ACOUSTIC EFFECTS OF OIL PRODUCTION ACTIVITIES ON BOWHEAD AND WHITE WHALES VISIBLE DURING SPRING MIGRATION NEAR PT. BARROW, ALASKA--1991 PHASE:

PRELIMINARY DATA ON SOUND PROPAGATION AND WHALE RESPONSES TO PLAYBACKS OF ICEBREAKER NOISE

by

LGL LIMITED

environmental research associates

for

U.S. Minerals Management Service, Alaska OCS Region
949 East 36th Ave., Anchorage, AK 99508-4302

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by

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PROJECT ORGANIZATION

The 1991 phase of this contract was conducted by LGL Ltd., environmental research associates, assisted by subcontractor Greeneridge Sciences Inc. LGL organized the project as a whole, and conducted the biological aspects of the work. M. Smultea and B. Würsig of the Marine Mammal Research Program, Texas A & m University, worked with LGL on the biological components. Greeneridge was responsible for the physical acoustics components. The affiliations of the senior authors (in boldface) and co-authors are as follows:

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Another major contributor to the fieldwork was Kenneth Toovak Sr. of Barrow. Another major participant in the analysis was R. Blaylock of Greeneridge.

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Dr. Thomas Albert	North Slope Borough Dept of Wildlife Management,
Mr. Mark Fraker	BP Exploration (Alaska), Inc.,
Dr. Roger Green	University of Western Ontario,
Mr. Allen Milne	Sci. Rev. Board Chairman,
Mr. Ron Morris	Nat. Mar. Fish. Serv.,
Mr. Thomas Napageak	Alaska Eskimo Whaling Commission,
Mr. Burton Rexford	Barrow Whaling Captains' Association, and
Dr. Steven Swartz	Marine Mammal Commission.

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GLOSSARY

absorption. The process by which sound energy is converted into heat.

acoustic power. The energy per unit time, measured in watts. The acoustic power is proportional to acoustic pressure squared.

acoustic pressure. Pressure variations around an ambient static pressure (such as the hydrostatic pressure in water at some depth) at acoustic frequencies. These are very small pressures compared to the static pressure or compared to shock or blast wave pressures.

ambient noise. Background noise; noise not of direct interest during a measurement or observation. Excludes sounds produced by the measurement equipment, such as cable flutter.

ASL. Above sea level.

audiogram. A graphical depiction of auditory thresholds, showing the sound levels that are barely detectable by an animal, in the absence of significant background noise, as a function frequency.

auditory sensitivity. An animal's hearing sensitivity as a function of frequency.

auditory threshold. The minimum amplitude of sound that can be perceived by an animal in the absence of significant background noise. Auditory threshold varies with frequency and is inversely related to the animal's auditory sensitivity.

bandpass filter. A filter with high-pass and low-pass cutoff frequencies, designed to pass only a desired band of frequencies.

bandwidth, A range of frequencies.

blow interval. The interval, in seconds, between two successive respirations within the same surfacing by a whale.

CPA. Closest Point of Approach.

critical band. The frequency band within which background noise can affect detection of a sound signal at a particular frequency.

critical ratio. The ratio of power in a barely-audible tone to the spectrum level of background noise at nearby frequencies.

continuous wave. A sound whose waveform continues with time.

cylindrical spreading. Sound spreading as cylindrical waves. The transmission loss for cylindrical spreading is given by

$$10*\log_{10}(Range/R_0),$$

where R_0 is a reference range, The received level diminishes by 3 dB when range doubles, and by 10 dB for a tenfold increase in range.

cylindrical wave. A sound wave with cylindrical fronts. For a point source in shallow water, a cylindrical wave forms at distances that are large compared to the water depth because of the way sound reflected from the surface and bottom reinforces the direct wave.

decibel (dB). A logarithmically based relative measure of sound strength, A sound pressure P can be expressed in dB as a sound pressure level of $20*\log_{10}(P/P_{ref})$, where P_{ref} is a reference pressure (usually a standard pressure like 1 microPascal). Note that $20*\log(X)$ is the same as $10*\log(X^2)$, where X^2 is the mean square sound pressure and is proportional to power, intensity or energy.

DIFAR. A type of sonobuoy (AN/SSQ-53B) that has the ability to determine the direction of arrival of a sound.

electrical noise. Noise generated by electronic circuits, as distinct from acoustic noise.

F-40. A particular type of U.S. Navy-underwater sound transducer that can project high-frequency sounds, e.g. 1-10 kHz.

faired cable. A cable with many ribbon-like attachments to reduce strumming in currents.

filter. An instrument or mechanism for restricting or altering the frequency range or spectral shape of a waveform.

fluke-out dive. A dive in which the whale raises its tail flukes above the surface of the water as it dives.

frequency. The rate at which a repetitive event occurs, measured in hertz (cycles per sec.).

hertz (Hz). A measure of frequency corresponding to a cycle per second.

high-pass filter. A filter passing sounds above a specified frequency.

hydrophore. A transducer for detecting underwater sound pressures; an underwater microphone.

infrasound. Sound energy at frequencies too low to be directly audible to humans; generally taken to be sound at frequencies below 20 Hz.

J-11; J-13. Particular types of U.S. Navy underwater sound projectors. The J-1 1 is a broadband projector; the J-13 is a low-frequency projector.

Karluk. Karluk was a grounded ice platform that was constructed in 6 m of water near **Prudhoe** Bay, Alaska, during the winter of 1988-89. The ***Karluk ice*** platform was used as a **drill**-site during that winter. The underwater sounds projected during playback experiments in the 1989-90 phases of this study were recorded 130 m from ***Karluk*** while it was drilling during March 1989.

level. The term "level" is usually applied to sound amplitudes, powers, energies or intensities expressed in dB.

Lloyd mirror effect. The diminished pressure of a sound from an underwater source when it is received near the water/air boundary (the surface). ***The*** reflected sound wave is inverted (out of phase) with respect to the incident sound wave, and their sum at the receiver approaches zero as the receiver approaches the surface.

low-pass filter. A filter passing sounds below a specified frequency.

masking. The obscuring of sounds of interest by stronger interfering sounds.

microbar (µbar). A unit of pressure previously used as a reference pressure in **dB** level measurements. A **µbar** is equivalent to 1 **dyne/cm^2** and to 0.1 **pascal,** ***or*** 10^5 **µPa.**

noise. Sounds that are not of particular interest during an acoustic study and that form the background to the sound being studied. Noise can include both natural sounds and man-made sounds,

micropascal (pPa). The usual reference pressure in underwater sound level measurements.

octave band. A frequency band whose upper limit in hertz is twice the lower limit.

one-third octave band. A frequency band whose upper limit in hertz is 2^{1P} times the lower limit. Three %-octave bands span an octave band. Such bands have widths proportional to the center frequency; the center frequency is given by the square root of the product of **the** upper and lower limit frequencies, and the bandwidth is 23% of the center frequency. There is a standard set of **⅓-octave** frequency bands for sound measurements.

pascal. A unit of pressure equal to 1 newton per square meter.

peak level. The sound level (in **dB)** associated with the maximum amplitude of a sound.

point **source.** A hypothetical point from which sound is radiated. The concept is useful in describing source levels by a pressure level at unit distance. The concept is an abstraction; to describe a 300 m ship as a point source stretches the imagination, but at a distance of 10 **n.mi.** the received sound may as well have come from a point source radiator.

power density spectrum. The result of a frequency spectrum analysis to determine the distribution of power **in** a signal vs. frequency where continuously distributed sound (not tones) is the important signal component. Correct units of a power density spectrum are watts/Hz but the usual units in acoustics are **µPa^2/Hz,** because the power is proportional to the mean square pressure and pressure is the commonly measured quantity.

power spectrum. The result of a frequency spectrum analysis to determine the distribution of power in a signal vs. frequency where tones are the important components of the signal. Correct units of a power spectrum are watts but the usual units in acoustics are **µPa^2,** because the power is proportional to pressure squared and pressure is the commonly measured quantity.

pre-dive flex. A distinctive concave bending of the back occasionally exhibited by bowheads while they are at the surface but shortly before they are about to dive.

pressure. A physical manifestation of sound. The dimensions of pressure are force per unit area. The commonly used unit of acoustical pressure is the **micropascal.**

propagation loss. The loss of sound power with increasing distance from the source. Identical to transmission loss. It is usually expressed in dB referenced to a unit distance like 1 m. Propagation loss includes spreading, absorption and scattering losses.

proportional bandwidth **filters,** A set of filters whose bandwidths are proportional to the filter center frequencies. One octave and one-third octave filters are examples of proportional bandwidth filters.

pure tone. A sinusoidal waveform, sometimes simply called a tone. There are no harmonic components associated with a pure tone.

reflection. The physical process by which a traveling wave is returned from a boundary. The angle of reflection equals the angle of incidence.

refraction, The physical process by which a sound wave passing through a boundary between two media is bent. If the second medium has a higher sound speed than the first, then the sound rays are bent away from the perpendicular to the boundary; if the second medium has a lower sound speed than the first, then the sound rays are bent toward the perpendicular. Snell's law governs refraction: $c_2 * \sin\theta_1 = c_1 * \sin\theta_2$, where c is the sound speed, subscript 1 refers to the first medium and subscript 2 refers to the second medium, and the angles are measured from the perpendicular to the boundary. Refraction may also occur when the physical properties of a single medium change along the propagation path.

RL. Received Level; the level of sound reaching a location some distance from the sound source (*cf.* source level).

scattering. The physical process by which sound energy is diverted from following a regular path as a consequence of inhomogeneities in the medium (volume scattering) or roughness at a boundary (boundary scattering),

signal. A sound of interest during an acoustic study.

S:N. Signal-to-Noise ratio; the difference in level, measured in decibels, between a signal of interest (in this study, usually ***Karluk*** or icebreaker sound) and the background noise at the same location (in this study, usually ambient noise).

sonobuoy. A sound monitoring and transmitting device that includes a hydrophore, amplifier and an FM radio transmitter. Sonobuoys are designed to be dropped into the water from an aircraft. They can also be deployed from the surface. Sounds in the water can be monitored from a remote location via radio receivers,

sound, A form of energy manifested by small pressure and/or particle velocity variations.

sound pressure. The pressure associated with a sound wave.

sound pressure density spectrum. The description of the frequency distribution of sound pressure in which the actual pressure at any frequency is infinitesimal but, integration over any non-zero frequency band results in a non-zero quantity. The correct dimensions of sound pressure density spectrum are pressure squared per unit frequency; a common unit is $\mu Pa^2/Hz$. *cf.* power density spectrum.

sound pressure density spectrum level. The measure, in decibels, of sound pressure density spectrum. A common unit is dB re 1 $\mu Pa^2/Hz$.

sound pressure level (SPL). The measure, in decibels, of sound pressure. The common unit is dB re 1 µPa.

sound pressure spectrum. The description of the frequency distribution of a sound pressure waveform consisting of tones. The dimension is that of pressure; a common unit is the micropascal (pPa).

source level. A description of the strength of an acoustic source in terms of the acoustic pressure expected a hypothetical reference distante away from the source, typically 1 m, assuming that the source is a point source. Source level may be given in units of dB re 1 µPa-m. Source level may vary with frequency (see source spectrum level) but it may be given for some band of frequencies.

source spectrum level. A description in decibels of the strength of an acoustic source as a function of frequency. The description is meaningful for sources of tones. source spectrum levels are described in decibels referred to a unit pressure at a unit distance, such as dB re 1 µPa-m.

spectrum level. See "sound pressure density spectrum level".

spherical spreading. Sound spreading as spherical waves. The transmission loss for spherical spreading is given by

$$20*\log_{10}(\text{Range}/R_0),$$

where R_0 is a reference range. The received level diminishes by 6 dB when range doubles, and by 20 dB for a tenfold increase in range.

spherical wave. A sound wave whose fronts are spherical y shaped. Such a wave forms in free space without reflecting boundaries or refraction. Typically, spherical waves are emitted by point sources and retain their sphericity until the influence of reflected waves or refraction becomes noticeable,

spreading loss. The loss of acoustic pressure with increasing distance from the source due to the spreading wavefronts. There would be no spreading loss with plane waves. Spreading loss is distinct from absorption and scattering losses.

SSDC. Single Steel Drilling Caisson or Steel-Sided Drilling Caisson; this is a mobile bottom-founded drilling platform constructed from part of a supertanker.

surfacing. As defined in this study, a surfacing by *a* whale is the interval from the arrival of the whale at the surface following one long dive until the start of the next long dive. Periods while the animal is just below the surface between breaths (blow intervals) are not counted as dives. Equivalent to the term "surfacing sequence" used by some authors.

threshold of audibility, The level at which a sound is just detectable. The threshold of audibility depends on the listener and varies with frequency.

third octave. Abbreviation for one-third or ⅓ octave (see above).

time delay. A time difference between related events, such as the time between arrivals of a sound wave at two receivers, or the time between sound transmission and the reception of its reflection.

tone. A sinusoidal waveform, sometimes called a pure tone. There are no harmonics. A tone is distinct from waveforms consisting of components continuously distributed with frequency.

transducer. A device for changing energy in one form (say mechanical) into energy in another form (say electrical). An acoustic transducer might change a pressure waveform into an electrical waveform, or vice versa. Microphones, hydrophores, and loudspeakers are examples of transducers.

transmission loss. The loss of sound power with increasing distance from the source. Identical to propagation loss. It is usually expressed in dB referenced to a unit distance like 1 m. Transmission loss is includes spreading, absorption and scattering losses.

waterfall spectrogram. A graphical depiction of the intensity of sound components at various frequencies over time. Time and frequency are shown on the X and Y axes, and intensity is shown as a third dimension. A waterfall graph may indicate only relative powers,

waveform. The functional form, or shape, of a signal or noise vs. time.

wavelength. The length of a single cycle of a periodic waveform. The wavelength λ, frequency f, and speed of sound c are related by the expression $c = f*\lambda$.

INTRODUCTION

The possible effects of underwater noise from offshore oil and gas activities have been a significant concern to Minerals Management Services (MMS), the National Marine Fisheries Service (NMFS), and other agencies for several years. Hence, MMS has funded studies to document the characteristics of oil industry noises and their effects on the behavior of bowhead and gray whales. These and other disturbance studies have been reviewed and summarized by Richardson et al. (199 lb) and Richardson and Malme (in press).

Prior to this study, all systematic studies of disturbance to bowheads had been done in summer or early autumn when the whales are either in open water or in loose pack ice where their movements are relatively unrestrained by ice. There had been no work on the disturbance reactions of bowheads migrating in leads through areas of heavy ice cover—the normal situation in spring. Also, there had been no systematic scientific study of the suggestion by Inupiat whalers that bowhead whales are especially sensitive to noise in the spring.

The National Marine Fisheries Service took note of the above situation in its recent Biological Opinions on lease sales in the Beaufort and Chukchi seas. NMFS believes that development and production activities in spring lead systems used by bowheads might, in certain circumstances, jeopardize the continued existence of the Western Arctic bowhead whale population (Evans 1987; Brennan 1988; Fox 1990). The possibility of significant disturbance in spring lead systems, when bowheads may have few or no optional migration routes, was one of the factors about which NMFS was concerned.

The beluga or white whale is the one other cetacean that migrates through the spring lead systems in a manner similar to the bowhead. The sensitivity of various populations of white whales to several types of human activities and underwater noises has been found to vary widely. There was great tolerance in some situations. However, white whales exhibited strong avoidance reactions to ships and icebreakers at very great distances during spring in the eastern high arctic (Finley et al. 1990). The responsiveness of white whales to underwater noise during the spring migration around western and northern Alaska has not been studied previously.

In order to answer some of the questions about noise effects on bowhead and white whales during spring, MMS funded the present study. The main objectives are to determine the short-term effects of production platform noise and icebreaker noise on the movements and behavior of bowhead and white whales migrating through open leads and pack ice near Pt. Barrow, Alaska, in spring. A related objective is to determine the characteristics of sound propagation and of natural ambient noise in spring lead systems. These physical acoustic phenomena affect the received levels and prominence of man-made noise. Reactions of whales to helicopter overflights are also to be determined when possible.

This preliminary report describes results from 1991, the third year of a continuing study. The study is scheduled to continue for one additional spring season, in 1992. In 1989-1990, we obtained

- considerable information on physical acoustic phenomena (ambient noise and sound propagation) in spring lead systems,
- considerable data on reactions of bowhead and white whales to playbacks into spring lead systems of continuous sounds from one drilling platform-a rig on a bottom-founded ice pad, and
- limited data on reactions of bowhead and white whales to Twin Otter fixed wing aircraft and Bell 212 helicopters.

In 1991, our highest priority objective was to determine the reactions of bowhead and white whales to a second type of industrial noise, the variable noise from an icebreaker that was actively breaking ice. There were several additional related objectives (see below).

Weather and ice conditions were generally unfavorable for this type of work near Barrow, Alaska, during the spring of 1991. We obtained considerable information about physical acoustic phenomena and whale movement patterns past Barrow, but results from the playback experiments with icebreaker noise were quite limited. Consequently, the Minerals Management Service decided to continue the project for another spring season (1992), and to cancel the requirement for a detailed report on the 1991 data. MMS decided that the 1991 data should be analyzed during the late 1991-early 1992 period, but not reported officially until after the 1992 field season. At that time, a combined report on the 1991-92 results is to be produced.

The present report is a brief and preliminary account of the 1991 data. Although a full presentation has been postponed until after the 1992 data are available, a brief 1991 report is necessary for review by the project's Scientific Review Board and for submission to the National Marine Fisheries Service's permit office. This report presents most of the main results from 1991, but includes less interpretation and discussion than would normally appear in a final annual report. The final reports on the first two field seasons of the study (Richardson et al. 1990a, 1991a) contain much background information that is not repeated here.

Specific 1991 Objectives

The overall objectives of the study, the rationale for various study components, the specific objectives of the 1989-90 work, and the general approach taken in the field, were discussed in the earlier reports (Richardson et al. 1990a: 17-22, 1991 a:2- 10). That material is not repeated here.

The specific objectives of the 1989-90 and the 1991 phases of this project were similar, except that a different type of industrial sound was to be used during sound playback experiments near bowheads in 1991 than in 1989-90. When possible, reactions of white whales to this sound were to be determined as well. Physical acoustic measurements—including data on received sound levels near whales, sound propagation loss, and ambient noise—were necessary to interpret the playback results. Because of concern about the effects of low-frequency industrial sound components on bowheads, and the inability of a practical sound projector to reproduce those components, several indirect methods of addressing the importance of low frequency components were identified as objectives in 1990. As a lower priority, the reactions of bowhead and white whales to actual helicopter overflights were to be determined if opportunities allowed.

The first of the specific objectives for the third year of the project was as follows:

1. To record sounds from the SSDC caisson while it was drilling during winter conditions, including infrasonic components, and to analyze those sounds to determine their levels, spectral characteristics, and attenuation properties.

This work was to be done during the winter of 1990-91 at the ARCO Fireweed drillsite between Barrow and Prudhoe Bay. However, drilling by the SSDC ceased early in December 1990, before the caisson operator considered it practical to make the desired field measurements. Hence, this objective was not met in 1990-91. The part of specific objective 5 that was to be based on these recordings (see below) also could not be met in 1990-91. The SSDC is drilling again at another site east of Barrow during the winter of 1991-92, and the winter recording work near the SSDC is being attempted again in January 1992.

It had originally been hoped that the winter recording work at the SSDC caisson would provide a recording of sounds suitable for use during playback experiments in the spring of 1991. In the absence of such a recording, it was decided that a recording of underwater sounds from the Canmar icebreaker *Robert Lemeur* while it was actively breaking ice would be most appropriate for playbacks in 1991, This decision was made early in 1991 in consultation with MMS, the project's Scientific Review Board, the North Slope Borough's Dept of Wildlife Management, and the Barrow Whaling Captains' Association. The icebreaker sounds used for the playbacks vary widely during the duration of the recording. It was felt that the reactions of whales to these variable sounds, relative to their reactions to the very steady *Karluk* drilling platform sounds tested in the 1989-90 playbacks, would be of much interest. Tests of the reactions of whales to icebreaker sounds had been identified by MMS as one of the top priority objectives since the beginning of the project.

After it was decided that playbacks of icebreaker sounds would be the top priority in 1991, the specific objectives for the main 1991 field season were as follows:

2. To measure ambient noise levels and characteristics in leads and cracks along the spring migration corridor of bowhead and white whales in the western Beaufort Sea in 1991, including infrasonic components.

3. To measure and model transmission loss of underwater sound along that part of the spring migration corridor in 1991, based on playbacks of (a) test tones at selected frequencies, and (b) broadband industrial sounds. Infrasonic components cannot be projected.

4. To measure the short-term behavioral responses of bowheads and (as possible) white whales visible in open water areas along their spring migration corridor in the western Beaufort Sea to underwater playbacks of variable icebreaker sounds. Infrasonic components cannot be projected.

5. To collect some of the data needed to assess the importance of the infrasonic components of industrial noise. Specifically y, *(a)* to measure ambient noise at infrasonic frequencies during spring 1991, and ***(b)*** to determine whether bowhead calls contain infrasonic components (supplementing limited data from 1990). Also, based on the winter recordings of SSDC sounds (objective 1), we were *(c)* to determine the frequencies, levels and attenuation of the infrasonic components of drilling caisson sound. As noted earlier, objective 5c could not be met in 1990-91.

6. To measure, on an opportunistic basis, the short-term behavioral responses of bowheads and (as possible) white whales visible in open water areas along their spring migration corridor in the western Beaufort Sea to actual helicopter overflights (supplementing limited data from 1989-90).

7. To document, as opportunities allow, other aspects of the movements, behavior, basic biology, disturbance responses and acoustic environment of bowhead and white whales along their spring migration corridor in the western Beaufort Sea in 1991,

8. To assist and coordinate with other studies and local resource users to maximize collection of needed data and to avoid interference with subsistence whaling and other studies.

9. To analyze the data to test hypotheses concerning the effects of the icebreaker sounds and helicopter overflights mentioned in (4) and (6) on (a) the movement patterns and (b) the behavior of bowheads and white whales visible along their spring migration corridor in the western Beaufort Sea in 1991.

Of the higher priority objectives (numbers 1-5), objectives 2,3, 5a and 5b were more-or-less fully met during 1991. However, only limited data could be obtained relative to the key objective (number 4). Work on objectives 1 and 5c had to be deferred until early 1992, as explained earlier.

The lower priority objectives (numbers 6-8) have been the same each year of the study, Some progress was made toward meeting objective 6, and objective 8 was met. We obtained more than the expected quantity of data relevant to objective 7. The persistent low cloud usually prevented behavioral observation work, which was needed to address the highest priority objective (4). However, the cloud layer often was high enough to allow low-altitude flights. Reconnaissance surveys and vertical photographic work during the low-altitude flights contributed data on whale distribution, movements, individual identities, and sizes, all of which are relevant to objective 7.

This preliminary report contains some of the analyses that would be necessary to address objective 9. However, the definitive analyses and hypothesis tests required by objective 9 have been deferred to the combined 1991-92 report that is to be prepared after the planned 1992 field season.

The Null and Alternate Hypotheses

MMS initially indicated that the ***primary purpose*** of the study was to test the following generalized null hypothesis:

> "Noises associated with offshore oil and gas production activities ***will not*** significantly alter the migratory movements, spatial distribution, or other overt behavior of bowhead whales during the spring migration in the eastern Chukchi and western Beaufort Seas."

MMS indicated that the ***secondary purpose*** of this study was to test a similar generalized null hypothesis concerning white whales.

During the planning phase of this study, the hypotheses to be assessed were made more specific in four ways: (1) the types of oil and gas activities of concern, (2) the criteria of whale behavior to be considered, (3) the geographic location and environmental circumstances of the tests, and (4) the fact that playback techniques were to be used to simulate the noise from a platform. Four null hypotheses of a more specific nature were developed for each of the two whale species. For 1989-90, hypotheses 1 and 2 referred to playbacks of recorded noise from a bottom-founded platform. After modification of those two hypotheses to deal with icebreaker sounds, the hypotheses to be addressed in 1991 were as follows:

1. Playbacks of recorded noise from an icebreaker working on ice will not (or alternatively will) significantly alter measures of migration routes and spatial distribution of whales in the open water of nearshore lead systems during the spring migration near Pt. Barrow, Alaska.

2. Playbacks of recorded noise from an icebreaker working on ice will not (or alternatively will) significantly alter subtle aspects of individual whale behavior in the open water of nearshore lead systems during the spring migration near Pt. Barrow, Alaska.

3. Helicopter overflights will not (or alternatively will) significantly alter measures of migration routes and spatial distribution of whales in the open water of nearshore lead systems during the spring migration near Pt. Barrow, Alaska.

4. Helicopter overflights will not (or alternatively will) significantly alter subtle aspects of individual whale behavior in the open water of nearshore lead systems during the spring migration near Pt. Barrow, Alaska.

MMS indicated that greater emphasis should be placed on hypotheses (1) and (3) relating to effects on migration routes and distribution, than to hypotheses (2) and (4), relating to subtle aspects of the behavior of individual whales, However, LGL undertook to address hypotheses (2) and (4) as well, at least for bowheads. Difficulties in observing some aspects of the individual behavior of white whales from an aircraft circling at high altitude made it doubtful whether hypotheses (2) and (4) could be assessed for white whales.

Hypotheses 1 and 2 have already been addressed with respect to the effects on ***bowheads*** of playbacks of recorded continuous noise from a bottom-founded platform like ***Karluk*** (Richardson et al. 1991a, pages 226*ff* and 246*ff*). We concluded that, at least in the circumstances studied,[1] ***Karluk*** playbacks resulted in statistically significant small-scale changes in migration routes, spatial distribution, and individual behavior. However, there was no evidence of migration blockage, and we concluded that the observed effects were likely to be biologically non-significant, We have discussed elsewhere the numerous complications and limitations in applying these 1989-90 results from playback tests with one type of industrial sound to the situation of an actual drilling platform operating in or near a spring lead system (Richardson et al, 1991a, pages 10*ff* and 261*ff*). One of the purposes of the 1991 tests with a second and more variable type of industrial sound was to evaluate the generality of the 1989-90 results.

Hypothesis 1 has also already been addressed with respect to the effects on ***white whales*** of playbacks of the ***Karluk*** sounds (Richardson et al. 1991a: 281). We concluded that, in the circumstances studied,[1] playbacks of ***Karluk*** sounds had detectable but biologically non-significant effects on migration routes and spatial distribution of white whales. Again, various complications and limitations apply. Hypothesis 2, concerning effects on individual behavior, could not be tested for ***Karluk*** sounds vs. white whales.

Hypotheses 3 and 4, relating to effects of helicopter overflights on bowheads and white whales, were not formally tested during the 1989 or 1990 phases of the work, and they are not

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[1] For whales visible in open water amidst the pack ice and in the seaward side of the nearshore lead system during spring migration east of Pt. Barrow, Alaska.

tested in this report either. Relevant data were obtained in each year from 1989 through 1991, but this work *was* given a low priority; the 1989-91 data are opportunistic and are largely anecdotal. It is expected that further relevant data will be obtained in the planned 1992 work, whereupon hypotheses 3 and 4 will be evaluated,

Assumptions and Limitations

The most serious limitation of the 1991 work was the small number of systematic observations of whales in the presence and absence of icebreaker sounds. The difficult weather and ice conditions prevented us from obtaining many systematic data on whale distribution, movement or behavior near the sound projectors. Hence, it is not yet possible to test hypotheses 1 or 2 with respect to the effects of icebreaker noise on either bowheads or white whales.

During the project as a whole (1989-91), a number of assumptions had to be made in designing an experimental field study that would address the general and specific project objectives. Additional assumptions must be made in using the results to predict the reactions of whales to actual oil industry operations. Associated with most of these assumptions are various limitations. The following is a list of the assumptions and limitations, updated slightly to take account of the 1991 as well as the 1989-90 work, but excluding most discussion and explanatory material given in earlier reports (e.g. Richardson et al. 1991a:10*ff*).

(1) The study area, located NE, ENE and E of Point Barrow, is assumed to be reasonably representative of locations where bowheads and white whales migrating around northern Alaska in spring might encounter oil industry activities.

> ***Limitations***: (a) All sound propagation tests and behavioral observations in 1989-90 were necessarily performed in pack ice conditions or along the south side of the pack ice (north side of the nearshore lead). In 1991, however, the most useful results were obtained on 17 May when the projectors were on the edge of the landfast ice.
>
> (b) The applicability of the 1989-91 results to the Chukchi Sea is not verified, since all 1989-91 playback data were necessarily obtained in the western Beaufort Sea.
>
> (c) Water depths at many 1989-90 study locations were greater than those where bottom-founded drilling and production platforms are likely to be constructed. Water depth affects sound propagation.

(2) **In order to draw conclusions** about ***all*** **whales** migrating around **northern** Alaska **in spring,** it would be necessary to assume that whales visible in leads and amidst the pack ice (i.e. those studied here) react to underwater noise in about the same way as those that are not visible. The accuracy of this assumption is unknown, so we restrict our discussion (and the title of the report) to whales ***visible*** during spring migration.

> ***Limitations:*** (a) The likelihood of detecting and successfully observing whales differs greatly among ice types. We obtained no data on whales migrating through closed lead conditions, and very few data on whales traveling through heavy pack ice (but see 30 April 1989 results—Richardson et al. **1990a:174).**
>
> (b) Even in open pack ice, some individual whales are likely to behave in ways that make them more visible than other whales. Whales that come close to the noise source are most likely to be seen. This "observability bias" was a problem in 1989 and 1991, but not in 1990 (see Richardson et al. **1991a:225).**
>
> (c) Because of masking problems, acoustic monitoring and localization methods are not as useful in a noise playback study as in a study of undisturbed whales.

(3) Underwater playback of recorded underwater sounds from an industrial operation is assumed to be a useful method for evaluating the likely reactions of whales to actual industrial operations of corresponding types.

> ***Limitations:*** (a) Underwater playback techniques simulate the sounds emitted by an industrial site, but exclude other stimuli to which whales may be sensitive, e.g. sight, smell, effects of physical presence on water flow. This is an advantage in that it tests the effects of noise ***per*** se, but a disadvantage in that the playback does not simulate all aspects of the actual industrial operation.
>
> (b) The types of sounds available for use in this study were limited. It is uncertain how similar the sounds from a future drilling/production platform would be to the ***Karluk*** sound used in 1989-90. Any extrapolation of playback results to situations involving other types of industrial sounds is speculative.
>
> (c) Sounds emitted during playbacks do not simulate the full range of sounds that an actual industrial site would emit over a long period of time.
>
> (d) Sounds emitted during playbacks do not simulate the full frequency range of sound and vibration emitted by an industrial site. Practical playback systems underrepresent the low frequency components. This is not believed to be a significant problem for experiments on white whales, but may be a problem during tests on bowheads.

(4) **It is** assumed that the presence of the observers did not bias the results significantly. Three potential problems existed (see below). However, the potential for bias was limited, and comparison of playback vs. control data provided meaningful data.

***Limitations*:** (a) Whales are known to react to aircraft overflights in some situations; many of the 1989-90 observations were obtained from an aircraft circling above the whales. However, we avoided or excluded observations from periods when aircraft disturbance was a possibility.

(b) The projected drillsite noise came from a small camp located on the edge of an ice pan. This camp, including the ice-based personnel, may have been visible to some of the closer whales while they were at the surface.

(c) It was necessary to use a small gasoline-powered generator at the ice camp during playbacks and some control periods. This emitted underwater noise, which was detectable underwater within a few hundred meters of the campsite during control (quiet) periods in 1989-90. There may have been some short-range responses to acoustic (or non-acoustic) cues from the camp itself during 1989-90. However, these cannot explain the more pronounced responses observed during projection of industrial noise than when the projector was off. In 1991, underwater noise from the generator was greatly reduced through use of a new suspension system.

(5) It is assumed that disturbance of whales is evident by visual observations of their distribution and movements near the noise source, and (for bowheads) visual observations of the details of their individual behaviors. Previous studies have shown that bowhead and white whales often react in visually observable ways when subjected to strong noise from actual or simulated oil industry operations.

Limitations: (a) Even the most conspicuous whales are directly visible for only a fraction of the time—typically less than 20% in migrating bowheads.

(b) The calling rates of whales could not be compared under playback vs. control conditions.

(c) No direct measure of physiological stress is possible during field observations of passing whales. However, for bowheads, surfacing, respiration and diving cycles were monitored quantitatively.

(d) No data of any type could be collected on any whales that avoided detection, e.g. by remaining amidst heavy ice. This was not a significant problem in 1990 (see 2b, above).

(e) This study concerns the short-term reactions of migrating whales, mainly to a single source of simulated industrial noise. The long-term consequences with respect to the well-being of individuals and the population are not addressed directly.

More discussion of the these assumptions and limitations is given in Richardson et al. (1991a: 10*ff* and 261*ff*).

STUDY AREA, WEATHER AND ICE

1991 Study Area

The criteria for selecting our study area have been described in detail in Richardson et al. (1990a, 1991a). The criteria included logistic practicality and safety, access to as many migrating whales as possible, avoidance of interference with spring whaling, and avoidance of interference with the spring bowhead census. It was desirable to work as close to Barrow as possible, but it was necessary to remain to the northeast of Barrow to avoid interference.

The 1989 phase of the work showed that this study could be conducted without interfering with other groups. Therefore, in 1990 and again in 1991, after consultation with local groups and concerned individuals, it was agreed that we could work closer to Barrow than we had in 1989. In 1989, sound projection sites were to be a minimum of -32 n.mi. (60 km) northeast of Pt Barrow. In 1990 and 1991, it was agreed that our projector sites would be at least 15 n.mi. (28 km) NE of the northeastemmost whaling camp. In addition, when the census crew was working on the ice, we agreed to keep the projector at least 20 n.mi. (37 km) NE of the census site. In all years, we undertook not to fly within 5 n.mi. (9 km) of the whaling camps or census sites except as necessary to take off or land at Barrow.

Many bowhead and white whales travel northeastward close to the landfast ice edge when they are near Barrow and Pt. Barrow. However, NE of Pt. Barrow, the ice edge curves to the right; its orientation changes from SW→NE to W→E. Although the paths of whales also tend to curve somewhat to the right in this area, few whales remain along the landfast ice edge after they have traveled more than 30 km NE of Pt. Barrow. Most of our work has had to be at least that far to the NE in order to avoid possible interference with whaling or the census. Thus, in order to be near migrating whales, we have had to set up the sound projector on pack ice to the north of the landfast ice edge. Because the migration corridor “fans out” to the east, and is variable from day to day, this has made it difficult to place the projector in the paths of many whales.

In 1991, spring whaling at Barrow ended in mid-May, and there was no ice-based whale census. During consultations in mid-May, representatives of the Barrow Whaling Captains' Association, Alaska Eskimo Whaling Commission, and NSB Dept of Wildlife Management agreed that we could work close to Barrow, where the whale migration corridor seems to be more concentrated and consistent. Starting on 17 May 1991, we began to conduct aerial surveys west and north of Barrow as well as in our usual study area farther to the northeast. On 17 and 18 May, the sound projector was set up on landfast ice closer to Pt. Barrow than we had worked before. The sound playback results from 17 May were the most valuable playback results obtained in 1991. On other dates in mid- and late May 1991, experimental opportunities were better on the pack ice, and we worked there rather than on the landfast ice. However, we continued to work closer to Barrow than had been possible previously.

1991 Weather

During our 1991 field season, from 28 April through 26 May, temperatures tended to be well above normal (Fig. 1).

Low cloud was more frequent than normal. Although the cloud ceiling was high enough to allow low-altitude VFR flights on most days, days with clear skies or high clouds were very infrequent. This greatly curtailed our ability to obtain systematic aerial observations of whale movements and behavior. Such observations must be made from an altitude of at least 460 m (1500 ft) in order to avoid the possibility of aircraft disturbance to the whales, In 1991, it was rarely possible to climb that high without losing sight of the surface; on most occasions the cloud ceiling was at or below 305 m (1000 ft). Because of the prevailing cloud cover, only one usable satellite image of ice cover in the study area was obtained during the 1991 field season (Plate 1).

A prolonged period of strong easterly winds on 6-10 May had significant effects on ice cover, as described below.

1991 Ice Conditions

Sea ice dominates the Alaskan Beaufort Sea, with ice cover of almost 100% for 9 to 10 months each year (Norton and Weller 1984). There are three principal zones of ice cover in the Beaufort Sea: landfast ice, the shear zone, and the pack ice. A brief description of these zones and the annual variation in their occurrence can be found in Richardson et al. (1990a:28-29).

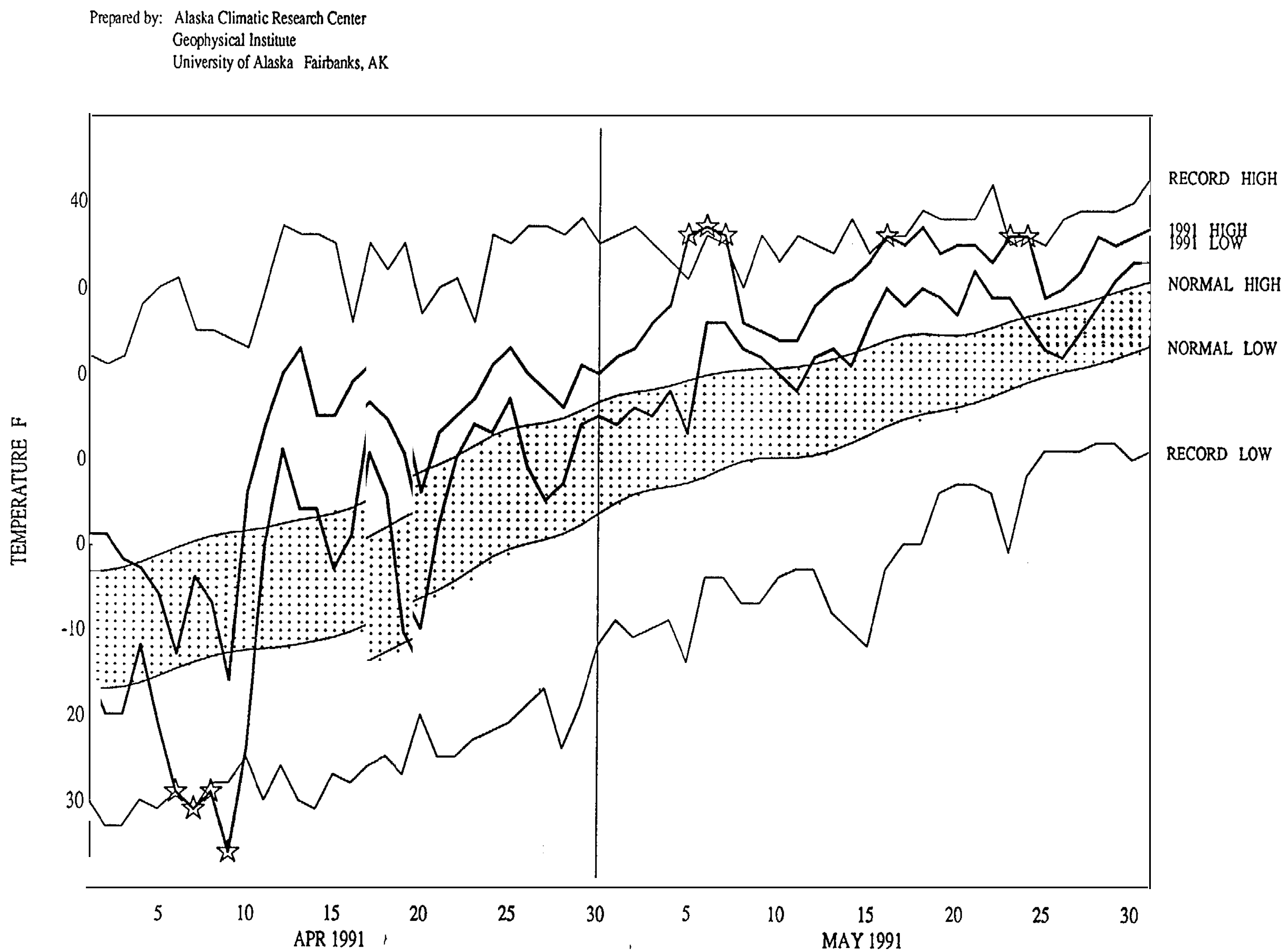


FIGURE 1. Daily weather in April and May 1991 at Barrow, Alaska. Normal and record highs and lows are based on data collected from 1951 to 1980. Stars show occasions in 1991 when the temperature was unusually high or low, i.e. outside the range for 1951-80. Source: Alaska Climatic Research Center, Geophysical Institute, University of Alaska, Fairbanks.

Descriptions of the ice conditions during our studies in 1989 and 1990 can be found in Richardson et al. (1990a, 1991a).

When our study began on 28 April 1991, ice conditions near Barrow were more open than during typical years. A wide nearshore lead was present along the landfast ice from southwest to northeast of Barrow (Plate 1). The ice within this lead was primarily newly-frozen ice with a few large pans of old ice. This broad lead extended far to the east. The situation was in great contrast to that in 1989, when there was nearly total ice cover, largely by thick ice. In 1990 the ice cover was intermediate between that in 1989 and 1991.

A long period of strong easterly winds on 6-10 May moved the pack ice against the landfast ice, ground up many of the ice pans into brash ice, and closed the lead north and northeast of Barrow. When the wind subsided, a wide lead remained west and southwest of Barrow, but north and northeast of Barrow the lead was closed. However, irregular openings were present along the landfast ice edge in that area. The prevalence of brash, small pans, and generally thin, unstable ice made it difficult to locate safe and suitable locations to install the sound projection system.

During mid-to-late May a narrow discontinuous lead was present along the landfast ice edge north and northeast of Barrow. The lead consisted of a series of small to large openings in the pack ice along the landfast ice edge. West and northwest of Barrow the lead remained open and was several kilometers wide. The ice along the northern margin of the lead was primarily unstable new ice.

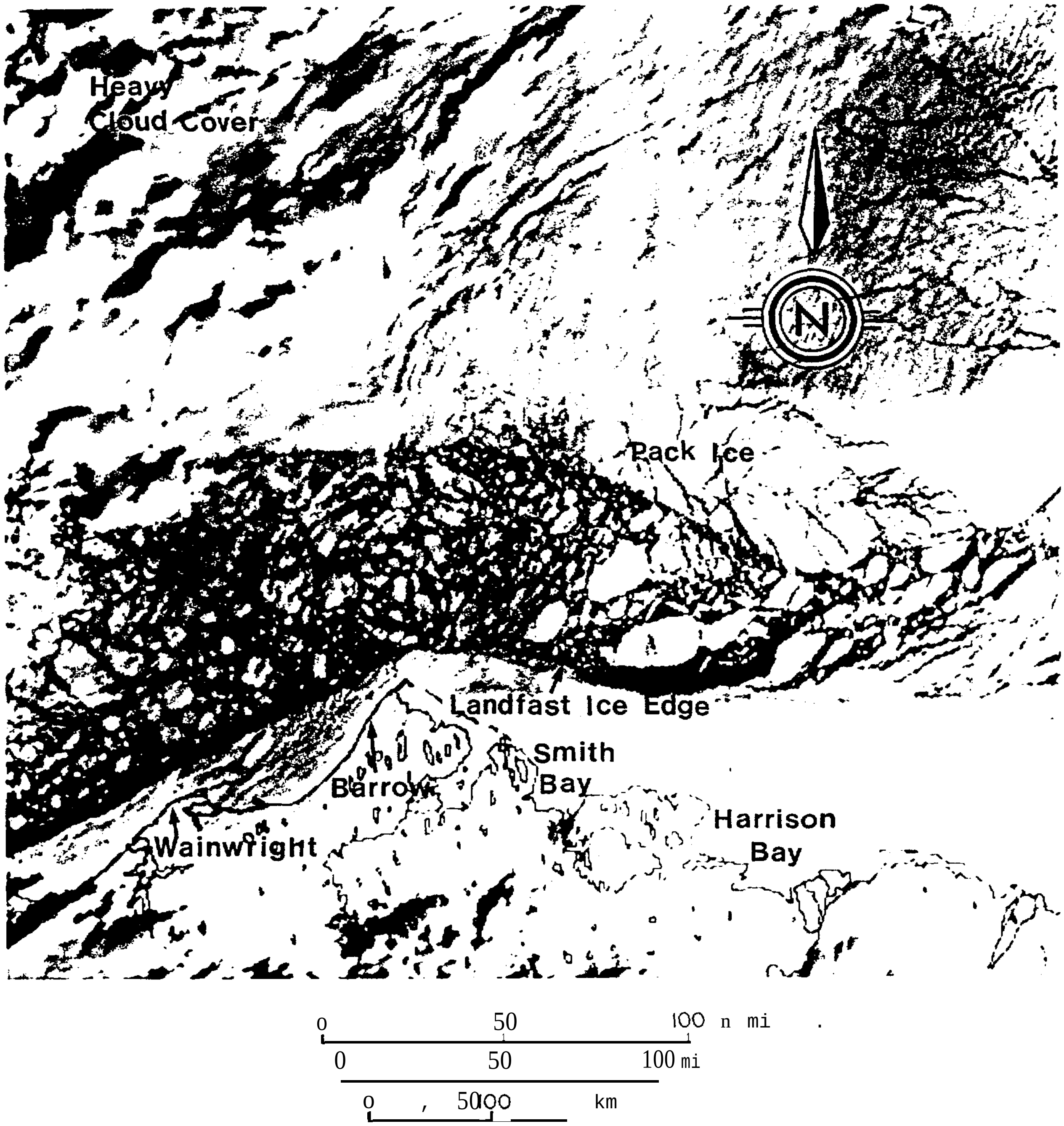


PLATE 1. NOAA satellite imagery of the Beaufort Sea, 4 May 1991, showing a well-developed nearshore lead and extensive offshore pack ice.

METHODS

Physical Acoustics Methods

Ambient Noise

Sonic Frequencies.—The methods used for measuring ambient noise were similar to those used in 1989-90 (Richardson et al. 1990a:44*ff*, 1991a: 19*ff*). During four transmission loss experiments in 1991 (see below), an ITC model 6050C hydrophore was used to obtain recordings of ambient noise at each receiving station before or after reception of projected test signals. The hydrophore was suspended from the edge of the ice to a depth of 18 m via a faired cable. During playback experiments, a monitor sonobuoy (usually an AN/SSQ-57A) placed about 1 km from the ice camp with its hydrophore at depth 18 m provided data on ambient noise before and after the playback periods. Ambient sounds received by the hydrophore and monitor sonobuoy were recorded with a TEAC RD- 10IT DAT recorder.

Analyses of power spectral densities used 1, 2 or 4 Hz bin widths (depending on sample rates) and averaged over -8 s. Some special analyses used longer averaging times. From the spectrum levels, power levels were determined for the 20-1000 Hz band and for %-octave bands centered at 10 through 6300 Hz. The one-third octave data from 46 ambient noise recordings during the spring of 1991 were used to determine percentile levels of ambient noise vs. frequency.

Infrasonic Frequencies.—As in 1990, an ITC model 1032 spherical hydrophore and low-frequency preamplifier were used to record sounds at frequencies below 20 Hz. The TEAC RD- 101T DAT recorder was used. The resulting recordings were analyzed down to 6 Hz. One-third octave band levels were determined for 1O, 12.5 and 16 Hz in the infrasonic band. The results showed wide variability.

Transmission Loss

Projectors.—Transmission loss experiments, as well as playback experiments, involved a different projector arrangement in 1991 than had been used previously. In an attempt to improve the low frequency performance of the projector system, we used a U.S. Navy model J-13 projector rather than the model J-11 used in 1989-90. In addition, because the J-13 is not designed for sound reproduction above about 2 kHz, we used a model F-40 spherical transducer for higher frequencies. They were suspended together at a depth of 18 m. We incorporated a 1 kHz crossover filter network designed for *use* with J-13 and F-40 projectors and loaned to the project by BBN Systems & Technologies Corp. The J-13 was used to project sounds at frequencies up to 1 kHz and the F-40 was to project sounds at higher frequencies. This system was expected to have higher overall output than did the J-1 1 used previously, and better reproduction of low frequency components.

In the first transmission loss (TL) test during 1991, the two projector centers were separated by 17" (0.43 m). In all other projector setups the spacing was close to 8" (0.2 m). It was important to minimize the separation so that interference in the crossover frequency range would be minimum. The signals emitted by the combined projector system were monitored via an ITC model 1042 spherical hydrophore mounted -1.6 m above the projectors. The specific distance was measured for each installation.

The combined projector system provided usable sound output, but these signals were not as satisfactory as expected. The 250 W Bogen MT250 power amplifier, in combination with the crossover network, did not drive the projectors adequately. The projected signal levels were no higher than they had been in previous years. The source level of the combined projector system used in 1991 was -164-167 dB re 1 µPa-m, vs. -166 dB with the J-11 used in 1990. This deficiency will be remedied in the planned 1992 work by three actions: (1) use of an ARGOTEC model 220 projector in lieu of the J-13; the ARGOTEC 220 has better low frequency power projecting capabilities than does the J-13; (2) an improved amplifier/crossover network combination; and (3) testing prior to the 1992 field season both in a tank facility at ARGOTEC and in the Santa Barbara Channel at a location at least 100 m deep. These tests will be conducted in March and early April to assure that there is time for remedial action if the initial performance is not satisfactory. A J-11 will be available in the field for backup.

Waveforms.-Two special types of waveforms were developed for the 1991 transmission loss tests. One was a combination of continuous wave (CW) tones at different frequencies, phased to assure that peak levels were not unnecessarily high. There were three waveforms of this type:

(1) a low-tone waveform containing 20 and 40 Hz; (2) a mid-tone waveform containing 50, 100, 200 and 500 Hz; and (3) a high-tone waveform containing 1000,2000, 5000 and 10,000 Hz tones. These three waveforms were transmitted for 30 s each, replacing 8 pure-tone waveforms, each 20 s long, used in 1989-90. The 1991 signals included components at 20-10,000 Hz, as opposed to 50-10,000 Hz in 1989-90. The benefits were shorter test transmission times, more easily detected sounds, and the addition of test signals at 20 and 40 Hz.

The second special type of waveform replaced the frequency sweeps used in 1989-90, The new waveform was a cluster of narrowly-spaced tones spanning 20 Hz. There were two waveforms of this type: (1) a waveform with clusters centered at 150 and 300 Hz; and (2) a waveform with clusters centered at 500 and 1000 Hz. Each of these waveforms was transmitted for 30 s.

In addition to these waveforms, a 60-s segment of the ***Robert Lemeur*** icebreaker sound used in the 1991 playback experiments was transmitted. The total length of the sequence of test signals (tones, tone clusters, icebreaker) was 4 minutes.

TL Test Procedures.—The test signals were projected repeatedly at depth 18 m, and the corresponding received signals were determined at distances ranging from 100 m to 10-19 km. The distances to the stations at 100-400 m were measured by a surveyor's measuring wheel. More distant receiving stations were reached by helicopter. In 1991, distances to those stations were determined from GPS (Global Positioning System) receivers at the projector site and on the helicopter. The GPS system provided more precise and more frequent position data than had been available in previous years.

A Sony DAT Walkman digital tape recorder/player was used to play a composite tape of the TL waveforms and icebreaker sounds for amplification and projection. A TEAC RD-101T DAT machine was used to record the signals received by an ITC 6050C hydrophore suspended on a faired cable at depth 18 m at each receiving station. The DAT recorders provided excellent speed and frequency control even in cold field conditions. Thus, a tone intended to be at 10,000 Hz actually appeared in the 10,000 Hz analysis bin (bin width = 4 Hz) when the received waveform was analyzed. The recorded signals on the audio cassette recorders used earlier were generally within 1 % of the desired frequencies, but 1% translates into a possible 100 Hz error at 10,000 Hz.

The sound signals projected during transmission loss (TL) tests included tones, tone clusters, and a sample of icebreaking noise. These signals were all recorded on the 4-minute TL tape at uniformly high levels to achieve a high dynamic range. However, the highest level at which undistorted signals could be projected was lower for the lowest frequencies than for the higher frequencies. This limited the amount of amplifier gain that could be used. As a practical matter, the operator could not adjust the gain separately for the different parts of the tape. Consequently, the sample of icebreaker sounds projected during the transmission loss tests was generally projected at lower source levels than were used during playback tests. As a result, the icebreaker sounds diminished to the background noise level at relatively short ranges. A second TL signal tape, recorded with lower amplitudes for the low frequency tones, did not solve the problem adequately. This preliminary report does not include the transmission loss results for the samples of icebreaker sound. Those results will be included in the final report on the 1991-92 work.

Playback Experiments

General Approach.—The general approach was very similar to that in preceding years of this project, as described by Richardson et al. (1991a:30*ff*). Icebreaker sounds were projected from a mobile ice-based camp that was established on the pack or landfast ice each day when weather or ice conditions were suitable. The reactions of whales to these sounds were determined bys ystem-atic observations of whales approaching, passing and moving away from the ice camp. Such observations were obtained both when the projectors were operating ("playbacks") and when they were silent ("control"). These types of observations were to be obtained both by observers at the ice camp and by observers in an observation aircraft, as described under "Behavioral Observations" (p. 24). Sound levels received by the whales during playbacks were to be determined by monitoring the source level of the projected sound, its received level at a monitor sonobuoy ~1 km from the projectors, and its received level near the whales as determined by air-dropped sonobuoys.

Playback Procedures.—About 14 minutes of continuous recording of icebreaking sounds from ***Robert Lemeur*** were copied onto a digital audio tape (DAT) in repeated segments to create *a* two-hour playback tape. The characteristics of these sounds are described on p. 48, The end time of the segment was selected such that the levels at the start and end of the segment were closely matched. Thus, there was ***no*** sharp change in the sound at 14-min ***intervals*** when the segment began to repeat. Two such tapes were made so that a 4-h playback could be obtained without the need to rewind the tape. After the first 2 hours of playback, there was a quiet period of about 20s while the tapes were changed.

A Sony DAT Walkman tape recorder/player was used to play back the icebreaker sounds. This resulted in accurate speed and frequency reproduction for the playbacks. These sounds were projected into the water by the J-13/F-40 system described above, again suspended at a depth of 18 m. A TEAC RD- 101T DAT machine was used to record the sounds received at the monitor hydrophore adjacent to the projectors and by the AN/SSQ-57A sonobuoy placed ~1 km away during each playback experiment. As in previous years, the project's Twin Otter aircraft was equipped to drop sonobuoys near bowheads in order to monitor the sounds received by whales. However, the prevailing low cloud made it impractical to conduct aircraft operations near the projector site during playback experiments in 1991.

At the start of each playback experiment, the power amplifier gain was raised gradually from zero to maximum over a 2-5 minute period. The gain was then left constant throughout the remainder of the experiment. However, because the level of the recorded icebreaker sounds varied, the level of the projected sounds also varied on a 14-minute cycle (see p. 53).

The amplifier was powered by the same type of 2.2 kW portable generator used in 1990. However, in 1991 bungee cords were used to suspend the generator from a frame that stood on the ice. This significantly reduced the amount of generator noise and vibration that entered the water (see p. 65).

<u>Bowhead Calls</u>

There is interest in the possibility that some bowhead calls may contain energy at infrasonic frequencies inaudible to humans (<20 Hz), If they do, this would increase the likelihood that bowheads can hear infrasounds, since bowheads are unlikely to emit sounds that they cannot themselves hear. Narrowband spectral density analyses were performed on all bowhead calls received on the 6050C hydrophore or sonobuoys and recorded on the TEAC DAT recorder during five dates: 1, 11, 18,25 and 26 May 1991. Waterfall spectrograms were plotted for the frequency range 6-250 Hz to support a search for call energy at frequencies below 20 Hz. Of the 73 calls analyzed from these 5 days, eleven showed energy at infrasonic frequencies that may have been associated with the call (p. 60).

Aerial Reconnaissance and Surveys

General Approach

Aerial reconnaissance of the study area was necessary on a daily basis in order to locate whale migration corridors, which changed from day today. This information was used in selecting the location where the sound projectors were set up on any given day. In addition, the aerial reconnaissance was a necessary first step in locating and selecting the specific whales to be observed and photographed from the air.

The flight route depended upon ice conditions, and was non-systematic. In general, a series of widely-spaced transects was usually flown, to determine the ice conditions, the locations and orientations of leads, and the locations of any bowhead concentrations. After a location for the sound projectors had been selected, additional surveys were usually conducted as far as ~20 km west and southwest of the projector site. At the point when it became apparent that further reconnaissance surveys were unnecessary in meeting that day's objectives, the aerial crew

- began to conduct aerial observations of whale behavior if bowheads were found and if clouds either were absent or were above 460 *m* Above Sea Level (1500 ft ASL); or
- began to photograph bowheads if bowheads were present but low cloud prevented behavioral observations from 460 m ASL; or
- returned to Barrow if no bowheads could be found or if the weather was too marginal for productive or safe flying.

Insofar as possible, we avoided flying low (at <460 m) over the main nearshore lead during the midday period. At that time of day, a National Marine Mammal Laboratory (NMML) crew was usually flying low over the leads within our study area, searching for bowheads to photograph.

We avoided flying within 5 n.mi. (9 km) of active whaling camps except when this was unavoidable because of the presence of camps within 5 n.mi. of the approach to B arrow's airport. In 1991, whaling at Barrow ended in mid May. From 17 May onward, we conducted reconnaissance surveys along the landfast ice edge and nearshore lead west and northwest of Barrow as well as in the usual study area farther northeast of Pt. Barrow.

Survey Methods and Data Recording

We conducted aerial surveys from 28 April through 26 May 1991 in a DHC-6-300 Twin Otter aircraft. In addition to the standard belly fuel tanks, this aircraft had wingtip tanks and an additional tank in the cabin; total aircraft endurance under our typical operating conditions was 9+ hours. Other special equipment included marine VHF radios, VLF/GPS navigation system, radar altimeter, invertors for 120 V/60 Hz power, three bubble windows (right center, left center, left rear), intercom system with voice activated microphones, and ventral camera port.

The aircraft was equipped with a Wulfsburg combined VLF/GPS navigation system that operated in GPS mode normally and reverted to the less-precise GNS-VLF mode during the small percentage of the time when GPS was unusable. When GPS became usable again after a period of VLF navigation, the GPS automatically updated the VLF system to correct for accumulated errors. When the GPS was usable, position readouts were usually accurate within 0.2 n.mi., based on the readout upon return to a known location at Barrow. As usual, position errors as large as 1 km were common when operating in VLF mode. A microcomputer interfaced to the VLF/GPS system and the radar altimeter automatically recorded aircraft position and altitude at intervals of 10 s or less.

There were a total of 30 offshore flights on 23 different dates during 1991. On five of these days, the single flight was terminated within 0.3- 1.0 hours because of poor weather offshore. The remaining 25 flights ranged from 1.6 to 5.2 hours in duration. Longer flights were not warranted during 1991 because of the low clouds that almost always prevented observations from altitude 460 m. Total flight time during the 30 offshore flights was 75.4 h.

Flight and observation procedures were consistent with those during the 1989-90 phases of this project. During reconnaissance work, the aircraft was flown at -185-200 km/h groundspeed and, when possible, at 460 m ASL. When the cloud ceiling was lower than 460 m, as it almost always was in 1991, the maximum possible altitude below the cloud layer was maintained.

Four observers were present during almost all surveys. During surveys, one observer (right front) was in the co-pilot's seat, two were at bubble windows on the left and right sides of the aircraft two seats behind the pilot's seat, and the fourth was at a rear-left bubble window. When a whale was sighted, the observer(s) notified other members of the crew via the intercom. Most bowheads were circled at least briefly to obtain information on the activity of the whale and to determine whether additional whales were present nearby. White whales were usually not circled, but large groups were sometimes circled to obtain more accurate counts and heading information. For each whale sighting, we dictated *into* a tape recorder the time, location, species, number, general activity, orientation, and ice conditions. Ice conditions were recorded throughout the survey, particularly whenever a change in ice type or percent cover occurred. Aircraft position and altitude were recorded manually from the VLF/GPS system whenever sightings were made and whenever the aircraft changed course. Position and altitude were also logged automatically throughout each flight, as noted earlier.

All 1991 sightings of bowheads and white whales have been transcribed into a standard numerical format, computerized, and mapped in this report.

Aerial Photograph of Bowheads

Aerial photography of bowheads was one of the lower priorities during this project, but it was often possible at times when higher priority work was prevented by the low clouds that prevailed during the spring of 1991. Hence, more time than anticipated was devoted to photographic work. Vertical photos of bowheads were obtained during 11 flights on 10 dates ranging from 29 April through 26 May 1991. Similar work was done during the 1989 phase of this project, but was not possible in 1990.

We used the calibrated vertical photography technique developed by LGL and described by Davis et al. (1983). The resulting photos provided data on the individual identities and sizes of many of the whales photographed, These data are relevant to specific objective 7 concerning the movements, behavior and basic biology of bowheads (p. 5). The data would have been relevant in evaluating the effects of the top-priority playback work (specific objective 4) if the weather and ice conditions had allowed more extensive playback work in 1991.

Field procedures were as described by Davis et al. (1983) and Richardson et al. (1990a:60*ff*). Briefly, the aircraft, flying at an airspeed of-160 km/hand-cloud ceiling permitting-an altitude of -137 m (450 ft), passed directly over bowheads. Because of the prevailing low clouds, some photographs were taken from lower altitudes. Photographs were taken through the aircraft's ventral camera port with one of two hand-held Pentax medium-format cameras (6x7 cm film size), each with a 105 mm *f*2.4 lens, pointed directly downward. Ektachrome 200 color positive film was used. Aircraft altitude was recorded from the radar altimeter, both manually and via the computerized data logger, at the moment the camera shutter fired. On one date, a calibration target of known dimensions was spread out on flat lagoon ice and photographed five times with each of the two cameras from each of three altitudes (-137, ~107 and -76 m).

When behavioral observations of whales were possible either from the aircraft or by ice-based observers, low-altitude photographic work was avoided until the behavioral observations were completed. We also did not purposefully photograph bowheads at locations where the NMFS/NMML crew had photographed bowheads on the same date. We supplied NMML with copies of our 1991 photos of identifiable bowheads, and they reciprocated with copies of their 1991 photos.

The procedures used to identify individual whales and to determine their sizes are summarized by Richardson et al. (1990a:62-63). The sizes of all bowheads photographed by LGL in 1991 have been determined, including allowance for measurements of a calibration target, However, the sizes of some whales photographed by NMML are not yet available. Also, the NMML lengths referenced here are approximate; they are measured lengths that have not been converted to actual whale lengths by application of correction factors developed from calibration photographs.

Measurements of the LGL calibration target as photographed from -76 m were more variable than those from higher altitudes. Hence, we considered whale lengths determined from photographs taken at <91 m (<300 ft) to be approximate. Such lengths are included in histograms when no "better" measurement was available for the whale in question. However, these approximate lengths will be excluded from analyses that require precise length measurements, e.g. analyses of growth rate.

All of LGL's 1991 photos have been compared with one another to check for whales photographed more than once. LGL's 1991 photos have also been compared with some of NMML's 1991 photos; however, the LGL/NMML comparisons for 1991 are still underway at the date of writing. We also compared LGL's 1991 photos of whales that were potentially re-identifiable between years (Grade A) with the complete LGL and NMML photo collection for 1981-90. In these inter-year comparisons, LGL's Grade A whale images from 1991 were compared with all 1981-90 Grade A images in the same file and in" adj scent" files. The adjacent files are those containing whale images with similar characteristics (Rugh et al. in press).

Behavioral Observations

Aerial Observations

Our standard procedures for aerial observations of bowheads (e.g. Richardson et al. 1991 a:27*ff*) were applied whenever observations were possible from an altitude of 460 m. Unfortunately, the prevailing low cloud usually prevented useful observations in 1991. We obtained only 4.1 h of systematic behavioral observations; these came from 7 observation sessions on 5 dates (29 April, 4, 6, 20 and 25 May). In 1991, we were never able to obtain aerial observations of bowheads near the operating sound projectors. The few times when the aircraft crew could observe from 460 m ASL near the ice camp were times when no bowheads were present, or the sound projection equipment was still being setup, or when dangerous ice conditions or encroaching fog forced termination of ice camp and/or aircraft operations before useful data could be obtained.

Thus, the few aerial observations of bowhead behavior obtained in 1991 all concerned "presumably undisturbed" whales, not whales exposed to playbacks of icebreaker noise. These "control" data were too meager to be of value in themselves. They have been coded numerically in our standard format, computer validated, and set aside for future analysis in combination with data from other years.

Ice-based Observations

Ice-based observations of bowheads and white whales were obtained to help meet specific objectives 4, 6 and 7 (p. 4). When no whales were present, ringed and bearded seals were observed opportunistically, or the day's plan was changed to conduct a transmission loss test,

Field procedures, primarily involving use of a surveyor's theodolite to observe and locate whales, were very similar to those during 1990 (see Richardson et al. 199 1a:29*ff*). We again used a Lietz/Sokkisha model DT5A digital theodolite with 10 second precision. The height of the theodolite was determined each day by taking a gravity-referenced horizontal reading from a vertical stadia rod at the projector location. Theodolite readings in degrees, minutes and seconds were referenced to magnetic north and to gravity. Most ice ridges on which the theodolite was placed were less stable than desired. To control for error, the horizontal and vertical zeroes were checked about every 30 min and after tracking episodes, and were reset if off by >1 minute of arc,

One difference from previous years was that, on most dates, the digital theodolite was interfaced by way of an RS-232 serial interface to a Hewlett Packard 71 B "palmtop" computer. This allowed direct logging of bearings and depression angles in relation to time. The program also permitted entry of notes about whale behavior and identification. Distances were computed using an iterative equation that included correction for curvature of the earth,[2] Data were stored on diskette and, for backup, printed in real time via a portable ink jet printer. A car battery heating pad powered by the generator at the ice camp kept the computer batteries and ink jet printer warm enough to work on the ice. The addition of this data logging system in 1991 allowed for automated and hence quicker collection of theodolite readings, resulting in more detailed tracks of successive animal positions.

During 1991 all personnel at the ice camp wore long white snow-shirts over their parkas to minimize their visual conspicuousness.

[2] The computer program that acquired and processed the theodolite data was prepared by F. Cipriano, Dept of Ecology and Evolutionary Biology, University of Arizona.

GENERAL CHRONOLOGY OF 1991 FIELD ACTIVITIES

Field activities during 1991 are summarized in Table 1. This table shows the types of fieldwork done each day, and gives some information about the ice and weather conditions that affected the fieldwork. The numbers of bowheads and white whales sighted each day by the ice-based and Twin Otter crews are also summarized.

Ice-based work was possible on 13 days in 1991. The 13 locations are mapped in Figure 2. Bowheads were seen by the ice-based crew on 8 of these days (Tables 1A, 2):

1. During 4 of the 13 days, only "control" observations were obtained; the projectors did not operate (Table 2). On three of these days deteriorating ice and/or weather conditions forced the crew off the ice before the playback could begin (3, 6 and 20 May). On one day equipment problems prevented a playback (28 April). Bowheads were seen from the ice during two of these 4 "control" days (28 April, 3 May), White whales were not seen from the ice on "control" days.

2. During 6 of the 13 days, icebreaker sounds were projected for prolonged periods (Table 2). Bowheads were seen from the ice during three of these 6 days(11, 17 and 22-May). On the 1 lth and 22nd, bowheads were seen only during the periods of "control" observations before and after icebreaker sounds were projected. Bowheads were seen during the actual playback period only on 17 May. White whales were seen from the ice on 3 of the 6 days with playbacks (5, 11 and 17 May). They were seen during the specific playback period on 11 and 17 May, and during the control periods on 5, 11 and 17 May.

3. During 4 of the 13 days, transmission loss tests were conducted. (On one of these 4 days-18 May—there also was a prolonged playback.) Bowheads were seen within 5 km of the projector site on three of these 4 days, always while the projectors ***were*** silent. However, on one occasion (25 May) the observation was only 11 min after test sounds were projected. White whales were not seen ***during*** TL tests.

The aircraft crew conducted a total of 30 flights on 23 different days from 28 April to 26 May 1991. However, on five of these days, poor weather (low ceiling, poor visibility, or high winds) prevented any useful work. The remaining 25 flights ranged from 1.6 to 5.2 hours in duration. Longer flights were not warranted during 1991 because of the low clouds that almost always prevented observations from altitude 460 m (1500 ft). The ceiling was below 460 m during 18 of the 25 "effective" flights. Total flight time during the 30 offshore flights was 75.4 h.

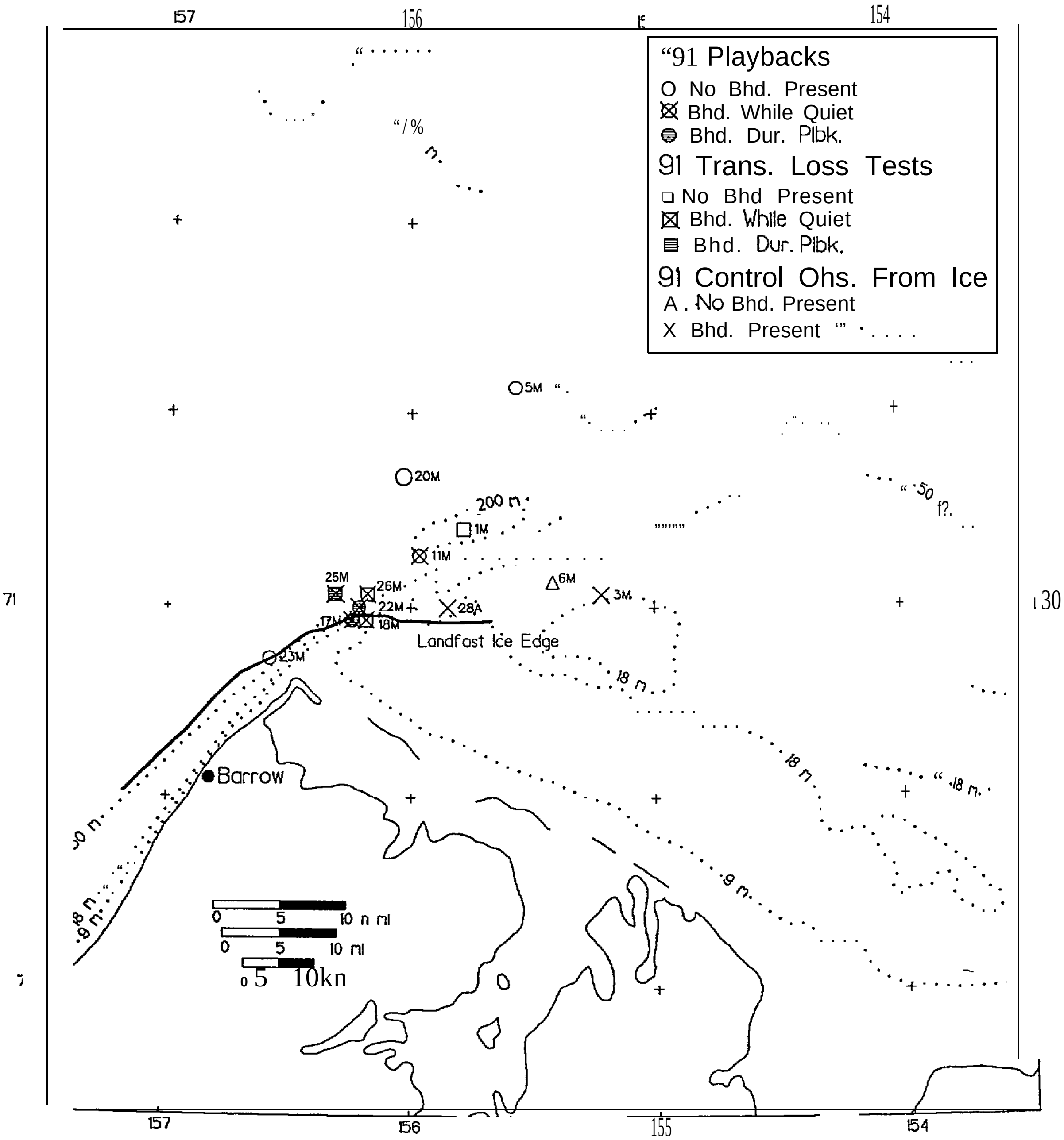


FIGURE 2. Locations where ice-based crews broadcast icebreaker sounds, conducted transmission loss tests, and made control ice-based observations, 28 April to 26 May 1991, X and solid symbols represent days when bowheads were observed. Locations on the pack ice are approximate because of ice drift during the course of each day's work.

Table 1A. **Summary** of daily **activities** and weather and ice conditions, 28 April-26 May 1991.

Date	Ice-based Crew: No. Ferry Flights	Trans. Loss Test	Icebr. Plbk.	Number of Bhd.	Number of White Whales	Ice camp Location	Other	Overall Ice Conditions
28 Apr	1		-	2 (2)*	0	71″30′ 155″51′	Control ohs.; equip. checkout.	85%. Lead wide on **Chukchi** side: discontinuous to E. Much new ice.
29 Apr	0		-				Equip. checkout at Barrow.	85%
30 Apr	0		-					85%
1 May	2	#1	-	0 (3)	0 (5)	71″36′ 155″47′	TL test #1. 3 bhd. seen near 5 **nmi** TL station.	85%
2 May	0		-					8.S%
3 May	1		-	9 (4)	0	**71°31′** 155″13′	Control ohs. Plbk **cancelled** - weather **&** ice deteriorating.	85%
4 May	0		-					85%. Strong winds move pack ice close **to** fast ice. Many isolated openings but no leads.
5 May	2		**P1**	0	46 (39)	**71°47′** 155″34′	Icebreaker **plbk.** No whales during **plbk** .	85%. Strong winds move pack ice close to fast ice.
6 **May**	1		-	0 (3)	0 (3)	**71°32′** 155°25′	Brief control ohs. Work aborted due to extreme winds & unstable ice.	93%
7 May	**0**							93%. Wide lead **W** of Barrow, **inter-mittent** to E. Elsewhere 90% pack ice.
8 May	0							93%
9 May	0							93%
10 May	0							93%. Nearshore **lead closed** to E, but corridor **of** 97% brash ice remains. Many N-S tracks in pack ice.
11 May	2		P2	7 (2)	38	71″34′ 155°58′	Icebreaker **plbk.**	93%
12 May	0							93%

* Numbers in parentheses indicate **additional whales observed during** ferry **flights or** at **TL** receiver stations.

Table lB. Summary of daily activities and weather and ice conditions, 28 April-26 May 1991 (continued).

		Aircraft-based Crew					
					Number of		
Date	Weather	Survey (h)	Behavior Obser. Sess. (h)	Photogr. (h)	Bowheada	White Whales	Other
28 Apr	Low overcast, occ. light snow.	2.2			0	115	-
29 Apr	Scat. low cloud and fog.	1.2	0.9	0.7	5	0	Ohs. of presum. undist. behav.
30 Apr	Fog .						Fog, no flying.
1 May	Low overcast, good vis.	2.5		1.8	49	17	
2 May	Fog .	0.5			0	0	Fog; aborted flight.
3 May	Low overcast, some fog.	1.7			6	57	-
4 May	Thin fog except in evening.	1.6	0.6		7	30	Ohs. of presum. undist. behav.
5 May	Mostly clear.	5.2			2	128	No whales present during plbk.
6 May	Clear with strong ENE winds.	3.9	1.6		11	105	Ohs. of presum. undist. behav.; abort. due to strong wind.
7 May	Low overcast after 10 AM. High winds.	1.0			10	0	Too windy; abort flight.
8 May	Low overcast, high winds, and poor vis.	0.8		0.8	7	0	-
9 May	Low overcast, high winds.						Poor weather, no flying.
10 May	Low overcast, high winds.	3.1		0.7	32	126	-
11 May	Low overcast, windy.	3.5		1.8	28	135	Cloud toolow for aerial ohs. during ice-breaker plbk.
12 May	Fog.	0.8			4	, 5 6	Fog: aborted flight.

Continued...

Table 1A. Concluded.

Date	Ice-based Crew: No. Ferry Flights	Trans. Loss Test	Icebr. Plbk.	Number of: Bhd.	Number of: White Whales	Ice camp Location	Other	Overall Ice Conditions
13 May	0							93%
14 May	0							93%
15 May	0							93%
16 May	"O							90%
17 May	4		P3	11	165 (15)	71°30′ 156°13′	Icebr. plbk. from fast ice edge.	90%
18 May	4	#2	P4	2	0	71"30′ 156°13′	Brief icebr. plbk. from fast ice edge. No whales seen, so switched to TL test #2.	90%
19 May	0							90%
20 May	2			0 (1)	0	71°40′ 156°02′	Control ohs.; plbk cancelled - weather & ice deteriorating.	90%
21 May	0							90%
22 May	1		P5	1 (2)	0	71°29′ 156°13′	Icebreaker plbk.	90%. Nearshore lead opens to 154"15′.
23 May	2		P6	0	0	71"26′ 156°35′	Icebreaker plbk. Camp on fast ice edge.	90%
24 May	0							90%
25 May	2	#3	-	2 (3)	0	71°31′ 156°19′	TL test #3. Camp on fast ice edge.	90%
26 May	1	#4	-	1	0	71°31′ 156°11′	TL test #4. Camp on pack ice.	90%

* Numbers in parentheses indicate additional whales observed during ferry flights or at TL receiver stations.

Table lB. Concluded.

		Aircraft-based Crew					
					Number of		
Date	Weather	Survey (h)	Behavior Obser. Sess. (h)	Photogr. (h)	Bowheada	White Whales	Other
13 May	Fog.	0.4			0	0	Fog; aborted flight.
14 May	Fog.						Fog, no flying.
15 May	Fog.						Fog, no flying.
16 May	Patchy fog.	1.7			7	66	Flying hampered by fog.
17 May	Low overcast, fog patches, snow showers.	3.0		2.8	27	486	Cloud too low for aerial ohs. during icebreaker plbk.
18 May	Low overcast, fog patches.	3.9		1.6	37	319	Icebreaker plbk; then TL test. Cloud toolow for aerial ohs.
19 May	Fog.						Fog, no flying.
20 May	Fog patches.	4.3	0.9		11	31	Ohs. of presum. undist. behav.; curtailed by fog.
21 May	Low cloud, fog and snow.	0.7			0	6	Poor weather; aborted flight.
22 May	Low cloud, fog til late after-noon.	2.3		2.0	34	156	Cloud toolow for aerial ohs. during icebreaker plbk.
23 May	Low overcast.	2.5			4	82	Cloud toolow for aerial ohs. during icebreaker plbk.
24 May	Fog and snow.						Poor weather, no flying.
25 May	Mostly low overcast; briefly clear far to east.	5.4	0.1	2.4	20	79	Cloud near ice camp too low for aerial ohs. during plbk. Brief ohs. of behav. farther east until curtailed by low cloud.
26 May	Low overcast.	3.6		0.9	6	1	

Table 2. Summary of ice-based work, 1991.

Projector Status	No Bhds Seen	Bhds in Quiet Period Only	Bhds in Playback Period Only	Bhds in Both Periods
Days When No Sounds Were Projected	6 May, 20 May	28 Apr, 3 May		
Days With Icebreaker Sound Playbacks	5, 18a, 23 May	11 May, 22 May[b]	no days	17 May
Days With Transmission Loss Test	1 May	18a, 25[c], 26 May	no days	no days

[a] On 18 May, there was both a playback and a TL test.
[b] On 22 May, aerial observations during the playback combined with ice-based observations immediately before the playback provided circumstantial evidence about a bowhead exposed to drilling noise.
[c] On 25 May, a bowhead was seen near the ice camp only 11 min after it was exposed to TL test sounds.

On five days when it was possibleto see the surface from an altitude of460 m, the aerial crew conducted 7 behavior observation sessions totaling 4.1 h (Fig. 3; Table 3). Although this work was ourtoppriority, the prevailing low cloud rarely allowed it. Furthermore, ofthe7 flights when we could observe from460 m, the winds were too strong for effective observations during two flights, Bowheads were very scarce (only 1 seen per flight) during two additional flights. Thus, onlythreeof the 1991 flightsprovided a reasonable prospect for obtaining many behavioral observations. All behavioral observationsin 1991 involved presumably undisturbed whales. The aircraft crew did not obtain observations of whales subjected to icebreaker noise because, during our opportunities to project icebreaker noisesto whales, cloud ceilings were too low to permit aerial observations near the projectors (Table 1B).

Because the top-priority behavioral observations were rarely possible, a higher-than-expected proportion of the aerial effort was devoted to vertical photography of bowheads. A total of 15,5 flight hours were spent on aerial photography during 11 different flights on 10 different days (Table 1B).

Because of the difficult weather and ice conditions in 1991, we were able to project industrial sounds on fewer occasions in 1991 (6 days) than in 1989 (11 days) or 1990 (8 days). The prevailing low clouds in 1991 had a particularly severe effect on aerial observations of whale behavior: we were able to observe bowheads during only 7 sessions in 1991, as compared to 17

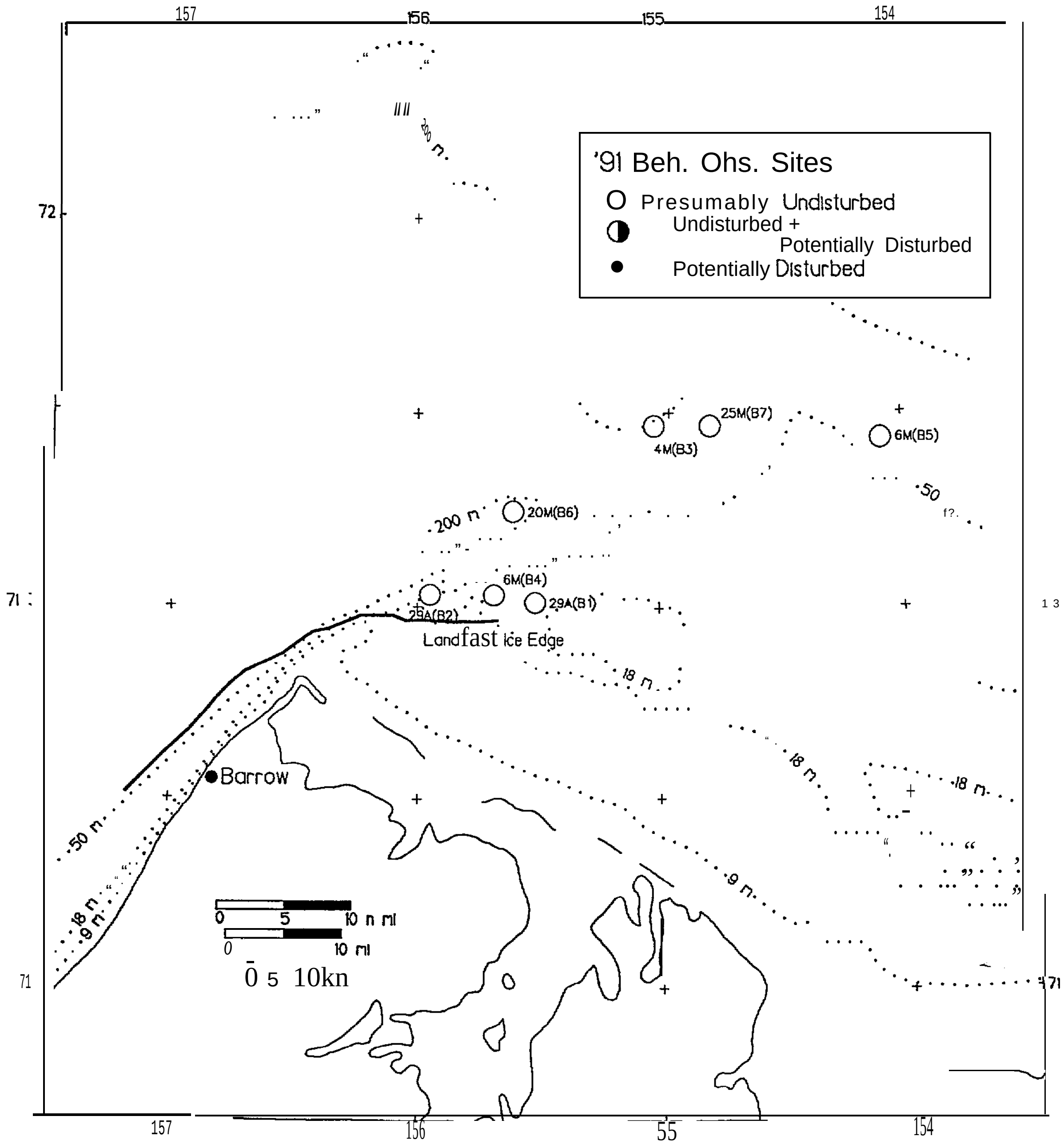


FIGURE 3. Locations where behavior of bowhead whales was observed by the aerial crew, 28 April to 26 May 1991. Annotations represent the date in April (A) or May (M) and, in parentheses, the behavioral observation session number (B **1-B7).** See Table 3 for more details. On other dates, behavioral observations were prevented by low clouds that precluded observations from altitude 460 m ASL.

Table 3. Summary of [illegible] observation sessions, Twin Otter crew, 1991.

Date	Behav. Obs. Sess.	Location	Obs. Period	No. Bowheads circle	No. Bowheads area	General Activity	Predom. Orient. °T	Predom. Speed of Travel	Size Classes	Disturbance	Water Depth (m)	Sea State	% Ice in circle	% Ice overall
29 Apr	1	71°30' 155°28'	11:30-12:14	2	2	unknown	various	slow-medium	mother + yearling	none	19	1	50	85
29 Apr	2	71°31' 155°57'	13:06-13:13	2	2	travel	070-090	medium	unknown	none	19	1	90	85
4 May	3	71°44' 155°04'	20:52-21:28	1	1	travel?	various	slow	subadult	none	180	1	85	85
6 May	4	71°31' 155°41'	11:20-12:29	2	3-1-	travel	090-120	medium	unknown	none	19	3-5	35	93
6 May	5	71°43' 154°05'	14:56-15:24	2	2	social/ travel	various	medium	unknown	none	130	5	65	93
20 May	6	71°38' 155°37'	15:04-15:55	2	2	travel	060-090	medium	mother + calf	none	210	2-3	15	90
25 May	7	71°44' 154°50'	16:12-16:17	4	13	travel	180/230	medium	2 mothers + 2 calves	none	--130	1	I	90

sessions in 1989 and 29 sessions in 1990. The low clouds totally prevented systematic aerial observations of bowheads near the operating projectors in 1991. Because of the extensive areas of new ice and brash ice in the study area during 1991, there were far fewer suitable locations for the sound projectors in 1991 than in 1989 or 1990. Also, on several occasions in 1991, drifting ice encroached on the projector site after it was established, forcing curtailment of ice-based work.

PHYSICAL ACOUSTICS RESULTS

In this section we present results from the 1991 measurements of ambient noise, sound transmission loss, icebreaker sounds used during playbacks, low frequency components of bowhead calls, and generator noise. For some of these topics, additional analyses are still underway. Final results from 1991 will appear in the combined 1991-92 report.

Ambient Noise

Measurements of ambient noise were one of the specific objectives of this study (objective 2 in 1991; see p. 4). Ambient noise data are needed because ambient noise levels have a large influence on the radius of detectability of man-made sounds propagating from a specific source. Also, ambient noise levels are one of the main factors determining the "signal to noise" ratio (S:N) of a sound of interest. S:N is the number of decibels by which the sound signal exceeds the ambient noise level in the corresponding band. Measurements of ambient noise at infrasonic frequencies (<20 Hz) were of special interest because of the uncertainties about sound propagation and bowhead hearing in the infrasonic range (see specific objective 5, p. 5).

Ambient Noise at "Sonic" Frequencies

Figure 4 is an overview of the 46 broadband ambient noise measurements from 1991. Most 1991 results are similar to the 1990 results (*cf.* Richardson et al. 1991 a:47). -However, substantially lower values were measured on one day in 1990. Excluding that one exceptional day in 1990, the 1990 and 1991 values both tended to be higher than those in 1989 (*cf.* Richardson et al. 1990a: 110). The 1989 field season was distinguished by little open water and ambient noise measurements were often made through small openings in the ice,

Figure 5 and Table 4 summarize the one-third octave levels obtained from the same 46 measurements of ambient noise. Bands centered at frequencies from 10 to 6300 Hz are considered. The 50th percentile levels were 2-4 dB lower in 1991 than in 1990 (*cf.* Richardson et al, 1991 a:55). Of the 46 measurements, 39 were via hydrophores (mostly ITC 6050C; a few ITC 1032) and 7 were via sonobuo ys (mostly AN/SSQ-57A; some AN/SSQ-41 B). The data from these

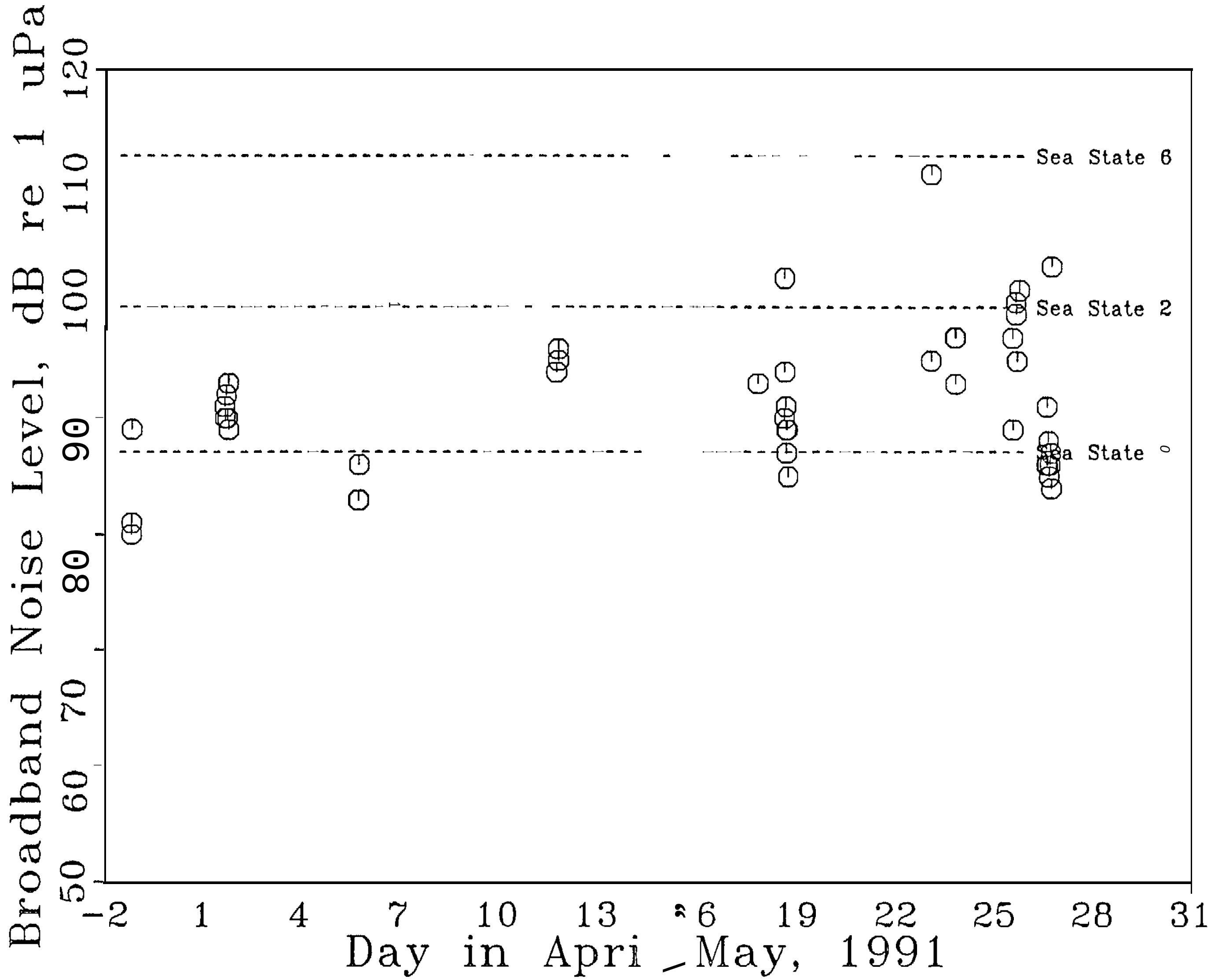


FIGURE 4. Broadband ambient noise levels (20-1000 Hz) measured during the 1991 field season, plotted against date and time (n=46). Several measurements were made on most days, resulting in the apparent vertical structure. Cases including man-made sounds are excluded. Dashed horizontal lines show predicted ambient noise levels (20-1000 Hz) at sea states 0 (calm), 2 (light wind) and 6 (storm).

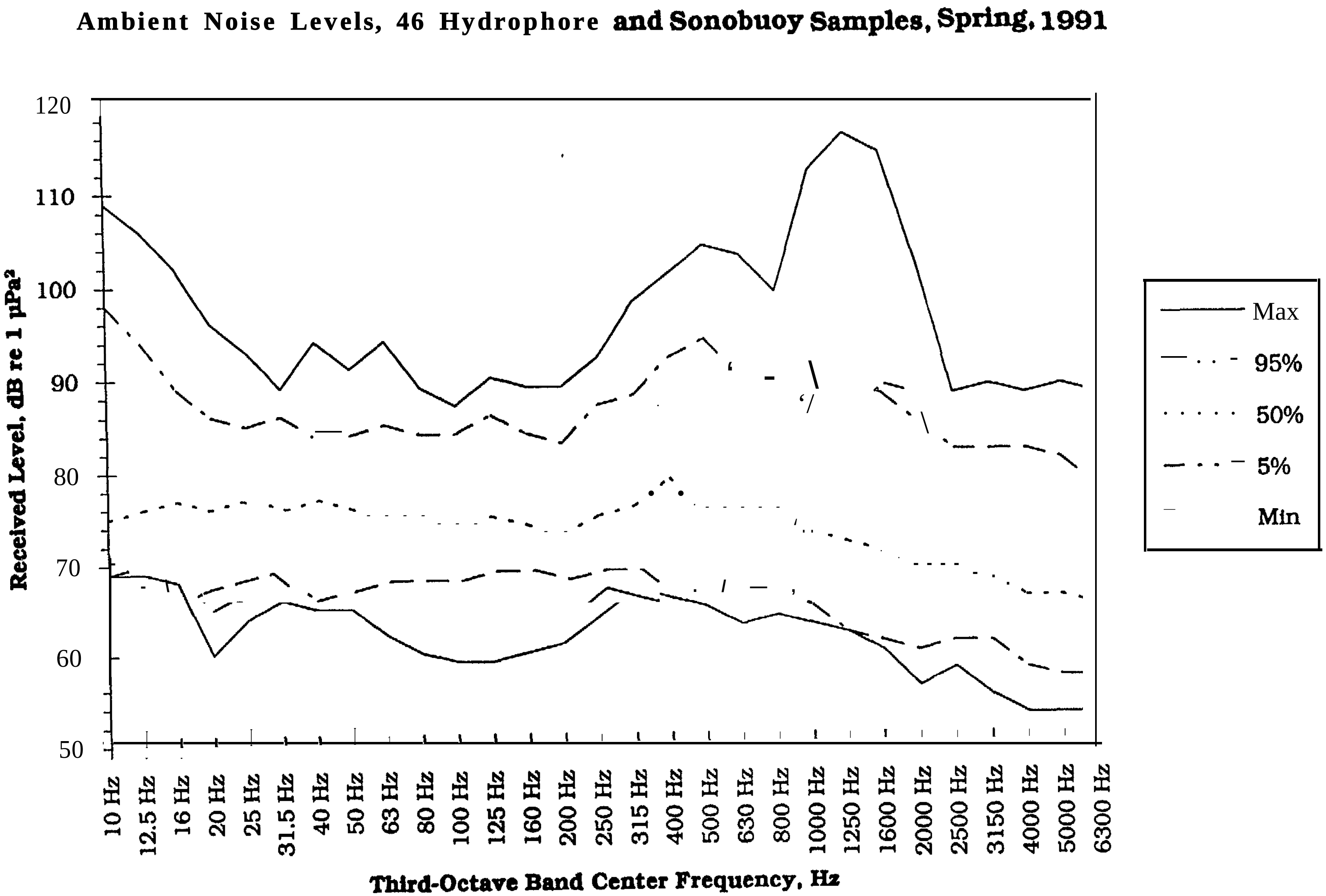


FIGURE 5. Extreme and percentile one-third octave band levels of ambient noise for 46 measurements of ambient noise taken in 1991.

Table 4. Extreme and percentile ambient noise levels for one-third octave bands and 20-1000 Hz band, 1991. Based on 46 ambient noise measurements obtained via sonobuoys (n=7) and ice-based hydrophore (n=39).

A.

	All						
	Max	95%	90%	50%	10%	5%	Min
10 Hz	109	98	95	75	69	69	69
12.5 Hz	106	94	91	76	70	70	69
16 Hz	102	89	68	77	70	69	68
20 Hz	96	86	86	76	69	65	80
25 Hz	93	85	84	77	69	67	64
31.5 Hz	89	86	84	76	70	66	66
40 Hz	94	84	83	77	70	69	65
50 Hz	91	84	63	76	69	66	65
631-L?	94	85	83	75	69	67	62
80 Hz	89	84	83	75	69	68	60
100 Hz	87	84	82	74	68	68	59
12s Hz	90	86	83	76	68	66	59
160 Hz	89	84	82	74	60	68	60
200 Hz	89	83	82	73	69	69	61
250 Hz	92	87	84	75	69	68	64
315 Hz	98	88	87	76	70	60	67
400 Hz	101	92	89	70	69	69	66
500 Hz	104	94	91	75	68	66	65
630 Hz	103	90	90	76	68	67	63
800 Hz	99	90	87	75	68	67	64
1000 Hz	112	66	86	73	65	65	63
1250 Hz	116	89	87	72	64	62	62
1600 Hz	114	88	86	71	62	61	60
2000 Hz	102	85	84	69	62	60	56
2500 Hz	88	82	81	68	63	61	58
3150 Hz	89	82	81	68	63	61	55
4000 Hz	88	82	78	66	60	58	53
5000 Hz	89	81	7s	66	56	57	63
6300 Hz	88	78	75	65	58	57	53
20-1000 Hz	111	101	99	91	84	83	80

46 Samples

B.

	Hydrophores						
	Max	95%	90%	50%	10%	5%	Min
10 Hz	109	98	95	75	69	69	69
12.5 Hz	106	95	91	76	70	69	69
16 Hz	102	90	86	77	70	69	68
20 Hz	96	87	86	76	70	69	69
25HZ	93	85	64	77	70	69	67
31.5 Hz	89	87	84	76	70	66	66
40 Hz	94	86	83	77	69	66	65
50 Hz	91	85	64	77	68	65	65
63HZ	94	86	83	75	69	66	62
80 Hz	89	87	84	76	68	67	60
100 Hz	87	87	63	75	68	66	59
125 Hz	90	87	84	76	68	65	59
160 Hz	89	86	83	75	69	66	60
200 Hz	89	84	82	73	69	64	61
250 Hz	92	87	64	75	69	66	64
315 Hz	98	87	66	76	69	68	67
400 Hz	101	96	88	79	69	69	88
500 Hz	104	94	91	78	68	66	66
630 Hz	103	94	88	77	67	64	63
800 Hz	99	95	87	75	67	65	64
1000 Hz	112	88	88	73	65	64	63
1250 Hz	116	97	89	72	63	62	62
1600 Hz	114	69	66	72	61	61	60
2000 Hz	102	85	84	60	61	60	56
2500 Hz	88	83	81	68	63	60	56
3150 Hz	89	64	81	68	62	60	55
4000 Hz	88	82	81	66	58	S4	53
5000 Hz	89	82	78	65	58	55	53
6300 Hz	68	82	76	65	57	56	53
20-1000 Hz	111	102	100	91	85	81	80

39 samples

C.

	Sonobuoys						
	Max	95%	90%	50%	10%	5%	Min
10 Hz	98	96	96	79	70	70	70
12.5 Hz	94	93	83	60	70	70	70
16 Hz	89	89	89	81	66	68	68
20 Hz	86	84	84	77	60	60	60
25 Hz	85	82	82	75	64	64	64
31.5 Hz	64	78	78	74	68	66	66
40 Hz	64	78	78	75	70	70	70
50 Hz	63	79	79	74	71	71	71
63 Hz	63	76	76	74	70	70	70
80 Hz	81	75	75	74	68	68	69
100 Hz	80	74	74	73	70	70	70
125 Hz	80	74	74	72	69	69	69
160 Hz	81	76	76	73	60	69	69
200 Hz	63	81	81	74	70	70	70
250 Hz	90	84	84	75	66	68	66
315 Hz	89	88	68	75	70	70	70
400 Hz	82	89	89	78	66	66	66
500 Hz	91	90	80	75	65	6S	65
630 Hz	80	90	90	74	66	66	66
800 Hz	67	79	79	73	68	69	69
1000 Hz	84	78	78	75	65	65	65
1250 Hz	78	75	75	74	65	65	65
1600 Hz	87	76	76	71	67	67	67
2000 Hz	66	74	74	69	64	64	64
2500 Hz	76	75	75	69	64	64	64
315a Hz	72	70	70	68	64	64	64
4000 Hz	71	68	68	68	64	64	64
50001-17,	71	68	66	67	63	63	63
6300 Hz	72	67	67	67	64	64	64
20-1000 Hz	97	97	97	93	83	83	63

7 Samples

two types of sensors are presented separately in Figure 6. The relatively high levels that occasionally occurred at 800-1600 Hz, as evidenced in the 95th percentile and maximum levels, are largely if not wholly attributable to calls from bearded seals.

Infrasonic Ambient Noise

Three of the third-octave bands that were analyzed, those centered at 10, 12.5 and 16 Hz, were within the infrasonic range. Ambient noise levels in these bands were considerable y more variable than those in most bands between 20 and 200 Hz. In particular, the 95th percentile and maximum values tended to be far above the median values (Fig. 5, 6). The 1990 data showed similar variability in the ambient noise levels at infrasonic frequencies. (The 1989 ambient noise data were not analyzed in this way.)

At least some of the infrequent cases of strong infrasonic noise maybe measurement artifacts resulting from water flow noise or hydrophore suspension noise (cable strum) at sites with strong current. Infrasonic noise levels are easily contaminated by hydrophore suspension noise in currents. Several measurement stations used in 1991 were located on the shorefast ice, and at times the current was strong. The cables for the 6050C and spherical hydrophores were faired and apparently did not strum or flutter. The sonobuo y hydrophores, although specially decoupled from the surface unit, did show contamination; no such results were included in this report. However, it is possible that flow noises from the water passing the sensors increased some of the measured noise levels.

Transmission Loss

Measurements of acoustic transmission loss were another of the specific objectives of the 1991 work (p. 4). Transmission loss data are necessary in order to predict the received levels of man-made sounds at a given distance from their source.

Four transmission loss (TL) tests were done in May 1991. The projection and receiving sites are mapped in Figure 7. Tests 2 and 3, near the shorefast ice north of Pt. Barrow, were in an area not studied in 1989 or 1990.

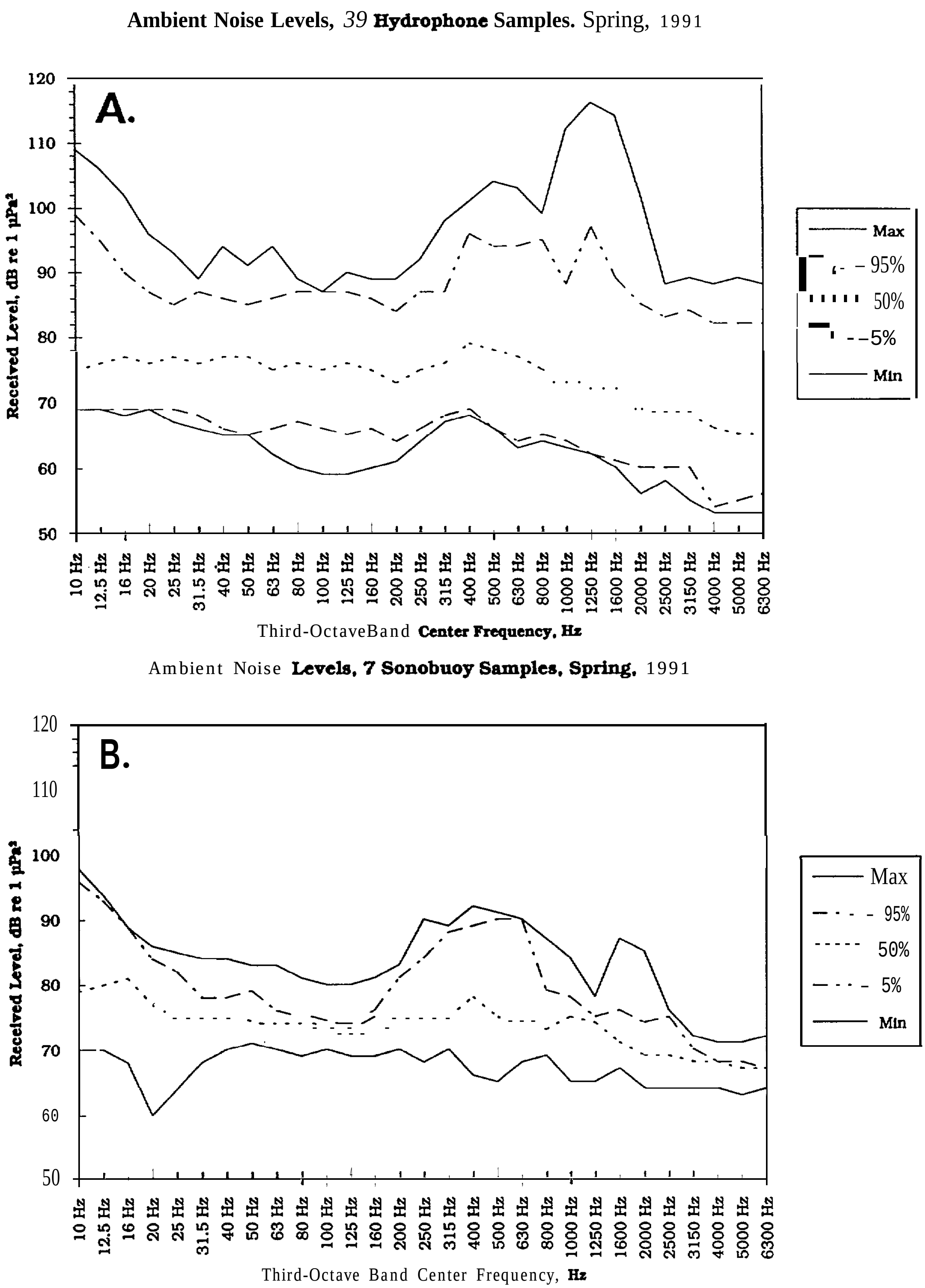


FIGURE 6. Extreme and percentile one-third octave band levels of ambient noise in 1991 for (A) hydrophore samples (n=39), and (B) sonobuoy samples (n=7).

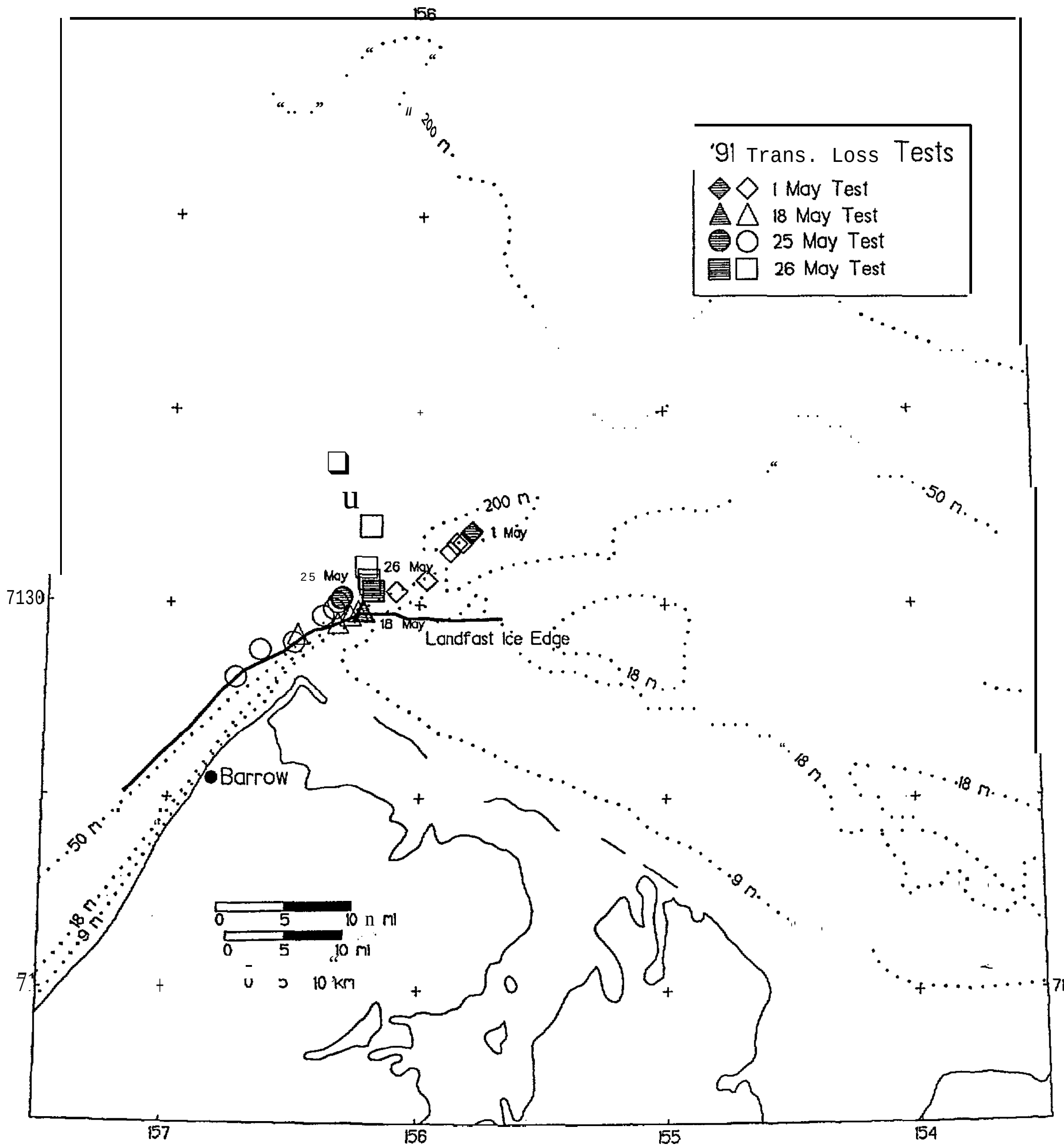


FIGURE 7. Projector sites (solid symbols) and receiving station sites (corresponding open symbols) during transmission loss tests **#1-#4,** May **1991.**

TL Test #1, 1 May 1991

Figure 8 presents the results of the first TL test for tones and tone clusters. The water depths at the various receiving stations, and the distances to the projector, were as follows:

Time	Distance (km)	Water Depth (m)
10:16	0	56
16:06	1.96	Sounder inop.
16:44	2.78	Sounder inop.
17:16	4.17	Sounder inop.
17:50	9.62	Sounder inop.
18:24	13.85	Sounder inop.

TL Test #2, 18 May 1991

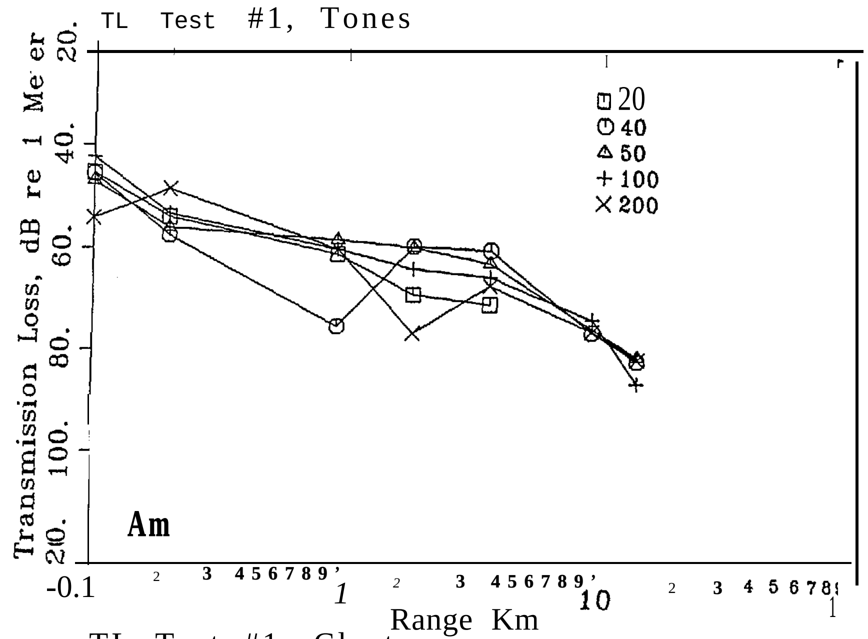
Figure 9 presents the results of the second TL test for tones and tone clusters. The water depths at the various receiving stations, and the distances to the projector, were as follows:

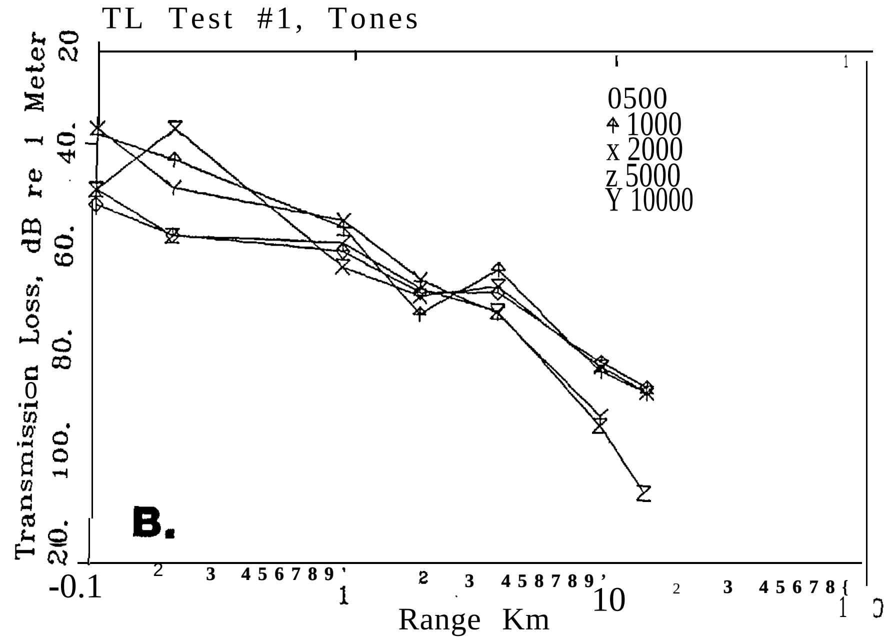
Time	Distance (km)	Water Depth (m)
09:43	0	110
15:08	0.80	113
15:48	2.05	110
16:26	4.06	98
17:07	9.96	84

TL Test #3, 25 May 1991

Figure 10 presents the results of the third TL test for tones and tone clusters. The water depths at the various receiving stations, and the distances to the projector, were as follows:

Time	Distance (km)	Water Depth (m)
09:53	0	146
14:03	0.94	136
14:40	2.04	128
15:07	3.80	117
15:40	9.41	73
17:01	13.86	90
18:03	18.87	8 5





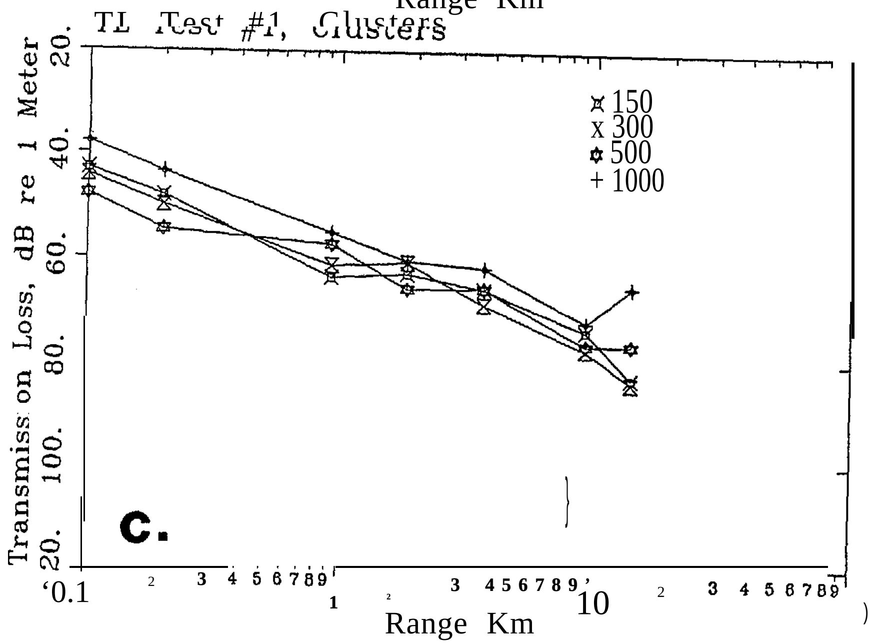


FIGURE 8. Transmission loss vs. distance, tones and tone clusters, test #1, 1 May 1991.

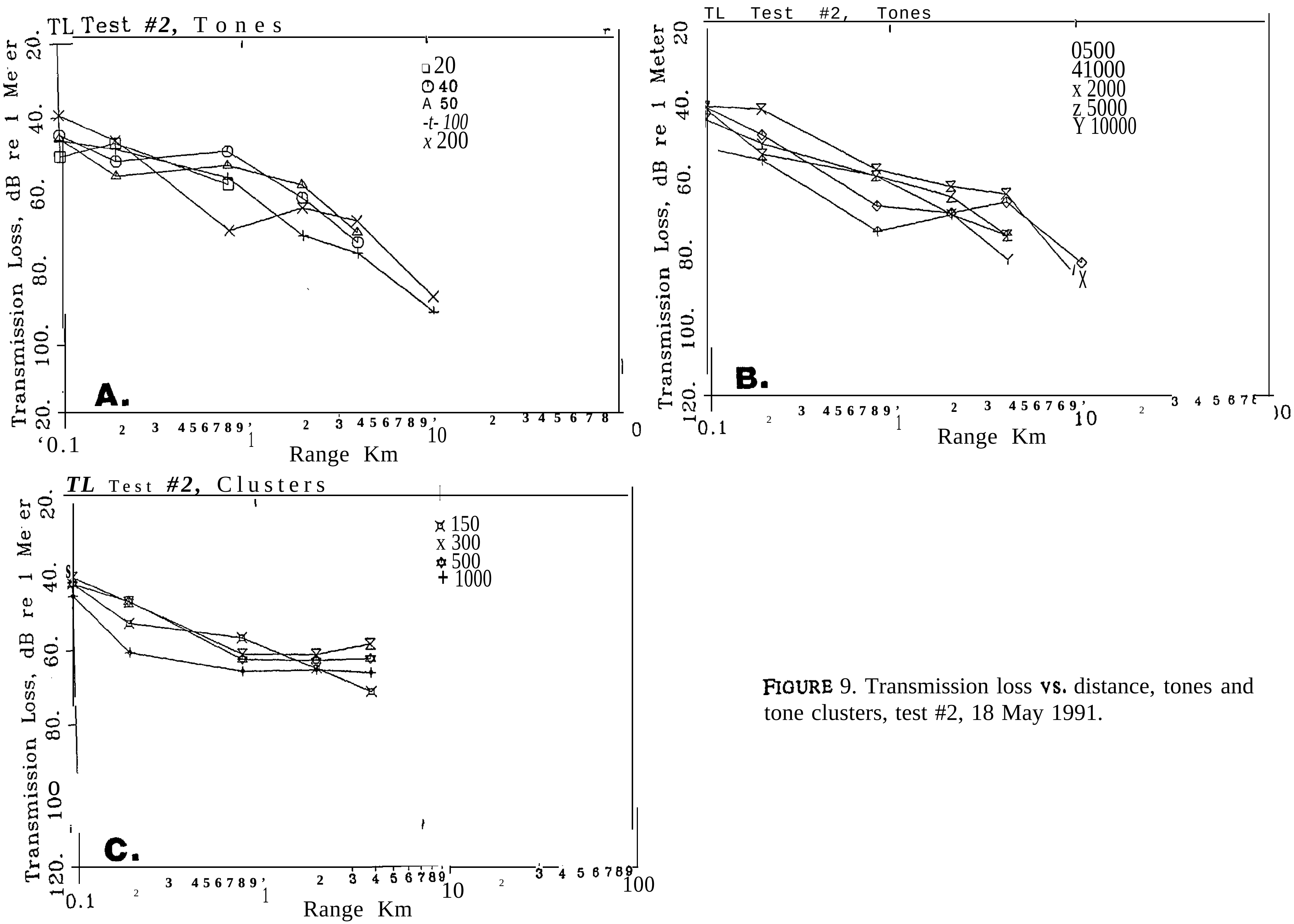
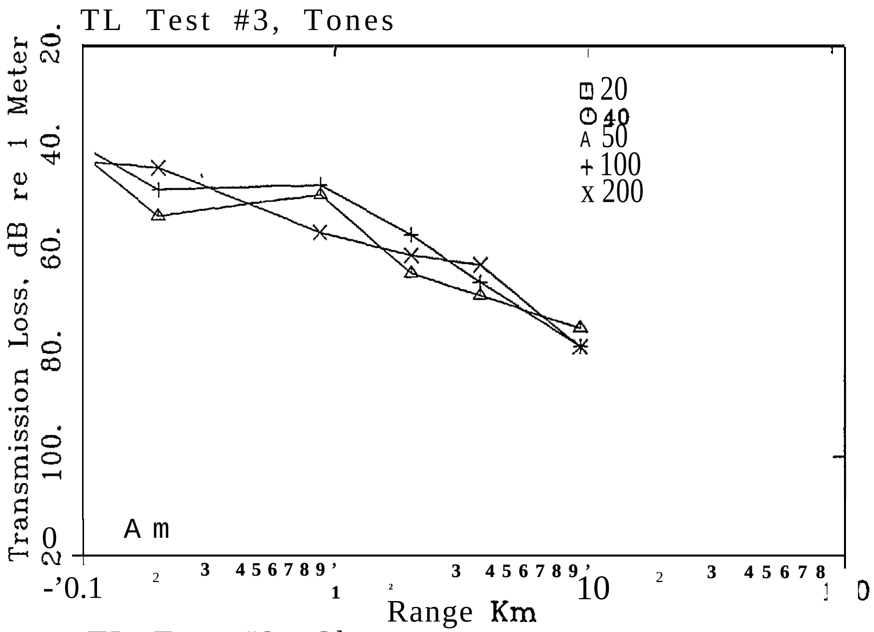
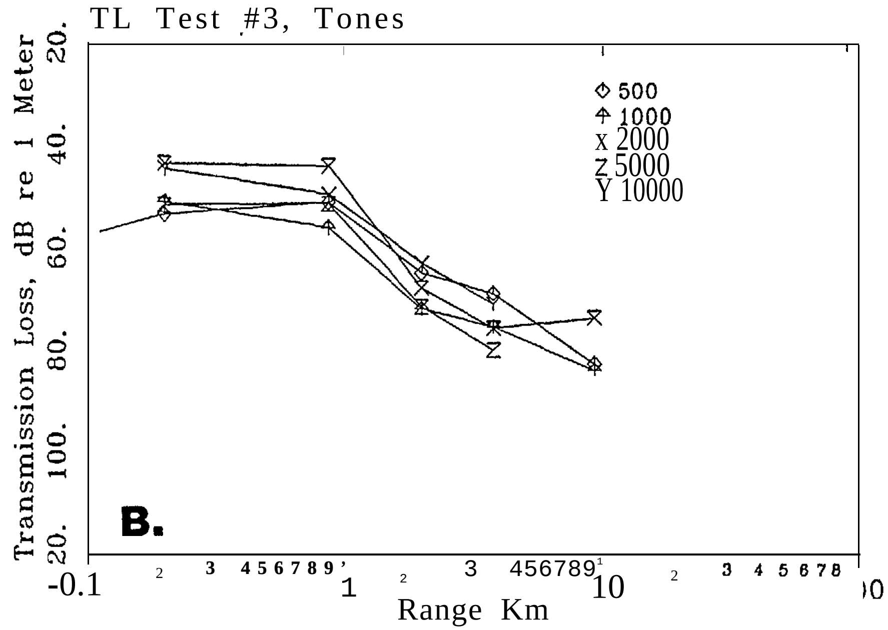


FIGURE 9. Transmission loss vs. distance, tones and tone clusters, test #2, 18 May 1991.





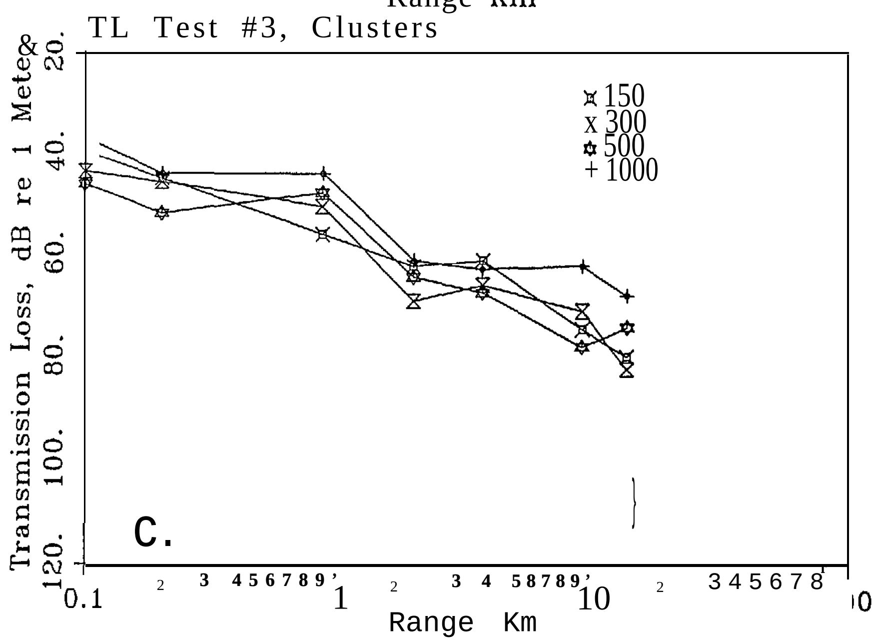
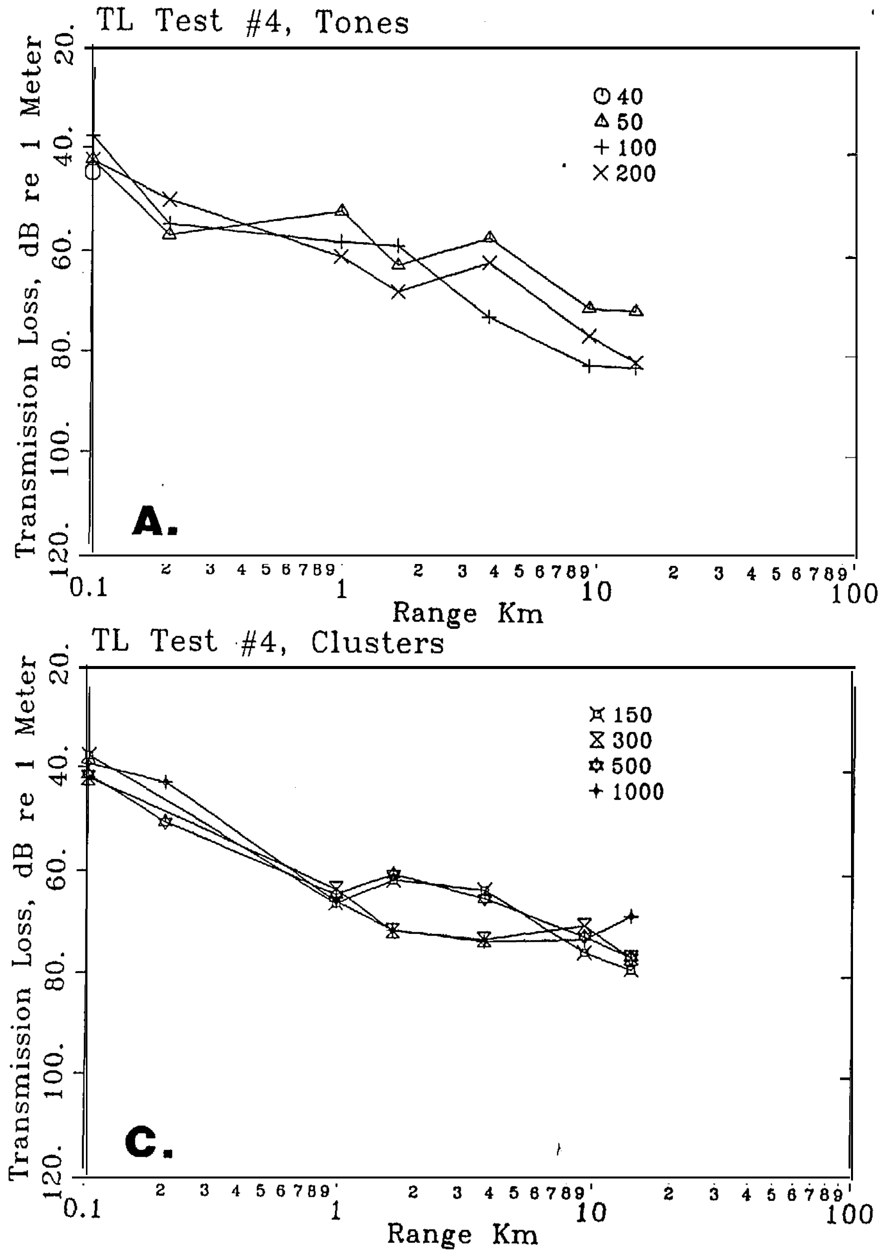


FIGURE 10, Transmission loss vs. distance, tones and tone clusters, test #3, 25 May 1991.



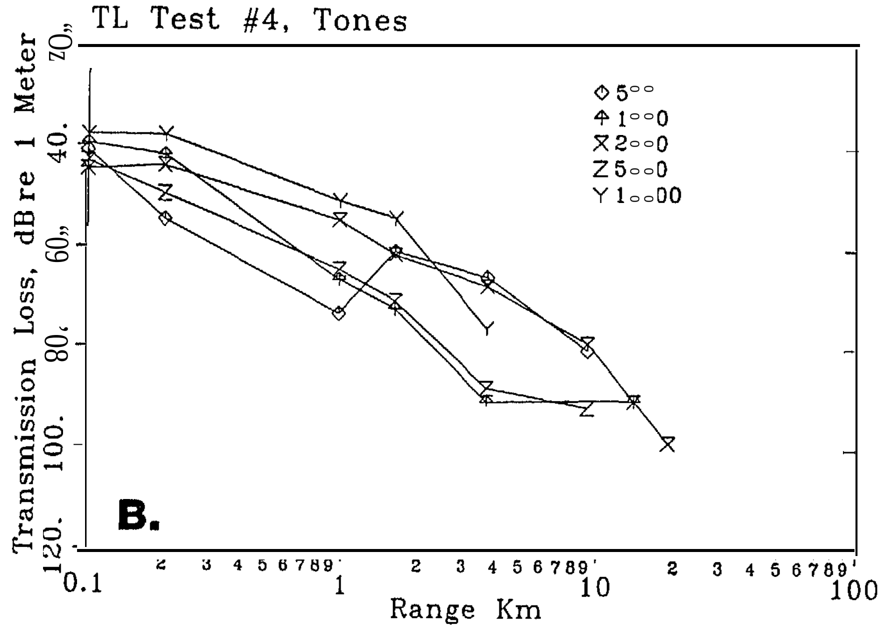


FIGURE 11. Transmission loss vs. distance, tones and tone clusters, test #4, 26 May 1991.

TL Test #4,26 May 1991

Figure 11 presents the results of the fourth TL test for tones and tone clusters. The water depths at the various receiving stations, and the distances to the projector, were as follows:

Time	Distance (km)	Water Depth (m)
10:58	0	151
13:54	0.96	158
14:26	1,60	166
14:53	3.45	163
15:32	9.17	184
16:04	13.74	1 1 0
16:34	18.90	96

Discussion of TL Test Results

The TL values shown in Figures 8-11 are generally similar to those from 1989 and 1990 (*cf.* Richardson et al. 1990a, 199 la). Results from all TL tests remain to be integrated and related to water depth, ice cover, and bottom conditions. In addition, the results concerning transmission 10SS of the sample of icebreaker sound projected during the 1991 TL tests require further analysis. These analyses will be reported in the combined report on the 1991-92 work.

Characteristics of Icebreaking Sound Used in Playbacks

The top priority objective in 1991 was to test the behavioral responses of bowheads and white whales to playbacks of variable icebreaker sounds (see specific objective 4, p. 4). Thus, it was important to document the characteristics of the icebreaker sounds (1) near the icebreaker itself and (2) as received by whales during playback experiments.

Source Recording of *Robert Lemeur* Sounds

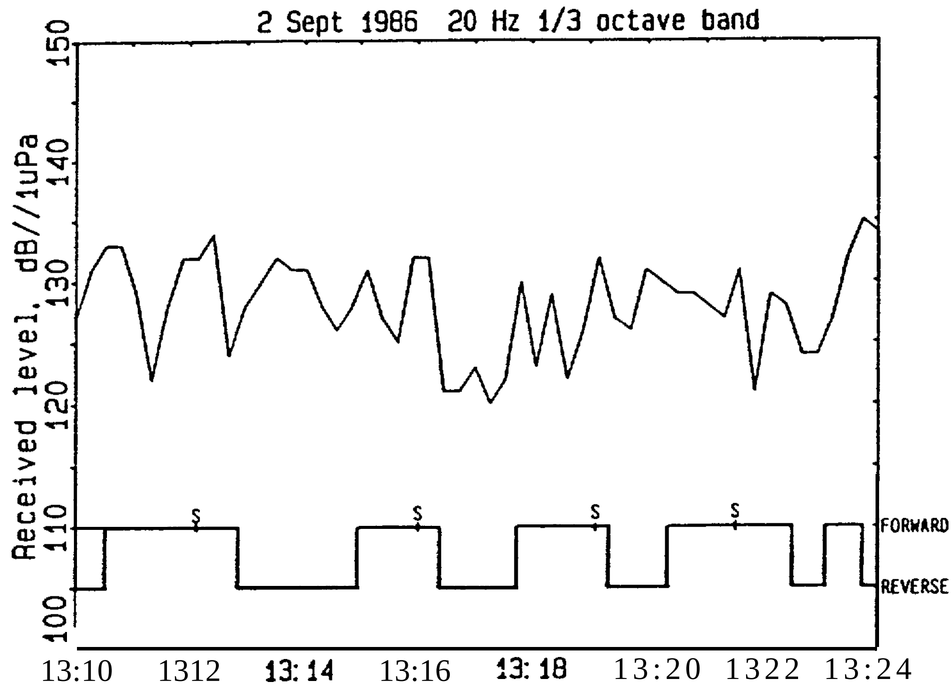
The icebreaking sounds projected during the playback experiments in 1991 came from a recording of the oil industry icebreaker ***Robert Lemeur*** working on ice near the Corona drillship site in the Alaskan Beaufort Sea during September 1986 (Greene 1987). The sounds were recorded at a range of 0.46 km (0.25 n.mi) from the icebreaker. The recording continued without interruption or gain change for 14 minutes. A detailed analysis is included in Greene (1989).

Within the 14-min period, the sounds varied considerably with time. The pattern of variation depended on frequency. Figure 12, from Greene (1989), shows the variability of the received levels in the one-third octave bands centered at 20, 50, 500 and 3150 Hz, It also shows that the levels are, to some degree, related to the activity of the icebreaker activity (moving forward into ice, coming to a stop while pushing against the ice, reversing out of the ice). Figure 12 is based on a series of 16.5-s analyses.

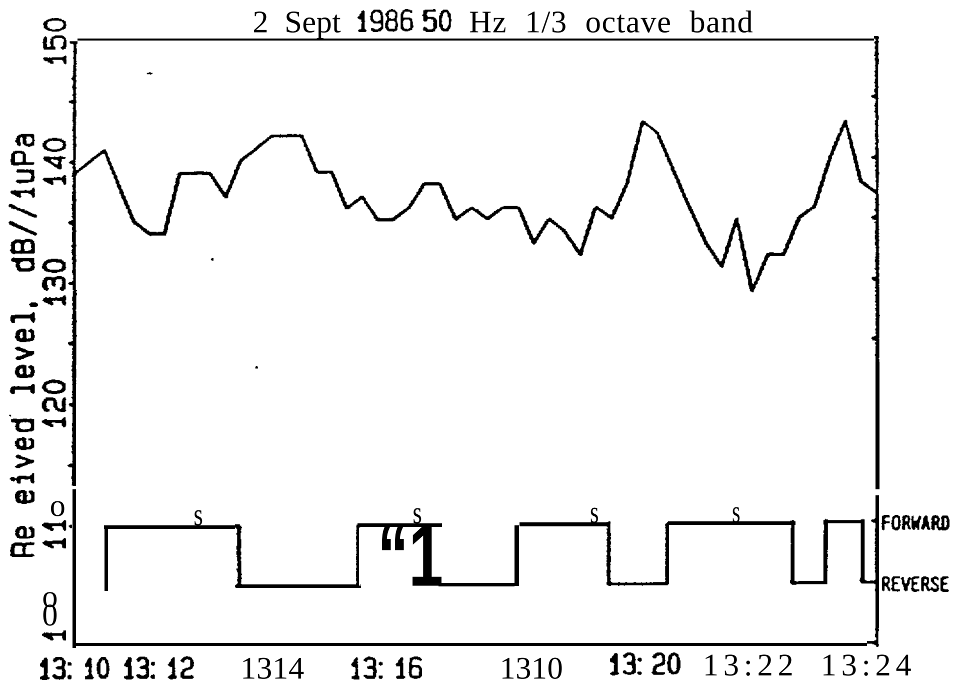
The original icebreaking recording was about 14 min long. A place near its end was found where the levels were close to those at the beginning. This segment of the original tape was repeated just over eight times to form the 120-min tape used for the actual playbacks. Thus, the variations during the first 15 min describe the variations over the full 120-min playback tape. Figures 13 and 14 summarize the variations in the broadband and one-third octave sound levels during the first 15 min of the playback tape. The analyses used to form those Figures were based on analyses of successive 8.25-s segments of the tape.

The levels shown in Figures 13 and 14 are in dB relative to the minimum level measured. This allows comparisons across time and across ⅓-octave frequency bands. The levels are not related to reference pressure units (e.g. 1 µPa) because the amplifier and transducer gains during playback are somewhat arbitrary and can cause the playback levels to vary. Also, it should be noted that Figures 13 and 14 describe variations in the signals on the source tape, not the variations in projected signals. Any deviation from a flat response by the amplifiers and projectors will change the relative levels at the frequencies where the response is not flat. For example, the output of the J-13/F-40 projectors ystem diminishes at low frequencies, e.g. below 50 Hz.

For the 20-1000 Hz band, the maximum level within the 15-min period was 11 dB above the minimum level. The maximum level occurred only once, and the minimum level occurred twice. Most of the time, the levels were within a 9 dB range. A range of 9 dB is the same as a ratio of 8:1 in acoustic watts; a range of 11 dB corresponds to a power ratio of 12.6:1. Humans are able to detect a 1 dB change in level (a power ratio of 1.26; Kinsler et al. 1982), and the intensity discrimination abilities of toothed whales appear to be similar to those of humans (Bullock et al.

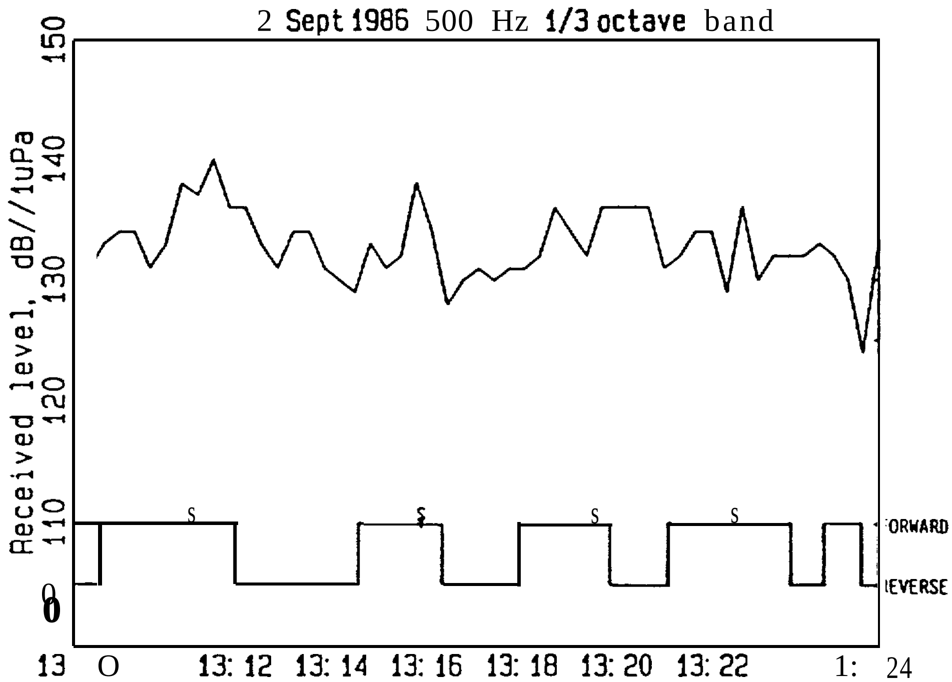


A. 20 Hz 1/3 Octave Band

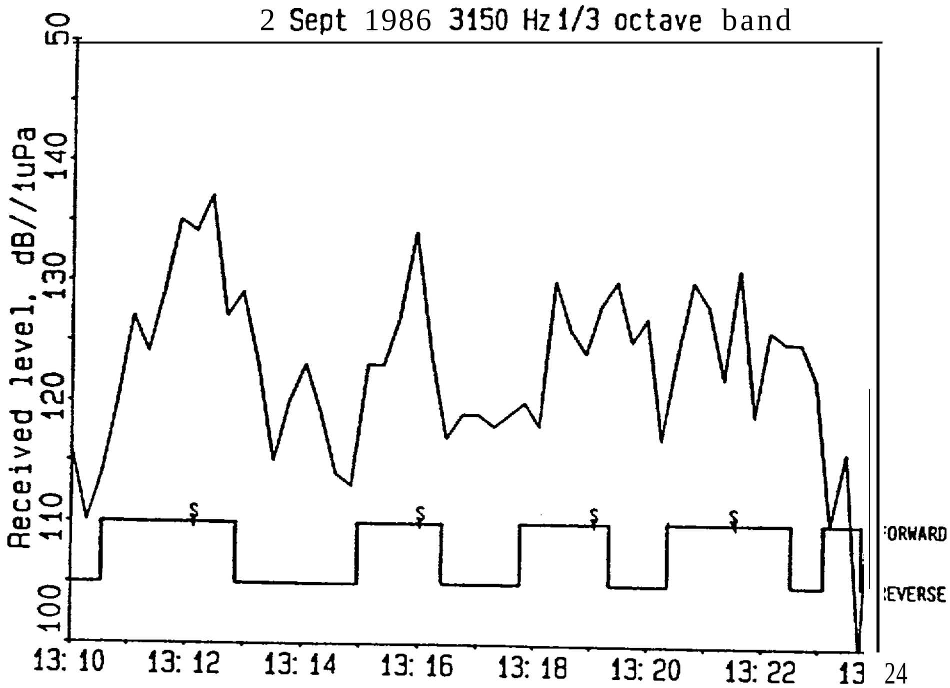


B. 50 Hz 1/3 Octave Band

FIGURE 12. Time series of the levels of the sound from icebreaker ***Robert Lemeur*** as received at range *0.46 km (0.25* n.mi.) in the one-third octave bands centered at four frequencies: (A) 20 Hz, (B) 50 Hz, (C) 500 Hz, and (D) 3150 Hz. Travel direction of the icebreaker (forward or reverse) is indicated at the bottom of each graph; "S" indicates times when the ship's forward motion was stopped by the ice.



c. 500 Hz 1/3 Octave Band



D. 3150 Hz 1/3 Octave Band

FIGURE 12 (continued).

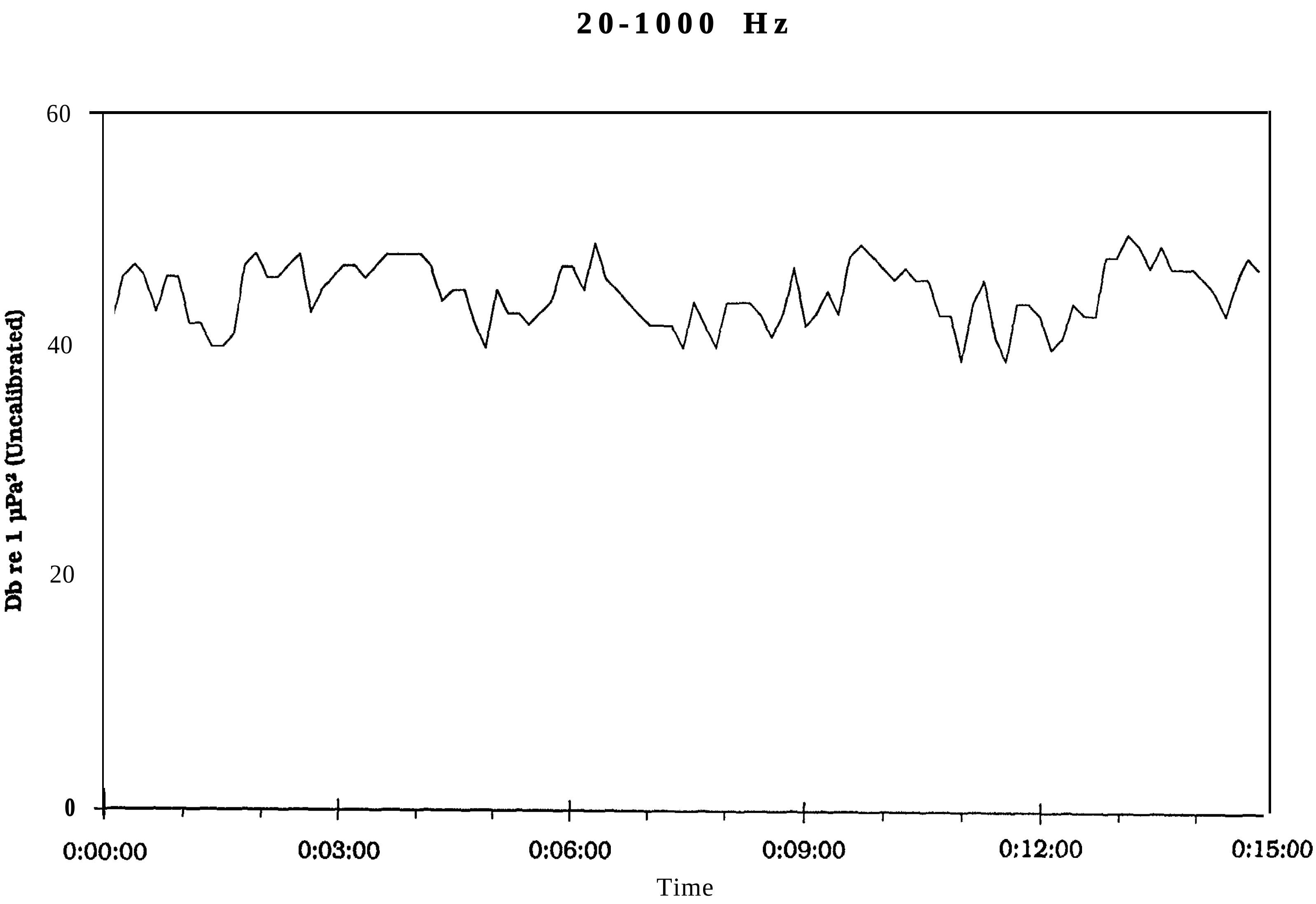


FIGURE 13. Variability of the icebreaking sounds, 20-1000 Hz band level, during the first 15 min of the playback tape. Levels are in dB relative to the minimum one-third octave level observed during the 15 min period.

1968; Johnson 1971, 1986; reviewed in Richardson et al. 1991b: 190). There are no data on intensity discrimination thresholds of baleen whales. It is very likely, however, that both white whales and bowheads will detect 9 dB changes in level.

How do the signal levels on the source tape for the icebreaker playbacks vary at different frequencies? To investigate this, we analyzed the same 15-min portion of tape by '%-octave frequency band for center frequencies from 10 Hz to 1600 Hz. Retaining the same reference level used in Figure 13, the results for bands centered at 10 Hz, 20 Hz, 400 Hz and 1600 Hz are presented in Figure 14. For the 10 Hz band, the source signals range over 33 dB from minimum to maximum, while in the 20 Hz band the range is only 16 dB (Fig. 14 A, B). The range of variability remained <20 dB from 20 Hz up to 800 Hz, above which the variability increased (Fig. 14 C, D).

Near 400 Hz, sharp dips in levels appear at two times in the 15-min tape: about 06:30 and 13:20. Those dips became more prominent with increasing frequency, and were most prominent for the highest %-octave band analyzed (1600 Hz). The level at 06:30 in the ⅓-octave band centered at 1600 Hz was the lowest 'A-octave level found in any band; it is the reference level for all other levels graphed in Figures 13 and 14. At most of the lower frequencies, the levels also drop at 06:30 and 13:20, but the effect is less pronounced than at the high frequencies (Fig. 14),

Much of the high frequency energy from an icebreaker or other ship is attributable to propeller cavitation. On the ***Robert Lemeur, the*** propellers turn at a constant speed whether going ahead or astern; the propeller pitch changes to control power and the direction of thrust. There were several reversals of thrust direction during the icebreaker recording as the ***Robert Lemeur*** advanced, retreated, and advanced again (Fig. 12). It appears that most of these reversals were performed rapidly with respect to the 8.5 s averaging time of our analysis, and high-frequency sound from propeller cavitation was almost always present. The exceptions were the two times when the high frequency levels dipped sharply. At those times the officer controlling the propellers apparently hesitated in the neutral position, allowing the cavitation to subside,

Projected Icebreaking Sounds

Figure 15 presents waterfall spectrograms for five minutes of playback on 17 May 1991 as recorded simultaneously (A) at the monitor hydrophore near the projectors, and (B) at a sonobuoy

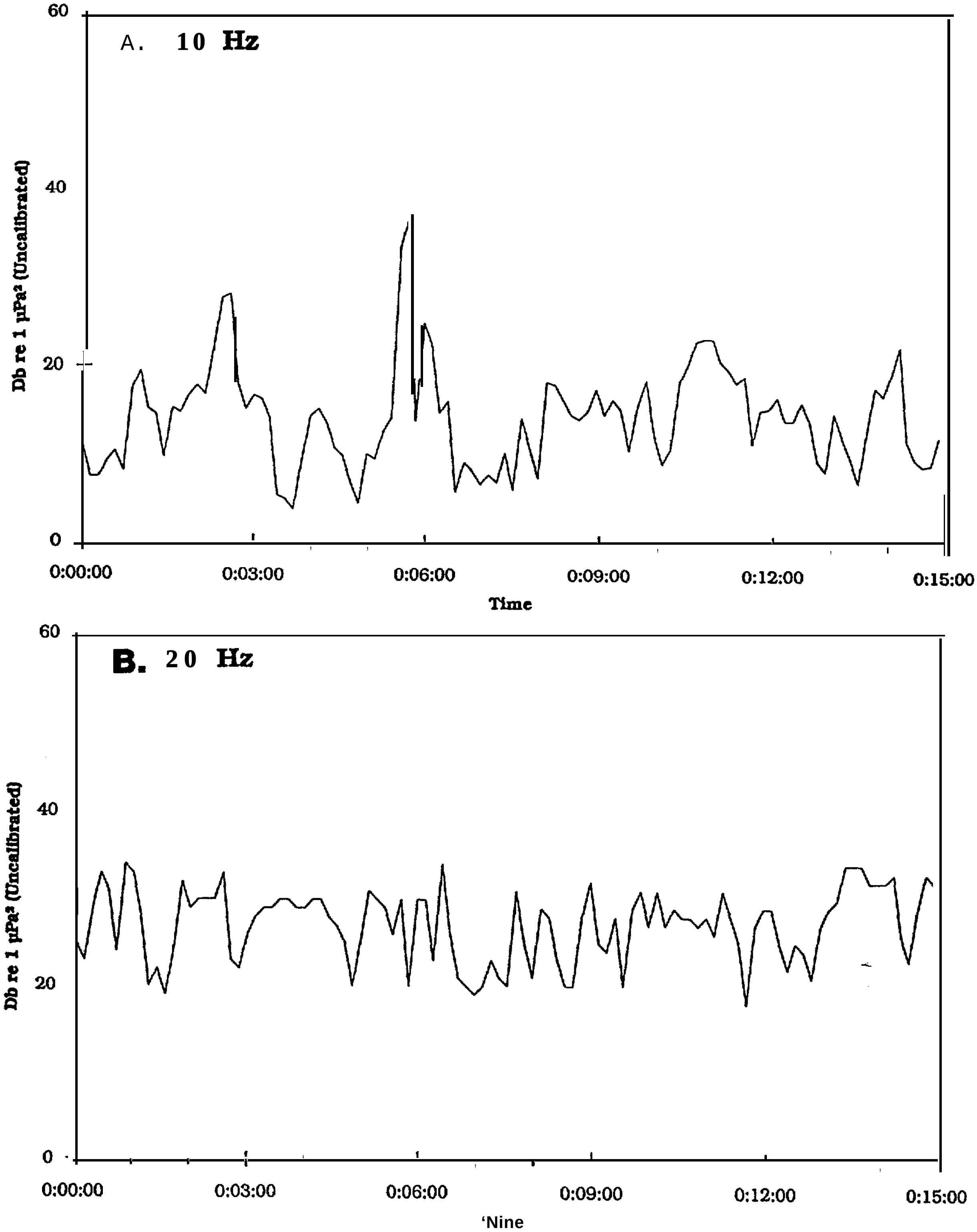
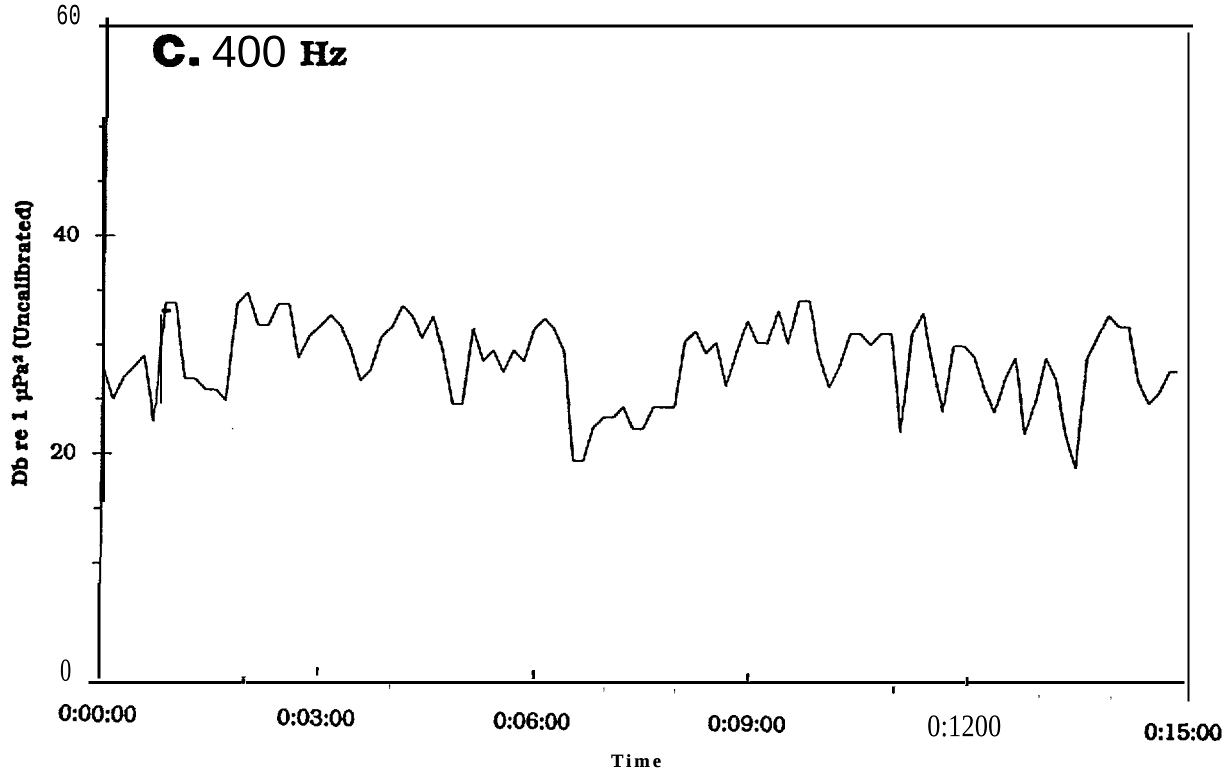


FIGURE 14. Variability of the **icebreaking** sounds in four one-third octave bands during the first 15 min of the playback tape. The **one-third** octave bands were centered at **(A)** 10 Hz, (B) 20 Hz, (C) 400 Hz, and (E) 1600 Hz. Levels are in **dB** relative to the minimum one-third octave level observed during the 15 min period.



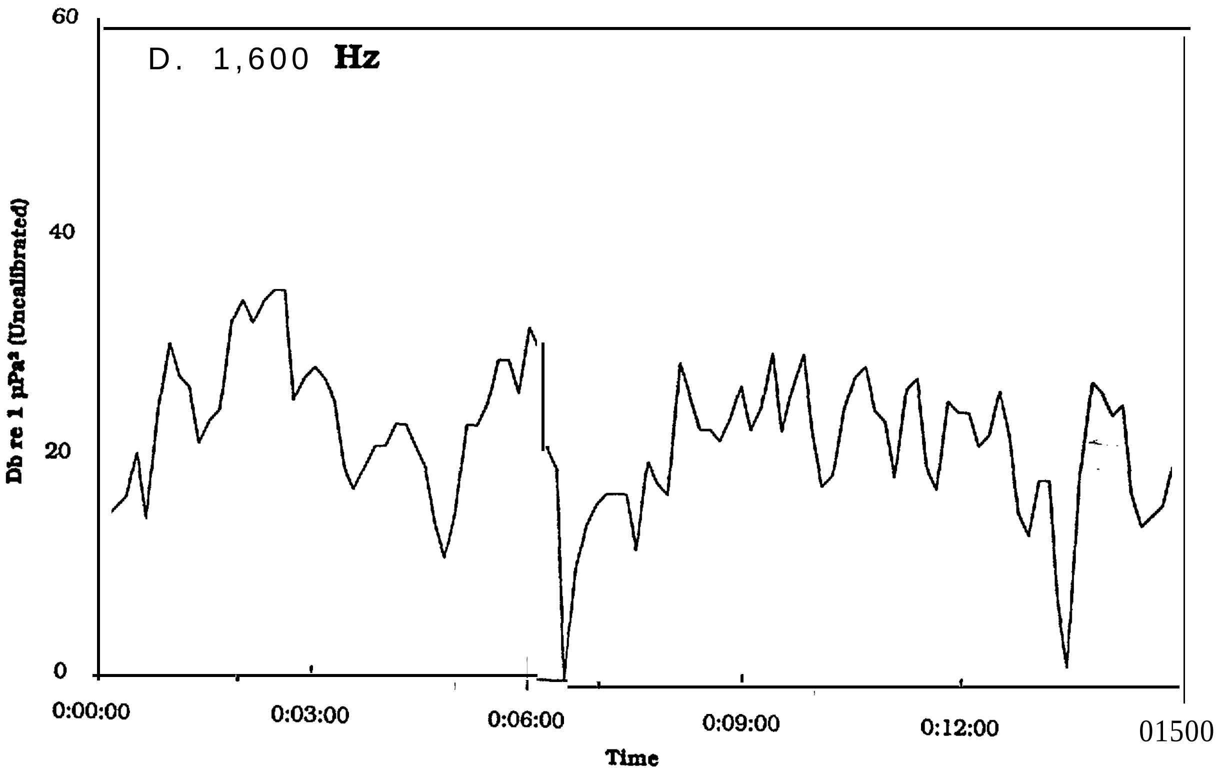


FIGURE 14 (continued).

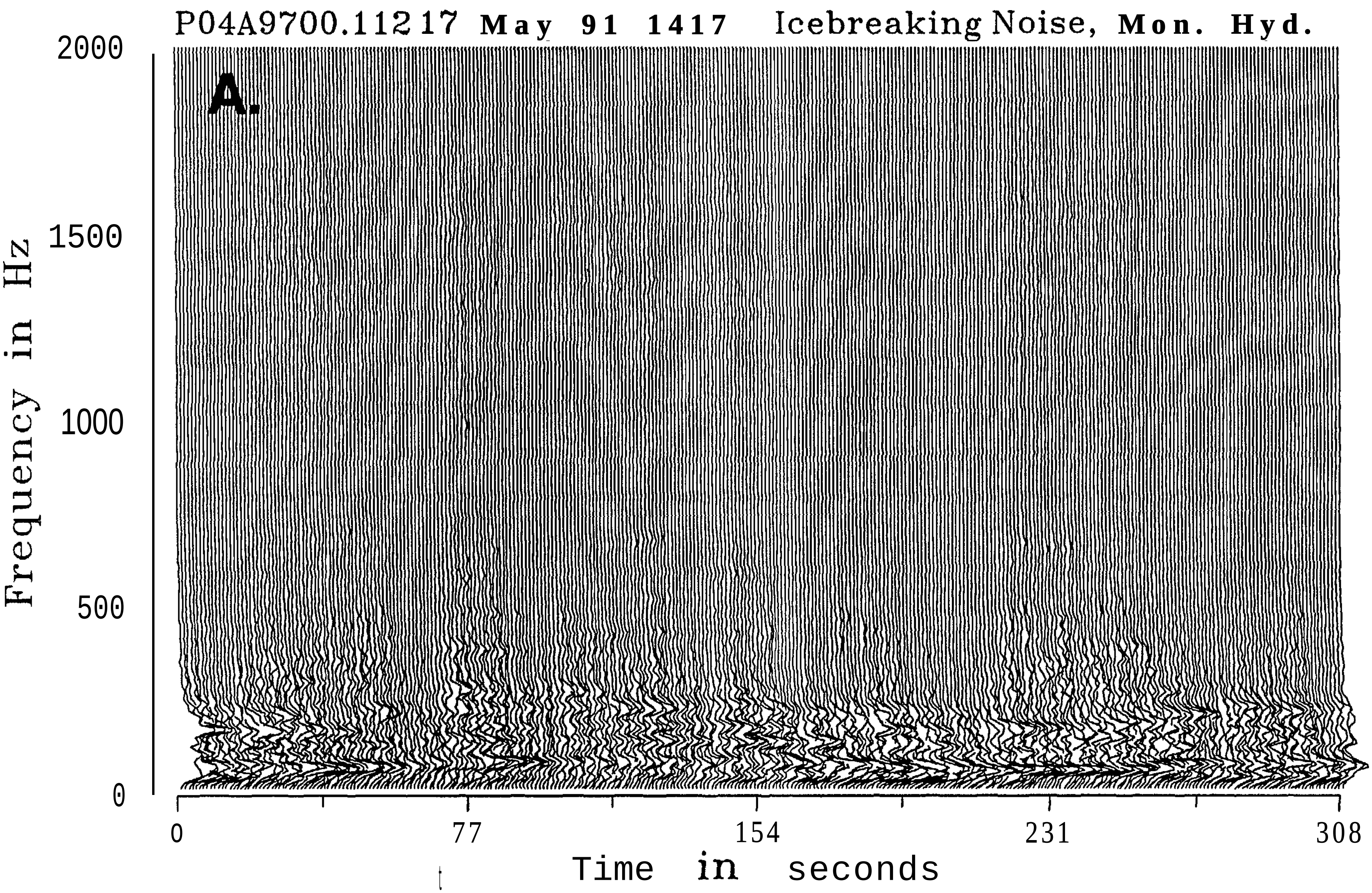


FIGURE 15. Waterfall spectrogram of the icebreaker playback sounds extending over 5 min starting at 14:17 on 17 May 1991. The data span the frequency range 20-2000 Hz. (A) is for the signal at the monitor hydrophore near the projectors. (B) is for the signal received at a sonobuoy 0.73 km from the projectors.

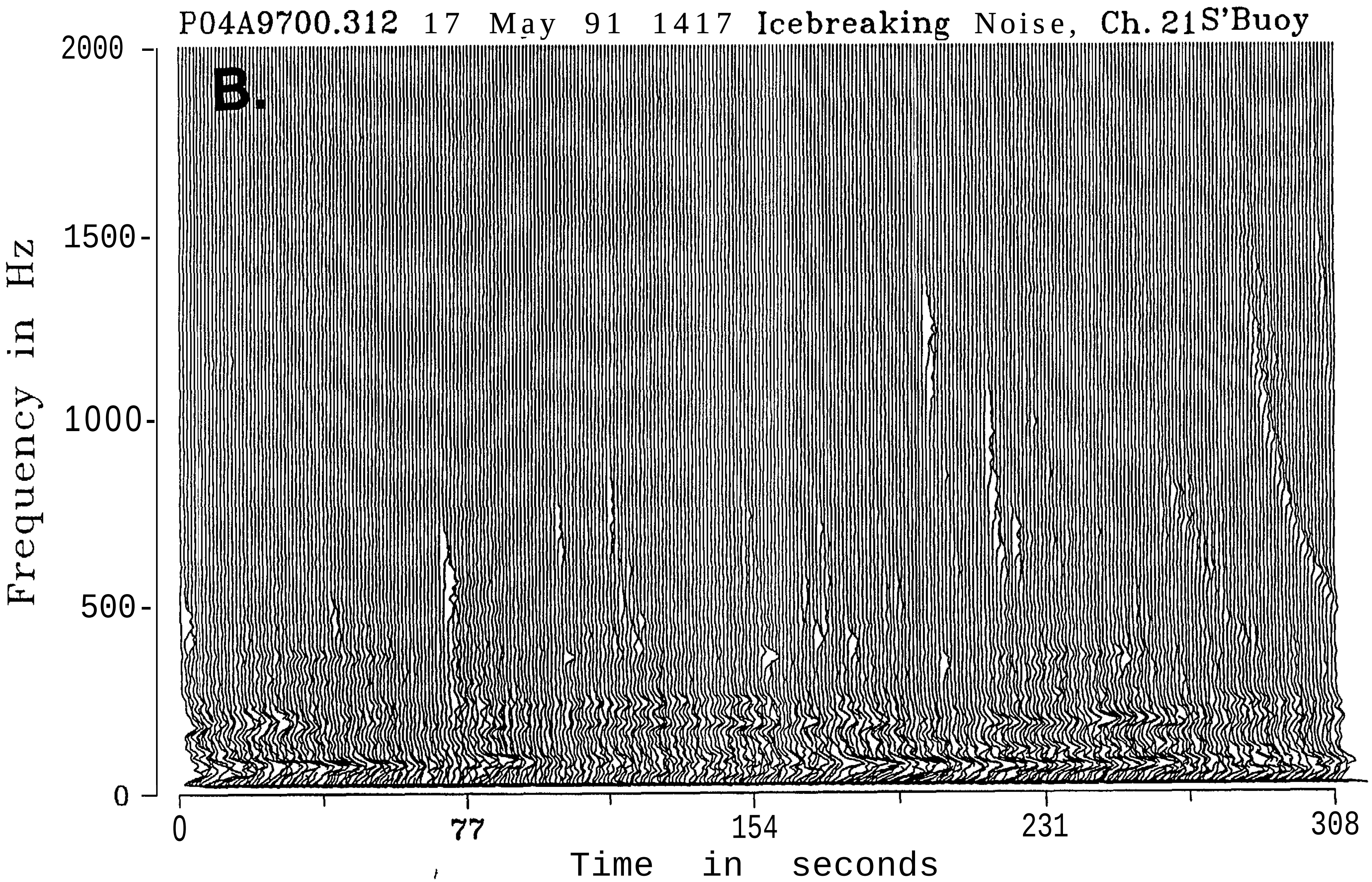


FIGURE 15 (continued).

0.73 km distant. These waterfall graphs display relative pressures per se, not logarithms of pressure (dB); this procedure tends to emphasize the dominant frequency components. The dominance of low frequency components is evident both near the source and at the receiver 0.73 km away. However, faint indications of the energy at high frequencies (500-1500 Hz) can be seen in the waterfall spectrogram of the projected sounds (Fig. 15A). Careful inspection of Figure 15A shows that the projected amount of high frequency energy varied at intervals of about 45-90 s, no doubt reflecting the forward-stop-reverse cycle of the original icebreaking activity.

Many parallels can be found between the frequency-time patterns evident at low frequencies (<500 Hz) in Figures 15A and 15B. In contrast, the weaker high-frequency components evident near the source (Fig. 15A) are not readily evident in the waterfall spectrogram for the received sounds (Fig. 15B). Instead, in the latter waterfall there are prominent sound pulses from ice cracks, and there is a downsweeping call from a bearded seal near time 300 s. To the human ear, the icebreaker sounds were clearly audible at the sonobuoy, even at the higher frequencies.

Two significant features of the icebreaker sounds, in comparison to the *Karluk* drilling sounds used for playbacks in 1989-90, are as follows: (1) there is more energy at frequencies above 400 Hz, and (2) the sound levels are not constant but vary notably with time (*cf.* Richardson et al. 1990a:80*ff*).

Figure 16 compares the wideband (20-1000 Hz) levels of the projected and received icebreaker sounds, showing the source levels near the projectors and the received levels at the sonobuoy 0.73 km away during a 5-rein period on 17 May 1991. Source levels were derived from the monitor hydrophore signals, adjusted to range 1 m. As expected, the source and received levels tended to vary in parallel over the 5-rein analysis period. During the 17 May playback, received wideband levels of icebreaker sound at range 0.73 km varied between about 103 and 112 dB (Fig. 16), well above the 93 dB level of the ambient noise measured later on 17 May, after the end of the playback.

The difference between the source level and received level curves in Figure 16 is close to 53 dB, representing the wideband signal transmission loss for this 0.73 km path. Note that 53 dB is a reasonable value for TL between 1 m and 0.73 km, given the TL results shown in Figures 8-11 for tones and clusters of tones.

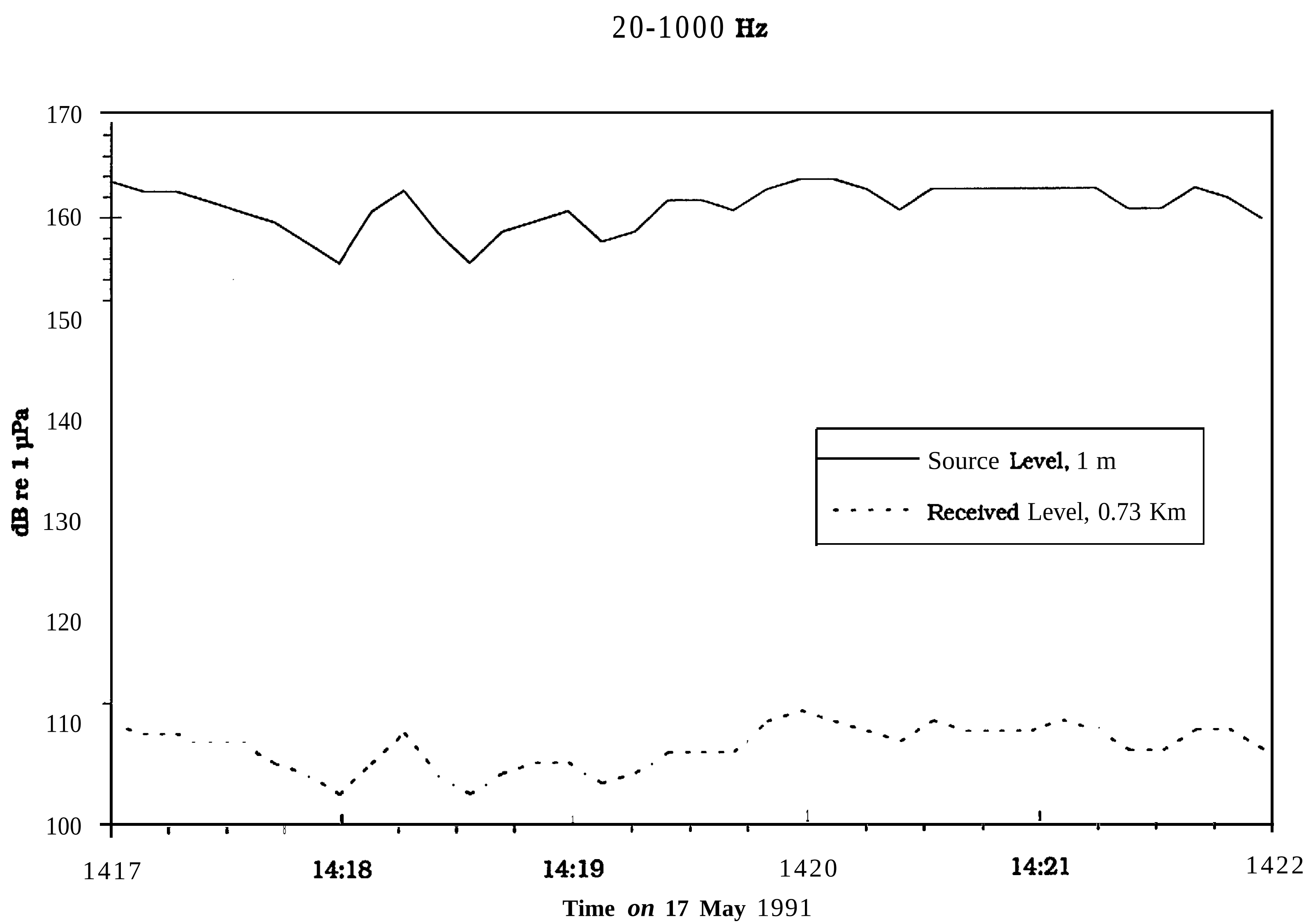


FIGURE 16. Source and received levels of projected icebreaker sounds (20-1000 Hz band) over a 5 min period beginning at 14:17 on 17 May 1991. Source levels were based on the monitor hydrophore (adjusted for 1 m range); received levels were measured at a sonobuoy 0.73 km from the projectors.

Figure 17 presents four examples of the icebreaking noise received at the sonobuoy 0.73 km from the projectors during the playback on 17 May 1991. These spectra reinforce the waterfall displays (Fig. 15) and other evidence showing that the icebreaker energy was strongest at low frequencies. However, as noted above, the icebreaker sounds contained more energy at moderately high frequencies, above 400 Hz, than was present in the ***Karluk*** sounds. Occasional animal calls account for some of the irregularities in the spectra shown in Figure 17.

Information about the one-third octave levels of the projected and received sounds during the 17 May 1991 playback is given in Figure 34, in the "Bowhead Results—Playbacks" section.

Do Bowhead Calls Contain Infrasonic Components?

Data on the possibility that bowhead calls contain infrasonic components are relevant in evaluating the significance of industrial infrasounds to bowheads (see specific objective 5, p. 5).

All bowhead calls recorded during ambient noise recordings in 1991 were analyzed for infrasonic energy content. Waterfall spectrograms were computed for 45 samples of recorded signals. These 45 spectrograms contained -73 calls, of which 11 occurred coincidentally with infrasonic energy. Figure 18 shows two spectrograms and five calls without perceptible infrasonic components. Figure 19 shows two spectrograms and three (or possibly four) calls, of which at least one occurs with infrasonic energy. Figure 20 shows two more spectrograms with infrasonic energy associated with bowhead calls.

Of 45 calls recorded in the spring of 1990 and analyzed in a similar way, one call was associated with the occurrence of infrasonic energy (Richardson et al. 1991:91-96).

Simultaneous arrival at the hydrophore of a bowhead call and an infrasonic signal does not prove that the infrasonic component came from the calling whale. However, it is possible that at least some of the cases listed above did represent bowhead calls with infrasonic components. This possibility could be tested more readily in a study employing widely-spaced hydrophores to localize calling whales (e.g. Cummings and Holliday 1985; Clark et al. 1986; Greene 1987). If whale calls and infrasonic signals are received simultaneously from the same location, this would provide much stronger evidence that some bowhead calls include infrasonic components.

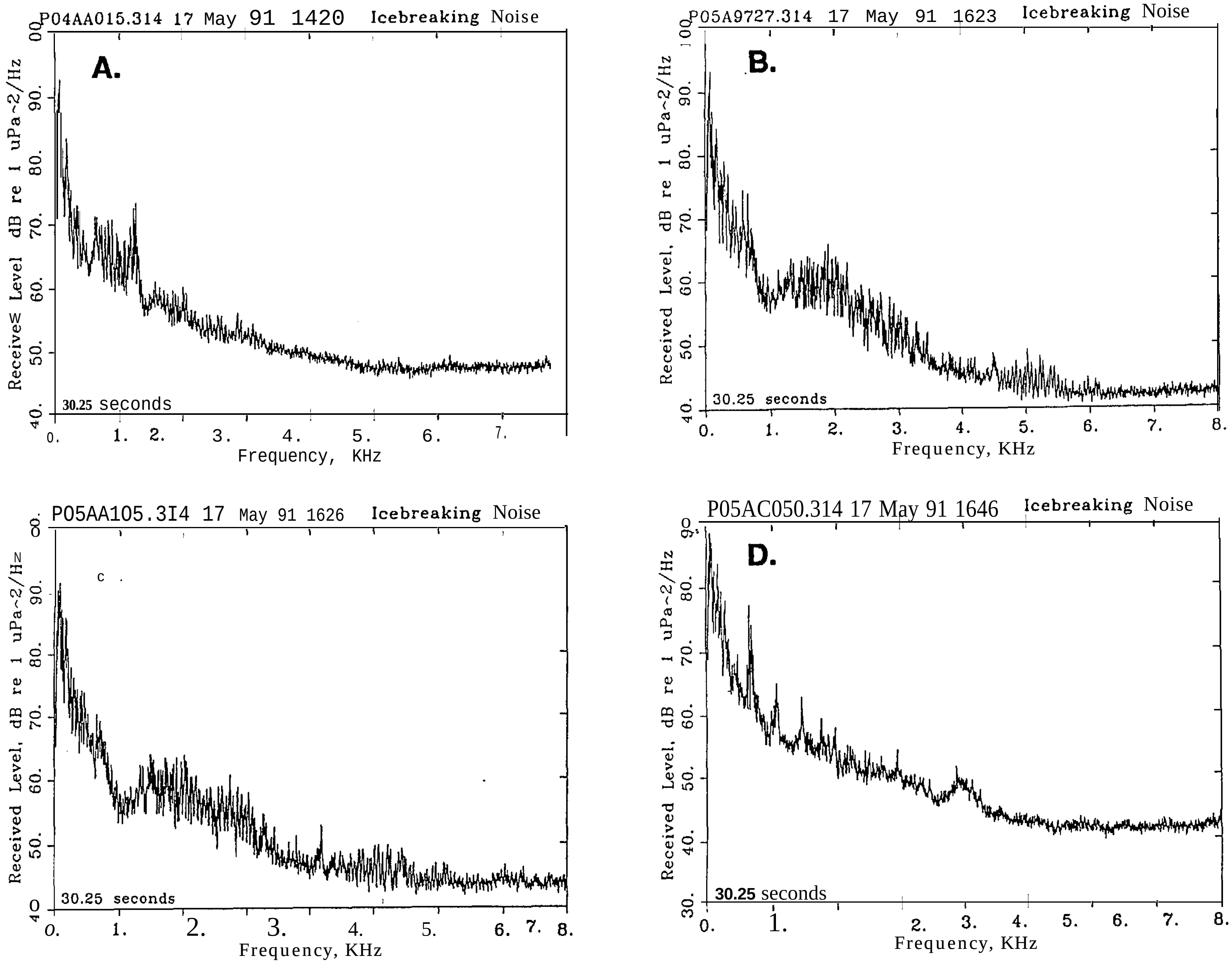


FIGURE 17. Four examples of icebreaking noise spectra for sounds received at the sonobuoy during a playback experiment, 17 May 1991, range 0.73 km.

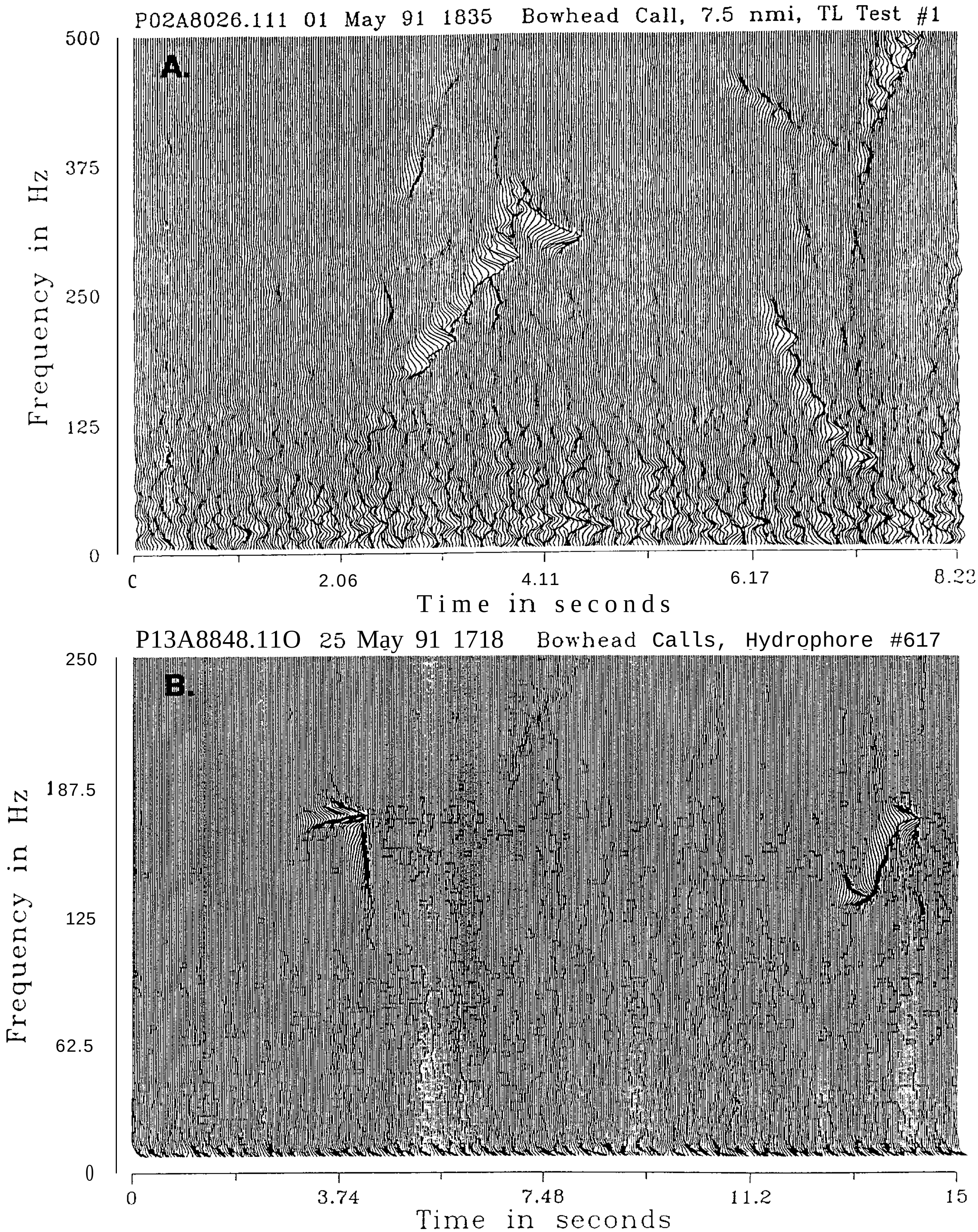


FIGURE 18. Waterfall spectrograms of bowhead calls without perceptible infrasonic components. **(A)** shows three calls; (B) shows two calls.

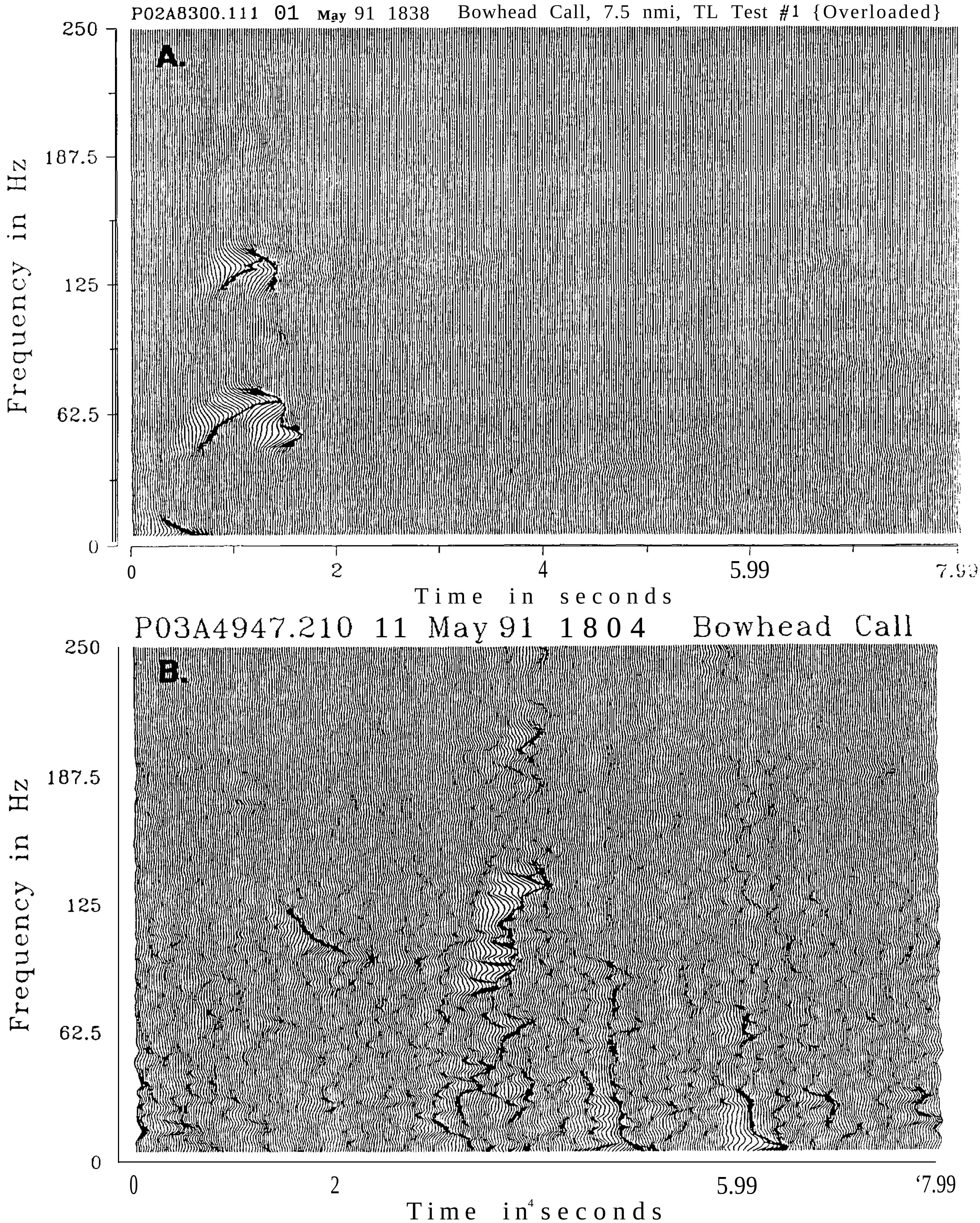


FIGURE ***19.*** Waterfall spectrograms of bowhead calls with possible infrasonic components. (A) shows one call. (B) shows two calls, the second of which—at time 3-4 s—has associated infrasonic energy. A third possible call in (B) at time 6 s has energy only at frequencies below 30 Hz; it cannot be proven that this sound is from a bowhead.

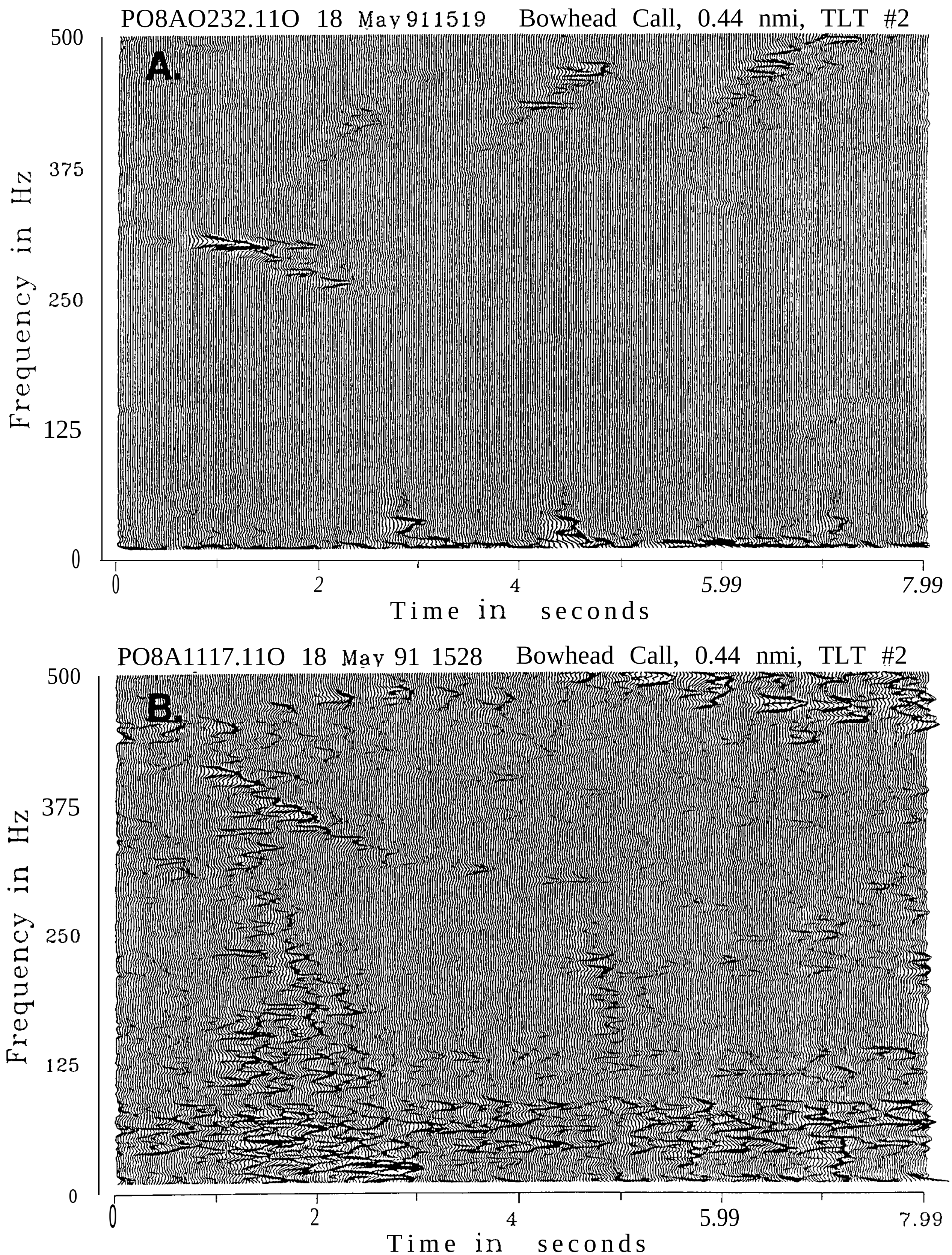


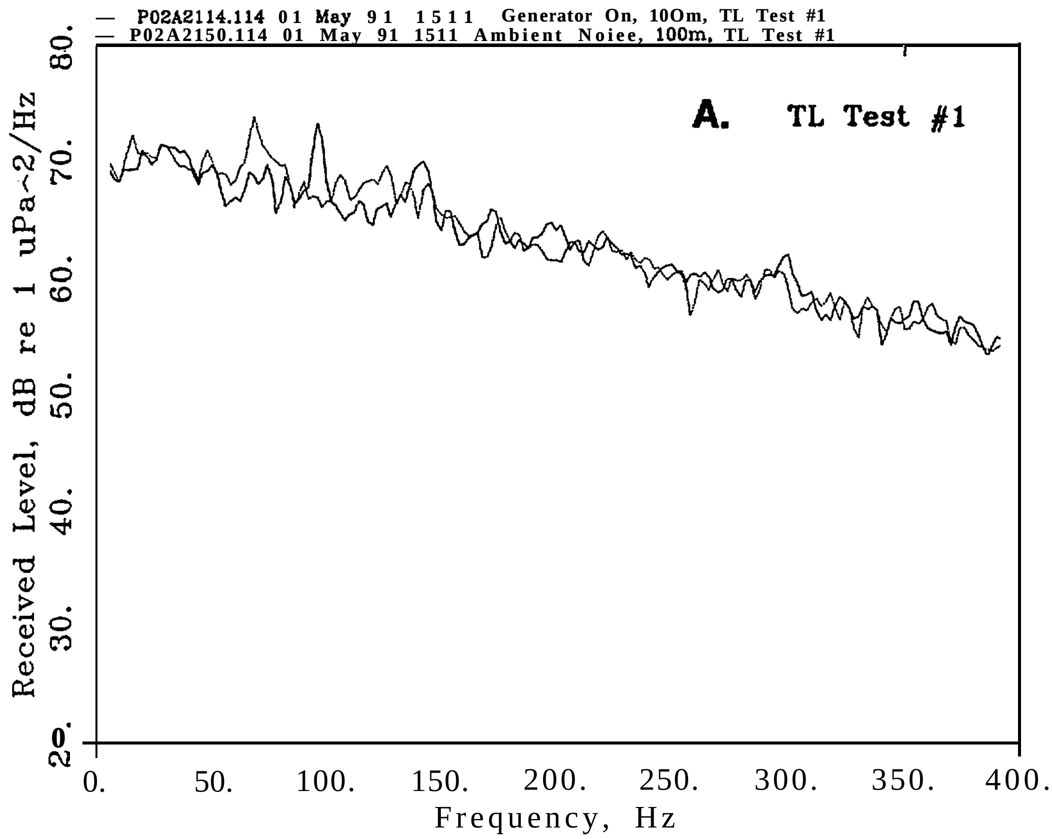
FIGURE 20. Waterfall spectrograms of bowhead calls with possible infrasonic components. (A) shows three calls, at 1, 4.5 and 7 s; infrasonic energy appears at 3 and 4.5 s. (B) shows two or three calls, at 1.5, 4.8 and possibly 8 s, with infrasonic components at 1.5-3 s.

Generator Noise

Thegenerator usedin 1991 wasthesame 2.2kWmodel usedin 1990. In 1989 and 1990, the generator operated on the snow-covered ice. Four rubber pads supported the generator, but vibrations coupled to the ice. When we examined the spectra of underwater sounds recorded near the ice camp during 1989-90 in the absence of playbacks, we detected generator tones at integer multiples of 60 Hz (or close to 60 Hz, depending on the speed governor). These tones were detected at ranges up to 400 m, depending on background noise level. The levels were weak compared to projected sound levels at those frequencies. However, in the absence of playbacks we could hear the tones above the ambient noise at range 100 m and often at somewhat greater ranges. We were concerned about the possibility that whales close to the ice camp might react to this generator noise during “control” (non-playback) periods (Richardson et al. 1991 a:244-246).

In 1991, at the suggestion of A. Milne, the generator was suspended by bungee cords from a PVC pipe frame whose four legs stood on the ice. No part of the generator touched the ice. Background noise recordings with and without the generator on were made at ranges 0.1-1 km during each transmission loss experiment. We could not hear generator sounds, or any change in the audible background noise, when the generator was started or stopped at any range. Underwater sound spectra from depth 18 m were computed for the different ranges but no tones that could be associated with the generator were evident. For example, Figure 21 shows the spectra of the noise received at range 100 m, generator on and off, during each of the four transmission loss experiments in 1991. The peaks in the noise spectra do not occur at multiples of 60 Hz or show any other similarities that might be attributable to the generator.

Thus, the suspension system adopted in 1991 successfully isolated the generator from the ice and avoided transmission of significant levels of generator sound into the water.



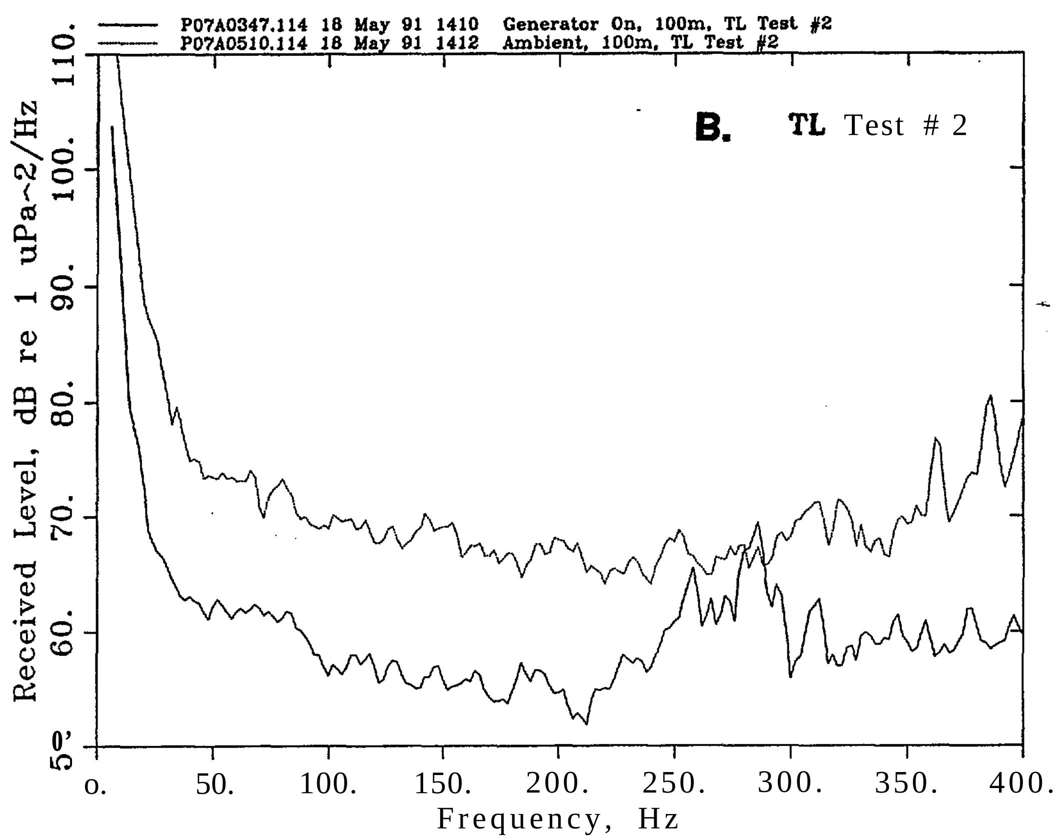
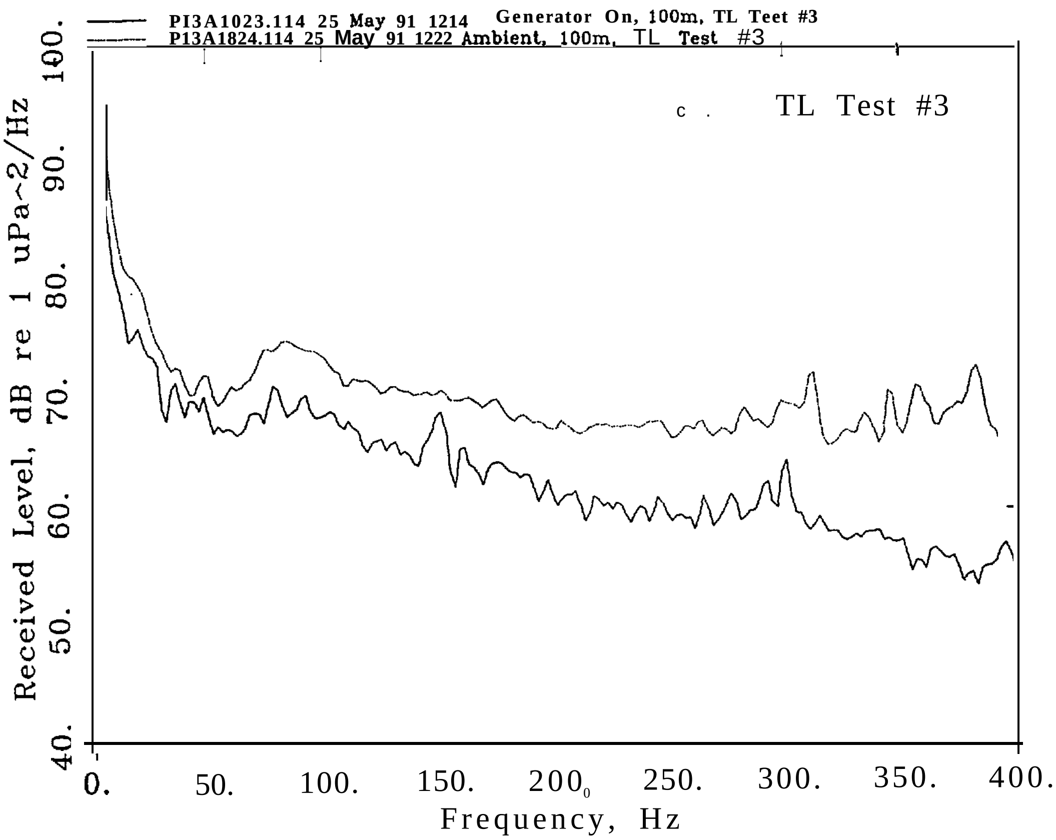


FIGURE 21. Noise spectra observed 100 m from the ice camp with the generator on and off. Data were obtained during the four transmission loss tests in 1991. The sound projectors were silent during these measurements.



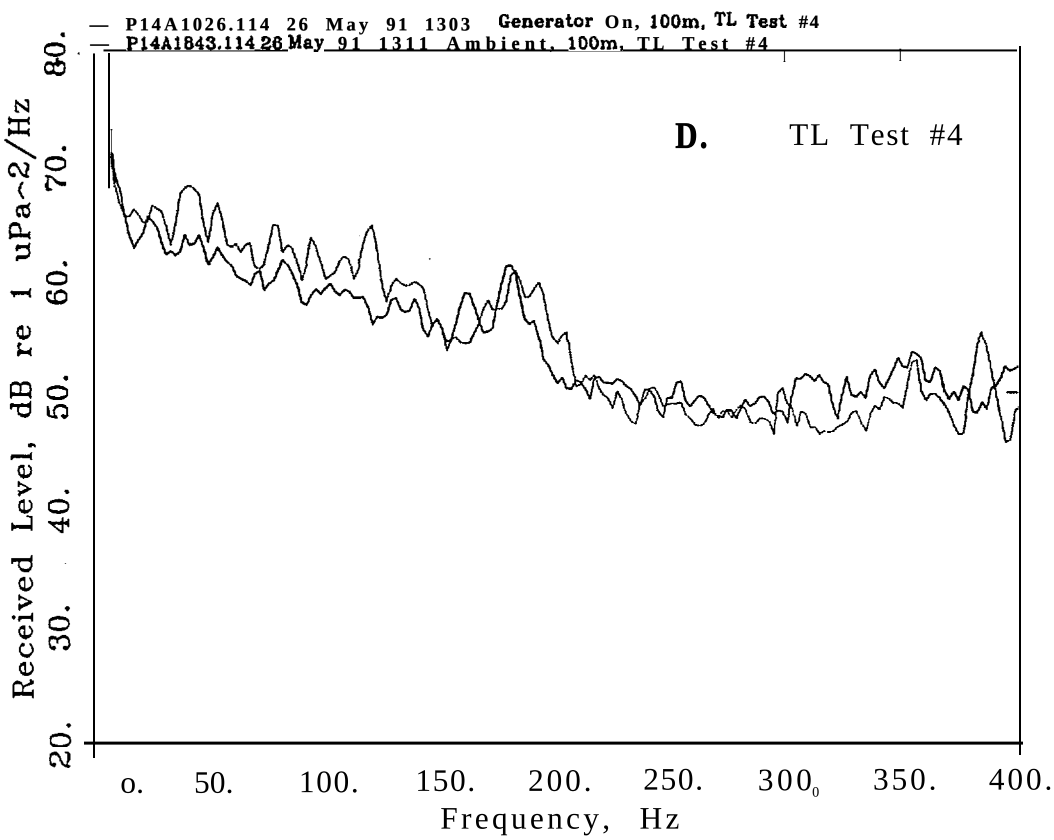


FIGURE 21 (continued).

BOWHEAD WHALE RESULTS

Distribution & Movements of Bowheads, Spring 1991

Bowheads in General

Specific objective 7 for 1991 included a requirement to document, as opportunities allowed, the movements and basic biology of bowhead whales. The bowhead sightings during reconnaissance flights, helicopter ferry flights, and ice-based work provided information about the timing and routes of bowhead migration through the study area in 1991.

Ice conditions were loose enough to allow bowheads to travel northeast and east across the study area throughout our field season (28 April-26 May). There was a passable migration corridor close to the landfast ice edge throughout the spring. Early in the season, this was in the form of a wide nearshore lead extending northeast past Pt. Barrow far into the Beaufort Sea (e.g. Plate 1). Later in the season the broad, continuous lead did not extend as far to the east, but there were—at the least—discontinuous openings near the landfast ice edge and elsewhere in the pack ice. Many bowheads traveled northeast and then east along that corridor (Fig. 22).

There were more bowhead sightings close to the landfast ice edge in areas well east of Pt. Barrow than we had observed in 1990 and especially 1989. In 1989-90, almost all bowheads seen east of about 156°W were either near the northern edge of the main nearshore lead or in the pack ice north of that lead—not along the south edge of the lead near the landfast ice. In 1991, in contrast, numerous bowheads were seen quite close to the landfast ice edge well to the east of 156° (Fig. 22). However, in 1991 as well as 1989-90, other bowheads continued to the NE or ENE after passing Pt. Barrow, moving well offshore into the pack ice as they moved east into the Beaufort Sea (Fig. 22). This pattern is also evident in the pattern of sightings during the National Marine Mammal Lab's bowhead photography flights in 1991 (Fig. 23).

Our primary objective when conducting reconnaissance flights was to locate the main bowhead migration corridor and, within that corridor, concentrations of bowheads. We did not conduct systematic surveys, and we devoted much less effort to areas where few or no bowheads were expected than to the more promising areas. NMML's strategy during their flights was similar. Hence, the relative numbers of sightings in different parts of Figures 22 and 23 should not be taken as a quantitative measure of densities of whales in those areas. East of Pt. Barrow, both NMML and ourselves devoted much more effort to areas between71“30’N and 71 °40’N, the main bowhead migration corridor in 1991, than to areas farther north or south. However, occasional reconnaissance north of 71040 showed that densities of bowheads were much lower there than in the main migration corridor for eastbound bowheads.

We did relatively little reconnaissance to the west and northwest of Pt. Barrow, and we did so only after mid-May, when spring whaling ended. However, it was apparent that, in the latter half of May 1991, at least a few bowheads were occurring many kilometers to the northwest, far from the landfast ice edge (Fig. 22). The National Marine Mammal Lab's aerial photography crew also saw a few bowheads far to the northwest (Fig. 23).

Figures 24 to 28 show our bowhead sightings on a chronological basis from 28 April-5 May through 21-26 May. The area northeast and east of Pt. Barrow was searched throughout the field season. The general distribution of sightings east of Pt. Barrow did not change substantially during most of this period. However, late in the season (21-26 May) there seemed to be a tendency for bowheads to travel ENE rather than east. At that time, the nearshore lead provided an open corridor to the ENE as well as the east. The numbers of bowheads seen each day are shown in Table 1 B, along with a measure of reconnaissance survey effort—the number of hours of reconnaissance flying each day.

Although the number of bowheads in the area varied from day to day, bowheads were detected quite consistently in 1991. We saw bowheads during 24 of the 25 effective offshore flights (those >1 h in duration). This is an unusually high proportion. In 1989, in contrast, bowheads were sighted during only 15 of the 24 days with flights (>1 h of flying on all of 24 days). In 1991, the flight on 28 April was the only prolonged flight when no bowheads were seen, Indeed, bowheads were also seen during 2 of the 5 short flights that were terminated within 1 h because of bad weather.

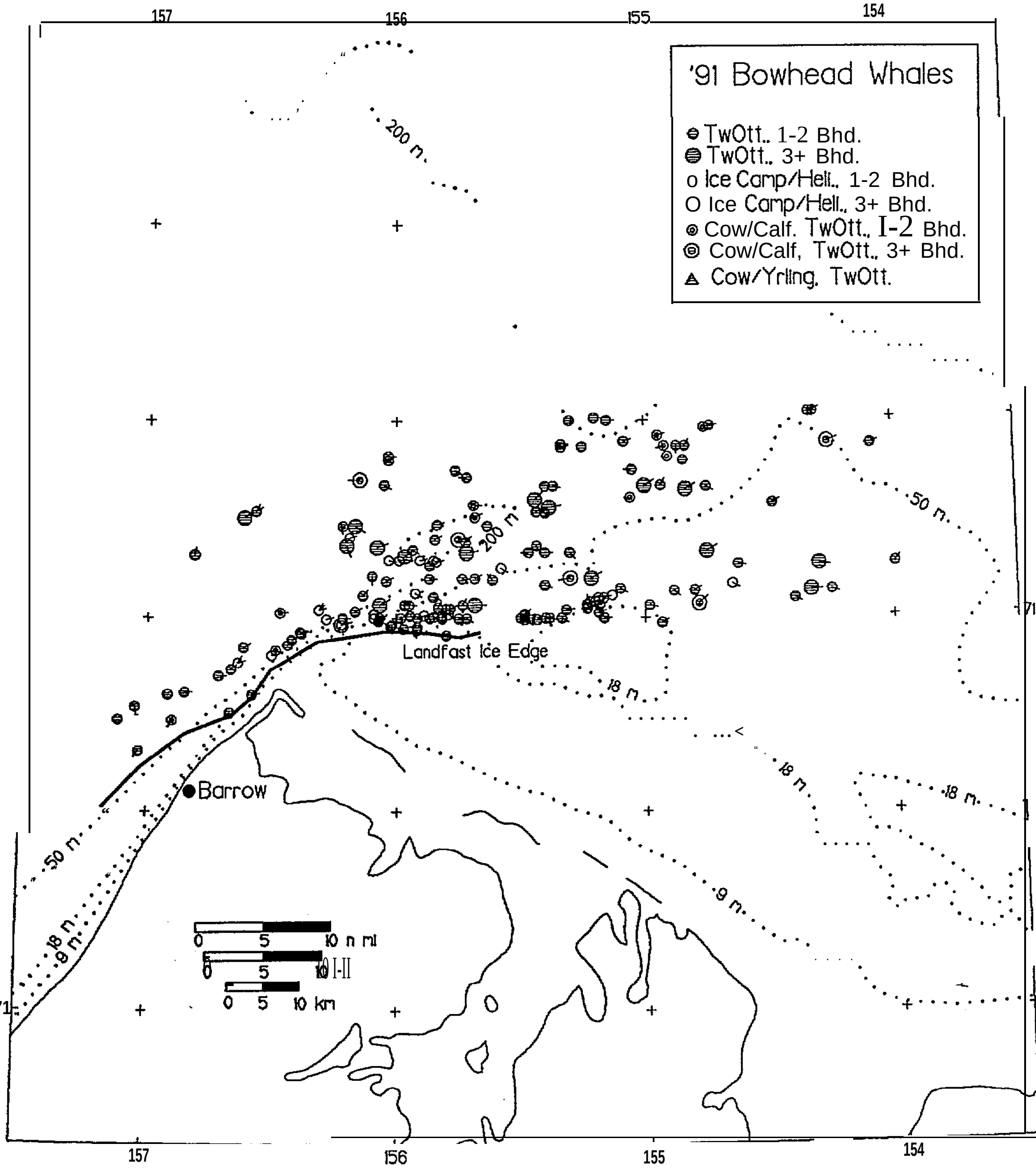


FIGURE 22. LGL sightings of bowhead whales, 28 April to 26 May 1991, Symbol type distinguishes sightings by the two crews, sightings of 1-2 vs. **>2** bowheads, and sightings of mother/calf pairs vs. non-calves. Headings toward which the whales were oriented when first seen are also shown when available. Survey effort was not uniform across the area mapped; the most intense effort was in the **nearshore** lead just north of the landfast ice.

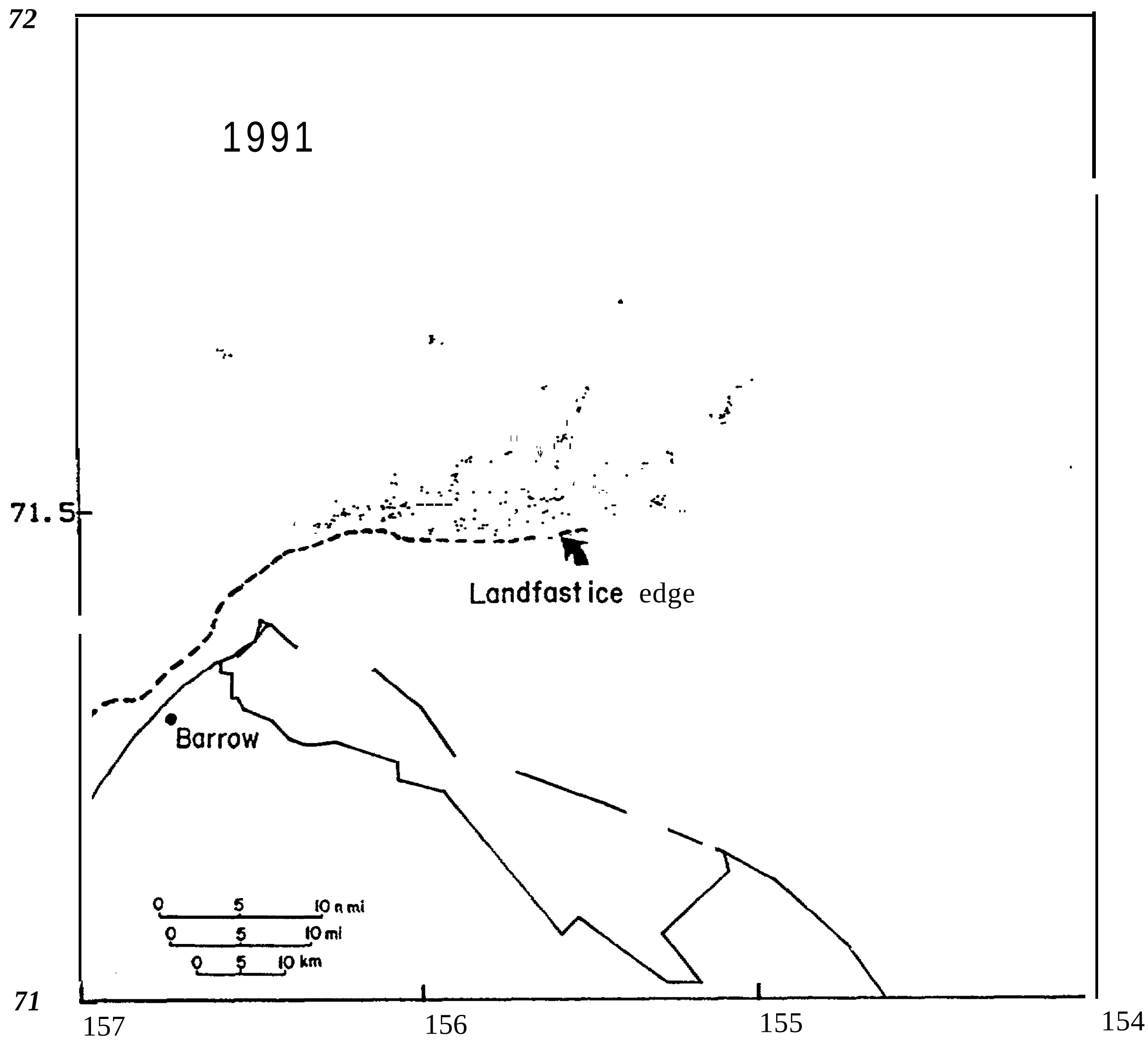


FIGURE 23. Locations where bowheads were photographed during spring photogrammetric surveys conducted by the U.S. National Marine Mammal Laboratory in 1991 (NMML unpubl. data, courtesy D. Withrow and D. Rugh, NMML). Survey effort was not uniform across the area mapped; the most intense effort was in the nearshore lead just north of the landfast ice.

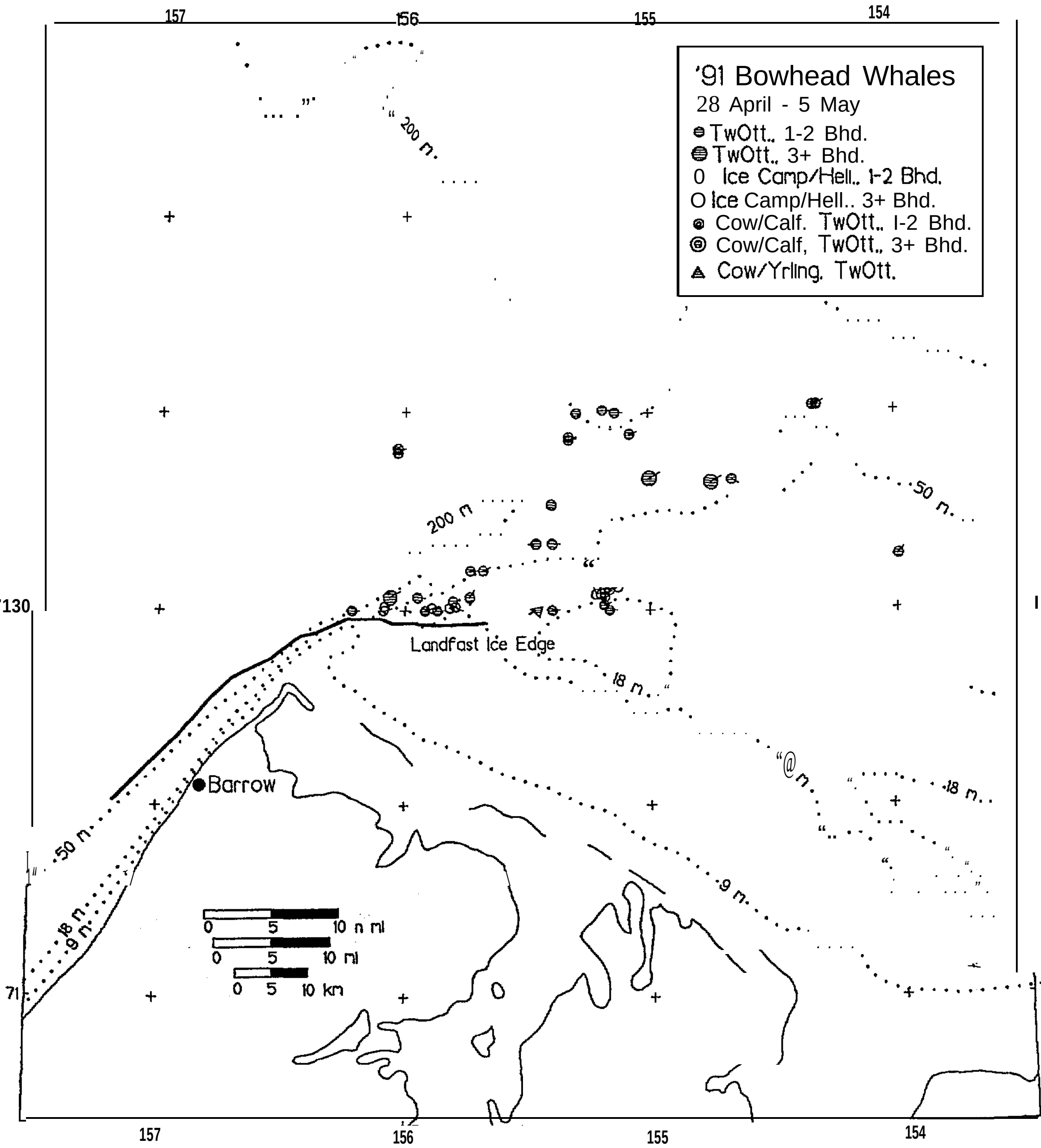


FIGURE 24. LGL sightings of bowhead whales, 28 April to 5 May 1991. Format as in Fig. 22.

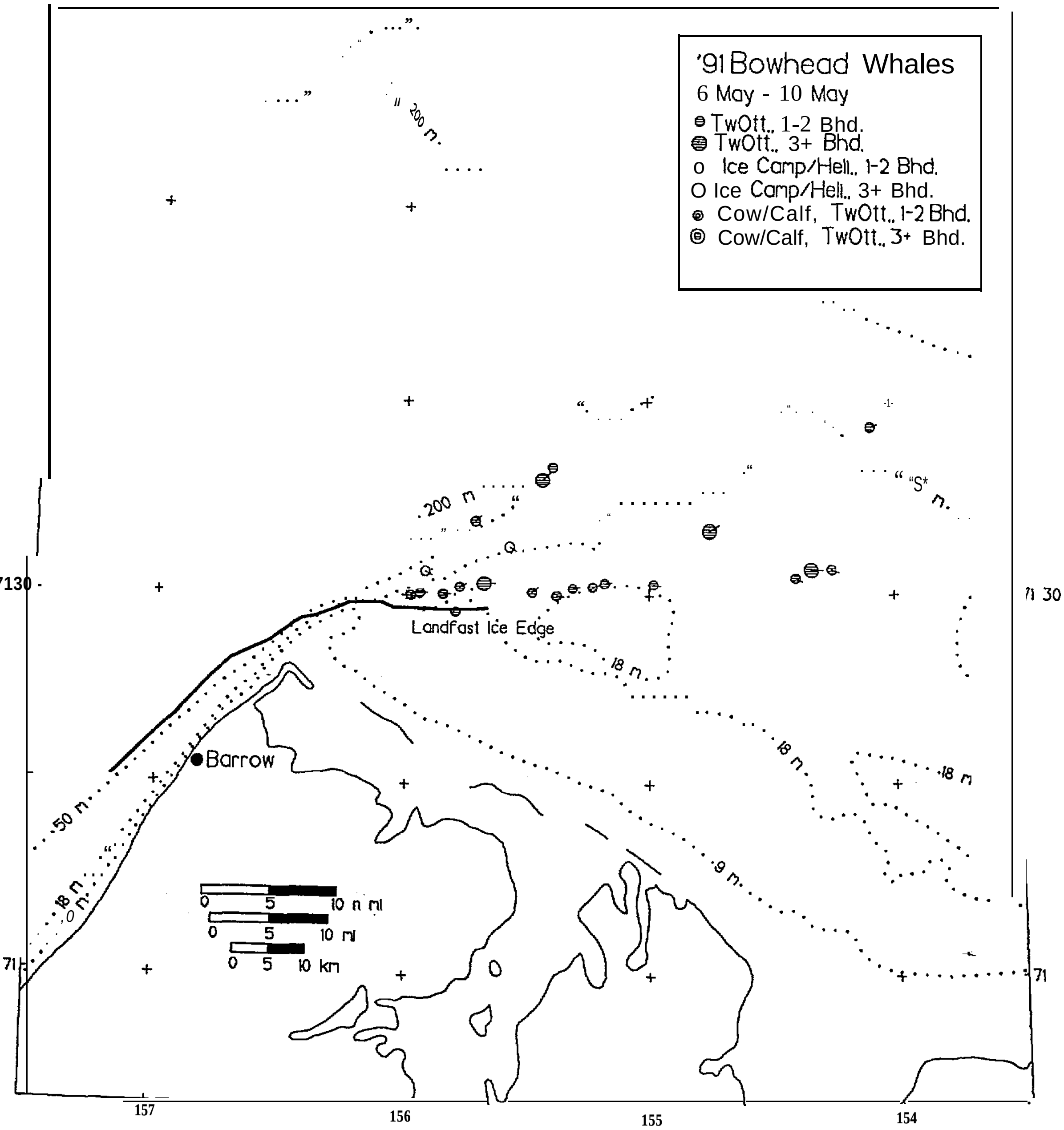


FIGURE *25.* LGL sightings of **bowhead** whales, 6-10 May 1991. Format as in Fig. 22,

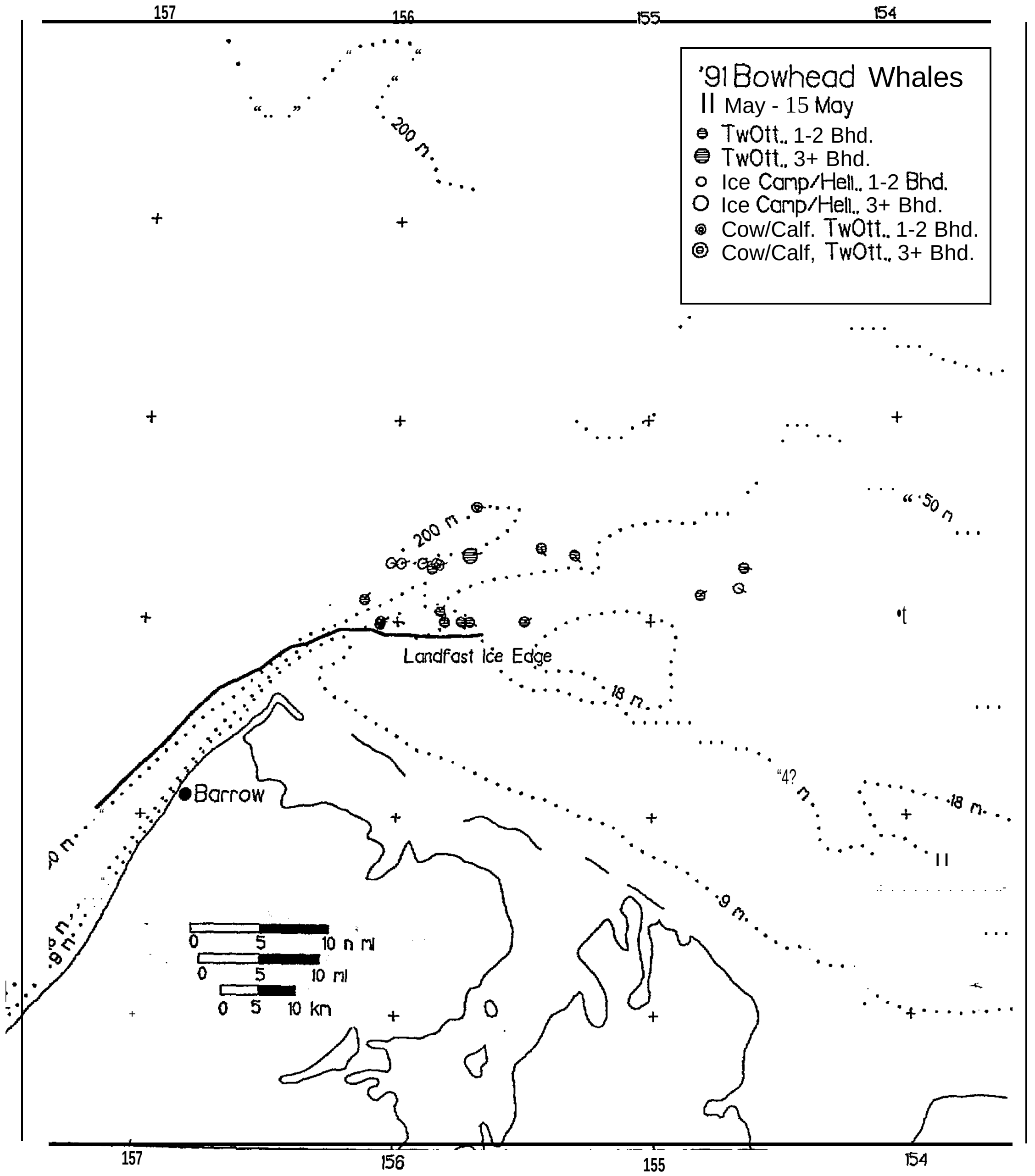


FIGURE 26. LGL sightings of bowhead whales, 11-15 May 1991. Format as in Fig. 22.

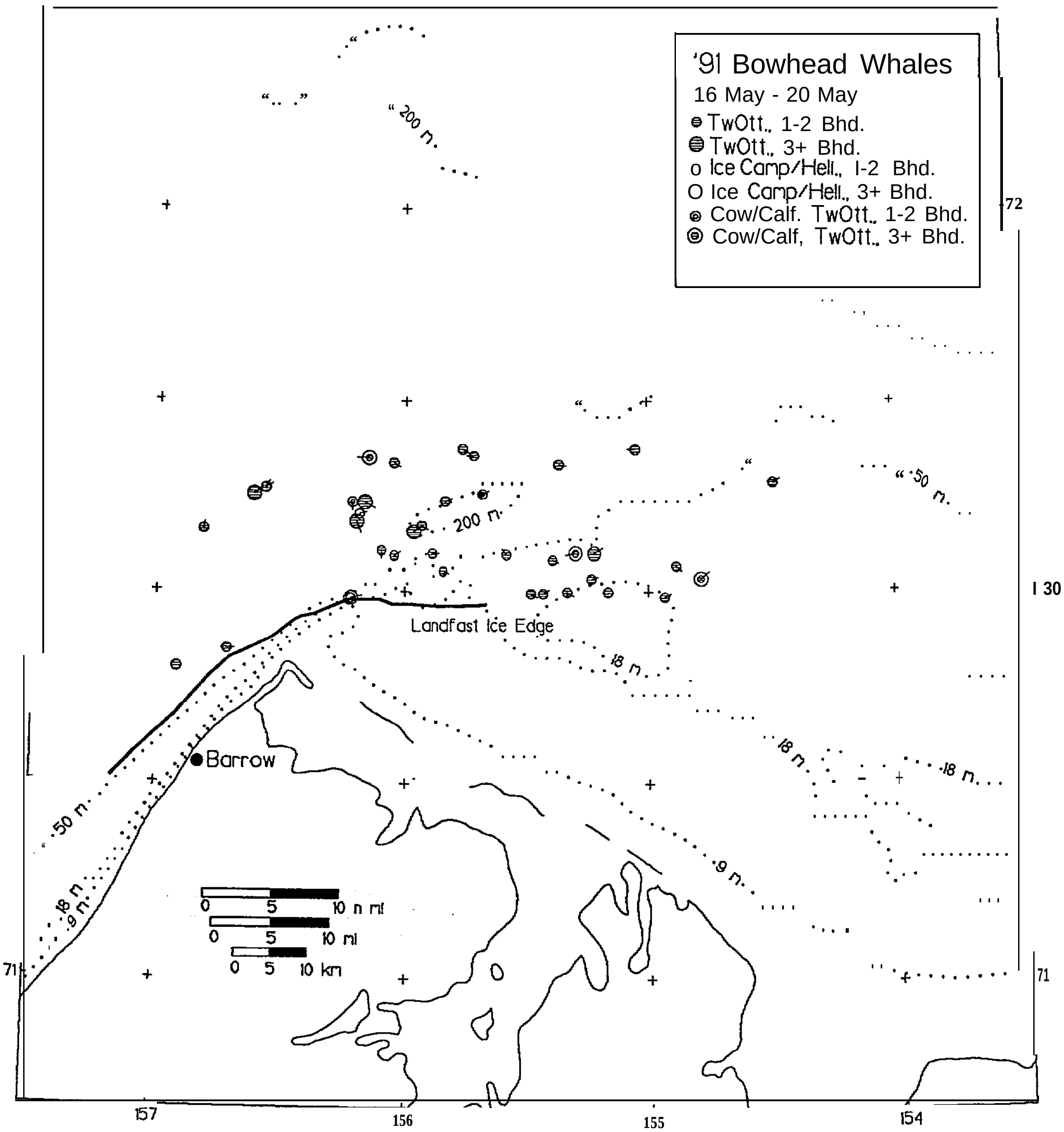


FIGURE *27.* LGL sightings of bowhead whales, 16-20 May 1991. Format as in Fig. 22.

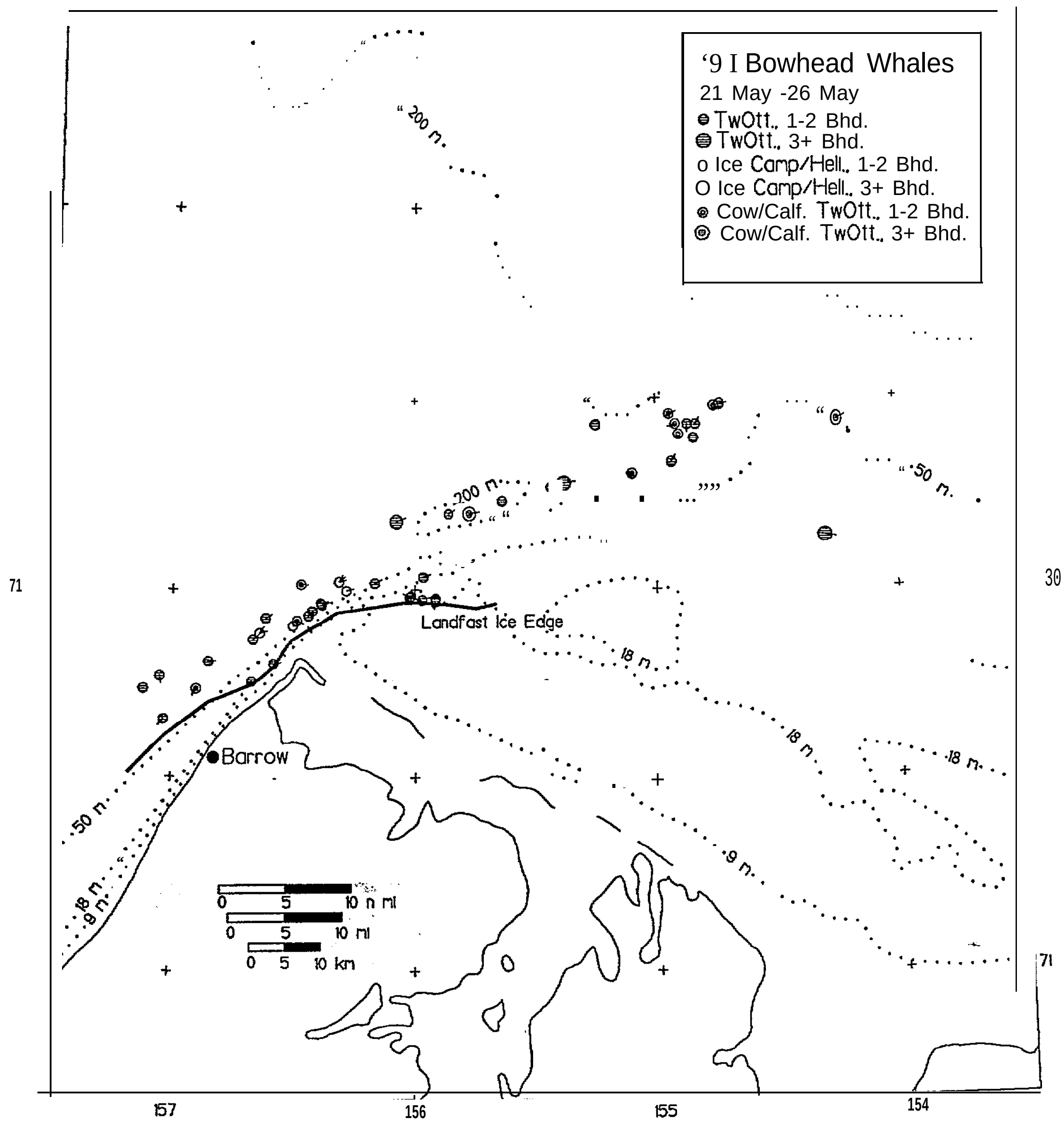


FIGURE **28.** LGL sightings of bowhead whales, 21-26 May 1991. Format as in Fig. 22.

Mothers and Calves

Aside from a mother and yearling bowhead sighted on 29 April, our first mother-calf sighting in 1991 was on 11 May, and the next mother-calf sightings were not until 17 May. Mother-calf pairs were seen regularly from 17 May until the end of our field season on 26 May. They constituted a substantial proportion of all bowhead sightings during the last few days of the field season. Prior to 16 May in 1991, only 2 of 159 bowheads seen from the Twin Otter were mothers or calves (mother/yearling excluded). From 16 to 20 May, 12 of 82 bowheads seen from the Twin Otter were mothers or calves. From 21 to 26 May, 20 of 64 were mothers or calves. The concentration of mother-calf sightings late in the spring was also evident in 1989 and 1990 (Richardson et al, 1990a:153,1991a:105).

Figure 29 shows all of our 1991 sightings of bowhead mothers accompanied by calves. Their distribution in 1991 was generally consistent with that of other whales seen during the latter part of the field season (Fig. 29 vs. 27-28). As in 1989-90, mothers and calves often headed in directions other than northeast or east (Fig. 29).

Bowhead Photogrammetry & Photoidentification, Spring 1991

Data on bowhead sizes and on re-identifications of previously-photographed bowheads were relevant to specific objective 7, "to document... other aspects of the movements, behavior, basic biology ...of bowheads".

Bowhead Sizes

Vertical photographs of bowhead whales were obtained on ten days in 1991; the locations where these photographs were taken are shown in Figure 30. Usable length measurements (grades 1-6) were obtained for 71 different bowheads during this study. Approximate lengths were obtained for an additional 12 whales. The latter were whales that were deeply submerged or were photographed from uncertain altitudes (i.e. aircraft altitude <91 m or changing rapidly). We assume that bowheads <13 m long were subadults, and that those ≥13 m long were adults (Koski et al. in press a).

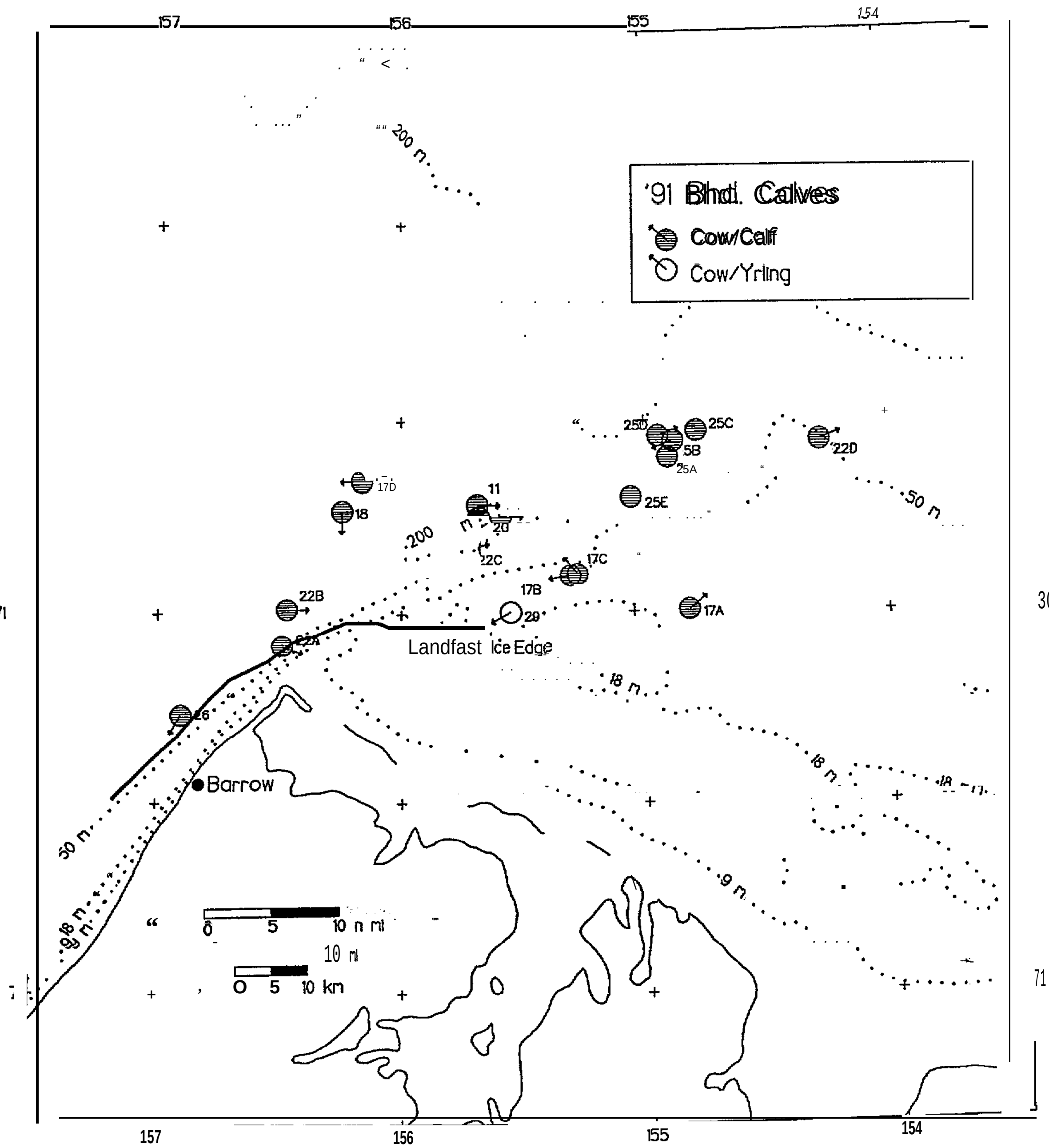


FIGURE 29. Locations where bowhead mothers and calves were seen by LGL, 1991. Numbers are dates in May 1991 (29 April for mother/yearling pair); letters distinguish the multiple mother/calf pairs seen on some dates. Headings toward which the whales were oriented when first seen are also shown when available,

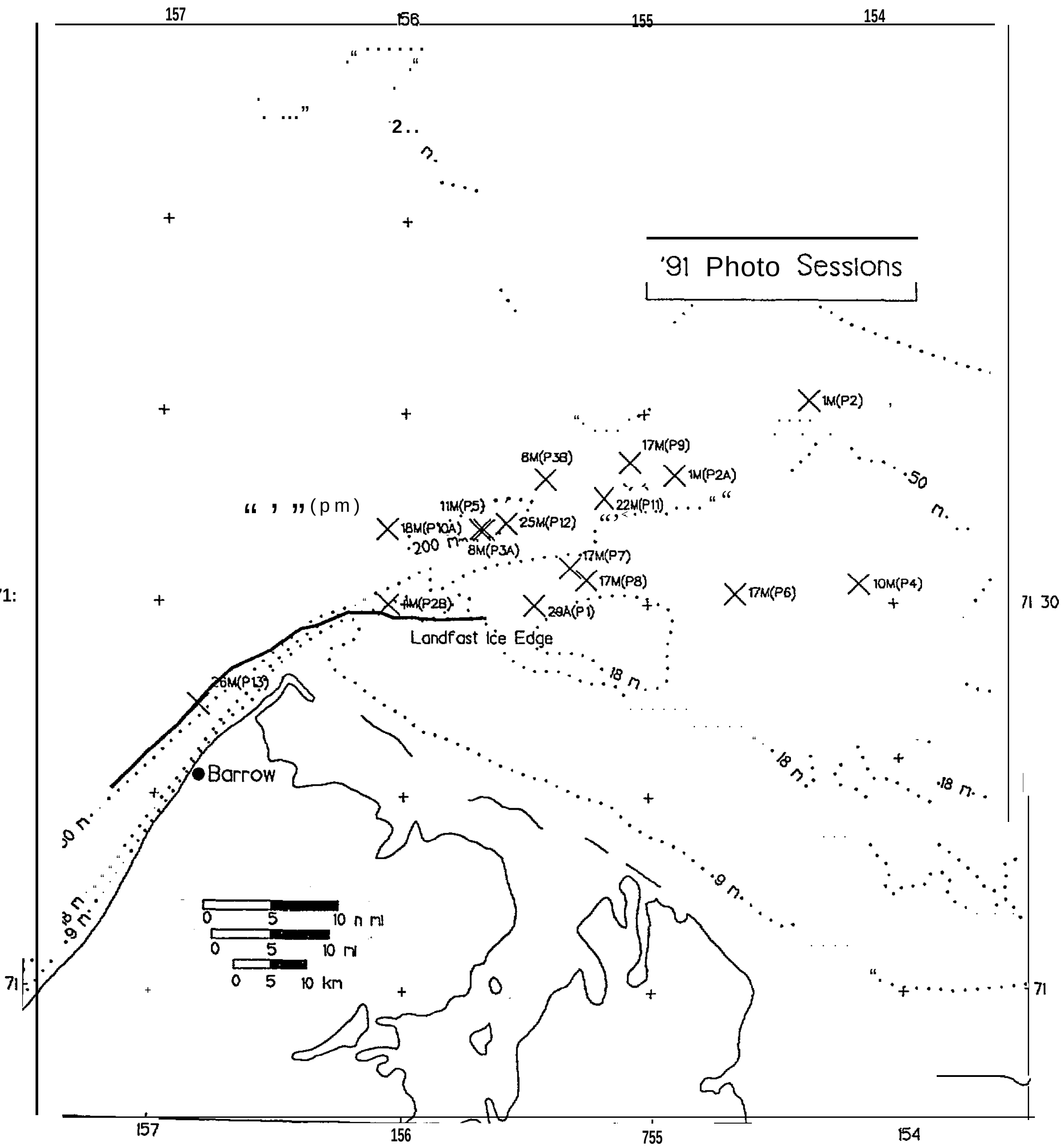


FIGURE **30.** Locations where vertical photographs of bowhead whales were obtained by the aerial crew, 28 April to 26 May 1991. Annotations represent the date in April (A) or May (M) and, in parentheses, the photo session number (P 1-P 13).

Following a brief behavior observation session on 29 April 1991, the mother of a mother-yearling pair was photographed; she was slightly shorter than 16.0 m (Fig. 31).

Length measurements were obtained for 20 different whales on 1 May. Most of these whales were small, which is typical of the early part of the migration (Nerini et al. 1987). Eighty percent of the whales measured on this day were subadult animals (<13 m; Fig. 31).

Two adult whales were photographed on 8 May and a large subadult and small adult were photographed on 10 May. Three subadult and 3 adult whales including the first mother of the season were photographed on 11 May. This is the earliest confirmed sighting of a mother-calf pair by us during the three years of this study (*cf.* Richardson et al. 199 la: 105-108). The mother was 14.8 m long; the calf was not measurable because it was below its mother.

Thirteen bowheads were measured on 17 May; they included 3 mother-calf pairs and 5 small subadult whales. The sighting of five small subadults 7.1-8.1 m in length this late in the season is interesting, The migration of adults, including mothers with calves, had already started. It is possible that these 7.1-8.1 m whales were yearlings that had recently separated from their mothers.

Bowheads photographed on 18 and 22 May were primarily adults (66% and 75%, respectively). On each of these days, we photographed one mother-calf pair and one small subadult (yearling? 8.1 and 7.6 m long). The only other subadults photographed on these dates were 10.4, 11.2 and 12.9 m long (Fig. 31).

Seventy-three percent (11 of 15) of the whales photographed on 25 and 26 May were known mothers or calves. The remaining four whales were adults. These data are consistent with previous studies by Nerini et al. (1987) and Richardson et al. (1990a), who found that mothers and calves formed a high proportion of the migrants late in the season.

The mean length of 11 mothers measured during this 1991 study was 14.87 m ± s.d. 0.88 m, with ***range 13.3 -16.0*** m (excludes one approximate length; no inter-day repeats). This mean length for mothers was similar to the means found in other studies (14.96 m, Richardson et al. 1990a; see also Withro w and Angliss 1991).

The mean length of 10 calves measured during this 1991 study was 4.25 m ± s.d. 0.46 m, with range 3.7-5.1 m (excludes one approximate length; no inter-day repeats). This mean length for calves is smaller than the value reported for the spring period in 1985-90: 4.74 m ± s.d. 0.45 m, n = 88 (Koski et al. in press a). The smallest calf measured during this 1991 study (3.7 m long) was, however, larger that the smallest calf (3.6 m) reported by Koski et al. (in press a).

The length data collected during this study are consistent with previous studies in documenting length segregation during the spring migration (Nerini et al. 1987; Richardson et al. 1990a; Withrow and Angliss 1991). Our 1991 data also hint that yearling bowheads may tend to migrate later than other small subadults. However, this needs confirmation from a larger data base (i.e. the NMML study) and from other years.

Within-Season Resightings

Besides providing data on the sizes of bowheads, aerial photography documented the movements of bowheads that were photographed during more than one photo session. Within-season resightings were recognized by comparing each of our recognizable photographic images from 1991 with (1) all other LGL images photographed within seven days of that image and (2) a portion (about 30%) of the photographic images obtained by NMML in the spring of 1991. Each NMML image was compared to all other images (NMML and LGL) photographed within seven days of the date that the NMML image was obtained. (We assumed that no bowheads lingered in our small study area for more than 7 days.) Approximately 190 NMML photographs recently received by LGL could not be included in these analyses, but will be examined later.

In late April and May 1991, LGL acquired a total of 185 potentially re-identifiable (grade A and B) images of bowheads. Excluding calves, which were recognizable primarily through their associations with their mothers, 89 different bowheads were photographed from 29 April to 26 May (Table 5). This included 12 different adults photographed with calves. Within the LGL photos, the only between-session resightings were two bowheads that were each photographed in two different photo sessions conducted 3.4 h apart on 17 May. One of these two whales was accompanied by a calf.

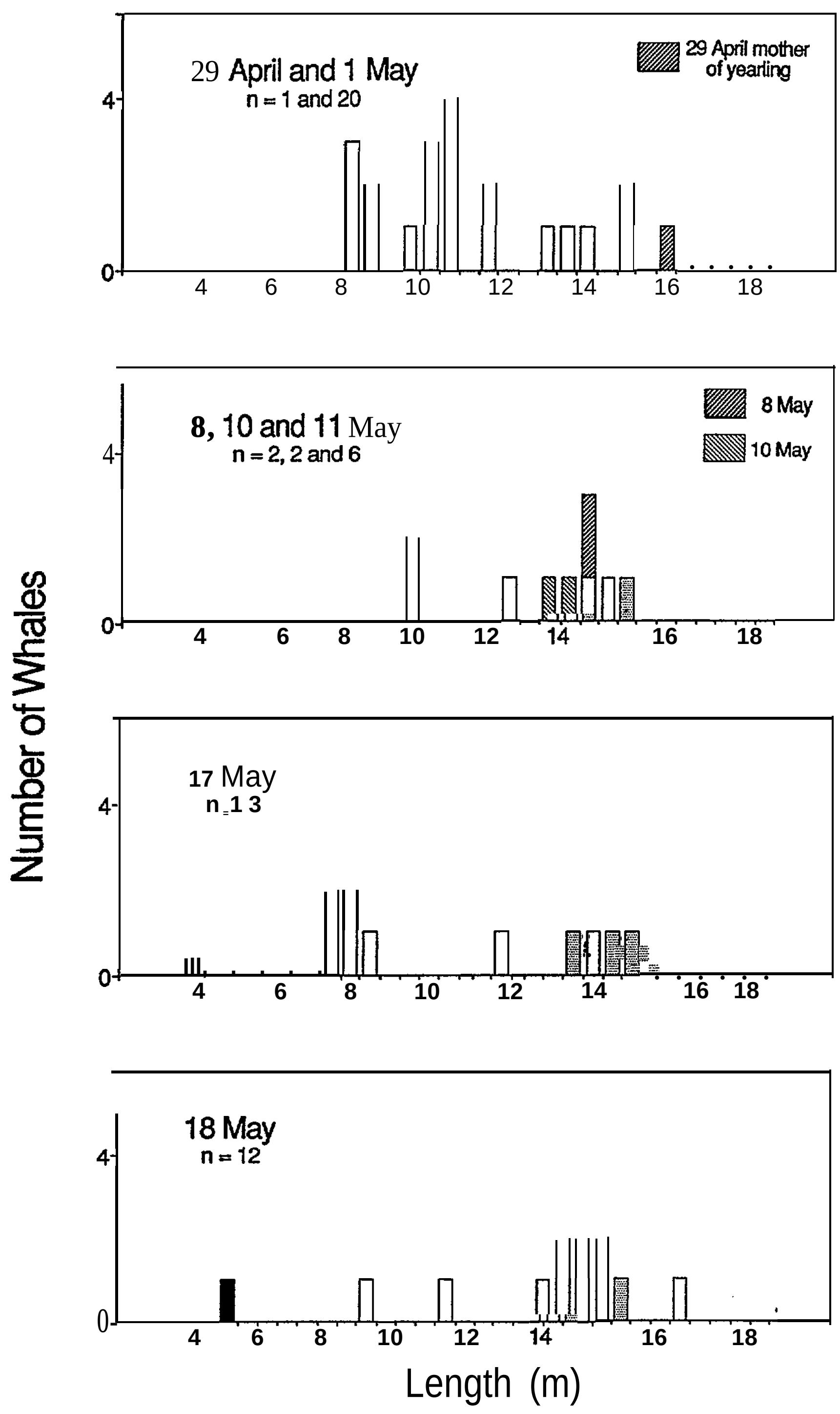


FIGURE 31. Length-frequency distribution for bowhead whales photographed during this study, 29 April-26 May 1991. Calves are represented by black bars and mothers by stippled bars. Repeat measurements are excluded.

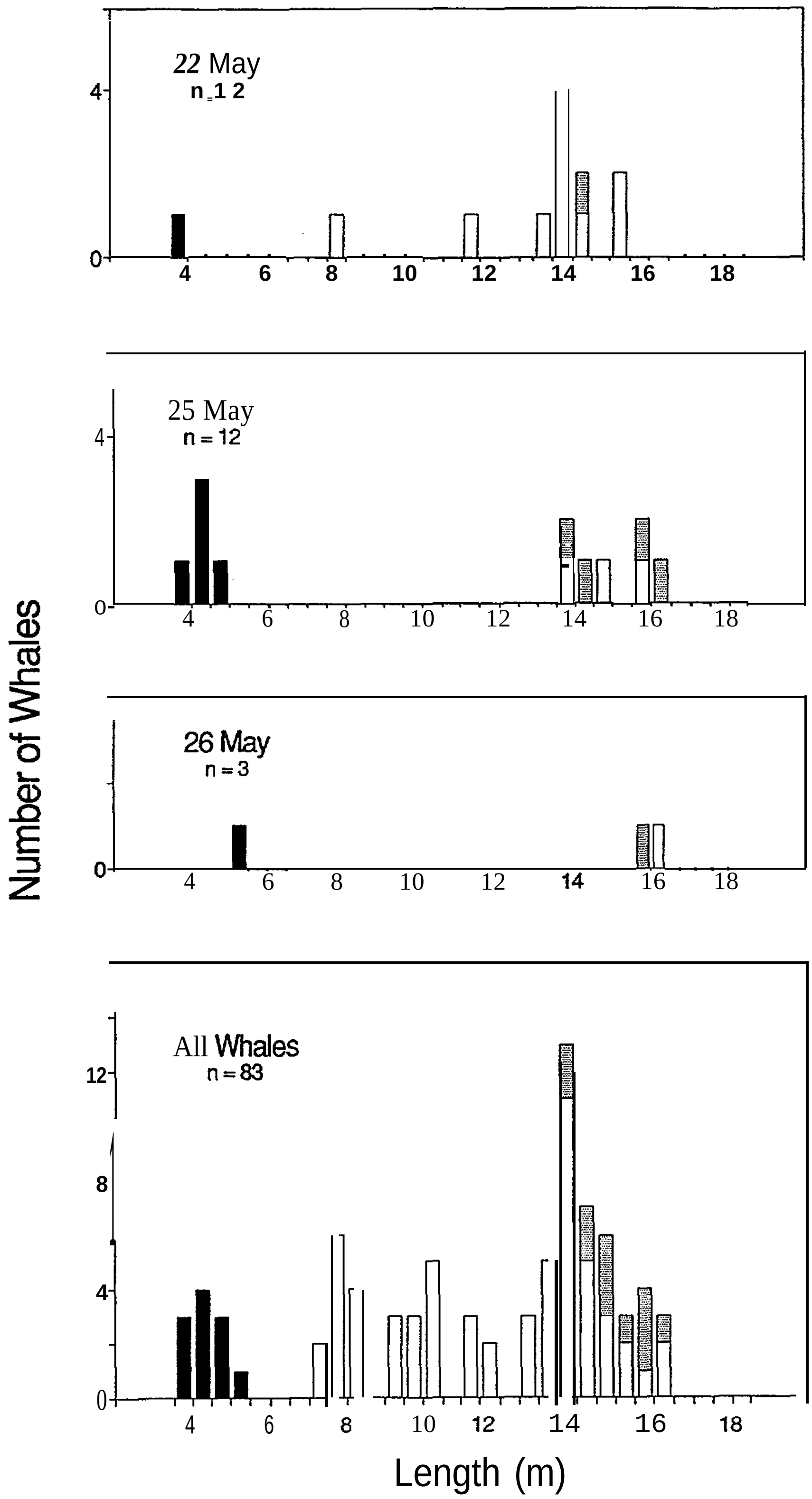


FIGURE 31 (continued).

Table 5. Number of photographs of recognizable bowhead whales acquired during LGL's 1991 photo sessions.

Photo Session	Date	Number of Whale Images: Printed	Grades A and B*	Number of Whales Photographed 1, 2, ...7 Times: 1[b]	2	3	4	5	6	7	Number of Whales Potentially Recognizable Between Days[b]	Number of Between-Session Refighting
P1	29 Apr	1	1	1							1	
P2	1 May	0	0								0	
P2A	1 May	20	20	9	2	1	1				13	
P2B	1 May	8	8	8							8	
P3A	8 May	1	1	1							1	
P3B	8 May	2	1	1							1	
P4	10 May	8	6	6							6	
P5	11 May	11	10	6	2						8	
P6	17 May	3	3	3							3	
P7	17 May	22	12		1	1					3	
P8	17 May	10	9	4	1	1					6	2 (P7)
P9	17 May	6	4		2						2	
P1OA	18 May	5	5		1	1					2	
P1OB	18 May	29	22	5	2	2				1	10	
P11	22 May	29	25	7	3	4					14	
P12	25 May	38	19	8	1	1					11	
P13	26 May	7	5	—	1	1	—		1	—	2	
		200	151	59	16	12	1		1	2	89[c]	

[a] Excludes calves, which were individually recognizable primarily through their associations with their mothers.
[b] These figures are maxima because some repeat photographs may not have been recognized.
[c] This total was reduced by two to account for between-session re-identifications.

To date, we have also compared our photos with 74 re-identifiable bowhead images (S 1 different bowheads, calves excluded) photographed by NMML from 22 April to 3 June 1991. Three of our 89 different bowheads were also in this subset of the photos obtained by NMML in 1991. Two of these whales were photographed by NMML on the same day that they were photographed by LGL, and one was photographed by NMML the day before it was resighted by LGL. Two of these three resighted bowheads were accompanied by calves. In addition, to date we have recognized two bowheads, not photographed by us, that were each photographed by NMML on two different days.

Overall, six different whales have thus far been recognized on photographs from more than one 1991 photo session. Of these, three were resighted on the same day as originally photographed, and three were re-photographed on different days (Table 6).

The net movements of the re-identified bowheads are shown in Figure 32. Rugh (1990) reported that a sample of 30 resighted bowheads migrating through the Barrow area in the expected migratory direction (49- 105°) during spring traveled at an average rate of 4.0 km/h. Only one of the six whales resighted in 1991 exhibited what might be considered atypical migratory speed and direction: an 11.7 m bowhead resighted after 2.47 h on 11 May had traveled 11.7 km to the NE at an apparent rate of 4.7 km/h (Fig. 32, Table 6). Considering the relatively small and almost totally overlapping areas within which LGL's and NMML's photo sessions were confined (Fig. 30 vs. 23), we would not have been likely to resight whales migrating at this speed over periods exceeding 24 h. The remaining bowheads involved in same-day resightings traveled more slowly:

- A 7.8 m bowhead resighted after 3.8 h on 17 May had traveled only 3.8 km to the east, a rate of only about 1 km/h.

- A 13.3 m mother with a 4.0 m calf traveled 1.7 km to the *west* over a one hour period (1.7 km/h) on 17 May. This mother-calf pair was resighted again 2.7 h later about 3.4 km to the NE of its second location, having moved at an apparent rate of about 1.2 km/h. Considering only the first sighting and final refighting, this pair traveled 2 km to the NE over a 3.7 h period at an apparent rate of only 0.53 km/h.

- A 14.8 m mother and 4.2 m calf photographed on 10 and 11 May traveled a net distance of only 3.1 km to the NW over a 28 h period, for an apparent rate of movement of only 0.1 km/h.

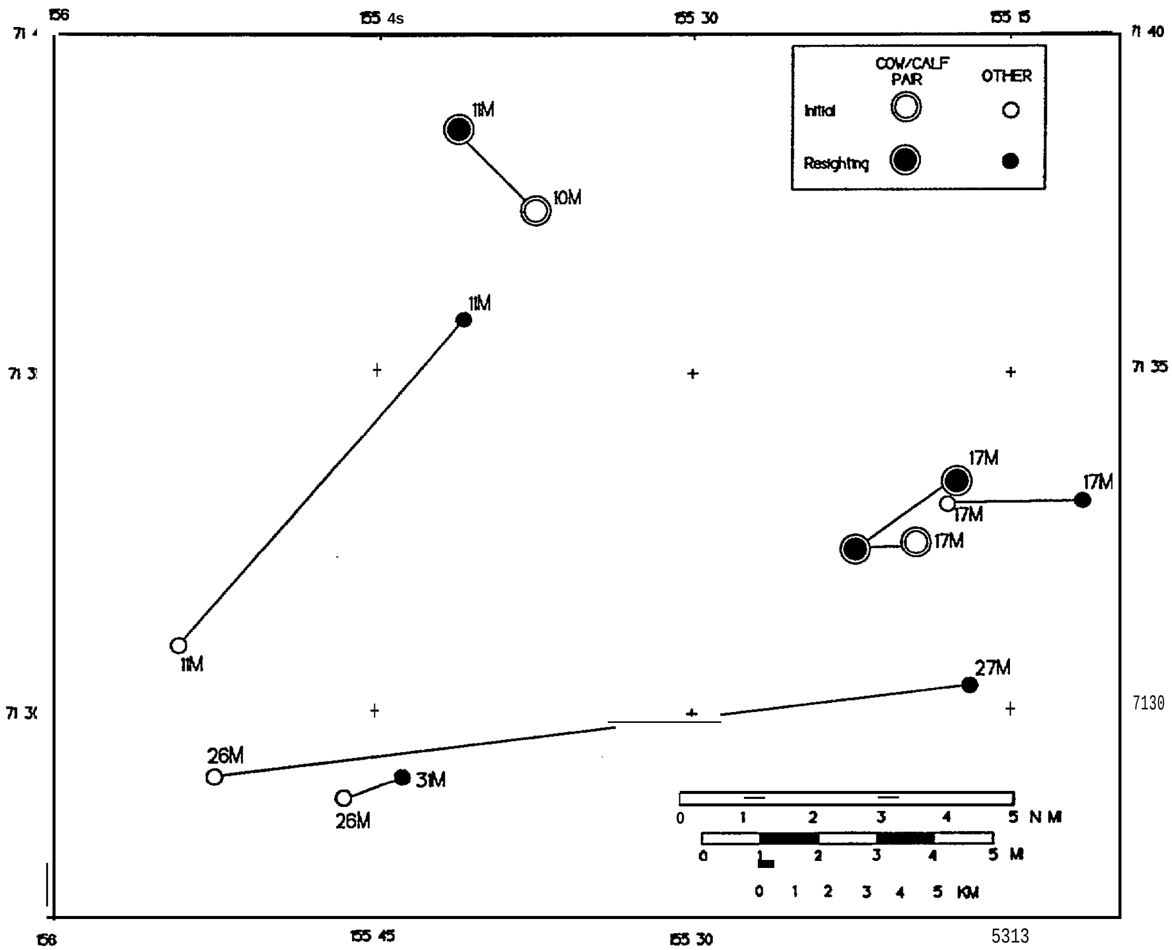


FIGURE 32. Resightings (>1 h apart) of bowhead whales photographed by LGL and NMML northeast of Barrow during May 1991. See Table 6 for details. Evaluation of the NMML photos is incomplete at the date of writing, so additional resightings may be identified later.

Table 6. Inter-session resightings of bowheads photographed by LGL and NMML, spring 1991. NMML vs. LGL comparisons are incomplete at date of writing.

Source of Photos	Firat Photographed				Resighting (s)				Houra Between Sightings	Net Distance Between Sightings (km)	Apparent Rate of Movement (km/h)	Heading (°T)	Whale Length (m)	Accompanied by Calf?
	Date	Time	Latitude	Longitude	Date	Time	Latitude	Longitude						
NMML-LGL	10 May	12:33:33	71°37.4'N	155°37.6'W	11 May	16:38:01	71°38.6'N	155°41.3'W	28.07	3.1	0.11	316	14.8	yes
NMML-LGL	11 May	13:08:27	71°31.0'N	155°54.0'W	11 May	15:36:35	71°35.8'N	155°41.0'W	2.47	11.7	4.74	040	11.7	no
LGL-NMML	17 May	13:21:30	71°32.5'N	155°19.4'W	17 May	14:21:55	71°32.4'N	155 °22.3'W	1.01	1.7	1.70	264	13.3	yes
-LGL					17 May	17:06:05	71°33.4'N	155°17.5'W	2.74	3.4	1.23	057		
LGL-LGL	17 May	13:08:53	71 °33.2'N	155 °18.1'W	17 May	165938	71°33.1N	155°11.7'W	3.85	3.8	0.98	093	7.17	no
NMML-NMML	26 May	11:53:07	71°29.1'N	155°52.3'W	27 May	11:46:57	71°30.4'N	155°16.9'W	23.90	20.9	0.88	083	13.7'	no
NMML-NMML	26 May	13:10:36	71°28.8'N	155°46.4'W	31 May	11:58:31	71 °29.1'N	155°43.7'W	118.80	1.7	0.01	071	14.7'	no

[a] Preliminary lengths from NMML.

Table 7. Between-year bowhead resightings, various origins and years, to MMS study area, May 1991.

Source of Photos'	Whale Number	Year	First Photographed				Refighting				whale Length in Year of Refighting	With Calf?	
			Date	Loc'n[b]	Latitude	Longitude	Date	Loc'n[b]	Latitude	Longitude		First Sighting	Refighting
LGL-LGL	1552	1982-91	4 Sep	HI	70°02.3'N	138 °50.9'W	26 May	BR	71 °22.6'N	156 °40.5'W	16.2	yes	no
LGL-LGL	4220	1984-91	23 Aug	FB	70°21.7'N	127 °03.0'W	1 May	BR	71°40.3'N	154 °55.9'W	12.9	no	no
NMML-LGL	9692	1984-91	8 May	BR	-	.	8 May	BR	71 °35.8'N	155°43.2'W	13.6"	no	no
LGL-LGL	4239	1984-91	23 Aug	OB	70°40.4'N	127"24.8'S4	18 May	BR	71°38.1'N	156 °14.8'W	14.8	yes	yes
LGL-LGL	5679	1985-91	6 Sep	RF	69°13.7'N	137 °19.5'W	1 May	BR	71°40.3'N	154°55.9'W	10.3	no	no
CRC-LGL	7781	1986-91	31 Aug	TP	70 °44.6'N	130°50.8'W	18 May	BR	71°35.6'N	156 °06.2'W	14.0	no	no
NMML-LGL	8288	1987-91	8 May	BR	70°27.9'N	156"10.7'W	25 May	BR	71°39.1'N	155 °03.5'W	16.0"	no	yes
NMML-NMML	9304	1989-91	31 May	BR	71°36. 0'N	154°32.6'W	10 May	BR	71 °37.4' N	155 °37.6' W	14.8	no	yes
-LGL		-91					11 May	BR	71°38.6'N	155°41.3'W			yes

[a] LGL - Photographic studies by LGL during summer (Davis et al. 1983, 1986a,b) and spring (this study). NMML - Spring photographic studies by National Marine Mammal Laboratory. CRC - Summer photographic study by Cascadia Research Collective (Ford et al. 1987).

[b] HI = Herschel Island, Y.T., BR = Barrow Region, AK, FB = Franklin Bay, N.W.T., OB = Offshore Bathurst Peninsula, N.W.T., KP = King Point, Y.T., TP = Tuktoyaktuk Peninsula Shelf, N.W.T.

[c] Approximate length.

Similar slow rates of travel were observed in resighted mother-calf pairs in 1989 (Richardson et al. 1990a: 157). In 1989, average rates of movement determined for three mother-calf pairs resighted 1-2 days after they were first photographed ranged from 0.2 to 1.0 km/h. In 1989, one mother with a calf was observed in our study area over a 43-h period (27-29 May); they were photographed on three consecutive days (Richardson et al. 1990a: 159).

Two other bowheads not accompanied by calves were photographed on more than one day:

- A 13.7 m bowhead photographed on 26 and 27 May traveled about 20.9 km to the E over a 23.9-h period-an apparent rate of 0.9 km/h.
- Another adult bowhead (14.7 m long) traveled only 1.7 km over a five day period (0.01 km/h, 26-31 May).

The last of these whales had a net speed slower than has been documented previously in the Barrow area during spring. Rugh (1990) resighted a bowhead over a 5-d period during spring migration, but that individual traveled at nearly 1 km/h. The lingering of an apparently healthy individual in our study area in the spring of 1991 was apparently unusual, especially for an bowhead not accompanied by a calf. This case cannot be accounted for by any hypothesized "migration blockage" as a result of the noise playback work. This whale was first photographed on the last day of our field season, when the projector site for transmission loss test #4 was 15 km to the WNW of the whale (Fig. 2). Thus, when first photographed this whale had already passed the last of the projector sites that we used.

Between-Year Resightings

We documented between-year resightings by comparing LGL's 1991 grade A photos with all grade A photos obtained during previous photographic studies conducted in the Alaskan and Canadian Beaufort Sea. NMML's 1991 photos have not yet been compared with photos from previous years.

Eight of the 36 (22%) grade A whales photographed by us in the spring of 1991 were also photographed in an earlier year. These resightings, which spanned intervals of two to nine years, are listed in Table 7.

Three of the eight resightings involved whales that were originally photographed near Barrow:

- One whale (#9692) was photographed on 8 May in both 1984 and 1991.

- Another bowhead (#8288) was first photographed on 8 May 1987. This whale was accompanied by a calf when it was resighted on 25 May in 1991. Mothers with calves typically pass through the Barrow region in the latter stages of the spring bowhead migration (p. 77). This whale's passage by Barrow 17 d later in 1991 than in 1987 suggests that adult females pass Barrow later in springs when they have given birth than in other springs,

- The third bowhead (#9304), first photographed on 31 May in 1989 without a calf, was accompanied by a calf in 1991. However, in contrast to the expected pattern, this whale was resighted on 10 and 11 May in 1991, 20-21 d earlier than the 1989 sighting. In fact, this 1991 sighting represents our earliest sighting of a mother-calf pair in the three years of this study.

Five other resightings involved whales that were originally photographed at various locations in the Canadian Beaufort Sea during late summer (Table 7). These resightings include a nine year (1982-91) refighting, which is as long as any refighting interval recognized to date.

Four of the eight between-year resightings involved whales that had a calf in at least one of the two years, Three of these whales had calves in only one of the two years. All three of those whales were definitely or probably mature in the year when first photographed. One whale (#1552) had a calf in 1982 but not in 1991. Two others had calves in 1991 but not in the year they were first photographed (1987, 1989). We do not know the lengths of these two whales in the years when they were first photographed, However, they were 14.8 and 16.0 m long in 1991. Given the slow growth rates of bowheads (Koski et al. in press b), they probably were already sexually mature when first photographed in 1989 and 1987, respectively.

Thus, adult females that had a calf in only one of the two years in which they were photographed were resighted in 1991 at intervals of 2,4 and 9 years after the initial sighting. The three new resightings of mothers that had calves in only one of two years bring the total number of resightings of this type to 10. Previously recognized refighting intervals for mothers that had calves in only one of the two years were 1, 1, 2, 3, 4, 5 and 7 years (Miller et al. in prep.).

One whale (##4239) that we photographed with a calf in 1991 also had a calf when we photographed it 7 years earlier, in 1984. This is one of only five cases in which bowheads have been photographed with calves in each of two different years. Prior to this refighting, only two 4-yr and two 7-yr intervals between calves had been found. It is not known whether the 7-yr intervals are real or represent a combination of 3-yr and 4-yr calving intervals.

The between-year resightings obtained during this 1991 study have added considerably to the available information concerning bowhead calving intervals. Additional between-year resightings will probably be found when comparisons of NMML's 1991 photos with the 1981-90 collection are completed. The scarcity of data on the calving interval of bowheads has been one of the key data gaps that has limited previous attempts to derive a reliable model for the population dynamics of the Bering/Chukchi/Beaufort stock of bowheads. As additional data on calving intervals become available, population models will become more reliable.

Because of the large number of distinctive bowheads that are now represented in the LGL/NMML photo collection, we can recognize a substantial percentage of the Grade A whales photographed during a study such as this one. Even when photos are acquired incidental to other higher-priority objectives, they can provide valuable data on several aspects of bowhead biology.

Playback Results, Spring 1991

There were only a few observations of bowhead whales near the operating sound projectors in 1991 (Tables 1A, 2). Icebreaker sounds were projected into the lead for prolonged periods on a total of 6 days in 1991; transmission loss tests were done on one of those days and on three additional days:

- During three playback days, no bowheads were seen near the projector,
- Of the three playback days when bowheads were seen,
    - Two were days when the only bowheads seen by the ice-based crew were seen during "control" periods, while the projector was not operating (11 and 22 May 1991). (However, on 22 *May 1991* there was circumstantial information about a whale exposed to icebreaker noise.)
    - Bowheads were seen during the playback itself on only one day, ***17 May 1991***. On that date, the ice-based crew observed 9 or 10 bowheads migrating within 1.3 km of the projectors while they were broadcasting icebreaker sounds.

- During one transmission loss test, no bowheads were seen near the projector (1 May).
- During three TL tests (18, 25 and 26 May), bowheads were seen by the ice-based crew, but not during times when test sounds were being projected. However, on 25 ***May 1991,*** the ice-based crew saw a bowhead -350 m from the projectors only 11 min after they had been projecting a variety of sounds during a transmission loss test.

The following subsections give detailed descriptions of the observations on the three days in 1991 (17, 22 and 25 May) when there was at least limited information about bowheads exposed to projected sounds. As noted earlier, all systematic observations of whales near the ice camp in 1991 were obtained by ice-based observers. Low cloud preventeds ystematic aerial observations of the few whales that passed the ice camp while the projectors were operating.

Icebreaker Playback on 17 May 1991

On 17 May 1991, the projectors were set up along the edge of the landfast ice several kilometers northeast of Point Barrow (Fig. 2). Spring whaling at Barrow had ended by this date. As a result, it was possible to project icebreaker sound into the water closer to Barrow than had been possible earlier in 1991 or at any time during 1989-90.

All observations of whales near the projector site on 17 May 1991 were obtained by the ice-based crew stationed at the projector site. The landfast ice edge and the nearshore lead were oriented from west to east (True) in this area. The measured water depth at the projector location was 110 m. The main nearshore lead adjacent to the landfast ice edge was several kilometers wide and largely ice-free. However, a band of pack ice was drifting in the lead west of the ice camp (Fig. 33A). This ice blocked the ice-based observers' view of the open nearshore lead farther west. This band of ice drifted closer to the camp as the day progressed (Fig. 33A). Whales traveling east in the main nearshore lead swam under this ice. The crew was on the landfast ice edge from 10:46 through 20:59. Icebreaker sounds were projected into the lead from 12:42 through 18:01.

The Twin Otter crew made two flights on this date for purposes of whale reconnaissance and vertical photography, and with the hope of making behavioral observations. However, there 'was low cloud all day, together with patches of fog. This prevented us from circling at 460 m altitude to make aerial observations of whales near the projector site or elsewhere, To avoid any

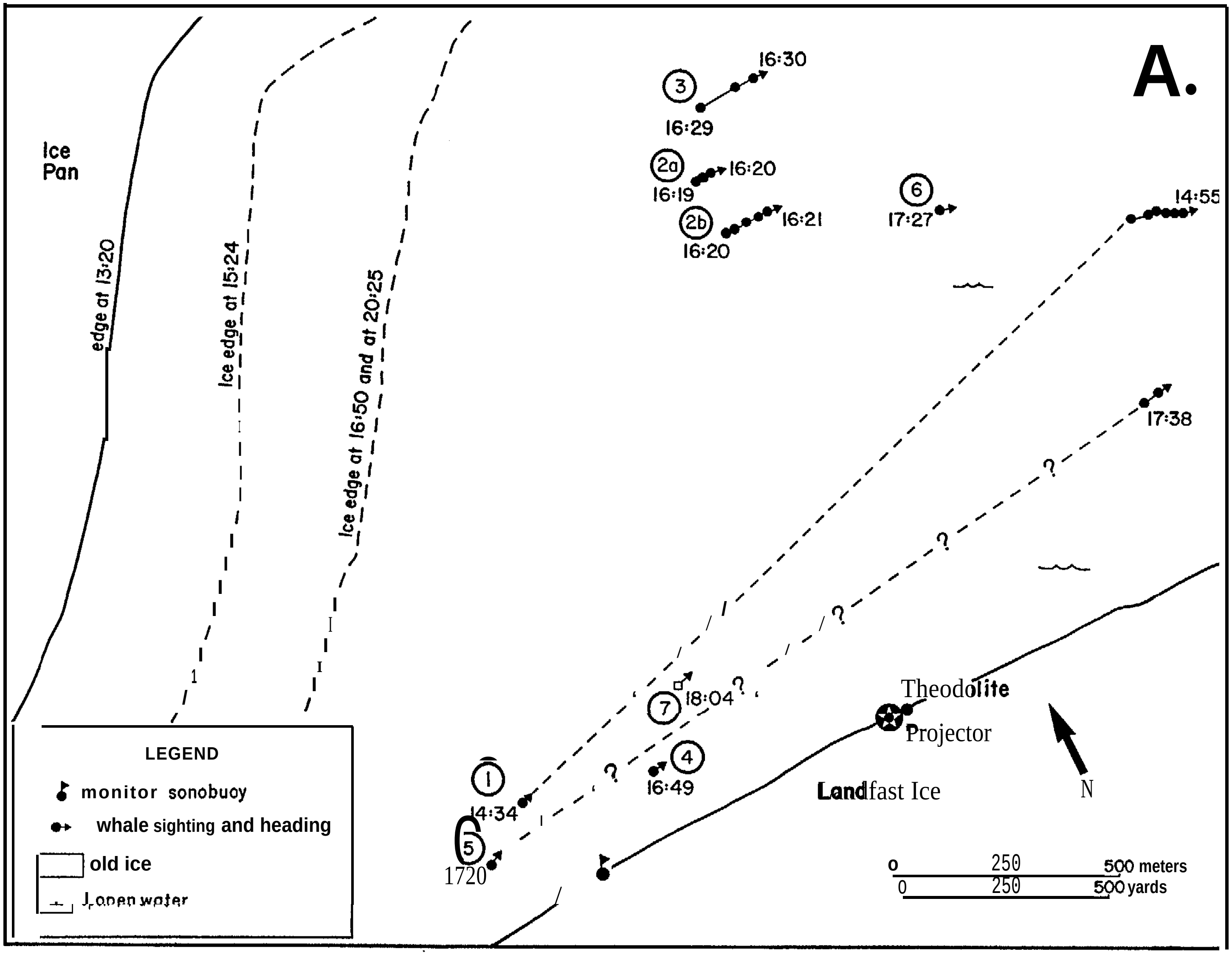


FIGURE 33. Ice-based **theodolite** observations of bowhead whales that passed the ice camp along the landfast ice NE of Pt. Barrow, 17 May 1991. (A) Projectors broadcasting icebreaker sounds; (B) projectors silent. The projectors operated from **12:42** to 18:01; no bowheads were seen before **12:42.** The whale seen at 18:04, 3 min after the end of the playback, **is** shown in (A) because it was exposed to icebreaker noise as it approached. Dashed lines represent presumed paths of whales while they were below the surface.

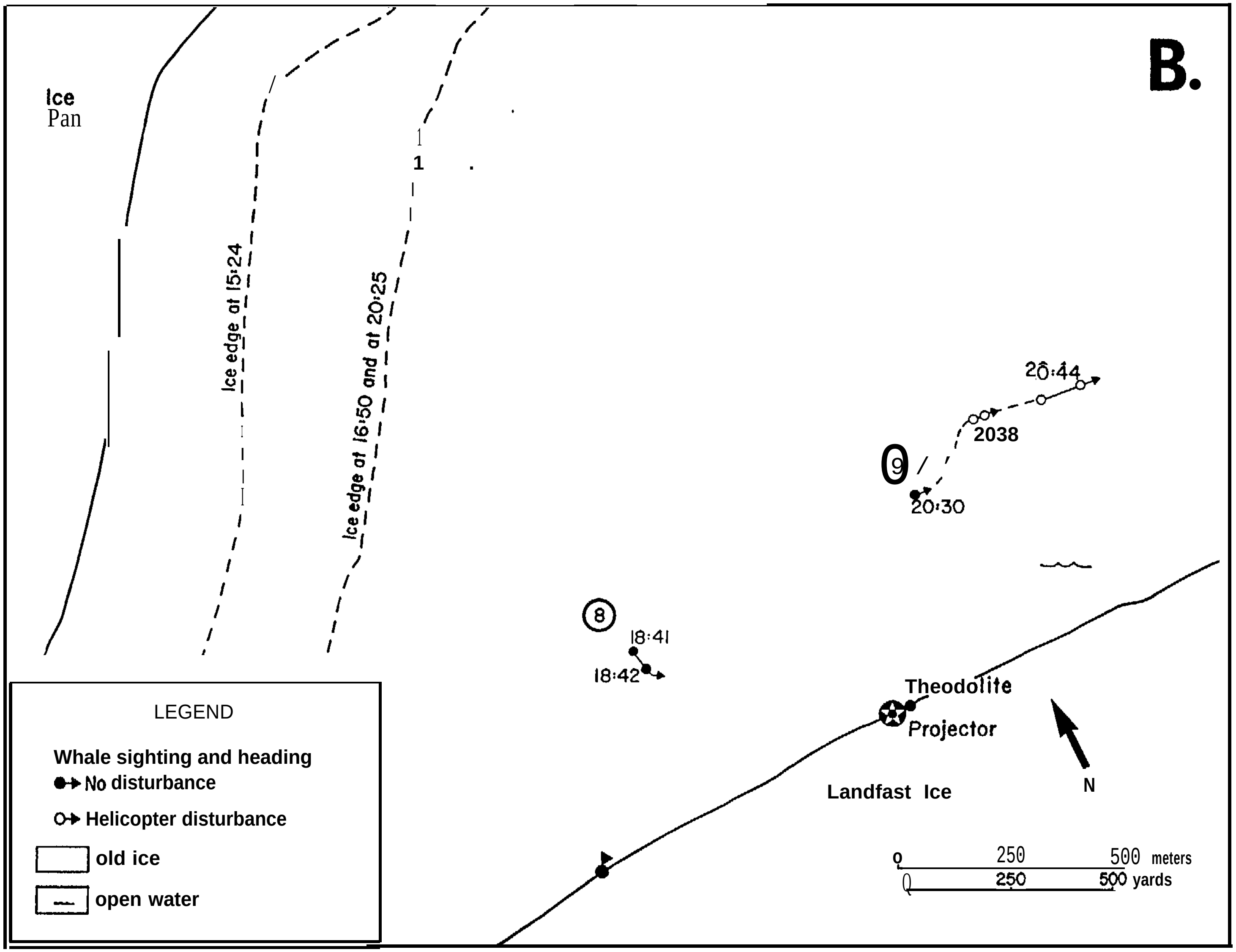


FIGURE 33 (continued). Post-playback "control" observations, 17 May 1991.

possibility of aircraft disturbance to whales being observed by the ice-based crew, the Twin Otter remained a minimum of *several* kilometers *away* from the ice camp.

Ice-based Observations.—No bowheads were sighted from the ice during the period of pre-playback control observations. Five or six single bowheads plus two pairs were seen traveling east past the ice camp during or immediately after the icebreaker playback, i.e. a total of 9 or 10 whales in 7 or 8 groups. There were two additional "control" sightings of single bowheads well after the playback had ended.

Small numbers of bowheads traveled past the ice camp during the period while icebreaker noise was projected into the lead. The closest observed distances of these whales relative to the projectors ranged from 540 to 1360 m (Table 8A). Some whales were apparently at or close to their closest points of approach when seen. However, others were approaching and/or moving away when seen at the surface, and were below the surface when they passed the projectors (Fig. 33A), The closest points of approach of the whales for which we have reliable measurements or estimates were -450 to 1300 m (n=4 sightings; Table 8A). Some or all of the other three single whales may have come closer than 450 m, but the CPA estimates for those three whales (sighting numbers 4, 5, 7 in Table 8A) are subject to considerable uncertainty.

The sightings during or immediately after the playback were as follows (see Table 8A and Fig. 33A as well):

1. At 14:34, a group of two bowheads was sighted twice traveling east at medium speed at a location 840 m west (True) of the operating projectors, and approximately% of the way across the lead. The same group surfaced again at 14:50 when it was 1.87 km ENE of its 14:34 position and 1.24 km NE of the projectors (Fig. 33A). A total of 11 position fixes were obtained from 14:50 to 14:55 as these whales traveled east at medium speed up the lead while remaining at the surface. If they traveled on a straight line between the 14:34 to the 14:50 positions, their closest point of approach (CPA) to the operating projectors was about 450 m. It is unlikely that they diverted far from the straight line, given that their net speed between the two sighting locations was relatively high: 7.1 km/h (1.87 km in 0.262 h). Thus, actual CPA distance was less than 840 m, and probably not much above 450 m.

2. At 16:19-16:21, two more eastbound bowheads were seen 1100 m and 1250 m north of the operating projectors. They were at their closest points of approach when they surfaced (Fig. 33A). These whales were about 150 m apart and were traveling east at medium speed. We obtained three position fixes on one and five fixes on the other.

Table 8. Summary of sightings of bowhead whales seen passing the sound projector located on the landfast ice edge NE of Pt. Barrow on 17 May 1991 when the projectors were (A) broadcasting icebreaker sound and (B) silent. All observations were by the ice-based observers.

Sighting No.	Time	No. Bhds.	Closest Observed Distance (m)	CPA (m)	Method for Determining CPA”	Nature of Track
A. Icebreaker Playback						
1.	14:34	2	840	‘-450	3	Passed operating projectors underwater; seen before and after CPA
2.	16:19	2	1100, 1250	1100, 1250	1	Seen once, at apparent CPA
3.	16:29	1	1360	1300	3	Seen once, just after apparent CPA
4.	16:49	1	540	200?	4	Seen once, approaching
-5.	17:20/ 17:38	1	-1000/ 900	300?	4	Seen while approaching and after passing; same whale?
6.	17:27	1	1130	1100	3	Seen once, just after apparent CPA
7.	18:04	1	800	<800	4	-800 m away and approaching at end of peak-level playback
B. Silent Projector						
8.	18:41	1	540	<540	4	Changed course, approaching
9.	20:30	1	500	-400	4	Seen after CPA

ª 1 = measured by theodolite at CPA; 3 = estimate based on theodolite measurement(s) to nearby surfacing(s); 4 = estimate based on whale position(s) and heading(s) during sighting(s) distant from CPA position (possibly unreliable).

3. At 16:29, a lone bowhead traveling east at medium speed was seen 1360 m north of the operating projectors. This whale surfaced shortly after passing its apparent CPA position, which would have been about 1300 m from the projectors (Fig. 33A). Three position fixes were obtained during a 1½-min interval.

4. At 16:49, another single whale 150 m away from the landfast ice edge was sighted as it traveled ENE at medium speed. It was 540 m west of the operating projectors when seen, but dove at that position. It would have passed within 200 m of the projectors if it did not change course, but we have no information about its actual CPA distance.

5. At 17:20, another single bowhead was seen close to the ice edge about 1 km west of the operating projectors (distance estimated). It was traveling ENE toward the projectors, swimming at medium speed. The actual CPA distance is unknown, but less than ~1 km. A whale that was seen 900 m ENE of the projectors at 17:38, traveling ENE at medium speed, might have been the same one, based on the distance, bearings, and times (Fig. 33A). If so, and if it traveled on a straight line, its CPA distance was -300 m.

6. At 17:27, a single bowhead traveling east at medium speed was seen 1130 m NNE of the operating projectors. It was slightly past its apparent CPA position. The CPA distance would have been -1100 m if this whale was traveling on a straight line (Fig. 33A).

7. At 18:04, just after the end of the icebreaker noise playback, a single bowhead heading ENE at medium speed was seen 480 m WNW of the now-silent projectors. Assuming that it was swimming at 5 km/h, it would have been -800 m WNW of the projectors at 18:00, when we started to reduce the playback level, and -700 m away at 18:01:20 when the playback ended. Thus, this whale is treated as having a CPA distance of c800 m relative to the projectors operating at full power.

There were two additional "control" sightings well after the end of the icebreaker noise playback (Fig. 33B; Table 8B):

8. At 18:41, 40 min after the playback ended, a small bowhead—probably a calf or yearling—was first observed traveling SSE toward the landfast ice edge -580 m NW of the projectors. It continued on this heading, toward the ice camp, until 18:43 (Fig. 33B). It then turned to the ESE and was traveling at medium speed when last seen 540 m NW of the silent projectors.

9. At 20:30, a bowhead that was traveling east at medium speed was seen 500 m NE of the ice camp. It was sighted again at 20:38, 200 m ENE of its original position, and finally at 20:42. The helicopter landed at the ice camp during the interval between the last two sightings.

Noise Exposure.—Icebreaker sounds projected by the J-13/F-40 projector system were monitored in two ways: (1) Source level, in dB re 1 µPa-m, was determined with the monitor hydrophore suspended near the projectors. (2) Levels received 0.73 km from the projectors were measured with an omnidirectional sonobuoy. The sonobuoy was installed manually along the landfast ice edge 0.73 km west of the projector site; its hydrophore was suspended about 18 m below the surface. The sonobuoy signals were telemetered by the sonobuoy to a receiver at the ice camp. There they were recorded on one channel of a TEAC DAT recorder; the other channel was used to record the signals from the monitor hydrophore.

The projected icebreaker sounds varied in level, as described earlier (p. 48*ff*). On a third-octave basis, the strongest projected sounds on 17 May were between 50 and 250 Hz (Fig. 34). Projected levels diminished sharply with decreasing frequency in bands below 50 Hz, and diminished slowly with increasing frequency in bands above 250 Hz.

Figure 34 also summarizes the third-octave levels received at a distance of 0.73 km from the projector, The received levels fluctuated but, within the 50 to 250 Hz range they were at least 10 dB above the background ambient levels in the corresponding third-octave bands. At some times and frequencies, the received level at range 0.73 km was 20 dB or more above the corresponding ambient noise level (Fig. 34). At frequencies below 50 Hz and above 250 Hz, the received level of icebreaker noise was often but not always above the ambient noise level.

On a broadband basis (20-1000 Hz), the received sound levels 0.73 km from the projector ranged from 103 to 112 dB re 1 µPa (Fig. 16), and averaged 107 dB. The corresponding ambient noise level during the playback was not measurable because of masking by the projected icebreaker sound. However, after the playback the ambient level was 93 dB (20-1000 Hz band). Thus, on a broadband basis, the received levels 0.73 km from the projector were about 10-19 dB above the ambient level.

Levels of icebreaker sounds received by the whales that passed at specific times and CPA distances have not yet been estimated in detail. The projected and received levels of icebreaker sound vaned over time on a 14-minute cycle (Fig. 13). Hence, it is necessary to determine the source and received levels for the specific CPA times of each passing whale. This work is still in progress. However, it is apparent from Figure 34 that whales passing at CPA distances within 0.73 km were exposed to significant icebreaker sound. Likewise, whales with CPA distances out to at least double that distance (1.5 km) would also have received measurable levels of icebreaker

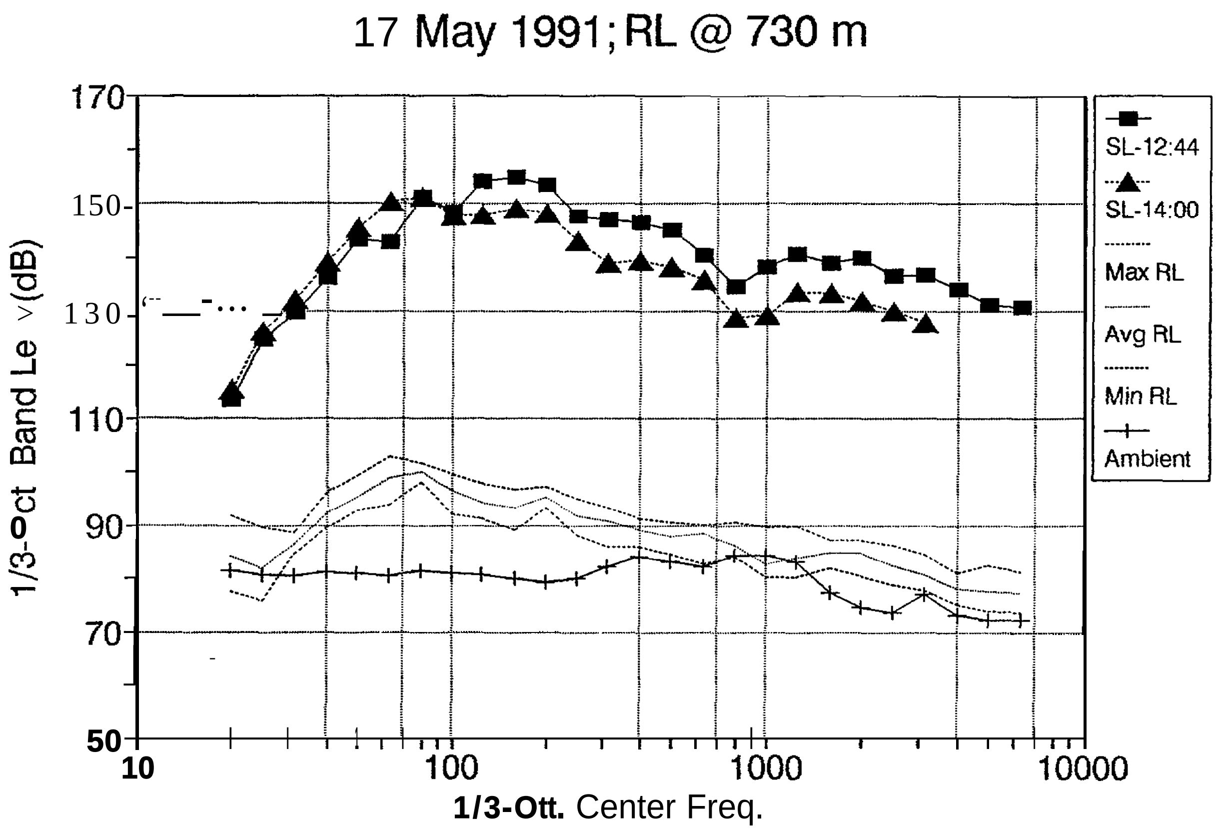


FIGURE 34. Third-octave levels of sounds 1 m from the projector (squares, triangles) and at a sonobuoy 730 m from the projector (max., mean and min. of 10 examples) during icebreaker noise playback on 17 May 1991. Plus signs show ambient noise levels after the playback. All data are in dB re 1 µPa.

Explanatory notes: (1) Because of projector limitations, components of the icebreaker sounds at low frequencies are underrepresented in the projector output relative to components at higher frequencies. ***(2)*** For each 1/3-octave band, the level received at the sonobuoy during the playback is the sum of the received icebreaker sound plus the natural ambient noise in that band. ***(3)*** In some frequency bands, received level at the sonobuoy during the playback is similar to or slightly below the ambient noise level recorded when the projector was off. In those bands, the icebreaker noise had attenuated to inaudibility by the time it reached the sonobuoy.

sound, given that the received level would not be expected to diminish by more than about 6 dB between 0.73 km and 1.5 km. Thus, all bowheads that were seen passing the projectors during the 17 May playback (Table 8A) were apparently exposed to measurable levels of icebreaker sound.

Icebreaker Playback on 22 May 1991

On this date, intermittent snowsqualls and fog prevented offshore work until late in the day, and even then persistent low cloud prevented aerial observations of whale behavior. A low-altitude aerial reconnaissance in the early evening showed that bowheads were migrating along the broad nearshore lead northeast of Barrow. The landfast ice edge had deteriorated to the point that its stability was questionable. Hence, the ice camp was placed on an ice pan drifting near the south side of the nearshore lead a few kilometers NNE of Pt. Barrow (Fig. 35). As on 17 May, projector operations this close to Pt. Barrow were permissible because there was no bowhead census in 1991 and because spring whaling at Barrow had ended.

Icebreaker sounds were projected from 21:50-21:56 (distorted) and from 22:21 to 23:34 (normal). At 23:34 it was necessary to retrieve the projector system because it was threatened by encroaching ice. The measured water depth during the playback was 125-134 m.

Ice-based and aerial sightings, in combination, provided ***circumstantial*** evidence that a bowhead—located ~1 km from the projector when the playback began—continued to migrate slowly ENE during the first 42 minutes of the playback: A single bowhead was sighted at 22:15-22:18, before the main playback period. At 22:15 it was migrating slowly to the east at its CPA distance of 650 m (Fig. 35). This whale was last seen at a distance of 850 m at 22:18 when it dove, heading ENE. The icebreaker noise playback began at low level 3 min later (22:21). The whale was probably ~1¼ km away from the projectors at 22:23 when the projected sounds reached their peak level. This whale was not resighted by the ice-based observers. However, at 23:03 the aerial observers saw a bowhead heading ENE at slow speed about 3 km ENE of the ice camp.[3] This whale may have been the one seen near the camp at 22:18. If so, the bowhead apparently continued its slow travel to the ENE during the first 42 min of the icebreaker noise playback.

[3] Aerial observations of whale behavior were impossible because of low cloud (ceiling 185 m). We did not circle this whale to determine its exact position because it was undesirable to circle at low altitude that close to the ice camp during a playback.

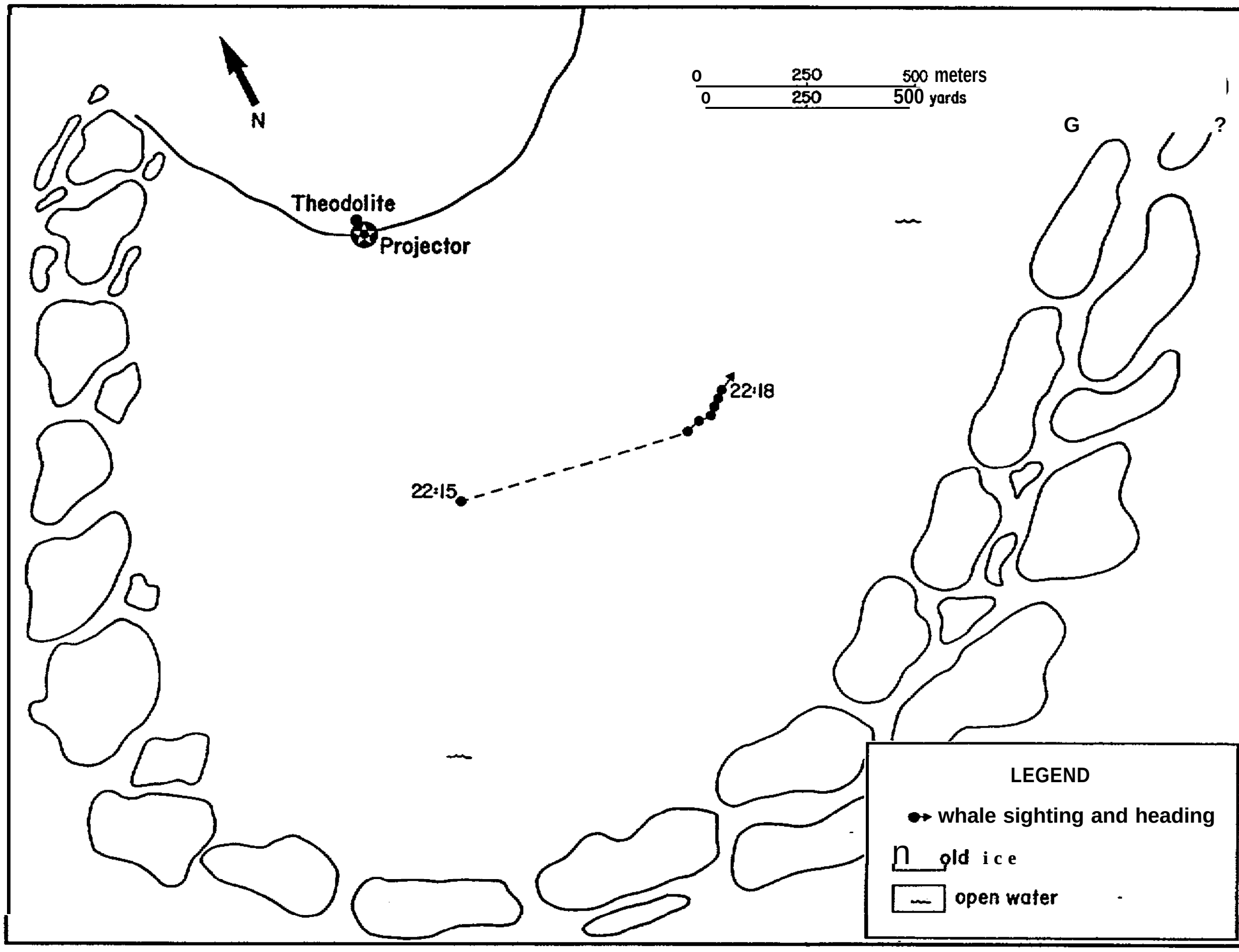


FIGURE 35. Ice-based observations of a bowhead whale that passed the ice camp on pack ice within the main nearshore lead NE of Pt. Barrow, 22 May 1991. The projectors began broadcasting icebreaker sounds at 22:21, 3 min after this whale was last sighted from the ice camp. Dashed line represents presumed path of whale while it was below the surface.

TL Test on 25 May 1991

A reconnaissance flight by the Twin Otter crew on the morning of 25 May 1991 revealed only a few bowheads. Also, low cloud overmuch of the study area prevented aerial observations of whale behavior. Given the unpromising conditions for an effective playback experiment, we decided to do a sound transmission loss (TL) experiment. The ice-based crew setup the projector system on pack ice northeast of Point Barrow (Fig. 2), and began TL test #3 (see p. 43). The projector site was on the west side of a small area of open water amidst small ice pans. The opening was initially about 800 m wide, but became smaller later in the day. The measured water depth was 146 m. The theodolite was not setup, given that the purpose of the work was a TL test. A 4-minute sequence of test sounds was projected intermittently from 11:18 to 18:25. This sequence included various combinations of tones and a short sample of the icebreaker sounds used during playbacks (p. 16-17).

Two confirmed bowheads were seen near the ice camp on this date. One was seen shortly after the crew first arrived by helicopter, and before any sounds were projected. A second bowhead, oriented NE, was seen at the surface -350 m (visual estimate) south of the projectors at 12:33. This was only 11 min after the conclusion of a playback of the series of test sounds.

This bowhead was not exposed to playbacks while it was being observed. However, this whale had been exposed to a variety of test sounds, including a brief sample of icebreaker sounds, only 11-15 min before it was seen. The speed of travel of this whale is unknown, However, assuming a typical speed of 5 km/h, it would have been 1¼- 1?4 km from the projectors during the most recent projection period. At that distance, it would have received some of the test sounds:

- Some test sounds were measurable at distances up to 9-14 km southwest of the projectors on this date (p. 46), and they were prominent at the 0.87 and ***2.0 km*** measurement stations.

- Interpolating between results from 0.87 and 2.0 km, the received level of the strongest tone at range 1%-1% km was -111 dB re 1 µPa (100 Hz tone). The average ambient noise level on this date was 81 dB re 1 µPa in the 1/3-octave band centered ‘at 100 Hz. Hence, the effective S:N ratio for the 100 Hz tone at 1¼-1½ km was -30 dB.

- Similarly, the broadband level of the sample of icebreaker noise was -106 dB at that distance, or 9 dB above the average broadband ambient noise level on that date (97 dB).

Despite exposure to the 4-rein sequence of test sounds 11-15 min before the bowhead was seen, it apparently moved toward the ice camp. Furthermore, it is possible that the whale was exposed to sound levels higher than those quoted here. If its swimming speed during the 11 minutes in question was less than 5.0 km/h, this whale would have been closer than 1¼ km during the most recent playback of test sounds. It is unlikely that it was farther away, because that would have necessitated an approach at >5.0 km/h immediately after exposure to the test sounds.

Control Observations on Other Dates

As described above, a few bowheads were observed passing the ice camp late on 17 May, after the end of the icebreaker noise playback. Bowheads were also seen during quiet periods on 22 and 25 May, as described above.

Besides these previously described "control" observations, a few bowheads were seen near the ice camp during quiet periods on four additional dates. On each of these dates the Twin Otter crew conducted one or two reconnaissance flights, sometimes combined with vertical photography of bowheads. The clouds were too low on these dates to allow observations of bowhead behavior:

28 April 1991 .—The ice camp was on the east side of a small lead through pack ice. Two bowheads were seen. One was traveling ENE 150 m from the camp; its estimated CPA distance was -125 m. The second bowhead approached to within 10 m of the ice camp on a curved course. This was the first day of ice-based work in 1991, and there was no playback on this date because of equipment problems.

3 May 1991 .—The ice camp was on the east side of another small lead oriented south-north through pack ice. A total of 9 bowheads (7 singles, one pair) were seen at distances of 20 to 600 m from the ice camp (Fig. 36). Given their positions and headings when they surfaced, some of these whales probably approached closer to the ice camp while underwater. Six whales were oriented to the ENE, crossing the narrow lead. Single whales oriented to the NNE, NNW, and on a curved course; these three individuals probably were adjusting their courses in order to prolong their stay in the narrow north-south lead. Four of these whales were seen while the helicopter was at the ice camp with its engines running (see Fig. 36 and p. 107). There was no playback on this date because a closing lead and deteriorating weather forced an early departure from the ice.

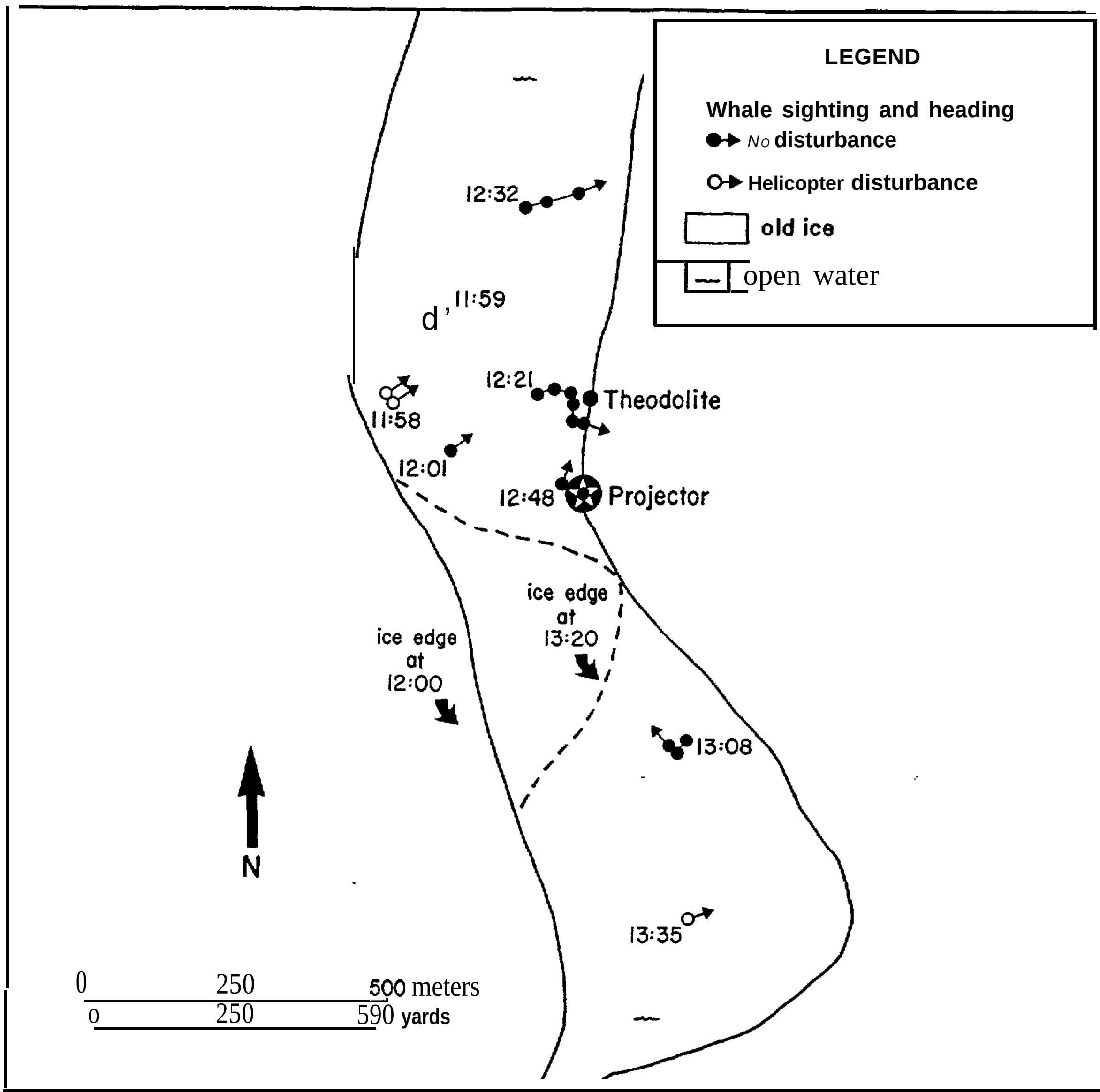


FIGURE ***36.*** Ice-based observations of bowhead whales that passed the ice camp on pack ice ENE of Pt. Barrow, 3 May 1991. The helicopter was on the ice at the camp during all observations; four bowheads (2 singles and a pair) were seen while the helicopter's engines were running. There was no playback.

11 May 1991.—The ice camp was at the north end of a giant ice pan, adjacent to an area of loose pack ice through which bowheads and white whales were migrating eastward. Icebreaker sounds were projected for 1.0 h, but the projector system then had to be removed from the water to protect it from drifting ice. During a 2.0 h period prior to the playback, three single bowheads were seen migrating east at distances 50-510 m from the ice camp (Fig. 37). None were seen during the playback or for 0.9 h thereafter. During the entire 2.9 h period after the playback, two single bowheads and one pair were observed to travel NNW, ENE and ESE at distances 470-990 m from the ice camp (Fig. 37).

18 May 1991 .—The ice camp was setup on the edge of the landfast ice bordering the broad nearshore lead. It was at the same location as on 17 May. The only whales seen were two bowheads traveling ENE, separated by ~100 m, and located about 1.5 km NW of the ice camp. If they continued on that course after they dove, their CPA distance while underwater was about 1 km. These whales were seen 1,2 h after the most recent of a series of broadcasts of test sounds during Transmission Loss test #2.

26 May 1991.—A transmission loss test was done amidst the pack ice on this date (Fig. 2). A single bowhead traveling NNW was seen as close as 50 m from the ice camp about 1 h after the last sound transmission.

Discussion

Because of the poor weather and ice conditions encountered in 1991, there were few systematic observations of bowheads near the ice camp during either playback or control conditions. All observations of bowheads exposed to prolonged playbacks of icebreaker sound came from a single date, 17 May 1991. Only 9-10 whales in 7 or 8 groups were observed during that playback.

An additional serious limitation was the fact that all systematic observations of bowheads exposed *to* icebreaker sounds had to be obtained by ice-based observers. The presence of an observation aircraft might have affected whale behavior if we had attempted to observe from an aircraft circling at low altitude (<460 m) under low cloud, The ice-based observers usually cannot see bowheads more than 1½-2 km from the ice camp. Without aerial observations, it is impossible

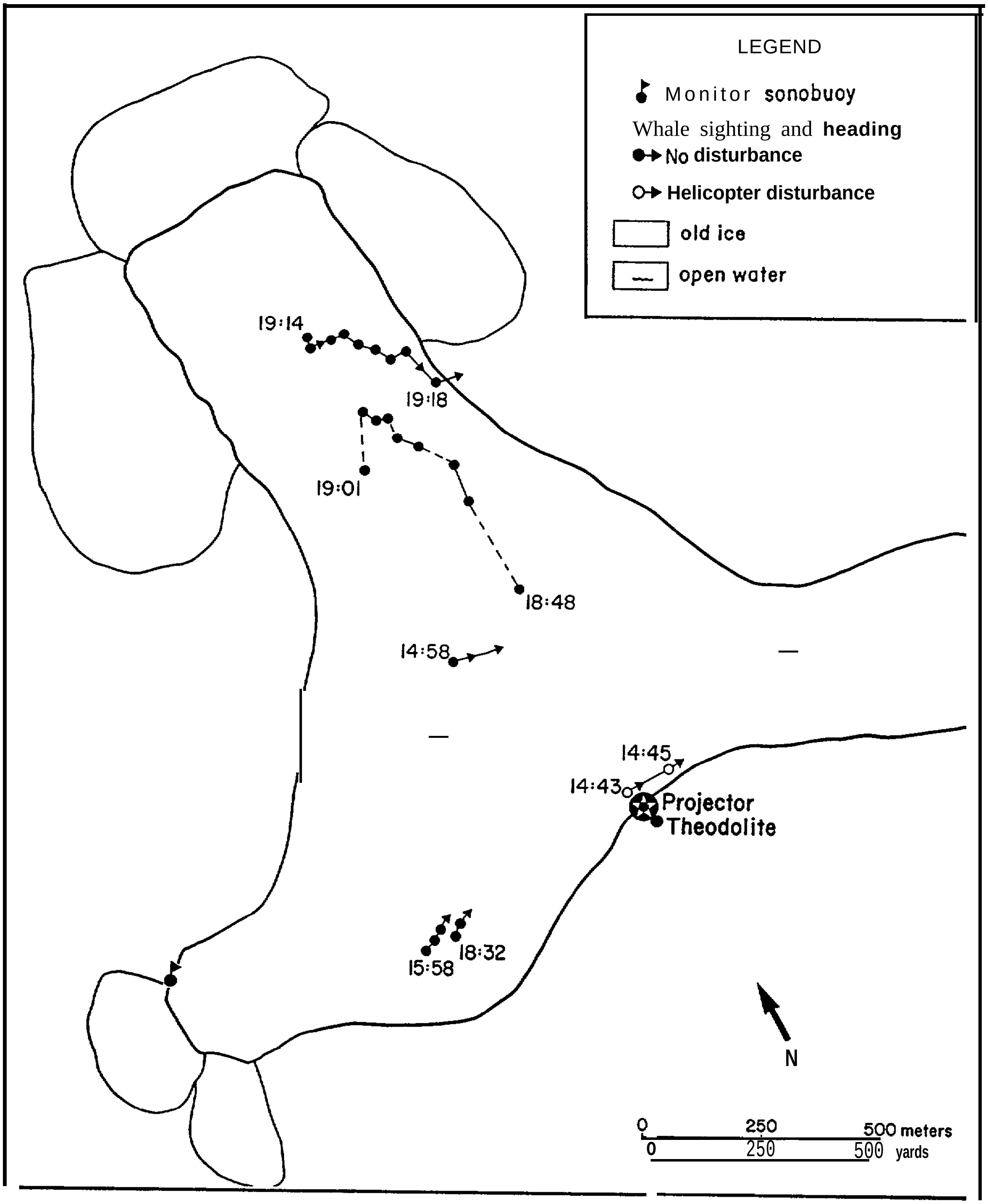


FIGURE 37. Ice-based observations of bowhead whales that passed the ice camp on pack ice NE of Pt. Barrow, 11 May 1991. All bowhead sightings were in the pre-playback (14:41-16:39) and post-playback (17:37-20:29) periods. The helicopter was near the theodolite site with engines running during the sighting at 14:43-14:45, No bowheads were seen during the icebreaker playback. Dashed line represents presumed path of a whale while it was below the surface.

to determine whether some bowheads that are more than 1%-2 km away change course to divert around the projector site.

Thus, it would be premature to attempt to assess the effects of playbacks of icebreaker sound cm bowheads migrating through the spring lead systems. It is apparent from the 17 May 1991 results that ***some*** migrating bowheads tolerated levels of projected icebreaker sound that were at least 10-20 dB above the ambient noise level. However, additional acoustic analysis is required to determine specific noise exposure levels on 17 May 1991. Also, aerial (or other) observations of whales approaching from greater distances are needed in order to determine whether some bowheads exhibit avoidance at sound levels similar to those tolerated by the few bowheads seen near the operating projector in 1991. Other actual or potential limitations of playback work are listed in the INTRODUCTION,

Several of the bowheads seen during control observation periods (projectors silent) came closer to the ice camp than did any bowhead observed during the icebreaker playback on 17 May 1991 (e.g. Fig. 36, 37 vs. 33A). This may have been a chance sampling effect, or it may have been a result of avoidance of the noise source. These two possibilities cannot be distinguished, given the small numbers of whales observed in playback and control conditions, and the small number of days with data. Additional playback tests with icebreaker noise are needed.

Bowhead Reactions to Aircraft, Spring 1991

Reactions to Bell 212 Helicopter

Specific objective 6 in 1991 was "to measure, on an opportunistic basis, the short-term behavioral responses of bowheads and (as possible) white whales visible in open water areas along their spring migration corridor in the western Beaufort Sea to actual helicopter overflights (supplementing limited data from 1989-90)." There were corresponding specific objectives during the 1989 and 1990 phases of the project. This work was assigned a lower priority than the playback work. Some limited opportunistic observations concerning responses to the project's Bell 212 helicopter were obtained in all three years. In addition, during 1990 there was one planned overflight of bowheads by the Bell 212 (Richardson et al. 1991 a:265). Helicopter sounds were measured in 1989 (Richardson et al. 1990a:8 1*ff*).

Whenever bowheads were accessible during May 1991, helicopter-supported work was devoted to noise playback experiments. We performed no specific tests of bowhead reactions to the helicopter in 1991. However, we kept notes on opportunistic observations of the behavior of bowheads seen near the Bell 212 helicopter,

Incidental Observations, 1991 .—The behavior of bowhead whales exposed to close approaches by the helicopter was observed briefly on eight occasions in 1991. Of these incidents, two involved the helicopter flying over or past bowheads:

- On 1 May, a single bowhead headed ENE dove immediately as the helicopter flew by at a horizontal distance of -150 m and at altitude 75 m.
- Also on 1 May, a group of two bowheads remained at the surface and continued traveling ENE as the helicopter flew by at a horizontal distance of -1000 m and at altitude 60 m.

In the other six cases, the helicopter was stationary on the ice with its engines operating:

- On 3 May, a group of two bowheads was sighted once at 11:58 while the helicopter was stationary on the ice with its engines operating. The helicopter had landed 2 min earlier. The whales were traveling ENE at a location -300 m WNW of the helicopter (Fig. 36).
- At almost the same time on 3 May (11:59:10), a lone bowhead surfaced -300 m NNW of the helicopter (Fig. 36). The helicopter was on the ice with its engines running when the whale surfaced. The bowhead was traveling ENE, and there were a total of 8 respirations. The engines were turned off at 11:59:33, during this surfacing. This bowhead did not appear to be disturbed by the helicopter.
- Again on 3 May, at 13:35, a single bowhead that was traveling ENE surfaced and blew 4 or 5 times -600 m SSE of the helicopter (Fig. 36), which was stationary on the ice with its engines operating. The bowhead was in the middle of the southern part of the lead and did not exhibit any apparent reaction to the helicopter.
- On 11 May, a single bowhead surfaced at 14:43, 2 min after the helicopter landed at the ice camp (Fig. 37). The whale was initially an estimated 50 m NW of the helicopter, which was stationary on the ice with its engines running. The whale maintained an E heading, paralleling the ice edge at a distance of -25 m. It respired at least six times. It was last observed diving to the Eat 14:45 when -100 m NNE of the helicopter and still 25 m from the ice edge, The helicopter engines were turned off 20 s later.
- On 17 May, the helicopter landed at the ice camp 1.0 minute after the start of a 4. l-rein dive by a bowhead that was traveling east about 700 m away (#9 in Fig. 33 B). The helicopter engines ran for 1.9 min after it landed, but were shut off 1.2 min before the whale

resurfaced. The whale was still headed east; it respired eight times during that surfacing, when the helicopter was silent.

- On 25 May, -30 s after the helicopter landed at the ice camp (09:53), a bowhead surfaced -125 m ESE of the helicopter and 75 m out into the lead. The whale blew three times and traveled NE while the helicopter was stationary with its engines operating. The engines were turned off at 09:58:30. The bowhead surfaced 15 s thereafter, slapping its flukes against the water while oriented NNE -300 m to the ENE of the ice camp. The animal respired five times and slapped its flukes three more times before fluking out at 10:01. It surfaced twice more before diving at 10:02. The whale maintained a NNE heading throughout these observations. Although the cause of the fluke-slapping is uncertain, it may have been a reaction to the helicopter. Fluke slapping is uncommon in spring; it was seen during only 1.4% of 369 surfacings by "presumably undisturbed" bowheads observed in the springs of 1989-90 (Richardson et al. 1991a: 113).

Summary, 1989-1991.—The 1991 observations of bowhead reactions to a Bell 212 helicopter are limited. The sample size was small and the observations were opportunistic. Only two of the eight cases involved observations while the helicopter was in flight, and only one of these passes was very close to the whale. However, most bowheads did not appear to respond overtly to the helicopter. Most whales maintained their headings and continued respiring at the surface when the helicopter operated nearby. During the one close helicopter pass, the bowhead dove when the helicopter came within a horizontal distance of 150 m at altitude 75 m, probably in response to the helicopter. Of the six observations while the helicopter was stationary on the ice with engines running, only one bowhead appeared to react. This whale (25 May case) showed no obvious reaction when the stationary helicopter's rotors were turning within 125 m of the bowhead. However, 15 s after the engines were turned off, the whale began slapping its flukes against the water surface, possibly in reaction to the abrupt cessation of the engines. During the other five encounters with the stationary helicopter (engine on), bowheads did not react in any obvious way at horizontal distances ranging from 50 to -700 m.

The 1990 results were similar to those from 1991. In 1990, we documented nine close encounters between bowheads and the operating helicopter. We noticed evidence of disturbance during one and perhaps two or three of these nine occasions (Richardson et al. 1991a:265*ff*): *(1)* One bowhead dove immediately when the helicopter flew directly overhead at altitude 150 m; this dive probably was in response to the helicopter. *(2)* Another bowhead dove as the helicopter approached to within 500 m; it was unclear whether the dive was a disturbance response or whether it would have occurred then even if the helicopter had been absent. *(3)* A direct overflight at altitude 150 m had no clear effect on the respiratory or general migratory behavior of two bowheads whose behavior had been observed for 1.0 hour before the overflight. However, mild social interaction began as the helicopter approached; whether this was related to the helicopter overflight was unknown. *(4)* During five occasions in 1990, no apparent disturbance reaction was noted when bowheads were seen 30 m to 1000 m from the helicopter while it was aloft (including both horizontal and vertical distances). *(5)* On one occasion, no reaction was evident when a bowhead was approaching the helicopter while it was on the ice with engines operating and rotor turning (range -500 m).

In 1989 we observed a mother/calf pair exposed to four low-altitude passes by a Bell 212 helicopter (Richardson et al. 1990a:2 11). The mother was at the surface in a newly refrozen lead during two passes, and dove on each occasion. The calf was at the surface during all four passes, and dove only once. In each case, the low flying helicopter flew within 200 m of the whales and once was <50 m from the mother. These bowheads showed no obvious signs of disturbance other than the dives, which may or may not have been attributable to the overflights. The mother and calf remained near the path of the helicopter for about 25 min after the mother was overflown at close range.

Evaluation of Helicopter Overflight Hypotheses.—Overall, the limited 1989-91 observations suggest that spring-migrating bowheads sometimes dive in response to a close approach by a turbine-powered helicopter. However, other bowheads show no obvious reaction to single passes—even at altitudes of 150 m or below. There is no evidence that single helicopter overflights at altitudes of 150 m (or below) disrupt spring migration of bowheads in any biologically significant way.

Two of the hypotheses to be evaluated during this study concerned the effects of helicopter overflights on whales (p. 6). Those hypotheses were as follows:

- Helicopter overflights will not (or alternatively will) significantly alter measures of migration routes and spatial distribution of whales in the open water of nearshore lead systems during the spring migration near Pt. Barrow, Alaska.

- Helicopter overflights will not (or alternatively will) significantly alter subtle aspects of individual whale behavior in the open water of nearshore lead systems during the spring migration near Pt. Barrow, Alaska.

Because the evidence available to date is mostly opportunistic, and additional relevant data are likely to be collected during the planned 1992 phase of this study, it is premature to draw conclusions about these hypotheses, However, the evidence available to date indicates that the first null hypothesis—concerning migration routes and distribution-is likely to be accepted, with some qualifications in wording. If future data are consistent with those from 1989-91, we would conclude that ***single*** overflights by a ***Bell 212*** helicopter ***at altitudes 150 m or below*** do not have ***biologically*** significant effects on the migration routes and distribution of migrating bowheads ***visible*** in ***areas of pack ice or on the seaward side*** of the main nearshore lead near Pt. Barrow. There have been no studies of the effects of other types of helicopters on the migration route and distribution in spring, However, it is worth noting that the Bell 212 used in this project is one of the noisier types of helicopters used by the offshore oil industry.

The second hypothesis, concerning helicopter effects on subtle aspects of individual behavior, will be evaluated if additional behavioral data, become available. Most aspects of behavior are difficult or impossible to study during brief, opportunistic observations of the types that have contributed most available data concerning spring-migrating bowheads and helicopters.

Reactions to Twin Otter

No systematic data on reactions of bowhead whales to the Twin Otter observation aircraft were obtained in 1991. Tests of responsiveness to the Twin Otter were not identified as a priority either in 1991 or in earlier years of this study. However, data on reactions to the Twin Otter are of interest with respect to specific objective 7,

> "To document, as opportunities allow, other aspects of the... disturbance responses...of towheads,..",

and in relation to possible effects of the observation aircraft on the whales. In the 1989 phase of this project, there were two observations of apparent reactions to the Twin Otter; in 1990 there were no such observations (Richardson et al. 199 1a:264).

During the 1991 fieldwork, there were two occasions when it was obvious, in real time, that bowheads were reacting strongly to the aircraft. In both cases the aircraft was making low altitude passes directly over the whales:

- On 1 May 1991, during a vertical photography session with the aircraft at altitude -130 m (-425 ft), several bowheads exhibited brief surfacings and rapid swimming. Their headings tended to be directly or partially away from the aircraft.

- On 22 May 1991, during a vertical photography session with the aircraft at 152 m (500 ft), a bowhead mother and calf exhibited hasty dives when the aircraft made passes overhead, and an S-turn during one of the later passes.

These were the only cases of apparent reactions to the Twin Otter that we noticed in 1991, despite the fact that most of the 1991 flights were at 10 w altitudes (most below 305 m; often below 150 m).

The observations listed above are cases where the observers judged the behavior to be unusual and very likely attributable to the proximity of the aircraft. Most other reports of whale reactions to aircraft are equally subjective. There has been no systematic comparison of the behavior of ***migrating*** bowheads in the presence vs. the absence of an observation aircraft, or during overflights at different altitudes. However, in a systematic study done during ***summer, we*** found subtle effects on bowhead behavior when an observation aircraft circled at altitudes below 460 m (1500 ft; Richardson et al. 1985a,b). It is not known whether similar subtle and unrecognized effects occur during spring migration. However, our subjective impression is that obvious reactions, like the two listed above, are no more common during spring than during summer or autumn.

WHITE WHALE RESULTS

Distribution & Movements of White Whales, Spring 1991

Specific objective 7 for 1991 included a requirement to document, as opportunities allowed, the movements and basic biology of white whales. Although priority was given to bowheads, sightings of white whales were more numerous than those of bowheads (Fig. 38 vs. 22). We recorded -1995 white whales as opposed to --307 bowheads during the Twin Otter flights in 1991 (Table lB). The sightings during Twin Otter flights, helicopter ferry flights, and ice-based work provided information about the timing and routes of white whale migration through the study area in 1991.

Survey effort was not systematic or uniform in different parts of the study area, Hence, the relative numbers of sightings in different parts of the study area must be interpreted cautiously. There was much more survey effort between 71 °30'N and 71 °40'N than in areas farther north. Hence, the sighting maps undoubtedly underestimate the numbers of white whales in the northern parts of the study area relative to the numbers in the central portion. Also, there was less survey effort near the eastern and western edges of the area mapped than in the middle of the study area.

Substantial numbers of white whales were seen throughout the 1991 field season (28 April to 26 May; Fig. 39 to 43). They were seen much more regularly in 1991 than in 1990. In 1991, as in past years, the area where white whales were seen was about the same as that where bowheads were seen (Fig. 38 vs. 22). However, at least during the first two weeks of our 1991 field season, there was a tendency for the main migration route of white whales to be somewhat farther offshore than that for bowheads (Fig. 39,40 vs. Fig. 24, 25). This tendency has also been noticed during ***some*** previous years (Braham et al. 1984; Ljungblad et al. 1984; Richardson et al. 1990a:217*ff*).

Playback Results, Spring 1991

White whales were seen near the operating sound projectors on only two dates in 1991:11 and 17 May. On both of these days, white whales were also seen near the projector site under

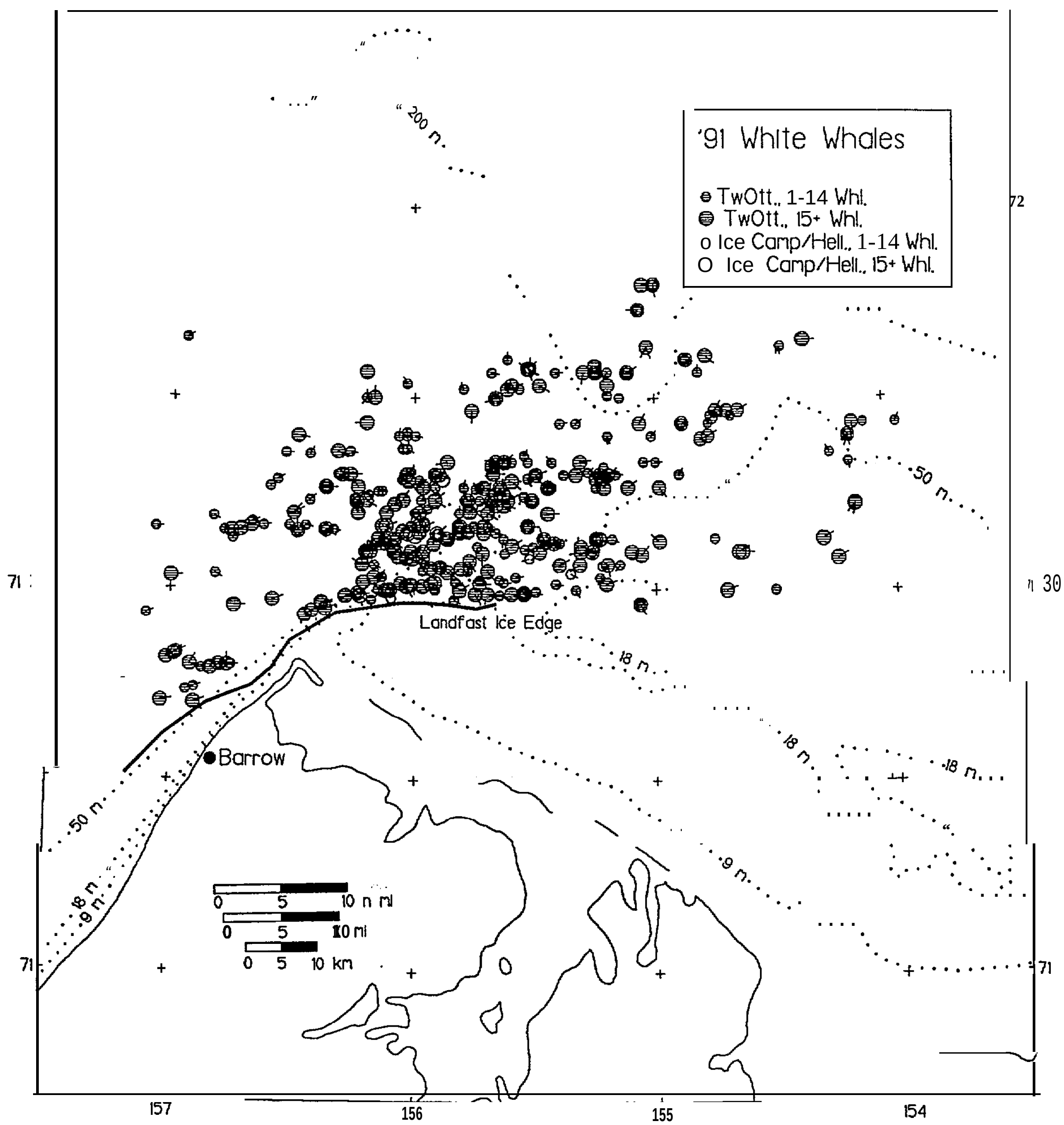


FIGURE 38. LGL sightings of white whales, 28 April to 26 May 1991. Symbol type distinguishes sightings by the two crews and sightings of 1-14 vs. 15+ whales. Headings toward which the whales were oriented when first seen are also shown. Survey effort was not uniform across the area mapped; the most intense effort was in the nearshore lead just north of the landfast ice.

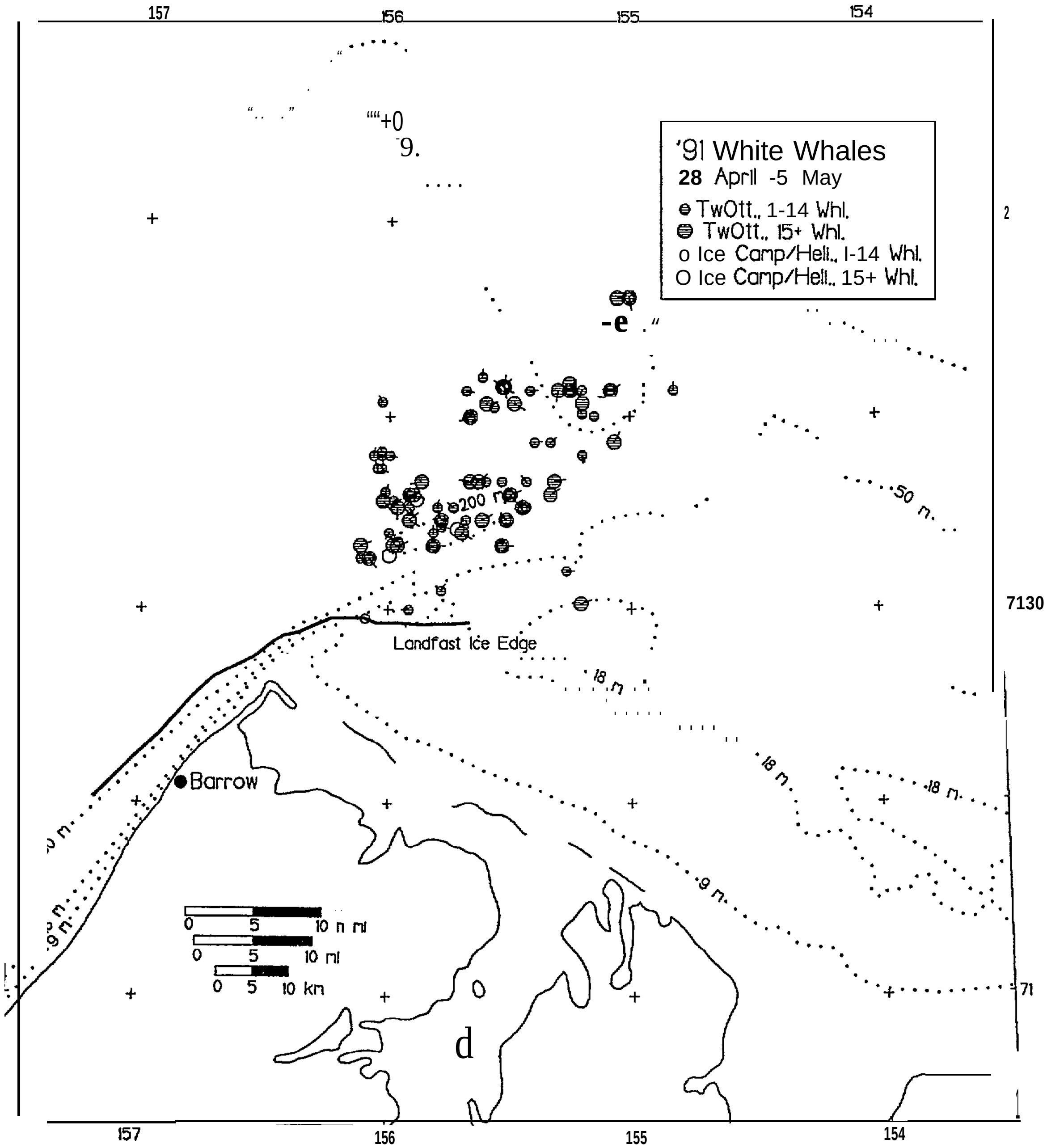


FIGURE 39. LGL sightings of white whales, 28 April-5 May 1991. Format as in Fig. 38.

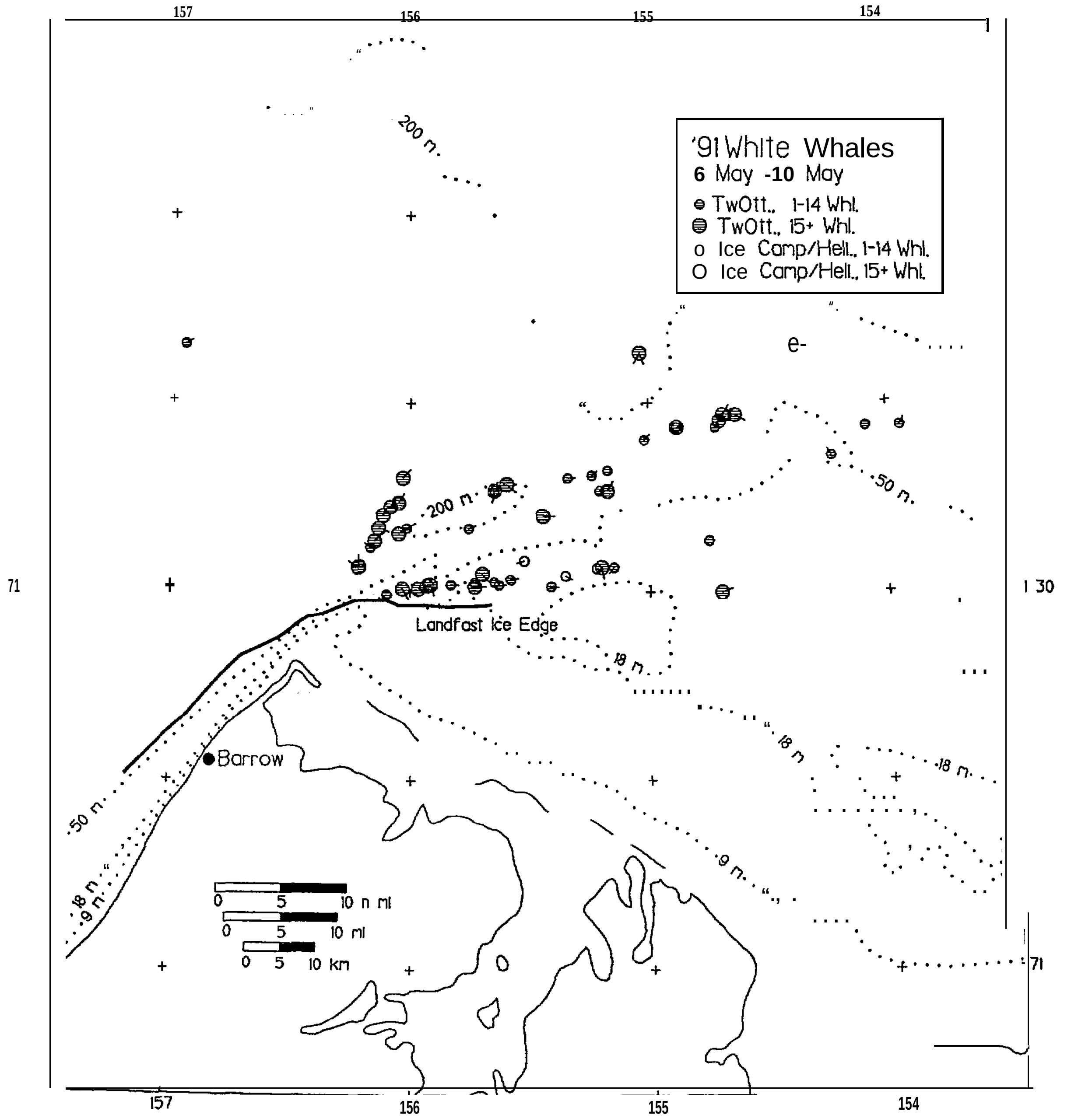


FIGURE 40. LGL sightings of white whales, 6-10 May 1991. Format as in Fig. 38.

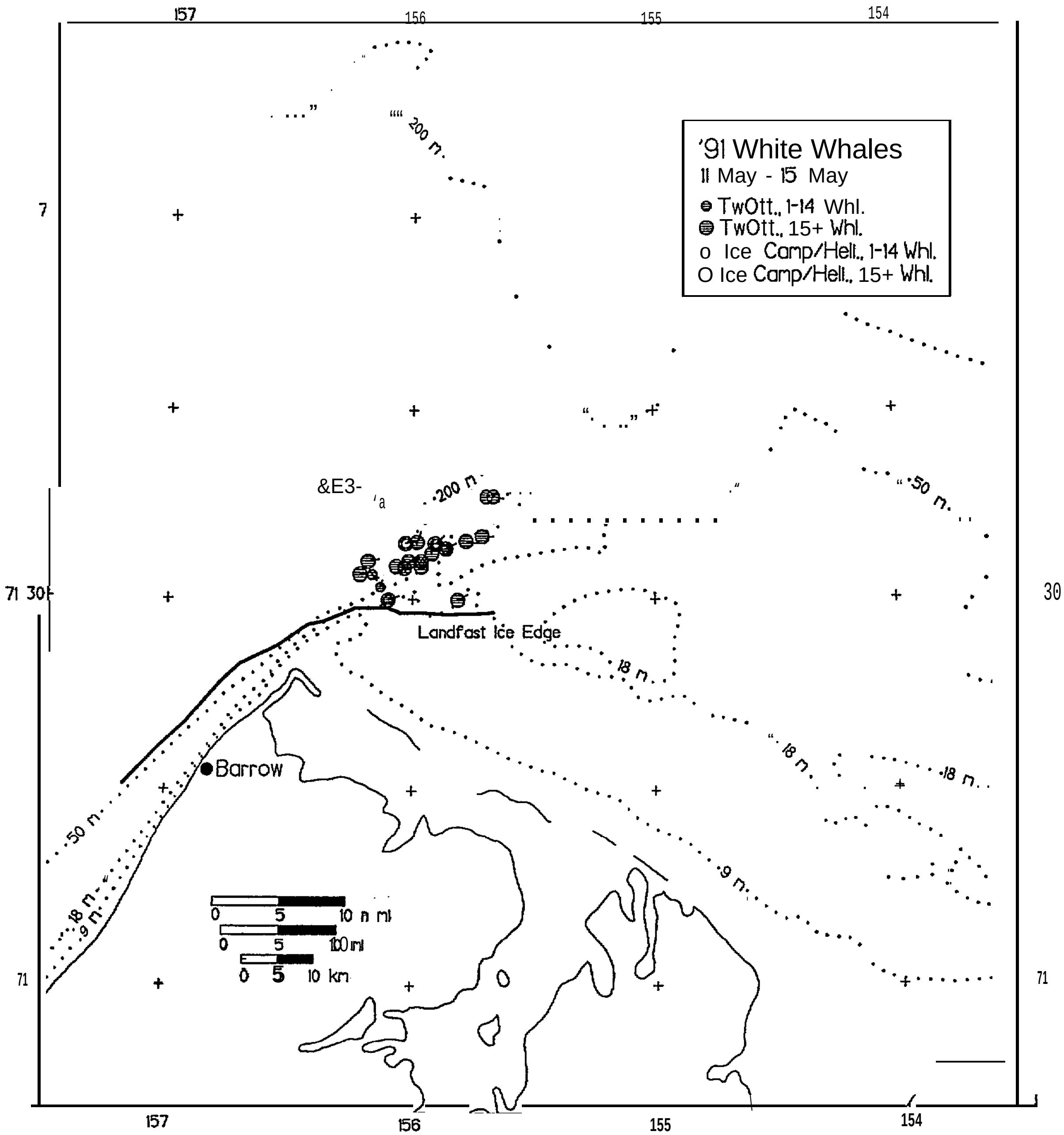


FIGURE 41. LGLsightings ofwhite whales, ll-15May 1991. Format asin Fig. 38.

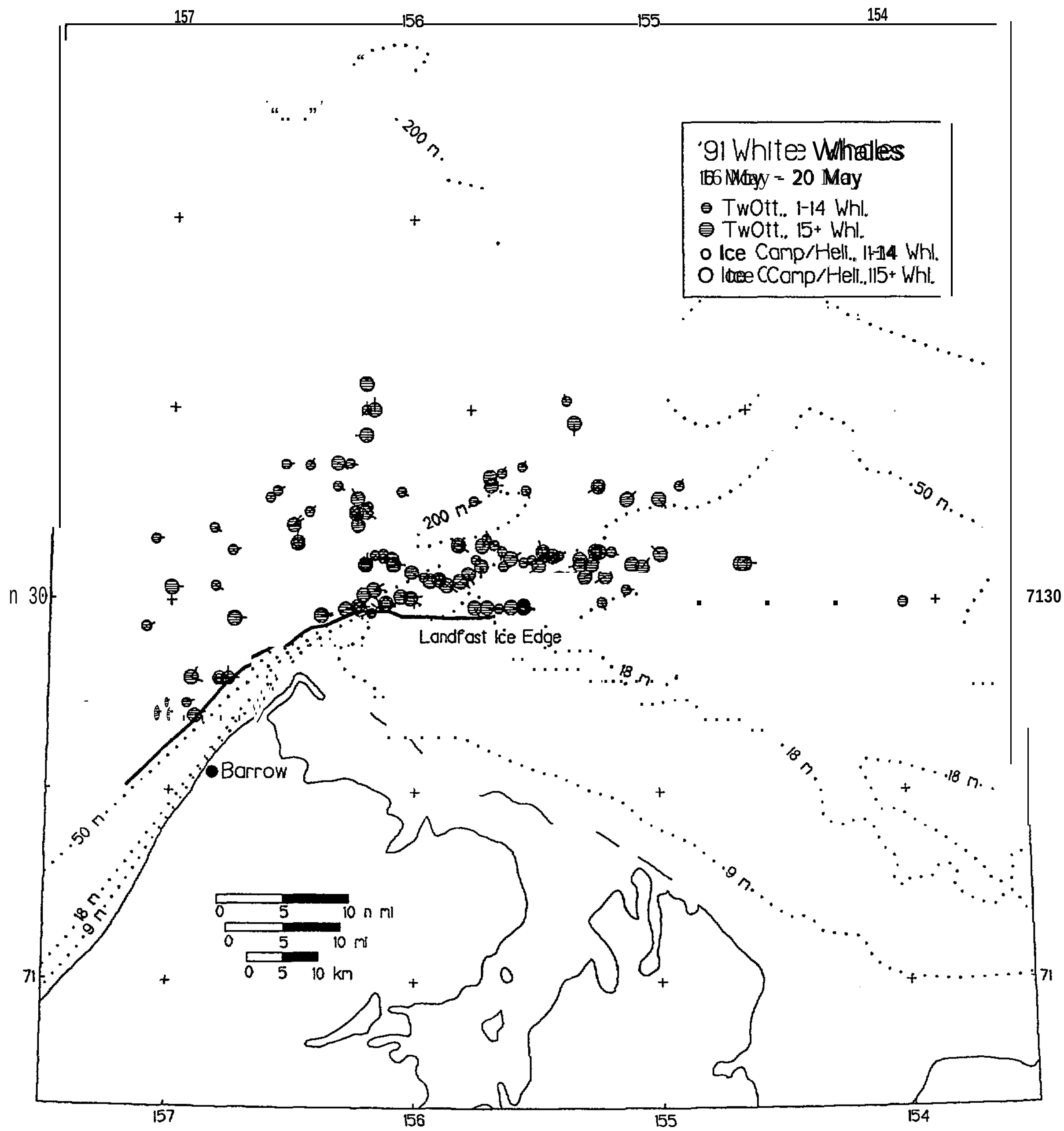


FIGURE **42.** LGL sightings of white whales, 16-20 May 1991. Format as in Fig. 38.

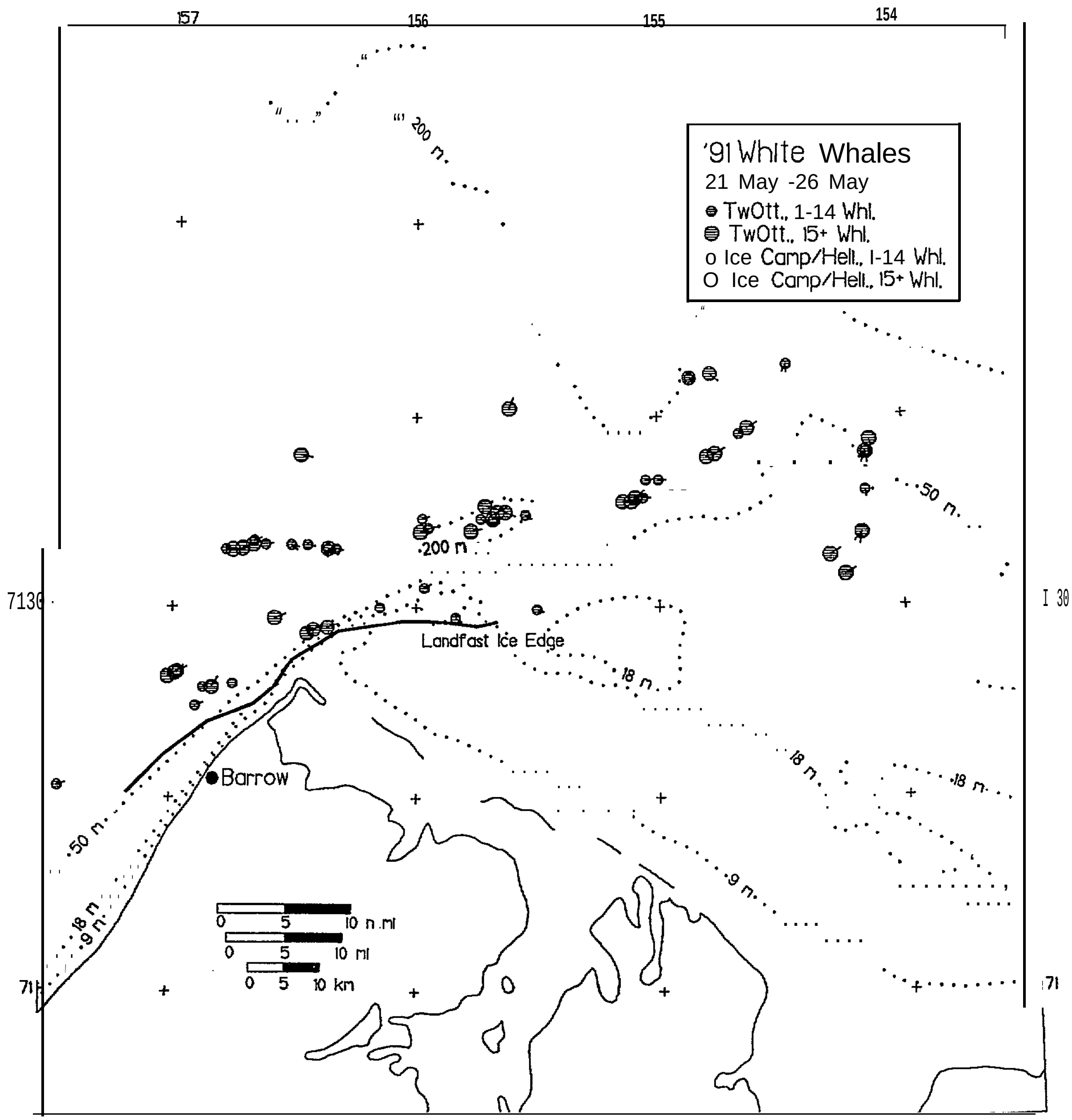


FIGURE 43. LGL sightings of white whales, 21-26 May 1991. Format as in Fig. 38.

quiet "control" conditions before and after the playback period. There were four additional dates when icebreaker sounds were projected into the water for prolonged periods. On one of these days (5 May), white whales were seen during the pre-playback quiet period, but not during or after the playback. On the other two days, no white whales were seen during either the playback or the control periods. All systematic observations of white whales near the ice camp were obtained by the ice-based observers. The prevailing low cloud usually prevented systematic aerial observations.

Icebreaker Noise Playback on 17 May 1991

On 17 May 1991, the ice camp was situated NE of Pt. Barrow on the landfast ice edge, which formed the south side of the broad nearshore lead. The lead was oriented from west to east (True) at this location. The measured water depth was 110 m. The ice-based crew was at this site from 10:46 to 20:59, and icebreaker sounds were transmitted continuously from 12:42 to 18:01. Low cloud and fog patches prevented systematic aerial observations of whale behavior.

Ice-based Observations.-A total of about 165 white whales in 39 groups were observed by the ice-based crew on this day. Most groups (32) were seen prior to or >30 rnin after the playback period. Of these, 23 groups were seen under quiet pre- or post-playback control conditions; 9 groups were seen while the helicopter was operating close enough to be a potential source of disturbance. Five groups were tracked during the playback, and two more groups within 30 min after the playback ended; there was no helicopter activity at these times (Table 9),

Most groups of white whales were migrating eastward along the lead (Fig. 44). There were only three exceptions: two groups that oriented west, at least for brief periods, when the helicopter was operating nearby (Fig. 44 C), and one group traveling NNW 21 min after the playback ended (Fig. 44 D).

During the ***pre-playback control period, 14*** groups of white whales—a total of 52 individuals-were seen when there was no helicopter disturbance (Table 9A). All of these whales were traveling more or less eastward along the lead within 200 m of the landfast ice. Over half of the groups sighted (9 of 14) were within 50 m of the landfast ice. Twelve of the 14 groups were oriented to the east, one to the ENE and one to the NE (Fig. 44A,B).

Table 9. Summary of sightings of white whales seen passing the sound projector located on the landfast ice edge NE of Pt. Barrow on 17 May 1991. All observations were by the ice-based observers.

Time	No. Of WW	Closest Observed Distance (m)	CPA (m)	Method for Determining CPA[a]	Heading (True)	Notes
A. Pre-Playback Control (no helicopter)						
11:00	1	~130[b]	-130	2	E	
11:02	2	~50[b]	-50	2	E	
11:19/22	6	90-175	90-175	1	E	Loose group
11:22	1	25	25	I	E	
11:23/26	8	30	30	1	E	
11:26	2	60	25	3	E	
11:30/33	2	50	50	1	ENE	
11:31	2	22	<22	3	E	
11:34/35	5	30	10	3	E	
11 :44/46	2	135	130	3	E	
11:48/53	8	37	37	1	E	
11:57/59	6	150	150	1	E	
12:07/08	2	160	160	1	NE	
12:34/35	5	235	-50	4	E	
B. Pre-Playback, Helicopter Operating						
10:46	2	-1oo[b]	-1oo	2	E	HeIi. landing -150 m away
10:50	1	-30[b]	-15	2	E	HeIi. on ice ~65 m away
11:09	18	~80[b]	-80	2	E	" " " ~130 m away
11:11	2	~50[b]	-50	2	E	" taking off -100 m away
11:12	20	~50[b]	4"50	2	E	<1 min after takeoff
12:08/13	5	30	30	1	E→NE→E	Veered NE as heli. landed
12:08/18	1 0	32	32	1	E→W→E	Temp. reversal as heli. landed
12:14/15	1	32	30	3	w	< 1 min after heli. landed
C. Icebreaker Playback						
12:38/44	2	957	-750	3	E	Near CPA when plbk started
14:17/19	1	205	95	1	E	Approached and passed; dove at CPA

Continued...

Table 9. Concluded.

Time	No. Of WW	Closest Observed Distance (m)	CPA (m)	Method for Determining CPA[a]	Heading (True)	Notes
14:17	1	210	-120	4	E	Seen briefly, approaching
14:18	3	185	-30	4	E	" " "
14:18/22	1	80	80	1	E	Approached and passed at surface
D. c30 min After Playback						
18:11	1	340	-30	4	E	Seen briefly approaching
18:22/23	1	720	<720	4	NNW	Far out in lead
E. Post-Playback Control						
18:48/50	8	480	-375	3	ENE	Beyond CPA
18:58/00	7	255	-100	4	E	Approaching
19:04/07	7	540	540	1	E	Passing
19:07/09	5	320	- 300	3	E	"
19:11	1	400	400	1	E	Seen briefly, passing
19:15	5	480	-100	4	E	Approaching
19:16/17	5	560	-500	3	ENE	Beyond CPA
19:18/25	2	600	-600	1	NE	Passing
19:25/26	?	440	-200	4	E	Beyond CPA
19:58/13	3	225	225	1	ENE	Passing; near heli. part of time

[a] 1 = measured by theodolite at CPA; 2 = visual estimate at CPA; 3 = estimate based on theodolite measurement(s) to nearby surfacing(s); 4 = estimate based on whale position(s) and heading(s) during sighting(s) distant from CPA position (possibly unreliable).

[b] Distance and position estimates before 11:15 are visual estimates made shortly after arrival on the ice, before the theodolite was set up.

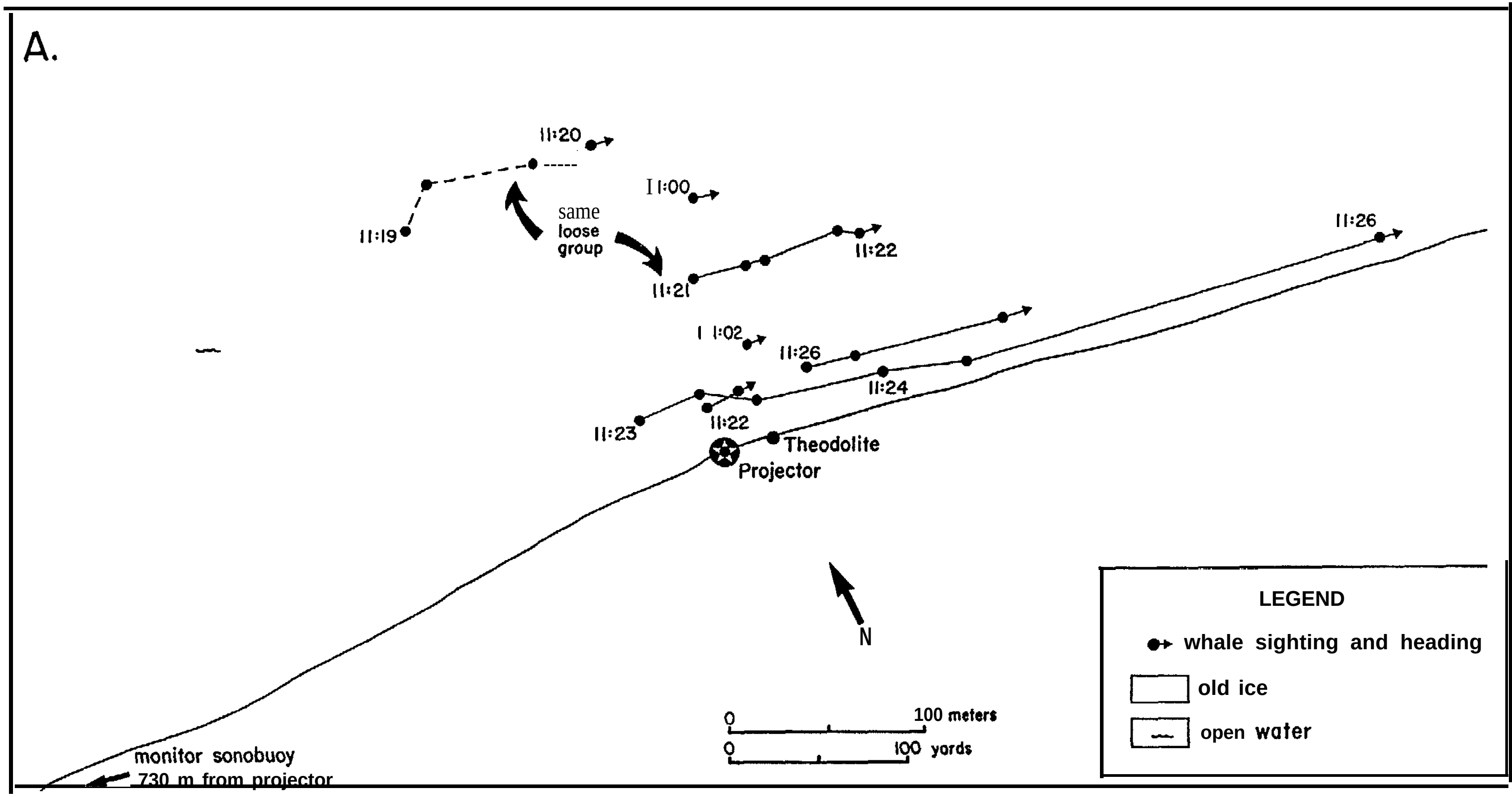


FIGURE **44.** Ice-based observations of white whales that passed the ice camp along the landfast ice NE of Pt. Barrow, 17 May 1991. (A) Initial **pre-playback** control observations, 10:46-11:28. (B) Continued pre-playback control observations, 11:28-12:42. (C) **Pre-**playback observations while helicopter operating nearby. (D) Observations while projectors were broadcasting icebreaker sounds, **12:42-**18:01, and within 30 rnin thereafter. (E) Post-playback control observations, **18:31-20:59.** Dashed lines represent presumed paths of whales while they were below the surface.

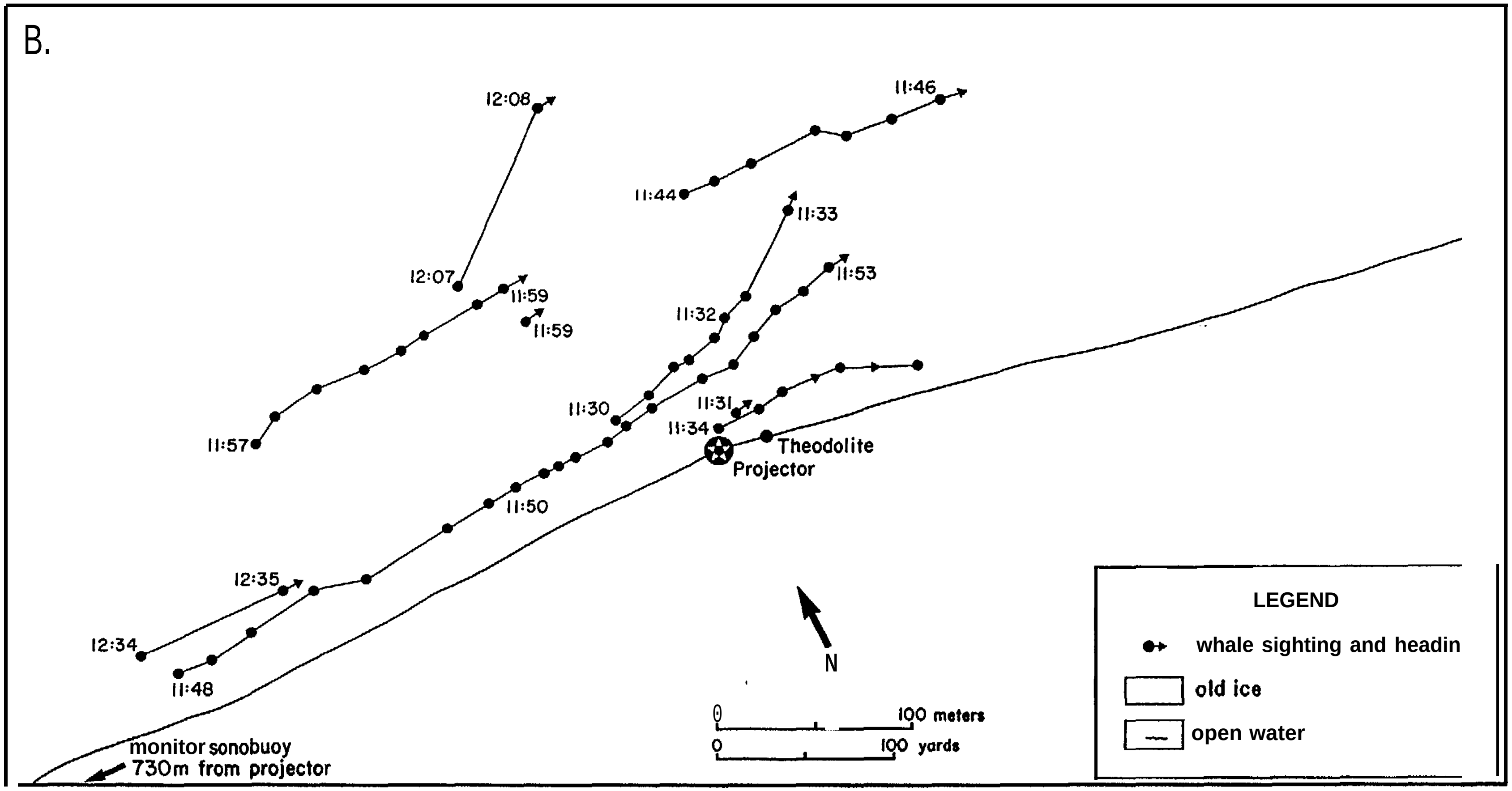


FIGURE 44B. White whales, 17 May 1991, continued pre-playback control observations, 11:28-12:42.

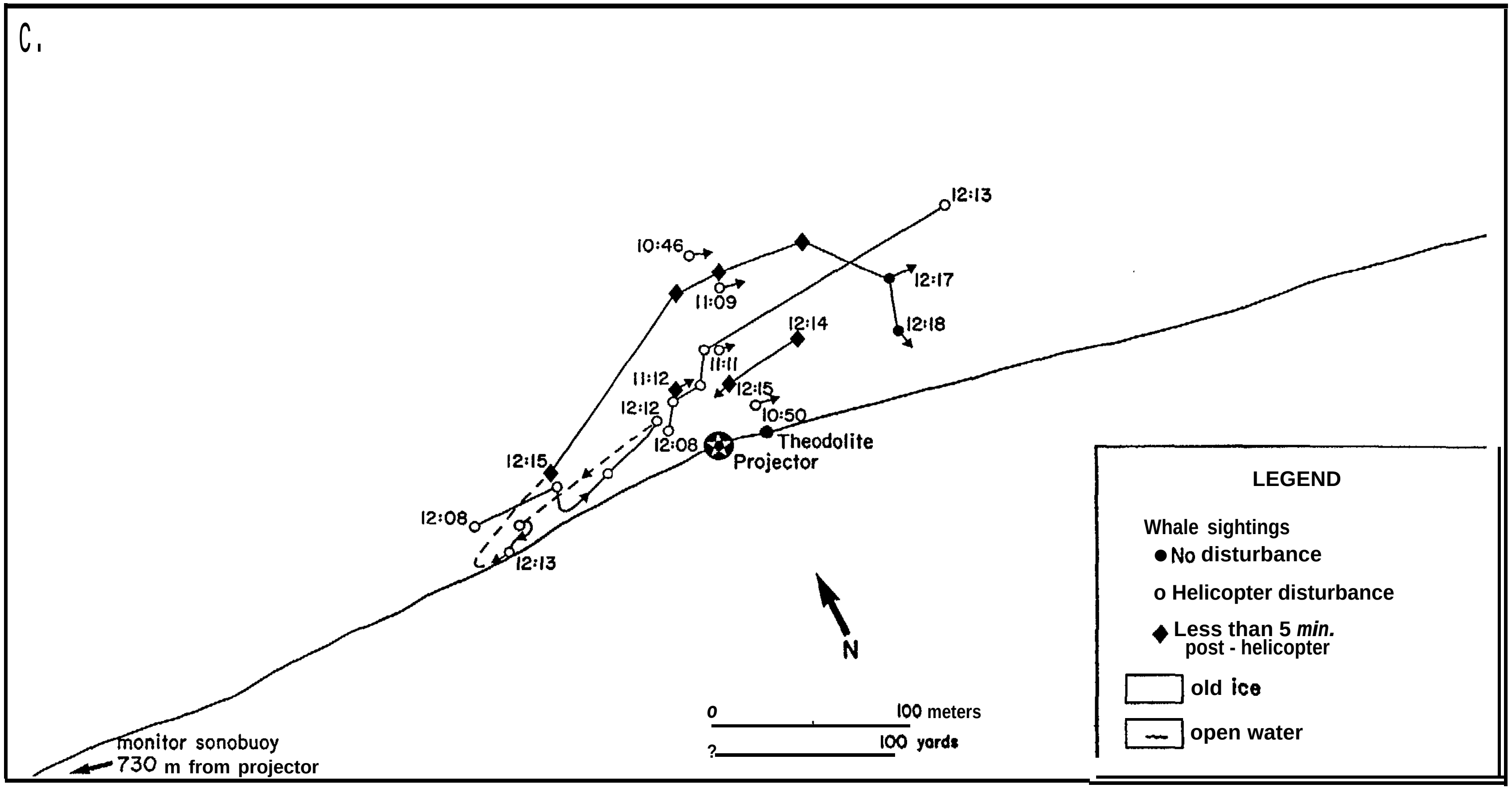


FIGURE 44C. White whales, 17 May 1991, pre-playback observations while helicopter operating nearby.

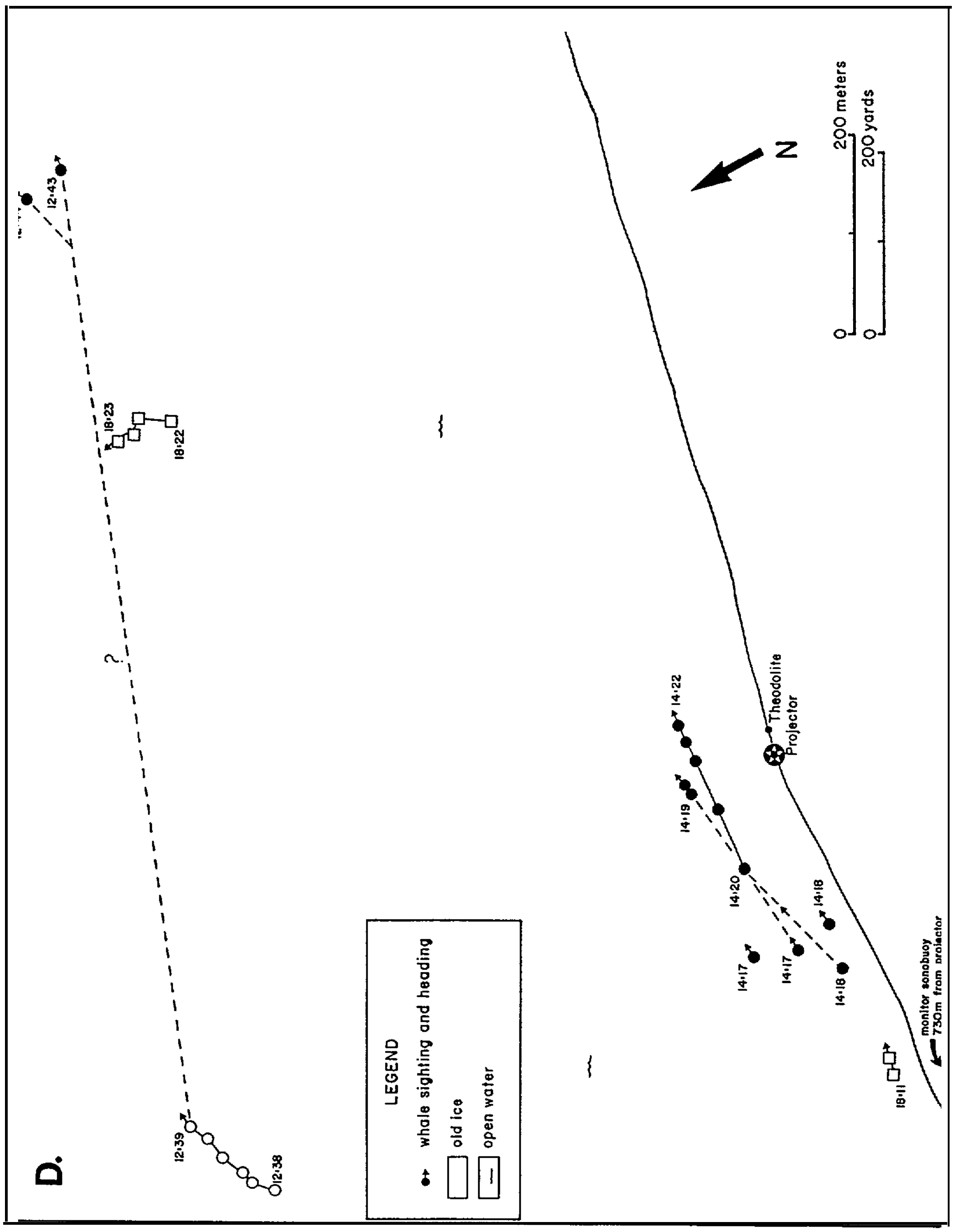


FIGURE 44D. White whales, 17 May 1991, icebreaker playback and 30 min thereafter.

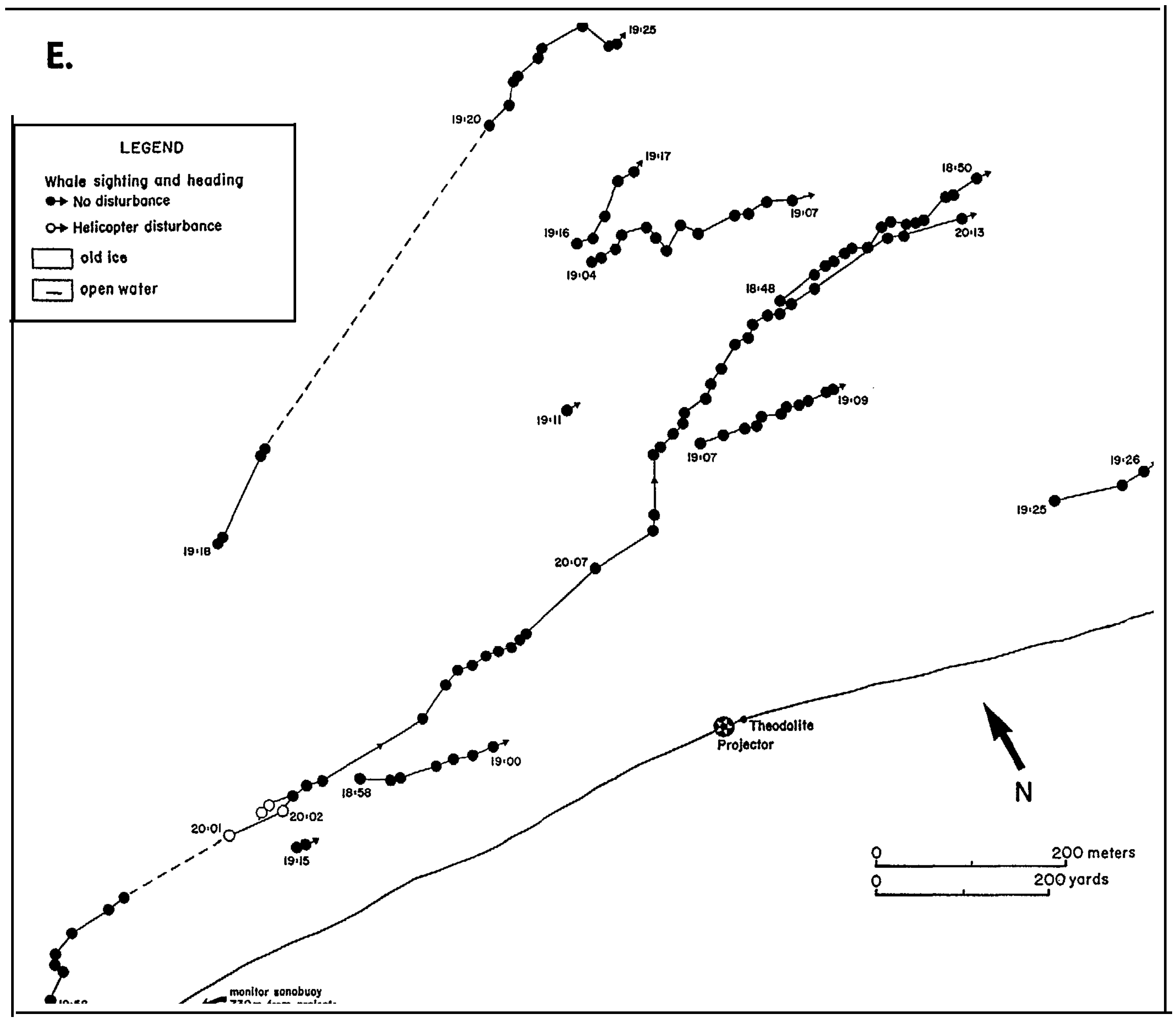


FIGURE 44E. White whales, 17 May 1991, post-playback control observations.

An additional 8 groups were seen during the pre-playback period while the Bell 212 helicopter was operating nearby (Table 9B; Fig. 44 C). These observations are discussed in the later section on helicopter disturbance (p. 136).

During the ***playback period, 5*** groups of white whales-a total of 8 individuals—were seen. An additional 2 single whales were seen within 30 min after the end of the playback (Table 9C,D; Fig. 44D).

The first group was seen just before and during the start of the playback. Two white whales were first sighted at 12:38:30, 2 min before the start of the playback, traveling ENE well out in the lead (693 m NNW of the projector). The playback began at low level while these whales were below the surface. The sound level increased gradually until 12:43:43. Two white whales, believed to be the same group, surfaced at 12:43:09 at a location 957 m to the NE of the operating projector, with one whale apparently oriented N and the other ENE. These whales had apparently passed their CPA position before the playback began, and were last seen at about the time the projected sound reached its peak level.

At 14:17-14:22, four groups totaling seven white whales were observed while the projector was operating at peak power. All groups were headed consistently eastward throughout these observations:

- The longest track involved a lone subadult for which six positions were determined between 14:18 and 14:22 (Fig. 44 D). When first seen, this approaching whale was about 35 m from the ice edge and 235 m west of the projectors. It moved slightly farther away from the ice edge as it approached, and was 80 m from the ice edge and at the surface as it passed the operating projectors and continued to the east.

- Another eastbound white whale was seen 95 m from the projector at 14:19; it dove out of sight while at that CPA position.

- Two other groups (a singleton and a group of three) surfaced briefly 210 m and 185 m from the projector as they approached. They were not seen again; if they did not change course subsequently, they would have come within -120 m and -30 m of the projectors.

The number of white whales seen from the projector site was considerably lower during the playback period than during the pre- and post-playback periods. This was true both on an absolute basis and (especially) on a “per hour” basis:

	Start	End	Duration	Groups No.	Groups /Hr	Individuals No.	Individuals /Hr
Pre-playback	10:46	12:42	1.93 h	22	11	111	58
Playback	12:42	18:01	5.32	5	1	8	1½
Post-playback*	18:31	20:59	2.47	10	4	44+	18+

* 30-min post-playback period excluded (2 whales in 2 groups) .

Furthermore, it should be noted that at least one of the two ice-based biologists was observing at all times during the playback period, with no other duties, whereas during parts ofthepre- and post-playback periods one or both biologists were involved in equipment setup or breakdown. Thus, fewer white whales were seen during the playback even though there was less likelihood of missing passing whales then than during the control periods.

Two single white whales were seen 10 and 21 min after the icebreaker playback ended. One eastbound whale was approaching the ice camp, traveling within 30 m of the ice edge. The second was heading in an unusual NNW direction well offshore in the lead (Fig. 44D).

During the ***post-playback control period*** (>30 min post playback), 10 groups of white whales totaling at least 44 individuals were observed. All groups were traveling east, ENE or NE along the lead (Table 9E, Fig. 44E). Their estimated CPA distances (assuming travel on straight lines during dives) were -100 to 600 m from the ice camp. One of these groups was exposed to helicopter operations for a small part of the period while it was under observation (see p, 137).

Noise Exposure.—Figures 15-17 and 34, in earlier sections, summarize the source levels, received levels and spectra of the projected icebreaker sound on 17 May 1991. These graphs are based on measurements near the projectors and 0.73 km away.

Figure 16 shows the broadband source and received levels (R=0.73 km) during the specific 5-minute interval (14: 17-14:22) when 4 groups of white whales migrated eastward within 80-210 m of the operating projectors (Table 9). Given the water depth (110 m), the underwater sound levels at those distances can be estimated from the source levels on the assumption of spherical spreading, i.e. transmission loss equals $20*\log(R)$. Based that assumption and the time-specific source levels given in Figure 16, the broadband received levels for the four whale groups were as follows:

CPA @ 14:19:11,	SL = 158 dB,	RL @ 95 m = 118 dB
Approaching @ 14:17:00,	SL = 163 dB,	RL @ <210 m = >117 dB
Approaching @ 14:18:17,	SL = 163 dB,	RL @ <185 m = >118 dB
CPA @ 14:21:00,	SL = 163 dB,	RL @ 80 m = 125 dB

Ambient noise levels at these specific times could not be determined because of masking by the projected icebreaker sounds. However, the broadband level (20-1000 Hz) after the playback was 93 dB re 1 µPa. If that level also occurred during the playback, the icebreaker noise levels were from at least 24 dB to at least 32 dB above the background level at the distances and times listed above.

Three of the four groups listed here eitherdove orwere below the surface as theypassed the projector (Fig, 44D). Thus, those three groups of whales were actually exposed to the estimated noise levels. However, the group with CPA distance 80 m was at the surface as it passed the projectors. That group probably did not receive the full 125 dB level and 32+ dB icebreaker : ambient ratio estimated above.

The white whale hearing system has relatively low sensitivity at the low frequencies where the icebreaker sounds were concentrated (Awbrey et al. 1988; Johnson et al. 1989). The results from 17 May 1991 require further analysis to evaluate the received sound levels at various frequencies in relation to hearing sensitivity of white whales at those frequencies.

<u>Icebreaker Noise Playback on 11 May 1991</u>

The ice camp was at the north end of a giant ice pan, adjacent to an irregularly-shaped lead amidst pack ice (Fig. 45). The measured water depth was 195 m. Icebreaker sounds were projected for 1 h, from 16:39 to 17:37. Unfortunately, the projector system then had to be removed from the water to protect it from drifting ice. Observers aboard the Twin Otter aircraft conducted an aerial reconnaissance in the area, but the cloud ceiling was too low (150-300 m) to allow systematic aerial observations of whale behavior.

A total of 11 groups of white whales consisting of 38 individuals were seen from the ice camp. Five groups were tracked during the 2. O-h pre-playback control period, one group during the playback, and five groups during the 2.9-h period of post-playback observations. The

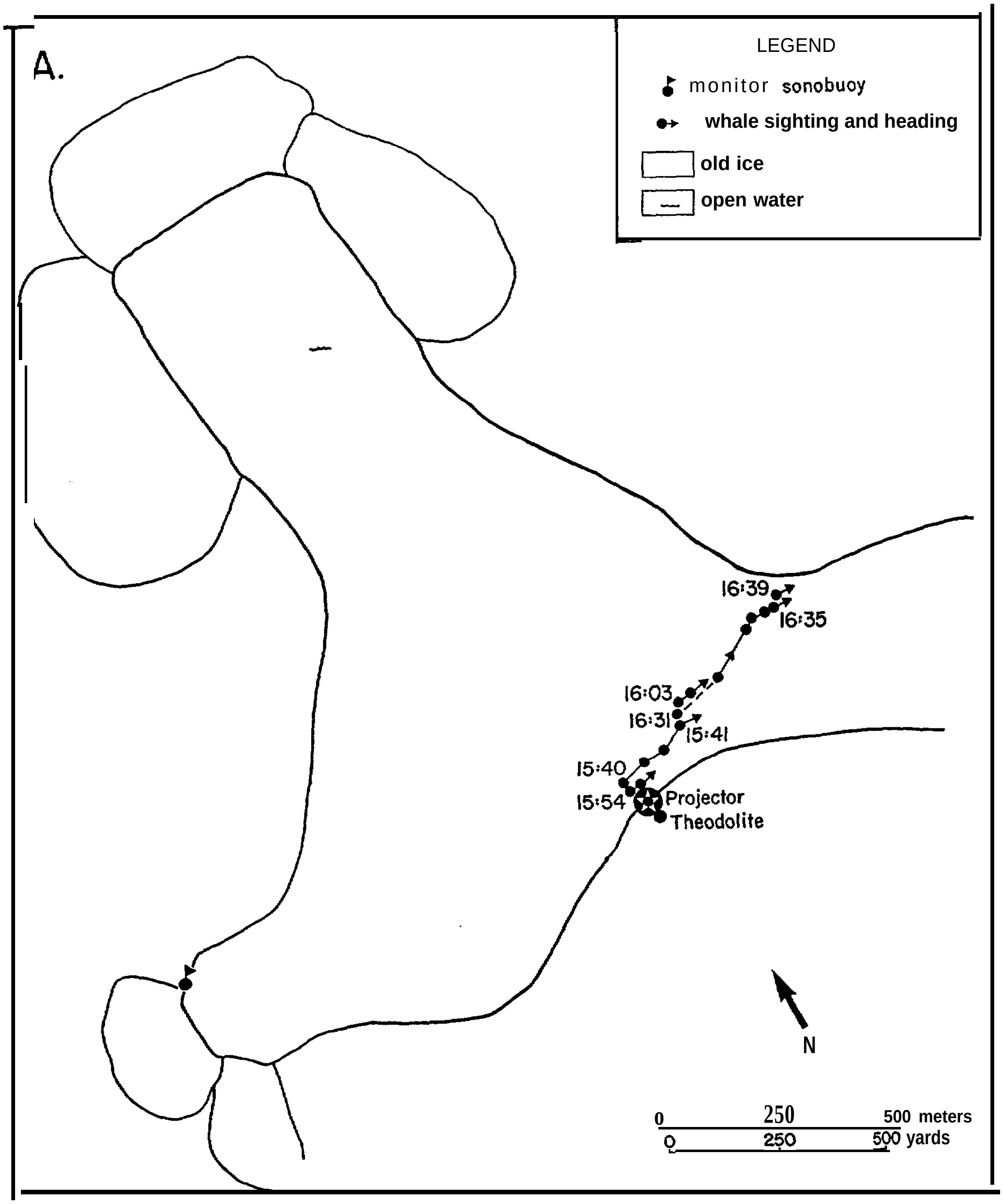


FIGURE 45. Ice-based observations of white whales that passed the ice camp on pack ice NE of Pt. Barrow, 11 May 1991. Icebreaker sounds were projected from 16:39 to 17:37. (A) Pre-playback control observations, no helicopter disturbance. (B) Observations during and after playback, with possible helicopter disturbance in each case.

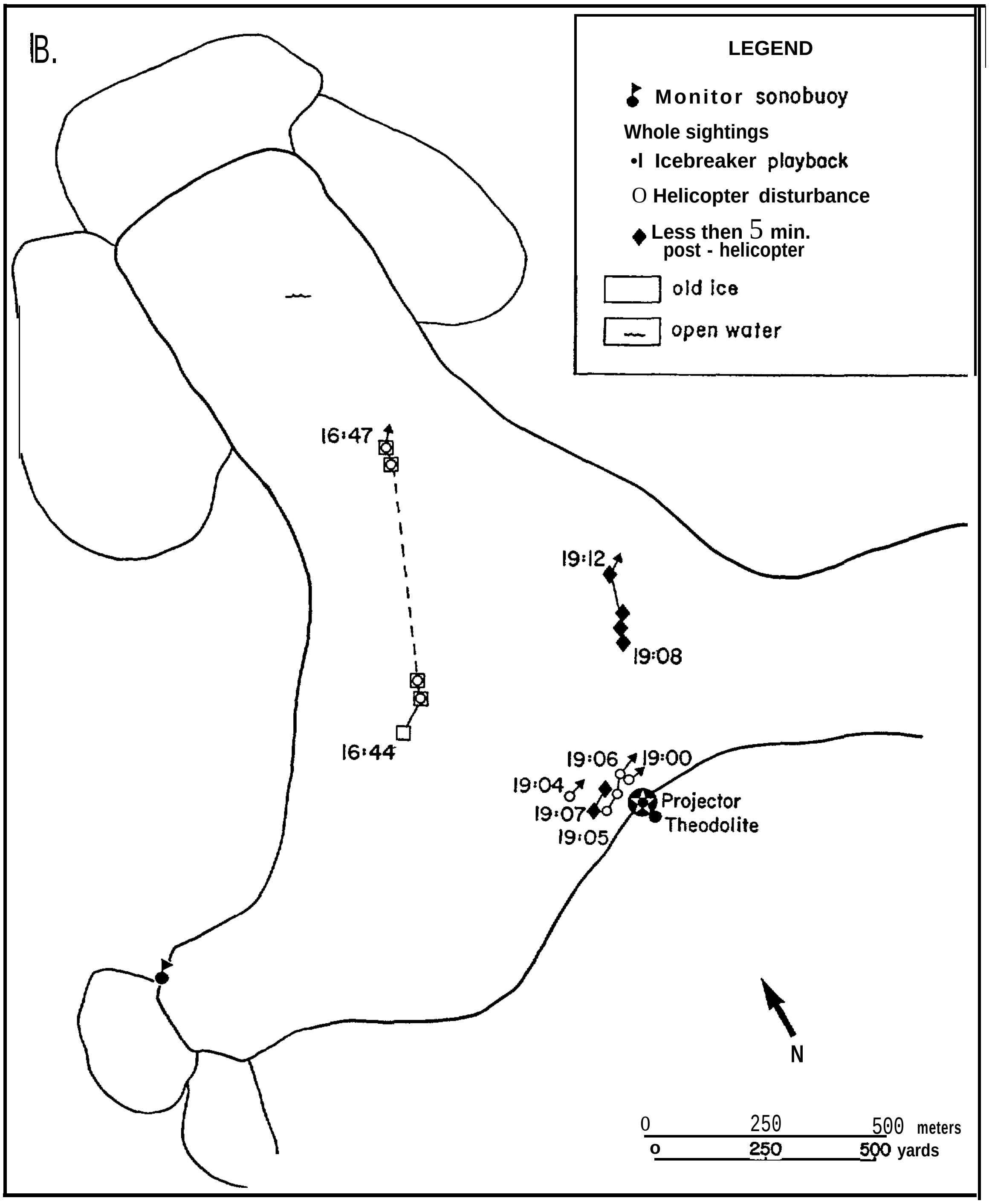


FIGURE 45B. White whales, 11 May 1991, playback and post-playback, with possible helicopter disturbance.

helicopter was at the ice camp with its engines running while four of the groups of white whales passed, including the one group seen during the playback period.

Figure 45A shows the paths of the five white whale groups observed during "control" conditions, i.e. while the projectors were silent and there was no helicopter disturbance. All five groups were seen before the playback, and all were traveling to the ENE in the southern part of the lead close to the ice camp:

- ➤ Two groups were seen at CPA distances 40 and 70 from the ice camp.
- ➤ Three groups surfaced after they had passed the ice camp and were 200-515 m away. If they were traveling on straight lines while underwater, they all passed the ice camp at CPA distances ≤200 m.

Figure 45B shows the paths of four groups of white whales seen during the playback and post-playback periods while the helicopter's engines were operating at the ice camp, plus two more groups that surfaced within 2 min after the engines stopped. (When the helicopter was standing by on the ice for prolonged periods, it was considered necessary to run the engines periodically to keep them warm.) Of the five groups seen during the post-playback period with possible helicopter disturbance, four showed no apparent reaction to the helicopter one group that was heading NNE may have diverted in response to the helicopter (see helicopter disturbance section, p. 137).

The one group of white whales seen during the icebreaker noise playback was first sighted at 16:44. This was 5 min after the playback had begun and 3 min after the projected sounds had reached near-peak level. When first seen, the six white whales were 515 m NW of the projector and were headed NE (Fig. 45B). As the whales surfaced for the second time <1 min later, the helicopter's engines were started. While the engines were operating, the whale position was measured four more times. The group traveled NNE across the lead toward the opposite edge. They apparently turned about 30° to their left, away from the projector and helicopter (Fig. 45 B). The whales were last observed at 16:47, 900 m NNW of the projector and helicopter.

The source level of the projected icebreaker sounds at 16:47-16:48, after the projectors reached their peak level, was 155-156 dB re 1 µPa-m in the 20-1000 Hz band. The corresponding source level in the strongest l/3-octave band, the one centered at 80 Hz, was 148-149 dB. The estimated received levels at the whale location—then 900 m from the projectors—were 98 dB broadband and 93 dB near 80 Hz.[4] The estimated broadband received level at 900 m range was only 3 dB above the average ambient noise level measured on this date. However, the estimated received level in the l/3-octave band centered at 80 Hz was 10 dB above the average ambient level in that band. Thus, the components of the icebreaker sound near 80 Hz would have been readily detectable by a hydrophore at range 900 m. It is not certain what components of the icebreaker sound would have been detectable by white whales, whose hearing sensitivity at low frequencies is apparently poor (Awbrey et al, 1988; Johnson et al. 1989).

The significance of the observations of the one group of white whales seen during the 11 May playback cannot be interpreted:

- It was the most distant group sighted on 11 May. In contrast, all five groups seen during pre-playback control observations were closer to the ice camp, as were all five groups seen during the post-playback period when the helicopter engines were operating. This suggests (but does not prove) that white whales may have avoided the immediate vicinity of the ice camp while the projector was operating.

- The 30° turn away from the ice camp and onto a NNEerly course may have been in response to the playback, the startup of the helicopter engines, or a combination of the two. All white whales seen on 11 May in quiet control conditions were traveling ENE, but one other group traveled NNE just after a period with helicopter engine noise.

- The fact that this group was seen just after the start of the playback was an additional complication. These whales were exposed to increasing levels of icebreaking sound in the several minutes before they were first seen.

Thus, the playback results from 11 May were inconclusive.

Control Observations on Other Dates

Aside from 11 and 17 May, discussed above, 5 May was the only other date when white whales were seen from the ice camp. On 5 May, the camp was set up on the NE side of a large

[4] No monitor sonobuoy was deployed at 16:47. However, ¾ hour later, when both source level and received level 1,12 km from the projector were measured continuously over a 4-rein period, the transmission loss (TL) over the 1 m to 1.12 km path averaged 59 dB for the 20-1000 Hz band, and 57 dB for the l/3-octave band centered at 80 Hz. Thus, TL from 1 m to 0.9 km at 16:47 can be estimated as 57-58 dB broadband and 55-56 dB near 80 Hz.

opening amidst the pack ice at 71°47'N, 155°34' W. This was location was -17 km north of the landfast ice edge, and was the most northerly site of ice-based work in 1991 (Fig, 2 on p. 27). The measured water depth was 122 m. This location was selected because our aerial reconnaissance flights had found bowhead whales nearby the previous day, and numerous white whales heading toward this area on 5 May. The ice-based crew was at this location from 10:15 to 19:33. Various tonal signals were projected intermittently from 13:42 to 15:23 in order to calibrate the projector system. Icebreaker sounds were projected from 15:29 to 17:51.

A total of 25 groups of white whales including an estimated 46 individuals were observed from the ice camp on this day, These whales formed part of a long, strung-out group that passed almost continuously from 10:32 until 12:58. The last whales were seen 0.7 h before the projection equipment was set up, so there was no opportunity to test their reactions to projected sounds.

Most of the whales were headed N or NE as they approached the ice camp. However, the camp was on an ice edge running from NW to SE, across their path. Many whales changed , heading as they approached this large ice pan, and diverted either to the left or to the right along the ice edge.

Discussion

The observations on 17 May 1991 provided our only meaningful results concerning reactions of white whales to playbacks of icebreaker sounds. White whales were migrating eastward close to the landfast ice edge prior to the playback. Eastward migration continued during the playback, including at least two whales whose closest points of approach were only 80 and 95 m from the operating projector. However, the numbers of whales and of whale groups passing per hour were considerably lower during the playback than during the pre- and post-playback control periods,

This difference in numbers is consistent with the possibility that some white whales avoided passing close to the ice camp as a result of the playback, However, observations on a single date cannot prove that the playback was the cause of the lower number seen during the playback. Pods of white whales often migrate in loose associations spread out over several kilometers. It is possible that the pre- and post-playback periods happened to coincide with times when two such associations were passing the ice camp. To resolve this question, replicated playbacks on a number of days are necessary, preferably in conjunction with aerial observations to determine the distribution of whales over a larger area than can be seen from the ice camp.

The levels of icebreaker sound received by the whales that were seen passing the projectors during the playback on 17 May were well above ambient on a broadband basis (20-1000 Hz band). However, much of the energy in the projected icebreaker sounds was at relatively low frequencies. The white whale auditory system does not seem to be very sensitive to those frequencies. It will be important to evaluate the noise levels received by the white whales during the 17 May 1991 playback as a function of frequency, and to compare the results with the white whale audiogram.

We need to conduct additional fieldtests before the white whale/icebreaker noise hypotheses stated in the INTRODUCTION can be evaluated.

White Whale Reactions to Aircraft, Spring 1991

Reactions to Bell 212 Helicopter

Information about the reactions of white whales to helicopter overflights is one of the secondary objectives of this project (see specific objective 6 on p. 5).

Results from 1989-90 showed that reactions of white whales to turbine-powered aircraft during the spring migration near Pt. Barrow are variable (Richardson et al. 1990a:239, 1991 a:282). Some individuals show no overt response to a Bell 212 helicopter or Twin Otter fixed-wing aircraft flying at low level, or to a Bell 212 standing on the ice edge with engines running within 100-200 m of the whales. Other white whales look upward or dive abruptly when an aircraft passes over at altitudes at least as high as 460 m (1500 ft). Some white whales whose paths come within 100 m of a helicopter on the ice with its engines running may divert as much as 100 m away from the helicopter. It is not known whether these small-scale and apparently brief reactions are to the noise from the aircraft, visual cues, or both.

Based on the 1989-90 results, we suggested that single overflights by a helicopter of the Bell 212 class do not cause blockage or biologically significant diversion of the spring migration of white whales traveling in pack ice or along the seaward side of the nearshore lead. However, a final evaluation of the hypothesis concerning effects of helicopters on distribution and movement of white whales was postponed until later in the project. The data from 1989-90 were not adequate for a test of the hypothesis concerning helicopter effects on subtle aspects of the individual behavior of white whales.

Incidental Observations, 199 1.—In 1991, useful information was obtained on five occasions when the helicopter flew near white whales. On three of these occasions, marked with * symbols, there was evidence of a disturbance reaction:

* On 6 May (11:16), a single white whale made a deep vertical dive as the helicopter flew over the whale at altitude 60 m ASL.

➤ On 17 May (10:43), about 15-20 white whales continued migrating east at the surface as the helicopter flew by at a horizontal distance of about 75 m and at altitude about 60 m ASL.

► Also on 17 May (10:46), two white whales continued traveling east as the helicopter landed -150 m south of the whales (Fig. 44C).

* Again on 17 May (12:08), a group of five white whales traveling east veered NE as the helicopter maneuvered 300→200 m to the south at about 65→30 m altitude, inbound for a landing at the ice camp at 12:11:15 (Fig. 44C). Although this group apparently veered away from the ice edge in response to the helicopter, the whales remained at the surface and continued to engage in social interactions.

* At the same time on 17 May (12:08), another group of 10 white whales, initially eastbound, milled in a closely-spaced group as the helicopter approached to within -250 m at -30 m ASL. They subsequently resumed eastward surface travel at reduced speed, but reversed course to the west shortly after the helicopter landed about 100 m to the SSE of the whales (Fig. 44C). They resumed travel to the NE after the helicopter engines were turned off, and later veered back toward the ice edge after passing the now-quiet helicopter and camp.

On an additional 11 occasions we obtained useful information about white whale behavior when the helicopter was stationary on the ice with its engines running and rotors turning. Three of these cases, marked with * symbols, showed evidence of possible or definite helicopter disturbance:

- On 5 May (12:02), an adult/juvenile pair had been milling before the helicopter's engines were started. At that time the helicopter was -150 m NE of the whales and the whales were headed SE, tangential to the helicopter. They maintained that heading and did not turn away.

- On 11 May (~19:00), 3 groups of white whales swam ENE past the ice camp while the helicopter's engines were running. The helicopter was about 10 m back from the ice edge. The whales were 70, 70 and 160 m from the helicopter (Fig. 45 B), and showed no obvious reaction.

- Also on 11 May (19:07), a group of 2 white whales that surfaced 100 m west of the camp 30 s after the engines were turned off passed directly in front of the camp at a CPA distance 90 m from the helicopter (Fig. 45 B).

* Again on 11 May (19:08), a group of 4 white whales that surfaced 2 min after the engines were shut down was heading NNE, directly away from the helicopter (Fig. 45B). This heading was in contrast to the ENE headings of the nine other groups seen passing the camp that day under quiet or "engines on" conditions (Fig. 45 A,B). This group was first sighted 320 m north of the ice camp, and may have diverted to the north in response to the helicopter.

- On 17 May (10:50), a single white whale traveled east past the ice camp -15 m from the ice edge (Fig. 44C) and ~65 m north of the stationary helicopter, which had landed 3 min earlier. The rotors were still turning.

- On 17 May (11:09), a group of 15-18 white whales traveled east -130 m north of the stationary helicopter (Fig. 44 C), whose engines had started up at 2 min earlier.

- On 17 May (11:11), an adult and yearling were observed traveling east 100 m north of the helicopter as it took off.

* On 17 May (12:14), about 3 min after the helicopter had landed near the ice camp and 30 s after the engines were turned off, one white whale was seen traveling slowly west, mainly below the surface, approaching to within 32 m of the camp (Fig. 44 C). The unusual W heading and the sub-surface swimming may have been related to the preceding helicopter activity.

* On 17 May, a group of three white whales was tracked from 19:58 to 20:13 as they headed ENE along the nearshore lead. During this period they passed the helicopter, which was on the ice (engines running) about 250 m south of the whales and 800 m west of the ice camp (Fig. 44E). There was no definite response. However, the ENE heading, veering away from the E-W alignment of the ice edge, may have been related to the presence of the helicopter.

Discussion.—The observations of the movements and behavior of white whales near the Bell 212 helicopter in 1991, although anecdotal, are consistent with those from 1989-90. The whales sometimes veered away, dove or showed other changes in behavior when the helicopter was operating within a few hundred meters. At other times no such reactions were noticed even when the helicopter was within 100 m.

The tentative conclusions about helicopter effects on white whales that were included in our 1989-90 report (summarized on p. 135, above) remain appropriate when the 1989-91 results are considered. We anticipate that more data of these types will be obtained during the 1992 field season. A final evaluation of the helicopter/white whale hypotheses is deferred until that time,

Reactions to Twin Otter

In 1991, observers in the Twin Otter aircraft noted apparent reactions of at least ten groups of white whales to the passing aircraft:

- On 3 May (11:45), two whales that had originally been heading west milled as the aircraft passed over at altitude 150 m.

- On 17 May, at least some of the individuals in six groups of white whales dove hastily, usually with an unusually vigorous tail thrash, as the aircraft passed overhead or close to the side at altitudes 60-125 m. Other groups, not specifically noted, did the same thing.

- On 18 May (10:30), one white whale turned sharply away from the aircraft as we flew directly overhead at 60 m ASL.

- Also on 18 May (17:53), a group of seven dove hastily with an unusually vigorous tail thrash when we flew over at 107 m ASL; this reaction was of the same type as had been seen on 17 May.

- On 22 May (20:24), a group of two whales heading east were overtaken by the eastbound aircraft at 150 m ASL. They turned 90°, away from the aircraft, as we passed -500 m abeam.

The ten+ white whale groups that reacted to the aircraft constituted a very small percentage of the total number of white whale groups sighted from the Twin Otter in 1991 (solid symbols on Fig. 38). Most groups that showed no overt reaction were also seen from altitudes below 300 m; the prevailing low cloud in 1991 forced us to fly at low altitude most of the time.

Likewise, in 1989 and 1990, there were only a small number of observations of apparent reactions of white whales to the Twin Otter: three groups in 1989 and two in 1990. These reactions were noticed while the aircraft was at 150-460 m ASL (Richardson et al. 1991 a:282).

SUMMARY AND CONCLUSIONS

The highest priority objective in 1991 was to test the reactions of bowheads and (as possible) white whales to underwater playbacks of icebreaker noise along their spring migration corridor in the western Beaufort Sea. Additional specific objectives were to collect further data on ambient noise, sound transmission loss, and infrasounds; on short-term reactions of bowhead and white whales to helicopters; and on other aspects of the movements, behavior, basic biology and disturbance responses of bowhead and white whales along their spring migration corridor.

Weather and ice conditions in the study area during the spring of 1991 were difficult. This limited the amount of playback work that could be done. Prevailing low cloud prevented us from obtaining systematic aerial observations of whale behavior during playbacks, and limited the aerial observation effort in the absence of playbacks. However, low-altitude flights could usually be done, allowing surveys and whale photography.

Because playback results from 1991 were limited by weather and ice, and follow-up work is planned for 1992, it was decided not to produce a comprehensive final report on the 1991 work, However, this preliminary report summarizes the main findings. A final report on the combined 1991 and 1992 results will produced after the planned 1992 field season.

The range of ambient noise levels was generally similar to that in previous years of this project. Levels of infrasonic ambient noise (10-20 Hz) were high.

The rate of transmission loss (TL) of underwater sounds during four TL experiments in 1991 was similar to that in 1989-90. Two of the 1991 TL tests were in a part of the study area where TL tests had not been done previously.

A 14-min recording of sounds from the industry icebreaker *Robert Lemeur*, recorded by Greeneridge Sciences in 1986, was used for the 1991 playbacks. The recorded icebreaker sounds varied over an 11 dB range (20-1000 Hz band) as the icebreaker moved forward and back. The frequency composition was variable with time, depending on icebreaker activity. These sounds were more variable than the *Karluk* drilling sounds used for playbacks in 1989-90, and included significant energy at 400-1500 Hz, unlike the *Karluk* sounds. During playbacks, variations in the sound levels received at range 0.73 km (and similar distances) closely tracked the variations in the projected levels.

Of 73 bowhead calls analyzed to determine if they were accompanied by infrasonic energy, there were 11 cases with infrasound. It is not certain that the infrasonic energy came from the calling whales. However, this question warrants further investigation using acoustic localization techniques to determine whether infrasounds come from the locations of the calling whales.

In 1991, generator noise was not detectable underwater at distances as close as 100 m from the ice camp. A new suspension system used in 1991 reduced the propagation of generator noise into the water.

Bowhead whales were seen consistently through the 1991 field season (28 April to 26 May). Mothers and calves were seen from 11 through 26 May.

Sizes of 83 bowheads were determined by aerial photogrammetry. Both subadults and adults were migrating through the study area early in the field season. In mid and late May most of the bowheads passing Barrow were adults. The 10 measurable calves were 3.7-5.1 m in length (mean 4.25 m).

Six bowheads have thus far been recognized as having been photographed during more than one 1991 photo session either by LGL or the National Marine Mammal Lab crew who were working in the same area. One whale remained in the area for at least 5 days. The unusual behavior of this whale cannot be attributed to the effects of our noise playbacks,

Eight bowheads photographed by LGL in 1991 were recognizable as whales that had been photographed in earlier years. One whale that had a calf in 1991 also had a calf in 1984.

Prolonged playbacks of icebreaker sound were done on six days in 1991, but bowheads were seen near the operating projectors on only one day. On 17 May 1991, 9 or 10 bowheads (7 or 8 groups) passed within -450 to 1360 m of the operating projector, These whales approached well within the area ensonified with icebreaker sounds. However, because low cloud prevented effective aerial observations, we do not know whether any other bowheads exhibited avoidance at distances greater than those where the 9 or 10 bowheads were seen.

Large numbers of migrating white whales were seen throughout the 1991 field season, Their migration route overlapped strongly with that of bowheads, but there was a tendency for a higher proportion of the white whales to occur farther offshore in the pack ice.

Five groups of white whales (8 individuals) approached within 80-957 m of the operating projectors during the icebreaker playback on 17 May 1991. These distances were well within the ensonified area. However, most of the projected sound energy was at low frequencies to which the white whale hearing system is not very sensitive. We do not know whether any other individuals exhibited avoidance at greater distances, given the impossibility of systematic aerial observations on that date.

Because of the weather and ice problems encountered in 1991, the results of the 1991 playback experiments with icebreaker sounds are not conclusive for either bowheads or white whales. Additional data are needed before a comprehensive evaluation will be possible.

Bowhead and white whale behavior in the presence of an operating Bell 212 helicopter was similar in 1991 to that noted in 1989-90. The 1989-91 results, mostly opportunistic, show that some but not all spring-migrating bowheads and white whales dive in response to a close approach by a turbine-powered helicopter. However, there is no evidence that single overflights, even at low altitudes, disrupt spring migration of either species in a biologically significant way. The question of helicopter effects on bowheads and white whales will be re-evaluated at the end of this project when additional data are expected to be available.

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