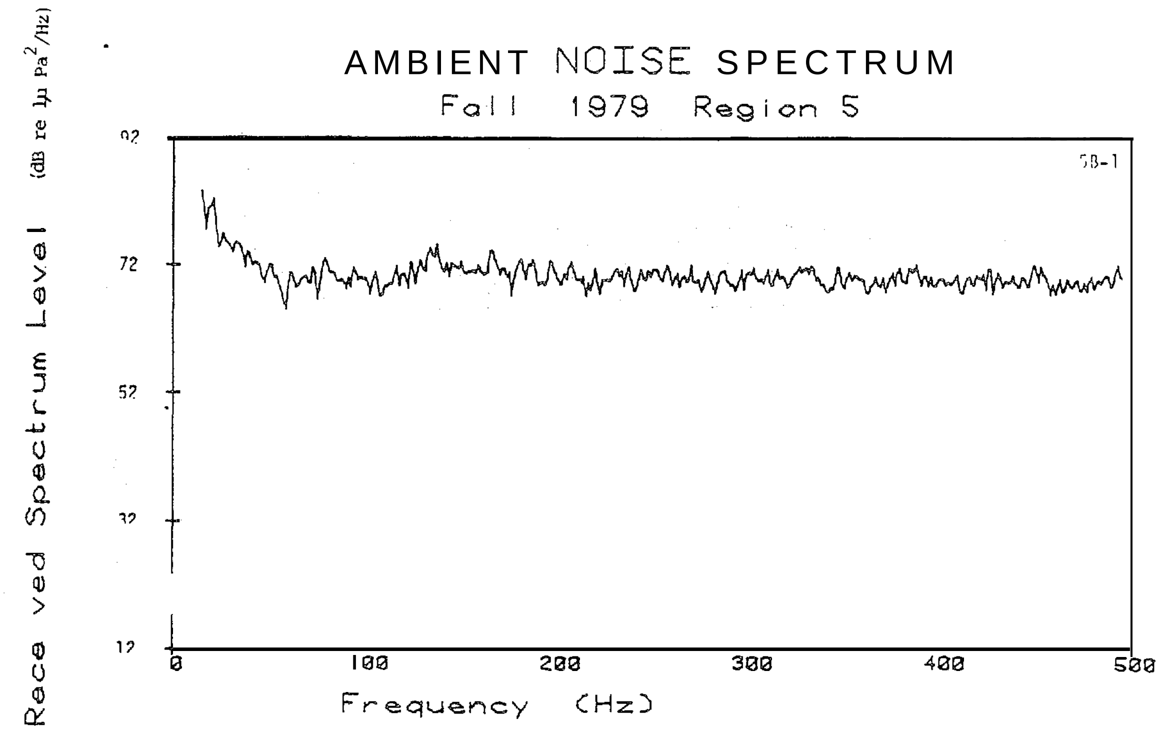
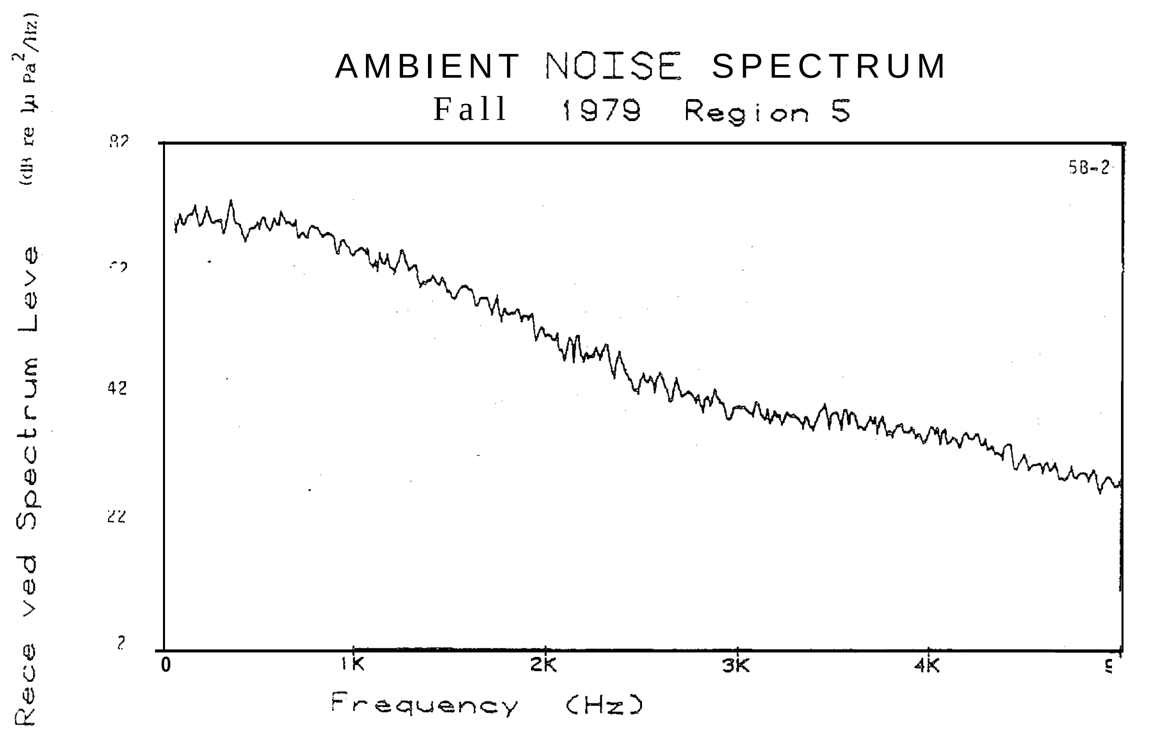


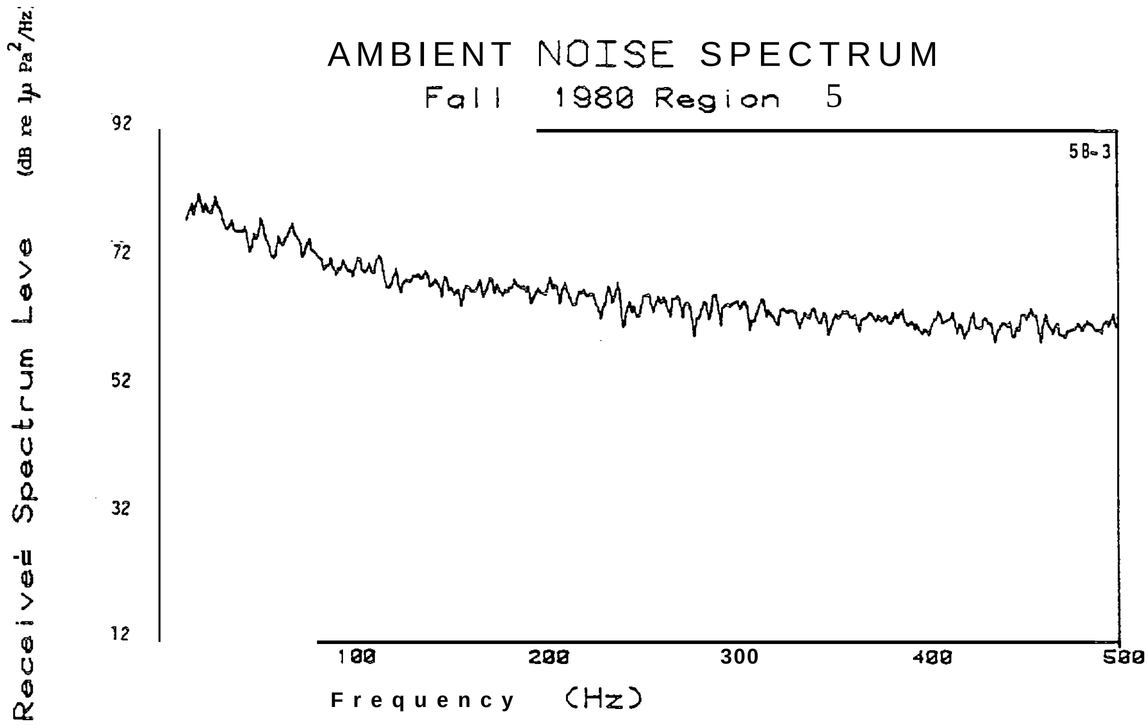
Figure 5. Received spectrum levels of ambient noise recorded in Region 4 (A), and Region 5 (B), in fall. Tape No./Tape Count on plots identifies data source.

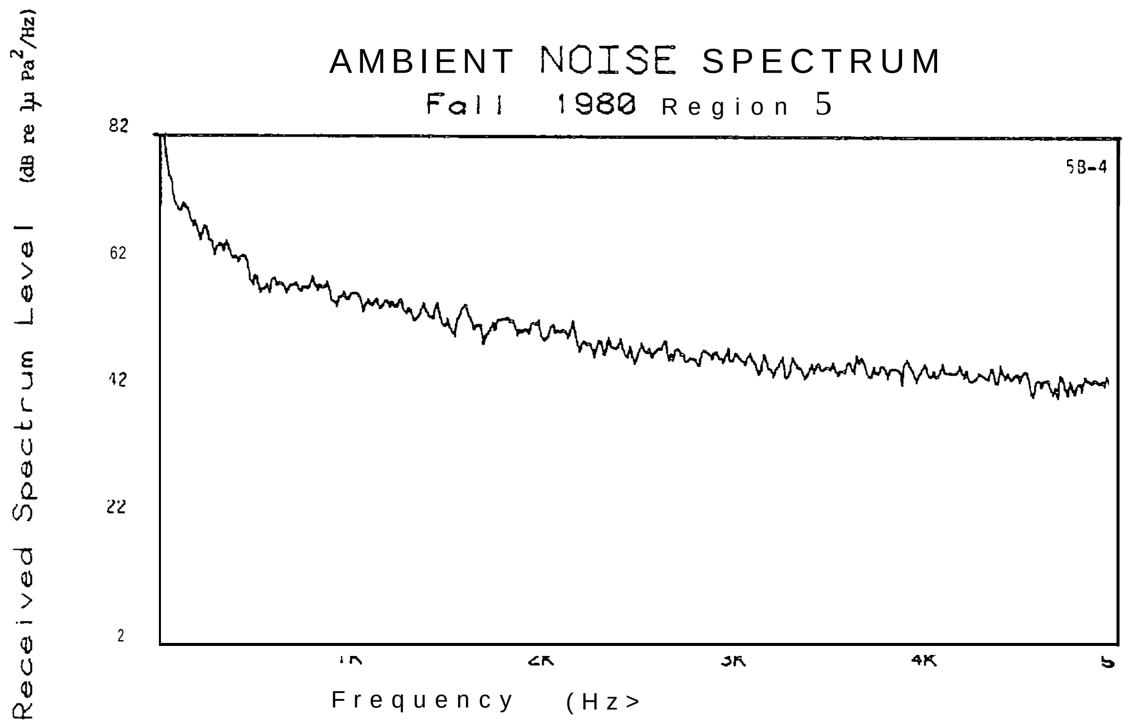




Date: 9/25/79
Location: 59 49.2N, 141 19.7W
57A SB 264/5.3

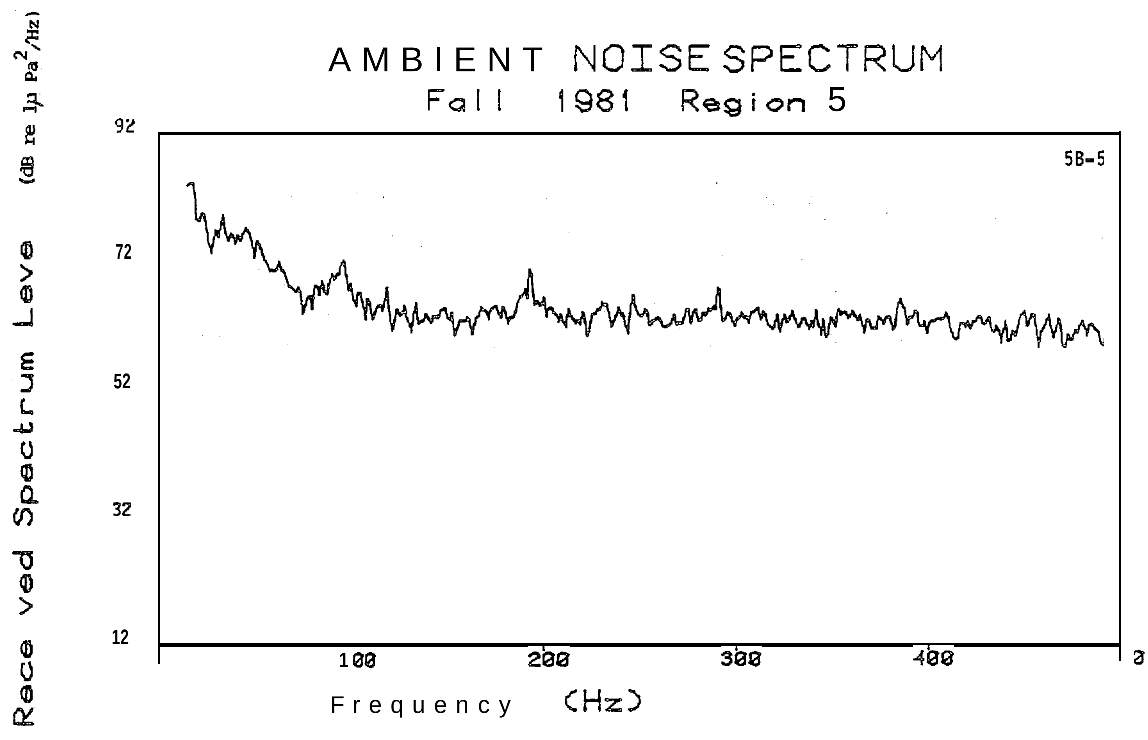
Figure 5 (cont). Ambient noise recorded in Region 5, in fall.

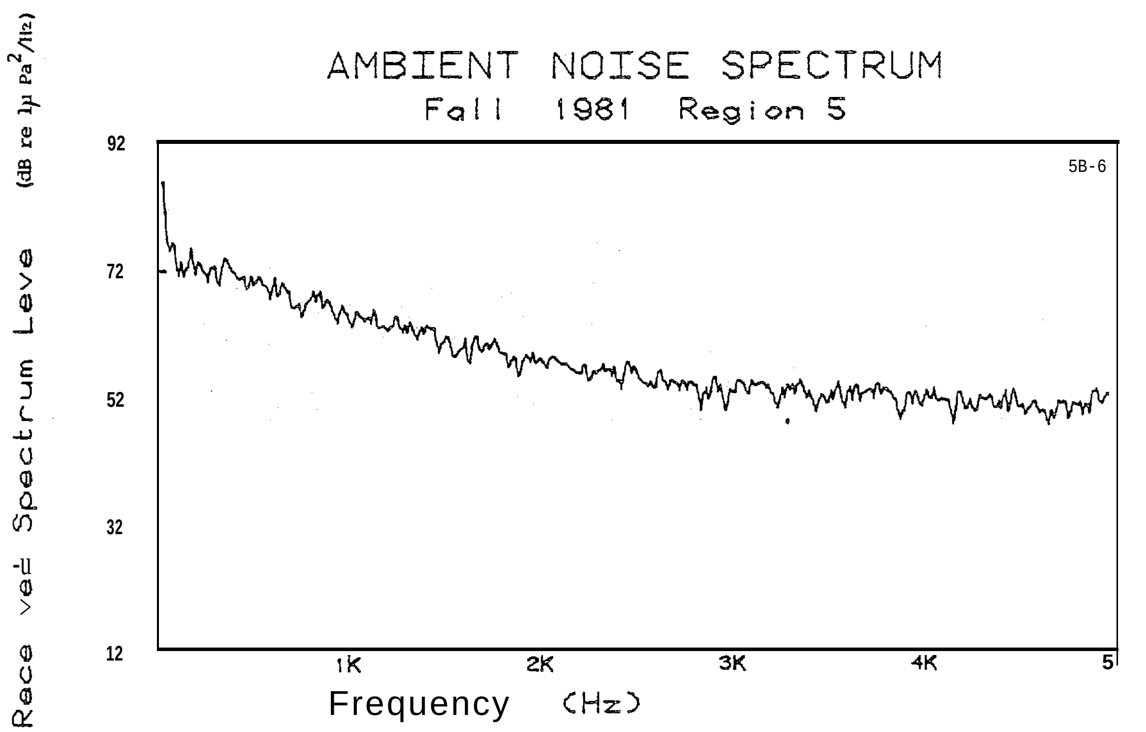




Date: 9/20/80
'Location: 70 32.0N,14659.5W
41B SB 546/0.3

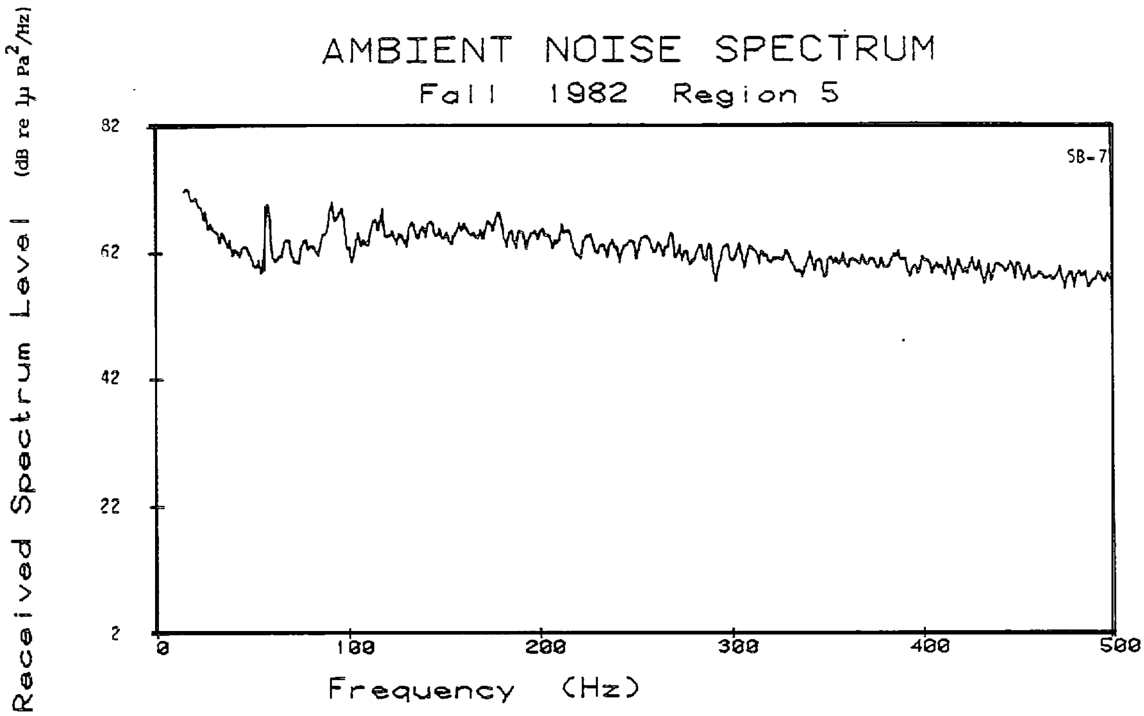
Figure 5 (cont). Ambient noise recorded in Region 5, in fall.

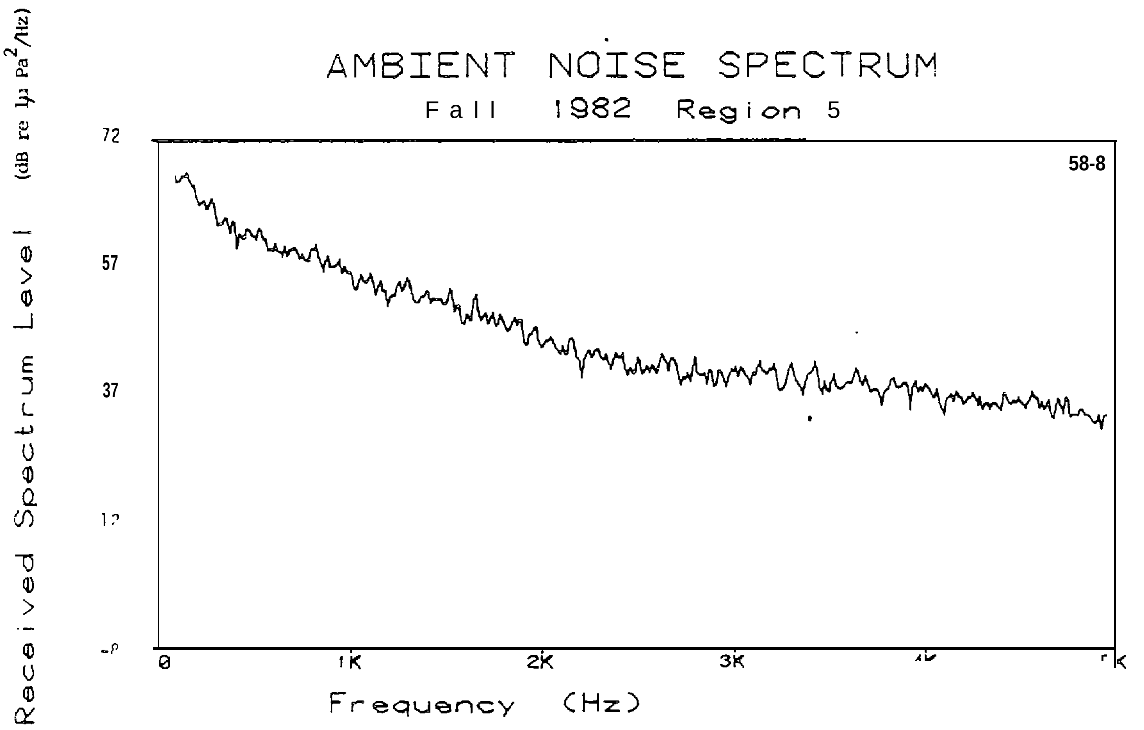




Date: 9/22/81
Location: 70 02.7N, 142 31.4W
4113 SB 828/1.5

Figure 5 (cont). Ambient noise recorded in Region 5, in fall.





Date: '3/15/82
Location: 69 59.7N, 141 07.7W
57A SB 992/24.2

Figure 5 (cont). Ambient noise recorded in Region 5, in fall.

Table 4. Logarithmic average of measured ambient noise spectrum levels and slope, by region and season. (All levels in dB re 1 μ Pa²/Hz)

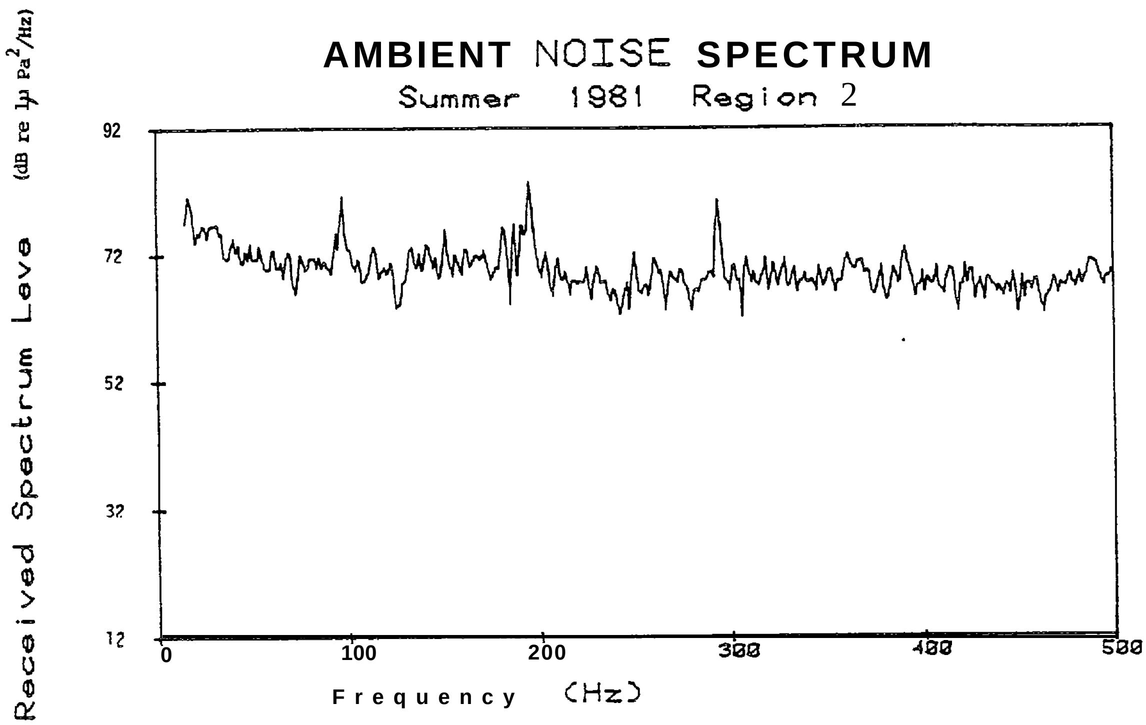
	Region	N	Average Spectrum Level 15-500 Hz	Roll Off (- dB/octave)	Spectrum Level at 5 kHz
SPRING	1	8	76.90	-9.00	46.52
	3	2	64*81	-5.32	44.90
	4	13	68.48	-8.88	38.29
FALL	4	3	65.65	-9.50	34.27
	5	34	66.38	-7.70	37.91

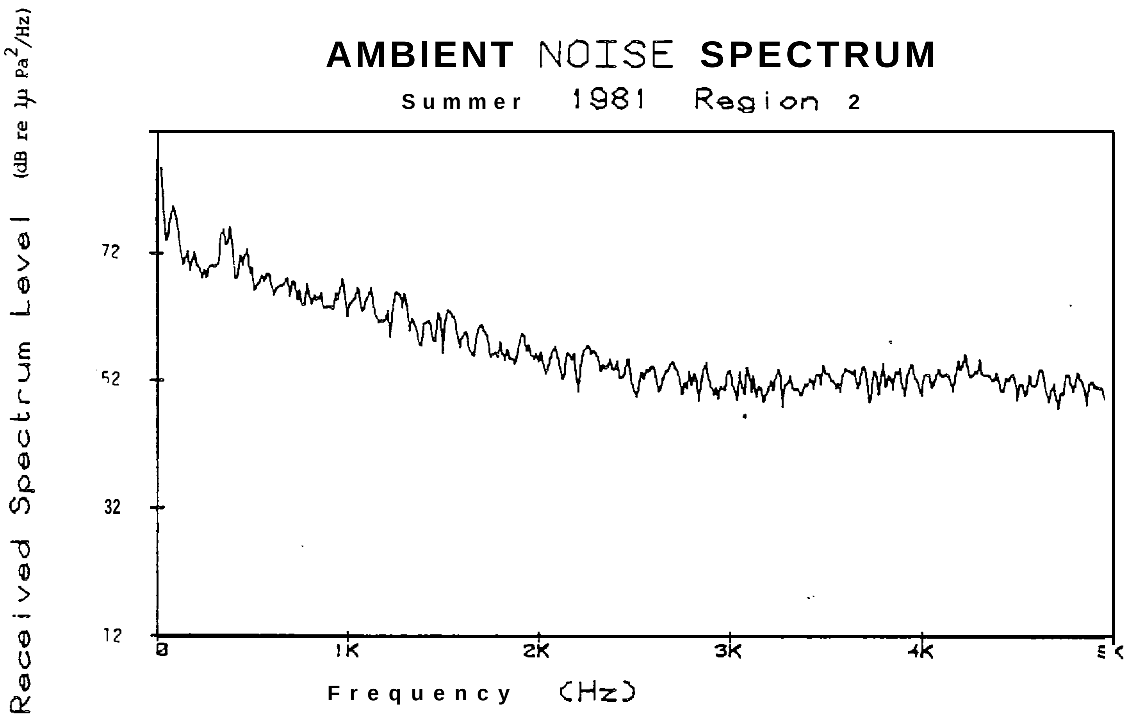
Summer: Region 2

A spectrum level of ambient noise recorded in region 2 in July 1981 is presented in Figure 6. The ambient level in the 500 Hz band was approximately 69 dB with a -5.9 dB/octave slope that fell to about 49 dB at 5 kHz. Sea state was Beaufort 01.-02 and water depth was 18 m. There is some contamination of this sample by noise from the survey aircraft as evidenced by harmonic components with a fundamental at about 95 Hz. This problem was recurrent and is discussed in the Industrial Noise section of this report.

Examples from the Canadian Beaufort Sea

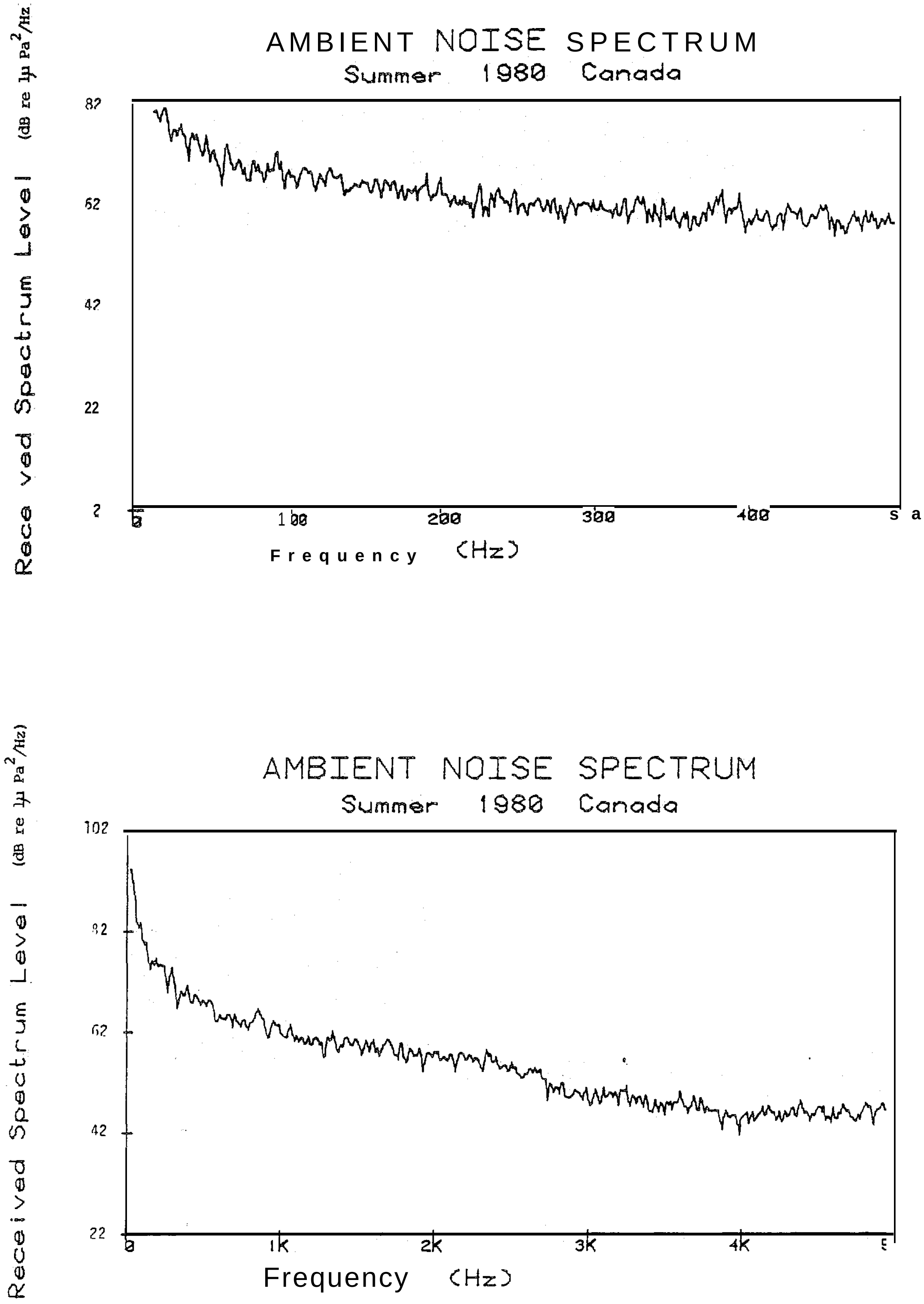
Examples of ambient noise spectrum levels analysed from tapes recorded in the Canadian Beauf ort Sea in August 1980 are presented in Figure 7, Table 5. The range of narrowband ambient spectrum levels in the Canadian Beaufort was 58 dB to 66 dB with a log average of 62 dB (Table 5). The measured roll off was -5.9 to -7.1 dB/octave (log avg.=- 6.6 dB/octave), to 30 dB to 60 dB at 5 kHz (log avg.= 34.5 dB). The Canadian Beaufort Sea is a feeding area for bowheads in summer (Grif fiths and Buchanan, 1982). These spectra indicate that the ambient noise that bowheads encounter on their feeding grounds may be somewhat lower than , but does not differ significantly from, that encountered on their seasonal migrations.





Date: 7/8/81
Location: 68 18.9N, 166 48.9W
57A SB 645/1.9

Figure 6. Received spectrum levels of ambient noise recorded in Region 2, July 1981. Aircraft noise contamination is evident as harmonic components with a fundamental at about 95 Hz.



Date: 8/1 9/80
Location: 7('I 05N, 132 45W
41B SB 345/3.2

Figure 7. Received spectrum levels of ambient noise recorded in the Canadian Beaufort Sea, August 1980.

-r'able 5. **Measured spectrum levels and associated sea state, ice coverage and water depth for ambient noise samples recorded in the Canadian Beaufort Sea, August 1980. (All levels in dB re 1 μ Pa²/Hz)**

Region		-rape No.	Tape Count	Location	SB	Average spectrum Level 15-500 Hz	Roll off (- dB/octave)	spectrum Level at 5 kHz	Sea State	Ice Cover	Depth (m)
Canada (N=5)	1980	845	8.9	6952.1 13248.0	41B	66	-5.9	60		-	10
		845	3.2	7005.0 1324.5	41B	65	-7.1	45		-	10
		846	6.5	6956.0 13152.5	41B	64	-7.1	33		-	10
		846	3.9	6956.0 13152.5	41B	58	-5.9	30		-	10
		846	2.0	6952.1 132 48.0	41B	59	-7.1	31		-	10
				Log $\bar{x}$		62.31	-6.59	34.46			

Sea State and Ice Coverage Effects on Measured Ambient Noise Levels

As previously mentioned, sea state has been cited as the strongest factor in determining overall ambient noise level in coastal waters both in open water and in partial ice cover conditions. Data collected in region 5 in August-September, 1982 support this contention (Table 6). In this example, the narrowband ambient spectrum level in Beaufort 02 sea state is approximately 64 dB in ice conditions ranging from 0/10 to 7/10 coverage. Ambient spectrum level in Beaufort 00 sea state in the 500 Hz band is 58 dB in 4/10 ice, and 53 dB in 2/10 ice. A mediate sample recorded in 3/10 ice with a Beaufort 01 sea state resulted in an ambient spectrum level of 52 dB.

A multiple linear regression was run on data presented in Table 6 to analyse the effects of sea state, ice coverage and depth on ambient noise in the 500 Hz band. Sea state was the only significant correlate ($r = 0.783$, $t = 2.62$, $p \leq 0.05$), with narrowband ambient noise level. Neither depth ($r = 0.350$, $t = 1.34$, $p \leq 0.50$), nor ice coverage ($r = 0.332$, $t = 0.652$, $p \leq 0.50$) appeared to influence recorded ambient levels in the 500 Hz band. This relationship was not borne out however, when a multiple regression analysis was performed on combined data from Tables 2 and 3. Neither sea state, ice coverage, nor depth were found to be significant contributors to

Table 6. Sea state and ice coverage effects on measured ambient noise spectrum levels, Region 5, 1982. (All levels in dB re 1 u Pa^2/Hz)

Sea State	Ice Coverage	Depth (m)	Average! Spectrum Level 15-500Hz	Roll off (- dB/octave)	Spectrum Level at 5 kHz
00	2/10	30	53	-9	22
00	4/10	2000	58	-9	22
01	3/10	34	52	-7	28
02	6/10	530	64	-8	39
02	7/10	2000	64	-6	45
02	0/10	34	64	-7	30

measured narrowband ambient levels. Therefore it appears that the significance of sea state may have been an artifact of the small sample size represented in Table 6.

It would appear that ice coverage has little effect on ambient noise to 500 Hz. Occasionaly, however, sounds thought to be produced by melting or drifting ice were aurally distinct on tape. A spectrum of such ice noise recorded on 14 October 1979 in 9/10 slush ice is presented in Figure 8. T-he ice noise on this tape was a "crackling" type of sound, perhaps similar to "bacon frying" sounds described by Milne et al (1967) for noise recorded in approximately 5/10 to 9/10 ice conditions in the Beaufort Sea. The ambient spectrum level of 62 dB in the 500 Hz band is in the range of that expected for this region and within the 62 dB to 67 dB levels reported by Milne et al (1967, p. 527). This sample was somewhat contaminated by noise from the survey aircraft, seen as harmonic components with a fundamental at about 80 Hz in the 500 Hz band. Two interesting anomalies in the 5 kHz plot were the steps around 1900 Hz and 2200 Hz, and resurgent slope between 3 kHz and 5 kHz.

To assess the effects of sea state, ice coverage and depth on measured ambient level at 5 kHz, a multiple regression analysis was performed on data presented in Table 6. Ice coverage was a stronger fit ($r=0.692$, $t=2.48$, $p \leq 0.10$) in this analysis than in the regression on narrowband levels. Sea state remained the strongest correlate ($r=0.853$, $t=4.91$, $p \leq 0.005$) and depth ($r=0.307$, $t=0.073$, $p \leq 0.50$) appeared to have no influence on ambient level at 5 kHz. To analyse this relationship within a larger data base, a multiple regression was performed on the combined data of Tables 2 and 3. In this analysis, ice coverage was the strongest

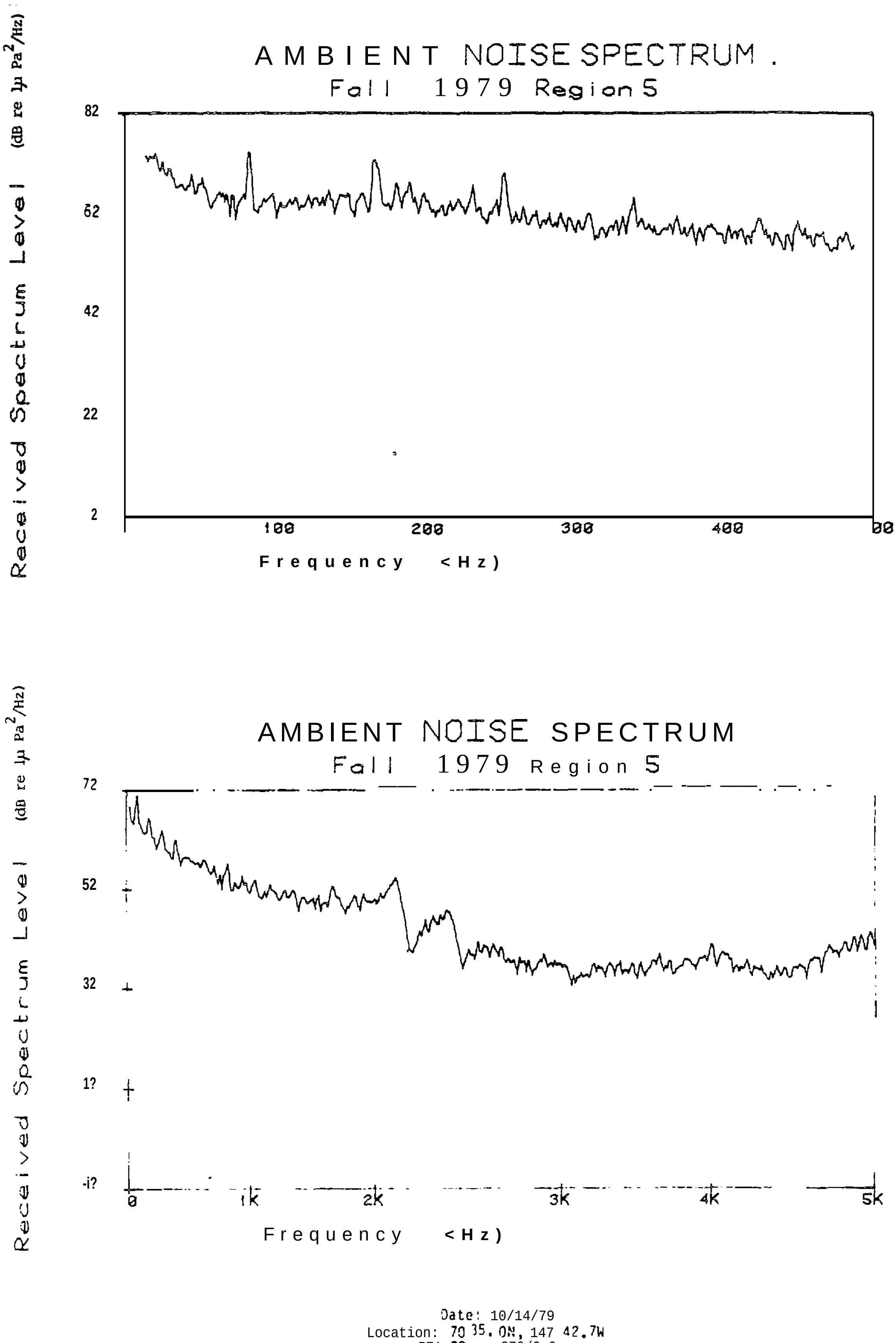


Figure 8. Received spectrum level of "crackling" ice noise recorded in 9/10 slush ice, Region 5, 1979.

of the correlates ($r = 0.254$, $t = 1.76$, $p \leq 0.20$) with measured ambient level at 5 kHz. Sea state and depth had no apparent influence. The inference that ice coverage affects ambient levels at higher frequencies is therefore weakly supported by both regression analyses. Other possible causal factors should not be ruled out however.

Ambient Noise Anomalies

Some ambient noise spectrums contained unexpected features, especially in the 5 kHz band. Examples of such data variations include:

- the previously mentioned "step down" anomaly (Fig.s 4B and 8)
- an apparent (hi) modality to ambient data recorded in region 5, in October 1979,
- single and paired tonal peaks apparent in data recorded "in the Canadian Beaufort Sea, August 1980 and
- an enhancement or "shoulder" to ambient noise, roughly between 300 Hz and 1800 Hz, recorded in region 5, September 1979.

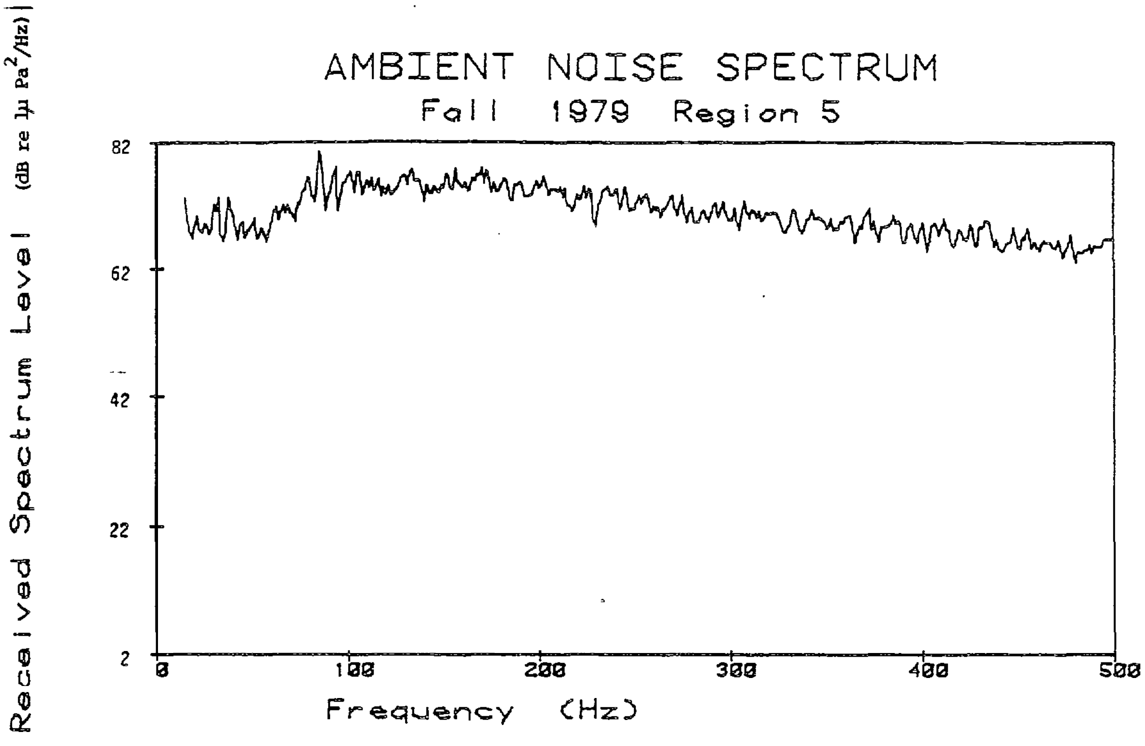
Sources of these data- variation are unknown at present. The frequency nature of such anomalies may allow some speculation however.

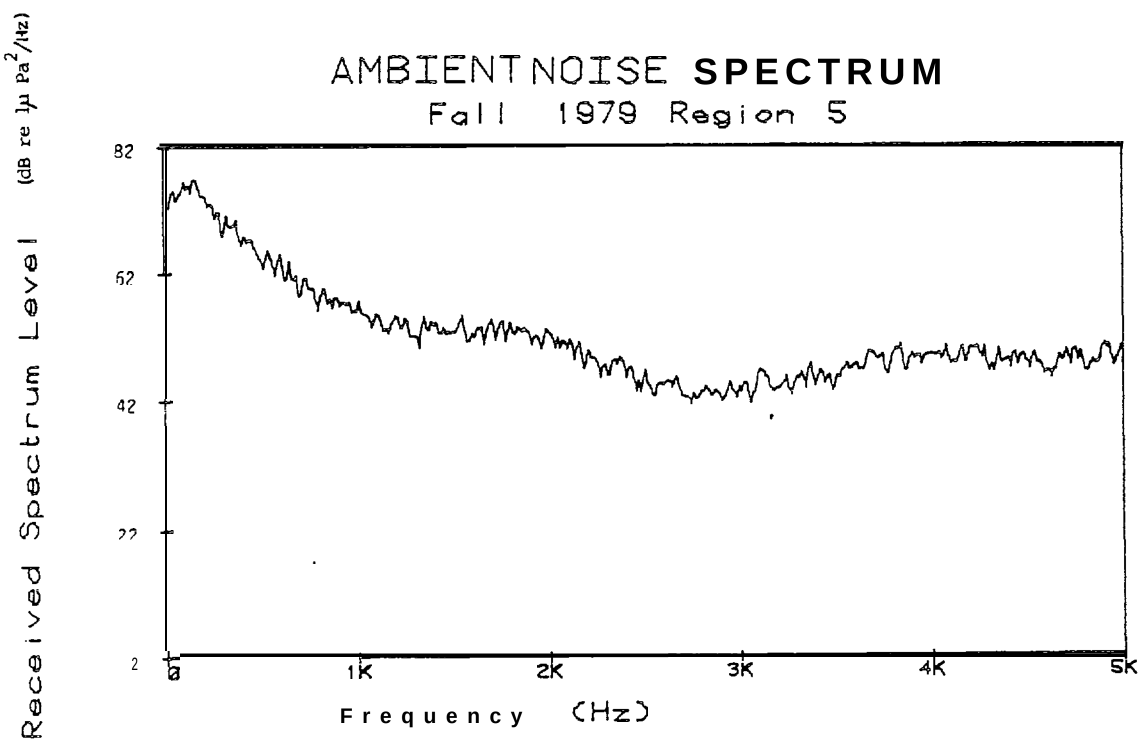
The abrupt "steps" in frequency may be the result of variations in individual sonobuoy response. Our best indication of this is from data recorded on 14 October 1979 using two 57A sonobuoys dropped approximately 17 km apart. The steps that appear around 2 kHz in Figure 8 are not present in data recorded at the second sonobuoy (Figure 9). This second sonobuoy was in a small open water pond in about 8/10 ice, and no "crackling" ice noise was audible. The steps in Figure 8 drop about 10 dB in level. A sound fluctuation with that level at approximately 2 kHz should be detectable[2] at the second sonobuoy, yet no steps are seen. This does not rule out other causal factors for the steps, but it may indicate the existence of variations within some sonobuoy units larger than the specified ± 2 dB.

The (hi) modality, or resurgent slope, noted in Figure 8 and Figure 10 may be the result of ice noise, though audible "crackling" sounds were only present on the portion of the tape represented in Figure 8. High frequency sounds attenuate rapidly, thus elevated ambient levels above 3 kHz would most. likely be from physical features near the sonobuoy.

---

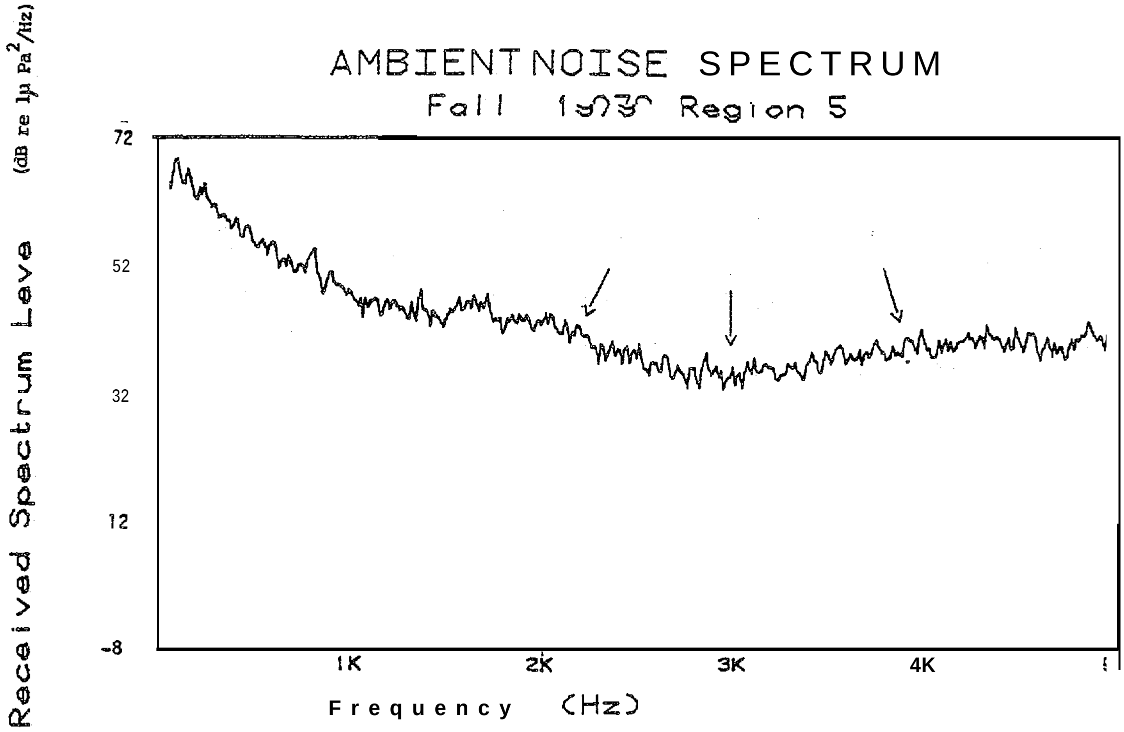
2) Using 20 log r transmission loss.

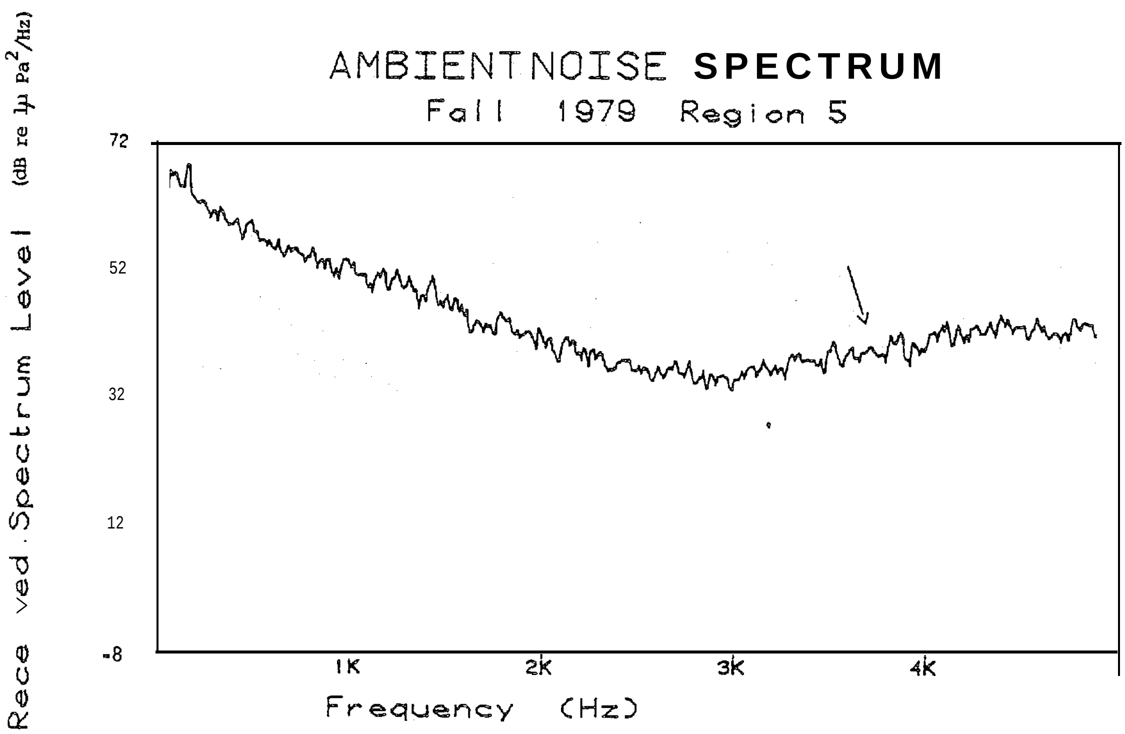




Date: in/14/7'l
Location: 70 29.4N, 147 15.5W
57A SB 253/1.0

Figure 9. Ambient noise spectrum from data recorded on a 57A sonobuoy 17 km from that used to record data presented in Figure 8. Note lack of "steps" in broad band spectrum.





Date: 10/14/79
Location: 70 31.3N, 147 13.2W
57A se 262/2.0 and 21.6

Figure 10. Anomaly in ambient noise spectrum: (bi) modality.

The tonal peaks in some spectrums may be the result of aircraft noise, though one or several harmonically related peaks, not paired peaks, would be expected from such a source (Figure 11). Tonal features may be expected from noise sources with temporal or frequency modulated components, but in anomalous data such as that presented in Figure 11 no such sounds were heard.

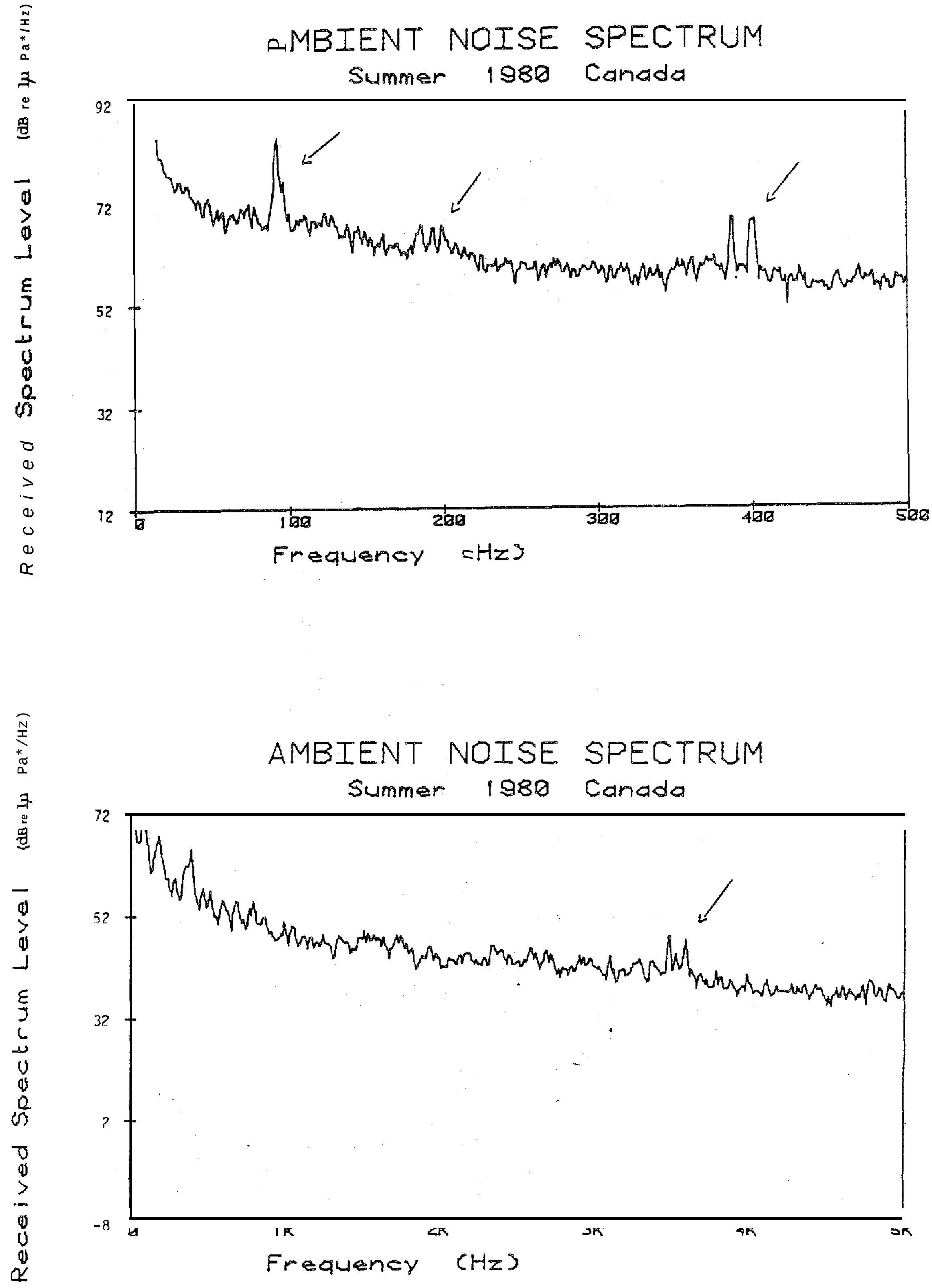
The "shoulder" in some ambient samples, roughly between 300 Hz and 1800 Hz, may be the result of distant, inaudible vessel noise (Figure 12). Some vessel noise spectrums from both large and small craft show relatively high levels in approximately the 200 Hz to 2 kHz frequency band (see Figures 15B, 18A-2, 18D- 2 and 19). This suggested relationship obviously does not rule out other possible sources for the relatively high ambient "shoulders" noted in some spectrums.

Industrial Noise

Recorded industrial sound sources included: a) three types of survey aircraft, b) small craft including an eskimo whaling boat and a Boston Whaler, c) an icebreaker, d) four geophysical vessels that produce engine noise and airgun blasts, and e) pipe driving sounds recorded near an exploratory drilling site. Geophysical vessel engine noise and airgun sounds are discussed as separate sources although they are often concurrently produced. Industrial noise was sometimes recorded from unknown sources and as such was excluded from this presentation.

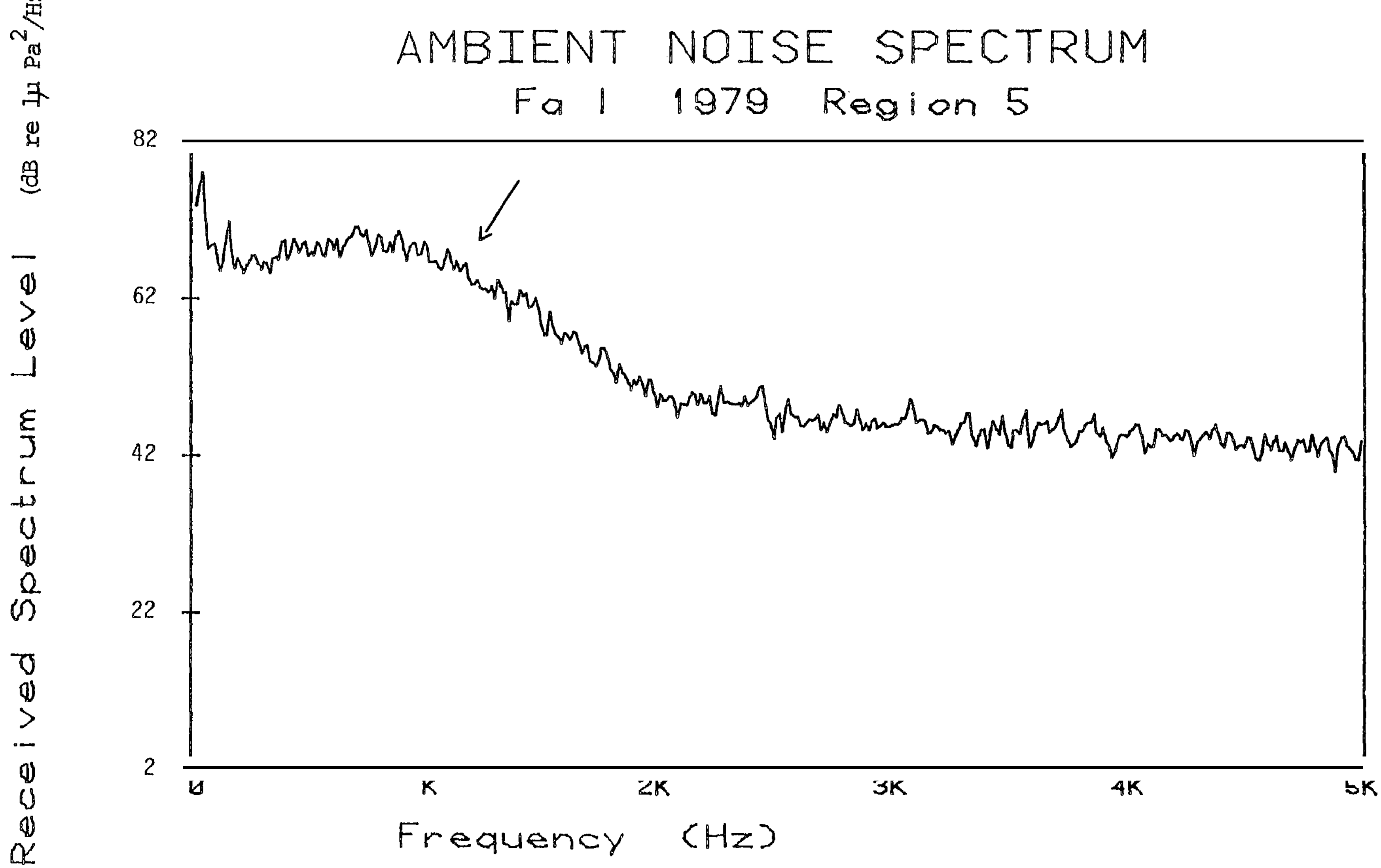
A summary of industrial noise sources, their approximate range and measured spectrum level is presented in Table 7. In the case of impulsive type noise, peak levels are tabularized. Each industrial source level is related to measured ambient spectrum levels averaged by region and season (see Table 4).

The level of industrial noise measured at some range (r) will depend not only on the source, but on propagation or transmission loss (TL) of the signal over the range. Spherical spreading and cylindrical spreading are the two basic models of transmission loss usually considered. Spherical spreading (TL=20 log r) describes sound spreading in three directions and is generally a near-source model. Cylindrical spreading (TL= 10 log r) occurs when sound spreads in two directions (i.e. sound bounces off the surf ace and bottom before it is received). In shallow water , spreading loss is often modeled as 1 5 log r to account for partial spherical and cylindrical loss effects (Malme et al, 1983). In shallow water sound is usually channeled by rays that are reflected from the surface and bottom many times as



Date: 8/19/80
Location: 69 56.0N, 131 52.5W
41B SB 846/6.5

Figure 11. Anomaly in ambient noise spectrum: single and paired tonal



Date: 9/26/79
Location: 69 49.2N, 141 10.7W
57A SB 264/2.7

Figure 2. Anomaly in ambient noise spectrum: 300 Hz- 800 Hz "shoulder".

Table 7. Summary of recorded industrial noise sources, approximate range and measured spectrum level, with comparisons to average measured ambient spectrum levels. (All levels in dB re 1 μ Pa^2/Hz).

Source	Range (Approx.)	Average Narrowband Noise Spectrum Level	dB Above Ambient 1	Spectrum Level At 5 kHz	dB Above Ambient Spectrum Level At 5 kHz	Spectrum Peak Level (dB)	Frequency (Hz)	Noise Characteristics
Aircraft:								
Single Engine Otter	214.1 m							Complex Tonals
Twin Otter	137.6 m	64dB	+2	34dB	-4	100dB	at 84 Hz	Harmonics
Grumman Goose	611.6 m	67dB	+5	41dB	+5	100dB	at 100 Hz	Harmonics
Small Craft:								
Whaling boat	500 m							Complex Harmonics
Boston Whaler	500 m	72-75dB	+2-5*	47-60dB	+7-20*	87-81dB	210-1850 Hz	Some Tonals/ Variations
Icebreaker:								
Polar Sea	7-8 km	58dB	-8	25dB	-9	74dB	at 89 Hz	Tonals
Geophysical Vessels:								
Arctic Star	1.4 km	85dB	+16	58dB	+9	104dB	at 9$ Hz	Harmonics
Mariner	1.5 km	88dB	+22	57db	+21		no peaks	
Western Polaris	43 km	62dB	-4	37dB	+3	78dB	at 111 Hz	Tonals and Harmonics
Western Aleutian	38 km	67dB	+1	20dB	-18	80dB	at 200 Hz	Tonals and 'Harmonics
Two Vessels	15 km	80dB	+14	53dB	+19	103dB	at 72 Hz	Tonals
Seismic Survey:								
Airgun Array	37 km		+23			89dB	at 174 Hz	Impulsive
Airgun Array	49 km		+42			108dB	at 195 Hz	Impulsive
Airgun Array	67 km 2	-	+38			107dB	at 79.5 Hz	Impulsive
Pipe Driving Sounds:	1 km	(97dB) 3	25-35	52dB 3				Impulsive/ Transient

1) averaged ambient narrowband spectrum level and spectrum level at 5 kHz from Table 4; *ambient measured at boat site before approach of craft, see Fig. 16A.
2) range calculated from company provided boat position
3) 50-200 Hz band; 1 kHz not 5 kHz spectrum level

they travel from source to receiver (Urick, 1967). Sound energy is additionally lost to absorption into the bottom, and scattering at the surface. Transmission loss is greatly affected by source, receiver and bottom depth. Source directivity, sound speed characteristics of the water column (i.e. temperature and pressure profiles), sea surface conditions, bottom contour and type and molecular absorption also impact transmission 10ss. Unfortunately, experiments to measure transmission loss of industrial noise sources could not be conducted within the framework of the primary study. Nor were physics.i oceanic measurements taken pursuant to developing regional or seasonal sound speed profiles, or delineating bottom topography. In addition, the range to each industrial source is usually approximated, and in the case of some vessels calculated from positions provided by the company operating the vessel. Thus, few inferences can be drawn regarding the nature of the industrial noise spectrum levels presented due to small sample size and insufficient data to support transmission loss modelling.

Aircraft

Over the four year study period, three types of survey aircraft were used. They included:

1) a piston powered Single Otter, used in the spring of 1979
2) a turbine powered de Havilland Twin Otter, used in the spring and fall of 1979, and
3) a turbine powered modified Grumman Goose, in service on this project each year since 1980.

Noise spectrum levels for each type of aircraft are presented in Figure 13. Noise samples were taken from portions of tape where aircraft sounds were aurally distinct. Such tape portions presumably resulted when the aircraft passed nearly directly over the hydrophore. Planned hydrophore overflights were not performed during surveys, so the precise position of the aircraft relative to the sonobuoy is unknown.

Single Otter

The noise spectrum recorded from the Single Otter at an altitude of 700' ASL[3] (213.4 m) is presented in Figure 13A. The narrowband noise spectrum of this piston powered aircraft contained a complex series of tonal elements beginning at about 30 Hz that are probably related to engine cylinder firing rate. A 41A type sonobuoy was used for this recording; therefore, absolute sound level can not be measured from this sample. A broadband spectrum was not made for the Single Otter data.

Twin Otter and Grumman Goose

Unlike that recorded from the Single Otter, the spectrums of aircraft noise recorded from the turbine powered Twin Otter arid the Grumman Goose (Figure 13B and 13C) show well defined harmonic elements in the narrowband. These harmonics, with fundamentals at 83.75 Hz and 100 Hz, respectively, have measured peak levels at 100 dB to 80 dB across the 500 Hz band. Notably, the Twin Otter was at 450' ASL (137.2 m), while the Grumman Goose maintained 2000' ASL (609.6 m), yet nearly identical peak levels were received from both sources. Our Twin Otter data agrees well with that of Greene (1982, p. 304-307) who reported an 82 Hz fundamental with 104 dB to 110 dB peak levels for noise recorded during a Twin Otter fly over at 500' ASL.

The greatest increase in noise level for each survey aircraft was in the 500 Hz frequency band where peak levels were measured at approximately 34 dB to 38 dB above ambient levels. Aircraft noise does not appear to dramatically affect ambient noise levels above 500 Hz. The broadband spectrums show low level harmonic bands at about 1200 Hz and 2400 Hz (Figure 1313-2) in the case of the "Twin Otter, and 1500 Hz and 3500 Hz (Figure 13C-2) for the Grumman Goose. The overall slope (-7 dB/octave) and 38 dB level at 5kHz does not differ significantly from ambient noise levels for this region and season.

To reiterate, the orientation of each aircraft relative to the hydrophore is not known for these sound samples, therefore the spectrum levels presented should not be directly compared. A ray-path diagram showing various air-water propagation paths for aircraft noise is presented in Figure 14. The altitude and distance (orientation) of the aircraft relative to the receiver greatly affects each propagation pathway (as outlined in Figure 14), and therefore the level received at the hydrophone. Without this information for each aircraft, it is impossible to model in any precise fashion the actual noise impact of each source.

---

3) ASL = Above Sea Level.

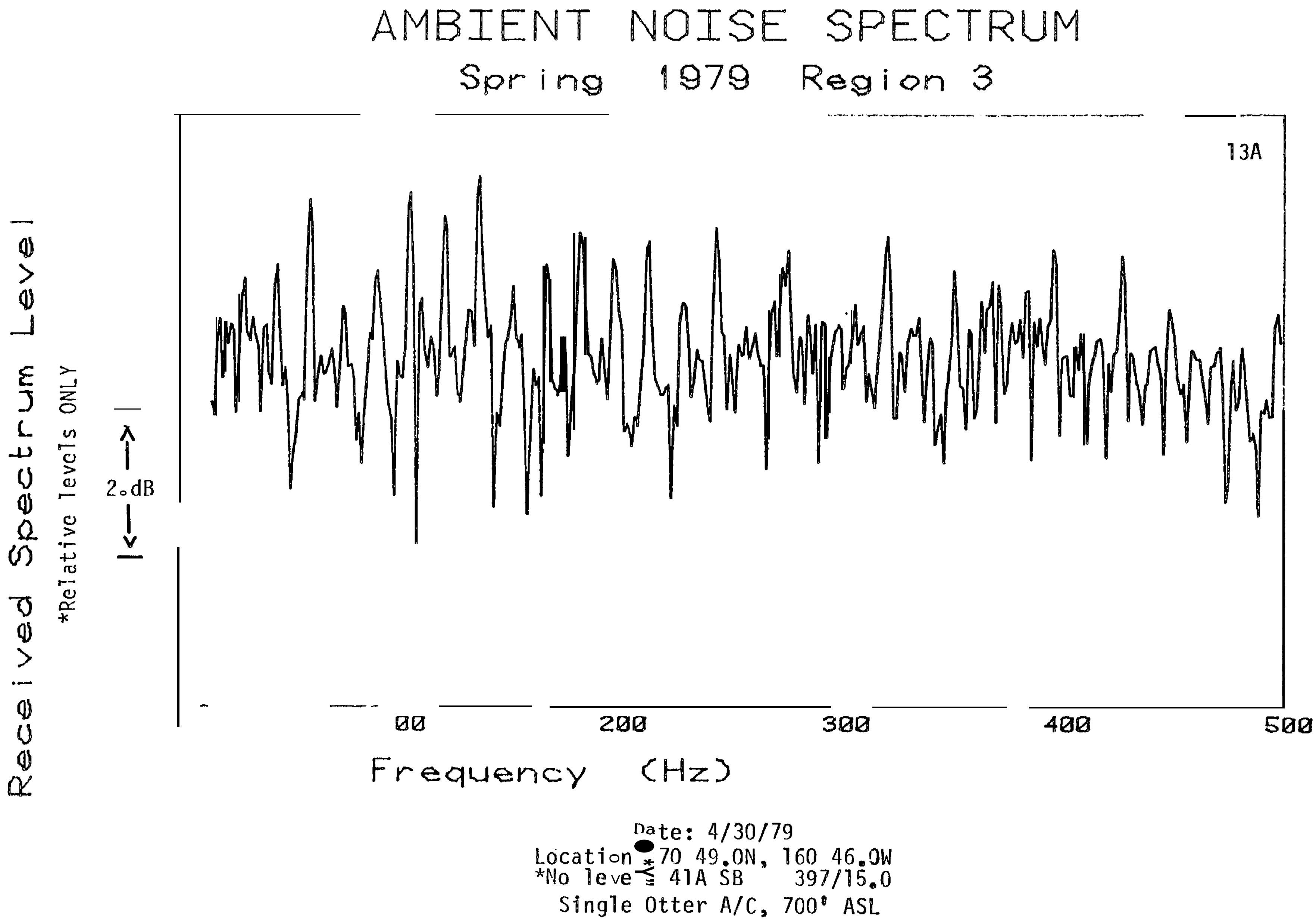
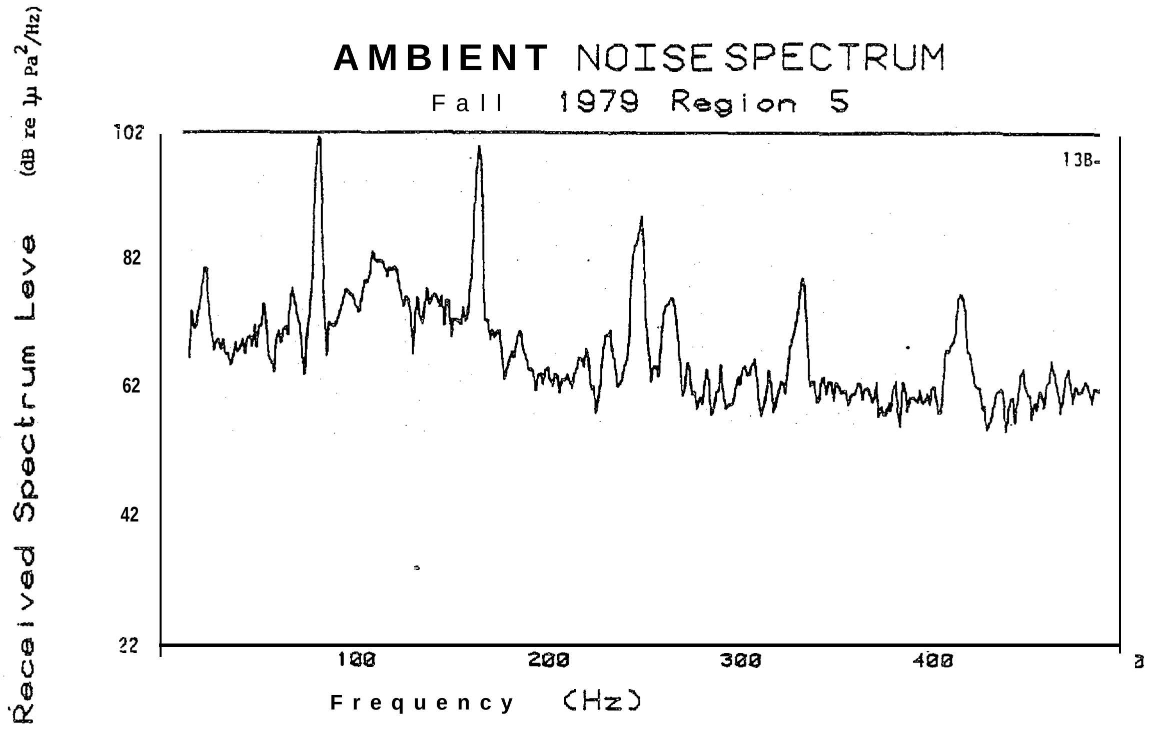
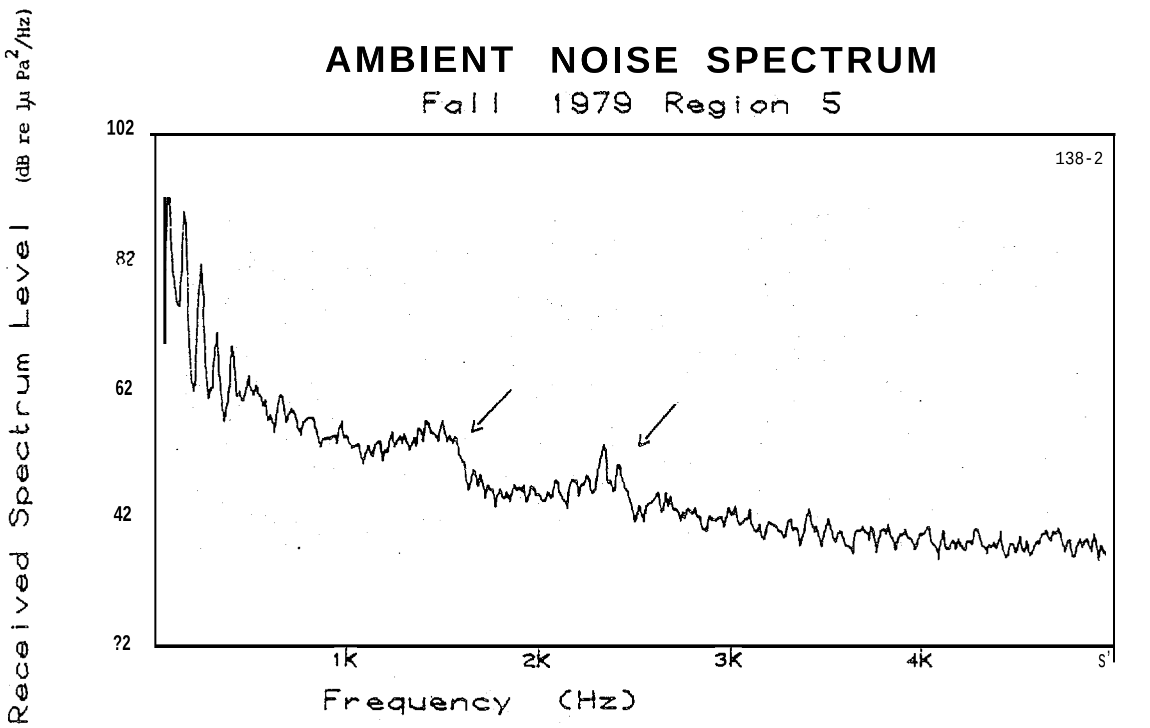


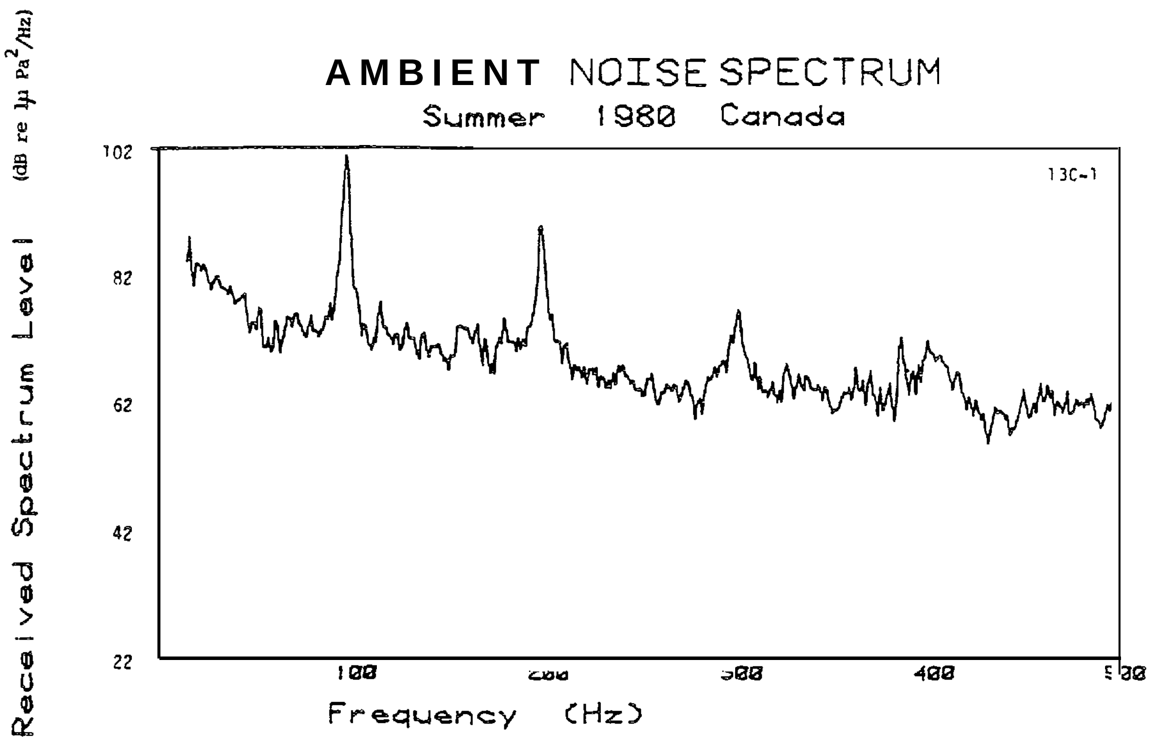
Figure 13A. Noise spectrum level for Single Otter (piston powered) airplane.





Date: 10/16/79
Location: 70 22.7N, 145 45.3W
57A SB 259/7.7
Twin Otter A/C, 450' ASL

Figure 13B (cont). Noise spectrum levels for Twin Otter (turbine powered) airplane. Arrows mark low level harmonics bands.



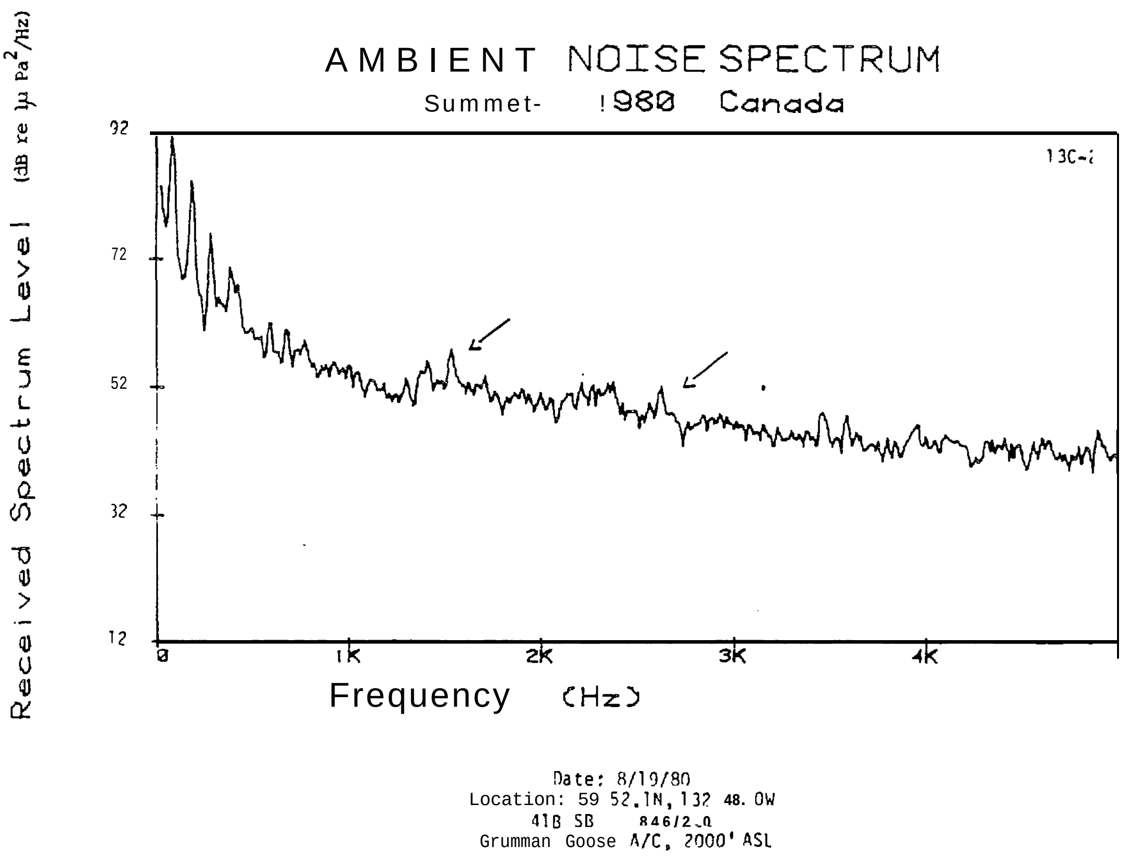
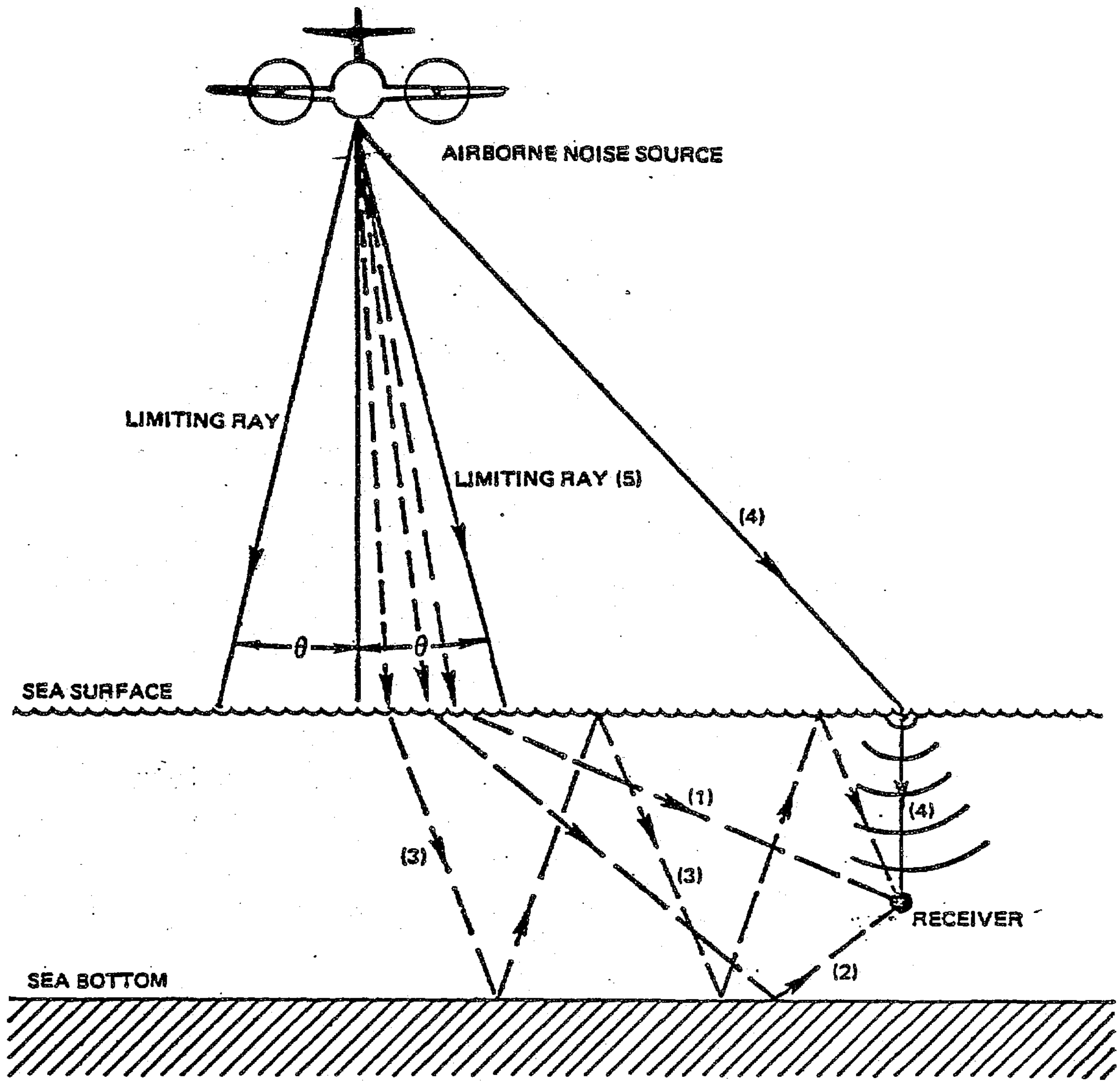


Figure 13C (cont). Noise spectrum levels for Grumman Goose (turbine powered) airplane. Arrows mark low level harmonic bands.



1. DIRECT PATH SHOWING BENDING AT SEA SURFACE
2. BOTTOM REFLECTED PATH
3. MULTIPLE BOTTOM-SURFACE REFLECTED PATH
4. SURFACE SCATTERED PATH
5. LIMITING RAY FOR CRITICAL ANGLE θ, BEYOND WHICH, RAYS ARE TOTALLY REFLECTED ($\theta = 13^{\circ}$)

Figure 14. Ray-path diagram showing various air-water propagation paths for aircraft noise (after Urick, 1972).

vessels

Vessels operating in the Beaufort Sea include small supply boats and launches such as Boston Whalers, tugs with large barges in tow, icebreakers and geophysical vessels. Engine noise from two small craft, an eskimo whaling boat, and a Boston Whaler used in a bowhead tagging effort, was recorded in 1980. Specifications of engine type for the eskimo whaling boat are unknown. We assume it was powered by a single outboard engine such as a Johnson, Mercury or Evinrude 80-90 horsepower, The Boston Whaler was powered by twin Mercury 90 horsepower engines.4 These Mercury outboards have 3-blade stainless steel propellers and a maximum engine speed of 4500 RPM. Distant noise from the icebreaker Polar Sea was recorded in 1982 when it passed 7 to 8 km from our sonobuoy. The Polar Sea is powered by twin diesel engines. Additionally, engine noise from four diesel powered geophysical vessels was recorded on several occasions between 1979 and 1982.

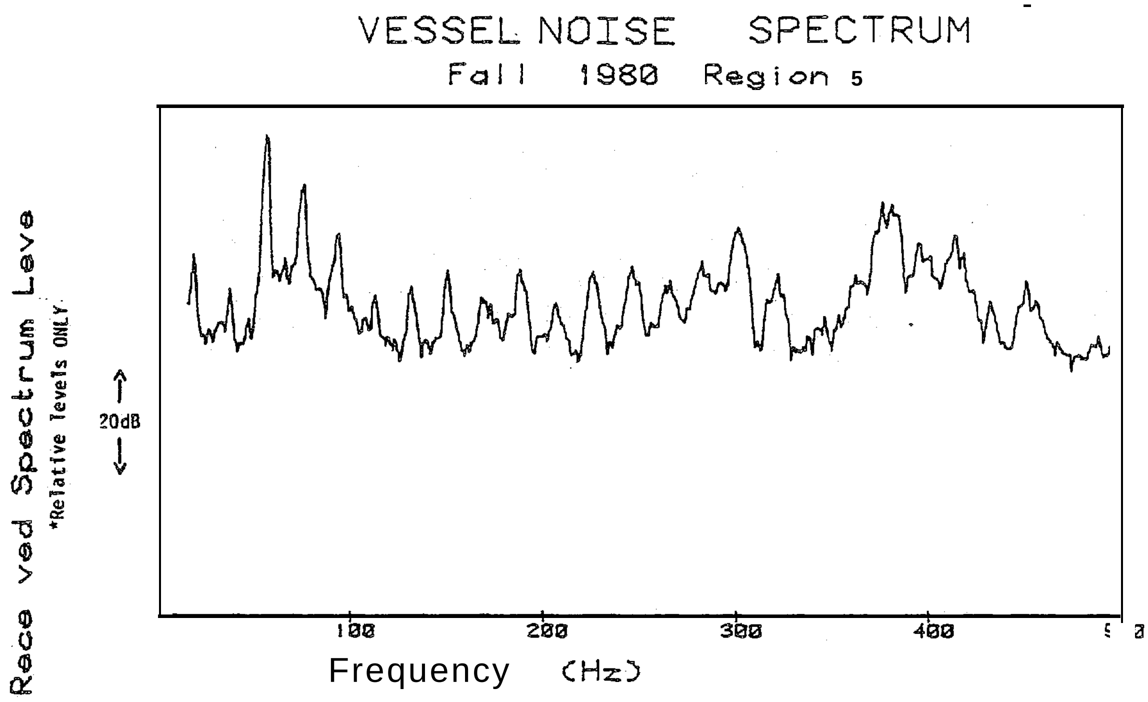
Small Craft

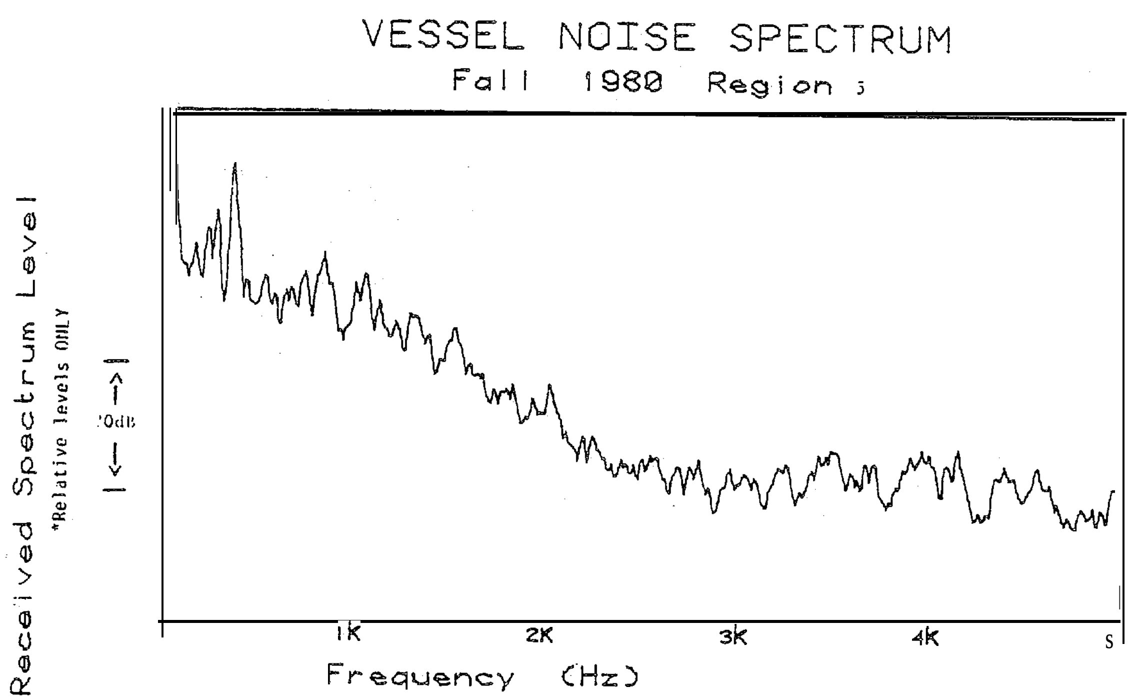
Noise from the eskimo hunting boat was recorded opportunistically on 2 October 1980 when whalers from Barter Island brought their small craft alongside our sonobuoy to investigate it. The noise spectrum from this boat when accelerating approximately 0.5 km from the sonobuoy is presented in Figure 15. Note that this recording was made with a 41A sonobuoy, thus absolute levels can not be measured. The harmonic pattern with a fundamental at 18.75 Hz in the narrowband is quite unusual and complex. There are numerous peaks and an overall bimodal shape to the spectrum with elevated relative levels at 50 Hz to 100 Hz, and 300 Hz to 410 Hz. The broadband spectrum shows a steep slope between 15 Hz to 2400 Hz, with a more gradual decline to 5 kHz.

A series of sounds recorded approximately 0.5 km from a Boston Whaler used in whale tagging efforts in 1980 provided useful comparisons to the whaling boat spectrums. A series of noise spectrums presented in Figure 16 A-E reflect data analysed from ambient (A), engine idle (B), accelerating RPM (C), 1000 RPM (D), and 2000 RPM (E) conditions. The sample taken during engine acceleration (Figure 16C) is the best comparison to the hunting boat data.

Ambient level in the narrow band (Figure 16A) was about 70 dB with a -7' dB/octave slope to 40 dB at 5 kHz. This is about 4 dB higher than the average

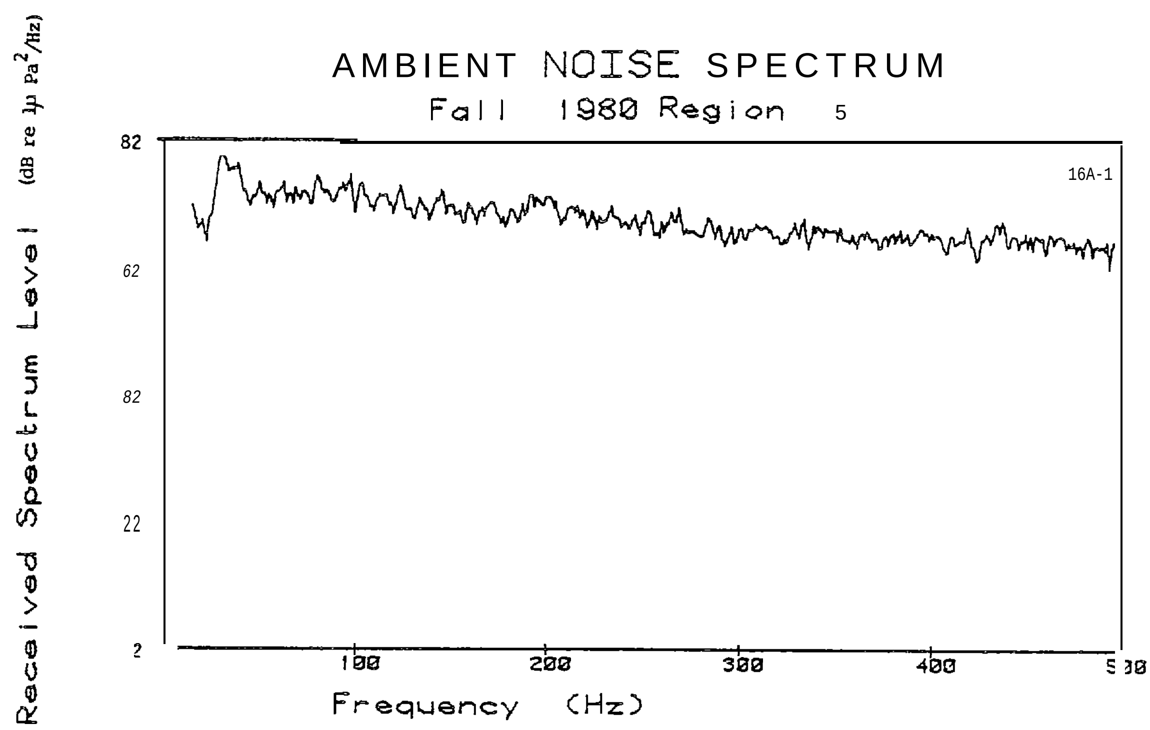
4) Per. Comm: Lloyd Lowry, Alaska Department Fish and Game, Fairbanks, Alaska.





Date: 10/2/80
Location: Approx 70 10.0N, 143 40.0W
*No level, 41A SB 549/6.3
Hunting Boat
Distance Approx 0.5 km

Figure 15. Received noise spectrum levels from an Eskimo hunting boat.



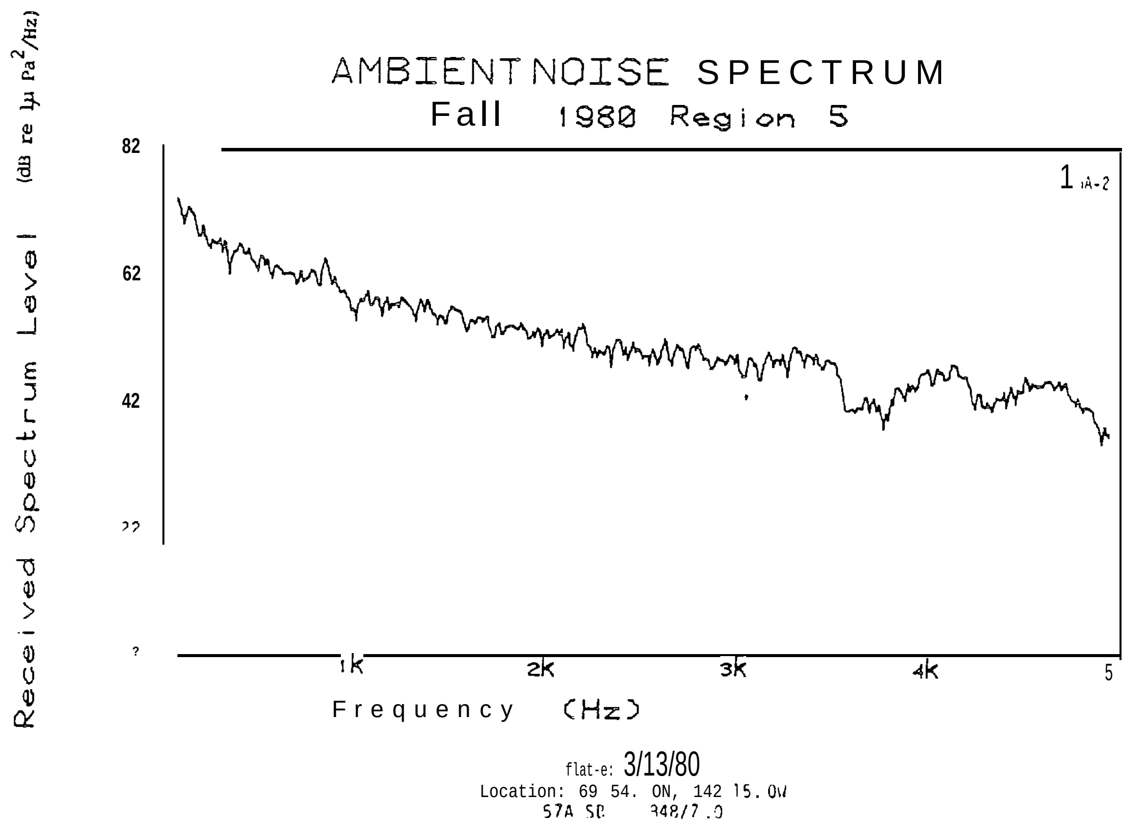
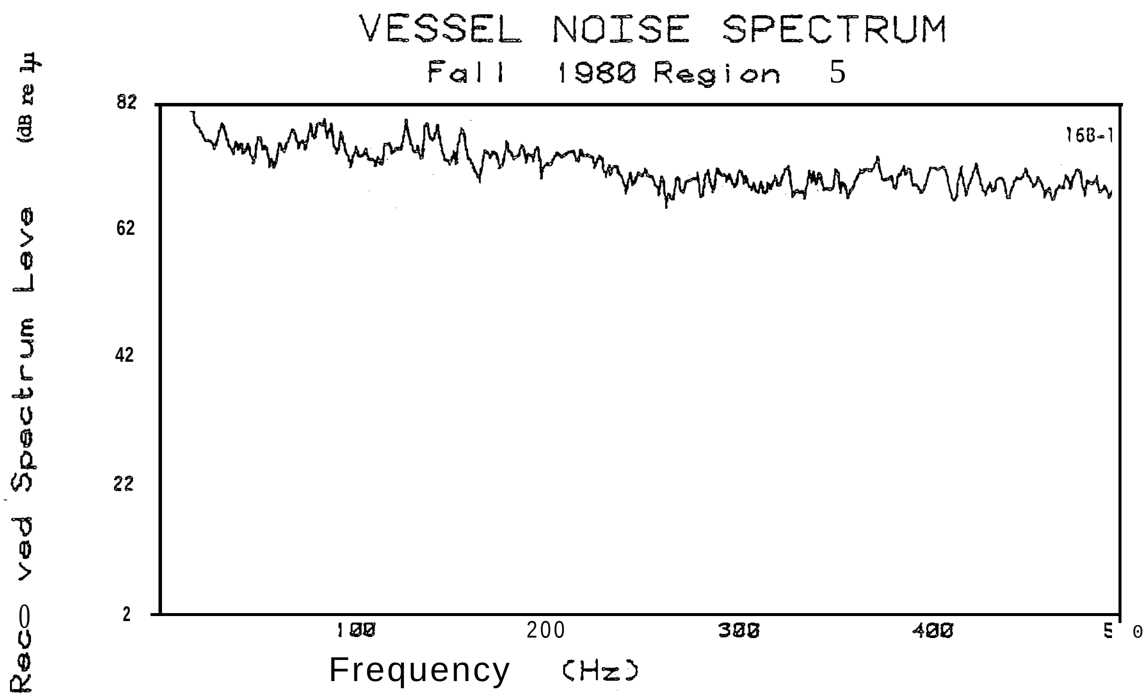
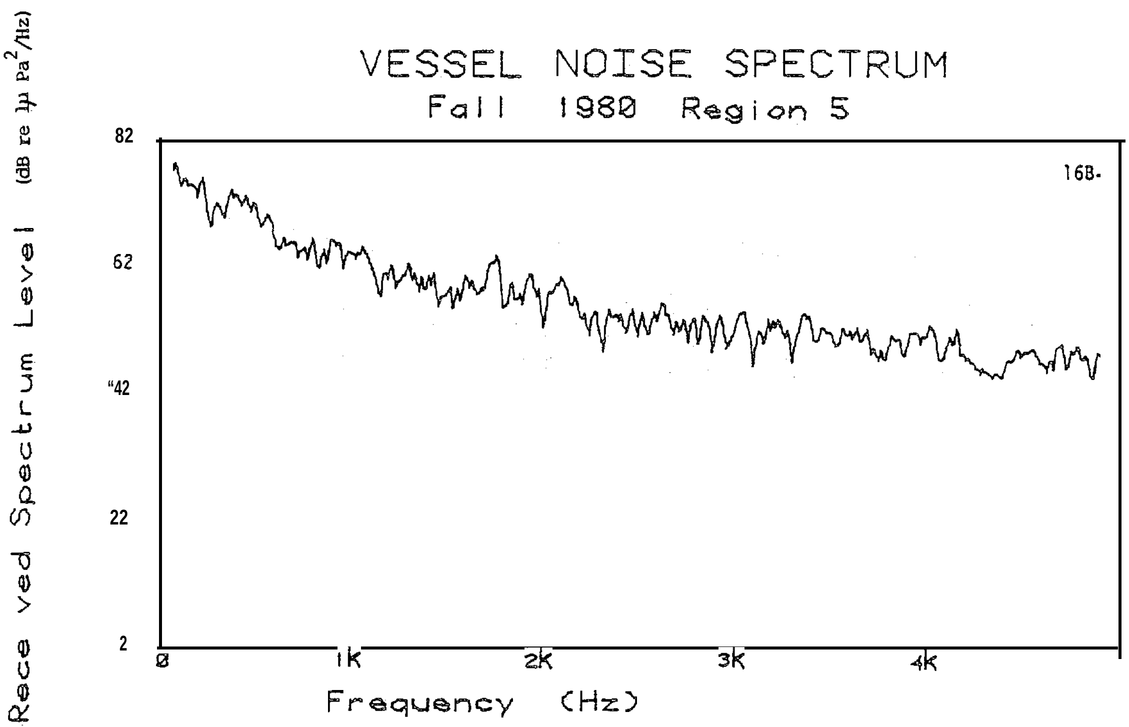


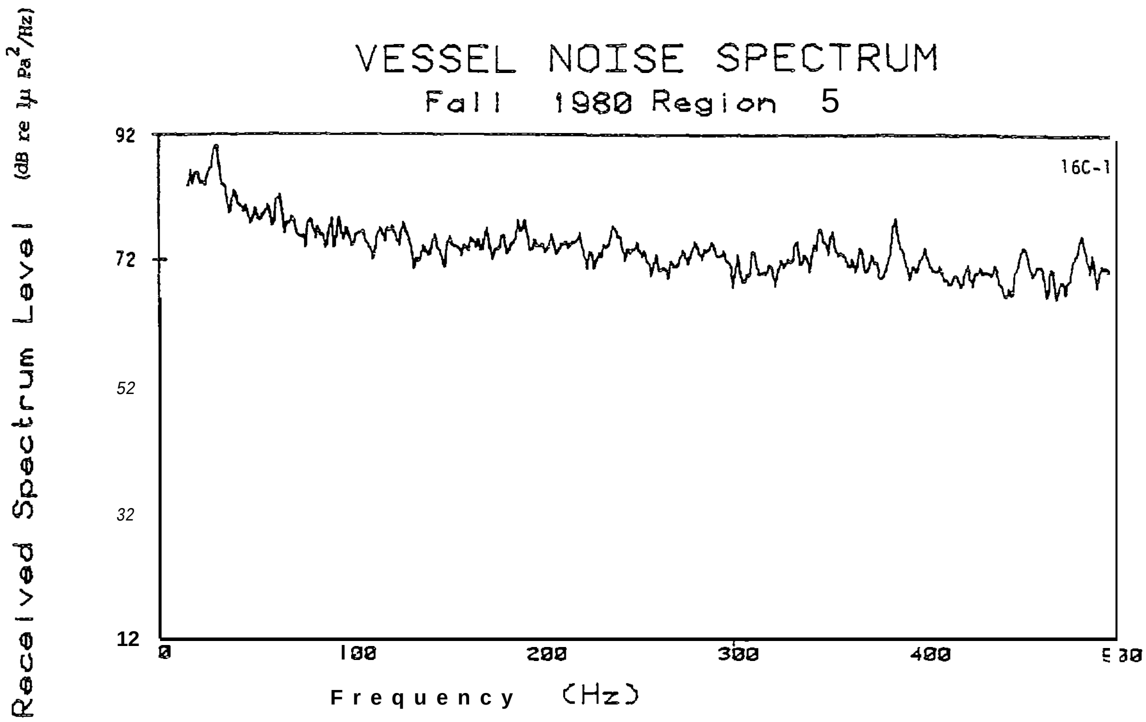
Figure 16A. Ambient noise spectrum levels prior to the approach of a Boston Whaler.

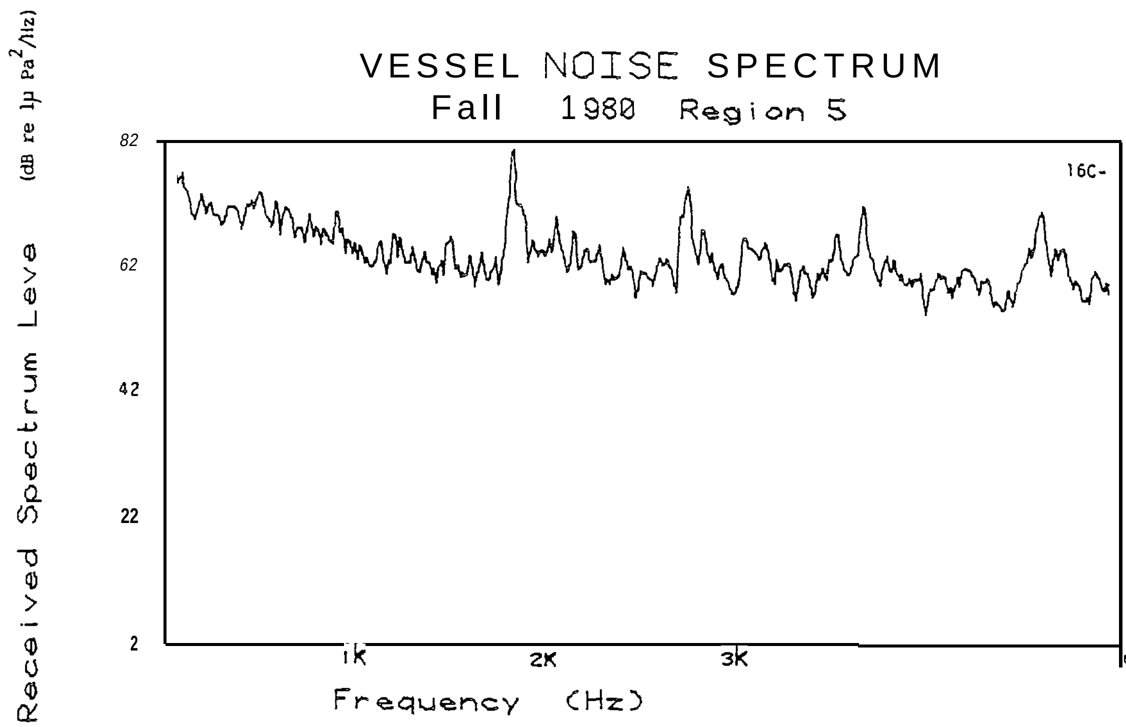




Date: 9/18/80
Location: 69 54. 0N, 142 15. 0W
57A S8 848/14.4
Boston Whaler: Idling Engines
Of stance: Aoprox 0.5 km

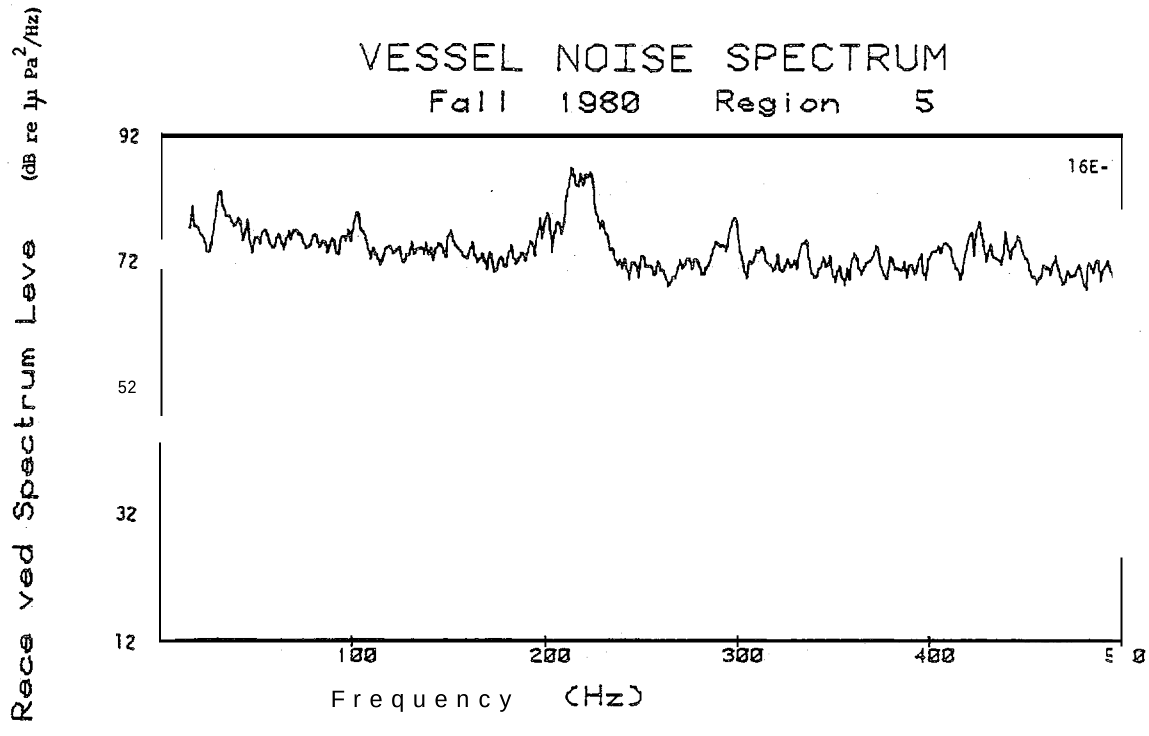
Figure 16B (cont). Noise spectrum levels from a Boston Whaler: engine idle.

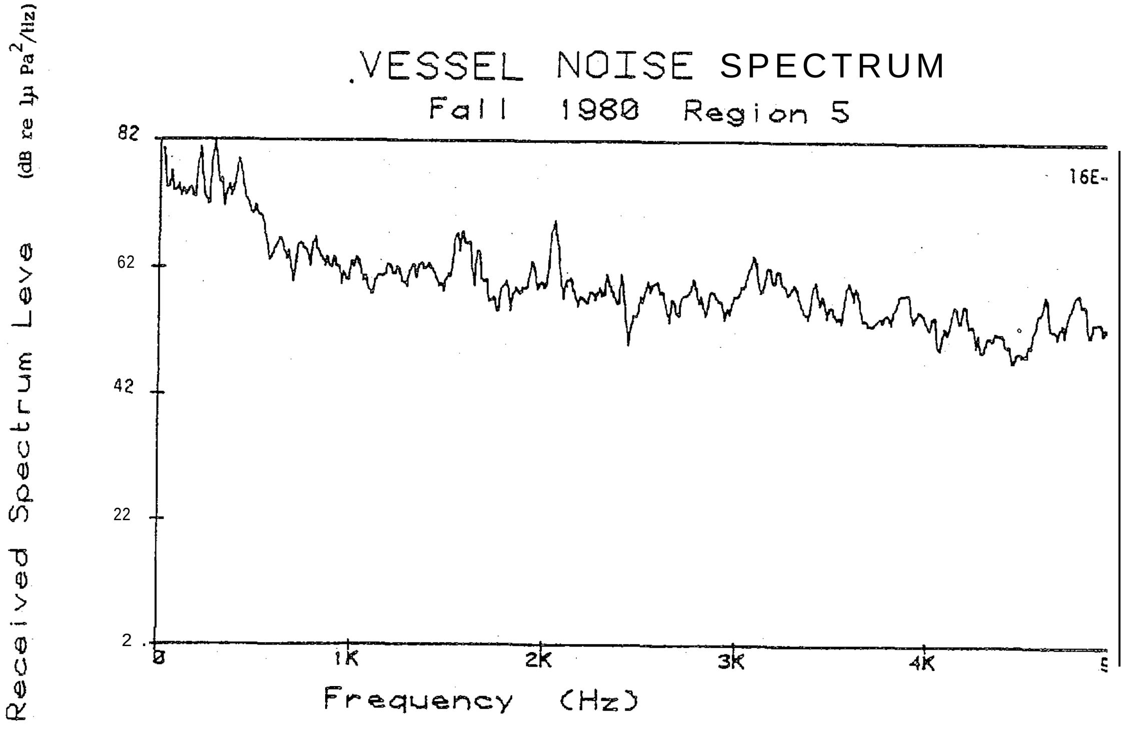




Date: 9/18/80
Location: 69 54. ON, 142 15. OW
57A SB 848/14.9
Boston Whaler: Accelerating
Distance: Approx 0.5 km

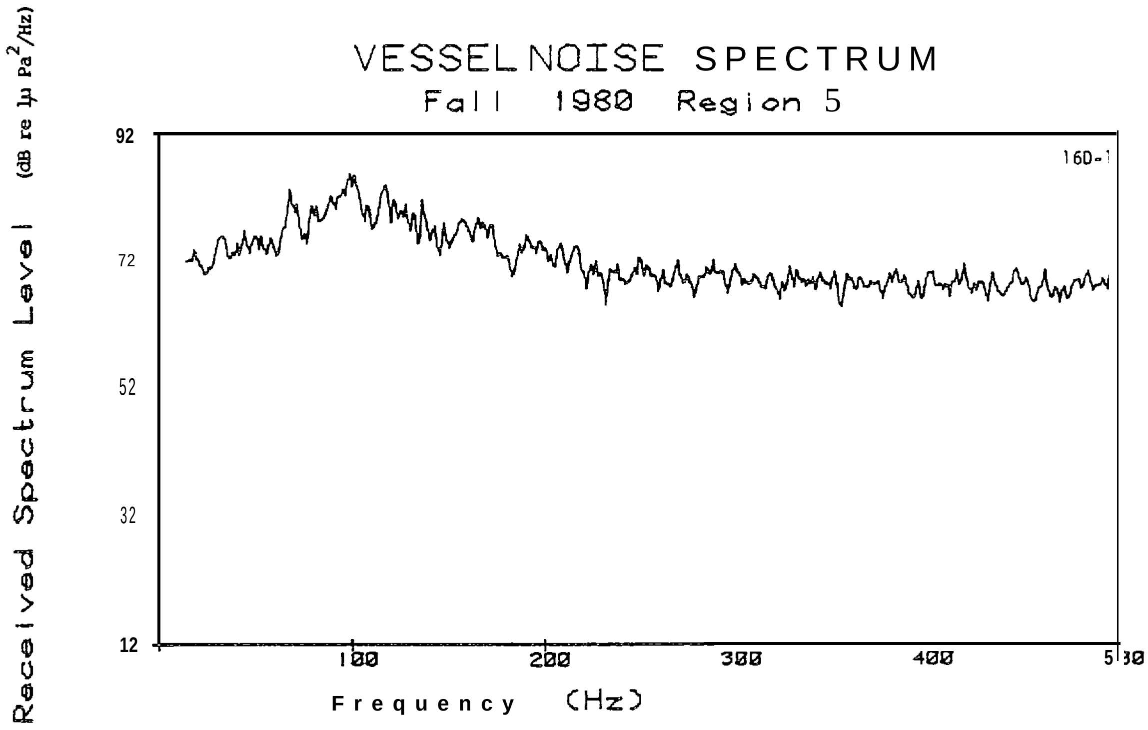
Figure 16C (cont). Noise spectrum levels from a Boston Whaler: accelerating RPM.

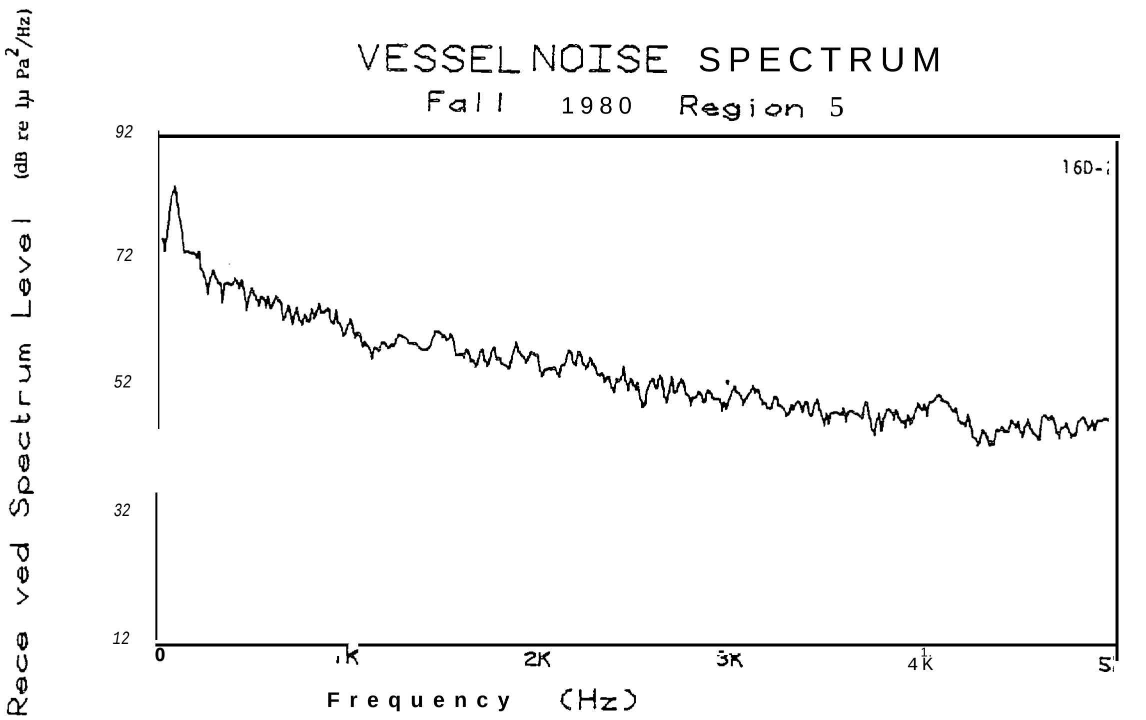




Date: 9/18/80
Location: 69 54. ON, 14? 15. OW
57A SB 848/14.6
Boston Whaler: 2000 RPM
Distance:Approx 0.5 km

Figure 16D (cont). Noise spectrum levels from a Boston Whaler: 1000 RPM.





Date: 9/18/80
Location: 69 54. ON, 142 15. OW
57A SB 848/14.5
Boston Whaler: 1000 RPM
Distance: Approx 0.5 km

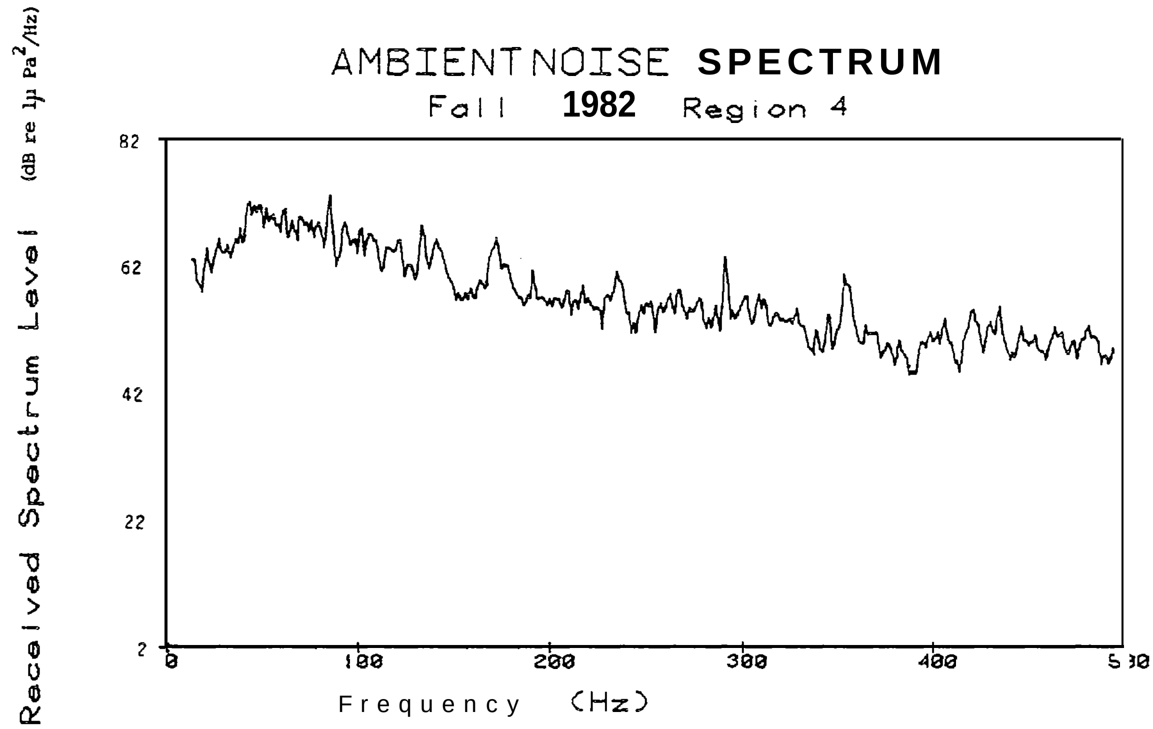
Figure 16E (cent). Noise spectrum levels from a Boston Whaler: 2000 RPM.

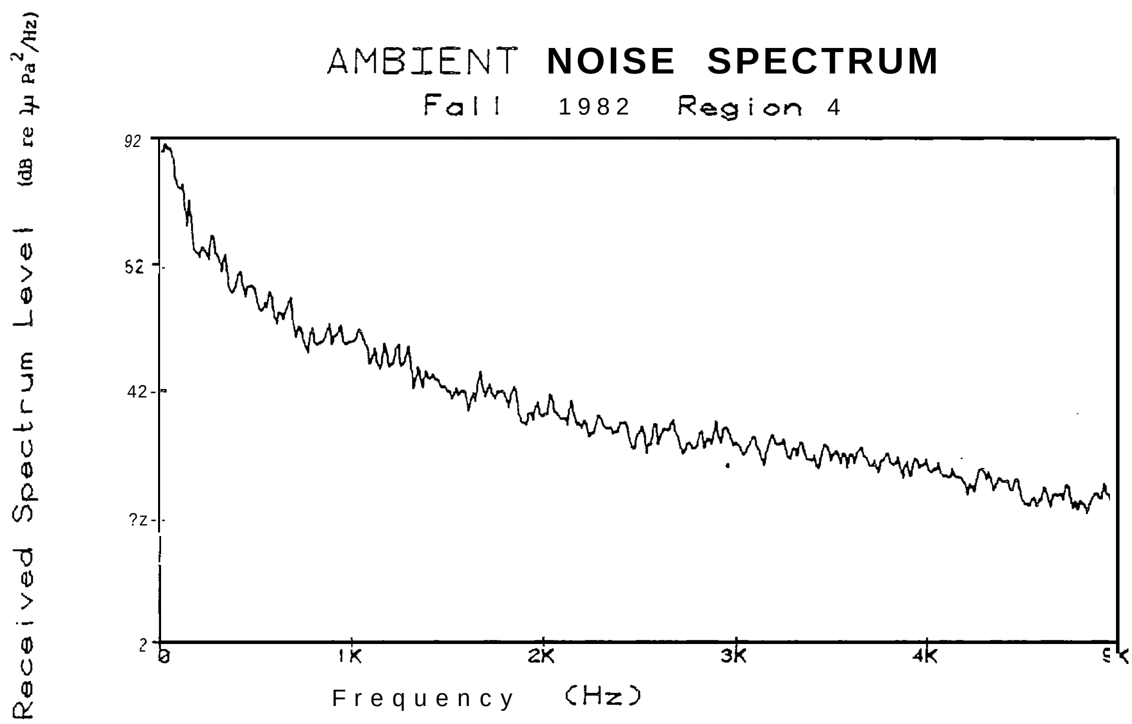
ambient level (66 dB) for region 5 in fall. The narrowband level for all but the engine acceleration sample (Figure 1 6(2.1) was 72 dB, with a drop to 47 dB to 56 dB at 5 kHz. The narrowband level for the engine accelerating sample was 75 dB, with a drop to 60 dB at 5 kHz. Thus, narrowband levels ranged from 2 dB to 5 dB above local ambient level. An elevated level (to 84 dB at 100 Hz) between 50 Hz and 150 Hz in the narrowband 1000 RPM sample (Figure 16D- 1), and a similar, but more sharply defined, spectra elevation centered around 216 Hz (to 87 dB at 210 Hz) in the narrowband analysis of the 2000 RPM sample (Figure 16E- 1) were the only unusual features. Tonal elements were evident only in the broadband spectrum captured during acceleration (Figure 16(3-2). The first tone, with a level at 81 dB, occurred at 1850 Hz f ollowed by three more of decreasing amplitude at 2762 Hz, 3675 Hz and 4600 Hz. Peak tonal and elevated levels were 15 to 21 dB above ambient.

The Boston Whaler data., coupled with that taken from the hunting boat, would imply that tonal or harmonic components result from small outboards when changing RPM,, and not during constant power stages. This is contrary to what is expected. Engines at constant RPM generally have a fairly regular propeller rate that produces corresponding tonal elements. The fact that these features are missing from our "constant" RPM samples is confounding. Possibly the elevated levels, near 100 Hz in the 1000 RPM and near 200 Hz in the 2000 RPM spectrums, are engine-variation produced. Additionally, our data suggests some synchrony to . prop rate in these small engines upon acceleration. Further speculation on these features of small craft noise spectrums is constrained due to small sample size and lack of additional specific information about the source.

Icebreaker

Sounds recorded when the icebreaker Polar Sea passed within 7 to 8 km of a 57A sonobuoy on 28 September 1982 were subsequently analysed for their spectrum content, though the vessel noise was largely inaudible to a listener on tape playback. The narrowband spectrum depicts a series of tonals beginning around 88.75 Hz and extending through five tones to 356.25 Hz (Figure 17). Overall narrowband level was about 58 dB with peaks to 74 dB. Broadband spectrum slope was approximately -8.6 dB/octave with a 25 dB level at 5 kHz.





Date: 9/28/82
SB Location: 71 30.0N, 156 51.0W
410 SB 995/22.7
icebreaker Polar Sea
Distance: 7-8 km
Sea state. 84
Ice: 0/10
Depth: Approx 164 m

Figure 17. Received noise spectrum levels from the icebreaker Polar Sea at a range of 7 to 8 km.

Geophysical Vessels

Characteristics of four geophysical vessels from which engine noise has been recorded are presented in Table 8. Engine noise spectrums from these geophysical vessels is presented in Figure 18 A-D.

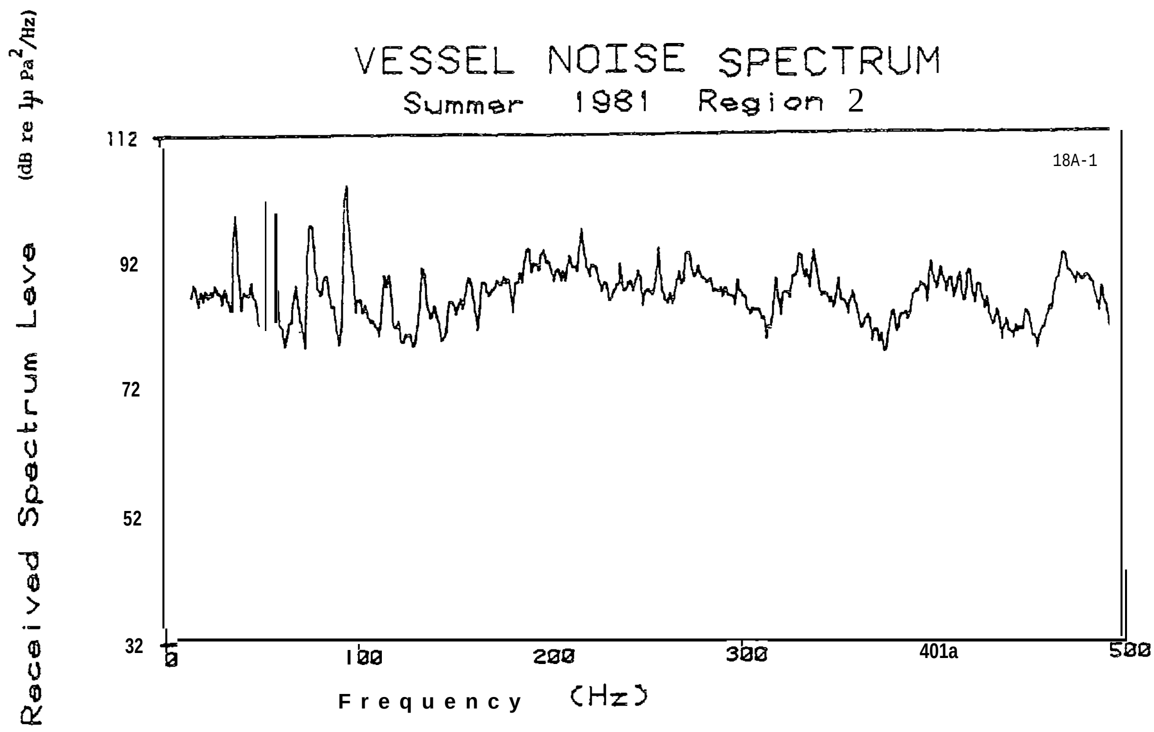
Table 8. characteristics of four geophysical vessels from which engine noise was recorded between 1979 and 1982.

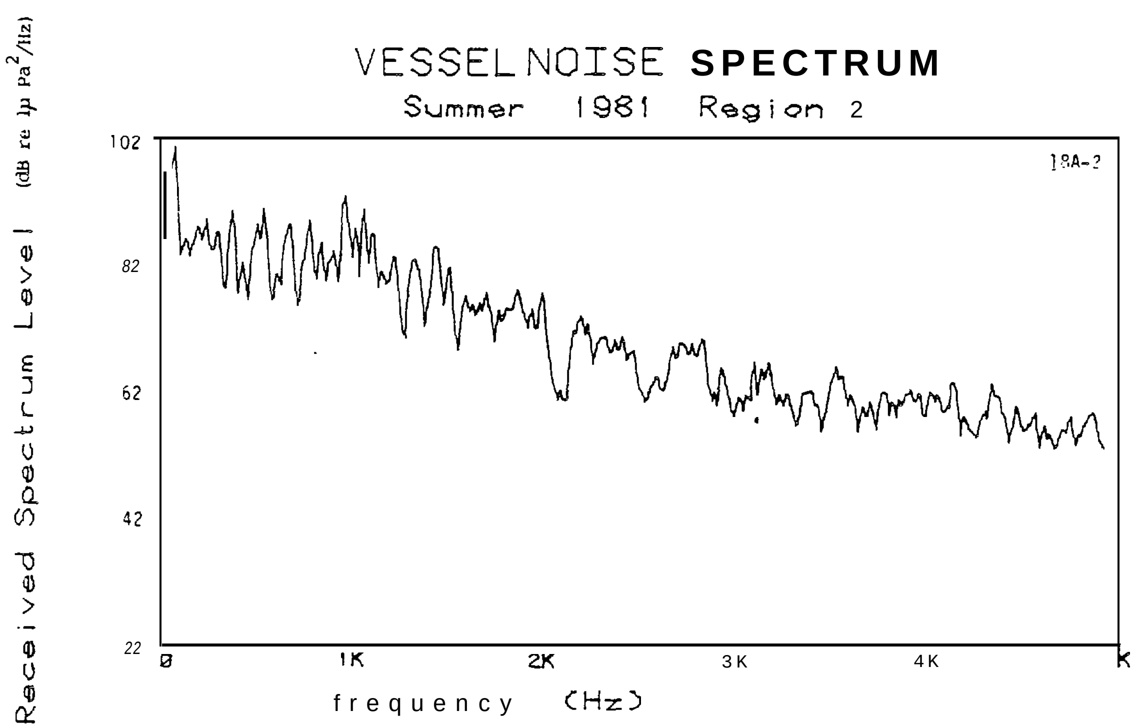
Vessel Name	Beam (ft)	Length (ft)	Type of Engine	Horsepower Rating	Screw
Arctic Star	30	100	16V71 Det. Diesel	980	Twin
Mariner	30	119	Two Diesel Cats 343	700 Each	Twin
Western Polaris	32	150	12V149 Det. Diesel	1350	Twin
Western Aleutian	32	150	12V 149 Det. Diesel	1350	Twin

The noise from the geophysical vessel Arctic Star was recorded on 24 July 1981 in region 2. This vessel had its airguns deployed and firing, thus samples of the engine noise had to be captured between seismic blasts. Harmonics with a fundamental at 40 Hz are evident in both the narrow and broadband spectrums (Figure 18A). Overall level at 1.4 km from the vessel in the 500 Hz band was 85 dB, approximately 16 dB above the ambient level recorded in July in region 2. broadband level at 5 kHz was 58 dB or about 9 dB above measured ambient level.

Engine noise was recorded from the Mariner on 18 September 1981 in region 5. This vessel too was firing its airguns and engine noise samples were taken from periods between blasts. There were no tonals nor harmonics apparent in either the narrow nor broadband spectrums (Figure 18B). This lack of harmonic content is unexplained. Noise level about 1.5 km from the vessel in the 500 Hz band was about 88 dB, approximately 22 dB above measured regional ambient levels. Measured level at 5 kHz was 57 dB, about 21 dB above averaged ambient level at 5 kHz.

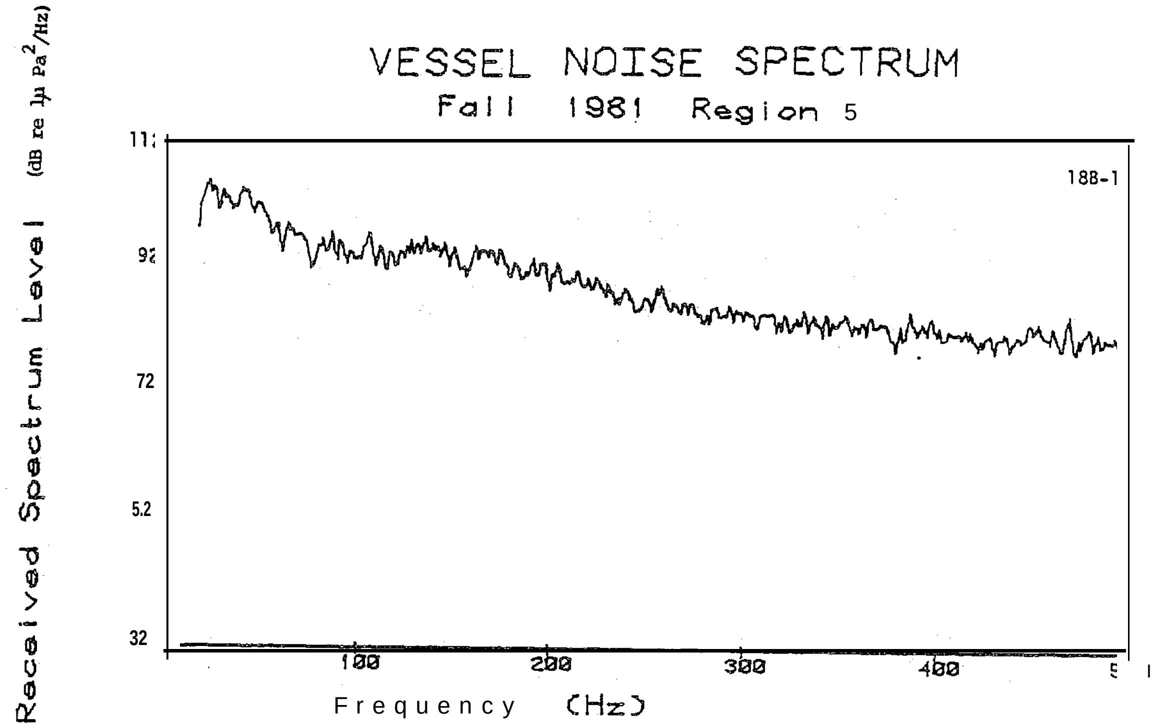
Engine noise from the Western Polaris and the Western Aleutian were recorded in regions 4 and 5 respectively on 23 September 1982. The W. Polaris was not firing its airguns during the recording period. The W. Aleutian was firing

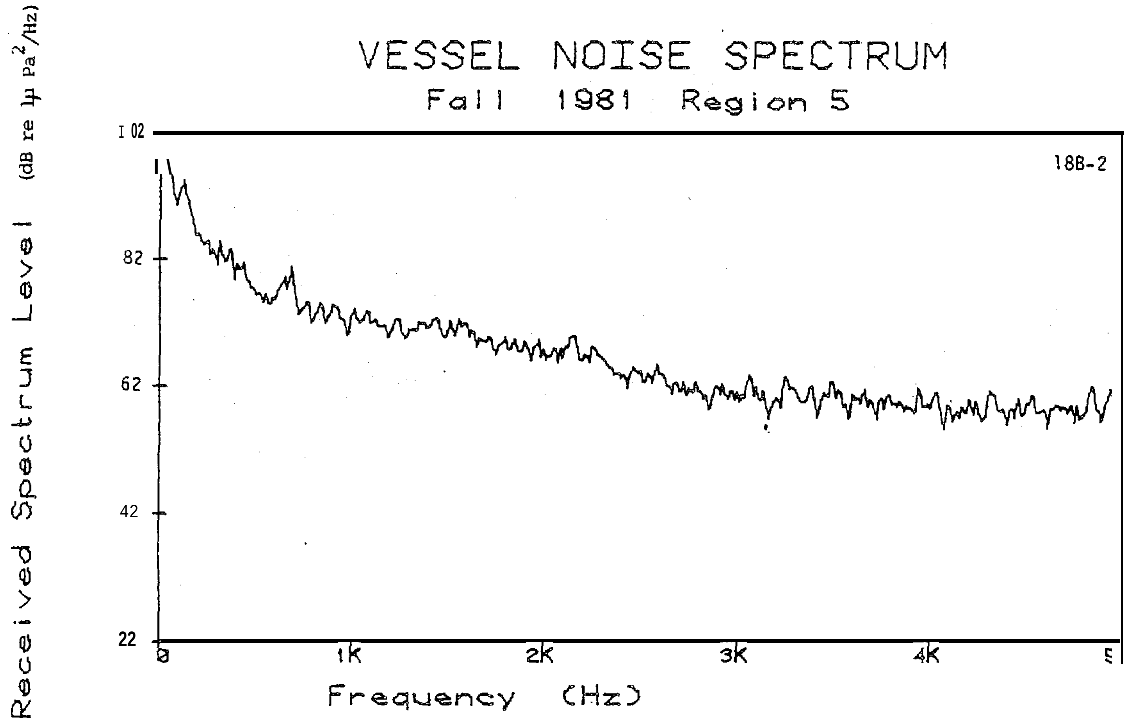




Date: 7/24/81
Location: 67 25.2N, 167 51 .4W
41B SB 975/7.5
Geo Vessel : Arctic Star
Distance: Approx 1.4 km
Sea state: BO1
[cc: 0/10
Depth: 42 m

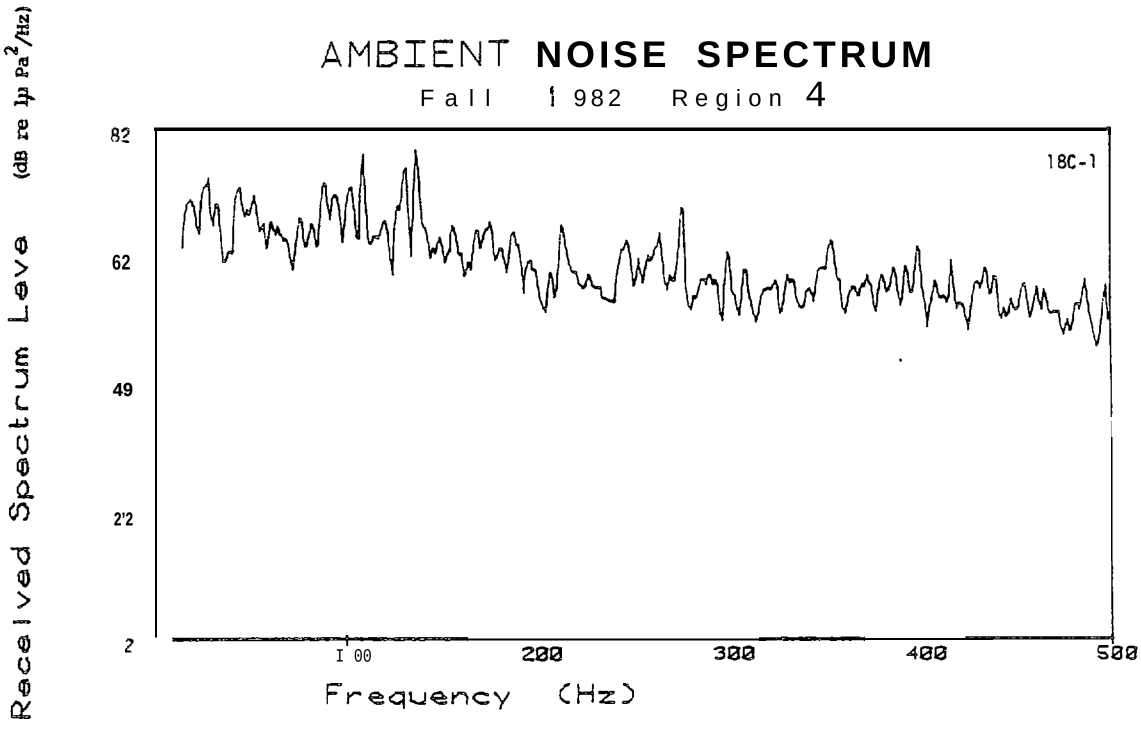
Figure 18A. Received engine noise spectrum levels from the Arctic Star, at 1.4 km.

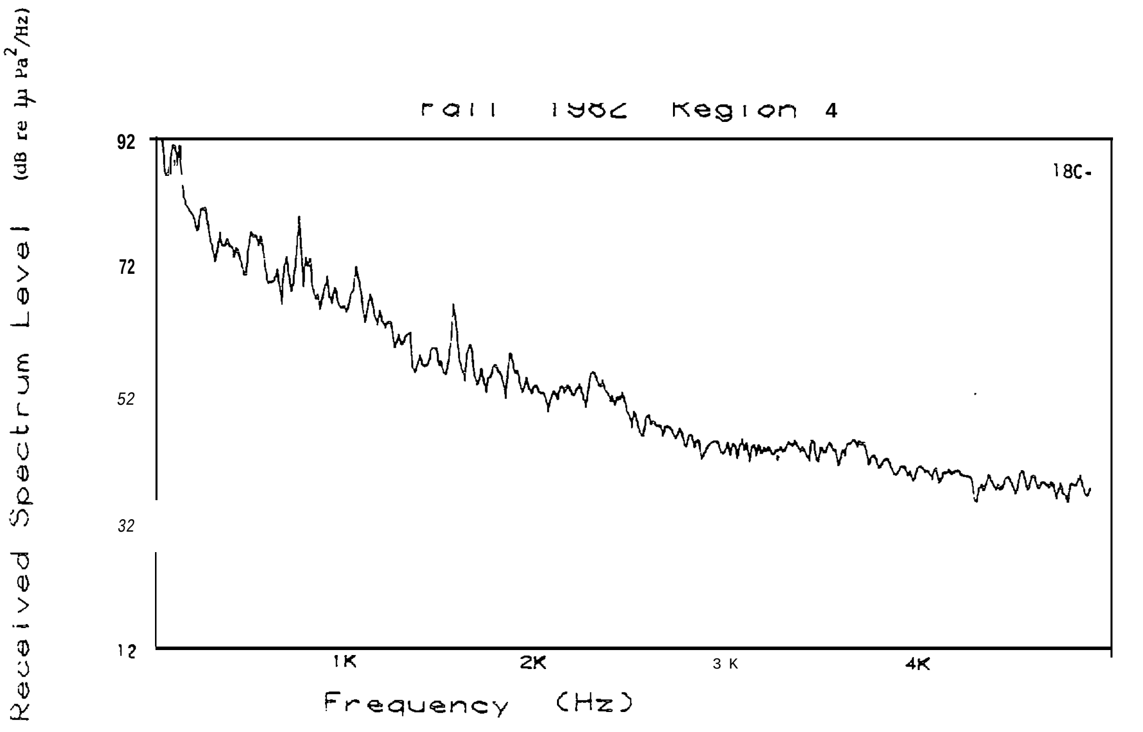




Date: **9/18/81**
SB Location: 70 42.8N, 142 26.9W
41B S6 972/2.0
Geo vessel : Mariner
Di stance: Approx **1.5** km
Sea state:804
Ice: 1/10
Depth: 400 m

Figure 18B (cont). Received engine noise spectrum levels from the Mariner at 1.5 km.

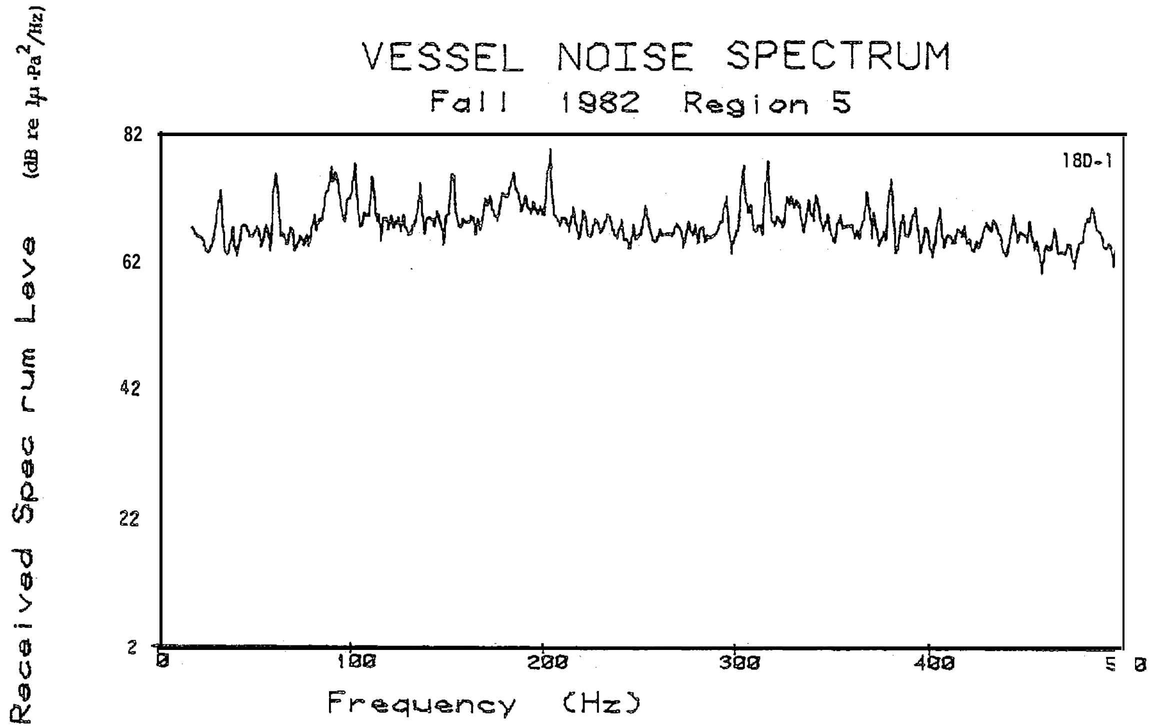


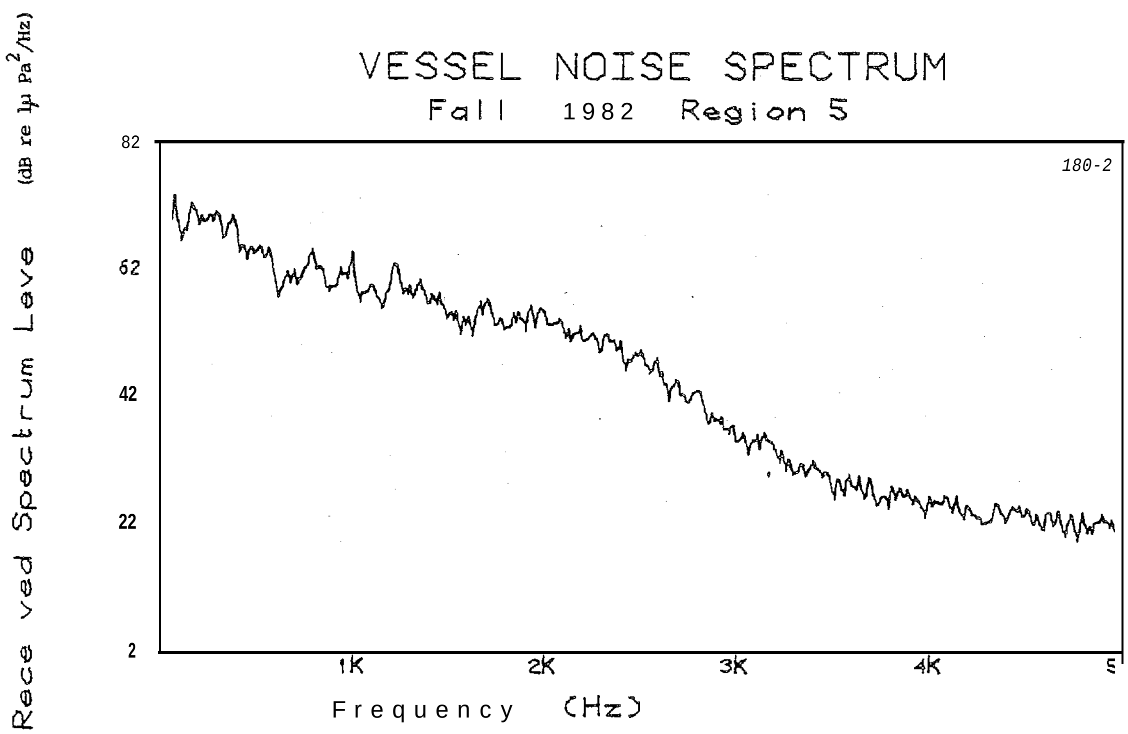


Date: 9/23/82
SB Location: 71 20. ON, 152 35. OW
41B SB 994/10.5
Geo vessel : Western Polaris
Distance: Approx 43 km
Sea state: 304
Ice: 0/10
Depth: 74 n

Figure 18C (cont). Received engine noise spectrum levels from the Western Polaris, at 43 km.

1





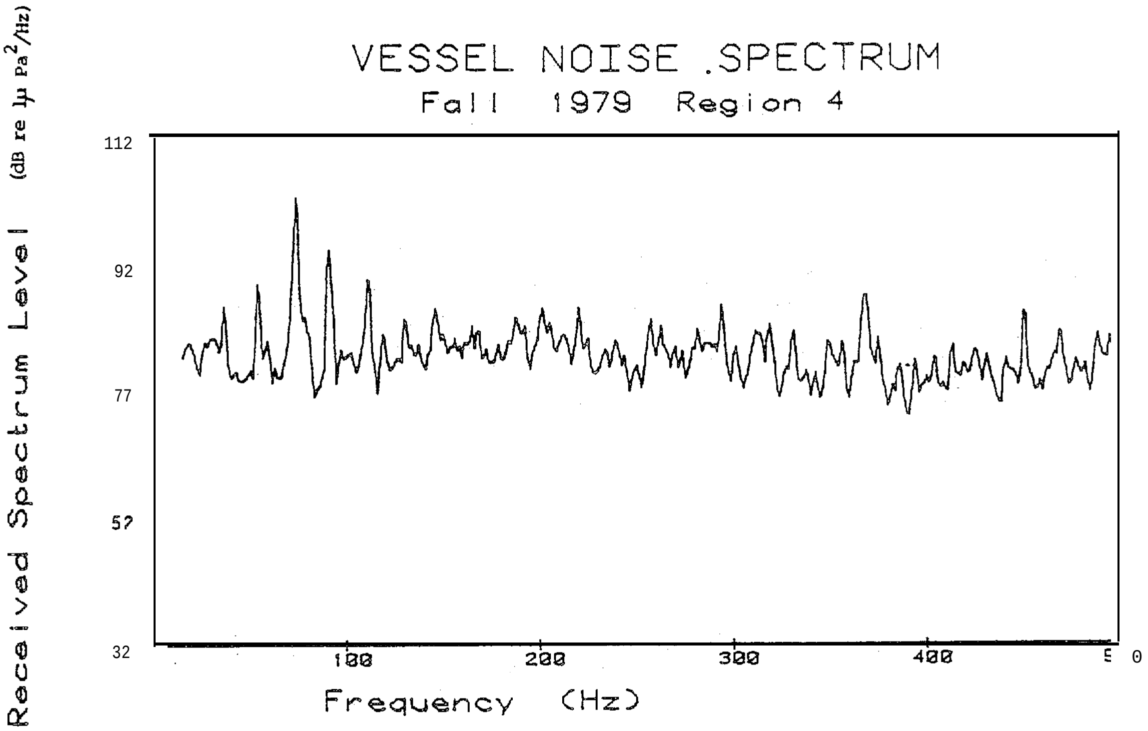
Date: 9/23/82
SB Location: 70 48.9N, 148 39.1 W
57A SB 679/4.9
Geo vessel: Western Aleutian
Distance: Approx 38 km
Sea state: 001
Ice: 0/10
Depth: SB=28 m
Depth: vessel=80 m

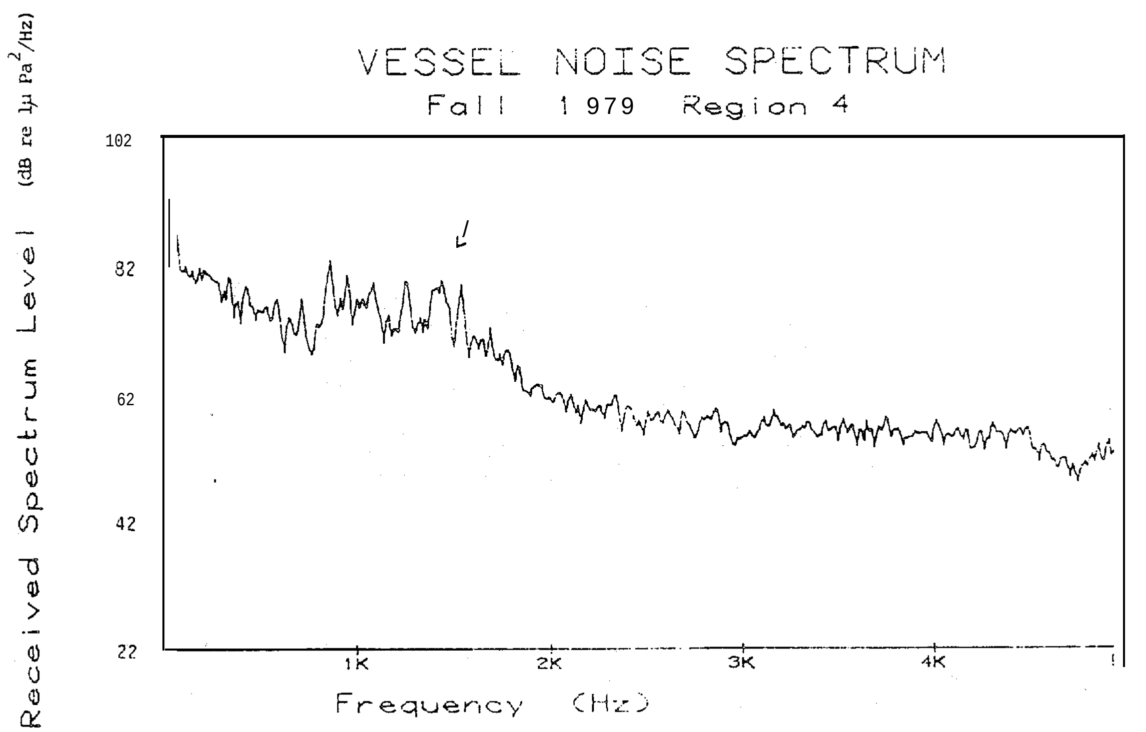
Figure 18D (cont). Received engine noise spectrum levels from the Western Aleutian, at 38 km.

and engine noise samples were captured between blasts. Tonal elements and harmonics are present in the spectrums from both vessels with fundamental bands at 111 Hz for the W. Polaris and 31 Hz for the W. Aleutian. Noise levels in the 500 Hz band were approximately 62 dB recorded 43 km from the W. Polaris, and 67 dB at 38 km from the W. Aleutian. These levels represent noise about -4 dB and +1 dB relative to ambient levels averaged by season in each region. Peak levels of harmonic and tonal elements were 78 dB and 80 dB, or approximately 12 dB to 14 dB above measured ambient level.

The roll off in the broadband engine noise spectrums was approximately -5.8 dB/octave for the Arctic Star in region 2, -9.5 dB/octave for the W. Polaris in region 4; and about -7.5 dB/octave for the Mariner and W. Aleutian in region 5. These slopes are comparable to those of the ambient noise spectrums indicating that engine noise is not dominant at higher frequencies, yet levels at 5 kHz ranged from -18 dB to +21 dB relative to measured ambient level at 5 kHz. Such variable levels at 5kHz may be a result of hand fitting roll off slopes to spectrums of widely diverging character, or to relatively small sample sizes.

The 500 Hz to 2000 Hz frequency band may be the most affected by cumulative effects of engine noise from geophysical vessels. Some increase in level in this frequency band is seen in the broadband noise spectrums depicted in Figure 18A-2 and 18D-2. The spectrum level of the combined engine noise of two geophysical vessels operating near to each other is depicted in Figure 19 and provides the best evidence of eievated levels. The recording was made on 26 September 1979, approximately 15 km from two geophysical vessels steaming on a parallel course about 1 km apart that were not firing airguns. Narrowband level was about 78 dB, approximately 12 dB above averaged local ambient levels. Tonal elements are apparent in the narrowband starting at about 36 Hz. These are represented as a single spike in the 5 kHz band. In the broadband spectrum there is a noticeable increase in level in roughly the 500 Hz to 2 kHz band. This broad maxima is centered roughly at 1200 Hz. The spectrum rolls off at about -8.0 dB/octave to 53 dB at 5 kHz.





Date: 9/26/79
SB Location: 70 32.0 N,148 39.9W
57A SB 268/6.5
Two Geo vessels
Distance: Approx 15 km
Sea state: 001
Ice: 0/10
Depth: Approx 20 m

Figure 19. Received spectrum levels from the combined engine noise of two geophysical vessles operating near (≤1 km) to each other at about 15 km range. Arrow indicates broad spectrum maxima between 500 Hz and 2 kHz, possibly due to cumulative engine noise effects.

Seismic Survey Sounds

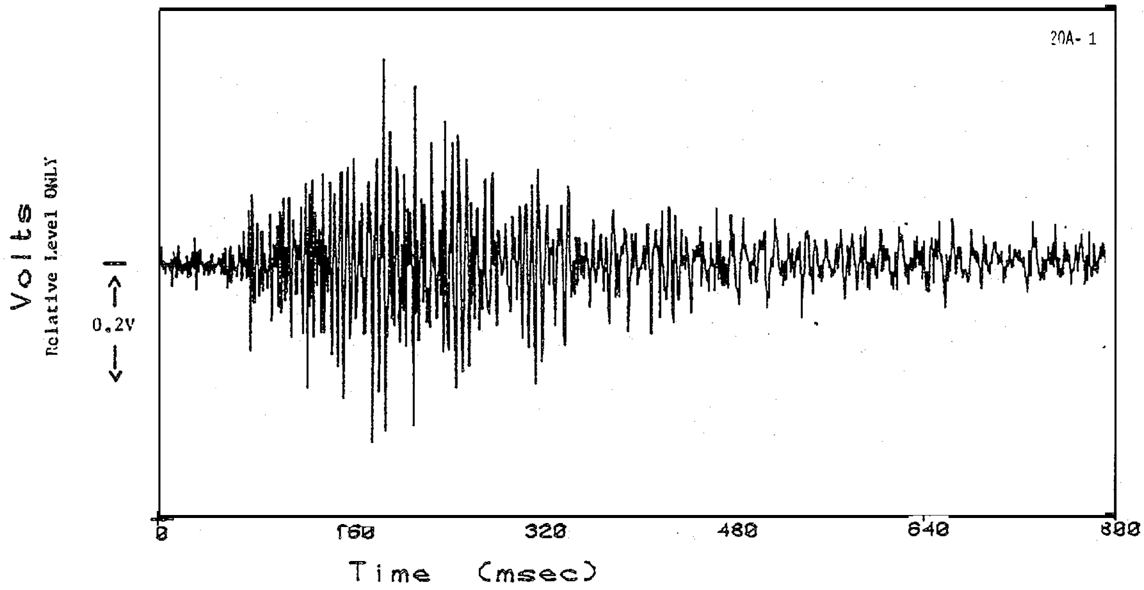
G   al vessels conduct seismic surveys each year in an effort to provide detailed maps of strata beneath the sea bottom to oil companies. Seismic surveys are conducted by towing an array of 12 to 24 airguns (signal sources) that produce loud (248 dB; Johnston, 1981) impulsive sounds focused vertically downward. The airgun array is towed 15 m to 30 m from the vessel's stern approximately 4 m to 8 m below the surface (e.g. Barger and Hamblen, 1980; Hoff and Chmelik, 1982). A 3000 m to 3600 m cable holding up to 24,000 individual hydrophones is towed behind the airgun array to receive the echoes from geologic formations beneath the sea floor in order to map their features.

Airgun sounds are the highest in level of the industrial sources and as such have been the focus of several studies seeking to investigate their possible effect on the behavior of bowhead whales. Airgun sounds have been recorded from active geophysical vessels since 1979. In 1982, during a study to assess the effects of airgun sounds on nearby bowheads, attempts to measure received levels of airgun sounds recorded at various ranges were made (Reeves et al, 1983). Upon analysing these signals, it was determined that sound pressure levels from the high-energy seismic sounds often resulted in system overloading and amplitude distortion due to the sensitivities of the available sonobuoys. It was found that the sonobuoys could measure sound levels to 136 dB at 50 Hz falling to 110 dB at 1 kHz. Many airgun sound samples exceeded this limit. To this end, samples in this report were chosen for presentation if we could reasonably assume the signal was not distorted due to proximity of the sonobuoy to the source. In the sonobuoy gain compensated spectra, the overload level was 110 dB for all frequencies (see Methods, p. 7). It is important to note that the details of the airgun arrays' geometrical configuration, orientation and movement are not known for any sound sample, though these physical parameters and the number of guns fired in any seismic sequence will strongly affect the value of source and received levels of the signals.

Time waveforms and corresponding spectra for three seismic sources are presented in Figure 20. The levels shown in time waveforms were not compensated for Nagra or sonobuoy response and are relative only (see Methods, p. 8). Distances from airgun array to sonobuoys were 37 km, 49 km and 67 km. The distance to the two nearest arrays was calculated when vessel position was obtained via overflight, while the 67 km range was calculated from a company

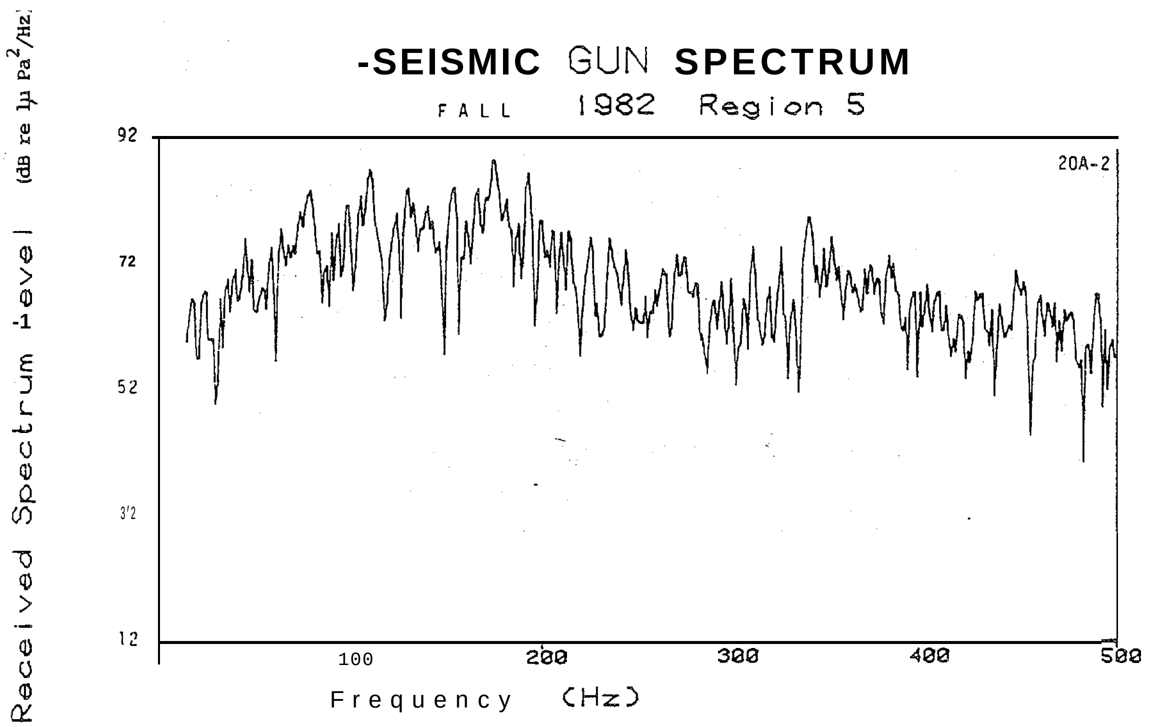
SEISMIC GUN TIME SIGNATURE

FALL 1982 Region 5



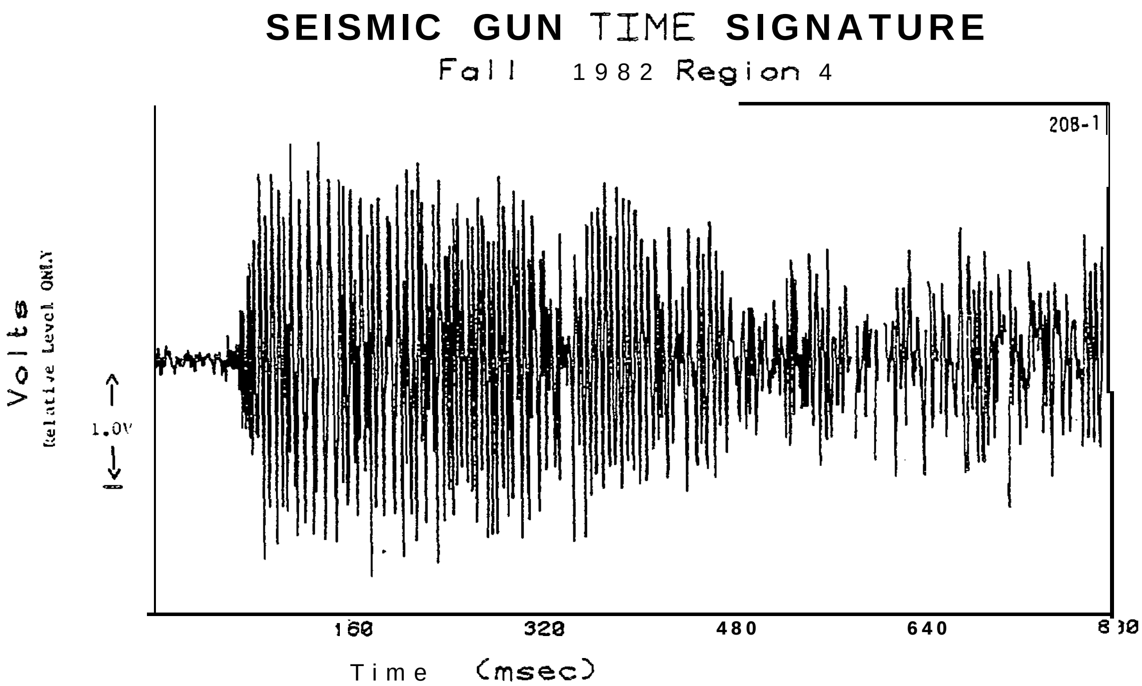
-SEISMIC GUN SPECTRUM

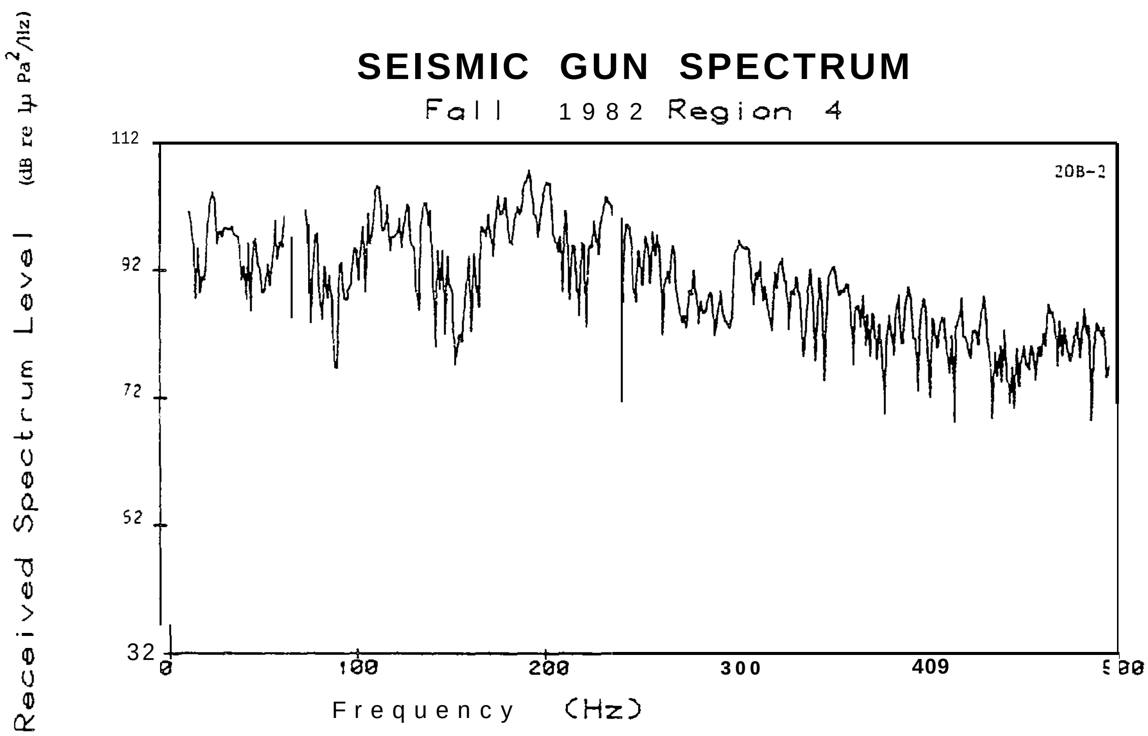
FALL 1982 Region 5



Date: 8/16/82
SB Location: 69 44.4N, 140 34.7W
41G SB 987/22.0
Canadian geo vessel
Distance: 37 km
Sea state: BO
Ice: 2-3/10
Depth: Approx 2000 m

Figure 20A. Time waveform and corresponding **spectrum of airgun sounds from the Mariner, at 37 km.**



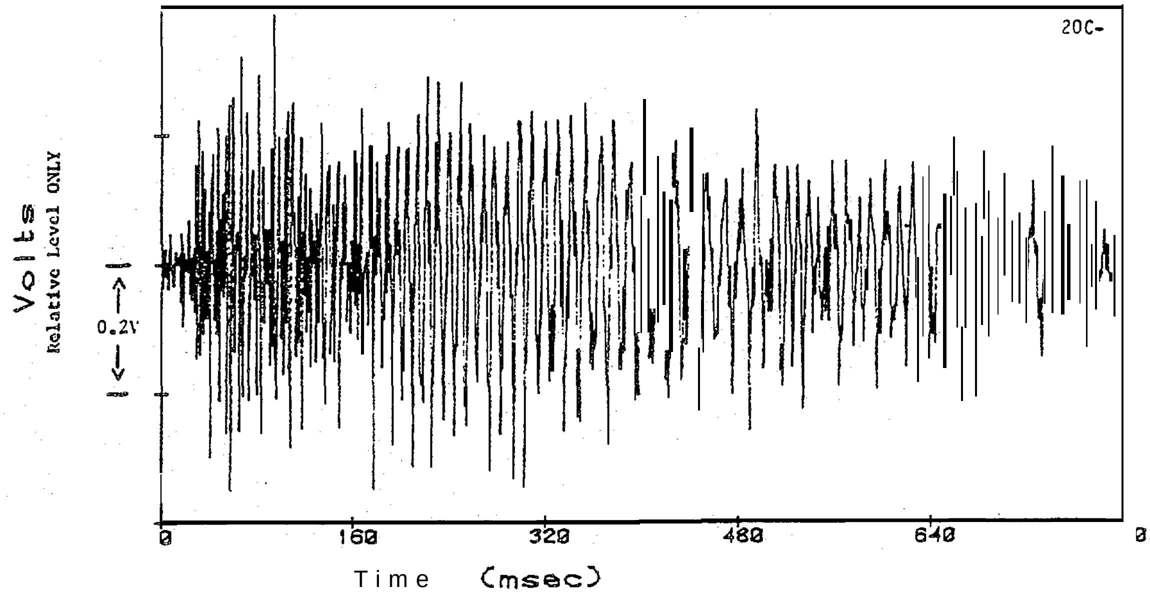


Date: 9/25/82
SB Location: 71 10.4N, 152 16. 9W
41B SB 995/13.0
Geo vessel : Krystal Sea
Distance: Approx 49 km
Sea state: 002
Ice: 0/10
Depth: SB=Approx 28 m
Depth: vessel=12 m

Figure 20B (cont). Time waveform and corresponding spectrum of airgun sounds from the Krystal Sea, at 49 km.

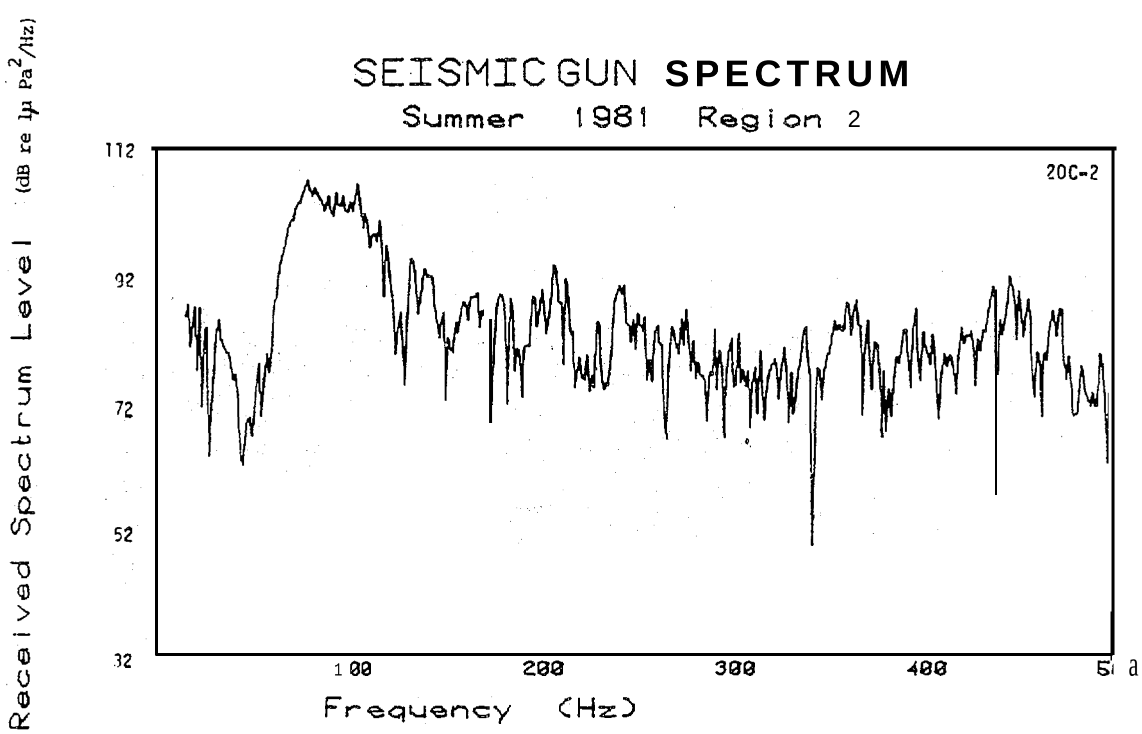
SEISMIC GUN TIME SIGNATURE

Summer 1981 Region 2



SEISMIC GUN SPECTRUM

Summer 1981 Region 2



Date: 7/8/81
SB Location: 68 18.9N, 166 48.9W
57A SB 645/4 .0
Unknown geo vessel
Distance: 67 km (coordinates from company)
Sea state : 0-2
Ice: 0/10
Depth: Approx 20 m

Figure 20C (cont). Time waveform and corresponding spectrum of airgun sounds from the Artic Star, at 67 km.

provided vessel position. Note the increase in the duration of pressure oscillation from the 37 km example (Figure 20A-1) to the 67 km example (Figure 20C- 1). The received signal length is approximately 340 ms at 37 km, shifts to about 480 rns at 49 km and is nearly 800 ms at 67 km. This stretching of the impulsive signal with distance was noted by Greene (1982) for signals recorded in the Canadian Beaufort Sea.

The peak sound levels and the frequency at which they occurred from the airguns recorded at 37 km, 49 km and 67 km were 89 dB at 174 Hz, 108 dB at 195 Hz and 107 dB at 79.5 Hz, respectively. The shape of the spectrums for each sample is somewhat different. The spectrums for the 67 km sample are dominated by a broad maximum between about 60 Hz and 1 20 Hz. This feature is not present in the spectrums of the shorter range samples. This trend is opposite that reported in Greene (1983, pp 236-239). In Greene's samples, spectrums from (relatively) nearby seismic signals show a dominant low frequency (S 150 Hz) component , while spectrums of samples recorded at increasing range show a shift to higher frequencies.

The peak levels and peak frequencies also present a confusing picture. Not only are higher levels recorded at (relatively) further distances, but emphasized frequencies are not those expected. High frequencies are usually attenuated more rapidly than lower frequencies, although in shallow water wave guide effects may attenuate low frequencies first. The effect of water depth confounds the comparison of airgun signals from 37 km (2000 m depth), 49 km (12-28 m depths) and 67 km (20 m depth). One might expect the peak frequency of the 49 km sample to be higher than the peak frequency of the 37 km sam pie, due to wave guide effects, yet the peak frequency recorded in shallow water at 67 km is much lower than that of the 49 km sample and does not reflect a similar emphasis of high frequency transmission in shallow water. Greene (1982) described impulsive seismic signals that became "chirp-like" with distance, with higher frequencies received first followed by a transition to lower frequencies. Greene (1982) states, "For a given range, high frequencies are emphasized first , then low frequencies, and the signal that began as an impulse appears as a chirp-like burst of energy." Figure 20C- 1 best shows this chirp effect that Greene describes. In short, our time waveform of airgun sounds recorded at furthest range (67 km) agrees with Greene's (1982) data, (i.e. the signal appears stretched, and high frequencies are emphasized first), but does not agree with Greene's (1983) spectral plots showing lower frequency emphasis at (relatively) closer range. Note that time signatures are from the signal at the sonobuoy, which is more sensitive at increasing frequencies (response is not flat).

The peak noise level of each airgun sample does not conform to expected levels calculated using standard transmission loss models and an assumed 248 dB source level. Array depth appears to play an important role in received airgun signal level (Malme et al, 1983). Airgun signals are produced relatively near the surface such that the sound reflected from the surface interacts strongly with the direct sound radiation paths. An interference pattern, known as the Lloyd mirror effect, is produced as sound reflected from the surface travels out of phase with -that of the sound source. This mirror effect is strongest in calm seas and at low frequencies. The interference pattern causes received level to fluctuate with range. When the source is less than ¼ wavelength from the surface, the source and reflected image become a dipole sound source with a vertical directionality of sin θ, where θ is the angle measured from the surface. The effect of this dipole source directivity has been shown to be an additional 10 log r energy loss added to expected signal transmission loss (i.e. 25 log r; Grachev, 1983). If the receiver is also less than ¼ wavelength in depth, an additional 10 log r is required to allow for the shallow receiver. The result for a shallow water source and receiver, assuming an initial shallow water spreading loss of 15 log r, is a 35 log r spreading loss model for airgun signals (see Malme et al, 1983 p. 5-4). If the 25 log r and 35 log r models are applied to the three distances at which airgun signals were recorded (37 km, 49 km and 67 km), calculated received levels bracket the measured peak spectrum levels, when a 248 dB source level is assumed.

It appears the source level of airgun signals in the horizontal plane may also be significantly affected by directivity. Airgun arrays are designed to optimize propagation of vertically directed low frequency sound. The horizontal directivity pattern of an airgun array was measured and found to have a substantial directivity index (DI) (Malme et al, 1983 p.5-23). The overall eff ect of strong signal directivity is to reduce expected source signal strength along the horizontal axis, and to expect a relatively strong pressure signature (side lobe) for the array at some angle (°x) off the broadside. This implies that receiver location and depth relative to the moving source (array) is critical to received level. The number, orientation and depth of airgun sources, and their movement relative to the receiver will also impact received level. For our present airgun sound samples, only approximate range and receiver depth is known. Malme et al, (1983) also suggest that the shift toward higher frequencies in airgun signals recorded with increasing range is primarily a directivity effect rather than a range dependent effect as previously discussed, and presented in Greene (1982). Clearly, additional measurements are needed to clarify airgun signatures and the expected transmission loss of their signals.

An example of airgun signal levels with local ambient measures is presented in Figure 21. The airgun levels are 20 dB to 25 dB above ambient with the vessel approximately 37 km away. Peak levels in spectra presented in Figure 20 ranged from 23 dB to 42 dB above ambient levels averaged by region/season. Without knowing more about source orientation and directivity, we may conclude that the peak level of airgun sounds above ambient levels remains high ($\leq$20 dB) 37 km to 67 km from the source.

Pipe Driving

On 2 October 1982 pipe driving sounds were recorded from a sonobuoy dropped approximately 1 km from Tern Island, a man made island near Prudhoe Bay in region 5. A time waveform and corresponding spectrum of these sounds is presented in Figure 22. The time plot shows the "bang" of the pipe driving to be a relatively loud transient signal. A one minute averaged spectrum of such signals shows a level of about 97 dB in the 50 Hz to 200 Hz band, with a slope of approximately -8.5 dB/octave to 52 dB at 1 kHz (Figure 23). Pipe driving levels appear to be 25 dB to 35 dB above ambient level at this close range. The source of the 400 Hz tone present in the ambient spectrum is most likely aircraft power pick up (audible tone to observers on aircraft).

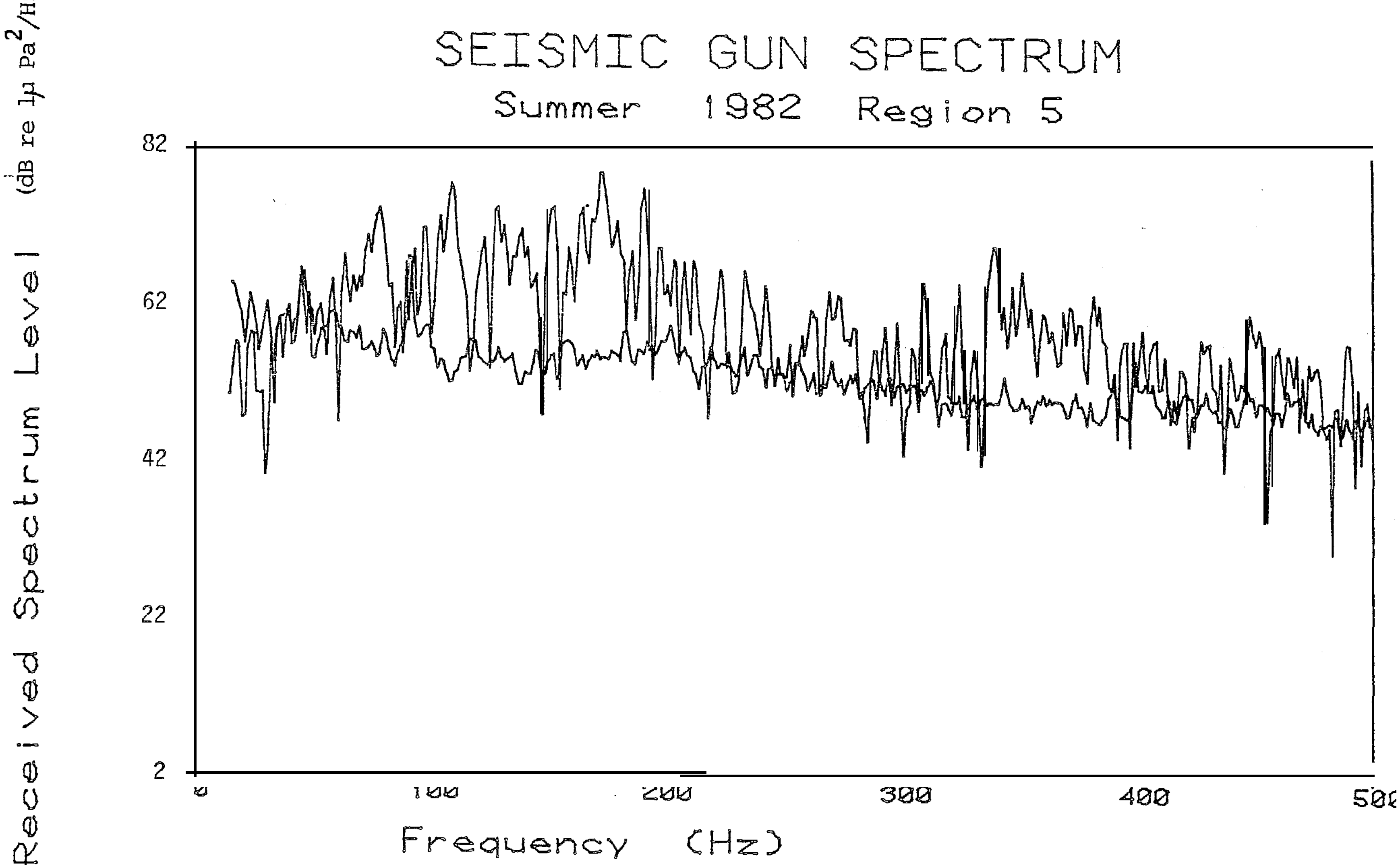
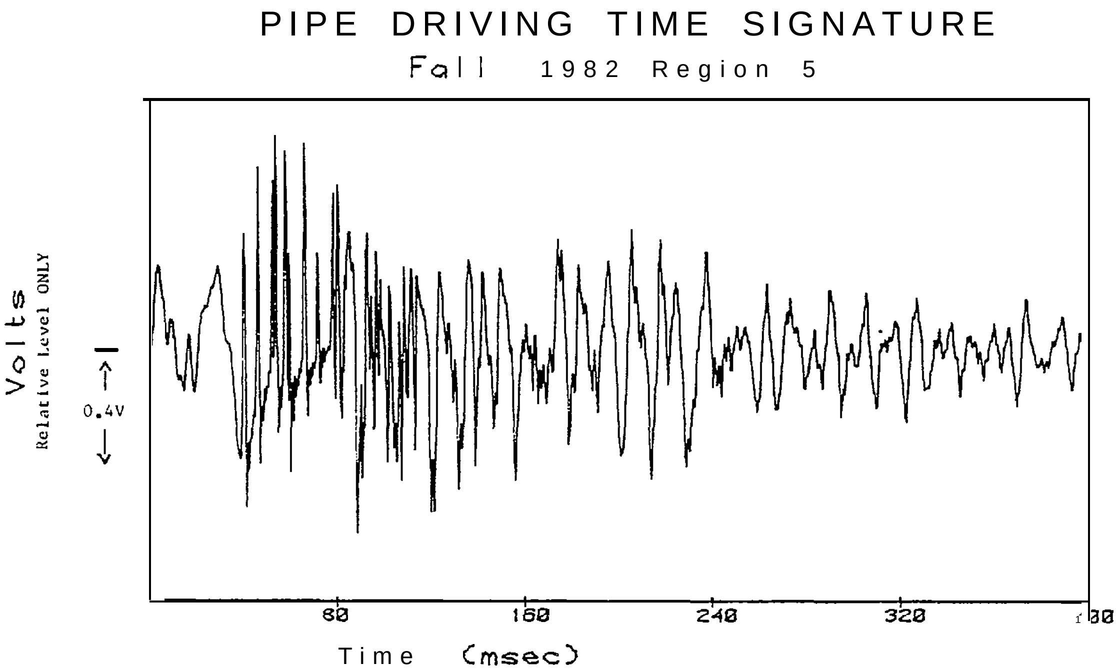
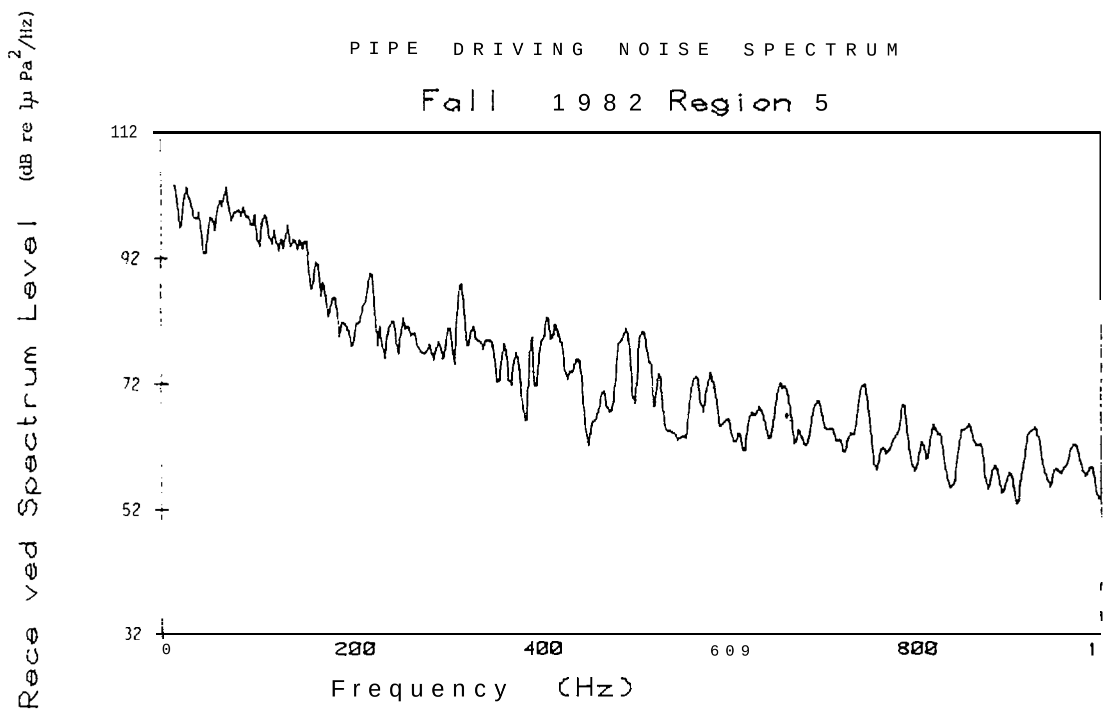


Figure 21. Received airgun signal spectrum level at 37 km, plotted with local ambient level.





Date: 10/2/82
SB Location: 70 16.8N, 147 30.5W
57A SB 5s4/20.5
Monitoring Tern island Pipe Driving
Sea state: 301
Ice: 2/10
Depth: Approx 4 m

Figure 22. Time waveform and corresponding spectrum of pipe driving sounds.

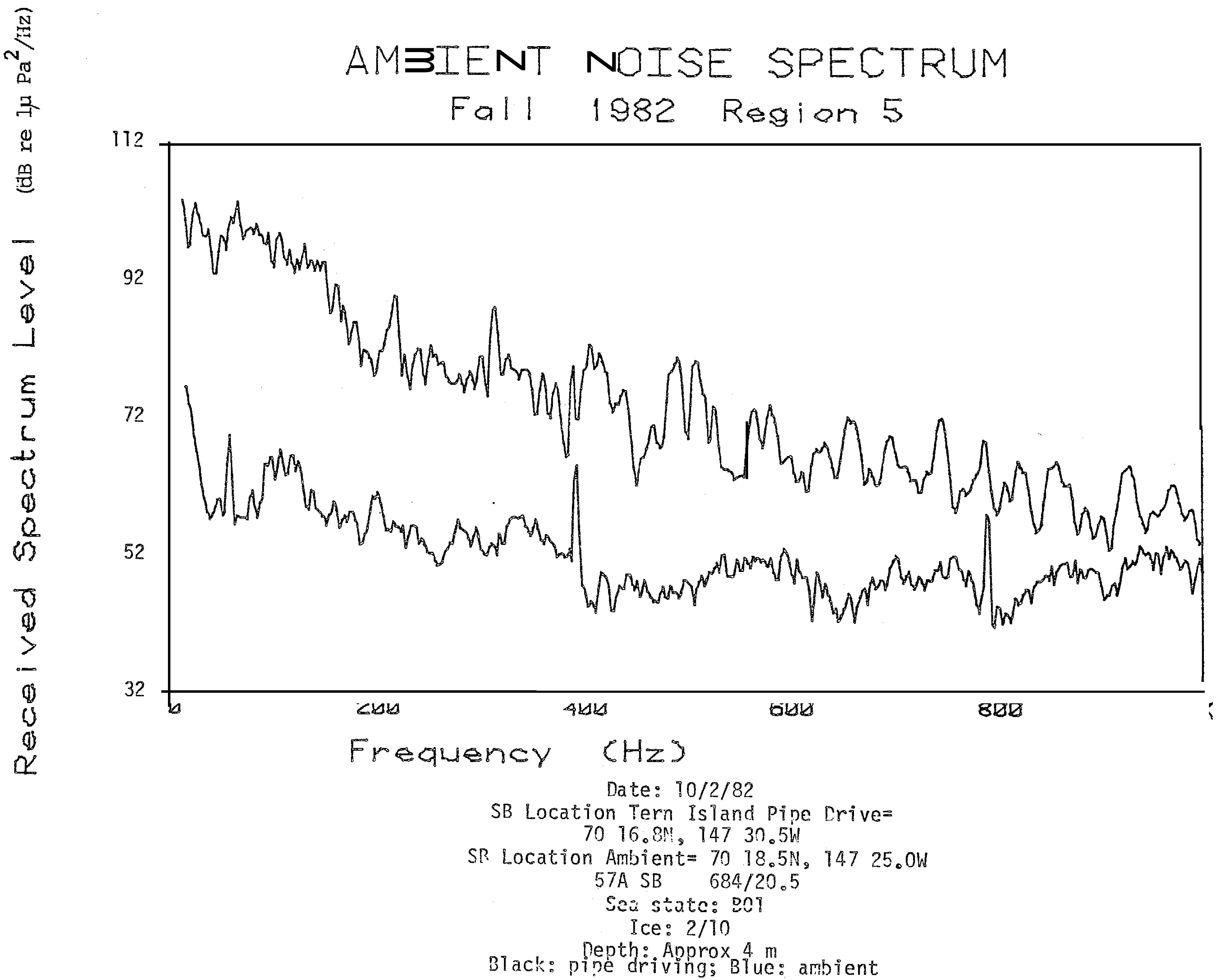


Figure 23. Received average spectrum of pipe driving noise and local ambient levels.

Biological Noise

Sonobuoys have been dropped most often over the years to record sounds produced by bowhead whales. Many hours of recording and a relatively large sample of bowhead sounds has been the result. A preliminary description of the types of bowhead sounds recorded is presented in Ljungblad et al, 1982b.

Sounds produced by belukha and gray whales, and bearded seals have also been recorded in the course of this study. All sounds recorded can not always be positively identified. Sounds produced by ringed or spotted seals, for example, may be recorded but remain unidentified on some tapes. We present here only a brief overview of the types of sounds produced by four species that experienced listeners can easily re-identify each time they are heard. Such identifiable sounds do not necessarily represent the full repertoire of the species. A summary of the identifiable sounds produced by each species will be followed by a brief presentation of seasonal and regional differences in their occurrence.

Bowhead Whale

Bowhead sounds may be tonal or pulsive in nature, sometimes with a combination of tonal and pulsive features in one call. Calls are most often produced in the 20 Hz to 2 kHz frequency band with some having energyto 4 kHz. Call duration is generally 0.5 to 3 s, and source level is thought to be between 175-180 dB. Most sounds are tonal, frequency modulated (FM) calls that have been termed simple moans if they contain little or no pulsive character. Such simple moans often have harmonic structure and may be further categorized by their temporal frequency modulation. Five categories of simple moans that have been used (Ljungblad et al, 1983 and 1984) for initial aural sound analysis are:

- FM_1: up - ascending frequency modulation
- FM_2: down -- descending frequency modulation
- FM_3: constant - no discernible frequency modulation
- FM_4: inflect - any combination of ascending and descending frequency modulation
- FM_5: high = short (0.5-1s) calls above 800 Hz

These categories are similar and comparable to those outlined for bowhead calls recorded in the Canadian Beaufort Sea reported in (Würsig et al, 1982). A spectrum and spectrographic example of a FM_1 (up) call is shown in Figure 24. Note that the spectrum plot is the frequency content over the captured signal time period (500 Hz = 800 ms) arid represents all frequencies and their levels present over that time only. The spectrographic plot presents the sounds' time history.

Sounds with a pulsive or amplitude modulated (AM) character have been termed complex moans. Two categories of complex moans that have been aurally recognized are:

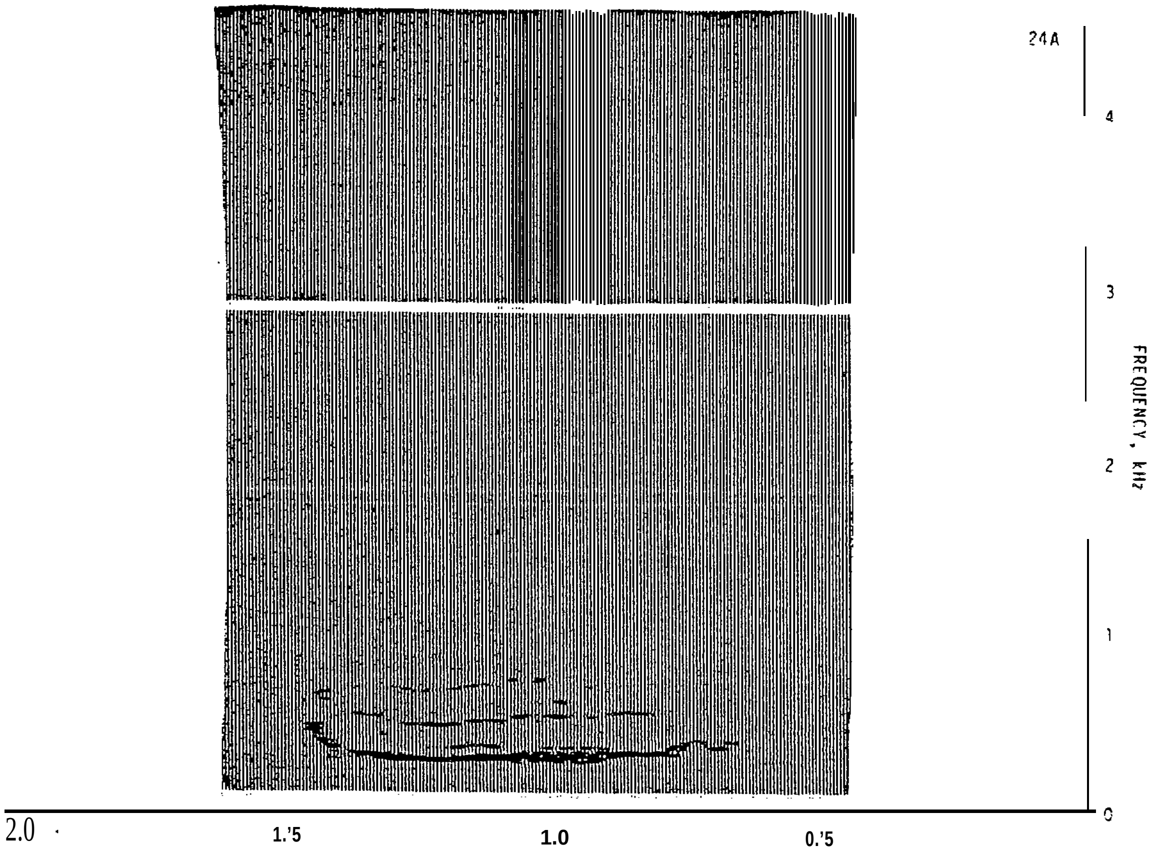
AM_1: growl - pulsive sounds with frequencies generally below 1 kHz

AM_2: trumpet - pulsive sounds with frequencies generally between 500 Hz and 4 kHz

Growls can (and do) grade into trumpets with a shift infrequency. Additionally, complex moans sometimes contain tonal AM components resulting from rapid amplitude modulation (Watkins, 1967). Aspectrum and spectrographic example of an AM_1 call is shown in Figure 25. Note that. this recording was made with a 41A sonobuoy, thus spectrum level is not absolute. An additional spectrographic example of an AM_1 sound appears in Figure 28.

Patterned sequences of bowhead calls have occasionally been recorded. A FM_1-AM_1-FM_4 series was reported in (Ljungblad et al, 1982b). A repetitive FM_1 -FM_1 series was recorded in spring of 1983, and a FM_1-FM_1-AM_1 series was noted in a tape recorded in fall 1983 (Ljungblad et al, 1984). Analysis of sequences of bowhead sounds is incomplete at this time.

Further analysis is needed to characterize the full repertoire of bowhead calls. A report of an unusual sound, possibly emitted by a bowhead, that was a 5 s series of broadband pulses with energy between 2 kHz and 8 kHz (Wursig et al, 1983) indicates that all sounds may not yet be classified. The classification scheme thus far implemented allows a seasonal tabularization of calls such as presented in Table 9. Such aural (i.e. based upon listener's hearing) call counts indicate that differential production of each call type does occur. Inferences can then be drawn when call types are correlated with observed behaviors. Generally, socializing animals (whales within a body length) appear to produce more AM calls, and swimming whales, or those that may be feeding, produce more FM calls (compare precentages Table 9).



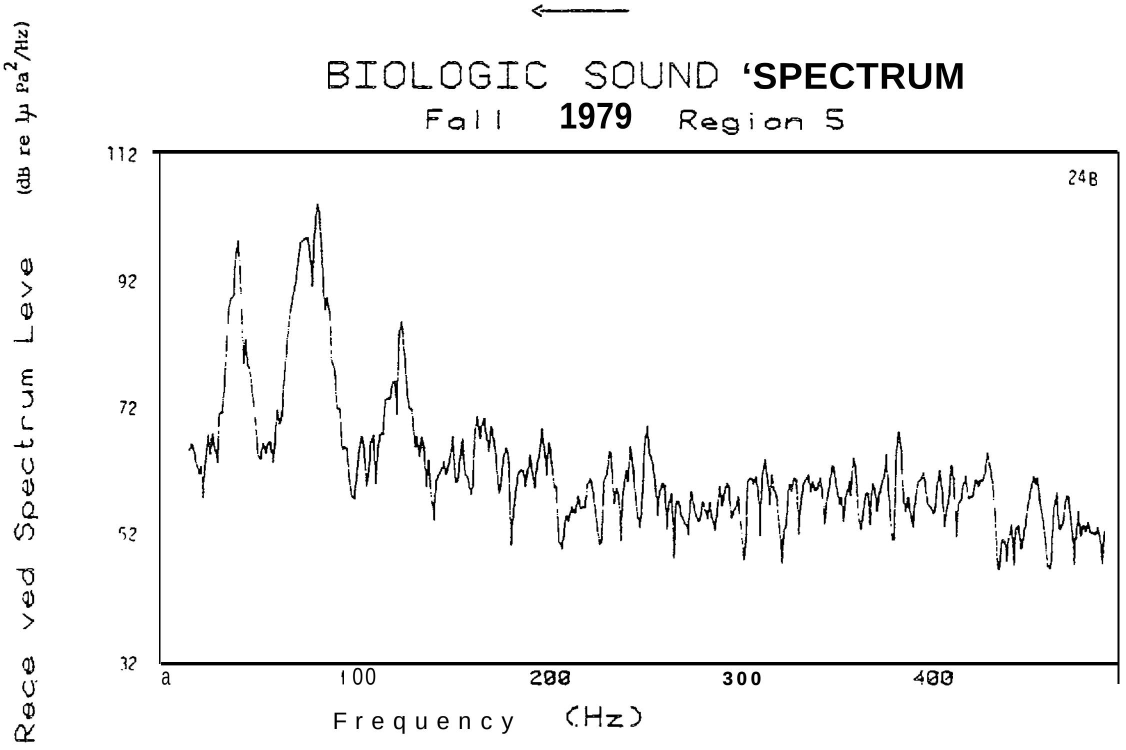


Figure 24. A spectrogrphic example (A) and spectrum (B) of a FM1 bowhead call.

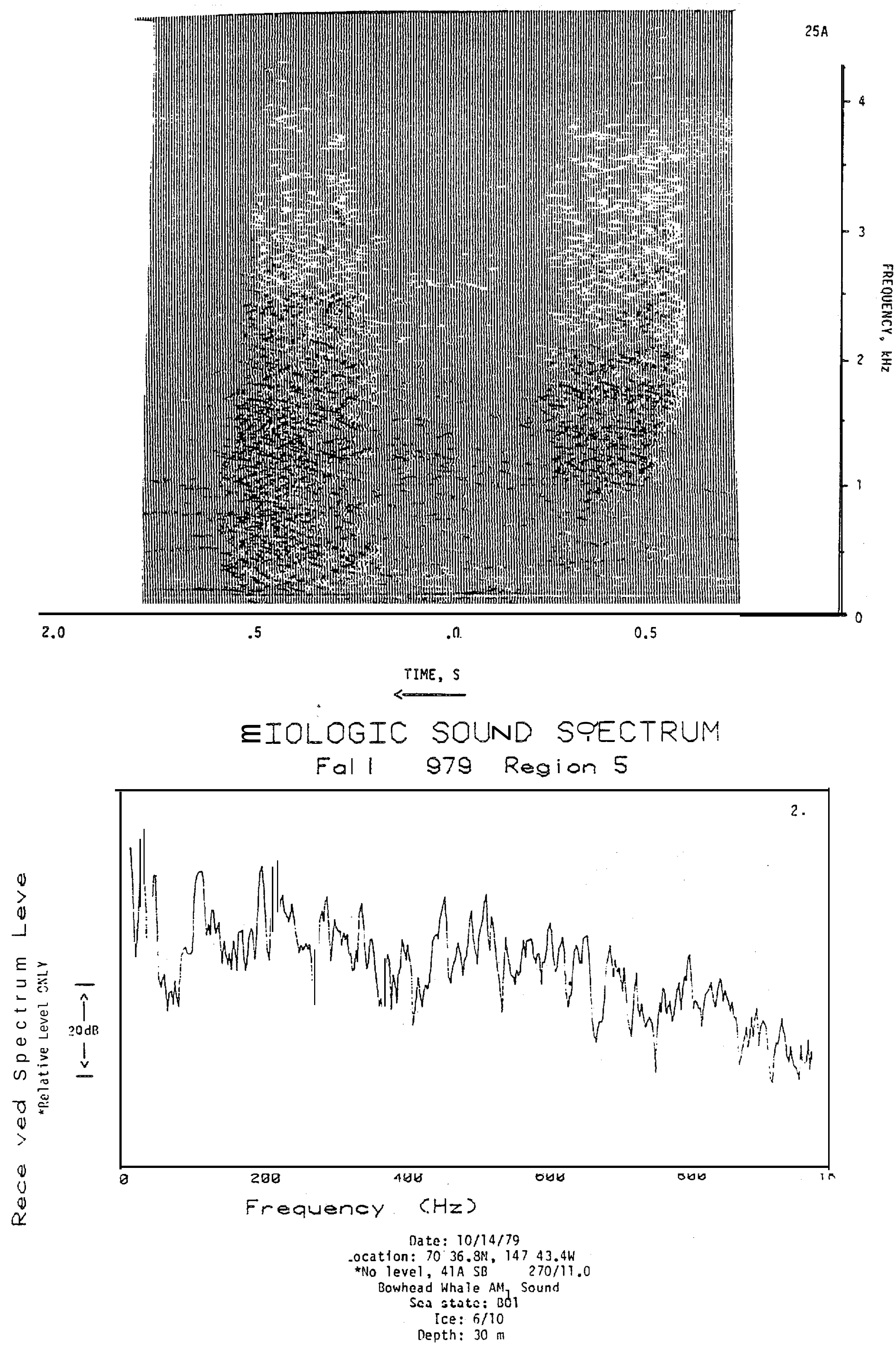


Figure 25. A spectrographic example (A) and a spectrum (B) of an AM_1 bowhead call.

Table 9. Results of initial aural analysis of bowhead sounds recorded in Spring 1982 and 1983. (BS = Bearded Seal; BE = Belukha Whale)

Year	Sample No.	Date	Sample Minutes Duration	Number Whales	Call Rate	General Behavior	Simple Up No./%	Simple Down No./%	Simple Const. No./%	Simple Inflect. No./%	Simple High No./%	Complex Growl No./%	Complex Trumpet No./%	N	Noise
1982	1	26 Apr	16"	28	0.08	Mild Social Swimming	8/23	4/11	-	-	3/9	16/46	4/11	35	BS, BE Aircraft
	2	29 Apr	22"	8	0.18	Mild Social Swimming	7/23	6/19	2/6	-	-	15/48	1/3	31	BE (100+) Aircraft
	3	3 May	51"	35	0.05	Swimming	40/42	18/19	9/9	7/7	4/4	18/19	-	96	BS, Aircraft
	4	4 May	95"	33	0.08	Mating, High Social	21/8	25/10	10/4	7/3	21/8	118/47	48/19	250	BS, BE, H_2O Noise
	5	5 May	36"	11	0.32	Swimming, Mild Social	15/12	19/15	4/3	5/4	3/2	52/41	29/23	127	BS, Aircraft
	6	13 May	58"	45	0.05	Swimming, Mild Social	28/22	13/10	12/10	4/3	-	61/49	7/6	125	BE (Good)
	7	14 May	35"	12	0.23	Mild Social	24/25	17/18	10/11	8/8	-	32/34	4/4	95	BE, Distant
		TOTAL	**307"**			**Mating, Swimming**	**143/19**	**102/13**	**47/6**	**31/4**	**31/4**	**312/41**	**93/12**	**759**	
1983	8	30 Apr	15"	4-7	0.12	1 Mating Pair, 2 Whales Swim Toward Pair	1/10	1/10	-	2/20	-	4/40	2/20	10	Aircraft
	9	1 May	20"	5-10	0.14	2 Mating Pair, Breach Tail Slap Swimming	3/14	6/29	-	3/14	-	8/38	1/5	21	Aircraft, H_2O
	10	2 May	50"	15-30	0.28	3 Mating Pair, Paired Swimming, Swim Toward Pair	143/51	15/5	-	9/3	2/1	109/39	4/1	282	Aircraft
	11	4 May	25"	3-4	0.39	1 Mating Pair Swimming	9/26	7/21	-	1/3	-	17/50	-	34	
	12	10 May	35"	4-7	0.20	1 Mating Pair Swimming	2/5	9/24	1/3	5/13	-	21/55	-	38	Aircraft
		TOTAL	**145"**			**Mating, Swimming, Displaying**	**158/41**	**38/10**	**1/0.5**	**20/5**	**2/1**	**159/41**	**7/2**	**385**	

Table 9 (co 'd Results of initial aural analysis of bowhead sounds recorded in Fall 1982 and 1983.
(BS = Bearded Seal; BE = Belukha Whale)

	Sample No.	Date	Sample Minutes Duration	Number Whales	Call Rate	General Behavior	Simple Up No./%	Simple Down No./%	Simple Const. No./%	Simple Inflect. No./%	Simple High No./%	Complex Growl No./%	Complex Trumpet No./%	N	Noise
	13	2 Aug	16"	4	0.41	Resting, Milling, Mild Social	6/23	3/12	-	2/8	5/19	5/19	5/19	26	Aircraft
	14	7 Aug	28"	10	0.04	Milling	5/50	3/30	2/20	-	-	-	-	10	
	15	8 Aug	40"	19	0.10	Milling, Mild Social	9/12	15/19	10/13	4/5	14/16	16/21	10/13	78	3 Slaps
	16	15 Aug	34"	20	0.12	Milling, Mild Social	28/34	6/7	12/15	3/4	17/21	2/2	14/17	82	1 Slap, Aircraft
	17	16 Aug	35"	14	0.08	Milling, Mild Social	4/12	9/3	2/6	-	4/12	19/58	3/9	41	Geophysical Boat (Distant)
	18	18 Aug	30"	9	0.14	Social Milling	21/57	1/3	13/35	-	1/3	1/3	-	37	Aircraft
	19	14 Sep	42"	1	3.40	Resting	24/17	16/11	8/6	15/10	17/12	17/12	46/32	143	None
	20	15 Sep	60"	32	0.14	Milling, Mild Socia	70/25	63/23	32/12	58/21	11/4	27/10	16/6	277	BS
	21	16 Sep	90"	60	0.19	Social Feeding, Milling	175/17	364/36	60/6	198/20	55/5	102/10	60/6	1014	Geophysical Boat (Distant)
	22	24 Sep	50"	133	0.05	Social Feeding	69/21	64/19	29/9	56/17	40/12	12/4	60/18	330	None
	23	25 Sep	10"	0	0	Unknown	-	6/100	-	-	-	-	-	6	
		TOTAL	435"			Milling, Feeding	411/20	550/27	168/8	336/16	164/8	201/10	214/10	2044	
1983	24	2 Aug	10"	3	0.93	2 Social Display, 1 Swimming	-	-	-	-	6/21	14/50	8/29	28	
	25	9 Aug	11"	6-8	0.05	2 Social Swimming	-	-	-	-	1/25	3/75	-	4	Airgun, Faint Aircraft
	26	21 Sep	16"	2	0.75	Social Nurture	3/12	5/21	-	-	-	16/67	-	24	Faint Aircraft
	27	26 Sep	6"	2	1.08	Swimming	8/62	2/15	-	1/8	-	2/15	-	13	Faint Aircraft
	28	2 Oct	88"	5	1.55	Social Nurture, Swimming	184/27	104/15	6/	156/23	8/1	203/30	23/3	684	Aircraft
	29	14 Oct	4.5"	3	1.62	2 Social Display	6/27	6/27	-	5/23	-	5/23	-	22	Aircraft
		TOTAL	135.5"			Swimming, Nurturing	201/26	117/15	6/1	162/21	15/2	243/31	31/4	775	

Würsig et al, (1982) have attempted to interpret the biological significance of bowhead call types by comparing them to similar work done on southern right whales (Eubalaena australis) (Clark, 1983). Such comparisons, if done carefully, as well as correlations of sounds with behavior in cases where behavior was closely observed, may yield a more specific guide to bowhead calls making them a valuable assessment tool.

Belukha Whale

Belukhas, or white whales, produce a wide variety of calls that have been described as clicks, whistles, yelps, rasps, blares, squawks, bangs and trills (Fish and Mowbray, 1962). All such sounds have been recorded near belukhas during surveys, but few have been analysed. Most sounds recorded by sonobuoy are calls produced by a group of belukhas as they pass the hydrophore. These samples often consist of a cacophony of sounds composed of simultaneous production of three or more of the call types as onomatopoetically described above. Frequency and amplitude modulated sounds are produced in approximately the 1 kHz to 25 kHz range (i.e. the upper limit of our recording gear). The source level of such sounds is virtually impossible to determine in the field. Studies on captive animals indicates that cetaceans may be able to control the level of the echolocation click sounds they produce (Moore, 1983).

One unusual belukha recording made on 6 April 1981 was of an echolocation or click train produced by a belukha (assumed) that was over one minute long. We assume this whale was investigating the hydrophore as the sounds start and stop suddenly and appear to be strongly directed. Another unusual recording was of a "peep" sound that seemed to be produced by a lone belukha. A spectrum of this sound is depicted in Figure 26 though absolute level is unknown as the recording was made with a 41A sonobuoy. Note the fundamental at 787.5 Hz with two harmonics. A spectrographic example of an (assumed) belukha echolocation series appears in Figure 28.

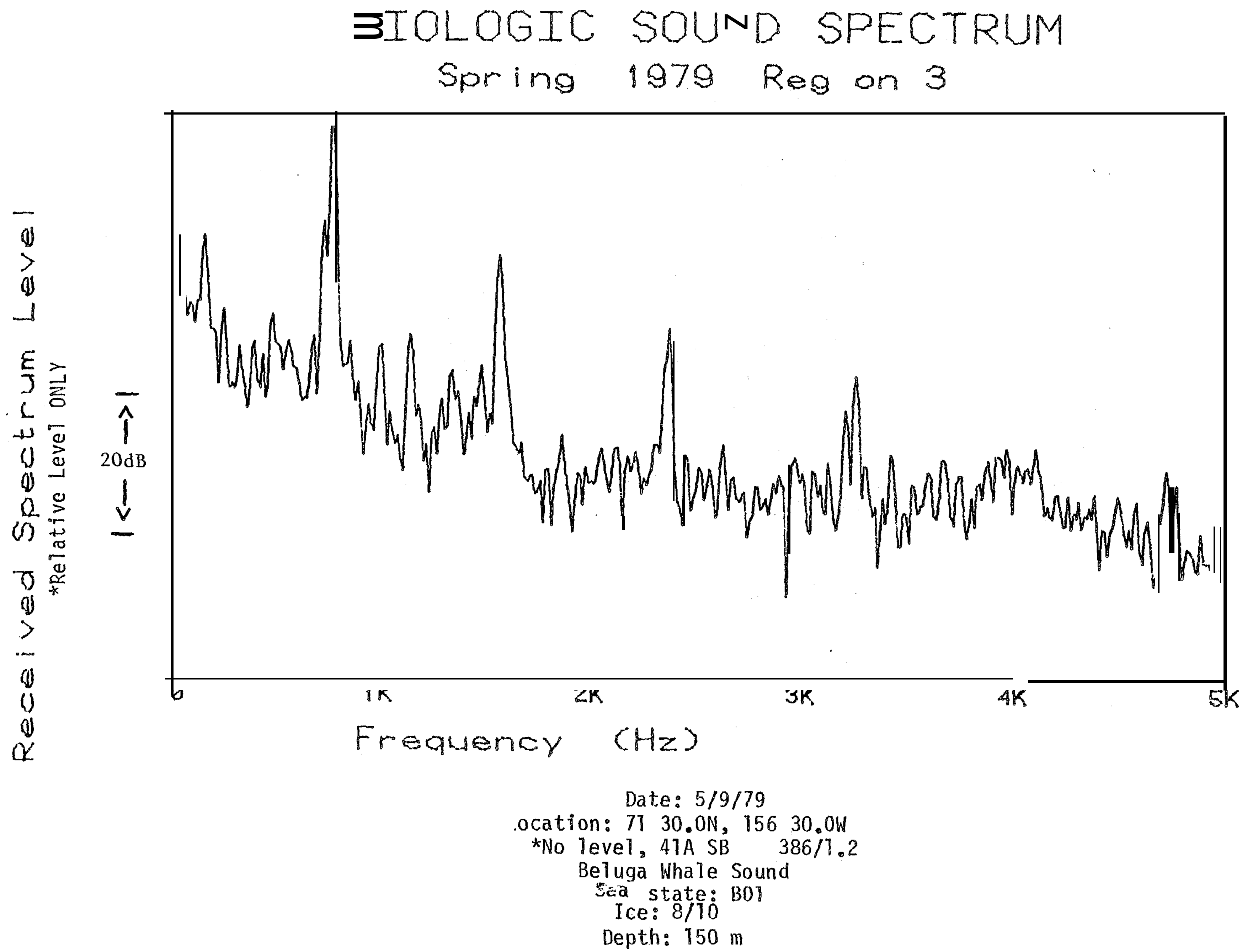


Figure 26. Spectrum of belukha whale "peep" sound.

Gray Whale

Gray whales produce pulsed and tonal sounds that are 0.3 s to about 3 s long, in roughly the 90 Hz to 4 kHz frequency band. Reported source level is 138 to 152 dB (Cummings et al, 1968). Dahlheim and Fisher (1983) reported that gray whales in their breeding lagoons appear to alter the level of sound produced in response to sound playback trials. Sounds have been recorded near feeding grays in the northern Bering Sea during aerial surveys and categorized into four types designated:

- N1: knock - metallic-sounding pulses, usually emitted in series (or bursts); most prevelant sound and most varied in frequency and time
- N3: moan - tonal FM sound
- N4: belch - pulsive AM sound
- N 6: underwater blow - explosive sound

Sound types N 1-N4 are described in Moore and Ljungblad (1984). The N6 type sound was recorded for the first time in the Bering Sea in July of 1983 and is described in Ljungblad et al (1984). The numbering scheme for the types of sounds produced by grays is after Dahlheim et al (1984). A spectrographic example of N 1, N 3 and N 4 gray whale sounds is presented in Figure 27.

Bearded seal

Bearded seals produce a distinct call often referred to as a trill. The trill is the only sound that has been positively associated with bearded seals during this study . Calls we have measured are long (1-5 s), modulated sounds usually descending in frequency beginning at about 2 kHz and ending around 300 Hz. Stirling et al 1983) reports that trill duration ranges from less than 1 s to 73 s, with a maximum frequency range from 750 Hz to 6 kHz, and a minimum frequency range from 500 Hz to 2000 Hz. The degree of modulation and frequency slope often varies greatly between trills. We have occasionally recorded trills that ascend in frequency.

Trills are predominantly heard in spring (recorded once in September) anti are thought to be produced by male seals during courtship (Ray et al, 1969). A spectrographic example of a bearded seal trill is presented in Figure 28.

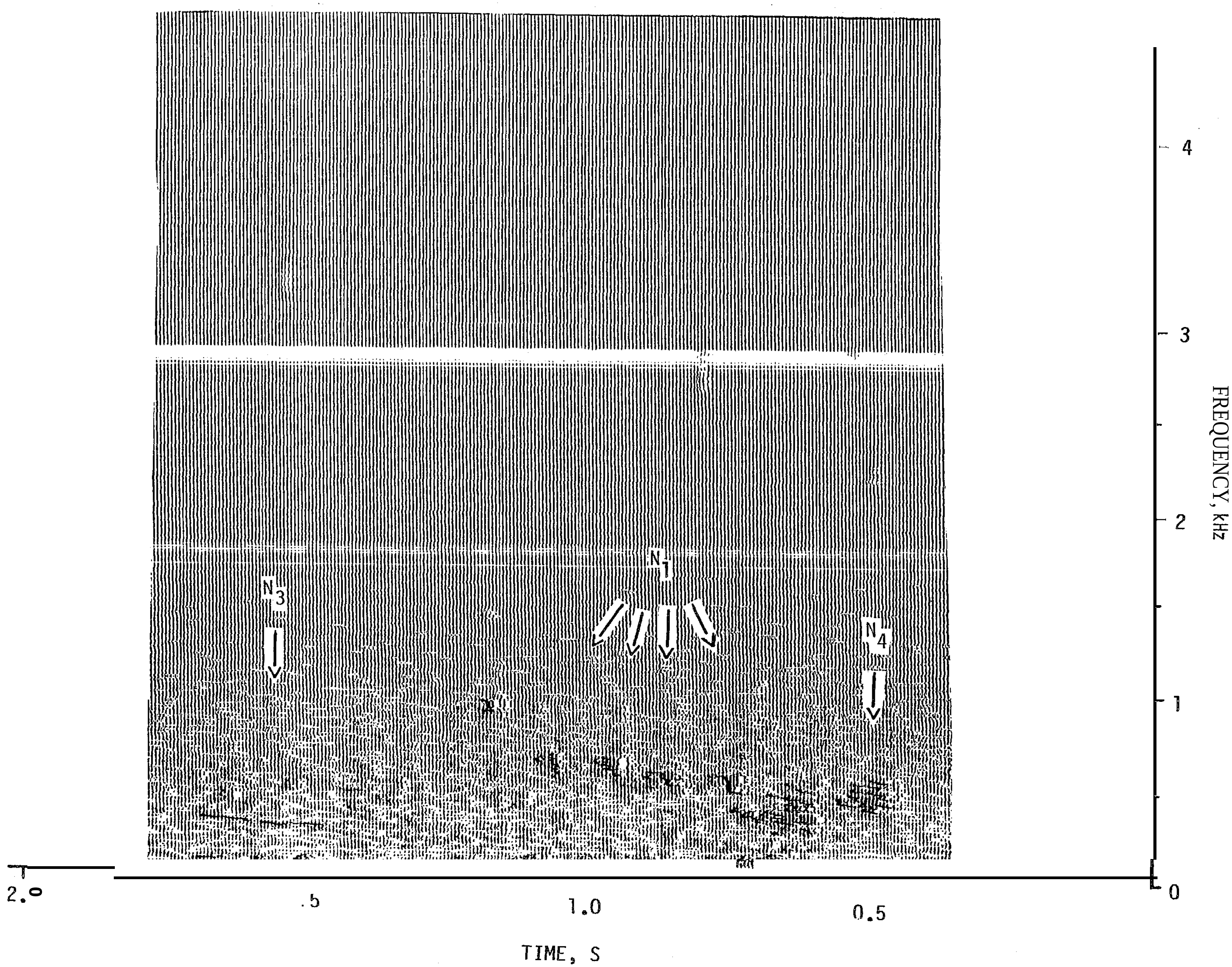


Figure 27. Spectrographic example of gray whale N_4, N_1 and N_3 sounds.

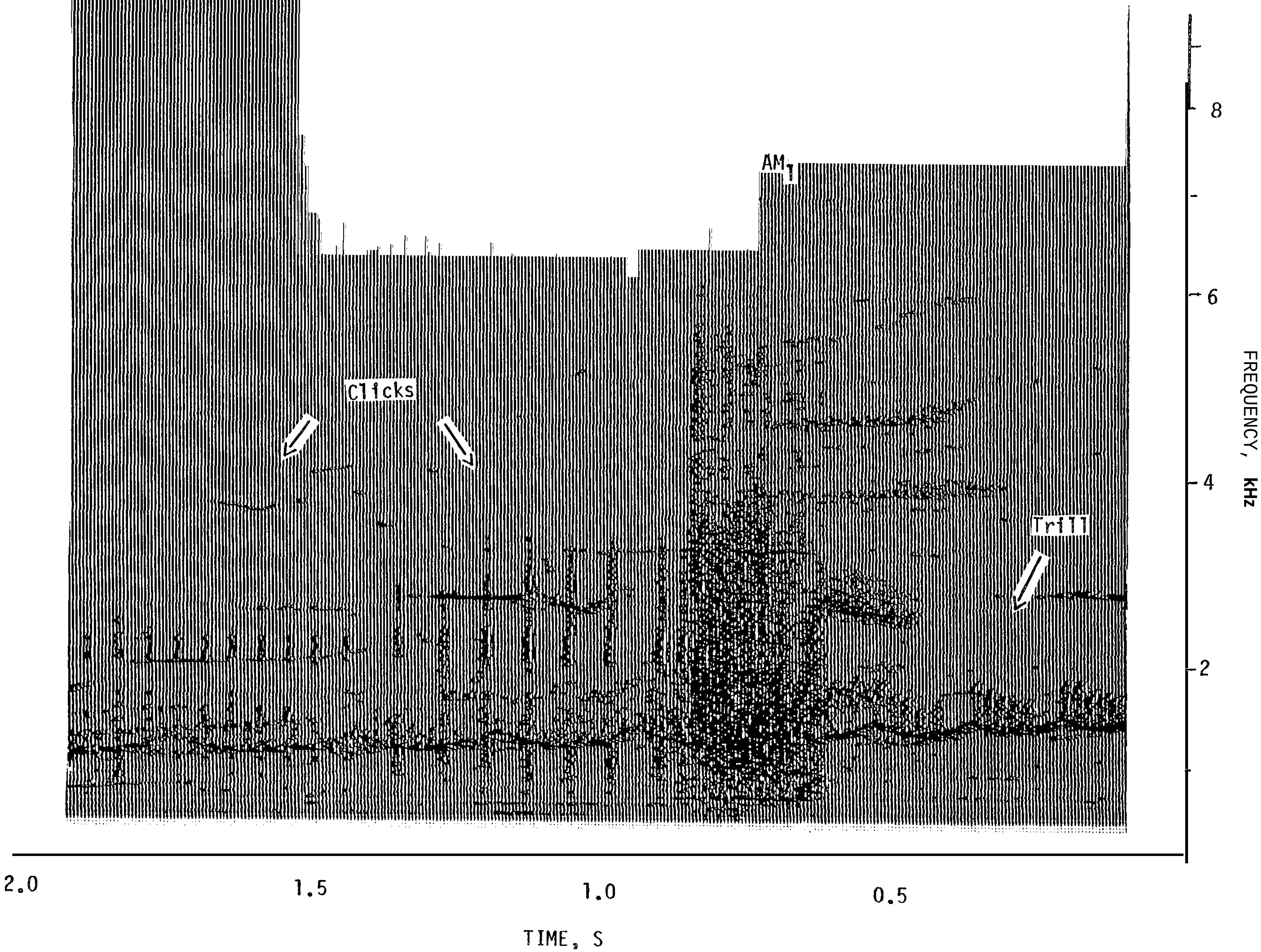


Figure 28. Spectrographic example of the trailing portion of a bearded seal trill. A bowhead AM_1 type call and some belukha echolocation clicks are also shown.

Seasonal and Regional Variations

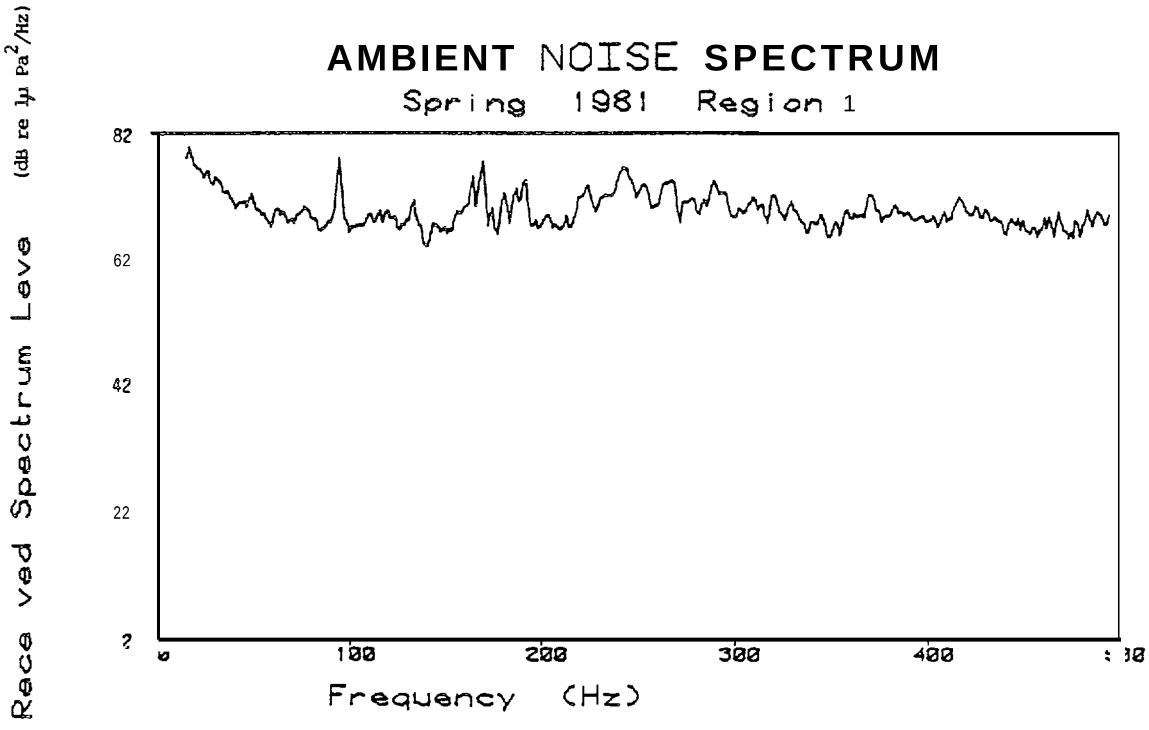
Spring recordings are usually "full" of biological sounds. Most recordings during spring are made in regions 1 and 3, reflecting our primary task of monitoring the bowhead migration in these areas. Recordings from these regions often consist of sounds simultaneously produced by bowheads, belukhas and bearded seals. The calls of one species often mask those of another and isolating calls is sometimes impossible. A 45 s average of audible biological sounds recorded in region 1 during spring is presented in the spectra of Figure 29. Note that the average narrowband level of 71 dB is actually below the calculated average for this region during spring. We surmise that biological sound, though not distinct on portions of tape analysed for ambient noise in spring, may have contributed heavily to the levels measured. In spring, regions 4 and 5 are often so completely covered by ice that sonobuoys can not be successfully deployed, thus few recordings are made there. "

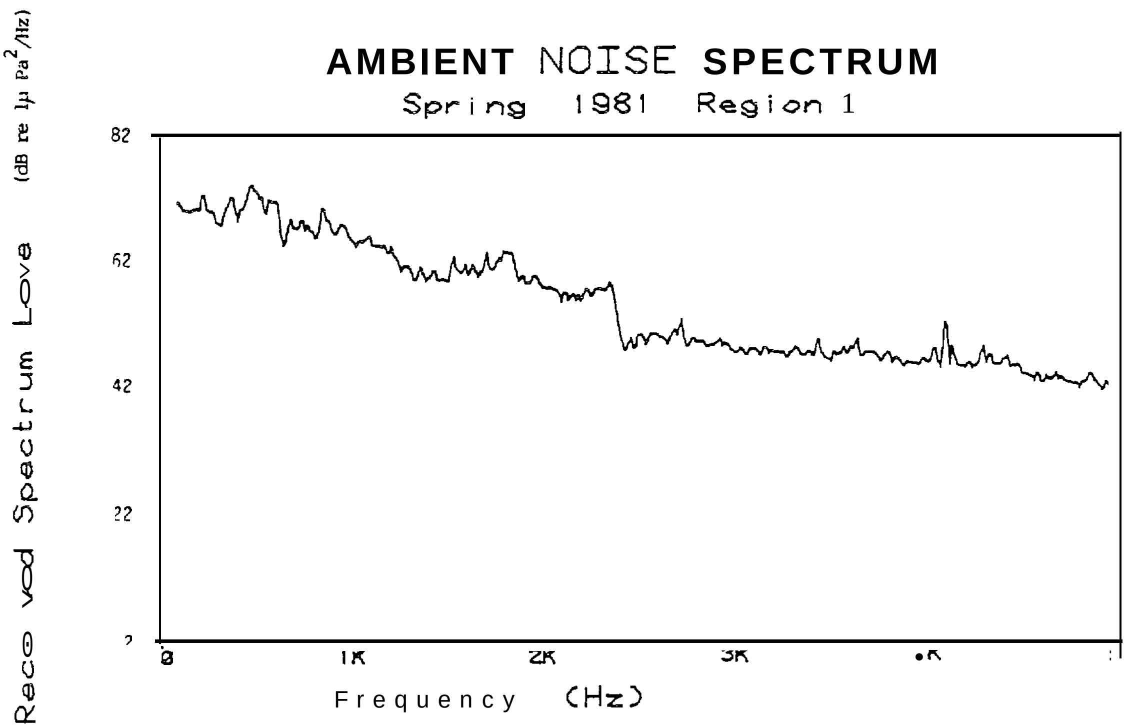
In contrast, fail recordings are generall y "quiet". Bowhead sounds are frequently recorded in regions 4 and 5 as the fall migration is monitored across Alaska's north slope. Belukha 'are occasionally recorded, bearded seals almost never.

Related Levels of Ambient, Industrial and Biological Noise

A schematic spectrum of ambient, industrial and biological noise is presented in Figure 30. Ambient level was approximated at 68 dB across the narrowband with a - 8.5 dB/octave" fall off to about 40 dB at 5kHz, by averaging all measured ambient levels (n=60). Industrial noise levels plotted here are approximations of previously presented measured levels for each source (see Table 7).

While the frequency band presented for each source may remain fairly constant, level will always vary with range to the source. For example, in Figure 30, vessel sounds appear much lower in level than pipe driving or airgun sounds. While this relationship is true of our measured examples, a better scenario is to think of Figure 30 as representing a composite stop-action frame of a very malleable acoustic network. Noise source level, range, depth (or altitude), directivity and movement, in concert with the varied physical properties that affect" the transmission of the sound through the water, will cause nearly continual change in relative received levels of industrial sources. Though airguns produce the highest sound level of the industrial noise sources, they may not





Date: 4/13/81
Location: 6418.5N, 17C 21.1 W
57A SB 704/25.0
45 sec Average of Biol Sounds
Ice: 9/10
Depth: 33 m

Figure 29. Example of received "biological noise" spectrum levels recorded in Region 1, spring 1981.

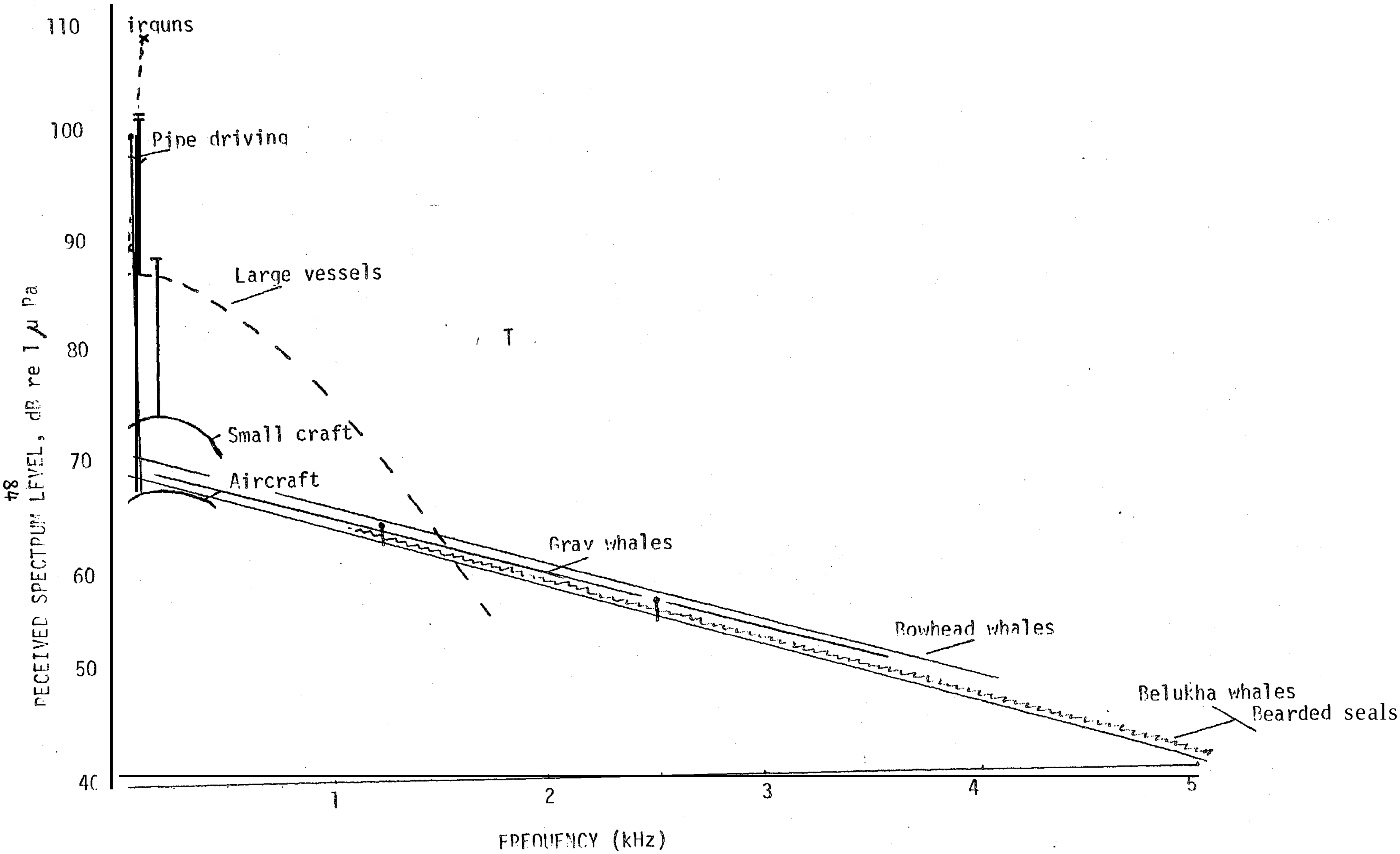


Figure 30. Schematic spectrum relating measured ambient, industrial and biological noise. Biological noise level is only grossly approximated as level was not measured.

always be the loudest received sounds if, for example, a Twin Otter aircraft is passing overhead, or a geophysical vessel is steaming nearby. Figure 30 then, is a single composite frame in a cinematic acoustic record, and should not be considered an absolute or static record of related sound levels. Aircraft and vessel noise were approximated from measured levels, with peak levels drawn in as tonals. The frequency range in which biological sounds are commonly produced are indicated by sloping lines, by species. Level is only grossly approximated for biological sounds, as it was not measured.

It is easily seen that most industrial noise occurs in the 15 Hz to 2000 Hz frequency band. This falls within the frequency range of bowhead and gray whale sounds, and overlaps the frequency band of sounds produced by belukha whales and bearded seals. It is commonly assumed that marine mammals have optimal hearing thresholds across the frequency band in which they produce sounds (Gales, 1982). Thus, it can reasonably be assumed that these animals may hear industrial noise within the range that its level exceeds that of ambient noise.

Overview of Data and Correlation with Other Studies

Ambient noise data that were collected between 1979 and 1982 are represented by 60 samples. An overall average ambient spectrum level for all seas and seasons was approximately 68 dB in the 500 Hz band, with an average -8.5 dB/octave roll off to about 40 dB at 5 kHz. When broken out by region and season, for comparative purposes, spring levels ranged from about 65 dB to 77 dB in the narrowband across three regions. Roll off was -5.3 to -9.0 dB/octave to 46 dB to 38 dB at 5 kHz. In fall samples from two regions showed somewhat lower and less variable levels, with a 66 dB average narrowband level in both regions, rolling off at -7.7 to -9.5 dB/octave to 38 dB to 34 dB at 5 kHz. This cross-seasonal 65db to 77 dB range of measured ambient noise falls within that reported by other researchers for shallow arctic waters (Milne, 1967). Cummings et al (1983) reported a 63 dB ambient level at 500 Hz for data collected near Barrow, Alaska in spring, Greene (1982) reported an ambient level of 52 dB at 100 Hz for data collected in the Canadian Beaufort Sea in August and remarked that this level was unusually low when compared to expected shallow water levels presented in Urick (1967). Notably, the lowest average ambient spectrum level was 62 dB across the narrowband from a sample recorded in the Canadian Beaufort Sea.

Several studies of ambient noise in arctic waters have been conducted (McPherson 1962; Milne and Ganton 1964; Greene and Buck 1964; Ganton and Milne 1965; Milne et al, 1967; Diachok 1980; and Buck 1981). Ambient noise in the Beaufort Sea has been found to vary with region and season, and in shallow water to be highly variable. For example, Buck (1981) reporting on ambient data collected from a drifting buoy in the Chukchi Sea found average shallow water sound levels were unexpectedly lower than levels recorded in deep water. Spring ambient levels were somewhat higher than fall levels in our samples, though the ranges of regional inter-seasonal levels did overlap such that a clear relationship between season and ambient level could not be defined. Analysis of biological noise indicated that it might be a significant contributor to ambient levels recorded in some regions in spring.

Urick (1967) gives non-arctic shallow water ambient noise as 80 dB at 100 Hz and 64 dB at 1000 Hz and notes that noise varies with wind speed and sea state. In arctic waters, ice conditions have also been cited as a contributor to ambient noise. Noise levels as high as 136 dB" have been reported for tonal components (to 200 Hz) measured near active ice pressure ridges (Greene, 1982). Diachok (1980) reported that high noise levels recorded near fields of pack ice decreased more rapidly with depth than with horizontal distance out towards open water, indicating that increases in ambient level caused by broken ice may be near-surface phenomena. This was supported by our analysis of ambient levels recorded at 18.2 m in variable ice and sea state conditions. As in Milne et al (1967), sea state rather than ice condition was found to have a much stronger affect on measured local ambient level. Ice coverage appeared to have some effect on ambient level at frequencies higher than 500 Hz, but this relationship was only weakly supported by our data.

Within the context of expected broad variability y in shallow water ambient noise, and in comparison with other shallow water ambient measures, our ambient data appears representative of prevailing conditions in shallow arctic waters. It must be borne in mind however that our ambient data represents small samples captured between sounds that were the intended subject of the recording. As such our ambient data present short time frame views of background noise, not long term sampling over which many averages may be run such as is commonly done for ambient noise analysis.

Anomalies in our ambient data precluded several data sets from measurements of level. Sources of such anomalies can be only speculated on at present.

Individual sonobuoy response differences, ice noise at frequencies above 500 Hz, aircraft produced tonal elements are all possible sources of “unusual” looking features in ambient spectra. The “shoulder” in some ambient spectra may be related to shipping. This relative increase in level in the 300 Hz to 1800 Hz band is roughly in the same frequency band and of the same shape as, noise spectra from the icebreaker and geophysical vessels. Wenz (1962) cited oceanic traffic noise as an important contributor to ambient noise in the 10 Hz to 1000 Hz frequency band. Without knowledge of the relative degree of vessel traffic during sampling periods with and without such anomalous "shoulders" it is impossible to do more than infer this relationship.

Examples of industrial noise sources recorded between 1979 and 1982 and presented here, are three types of survey aircraft, two small craft, an icebreaker, four geophysical vessels, airgun and pipe driving sounds. Airguns at 37 to 67 km, and pipe driving at 1 km were the loudest noise sources recorded with levels ranging from 89 dB to 108 dB. Geophysical vessel noise ranged from 62 dB to 88 dB at 43 km to 1.5 km range, with tonal and/or harmonic peaks from 78 dB to 104 dB. Small craft at 0.5 km produced measured noise levels of 72 to 75 dB, with peaks to 87 dB. The icebreaker, at 7 to 8 km range, was the quietest of the vessels at 58 dB average narrowband with tonal peaks to 74 dB. Two types of survey aircraft produced noise from 64 to 67 dB at 138 m and 612 m altitude, respectively. Tonal peaks of aircraft noise in both cases ranged to 100 dB. The noise level of the third aircraft could not be measured due to sonobuoy type used.

Industrial noise recorded by other researchers included that from oil drilling platforms (Gales, 1982),. a variety of vessels, aircraft and airguns (Greene, 1982,1 983) and single and array airguns (Malme et al, 1983). A review of measured levels from some of the industrial sources presented by these researchers is discussed here for comparative and illustrative purposes.

Gales (1982) measured noise levels from a variety of oil and gas platf orms and calculated source level (1/ 3 octave band at 1 yd.) for three classes of platforms designated as: semi-submersible drilling (SSD-1); Fixed Production, four legs (FP-1); and Fixed Production, three legs (FP-2). Peak levels were reported as 138 dB at 72 Hz (SSD-1), 137 dB at 40 Hz (FP-1) and 142 dB at 20 Hz (FP-2). At a distance of 33.3 m from each source platform noise in the 30 Hz to 300 Hz band ranged from 14 dB to 45 dB above “high ambient” levels (approximated from Urick, as heavy shipping or sea state 6). Obviously, this noise level range above ambient would be higher if lower ambient levels -were assumed.

Greene (1982) noted the strongest tones from three types of aircraft were: 100- i02 dB at 70 Hz for a Britten-Norman Islander aircraft; 104.=11 O dB at 82 Hz for a Twin Otter; and 109 dB at 22 Hz for a Bell 212 twin turbine helicopter. Additionally, predicted drill ship and dredge noise levels at 100 m were 133 dB at 278 Hz, and 120 dB at 380 Hz, respectively. Greene (1983], expanding on the previous years' work on seismic signals produced by sleeve exploder and airgun signals, reported peak levels of 177 to 123 dB at 0.9 to 14.8 km range, and 133 to 110 dB at 60 km and 75 km, respectively. On airgun spectrums, a low frequency ($\leq$100 Hz) precursor was noted that arrived at the hydrophore before the airgun signal and was surmised to travel via a higher-velocity sub-bottom path. For seismic sound data from both years, Greene proposed that the effect of extant sound transmission properties was to stretch the impulse source signal into a descending frequency "chirp" beyond 5 km. Frequency content at short range (<1.9 km) was reported as mostly below 150 Hz, and beyond 7.4 km sound energy was generally above 150 Hz. Greene (1983) then applied a least squares regression fit to the spherical spreading loss equation (20 log r) to derive a range dependent absorption loss term for airgun signals. Malme et al (1983), while attempting to measure transmission loss of airgun signals via a series of test runs, also noted a shift to higher frequencies but attributed it to source directivit y rather than range. Upon analysing sounds recorded during a traverse of an airgun array for horizontal directivity pattern, Malme et. al (1983) found that for angles greater than 50° a-beam of the array, higher frequency components begin to dominate. Thus, it would appear that range and angle to an airgun array source affects received" sound levels and frequency content. The frequency range and received levels of our airgun data may be at least partially due to directivity effects that have not previously been considered.

Biological sounds identified as produced by bowhead, belukha and gray whales, as well as bearded seals, were recorded and briefly summarized in the Biological Noise section. Pertinent literature for each species were was with each summary and may allow the reader a more complete species repertoire review. Gales (1982)$ in an attempt to characterize marine mammals as receivers of industrial source noise, reviewed current knowledge of cetacean and pinniped hearing thresholds. The belukha whale has a demonstrated hearing range of 1 kHz to 125 kHz, with a 40-45 dB threshold roughly in the 10 kHz to 90 kHz frequency band. In the case of mysticetes where no threshold measurements have been made, it is often assumed that the animals' optimal hearing frequency range is about the same as the frequency band in which it produces sound. This assumption should be used with caution as it is untested.

The question then arises: how far might one expect measured industrial noise levels to propagate and at what range would their level become negligible (i.e. fall to ambient). Given the summary data presented in Figure 30, and that just reviewed of the other researchers, we shall attempt to provide a scenario in which industrial noise sources hypothetically fall to ambient level at some calculated range.

Scenario: **Region** 4

The source-path-receiver (SPR) model, reviewed by Gales (1%32), is used here to facilitate an estimation of range in which noise level would remain above ambient and possibly be detected by marine mammal receivers. The elements of the SPR model are:

a) Source - various industrial noise emitters
b) Path - underwater sound transmission between source and receiver
c) Receiver - marine mammals (principally, bowhead, gray and belukha whales and bearded seals)

It is important to note that, for marine mammals where hearing capability has been tested, it appears there exists a critical frequency band that allows the detection of levels lower than the ambient level (Johnson, 1980; Popper, 1980; Gales, 1982 p. 27-33). A pulsed noise of bandwidth equal to that of the ambient, or a steady noise with a bandwidth narrower than that of the ambient may be detected. In human hearing, a signal as low as 20 dB below the overall level of the masking ambient noise may be detected. Region 4 was chosen as the scenario site because ambient noise levels were measured there in both spring and fall. Average narrowband ambient levels were 68 dB in spring, and 66 dB in fall with a -8.9 to -9.5 dB/octave roll off to 38 dB to 34dB at 5 kHz. Choosing the median narrowband ambient noise level of 67dB, the approximate range at which previously presented measured levels of industrial noise would fall to ambient level was calculated (Table 10). Industrial noise sources were identified as fixed

Table 10. ‘ Scenario, Region 4: calculated distances at which various industrial noise sources would be expected to fall to the median narrowband ambient noise level (67dB) in region 4.

	nd ıstrial Noise Source	Measured Range	Peak Level (dB)	Frequency (Hz)	CALCULATED DISTANCE VIA Transmission Loss Models		
					20 log r	15 log r	10 log r
XED	Drilling Platforms[1]						
	SSD-1	0.92 m	138dB	at 72 Hz	3.5 km	55 km	13000 km
	FP-1	0.92 m	137dB	at 40 Hz	3.2 km	47 km	10000 km
	FP-2	0.92 m	142dB	at 20 Hz	5.6 km	100 km	32000 km
	Drillship[2]	100 m	133dB	at 278 Hz	2.0 km	25 km	4000 km
	Dredge[2]	100 m	120dB	at 380 Hz	.45 km	3.3 km	200 km
	Pipe Driving	1 km	97dB	50 to 200 Hz	0.31 km	.1 km	1 km
MOB E	Aircraft						
	Twin Otter	137.6 m	100dB	at 84 Hz	.045 km	.16 km	2 km
	Grumman Goose	611.6 m	100dB	at 100 Hz	.045 km	.16 km	2 km
	Britten-Norman Islander[2]	152 m	100-102dB	at 70 Hz	.057 km	.22 km	3.1 km
	Bell 212 Helicopter[2]	152 m	109dB	at 22 Hz	125 km	64 km	16 km
	Small Craft						
	Boston Whaler	0.5 km	81-87dB	at 1850-210 Hz	.010 km	.022 km	.1 km
	Large Vessels						
	Polar Sea	7.8 km	74dB	at 89 Hz	.0025 km	.003 km	.005 km
	Arctic Star	1.4 km	104dB	at 98 Hz	.070	km .3 km	5 km
	Mariner	1.5 km	88dB	no peaks	.011 km	.025 km	.130 km
	W. Polaris	43 km	78dB	at 111 Hz	.0035 km	.005 km	.013 km
	W. Aleutian	38 km	80dB	at 200 Hz	.0045 km	.0075 km	.020 km
	Two Vessels	15 km	103 dB	at 72 ?-Iz	063 km	* 5 km	4.1 km
	Seismic Survey Sounds						
	Airgun Array	1 m	248dB3		10^5 km	10^8 km	10^{14} km
		37 km	89dB	at 174 Hz	.0125 km	.029 km	.160 km
		49 km	108dB	at 195 Hz	.110 km	.54 km	12.5 km
		67 km	107dB	at 79.5 Hz	.100 km	.46 km	10.0 km
		60 km[4]	133dB	no info.	2.0 km	25 km	4000 km
		75 km[4]	110dB	no info.	.130 km	.74 km	20.5 km
	Sleeve Exploder[4]	0.9 km	177dB	approx. 77 Hz	300 km	22000 km	10^7 km
		14.8 km		approx. 24 Hz	.63 km	5.5 km	400 km

1) Gales (1982)
2) Greene (1982)
3) Johnston (1981)
4) Greene (1983)

or mobile. Three simplified transmission loss models were used to estimate range, as outlined below:

1) 20 log r = spherical spreading; a conservative sound propagation model where sound level decreases at a rate of 6dB per meter doubled

2) 10 log r = cylindrical spreading; a model in which sound propagation is optimized and level decreases at a rate of 3dB per meter doubled

3) 15 log r = "hybrid" spreading; a model that attempts to address transmission loss attributable to both spherical and cylindrical spreading

It must be emphasized that estimates derived using these models provide only gross approximations of range. Absolute spherical or cylindrical spreading loss is never achieved under normal oceanic conditions? and although a spreading loss model midway between these two extremes has been shown useful when. calculating expected levels in shallow water (see Malme et al, p. 5-4), it too is an incomplete model. To these simple spreading loss models several factors should be added, including:

- a loss due to scattering reflection and absorption at the surface and the bottom; this loss would vary with bottom type and contour as well as surface conditions (ice and sea state).
- a possible energy increase or loss due to surface and bottom "image" sources; this factor includes the Lloyd mirror effect previously discussed for airgun signals
- a loss due to the number of expected "bounces" of the source as it travels along its path to the receiver; this will vary significantly within a constant range, if source and receiver are at appreciably different depths
- the effect of source directivity on received level
- the effect of (possible) sound charnels caused by thermoclines, ice caps, and hard bottom reflectors

We can not expand upon the simplified spreading loss models to account for these factors at this time due to a lack of pertinent data. We suggest that the ranges presented in Table 10 as derived by spherical (20 log r) or cylindrical (10 log r) spreading loss models be considered, at best, as outside limits. For the purpose of discussion, we will assume that the "hybrid" (15 log r) model best estimates ranges at which our measured industrial noise levels may be detected (Malme et al, 1983).

Because measured hearing thresholds and estimations of a critical band for arctic marine mammals are unavailable for all but the belukha whale, the marine mammal-as-receiver scenario must rest on assumptions that may be classif ied as:

a) conservative = marine mammals can detect any sound above ambient level, or

b) moderate = marine mammals can detect sounds only if above *(some)* threshold level within a limited frequency band

The conservative scenario simply assumes that for each of the industrial sources listed in Table 10, a marine mammal may be able to detect (and possibly react to) that noise if the animal is within the range calculated by the 15 log r model. For example, a bowhead within 55 km of a SSD- 1 platform, or within 1.7 km of the Arctic Star could hear the industrial noise generated by each source. The farthest ranges calculated using the 15 log r model in Table 10 are, those for those seismic survey sounds (to 85 km). As previously discussed, Malme et al (1983) proposes that interference patterns (Lloyd mirror effect) peculiar to seismic signals might dictate that signed loss for these sources be best modeled by:

a) 25 log r = for propagation from a shallow source to a deep receiver, or

b) 35 log r = for propagation between shallow source and, shallow receiver (after Grachev, 1983).

Transmission loss estimates calculated from these models for the seismic survey data are presented in Table 11. This calculation suggests that in the case of an airgun array source level of 248dB, an animal in region 4 could detect the signal above ambient level 145 km to 17,000 km away, depending on water depth at the source. Malme et al (1983) present evidence that seismic source directivit y along the horizontal path appears to heavily influence both received signal level and frequency content. A review of measured received seismic levels upholds the contention that directivity (or some other unknown factor) is affecting the received level and frequency of these signals (i.e. measured levels are generally lower than expected when standard transmission loss is calculated for a 248dB source level signal, and peak frequencies are not those expected). Using the

Table 11. Calculated distances at which seismic survey sounds would be expected to fall to median 67dB ambient level (in region 4) using 25 log r and 35 log r transmission 10ss models (after Malme et al, 1983)

seismic Survey sounds	Measured Range	Peak Level (dB)	Frequency (Hz)	CALCULATED DISTANCE VIA Transmission Loss Models 25 log r	35 log r
	1 m[3]	248dB[3]		17000 km	145 km
	37 km	89dB	at 174 Hz	.0075 km	.0043 km
Airgun	49 km	108dB	at 195 Hz	.044 km	.015 km
Array	67 km	107dB	at 79.5 Hz	.040 km	.014 km
	60 km[4]	133dB	no info.	.440 km	.076 km
	75 km[4]	110dB	no info.	.052 km	.017 km
Sleeve	.9 km	177dB	approx. 77 Hz	25 km	1.4 km
Exploder [4]	14.8 km	123dB	approx. 24 Hz	.175 km	.040 km

3) Johnston (1981)
4) Greene (1983)

conservative assumption then, an animal may be expected to hear the measured seismic signals at distances from 75.05 km (25 log r), to 75.02 km (35 log r).

The (conservative) assumption that animals can hear any sound above ambient level is not biologically supportable. Sound must reach some threshold level before it is audible to an animal. The moderate scenario, in which marine mammal receivers detect sounds only above hearing thresholds , is a more reasonable paradigm. Unfortunately there is very little information on marine mammal hearing capabilities. An audiogram derived via behavioral methods for a female belukha whale found that hearing threshold was about 98dB at 1 kHz, f ell to nearly 35dB at 12 kHz arid was again approximately 98dB at 125 kHz (White et al, 1978). Threshold in the 1 to 5 kHz band was about 98 to 72dB. Threshold level below 1 kHz is probably higher than 100dB. Thus, it would appear that even the measured peak levels of industrial noise sources presented in Table 10 would fall below belukha hearing threshold because of the frequency at which they occur. This may not be the case for the bowhead or gray whales. Though the technique of Average Brainstem Response (ABR) has been suggested as a feasible fall below belukha hearing threshold because of the frequency at which they occur. This may not be the case for the bowhead or gray whales. Though the technique of Average Brainstem Response (ABR)has been suggestedas a feasible method for acquiring mysticete audiograms (Ridgway and Carder, 1983), to date no such information is available. Attempts to estimate bowhead hearing capabilities based upon middle ear morphology (after Fleischer, 1978) have supported only "guarded speculation" that auditory thresholds range from "high infrasonic . . . to low ultrasonic" frequencies (Norris and Leatherwood, 1981). If we assume a hearing threshold curve for bowhead and gray whales that is similar in shape to that measured for belukha whales, but shifted down to the frequency band in which these whales produce sound (see Ljungblad et al, 1982b p. 479 and Moore and Ljungblad, 1984), a hypothetical audiogram such as that presented in Figure 31 develops. Obviously threshold levels can not be predicted. The overall shape and the relative shift in hearing capability across the 10 to 10,000 Hz frequency band implied by this hypothetical audiogram are the cogent points. Theoretically, a mysticete would have optimal hearing capability in about the 100 Hz to 1000 Hz frequency band. Peak levels of industrial noise are common but tend toward the lower end of this frequency range as presented in Table 10. Mysticetes then, would be the most likely marine mammal receivers of industrial noise sources, but at what range?

Gales (1982) presents several scenarios of detection of platform noise by a "hypothetical mysticete" in variable sound propagation and ambient noise conditions. Depending on the assumed conditions the calculated detection distance of platform noise ranged from 37 m (40 yd.) to 5488 km (2960 nmi). In the series of scenarios presented, Gales emphasized the importance of the sound propagation conditions and the receiver conditions (i.e. hearing capability) in controlling the minimum audible signal. The hearing threshold of the receiver will ultimately determine the minimum audible signal. It is important to note that if mysticetes have a relatively high hearing threshold below 300 Hz (range of most industrial noise), the major concern regarding industrial noise effects on these cetaceans would be greatly reduced. Without additional information on mysticete auditory threshold levels, developing scenarios of propagation loss for different sources given variable ambient and physical conditions seems a futile exercise.

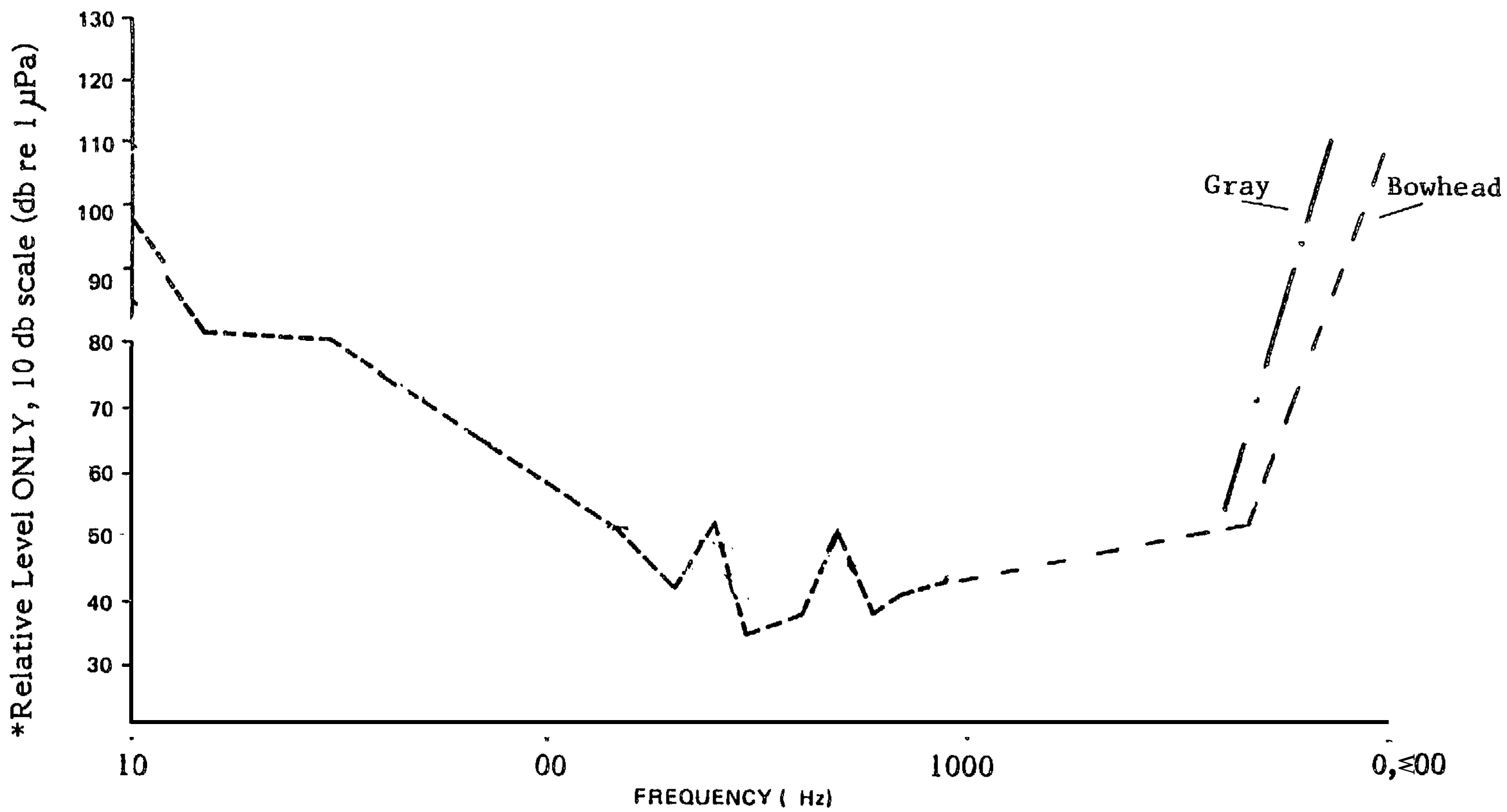


Figure 31. Hypothetical mysticete audiogram (after White et al, 1978: beluga whale audiogram; Ljungblad et al, 1982: bowhead frequency range; and Moore and Ljungblad, 1984: gray whale frequency range).

Recommendations

In reviewing the acoustical data collected between 1979 and 1982 it becomes clear that, with some additional effort, a more complete record of acoustical events in arctic waters could be realized. In support of an experimenal! framework in which the elemental hypothesis (HO) is:

HO: There exists a distance at which arctic marine mammals are unaffected by industrial noise;

we propose efforts to collect and analyse acoustic data in the following areas:

1. ambient noise
2. sound speed profiles
3. transmission loss experiments
4* radial modelling of active airgun arrays
5. correlation of sound production and behavior for biological sources
6. mysticete hearing capabilities

1. Ambient noise

'To date most arctic water ambient noise studies have been done under shorefast or pack ice. Ambient levels under these conditions do not necessarily reflect those expected in open water or partial ice coverage conditions. An effort directed toward collection of long segments of ambient noise data in all regions and seasons would provide a stronger baseline record against which to compare industrial and biological sounds. To this end sonobuoys could be dropped in areas where no whales were seen and no industrial activity apparent. Ambient levels derived via long period averaging would more clearly define expected regional and seasonal background noise. Additionally, the nearshore noise component could be monitored in areas of high industrial activity, and at sites where there is no such activity. Ground wave sources derived from coastal activity, as well as weather patterns, barometric variations, ice coverage and sea state conditions could be monitored and correlated with recorded ambient level to document, and allow predictions of, background noise.

2. Sound speed profiles

The speed of sound through water, and the formulation of a ray path diagram to model its transmission, depends primarily upon the temperature, pressure and salinity profile of the water column. While extant data on the physical oceanography of arctic seas (e.g., Coachman, 1969) allows rudimentary sound speed modelling, such examples may not adequately describe the physical components of the water column pertinent to a specific source-loss situation. Without precise data on the physical nature of the transport medium it is impossible to accurately model expected transmission loss of a signal. Sonobuoys that transmit water column temperature data from the surface to a preset depth are currently available. Dropping such buoys on a scheduled basis throughout the study area would allow the development of rudimentary sound speed profiles pertinent to sound transmission loss modelling.

3. Transmission loss experiments

To model a sound transmission system one must record sounds emitted from a known source at a specified distance using a calibrated receiver , as well as have knowledge of the physical features of the medium (i.e. aforementioned sound speed profiles). Active sonobuoys could be one such known source. A passive sonobuoy dropped at a measurable distance from an active buoy set to emit a prescribed sound (or sound sweep) at a known level and frequency would allow greater precision of any modelling effort.

4. Measurement and modelling of the directivity pattern of active airgun arrays

Seismic survey sounds, usually produced by airgun arrays, are the loudest of the industrial noise sources. Malme et al (1983) measured sound level alongside such an array and found strong evidence of horizontal directivity for this source. This feature of the noise source appeared to have direct impact on the behavior of migrating gray whales along the California coast. When a seismic vessel towing an active airgun array overtook and passed swimming grays, it appeared to elicit a strong behavioral response (swimming course change and movement shoreward). When the active seismic vessel did not overtake and move past the whales, no significant behavioral change was seen. The importance of modelling this horizontally directed side lobe of the seismic signal takes on new importance in light of this data. This feature of airgun signals may explain the lower-than-expected measured airgun levels, and the overall lack of observed responses by bowhead and gray whales to such seismic operations in arctic waters (see Ljungblad et al, 1982; Reeves et al, 1983; Richardson et al, 1983). An effort to develop a "radial model" of active airgun arrays (with varied number and sizes of guns) would provide a more complete picture of this industrial source. Currently, whale behaviors are documented as being airgun-influenced anytime airgun sounds are audible to human listeners. The whales may not in fact hear these sounds (or not experience them as loud sounds) until the sounds are "turned on" suddenly as the airgun array passes the whales and they fall in the acoustic wake of the side lobe beam.

A precise modelling of where such horizontal beam effects are likely would be a difficult task. From an aircraft, two sonobuoys dropped at some measurable distance in front and on either side of a vessel towing an array might be the simplest way to gain a rudimentary idea of source directivity. Theoretically, as the vessel passed between the two buoys, the measured level and frequency of received signal could be correlated with the position and orientation of the array to the hydrophores. A series of hydrophores dropped at known distances around an array might provide additional information. The complexity of data acquisition in such an effort comes not only in the deployment of many sonobuoys but in monitoring each with multichannel receiving and recording units while simultaneously estimating the path of the vessel and its constantly changing distance and orientation to the sonobuoys. A dedicated vessel might provide a better platform for controlled measurements around and alongside a seismic vessel towing an active array. A hydrophore (or series of phones) could be towed from a monitoring vessel while distance and orientation to the array were continually calculated. It would seem such an effort conducted from a small vessel free to travel around a moving seismic array would stand a better chance of success.

5. Correlation of sound production and behavior for biological sources

Initial aural tabulation of sounds produced by bowheads[5] indicates that there may be some differentiation in call types produced in relation to behavior observed. Such associations are very rudimentary at present. A systematic characterization of bowhead call types, followed by statistical correlation with observed behavior would provide a framework against which comparisons of field monitored sounds could be made. Within this paradigm, hypothetically, a human listener might use whale call types as aural cues in predicting general behavioral states. For example, if it were determined that feeding whales often produce a high percentage of FM2 calls, a listener hearing such calls might assume the observed whales to be feeding and not likely to soon leave the area. In the same fashion, if whales that are actively swimming in a directed manner were found to

---

5) Bowheads are used here as an example presumed to represent mysticetes as a group.

produce primarily FM_1 calls, the listener might assume the observed whales to be moving through the area and perhaps estimate their subsequent (probable) location based upon observed heading and estimated rate of travel.

The collection of bowhead sounds and behavior data currently on file would allow at least a preliminary investigation of the feasibility of such a correlative effort. Often behavior was not observed during recording periods such that the current data base would be restricted by this requirement. During future recordings, efforts to identify and sustain observation of whale behavior during recording periods could be made. A correlated sound-behavior paradigm would enhance the utility of passive acoustics as a marine mammal population monitoring tool.

6. Mysticete hearing capabilities

Ultimately, the effects of industrial noise on marine mammals will depend upon their ability to detect these sounds. At present, most researchers attempt to determine the possible effects of industrial noise on mysticetes by observing behaviors in the presence of industrial sounds, or while conducting industrial noise playback experiments. These approaches have been successful in providing some understanding of possible noise effects. Observing whale behaviors during exposure to relatively broadband industrial noise may verify that they do, or do not, respond to such signals, but there is no control to test for a (possible) critical frequency component of the noise that the animal is actually responding to. Efforts to determine the critical frequency band for bowheads and gray whales would be an important element of a study addressing industrial noise effects on these mysticetes. Controlled playback experiments in which tones of known frequency and level were presented to whales that were behaviorly monitored pre-, during, and post-trial might provide some tested hearing capability information. Areas frequented by these whales where such research might be conducted include the gray whale breeding lagoon (Dahlheim et al 1984), or along the grays' migratory route (Malme et al 1983); and possibly the bowheads' f ceding grounds, or off Point Barrow during the spring migration. Ideally, such behavioral-response hearing tests could be compared to hearing capability measured using Average Brainstem Response (ABR) techniques as described by Ridgway and Carder (1983). Such ABR tests require restraint of the subject, however, and would therefore be impractical in all but the most unusual circumstances.

In addressing the stated hypothesis, acquisition of acoustic data as outlined would:

- provide a seasonal baseline ambient noise level by region that could be correlated with prevailing weather and sea conditons, as well as proximity to coastal and/or industrial activity. Calculated levels of industrial noise could then be compared to this established ambient record;
- increase accuracy of transmission loss modelling for all industrial noise sources via sound speed profiling of the water columns, and calibrated measurements of known sources at specified distances;
- promote passive acoustic recording of marine mammal sounds to a framework in which it may be utilized to better assess and predict animal behavior, and in this way become an active management tool;
- enhance efforts to predict distances at which marine mammals would likely be affected by industrial noise based upon their tested hearing capabilities.

The set of recommendations outlined here is a preliminary one, presented with the intent of providing baseline acoustic data for more effective resource management of outer continental shelf areas. As. such, they should not be regarded as static or necessarily complete, but rather as a general direction that may be altered as new information comes to light.

LITERATURE CITED

Barger, J.E. and W .R. Ham Men. 1980. The airgun impulsive underwater transducer. J. Acoust. Sot. Am. 68(4):1038-1045.

Buck, B.M. 1981. Compilation of underwater acoustic ambient noise data in shallow Beaufort and Chukchi Seas. Unpubl. Rep. by Polar Research Lab, Inc. Santa Barbara, CA., for Sohio Alaska Petroleum Company, Anchorage. 50 p.

Coachman, L.K. 1969. Physical Oceanography in the Artic Ocean: 1968. Arctic, 22214-224.

Clark, C.W. 1983. The correlation of behaviors with sounds in the southern right whale (Eubalaena Australia). In: R.S. Payne (cd.), Communication and behavior of whales. AAAS Selected Symposia Series, Westview Press, Boulder, CO.

Cummings, W .C., D.V. Holliday and W .T. Ellison. 1983. Technical feasibility of passive acoustic location of bowhead whales in population studies off Point Barrow, Alaska, Rept. int. Whal. Comm. SC/35/PS19.

Cummings, W.C., P.O. Thompson and R. Cook. 1968. Underwater sounds of migrating gray whales, Eschrichtius glaucus (Cope). J. Acoust. Sot. Am. 44:1278-1281.

Dahlheim, M.E. and H.D. Fisher. 1983. Response of gray whales (Eschrichtius robustus) to nonbiological noise. J. Acoust. Sot. Am., Proc. 106th Meeting, p S55.

Dahlheim, M .E., H.D. Fisher and J.D. Schempp. 1984. Sound production by the California gray whale (Eschrichtius robustus) and ambient noise levels in San Ignacio Lagoon, Baja California, Mexico. pp. 499-529. In: M.L. Jones, S. Leatherwood and S. Swartz (eds.), The Gray Whale, Academic Press, San Francisco, CA.

Diachok, O. 1980. Arctic hydroacoustics. Cold Regions Sci. and Technol. 2: 185-201.

Fish, M.P. and W.H. Mow bray. 1962. Production of underwater sound by the white whale, or beluga. Y. Mar. Res. 20(2): 149-162.

Fleischer, G. 1978. Evolutionary principles of the mammalian middle ear. Advances in Anatomy, Embyology and Cell Biology 5%5--70.

Gales, R.S. 1982. Effects of noise of offshore oil and gas operations on marine mammals - an introductory assessment, Vol. 1. NOSC TR 884, 79 p.

Ganton, J.H. and A.R. Milne. 1965. Temperature and wind dependent ambient noise under midwinter pack ice. J. Acoust. Sot. Am. 38:406-411.

Grachev, G.A. 1983. Specific characteristics of signal attenuation in a shallow sea. Sov. Phys. Acoust. 29(2):160-161.

Greene, C.R. and B.M. Buck. 1964. Arctic ocean ambient noise. J. Acoust. Soc. Am. 36:1218-1220.

Greene, C.R. 1982. Characteristics of waterborne industrial noise. In: W .3. Richardson (cd.), Behavior disturbance responses and feeding of bowhead whales (Balaena mysticetus) in the Beauf ort Sea, 1980-81. Final Report, to: the Bureau of Land Management, prepared by: LGL Ecological Research Associates, Inc., 455 p.

Greene, C.R. 1983. Characteristics of waterborne industrial noise, 1982. In: W.J. Richardson (cd.), Behavior, disturbance responses and distribution of bowhead whales (Balaena mysticetus) in the eastern Beaufort Sea, 1982. Final Report to: U.S. Minerals Management Service, prepared by: LGL Ecological Research Associates, Inc., 357 p.

Griffiths and Buchanan. 1982. Characteristics of bowhead feeding areas. In: W.J. Richardson (cd.), Behavior, disturbance responses and feeding of bowhead whales (Balaena mysticetus) in the Beaufort Sea, 1980-81. Final Report to: the Bureau of Land Management, prepared by: LGL Ecological Research Associates, Inc., 455 p.

Hoff, B.J. and F.B. Chemlik. 1982. Better shallow water seismic data. Ocean Industry (Sum?): 19-23.

Johnson, C.S. 1980. Important areas for future cetacean auditory study. In: R.G. Busneal and J.F. Fish (eds.), Animal Sonar Systems, Plenum Press, New York, NY.

Johnston, R.C. 1981. Marine seismic energy sources: acoustic performance comparison. J. Acoust. Sot. Am. Suppl. Vol. 70, p. 546-547.

Ljungblad, D.K., M.F. Platter-Rieger and F.S. Shipp Jr. 1980. Aerial surveys of bowhead whales, North Slope, Alaska. NOSC TD 314.

Ljungblad, D.K. 1981. Aerial surveys of endangered whales in the Beaufort Sea, Chukchi Sea, and northern Bering Sea. NOSC TD 449.

Ljungblad, D.K., S.E. Moore, D.R. Van Schoik and C.S. Winchell. 1982a. Aerial surveys of endangered whales in the Beaufort, Chukchi and Northern Bering Seas. NOSC TD 486.

Ljungblad, D.K., P.O. Thompson and S.E. Moore. 1982b. Underwater sounds recorded from migrating bowhead whales, (Balaena mysticetus), in 1979. J. Acoust. Soc. Am. 71(2):477-482.

Ljungblad, D.K., S.E. Moore and D.R. Van Schoik. 1983. Aerial surveys of endangered whales in the Beaufort, Chukchi and Northern Bering Seas, 1982. NOSC TD 605.

Ljungblad, D.K., S.E. Moore and D.R. Van Schoik. 1984. Aerial surveys of endangered whales in the Northern Bering, Eastern Chukchi and Alaskan Beaufort Seas, 1983 NOSC TR 955.

McPherson, J.D. 1962. Some under ice acoustic ambient noise measurements. J. Acoust. Sot. Am. 34:1149-1150.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird. 1983. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Final Report to: U.S. Minerals Management Service, prepared by: Bolt Beranek and Newman, Inc., 376 p.

Milne, A.R. and J.H. Ganton. 1964. Ambient noise under arctic sea ice. J. Acoust. Sot. Am. 36:855-863.

Milne, A.R., J.H. Ganton and D.J. McMillin. 1967. Ambient noise under sea ice and further measurements of wind and temperature dependence. J. Acoust. Sot. Am. 41(2):525-528.

Moore, P.W.B. 1983. Behavioral control of echo location source level in the dolphin (Tursiops truncates). In: Abstracts of the Fifth Biennial Conference on the Biology of Marine Mammals, Boston, MA. p. 70.

Moore, S.E. and D.K. Ljungblad. 1984. Gray whales (Eschrichtius robustus) in the Beauf ort, Chukchi and Bering Seas: distribution and sound production. pp. 531-547. In: M.L. Jones, S. Leatherwood and S. Swartz (eds.), The Gray Whale, Academic Press, San Francisco, CA.

Norris, J.C. and S. Leatherwood. 1981. Hearing in the bowhead whale, Balaena mysticetus, as estimated by cochlear morphology. In: T.A. Albert (ed.), Tissue structural studies and other investigations on the biology of endangered whales in the Beaufort. Alaska OCS Office, prepared by Dept. of Veterinary Science, Univ. of Maryland.

Popper, A.N. 1980. Sound emission and detection by delphinids. In = L.M. Herman (cd.), Cetacean Behavior: mechanisms and functions. Wiley, New York.

Ray, C., W.A. Watkins and J. Burns. 1969. The underwater song of Erignathus (Bearded seal). Zoologica 54:79-83.

Reeves, R., D.K. Ljungblad and J.T. Clarke. 1983. Report on studies to monitor the interaction between offshore geophysical exploration activities and bowhead whales in the Alaskan Beauf ort Sea, f all 1982. Final Report, to: U.S. Minerals Management Service, prepared by: SEACO, Inc., 70 pp.

Richardson, W.J., C.R. Greene, J.P. Hickie and R.A. Davis. 1983. Effects of offshore petroleum operations on cold water marine mammals. Final Report, to: American Petroleum Institute, prepared by: LGL Limited, 247 pp.

Ridgway, S.H. and D.A. Carder. 1983. Audiograms for larger cetaceans: a proposed method for field studies. J. Acoust. Sot. Am. Suppl. 1 Vol. 74, p. S 53.

Ross, 13. 1976. Mechanics of underwater noise. Pergamon Press, New York, 375 pp.

Stirling, I., W. Calvert and H. Cleator. 1983. Underwater vocalizations as a tool for studying the distribution and relative abundance of wintering pinnipeds in the high arctic. Arctic 36(3):262-274.

Urick, R.J. 1967. Principles of underwater sound for engineers. McGraw-Hill, New York, 341 p.

Urick, R.J. 1972. Noise signature of an aircraft in level flight over a hydrophore in the sea. J. Acoust. Sot. Am. 52:993-999.

Watkins, W.A. 1967. The harmonic interval = factor artifact in spectral analysis of pulse trains. In: W.N. Tavolga (ed.), Marine Bio-Acoustics, Pergamon Press, New York, N.Y.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: spectra and sources. J. Acoust. Sot. Am. 34:1936-1956.

White, M.J., J.C. Norris, D.K. Ljungblad, K.S. Baron and G.N. DeSciara. 1978. Auditory thresholds of two beluga whales (Delphinapterus leucas). Hubbs-Sea World Research Institute, Manuscript, 22 p.

Wursig, B., C.W. Clark, E.M. Dorsey, M.A. Fraker and R.S. Payne. 1982. Normal behavior of bowheads, pp. 33-144 In: W.J. Richardson (cd.), Behavior, disturbance responses and feeding of bowhead whales (Balaena mysticetus) in the Beaufort Sea, 1980-81. Final Report to: the Bureau of Land Management, prepared by: LGL Ecological Research Associates, Inc., 445 p.

Wursig, B., C.W. Clark, E.M. Dorsey, W.J. Richardson and R.S. Wells. 1983. Normal behavior of bowheads, 1982. pp. ,25-116 In: W.J. Richardson (cd.) Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1982$357 pp.