NORTHSTAR MARINE MAMMAL MONITORING PROGRAM, 1995:

Baseline Surveys and Retrospective Analyses of Marine Mammal and Ambient Noise Data from the Central Alaskan Beaufort Sea

from

LGL LIMITED
environmental research associates

and

Greeneridge Sciences Inc.
4512 Via Huerto, Santa Barbara, CA 93110

for

BP Exploration (Alaska) Inc.
900 East Benson Blvd., POB 196612, Anchorage, AK 99519-6612

LGL Report TA 2101-2

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EXECUTIVE SUMMARY

This report describes results of aerial surveys for marine mammals in parts of the central Alaskan Beaufort Sea near BPX(A)'s planned Northstar Development. Results from BPX(A)/LGL surveys in late August 1995 and from Minerals Management Service surveys in Sept-Oct 1995 are summarized, as are results from MMS and LGL late summer/autumn surveys in past years (1979-94). Data from the 147°-150°W area near Northstar are emphasized, including a new analysis approach based on sightings and individuals per 100 km of survey effort vs. distance offshore and date.

Bowhead whales were sighted in unusually large numbers in 1995, a light ice year. The migration corridor was significantly ($P<0.001$) closer to shore than in 1979-94. In 1995, bowheads were seen 15-55 km from shore, with the median being 30-35 km offshore (vs. 45-50 km in 1979-94). Abundance indices within the area 10-60 km offshore averaged much higher in 1995 than in 1979-94 (0.40 vs. 0.07 bowheads seen/100 km^2). The planned Northstar seismic exploration area is inshore of the main bowhead migration corridor. No bowheads were seen within the planned Northstar seismic area in 1995, and there were only four sightings there in 1979-94. The headings of "swimming" bowheads seen in 1995 were predominantly westward, as in past years (mean vector 270°T in 1995 and 276°T in 1979-94). Much migration occurred up to 25 September in 1995, but bad weather thereafter prevented determining numbers passing during late September and October 1995.

Within the Northstar region (147°-150°W), the bowhead migration corridor was not significantly different in light and moderate ice years, but it was significantly farther offshore in heavy than in light ice ($P<0.001$) or moderate ice ($P<0.05$) years. The median distance offshore, allowing for variable survey effort, was 30-40, 30-40 and 60-70 km offshore in light, moderate and heavy ice years, respectively. During light ice years, the corridor was farther offshore in four years with substantial offshore industrial activity in the Northstar region than in two years with little or no industrial activity ($P<0.05$). Whether this difference was attributable to the industrial activity or to other factors deserves further investigation.

Gray whales are very uncommon as far east as Northstar, and have not been seen in the region in recent years.

Beluga whales migrated on a predominantly offshore migration corridor in 1995, as in 1979-94. Most were seaward of the 100 m contour and >65 km offshore. The closest sighting to Northstar was ~60 km away in 1995, but a few belugas apparently travel through the Northstar region in some autumns.

Ringed seals are common and widely distributed in the region, but are not reliably detected during aerial surveys designed for whales. There were no incidental sightings closer

than ~10 km from Northstar during aerial surveys in 1995, but ringed seals are known to occur in the area in late summer and autumn. Similar statements apply to the **bearded seal**, but it was less commonly seen than the ringed seal despite being larger. **Spotted seals** were not identified during aerial surveys of the Northstar region in 1995, but may occur in the area in small numbers. **Walruses** are infrequent this far to the east, and have not been seen during aerial surveys of the Northstar region since 1985.

Polar bear sightings are widely distributed in the region in late summer/autumn, and bears can be expected to occur within the planned Northstar seismic area at times. However, none were seen there during the 1979-95 aerial surveys.

Underwater ambient noise in and near the planned Northstar seismic area during late summer and autumn is comparable to underwater ambient noise in the world at large, extending over similar ranges of levels. The median levels at frequencies from 500 to 800 Hz correspond to Wenz' levels for sea state one to two, which are moderately low. However, during periods of high ambient noise, the levels in the Northstar region correspond to Wenz' noise for sea states exceeding six. During periods of low ambient noise, the levels correspond to Wenz' noise for sea state near zero. In the absence of human activities, wind speed is the primary influence on ambient noise level, but there is also a tendency for decreasing ambient noise levels with increasing ice cover.

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Janet Clarke and Sue Moore of SAIC Maritime Services, San Diego, assisted by merging the 1992-95 and 1979-91 MMS aerial survey datasets, editing the resulting dataset to make it easier to use, and answering our questions about the structure and content of this database.

Aerial surveys conducted by LGL in 1982, 1984 and 1985, whose data are used in this report, were funded by Shell Oil Co. and Shell Western Exploration & Production Inc.

Bob Blaylock of Greeneridge analyzed the recordings of ambient noise. Denis Thomson, Kathleen Hester and Bev Griffen of LGL assisted with graphics and report production.

1. INTRODUCTION

BP Exploration (Alaska) Inc., hereafter BPX(A), plans to conduct seismic surveys in the Northstar area northwest of Prudhoe Bay during the summer and autumn of 1996, in support of development plans for the Northstar Unit. A marine mammal monitoring program will be required during the seismic work in 1996. This monitoring is expected to be done under provisions of Incidental Harassment Authorization regulations recently developed by the National Marine Fisheries Service. In addition, BPX(A) wants to begin assembling other marine mammal and ancillary acoustic data that may be needed as part of the environmental approvals process for the Northstar development project.

During August 1995, BPX(A) awarded a contract to LGL Ltd., with subcontractors Greeneridge Sciences Inc. and SAIC Maritime Services Inc., to conduct preliminary marine mammal and acoustic work in 1995. The main focus of the work was on the bowhead whale, given its endangered status and its importance to subsistence hunters. However, all species of marine mammals occurring near the Northstar Unit were within the scope of the project.

The autumn migration corridor of bowhead whales is almost entirely north of the planned area of seismic exploration at Northstar. However, underwater noise from seismic exploration will reach the migration corridor, and it is possible that noise from some other development activities might do so as well. For this and other reasons, aerial surveys must extend well north of the area of seismic exploration, and acoustic studies must determine propagation loss and ambient noise north of as well as within the Northstar area.

For 1995, the work included the following major components:

- conduct aerial surveys in and near the Northstar area on 23-30 August, to supplement the Minerals Management Service (MMS) surveys scheduled to extend from 31 August to late October;
- exchange aerial survey data with MMS, as agreed between BPX(A) and MMS;
- evaluate marine mammal use of the Northstar area in late summer and autumn by using the original MMS sighting and survey effort database for 1979-95, supplemented by data from this and other non-MMS survey projects;
- collect ambient noise data from the Northstar area by dropping and monitoring sonobuoys during the BPX(A)-funded surveys on 23-30 August 1995; and
- reanalyze and compile relevant previously-recorded ambient noise data from nearby sites; use the results (a) to document ambient noise as a function of environmental conditions, and (b) to plan the 1996 data collection effort.

As regards bowhead whales, BPX(A) requested that the results of 1995 and previous aerial surveys be used to evaluate the following three null hypotheses:

H_{01}: There is no difference in bowhead whale distribution in the Northstar area in 1995 compared to previous years.

H_{02}: There is no difference in bowhead whale movement patterns relative to the Northstar area in 1995 compared to previous years.

H_{03}: There is no difference in bowhead whale relative abundance and estimated numbers in the vicinity of the Northstar area in 1995 compared to previous years.

In conducting this project, LGL was responsible for the work on marine mammals, including the August 1995 marine mammal surveys, the analyses, and the reporting (section 2 of this report). SAIC assisted in accessing the MMS aerial survey database, which SAIC personnel helped design and collect. Greeneridge Sciences Inc. was responsible for the ambient noise work (section 3 of this report).

2. MARINE MAMMAL DISTRIBUTION, NUMBERS AND MOVEMENTS[1]

2.1 Methods for Aerial Surveys of Marine Mammals

Aerial Surveys, 1995

LGL Aerial Surveys, 23-30 Aug 1995.—The study area for LGL's aerial surveys during late August extended from about 20 km west of the western edge of the Northstar seismic area east to ~50 km east of the eastern edge of that area, and from the barrier islands north to 71°00'N latitude. Within this study area two series of north-south transects were flown:

1. The "extensive" survey grid consisted of 12 transect lines (total of 689 km) spaced 8 km apart extending from 149°33'W east to 147°10'W. These lines extended roughly from the barrier islands north to 71°00' except that the eastern-most lines (lines 7-11) did not extend south of the 20 m contour seaward of Cross Island and the McClure Islands, where fall whaling activities take place (Fig. 2.1).

2. The smaller "intensive" survey grid consisted of 8 transects spaced 8 km apart, midway between the extensive grid's lines 0-8. These transects, totalling 221 km in length, extended south from 70°45'N roughly to the barrier islands, except that the eastern-most two lines remained north of Cross Island (Fig. 2.1).

When weather conditions permitted both survey grids to be surveyed, the extensive grid was flown first. Transects in each grid were flown in order from west to east, progressing eastward contrary to the normal direction of travel of autumn-migrating bowheads.

The surveys were flown in a Commander 680FL operated by Commander Northwest of Anchorage, Alaska. Surveys were conducted at an altitude of 1000 ft (305 m) and a ground-speed of 120 knots (222 km/h). This altitude was chosen because it is the minimum altitude at which the National Marine Fisheries Service considers aerial surveys to be permissible without risking significant aircraft disturbance and thus "take by harassment".

The two primary observers occupied the front right (co-pilot's) seat and a seat on the left side of the aircraft, immediately behind the pilot. A part-time third observer, who also operated a data logger and sonobuoy receiving equipment, was positioned behind the co-pilot's seat. The third observer surveyed when not occupied with other duties. All observers sat at bubble windows that allowed greater downward visibility than standard windows. The aircraft was equipped with a GPS navigation system for accurate navigation offshore.

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[1] By Gary W. Miller, Robert E. Elliott and W. John Richardson, LGL Ltd.

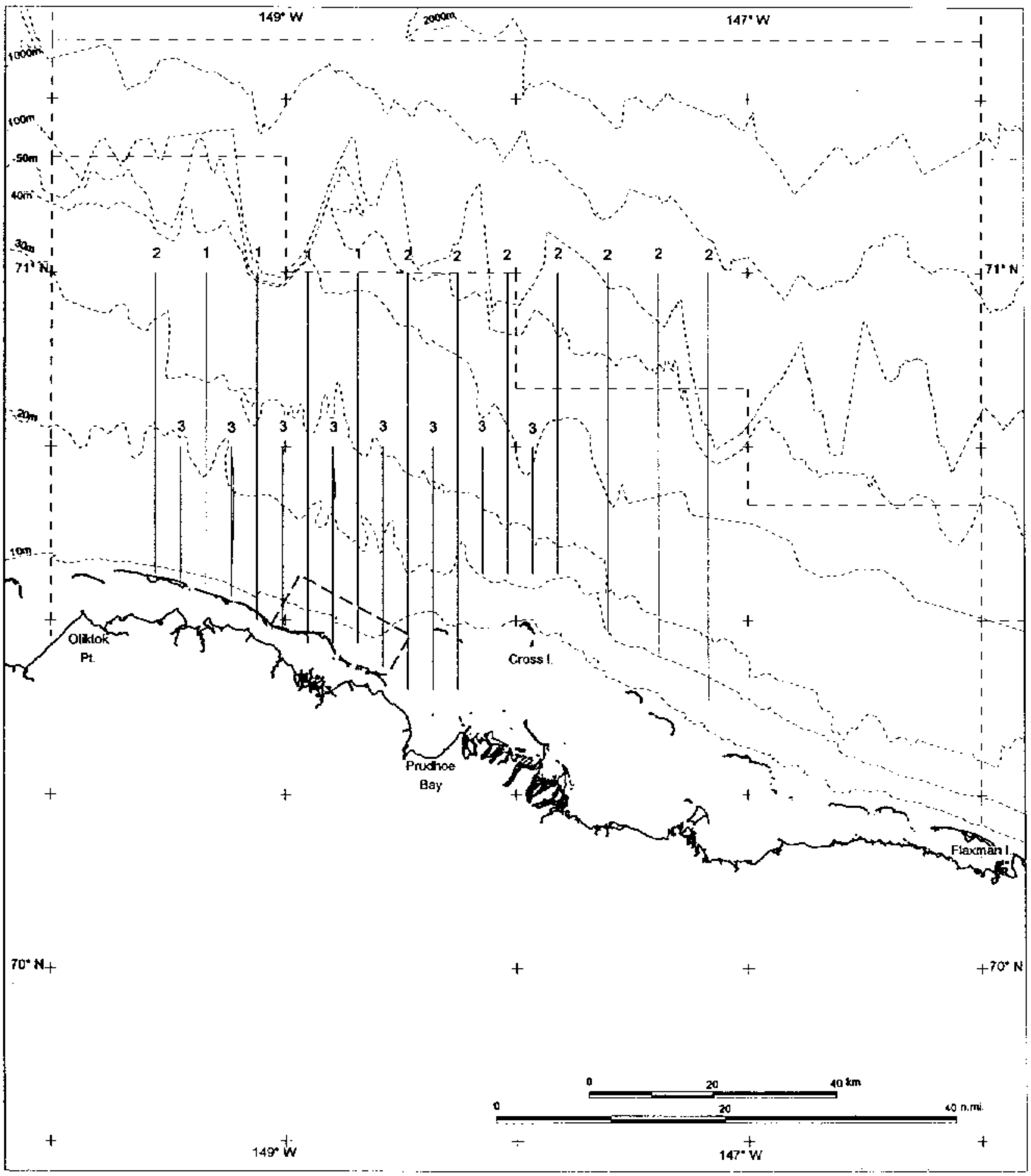


FIGURE 2.1. LGL's 1995 extensive (north to 71°N) and intensive (north to 70°45'N) aerial survey grids in relation to the Northstar seismic area (heavy dashed outline) and MMS survey blocks 1 and 2 (faint dashed lines; see also Fig. 2.2). Number at the N end of each transect indicates the number of times that transect was surveyed during late August 1995.

For each sighting the observer dictated the species, number, size/age/sex class when determinable, activity, heading, swimming speed category, sighting cue, ice conditions, and inclinometer reading. The inclinometer reading was taken when the animal's location was 90° to the side of the aircraft track. In conjunction with records of aircraft altitude, the inclinometer reading allowed calculation of lateral distance from the transect line.

Sighting data were entered into a GPS data logger, the BPX(A) GeoLink system, by the third observer, and simultaneously recorded on audiotape for backup and validation. In addition, the two primary observers recorded the position, time, visibility, sea state, ice cover and sun glare conditions at the start and end of each transect, and whenever these conditions changed along the transect. The last five variables were also recorded on audiotape at 2-min intervals. The data logger automatically recorded time and aircraft position (latitude and longitude) for sightings and transect waypoints, and at frequent intervals along the transects.

MMS Aerial Surveys, 31 Aug-20 Oct 1995.—The Minerals Management Service conducted aerial surveys of marine mammals in the Beaufort Sea from 31 August through mid October 1995. Their methods were consistent with those used by MMS in previous years (e.g. Treacy 1995), as summarized below. However, MMS undertook to obtain slightly more survey coverage than normal in MMS survey block 1 (see Fig. 2.2) in order to provide additional baseline data relevant to the planned Northstar development. MMS surveyed transects in blocks 1 and 2 on 11 days, beginning on 1 September and ending on 20 October. MMS transects flown in the Northstar study area during 1995 are mapped in Figure 2.3.

Aerial Surveys, 1979-94

MMS Aerial Surveys, 1979-94.—During the years 1979-94, late summer and autumn aerial surveys sponsored or conducted by MMS were flown over broad portions of the Alaskan Beaufort Sea (Fig. 2.2). The surveys were flown in a Grumman Goose and/or a deHavilland Twin Otter, in recent years flying at an altitude of 1500 ft (458 m). Some earlier surveys were conducted at lower altitudes. The three observers used inclinometers to measure the angle of inclination to each cetacean sighting when the initial sighting location was abeam of the aircraft. The observers and pilots were linked by a common communication system, and conversations and comments could be recorded on audio tape.

The aircraft were equipped with a navigation system (OnTrack III, Global Navigation System, or Global Positioning System) and radar altimeters. Starting in 1982, an on-board computer that interfaced with the navigation system was used to automatically store flight data (time and position) for later analysis. In 1983 and following years the on-board computer was also linked to the altimeter (radar altimeter or Global Positioning System) for automatic input of altitudes. Additional data including marine mammal sightings, environmental conditions (e.g. weather, sea state, ice cover), and start and end points of transects and other survey segments were manually entered into the computer. For more details

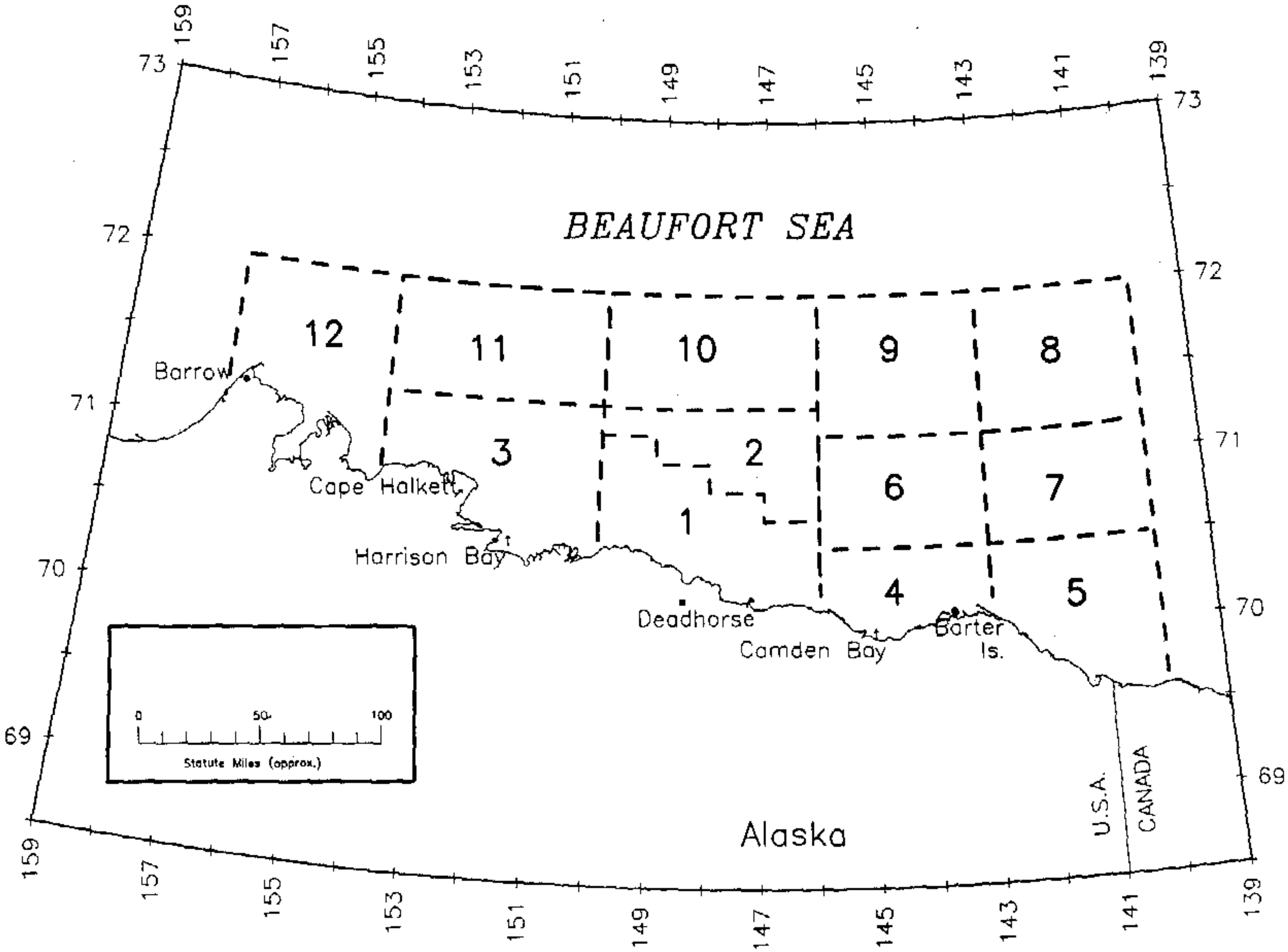


FIGURE 2.2. Alaskan Beaufort Sea, showing MMS survey blocks 1-12 (from Treacy 1995).

concerning the survey aircraft and other equipment used during the MMS surveys, see the reports summarizing each year's data (e.g. Ljungblad et al. 1987; Treacy 1995).

Daily flight patterns were based on sets of unique transect grids produced for each of 12 survey blocks (Fig. 2.2). Transects were derived by dividing each survey block into sections 30 minutes of longitude wide. One of the minute marks along the northern edge of each 30' section was selected at random to designate one end of a transect. The other endpoint of the transect was determined using a separate randomly generated number along the southern edge of the same section. A straight line, representing one transect, was drawn between the two points. The same procedure was followed for all 30' sections of the survey block. Transects were then connected alternately at their northernmost or southernmost ends to produce one continuous flight grid within each survey block. The selection of the survey blocks to be flown on a given day was non-random, based on such factors as observed weather conditions over the study area and coverage attained during recent days.

Non-transect flight segments were identified as "Connect" segments and "Search" segments. "Connect" segments were the east-west (or similar) flights from the end of one transect to the start of another. "Search" segments were flights to or from the survey block where the transects were flown, or non-random flights to find whales.

MMS transects flown in survey blocks 1 and 2 during the 1995 and 1979-94 periods are mapped in Figures 2.3 and 2.4 (excluding "Search" and "Connect"). The transect selection procedure used by MMS resulted in N-S "wheatsheaf"-shaped bands of heavy survey coverage alternating with N-S bands of relatively sparse coverage. For example, within the planned Northstar seismic area, there was relatively heavy transect survey coverage in central portions of the area, but sparse coverage in the eastern and SW corners.

In this report we consider only the MMS surveys in the longitude range 143°-150°W, i.e. survey blocks 1, 2 and 10 (146°-150°W) and 4, 6 and 9 (143°-146°W). Most attention is given to blocks 1 and 2, encompassing the area from 146° to 150°W, and from the shore north to 71°20'N. This area includes waters from 35 km west to 90 km E of Northstar, and out to about 100 km offshore. All LGL surveys considered in this report were within these two MMS survey blocks.

LGL Aerial Surveys, 1982, 1984 and 1985.—Also included in the dataset used for retrospective analyses were the results of LGL's industry-funded bowhead surveys conducted in MMS survey blocks 1 and 2 during 1982, 1984 and 1985 (Hickie and Davis 1983; Davis et al. 1985; Johnson et al. 1986). Those studies included repeated aerial survey coverage in and near the Northstar region, including (in 1984-85) some of the same transects that were surveyed in late August 1995. The transect grids flown during these studies ranged in length from 480 km (1982) to 655 km (1985) (Table 2.1). In general, the same survey grid was flown each day when weather permitted. The survey grids flown during these studies are mapped in Figures 2.5 and 2.6.

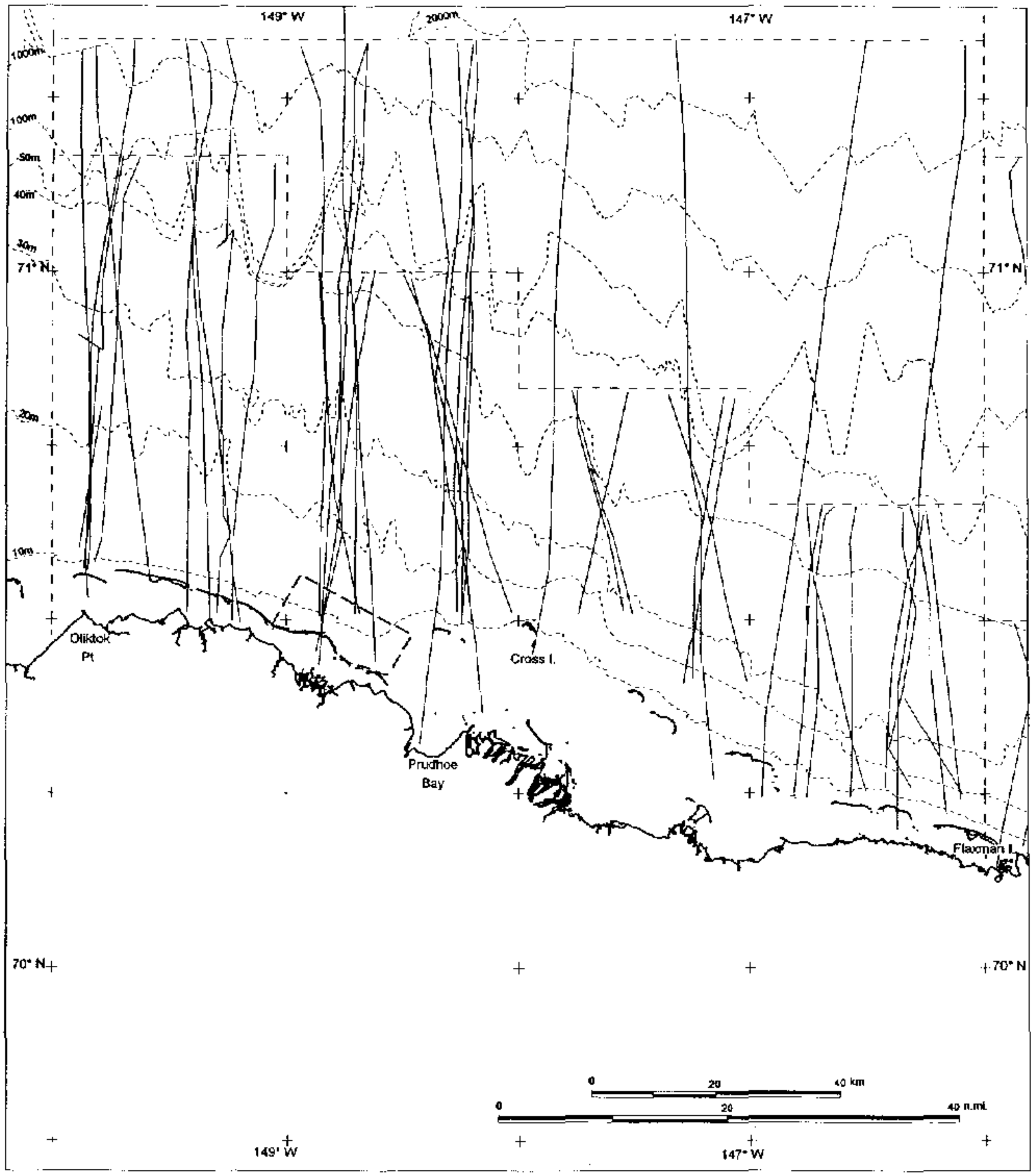


FIGURE 2.3. Aerial survey transects flown by MMS during 1995 in the Northstar region (MMS survey blocks 1 and 2). Northstar seismic area is outlined with heavy dashes. Excludes "Connect" and "Search" flights.

FIGURE 2.4. Aerial survey transects flown by MMS during 1979-94 in the Northstar area (MMS survey blocks 1 and 2). Excludes "Connect" and "Search" flights.

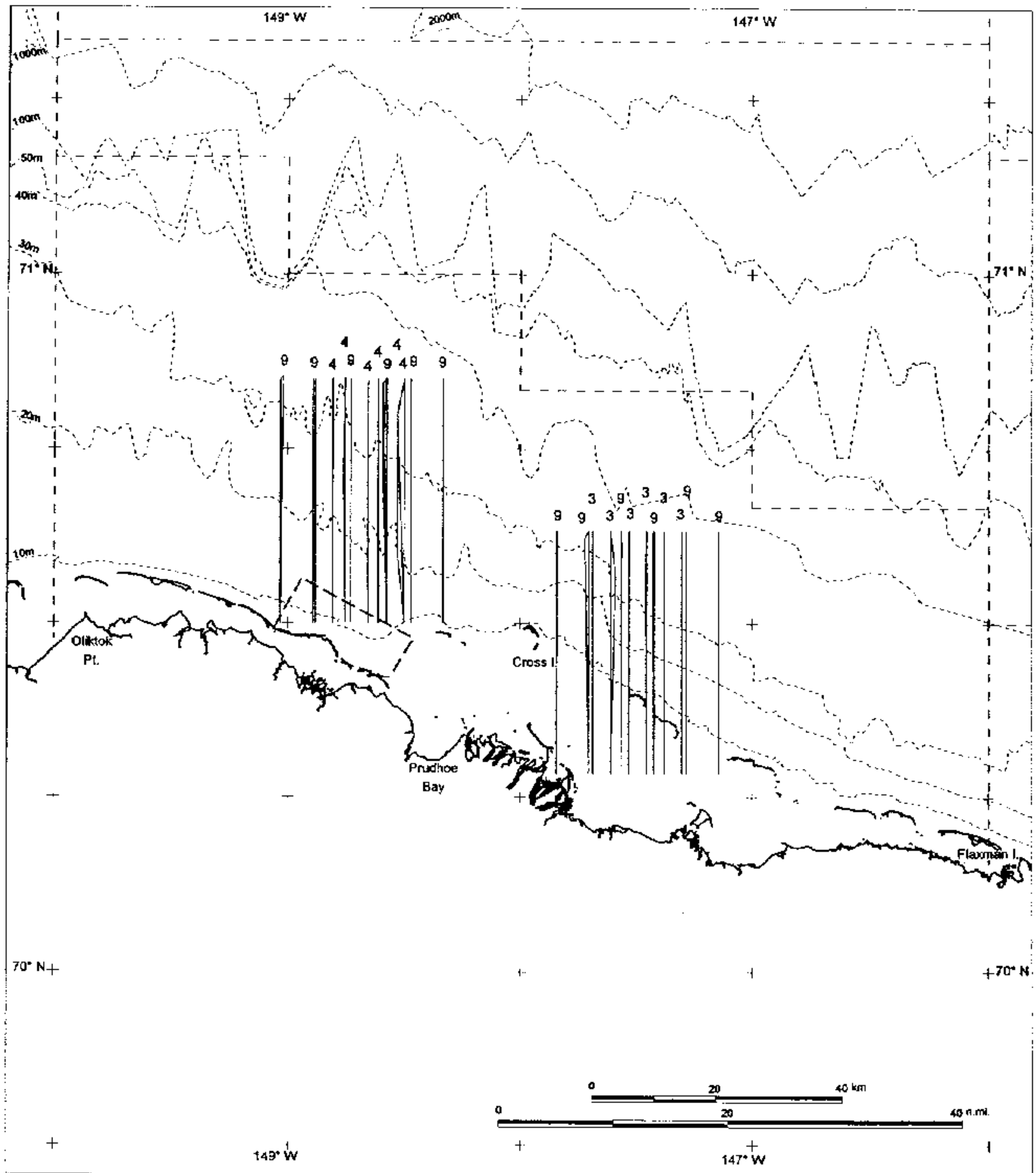


FIGURE 2.5. LGL's 1982 aerial survey transects in relation to the Northstar seismic area (heavy dashed outline) and MMS survey blocks 1 and 2 (faint dashed lines). Number at the N end of each transect indicates the number of times that transect was surveyed during autumn 1982.

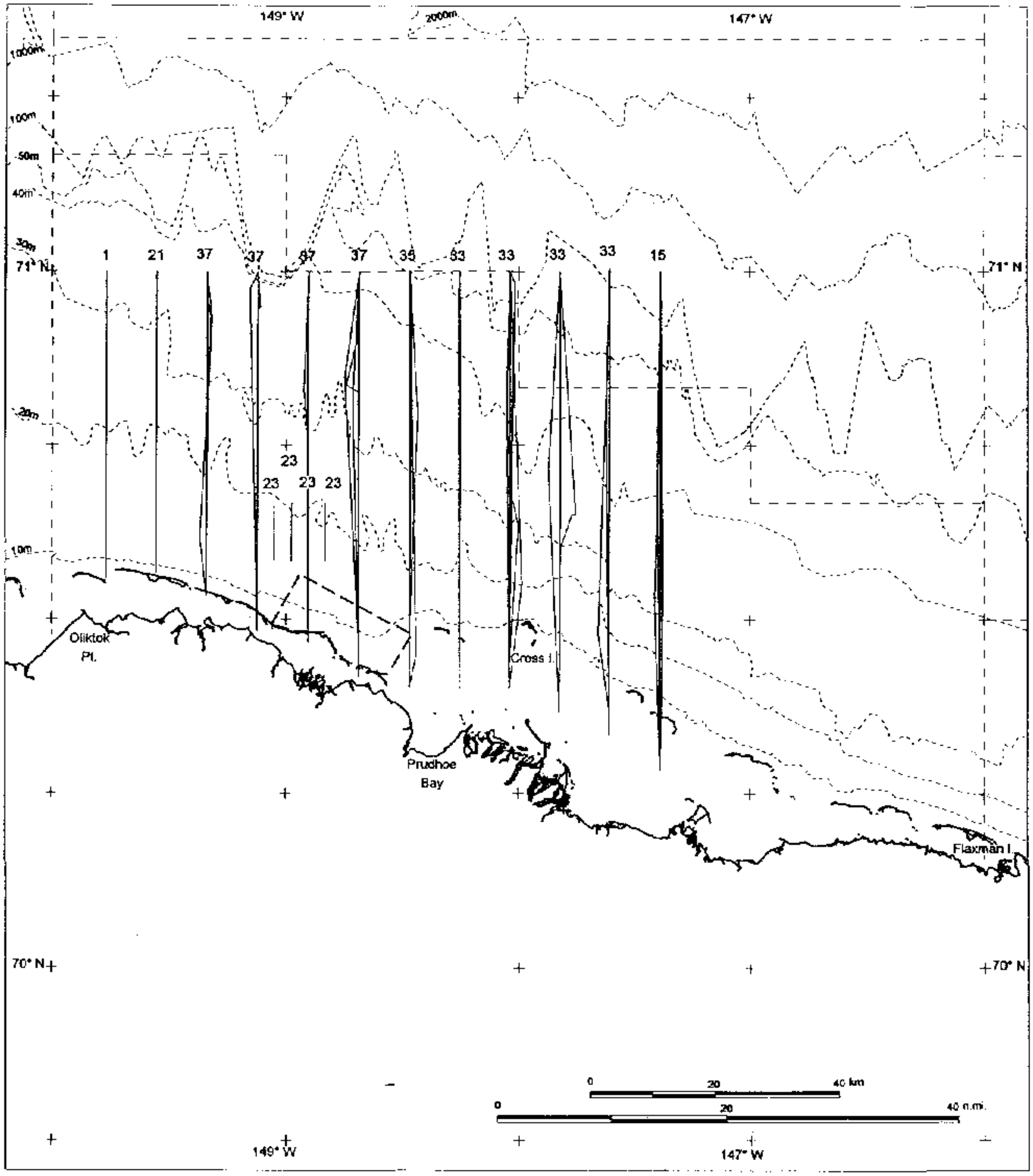


FIGURE 2.6. LGL's 1984-85 aerial survey transects in relation to the Northstar seismic area (heavy dashed outline) and MMS survey blocks 1 and 2 (faint dashed lines). Number at the N end of each transect indicates the number of times that transect was surveyed during the autumns of 1984-85.

TABLE 2.1. Dates of LGL's surveys in the Northstar region each year, and total lengths of daily survey patterns.

Year	Survey Dates First	Survey Dates Last	# Days With Surveys	km of Surveys/ Day*
1982	30 Sep	13 Oct	13	480
1984	16 Sep	14 Oct	16	644
1985	13 Sep	20 Oct	26	655
1995	23 Aug	29 Aug	3	910

* On days when grid(s) were completed.

The survey methods varied only slightly from year to year. Most surveys were conducted from a deHavilland Twin Otter (Series 200 or 300) equipped with a radar altimeter. The on-board VLF/Omega navigation systems were the GNS 500A (1982 and 1985) and the Collins LRN-70 (1984). The surveys were flown at an altitude of 500 ft (152 m). Standard survey speeds ranged from 200 to 222 km per hour during the three years. Inclinometer data from 1984 and 1985 are available to determine the distances at which marine mammals were observed from the centerline of the transect. In 1982 marine mammal sightings were categorized as "on-" or "off-" transect based on sighting angles determined with a clinometer. On-transect sightings were those sightings seen within the 700 m strips from 100 to 800 m on either side of the aircraft. For 1982 data, the on- or off-transect designations are known but the clinometer angles are not available for retrospective analyses. Ringed seal data for 1982 are not available for most survey dates and are not included in this report. However, bearded seal, polar bear, and bowhead and beluga whale data (all three years) and ringed seal data for 1984-85 are included in the retrospective dataset.

The LGL surveys have contributed a significant proportion of the total survey coverage within the region near Northstar even though the LGL surveys were restricted to only 3 years in the 1980s plus 1 week in 1995. Figure 2.8, later, summarizes the available survey coverage. The LGL surveys involved near-daily coverage of the Northstar region, whereas the MMS surveys sampled a much wider area with less frequent coverage near Northstar. Also, the LGL transects within this area were spaced closer together than is normal during the wide-ranging MMS surveys.

Analyses of Aerial Survey Data

Mapping.—This report includes many maps showing the sighting locations of the common marine mammal species during 1995 and during 1979-94, variously including the MMS data, the LGL data, or both. Most maps show sightings in the 146°-150°W region, from the shore north to about 71°20'N (MMS survey blocks 1 and 2). A few maps include the broader central Alaskan Beaufort Sea region, from 143° to 150°, and extend farther offshore (MMS survey blocks 1, 2, 10, 4, 6 and 9).

Each sighting symbol on these maps shows a sighting of one or more individuals. MMS and LGL sightings are shown by circular and triangular symbols, respectively. Sightings along formal transects (regardless of distance from trackline) are shown as filled symbols. Sightings during "Connect" or "Search" legs are shown as open symbols, and are not considered during most analyses.

There were a few sightings along transects when sighting conditions were poor, i.e. sea state 5 or more, or lateral visibility less than 1 km. Even when seen along formal transects, such sightings have been treated as "incidental" sightings and plotted with open symbols. These few sightings, and the associated survey effort under poor conditions, have been excluded from analyses of sightings per unit effort. Also, a few surveys coded as "Transect" in the MMS dataset were actually "Connect" or "Search" flights. These were recoded accordingly before use in the present maps and analyses. For both reasons, the total number of sightings during "Transect" surveys, and the total amount of "Transect" coverage, is slightly lower with our procedures than would be obtained by direct analysis of the MMS database.

The maps (and analyses) exclude sightings coded as "duplicates" or "repeats" of previous sightings, i.e. same animal(s) seen by more than one observer or on more than one occasion. Sightings of "whale tracks" in thin ice are not included on the maps (or in analyses) unless the responsible bowheads or belugas were seen. Polar bear kill locations (with no polar bear seen) are treated separately from actual polar bear sightings.

On maps of whale sightings, the headings of the animals, i.e. the directions in which the animals were oriented, are shown when these were recorded. Headings in the MMS database are coded relative to Magnetic North; these have been converted to True North. Headings are not shown for pinniped and polar bear sightings.

The area where Northstar seismic surveys are planned to occur in 1996 is outlined on each of the maps. The area shown is the primary seismic survey area, excluding various lower-priority contingency areas. The MMS survey blocks (as shown on Fig. 2.2) are also outlined on our maps. The bathymetric contours shown on the maps are newly-developed during this project, based on all available depth soundings. Sounding data, obtained on CD-ROMs from NOAA, included *Hydrographic Survey Data, Vol. 1, vers. 3.1*, and *Marine Geophysical Data / Bathymetry, Magnetics, Gravity, vers. 3.2*. Contours were developed using ArcInfo. In some regions, the locations of the new depth contours differ appreciably from those that various authors have used on their maps.

Distribution.—The maps described above provide much of the distributional information. However, they are difficult to interpret because survey effort varies greatly with distance from shore. Also, relative amounts of survey effort at different distances from shore have varied considerably from year to year. For bowhead and beluga whales, we have examined distribution relative to distance from shore, taking account of the differential survey effort vs. distance from shore. These analyses were restricted to sightings and survey effort within the 147°W to 150°W region, which is the approximate region spanned by the LGL aerial surveys conducted in 1984, 1985 and 1995, and planned for 1996. This region extends from about 50 km east of the planned Northstar seismic area to about 20 km west of it.

We divided that region into a series of strips, each 5 km in width, oriented parallel to the approximate orientation of the coast (113°-293° True; Fig. 2.7). The "0 km from shore" reference point is near the southern edge of the planned Northstar seismic survey area, which extends from 3 km inshore to 7½ km offshore of the "0 km" line (Fig. 2.7, 2.8A). Waters inshore of the "0 km" line are shallow nearshore waters, largely inside lagoons. Given the irregularities in the coastline, and the presence of islands along some but not all parts of the coast, we believe that it is more useful to categorize distance offshore relative to a straight line approximating the orientation of the coast, the depth contours, and the main whale migration corridor than to measure the distance from each sighting to the closest land.

We used MapInfo, supplemented by specially-written MapBASIC computer code, to determine the number of kilometers of transect survey coverage within each 5-km distance-from-"shore" strip during 1995 and 1979-94 (Fig. 2.8), and various other combinations of years. These analyses excluded non-systematic "Connect" and "Search" survey effort and sightings, and survey effort and sightings under poor conditions (sea state 5+ or visibility <1 km). Sightings or individuals per unit effort were determined for each distance from shore by dividing the number of sightings (or individuals) seen in each 5-km strip by the number of kilometers of transect coverage. In some cases, sightings and effort data in two or more adjacent 5-km strips were combined. For bowheads, this was especially necessary 90+ km offshore where bowheads are scarce and effort was limited.

The numbers of bowhead sightings and individuals at different distances from shore are summarized and compared for various combinations of years using Kolmogorov-Smirnov tests (Siegel 1956; Conover 1971), hereafter called K-S tests. The number of sightings is used as the sample size for both the sighting and the individual analyses, on the rationale that the individuals within one group should not be treated as independent. However, these simple comparisons do not correct for variable effort at different distances offshore. To do that, we applied the K-S test to the sightings-per-unit-effort data rather than raw sightings or individuals. Data from 5-km strips far offshore where there was little survey coverage were combined with adjacent survey strips to minimize problems involving anomalously high sightings-per-unit-effort figures when 1 or 2 sightings occurred in regions with little survey effort. Sightings-per-100-km data for each distance from shore category were converted to a cumulative distribution, which was then converted to a "0 to 1" cumulative distribution in the usual manner for K-S tests. We used the number of sightings as the effective sample size.

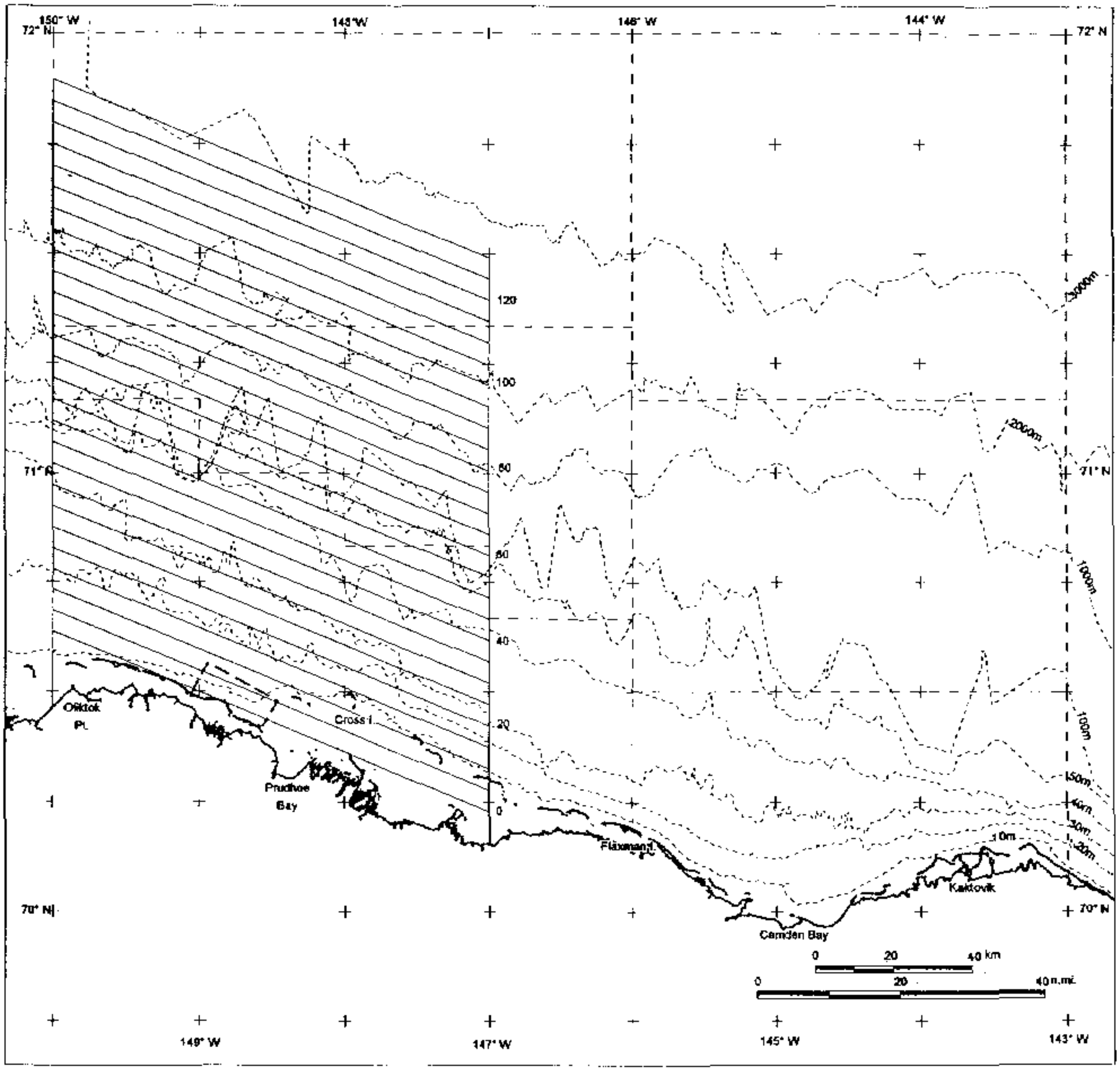


FIGURE 2.7. Categorization of the Northstar region (147°-150°W) by 5-km distance-from-shore intervals out to 130 km offshore, as used to tabulate mammal sightings and survey effort by distance from shore. The most inshore line is defined as the "0 km offshore" line; sightings and survey effort south of that line were also tabulated. For some analyses, data were combined into 10-km intervals.

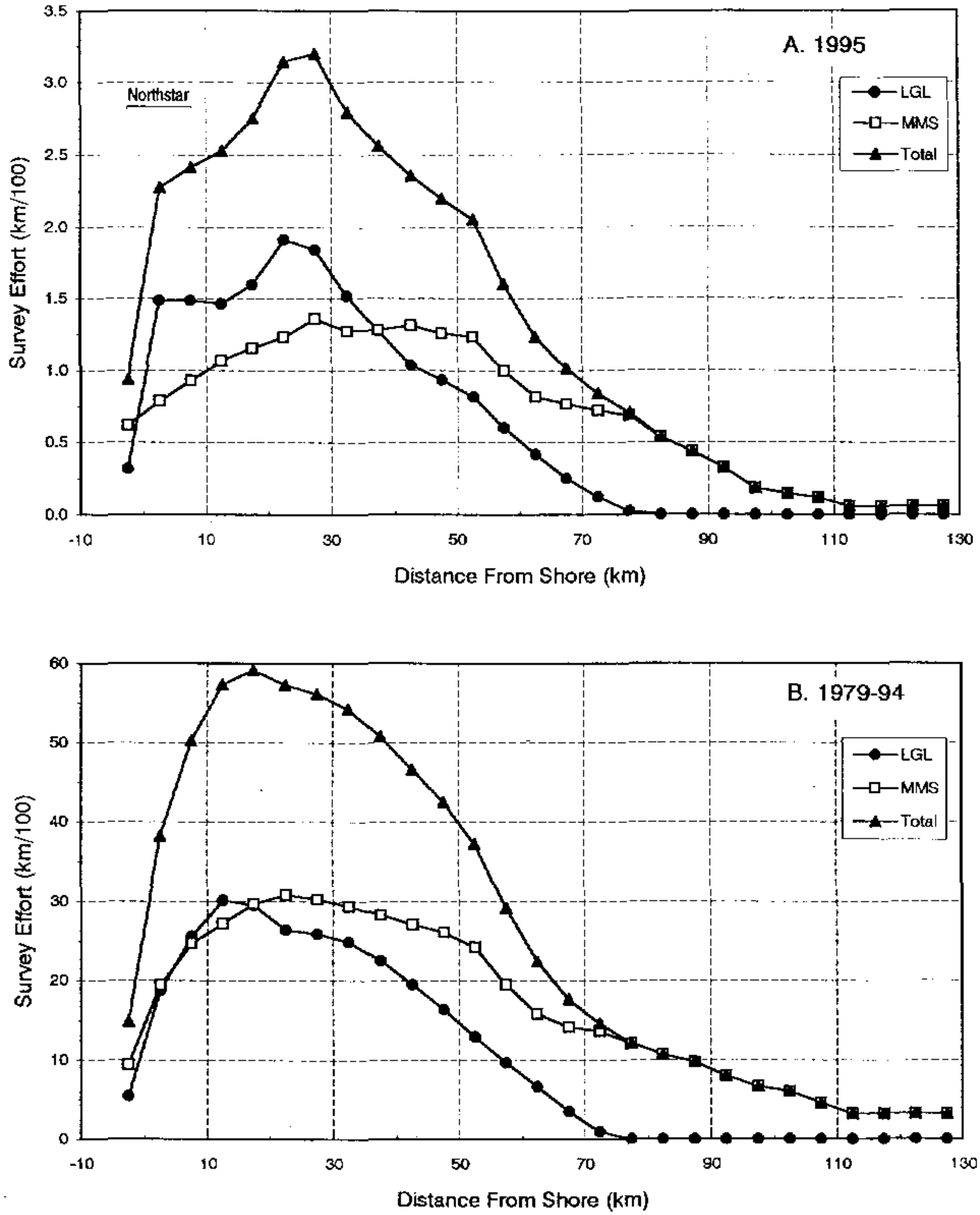


FIGURE 2.8. Kilometers of aerial survey effort at various distances from shore within the Northstar region (147°-150°W) during late summer and autumn, including only "Transect" surveys with sea state <5 and visibility >1 km. (A) 1995. (B) 1979-94. Survey effort is shown in hundreds of kilometers, for consistency with mammal sighting rates expressed as numbers of sightings or individuals per 100 km of surveying.

Seasonal Occurrence.—For common species, sightings during survey flights in the 147°-150°W region were compiled by 5-day or 15-day periods, as appropriate. These analyses were restricted to "Transect" sightings in order to allow meaningful calculations of sightings and individuals per unit effort during different parts of the season. Thus, "zero" sightings or individuals in a particular date range means no sightings during "Transect" flights, not necessarily that there were no sightings on those dates. Results from 31 August were included with those from 26-30 August.

Abundance Indices.—Abundance indices were determined for bowhead whales in the Northstar region (147°-150°W) as a function of distance from shore. These analyses were similar to those described above for "Distribution", but in this case only the sightings at lateral distances ≤1.5 km to either side of the aircraft track were considered (i.e. total strip width of 3 km). The numbers of individuals seen were converted to individuals seen per 100 km^2. For this preliminary analysis, no attempt was made to adjust for animals at the surface but missed, or for animals below the surface.

Year-to-Year Comparisons.—Each autumn from 1979 to date has been categorized as a light, moderate or heavy ice year in the various reports describing the MMS aerial surveys. The years have been categorized as follows:

- Light ice years—1979, 1981, 1982, 1986, 1987, 1989, 1990, 1993, 1994 and 1995;
- Moderate ice years—1984, 1985 and 1992;
- Heavy ice years—1980, 1983, 1988 and 1991.

The MMS aerial survey reports summarize bowhead distribution in the three groups of years based on water depths at the sighting locations of bowheads seen along transects.

In this report, we summarize the bowhead distribution vs. distance from shore during light, moderate and heavy ice years considering the 147°-150°W zone. For this purpose, we compile sightings and survey effort by various categories of distance from shore during those groups of years. This allows us to take account of uneven survey effort at different distances from shore and during different years. Also, bowhead sightings, effort and sightings per unit effort are compiled for different 5-day periods during light, moderate and heavy ice years.

A similar approach is taken in comparing the distances from shore and seasonal timing of migrating bowheads in years with much and little offshore industrial activity in the central Alaskan Beaufort Sea. To reduce the confounding effects of variable ice cover, this analysis was restricted to autumns (like 1995) when ice conditions were classified as light.

- During 1994 and 1995, there was little or no industrial activity in the Northstar region or in waters east to Camden Bay, and ice cover was light.
- During 1982, 1987, 1989 and 1990, there was light ice but also considerable marine seismic exploration and/or artificial island activity in the Northstar region, often combined with drilling operations off Camden Bay.

The years 1979, 1981, 1986 and 1993, also with light ice, have been excluded because of uncertainties about the amount of industrial activity near Northstar during those years.

2.2 Bowhead Whale

Introduction

The Western Arctic stock of bowhead whales is currently estimated at about 8000 animals, with the lower and upper 95% confidence intervals estimated at 6900 and 9200 animals (Zeh et al. 1995; Small and DeMaster 1995). This estimate is lower than the pre-exploitation 95% confidence intervals of 10,400 and 23,000 bowhead whales (Woodby and Botkin 1993). The current population is believed to be increasing at a rate of 2.3% per annum despite annual subsistence harvests of 14-74 bowheads from 1973 to 1993 (Suydam et al. 1995). The large increases in population estimates that occurred from the late 1970s to today are primarily attributable to better censusing techniques rather than a rapidly increasing population (MMS 1996). The Western Arctic stock of bowhead whales is currently listed as Endangered under the Endangered Species Act, and thus is classified as a strategic stock by NMFS (Small and DeMaster 1995).

Bowheads winter in the central and western Bering Sea and most of them summer in the Canadian Beaufort Sea (Moore and Reeves 1993). Spring migration through the Western Beaufort Sea occurs through offshore ice leads, generally from mid-April to mid-June (Braham et al. 1984; Moore and Reeves 1993). East of Point Barrow, the lead systems divide into numerous branches that vary in location and extent yearly, but are typically located well offshore. The route follows a corridor centered at 71°30'N latitude, and broadly occurring between latitudes 71°20'N and 71°45'N.

Bowheads first arrive in coastal areas of the Canadian Beaufort and Amundsen Gulf in late May and June. After feeding in coastal and offshore portions of these waters during the summer months, bowheads begin migrating westward in late August to early October. The fall migration route extends from the eastern Beaufort Sea through the central Beaufort Sea along the continental shelf, across the Chukchi Sea and along the coast of the Chukchi Peninsula—a route that brings bowheads much closer to the Alaskan Beaufort coast in fall than in spring (Moore and Reeves 1993). Fall migration into Alaskan waters is primarily during September and October, and most bowheads pass Alaska's north coast from mid-September to early October. Autumn sea ice conditions in the Alaskan Beaufort Sea can vary dramatically between years, from open water to over 90% ice coverage. The timing and distribution of fall-migrating bowheads may be influenced by ice cover and opportunities for feeding.

Distribution and Migration Route

1995.—No bowheads were sighted in the Northstar seismic area during aerial surveys conducted by LGL and MMS in 1995 (Fig. 2.9). The closest sighting was about 10 km N of Northstar. Most bowhead sightings in 1995 were in a 40 km wide band extending roughly SE→NW between the 20 and 50 m depth contours. The southern edge of this band was about 10 km N of the Northstar seismic area. There were a small number of sightings N and S of this band, including one sighting within a few kilometers of a barrier island about 30 km W of the Northstar seismic area (Fig. 2.9). The latter sighting was in water about 10 m deep.

The distribution of bowhead sightings in the central Alaskan Beaufort Sea as a whole in 1995 was also concentrated in a fairly narrow zone of nearshore waters (Fig. 2.10). Most sightings within the 143°-150°W region were within the confines of nearshore MMS survey blocks 1 and 4. Only 3 sightings were beyond the 100 m depth contour.

The 1995 LGL and MMS bowhead sightings recorded during late summer and autumn "Transect" aerial surveys are plotted as a function of distance from shore for the Northstar region (147°-150°W) in Figure 2.11. Within that range of longitudes, all 31 sightings of bowheads during "Transect" surveys in 1995 were in the 5-km strips ranging between 15 and 55 km from shore, with the highest number of sightings (8) in the 30-35 km from shore category (Fig. 2.11A). Of the 48 individual bowheads represented in these 1995 data, 12 were seen in the 30-35 km from shore category, and 12 more in the 25-30 km category (Fig. 2.11C). When the numbers of sightings per 100 km of survey effort are considered, relatively high (>1 sighting/100 km) sighting rates were recorded in the 5-km strips ranging from 20 to 45 km from shore, with a peak of about 2.9 sightings/100 km and 4.3 individuals/100 km at 30-35 km from shore (Fig. 2.11B,D).

1979-94.—During the 1979-94 period there were four bowhead sightings in the Northstar seismic area during aerial surveys conducted by MMS (Fig. 2.12) and no such sightings during surveys by LGL (Fig 2.13). An additional four sightings occurred within about 10 km of the boundary of the Northstar seismic area (Fig. 2.14—combined MMS and LGL sightings). Bowhead sightings in the Northstar region were distributed in a broad SE→NW band. Although sightings occurred in a variety of water depths ranging from very shallow (<10 m) coastal waters to deep (>1000 m) continental slope waters, bowhead sightings were concentrated in water depths ranging from 10 to 100 m (Fig. 2.14).

During MMS and LGL "Transect" surveys in the Northstar region (147°-150°W) within the late summer and autumn of 1979-94, bowheads were sighted within the 5-km strips ranging from 5 to 120 km from shore (Fig. 2.11, 2.15). The distance from shore categories with the highest numbers of sightings (≥10) ranged from 25 to 55 km from shore. When the numbers of sightings in each distance category were standardized for survey effort, the shape of the "sighting rate vs. distance from shore" curve was found to differ considerably from that of the "sightings vs. distance from shore curve" (Fig. 2.11A vs. B), with the sighting rate tending to diminish less rapidly with increasing distances from shore. This difference is a result of the diminishing amount of survey effort with increasing distance from shore (Fig. 2.8B). Sighting rates of >0.10 bowheads/100 km were recorded in all 5-km strips ranging from 25 to 80 km from shore, and also in the 110-130 km distance from shore category (5-km strips were grouped in the more northerly distance categories because of limited survey effort

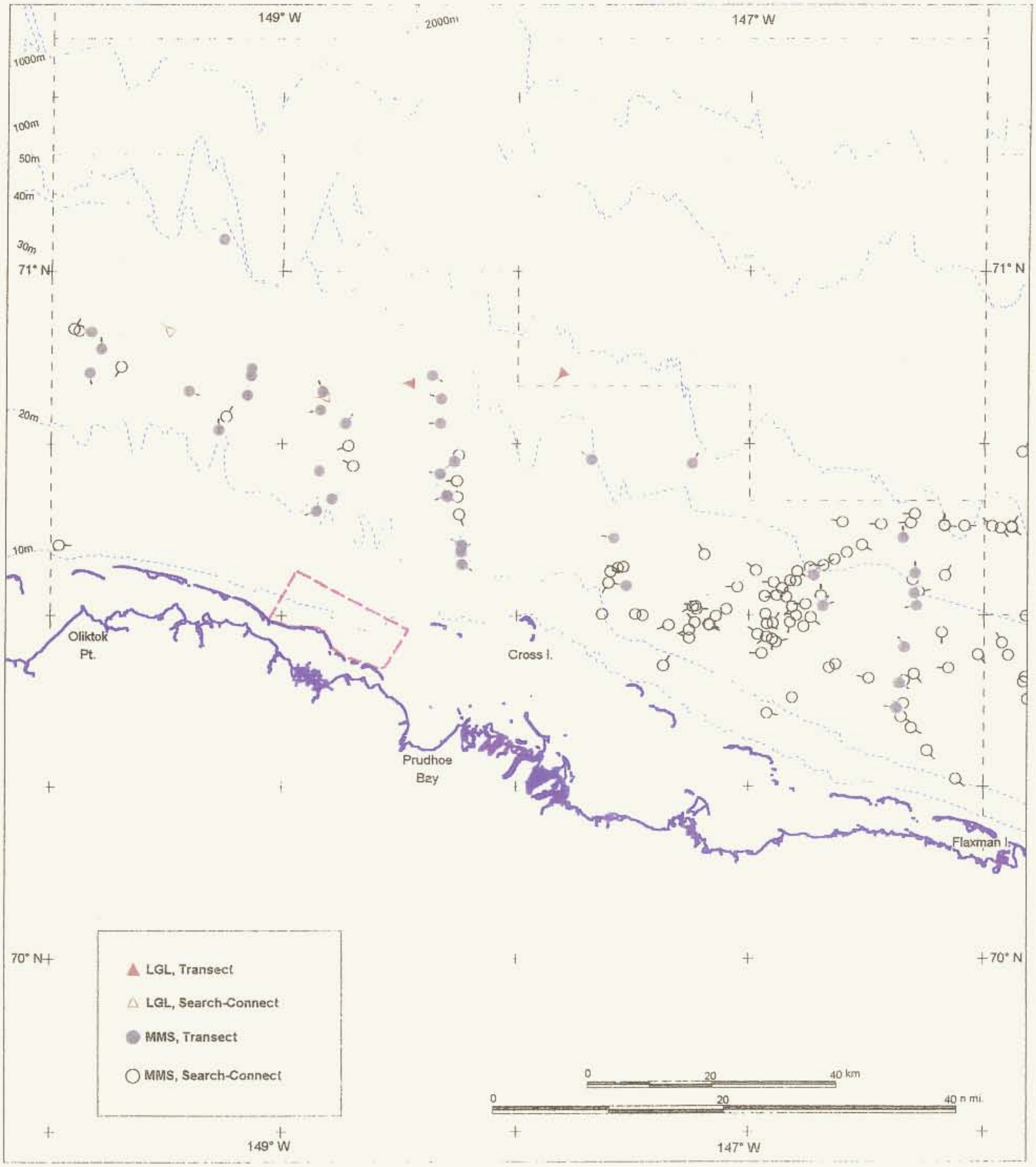


FIGURE 2.9. Bowhead whale sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1995 based on MMS and LGL aerial surveys. Arrows on symbols show whale headings. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

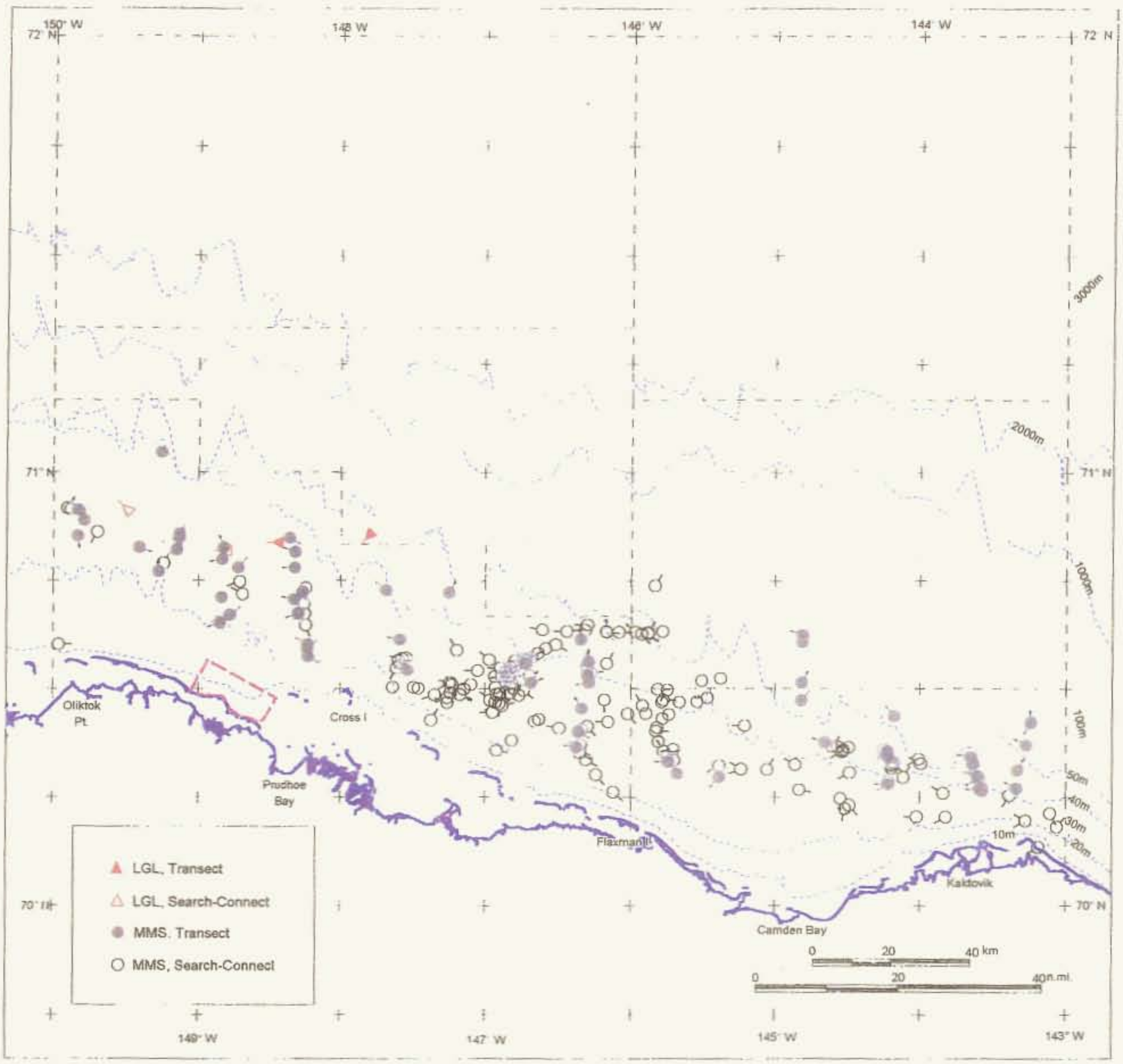
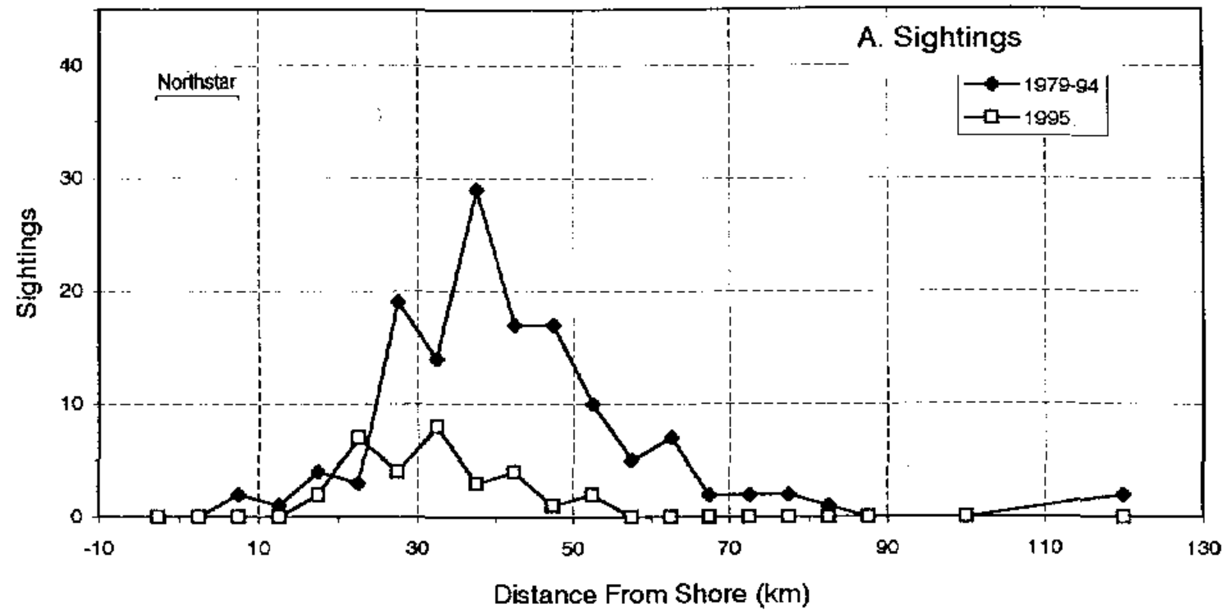


FIGURE 2.10. Bowhead whale sightings in the central Alaskan Beaufort Sea (143°-150°W) during late summer and autumn of 1995 based on MMS and LGL aerial surveys. Dashed lines show boundaries of MMS survey blocks 1, 2, 10 and 4, 6, 9 (*cf.* Fig. 2.2). Otherwise as in Fig. 2.9.



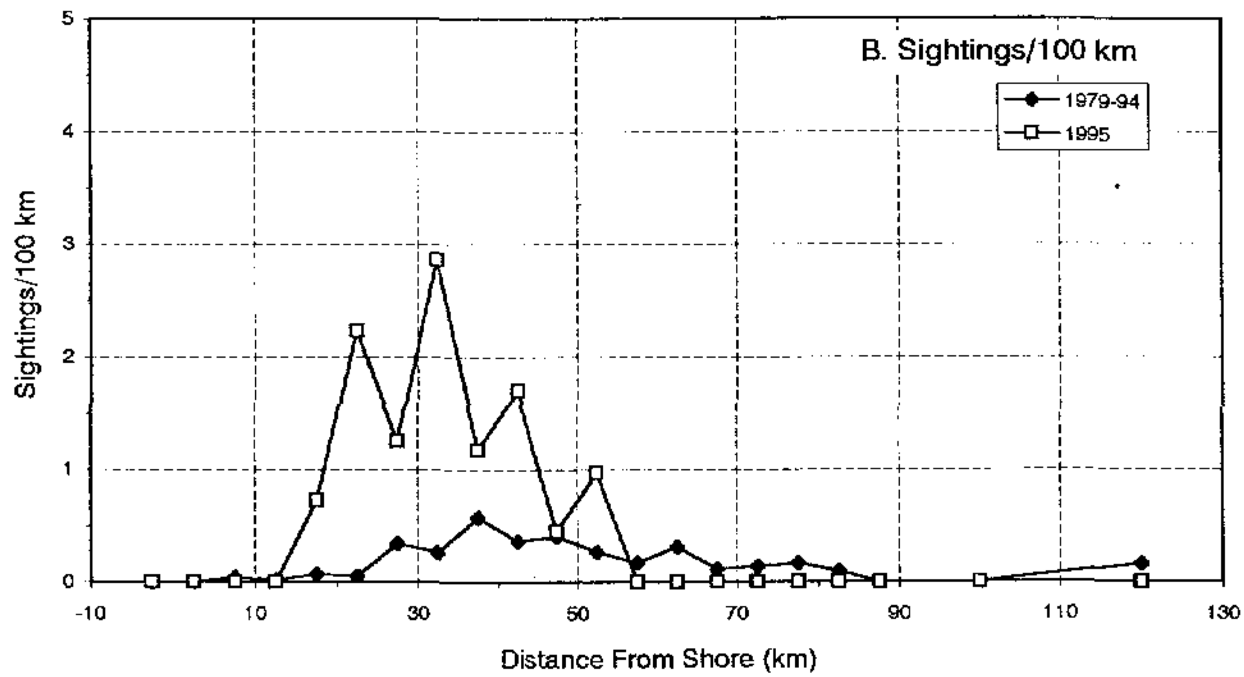
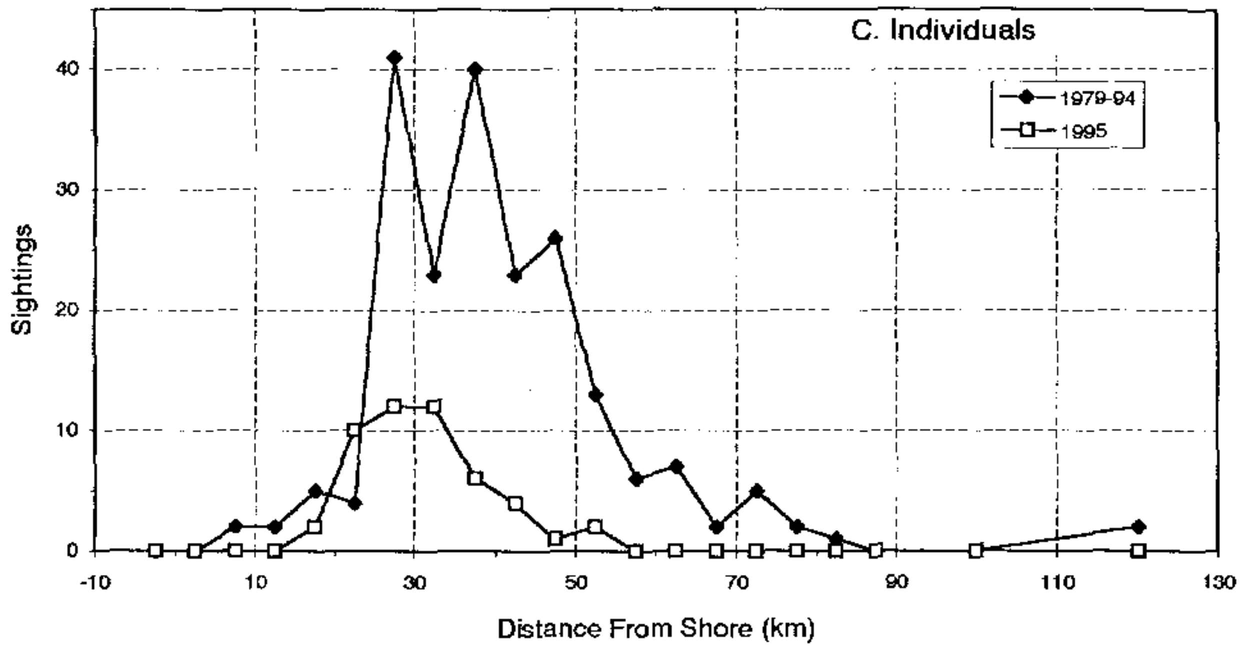


FIGURE 2.11. Distribution of bowheads vs. distance from shore in the Northstar region (147°-150°W) during late summer and autumn of 1995 vs. 1979-94, based on MMS and LGL "Transect" aerial surveys. (A) Sightings, (B) sightings per 100 km of surveys, (C) individuals, and (D) individuals per 100 km of surveys. See Fig. 2.8 for survey effort vs. distance from shore.



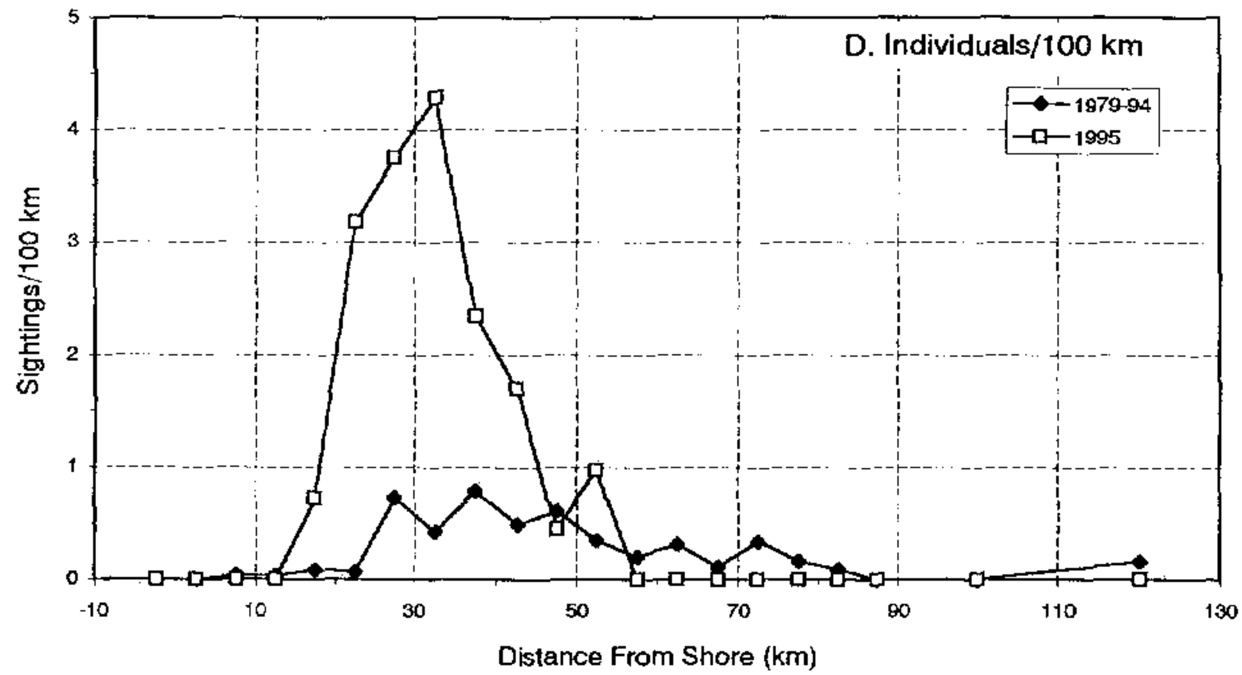


FIGURE 2.11. (continued)

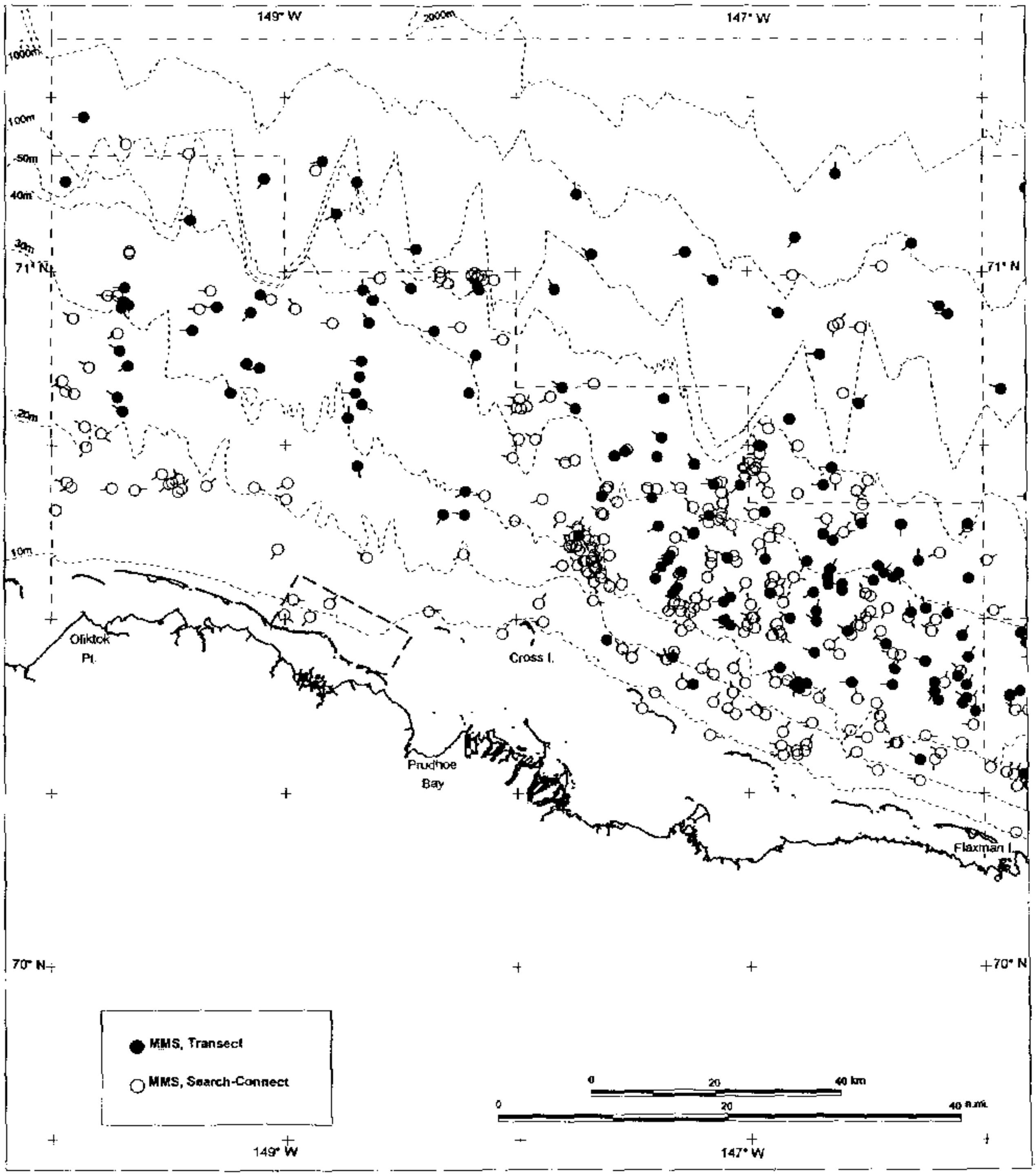


FIGURE 2.12. Bowhead whale sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-94 based on MMS aerial surveys. Plotted as in Fig. 2.9.

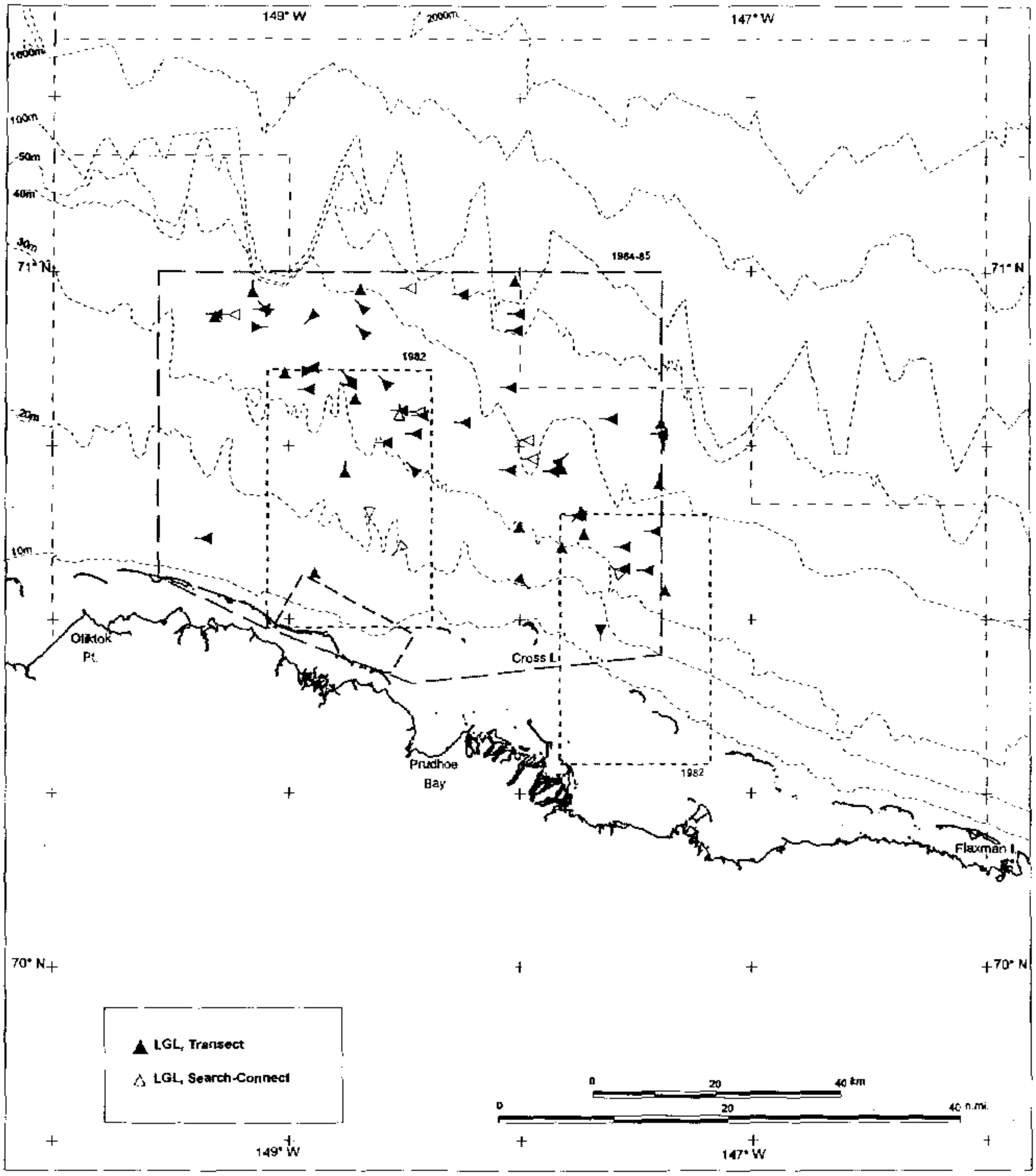


FIGURE 2.13. Bowhead whale sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1982 and 1984-85 based on LGL aerial surveys. Dashed lines labeled 1982 and 1984-85 show outlines of the areas surveyed by LGL in those years (see also Fig. 2.5, 2.6). Otherwise plotted as in Fig. 2.9.

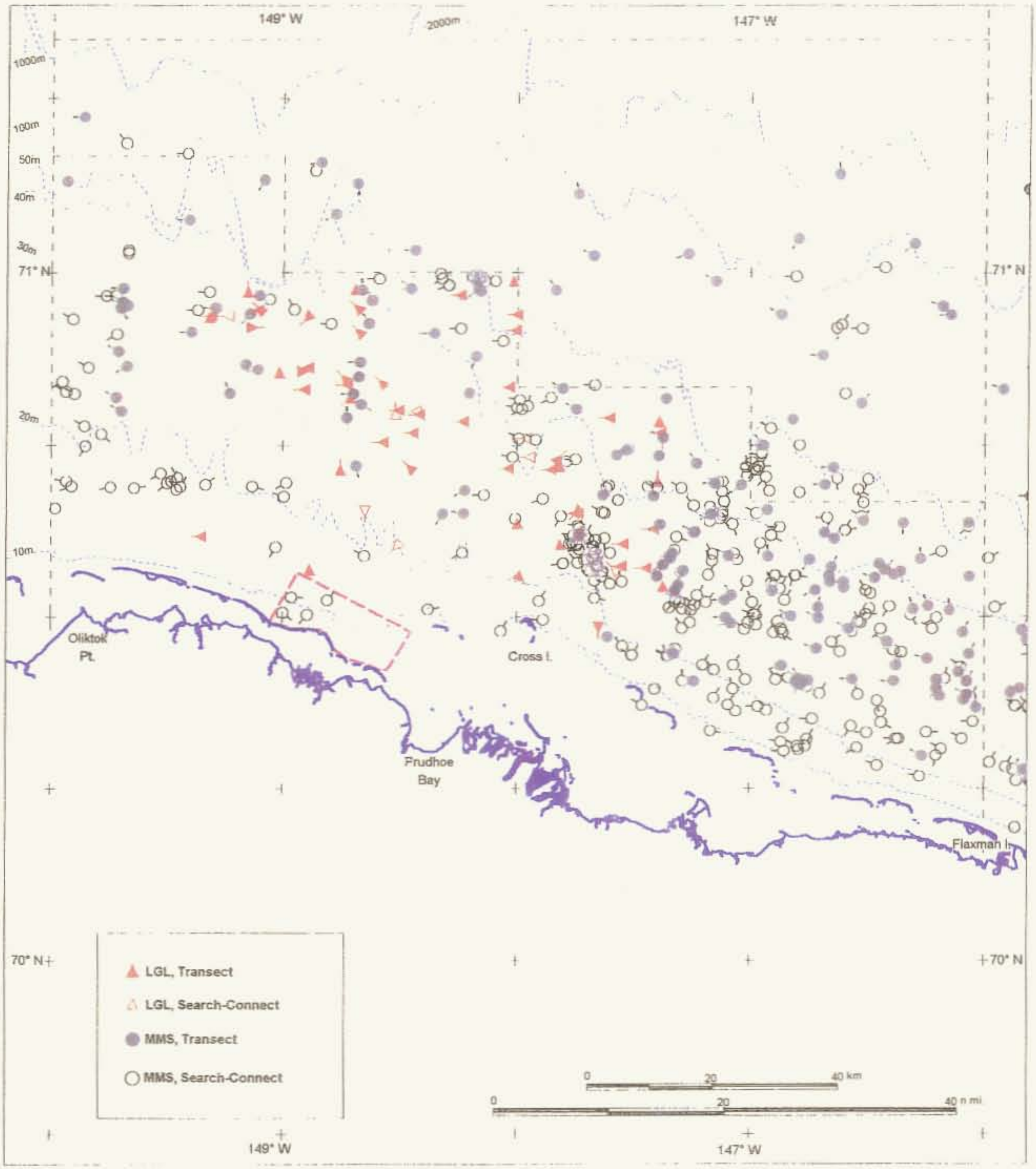


FIGURE 2.14. Bowhead whale sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys (data of Fig. 2.12 and 2.13 combined).

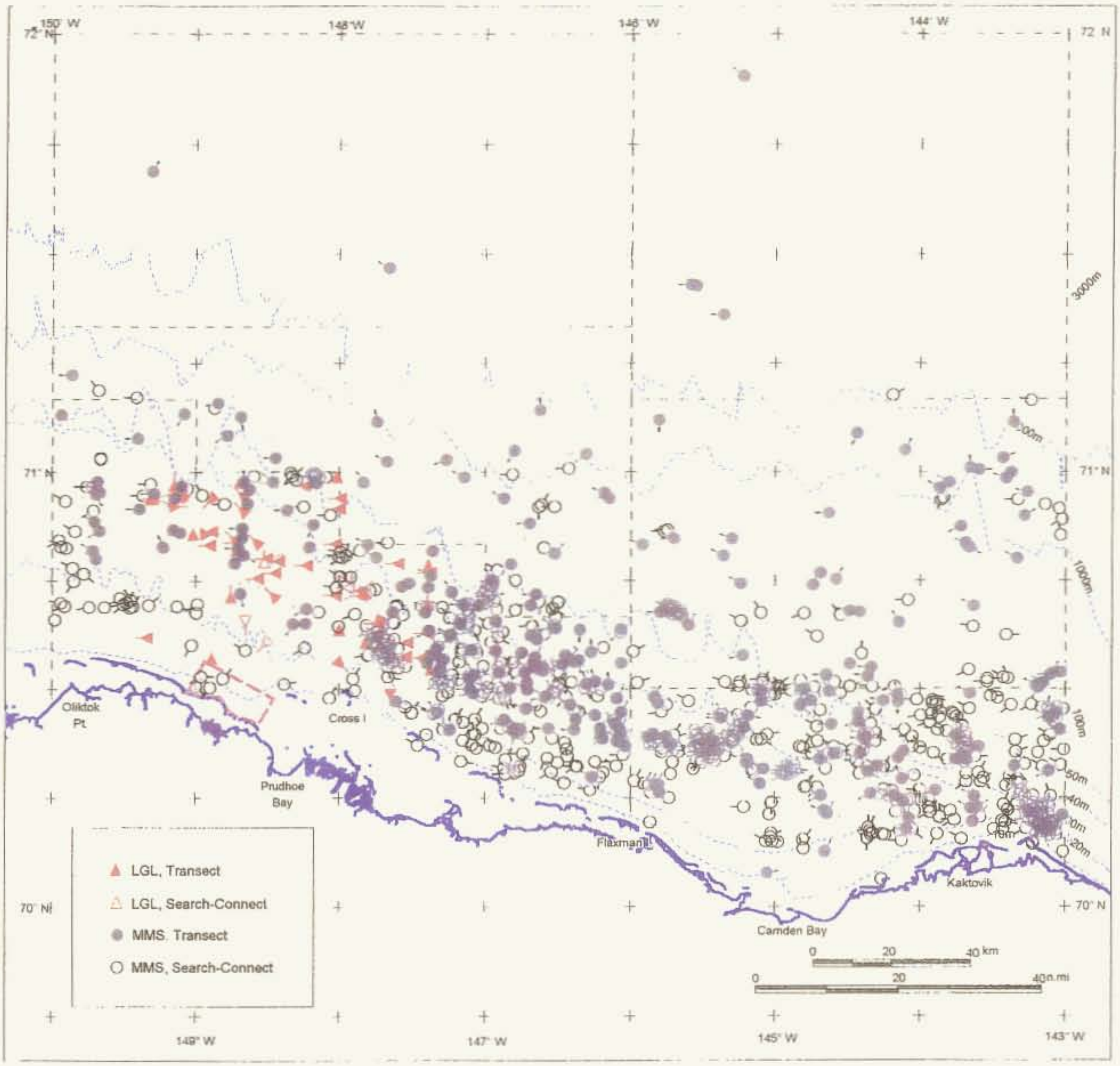


FIGURE 2.15. Bowhead whale sightings in the central Alaskan Beaufort Sea (143°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys. Excludes LGL and other non-MMS aerial surveys east of 147°W. Dashed lines show boundaries of MMS survey blocks 1, 2, 10 and 4, 6, 9 (*cf.* Fig. 2.2). Otherwise as in Fig. 2.9.

in those areas). The highest sighting rate for 1979-94 was 0.57 sightings/100 km in the 35-40 km from shore category.

Examination of corresponding 1979-94 data on individual bowheads and individuals per 100 km of surveying (Fig. 2.11C,D) leads to similar conclusions.

The distribution of late summer and autumn bowhead sightings in the central Alaskan Beaufort Sea as a whole during the 1979-94 period is shown in Figure 2.15. (Note that this excludes many additional bowhead sightings during various industry-funded and other non-MMS surveys in the Camden Bay area and elsewhere far to the east of Northstar.) Most sightings are concentrated in a fairly narrow nearshore band, in waters ranging from 10 to 100 m in depth. To the north of this band are widely dispersed bowhead sightings in deeper waters ranging from 100 to >3000 m deep.

Mother/Calf Sightings.—There were no bowhead mother/calf sightings in the Northstar seismic area during the 1979-95 MMS and LGL surveys (Fig. 2.16). Two mother/calf pairs about 30 km to the ENE were the sightings closest to the planned seismic area. The general distribution of mother/calf pairs in MMS survey blocks 1 and 2 appears similar to the overall bowhead distribution in that area (*cf.* Fig. 2.14), although there were no mother/calf sightings in waters <20 m deep. The absence of shallow water sightings may indicate that mother/calf pairs pursue a more offshore migratory path in autumn or it may simply reflect the small number of mother/calf sightings.

Comparison of 1995 with 1979-94.—We compared distributions of bowhead sightings during the late summers and autumns of 1995 (n=31) and 1979-94 (n=137), considering sightings during "Transect" surveys within the Northstar region (147°-150°). We applied Kolmogorov-Smirnov (K-S) tests, as described in section 2.1 METHODS, to the data summarized in Figure 2.11. The K-S test was applied both to the simple numbers of bowhead sightings in various 5-km distance from shore categories and to bowhead sightings/100 km. Both bowhead sightings and sightings/100 km of transect were distributed significantly closer to shore in 1995 than in 1979-94 ($D=0.364$, $P<0.01$ for sightings; $D=0.402$, $P<0.001$ for sightings/100 km).

The larger "D" value and higher degree of statistical significance for sightings/100 km reflects the difference in the shapes of the "sightings vs. distance from shore" and "sightings/100 km vs. distance from shore" curves in Figure 2.11A,B. These differences are, in turn, a function of the different amounts of survey effort at various distances offshore (Fig. 2.8).

For sightings during "Transect" surveys in the 147°-150°W zone, the median distance from shore was in the 30-35 km category in 1995 and near the outer edge of the 35-40 km category in 1979-94. Based on sightings/100 km, the difference was more conspicuous: a median distance from shore of 30-35 km in 1995 vs. 45-50 km in 1979-94.

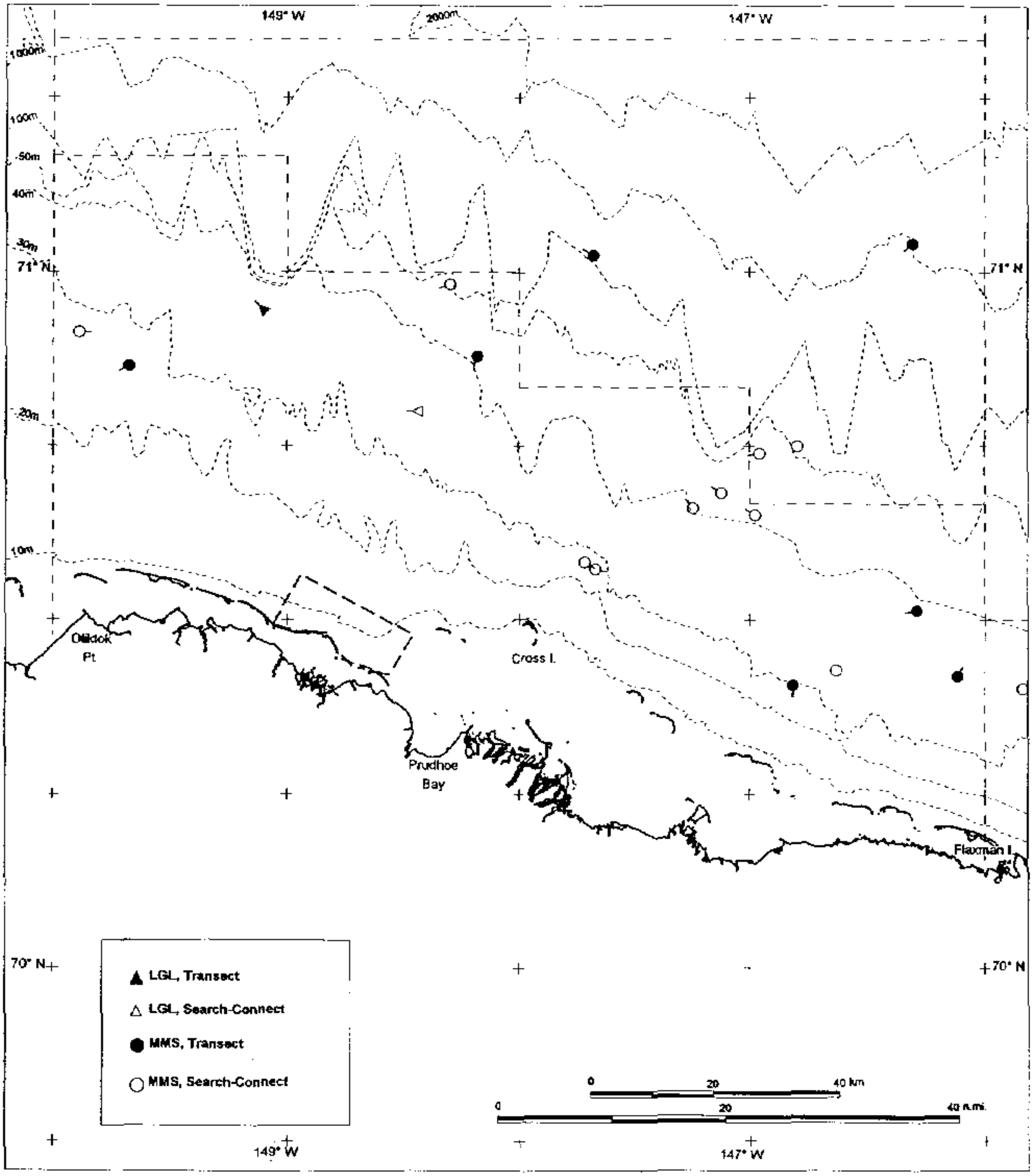


FIGURE 2.16. Bowhead whale mother/calf sightings in the Northstar region (146°-150°) during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. Otherwise plotted as in Fig. 2.9.

Headings

1995.—During 1995 "Transect" surveys conducted by LGL and MMS, headings were recorded for 16 singletons or groups of swimming bowheads, and for 10 singletons or groups whose behavior was other than swimming (e.g. milling, socializing) (Fig. 2.17A,C). The headings of the swimming whales ranged widely but on average were westerly (vector mean heading 270°T, angular deviation 60°). The vector mean heading of the "non-swimming" whales was north-northeasterly (20°T), but with a very wide angular deviation (66°). Angular deviation was calculated according to the method of Batschelet (1981).

1979-94.—During the 1979-94 period the headings of 72 groups of swimming and 38 groups of non-swimming bowheads were recorded during MMS and LGL "Transect" surveys (Fig. 2.17B,D). Most (43) of the "swimming" headings were westerly or northwesterly, with a vector mean of 276°T and angular deviation 44°. The headings of the whales whose behavior was recorded as other than swimming were also westerly on average (vector mean heading 283°T), with somewhat more variability (angular deviation 52°).

Comparison of 1995 with 1979-94.—We compared the headings of bowheads recorded during 1995 with those recorded in previous (1979-94) late summer and autumn studies conducted by MMS and LGL, considering the "Transect" sightings. Based on the parametric test described by Batschelet (1981:122), we found no significant difference between 1995 and 1979-94 with regard to headings of swimming whales ($F'=1.90$, $n_1=16$, $n_2=72$, $0.1>P>0.05$).

Migration Timing

1995.—During late summer and autumn aerial surveys conducted in 1995, bowheads were first sighted (includes Transect *and* Search-Connect sightings) in the Northstar region on 28 August. The final bowhead sighting of the season in that area was on 27 September, and the median sighting date was 14 September. During MMS and LGL "Transect" surveys in the 147°-150°W area, bowheads were observed during three 5-day periods (Fig. 2.18A,B). Peaks of 25 sightings and 43 individuals were recorded during the 11-15 September period. When numbers of sightings and individuals were corrected for survey effort, very high indices were found for that 5-day period: 3 sightings/100 km and 5 individuals/100 km. Effort during the 1995 study period was irregular, with frequent 5-day periods with no transect coverage (Fig. 2.18E).

1979-94.—During the 1979-94 period, the earliest bowhead sighting recorded during late summer and autumn aerial surveys within the Northstar region was on 31 August (1992) and the latest sighting was on 22 October (1993), including both "Transect" and "Search-Connect" sightings. During "Transect" surveys, peak numbers of bowhead sightings (47) and individuals (84) were recorded during the 21-25 September period (Fig. 2.18). Peak numbers were found during the same 5-day period after correction for survey effort (0.5 sightings/100 km and 0.9 individuals/100 km).

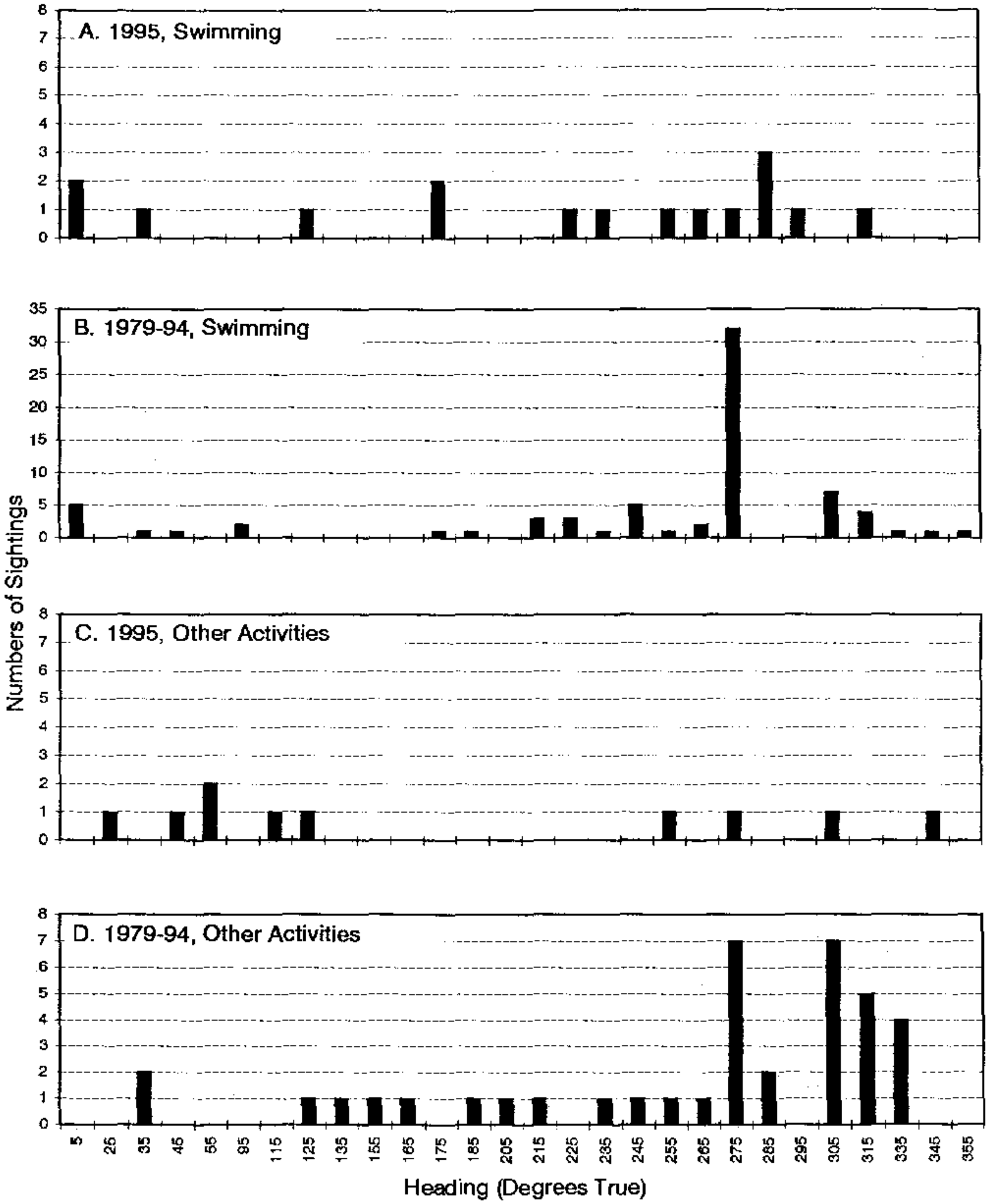
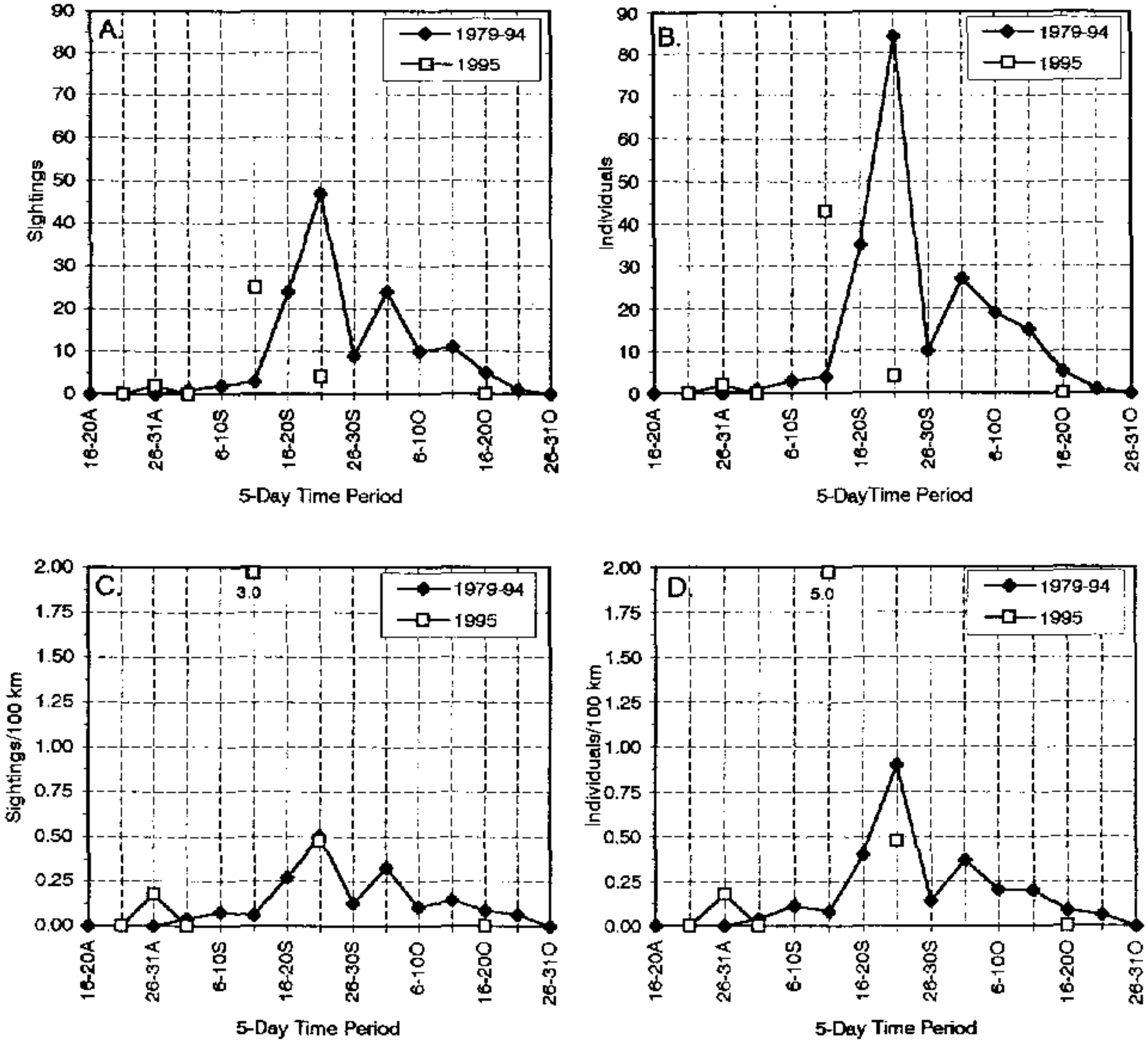


FIGURE 2.17. Bowhead whale headings (°True) in the Northstar region (147°-150°) during late summer and autumn of 1979-94 vs. 1995, separating bowheads categorized as "swimming" from all other bowheads. Based on sightings during "Transect" flying by MMS and LGL; each sighting counted once regardless of number of whales in group.



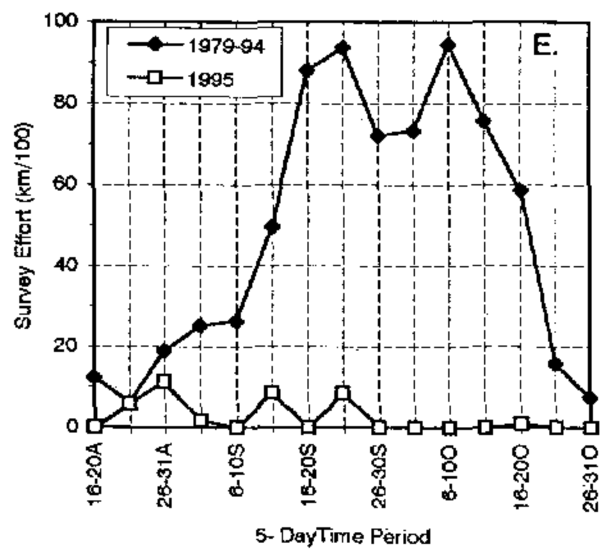


FIGURE 2.18. Seasonal pattern of bowheads in the Northstar region (147°-150°) during late summer and autumn, 1979-94 vs. 1995. Includes (A,B) sightings and individuals by 5-day period, (C,D) sightings and individuals per 100 km of surveying, and (E) "Transect" survey effort, in 100s of kilometers. Based on MMS and LGL "Transect" surveys.

Comparison of 1995 with 1979-94.—The timing of peak bowhead migration through the Northstar region appears to have been earlier in 1995 than in 1979-94 (Fig. 2.18). However, the temporal distribution of survey effort in 1995 was very different than in the combined earlier years, with almost all survey effort in 1995 occurring before the end of September. (Weather conditions were very poor for aerial surveying during October 1995.) Only 92 km of "Transect" surveys were flown in the Northstar region during October, and that effort was in mid-October. Thus, a meaningful comparison of migration timing in 1995 vs. earlier years is not possible based on data from the Northstar region alone.

Abundance Indices

1995.—During "Transect" surveys conducted by MMS and LGL in late summer and autumn of 1995, bowheads were sighted within 1.5 km of the aircraft trackline in 10-km zones ranging from 10 to 60 km from shore (Fig. 2.19). The total numbers of bowheads seen in these 10-km zones ranged from 1 to 15, with the highest number of bowheads recorded 30-40 km from shore. When the numbers of bowheads seen in each 10-km zone are converted to bowheads/100 km^2 based on a total strip width of 3 km, the resulting abundance indices range from 0 (many 10-km zones) to 0.93 bowheads/100 km^2 (30-40 km from shore zone). Over the entire area included in the analysis (i.e. all distance-from-shore categories out to 130 km offshore; 147°-150°W), the abundance index was 0.27 bowheads/100 km^2 or 30 bowheads seen within 1.5 km of trackline along 3658 km of transects. For the zone 10-60 km from shore, where all of the bowheads seen in 1995 occurred, 30 bowheads were seen along 2518 km of trackline or 0.40/100 km^2.

1979-94.—During late summer and autumn "Transect" surveys conducted from 1979 to 1994, bowheads were recorded within 1.5 km of trackline in distance-from-shore categories ranging from 0 to 120 km offshore (Fig. 2.19). Numbers of bowheads seen in various 10-km zones ranged from 0 to 42 (30-40 km from shore). When these numbers are converted to bowheads/100 km^2, the abundance indices for the various distance from shore categories range from 0 to 0.13 bowheads seen/100 km^2. In the entire study area the overall abundance index for the 1979-94 period was 0.06 bowheads seen/100 km^2, i.e. 123 bowheads seen within 1.5 km of trackline along 71,875 km of transects. For the 10-60 km from shore area, where most bowheads (105 of 123) were seen, the density index was 0.07 seen/100 km^2 based on 49,032 km of surveys.

Comparison of 1995 with 1979-94.—In 1995 bowheads were very abundant in the Northstar region. The overall 1995 index of abundance was 0.27 bowheads seen/100 km^2, compared to 0.06 bowheads seen/km^2 for the 1979-94 period. Considering the main migration corridor 10-60 km from shore, the density indices were 0.40/100 km^2 in 1995 vs. 0.07/100 km^2 in 1979-94. We compared the 1995 and 1979-94 distributions of bowhead abundance over the 12 distance-from-shore categories used in the above analyses. Considering the simple "number of bowheads seen by 10-km zone" data, no significant difference was found between the 1995 and 1979-94 distributions of bowheads with respect to distance from shore (D=0.289,

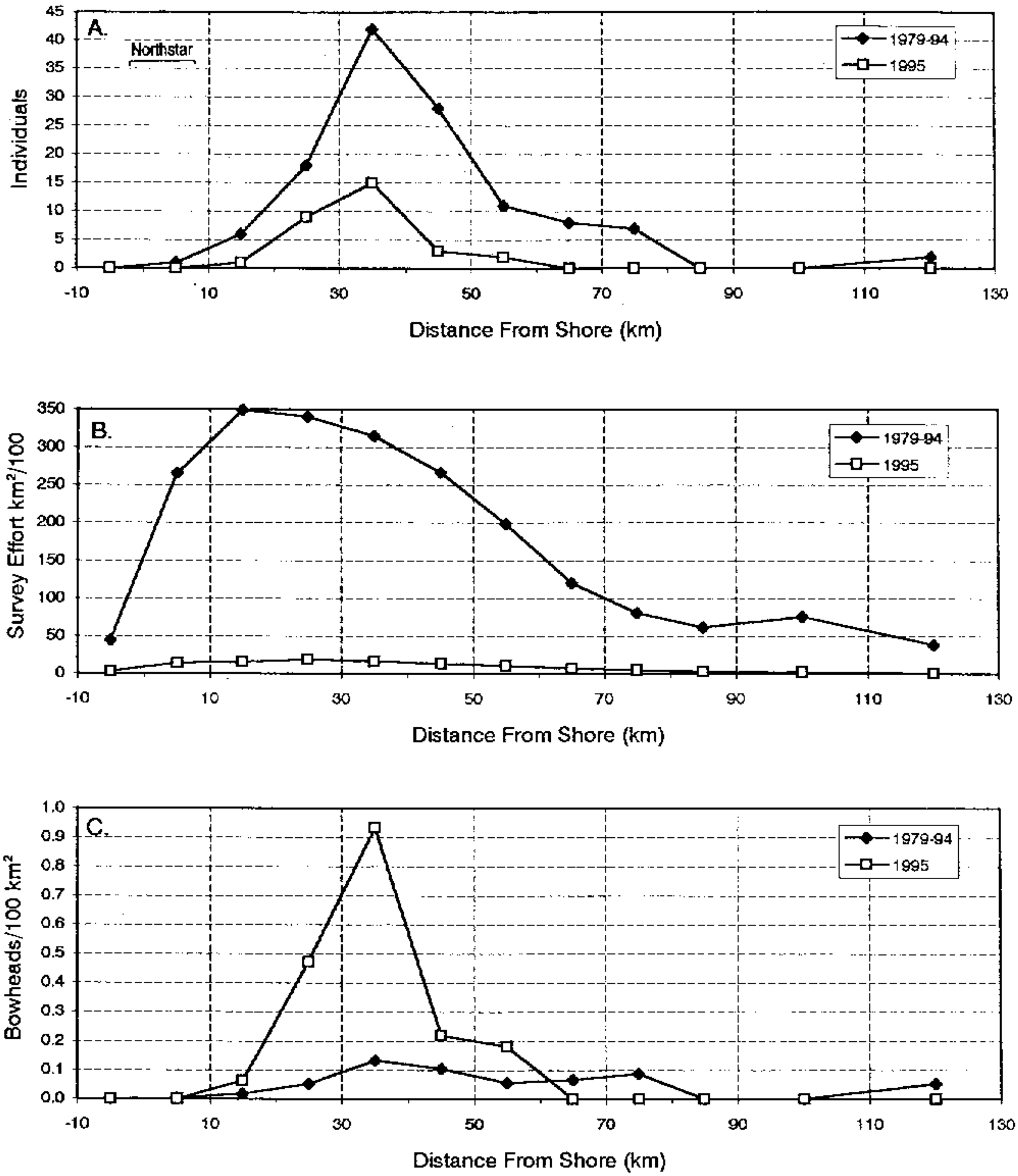


FIGURE 2.19. Bowhead abundance vs. distance from shore in the Northstar region (147°-150°) during late summer and autumn, 1979-94 vs. 1995. (A) Number of bowheads seen within 1.5 km of trackline, (B) area surveyed (assuming 3 km strip width), and (C) number of bowheads seen per 100 km^2. Based on MMS and LGL "Transect" aerial surveys.

P>0.10). However, when analyzed based on bowhead abundance (bowheads seen/100 km^2) in each 10-km zone, the bowheads tended to be significantly closer to shore in 1995 than in the 1979-94 period (D=0.339, P<0.01). In both these analyses, we took the conservative approach of using the numbers of sightings within 1.5 km of trackline (n_1=22, n_2=92), not the number of individuals (30, 123), as the effective sample size.

Annual Differences in Distribution, Abundance and Timing

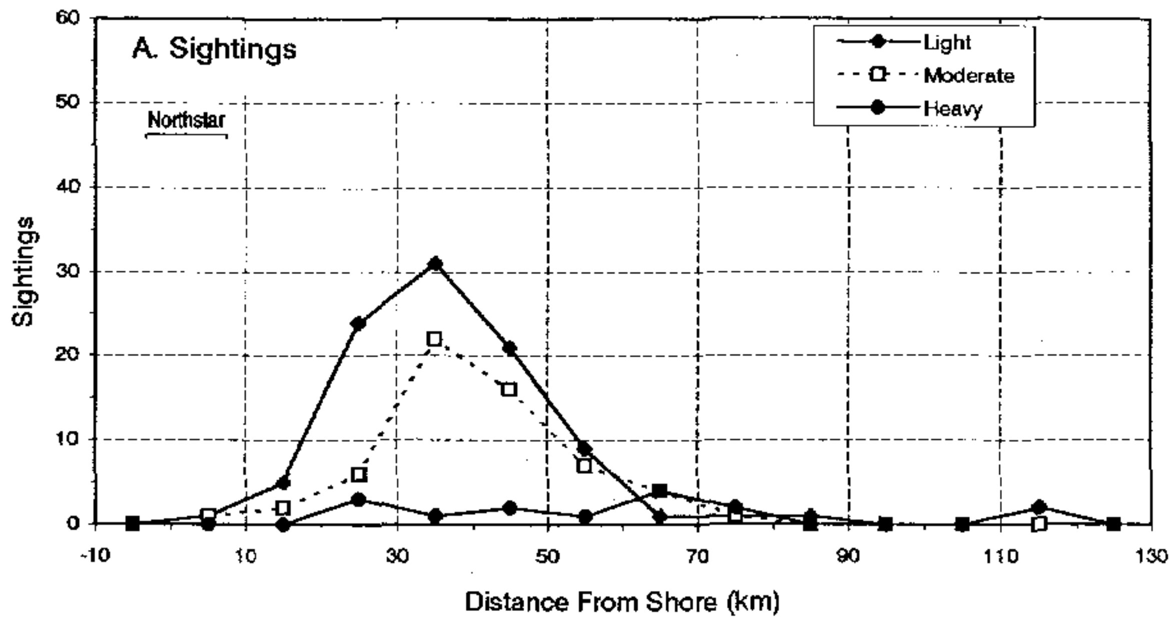
Comparison of 1995 with 1979-94.—Summarizing the above results, bowheads were unusually abundant in the Northstar region (147°-150°W) in 1995. Considering all waters out to 130 km offshore, 0.27 bowheads/100 km^2 were recorded during late summer and autumn "Transect" surveys in 1995 compared to 0.06 bowheads/100 km^2 in 1979-94. Considering the main migration corridor 10-60 km offshore, the corresponding figures were 0.40 vs. 0.07 bowheads/100 km^2. All of these figures consider only the whales visible at the surface as the survey aircraft passed, and underestimate actual density. Bowhead sightings, sightings/100 km, and abundance (bowheads/100 km^2) were distributed significantly closer to shore in 1995 than in the 1979-94 period. The headings of "swimming" bowheads observed in 1995 did not differ significantly from the headings of bowheads observed during earlier years. The timing of bowhead sightings may have been unusually early in 1995, but bad weather limited survey coverage late in 1995, so the 1995 data on timing are inconclusive.

Ice Effects.—Each year since 1979 has been categorized as a light, moderate, or heavy ice year in the MMS aerial survey reports. Those reports (e.g., Treacy 1995) summarize bowhead distribution in these three categories of year. We compared bowhead distribution and migration timing in the 147°-150° zone during light, moderate, and heavy ice years.

Distribution.—Distributions of late summer and autumn bowhead sightings in the Northstar region (147°-150°W) are plotted in Figure 2.20 for light, moderate, and heavy ice years. Peak numbers of sightings were in the 30-40 km from shore category during light ice and moderate ice years, and in the 60-70 km from shore category during heavy ice years. Without allowing for survey effort, the median distance from shore was near 35 km in light ice years, near 40 km in moderate ice years, and in the 60-65 km zone in heavy ice years.

Survey effort as a function of distance from shore differed considerably among light, moderate and heavy ice years (Fig. 2.21A). When the sighting distribution data are standardized for these different levels of effort, it is apparent that the bowhead sightings in heavy ice years were distributed farther offshore than in light and moderate ice years (Fig. 2.20). Peak sightings/100 km and bowheads/100 km occurred at 60-70 km offshore in heavy ice years, compared to 30-40 km offshore in light and moderate ice years. The farthest-offshore sighting (115-120 km offshore) was during a heavy ice year.

We compared distributions of bowhead sightings/100 km of transect survey in light, moderate, and heavy ice years using the K-S test. After allowing for survey effort, the



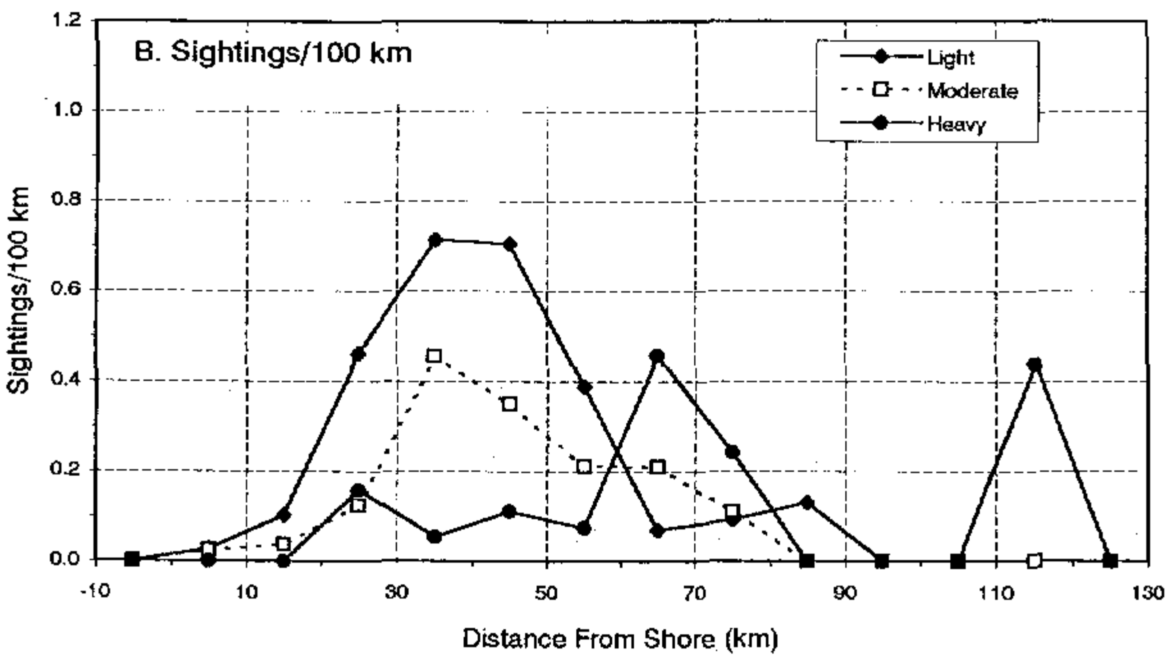


FIGURE 2.20. Distribution of bowheads vs. distance from shore in the Northstar region (147°-150°W) during late summer and autumn of light, moderate and heavy ice years, based on MMS and LGL "Transect" aerial surveys. (A) Sightings, (B) sightings per 100 km of surveys, (C) individuals, and (D) individuals per 100 km of surveys. See Fig. 2.21A for survey effort vs. distance from shore.

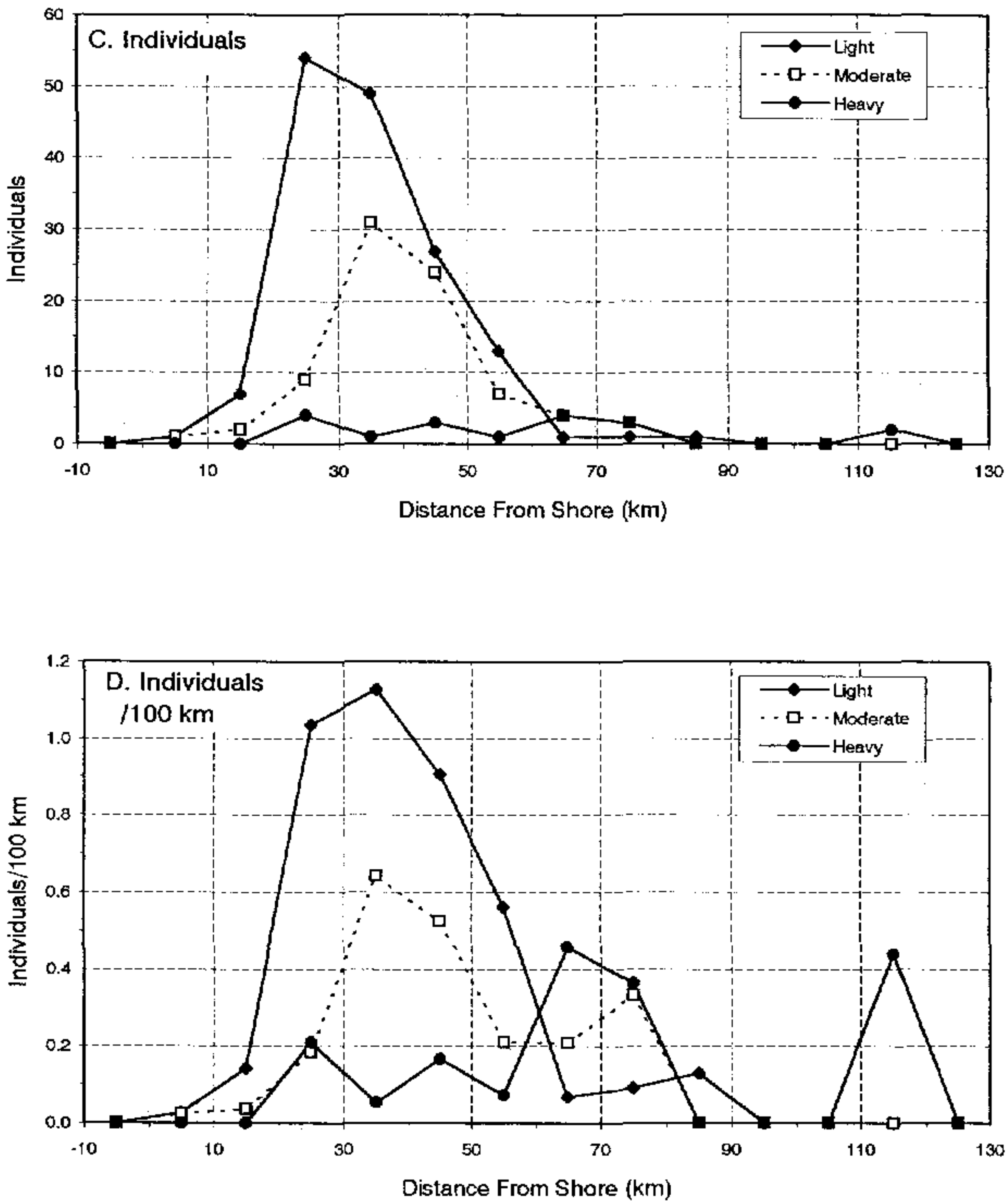


FIGURE 2.20. (continued)

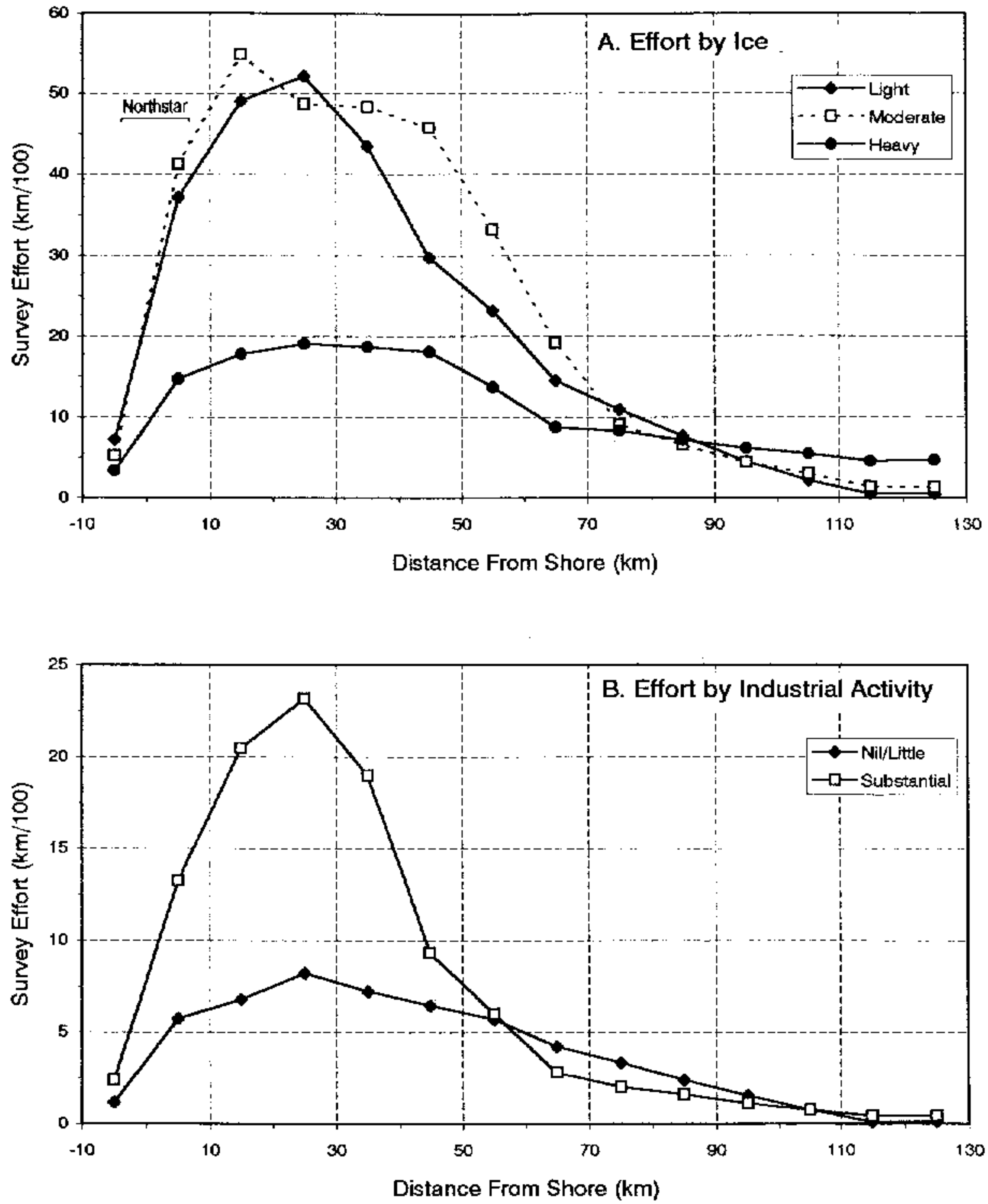


FIGURE 2.21. Kilometers of aerial survey effort at various distances from shore within the Northstar region (147°-150°W) during late summer and autumn, including only "Transect" surveys with sea state <5 and visibility >1 km. (A) Years with light, moderate and heavy ice cover. (B) Years with nil/little vs. substantial industrial activity. See Fig. 2.20 and 2.23, respectively, for corresponding bowhead data.

distribution of bowhead sightings did not differ significantly between light and moderate ice ($D=0.102$, $n_1=94$, $n_2=59$, $P>0.10$). However, the distribution of bowhead sightings did differ significantly between heavy ice years and both light ($D=0.634$, $n_1=94$, $n_2=15$, $P<0.001$) and moderate ($D=0.532$, $n_1=59$, $n_2=15$, $P<0.05$) ice years. Thus, after allowance for differences in survey effort among distance-from-shore and among ice categories, bowhead sightings in the Northstar region were distributed significantly farther offshore during heavy ice years (median 60-70 km offshore) than in light-moderate ice years (medians both 40-50 km offshore).

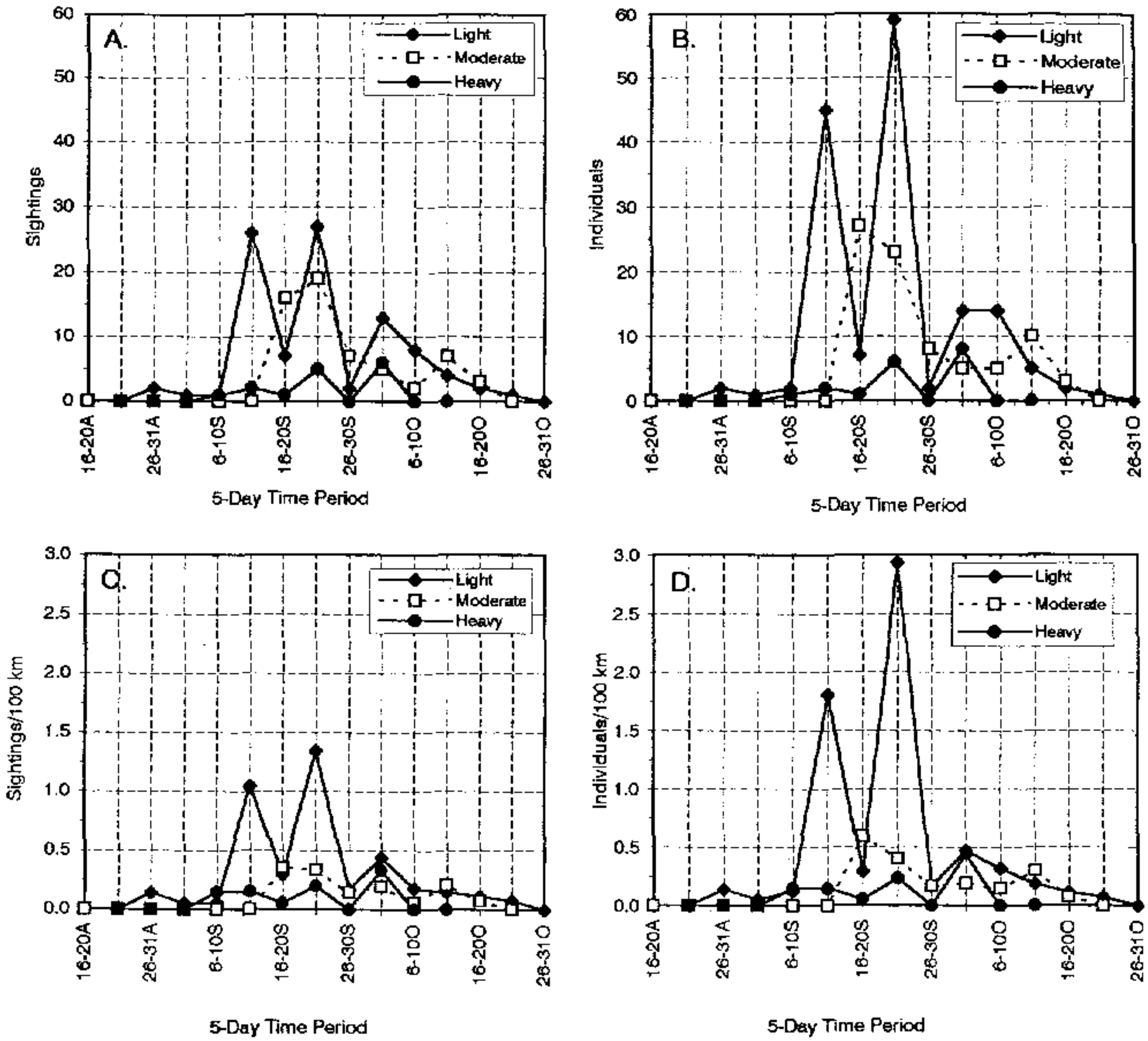
Similar comparisons were conducted for the distribution of individual bowheads/100 km in light, moderate, and heavy ice years. The median distances from shore were 30-40, 40-50 and 60-70 km, respectively, on an individuals/100 km basis. There were significant differences in bowhead distribution between heavy ice years and both light ($D=0.644$, $n_1=94$, $n_2=15$, $P<0.001$) and moderate ($D=0.465$, $n_1=59$, $n_2=15$, $P<0.05$) ice years. Again, no significant difference was observed in the distribution of bowheads between light and moderate ice years after allowance for survey effort ($D=0.181$). As noted earlier, we used the number of sightings as the effective sample size.

The distribution of bowhead sightings in 1995, a light ice year, was compared to the distribution of sightings and individual bowheads in all other light ice years. The 1995 distribution differed significantly from other light ice years in that sightings ($D=0.311$, $n_1=31$, $n_2=63$, $P<0.05$) and individual bowheads ($D=0.331$, $n_1=31$, $n_2=63$, $P<0.05$) were closer to shore in 1995 than in other light ice years.

Timing.—The seasonal distribution of bowhead sightings is plotted for light, moderate, and heavy ice years in Figure 2.22. Peak bowhead sightings/100 km occurred during the 16-20 September period in moderate ice years, the 21-25 September period in light ice years, and the 1-5 October period in heavy ice years. When the overall distributions rather than modal 5-d periods were compared, bowhead sightings/100 km were significantly *earlier* in light ice years than in moderate ice years ($D=0.320$, $n_1=94$, $n_2=59$, $P<0.01$). No significant differences in the timing of bowhead sightings/100 km were found between moderate vs. heavy ice ($D=0.337$, $n_1=59$, $n_2=15$, $P>0.05$) or light vs. heavy ice ($D=0.144$, $n_1=94$, $n_2=15$, $P>0.1$). The low sample size within our 147°-150°W area of interest during heavy ice years was apparently the main factor responsible for the lack of significance in the moderate vs. heavy ice comparison, as the D-value was larger than for the light vs. moderate comparison.

Comparisons of numbers of individual bowheads/100 km yielded similar results. Only the light vs. moderate ice year comparison showed a significant difference, with migrating bowheads tending to occur earlier in light than in moderate ice years ($D=0.318$, $P<0.01$).

Industrial Activity Effects.—Similarly, we have compared the distribution and timing of bowhead migration through the Northstar region during light ice years with nil or little vs. substantial offshore industrial activity in the Northstar region.



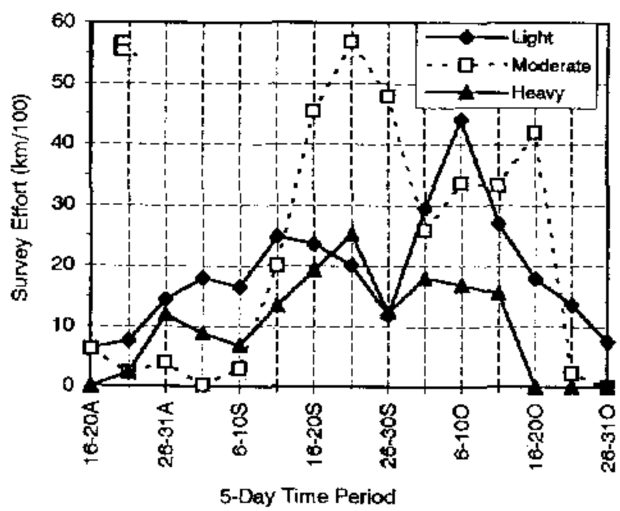


FIGURE 2.22. Seasonal pattern of bowheads in the Northstar region (147°-150°) during late summer and autumn of light, moderate and heavy ice years. Includes (A,B) sightings and individuals by 5-day period, (C,D) sightings and individuals per 100 km of surveying, and (E) "Transect" survey effort, in 100s of kilometers. Based on MMS and LGL "Transect" surveys.

Distribution.—Bowhead distribution relative to shore is plotted for light ice years with nil or little vs. substantial offshore industrial activity in Figure 2.23. This categorization is described in the METHODS, with 1994 and 1995 being "nil/little" industrial activity years and 1982, 1987, 1988 and 1990 "substantial" years. Survey effort tended to be concentrated closer to shore in years with substantial industrial activity (Fig. 2.21B). Corrected for survey effort, peak sightings/100 km occurred 30-40 km from shore in two light ice years with nil or little industrial activity, and 40-50 km from shore in four light ice years with substantial industrial activity (Fig. 2.23B). For individual bowheads/100 km, the peak was 20-30 km from shore during years with nil or little industrial activity and 40-50 km from shore in years with substantial offshore industrial activity (Fig. 2.23D). These data indicate that the center of the bowhead migration corridor was somewhat farther offshore in years with substantial offshore industrial activity. Based on one-sided K-S tests, the difference was marginally significant when considering bowhead sightings/100 km ($D=0.261$, $n_1=32$, $n_2=39$, $0.05<P<0.10$), and significant when considering individual bowheads/100 km ($D=0.308$, $P<0.05$). Whether this difference was attributable to industrial activity or other factors deserves further investigation.

Timing.—The temporal distributions of bowhead sightings and individual bowheads are shown in Figure 2.24. Peak numbers of bowhead sightings, sightings/100 km, individuals, and individuals/100 km were recorded in the 11-15 September period during two years with minimal offshore industrial activity, and in the 21-25 September period during four years with substantial offshore industrial activity.

Discussion

Distribution.—No bowheads were seen in the planned Northstar seismic area during the late summer or autumn of 1995, although a few had been seen there in the past. In 1995, the closest bowheads seen were ~10 km north of the northern edge of the planned seismic exploration area. In 1995, the bowhead migration corridor through the general Northstar region (147°-150°W) was 15-55 km seaward of the barrier islands, or about 5-45 km seaward of the northern edge of the planned seismic area. The center of the migration corridor, as defined by the modal and median distance from shore, was 30-35 km offshore, or ~20-25 km from the north side of the seismic exploration area.

The migration corridor was significantly closer to shore in 1995 than in 1979-94, based on analysis of sightings ($P<0.01$) or sightings per unit effort ($P<0.001$). The median distance from shore in 1979-94 was 35-40 km based on raw sighting data but 45-50 km from shore after adjustment for diminishing survey effort with increasing distance offshore (as opposed to 30-35 km in 1995 based on either method). The migration corridor was also closer to shore in 1995 than in other light ice years.

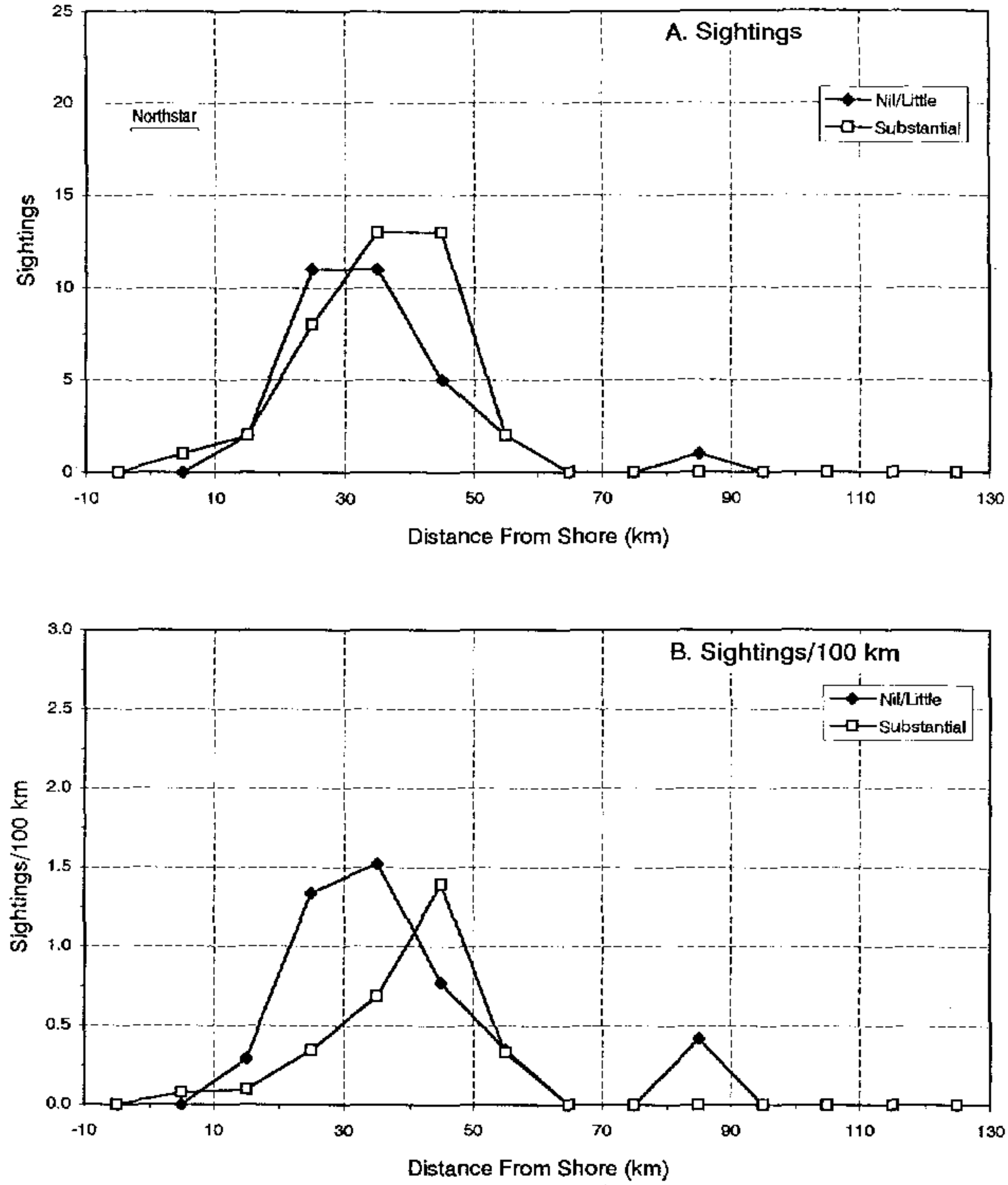


FIGURE 2.23. Distribution of bowheads vs. distance from shore in the Northstar region (147°-150°W) during late summer and autumn of years with little or no industrial activity vs. substantial industrial activity, based on MMS and LGL "Transect" aerial surveys. (A) Sightings, (B) sightings per 100 km of surveys, (C) individuals, and (D) individuals per 100 km of surveys. See Fig. 2.21B for survey effort vs. distance from shore.

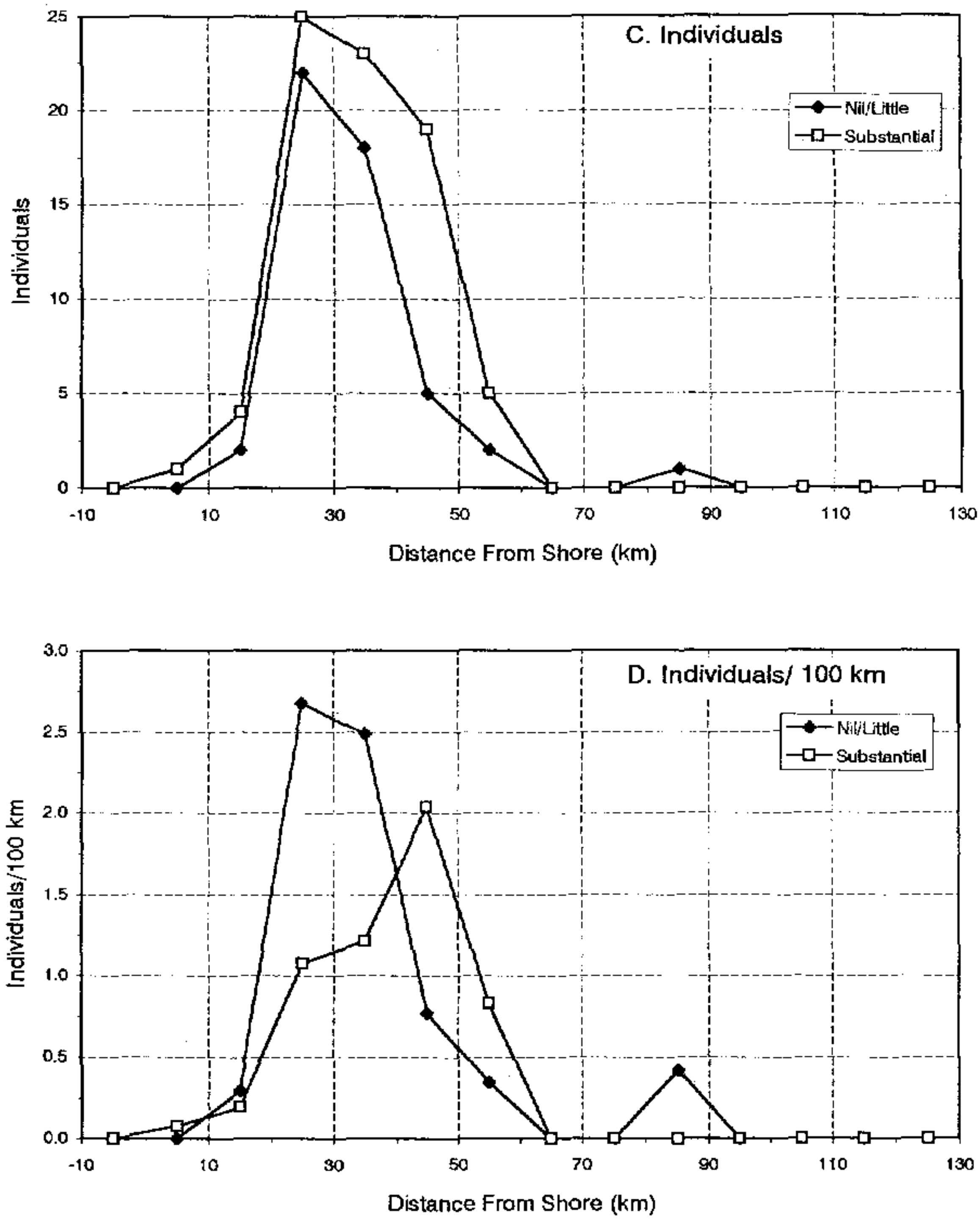
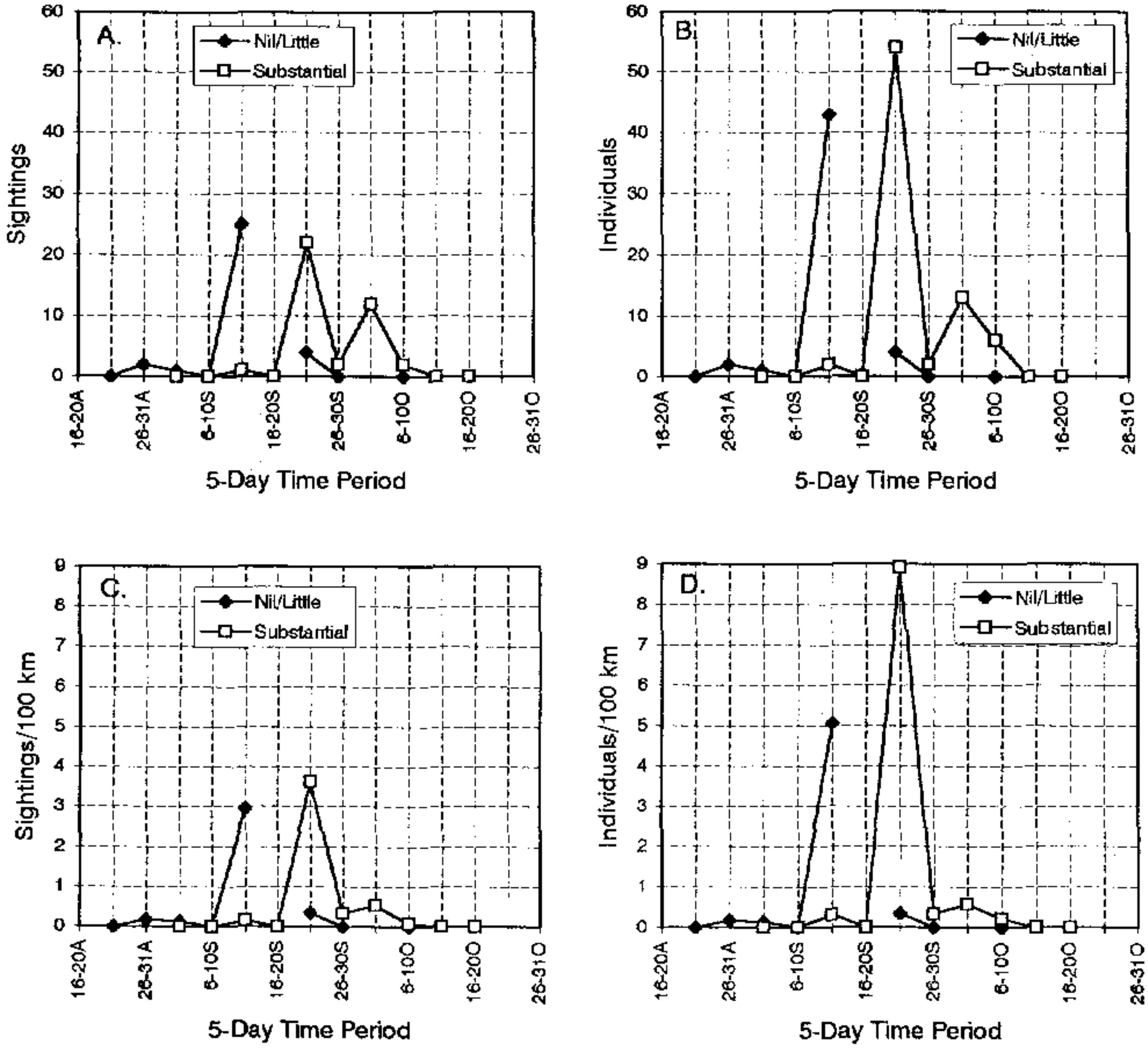


FIGURE 2.23. (continued)



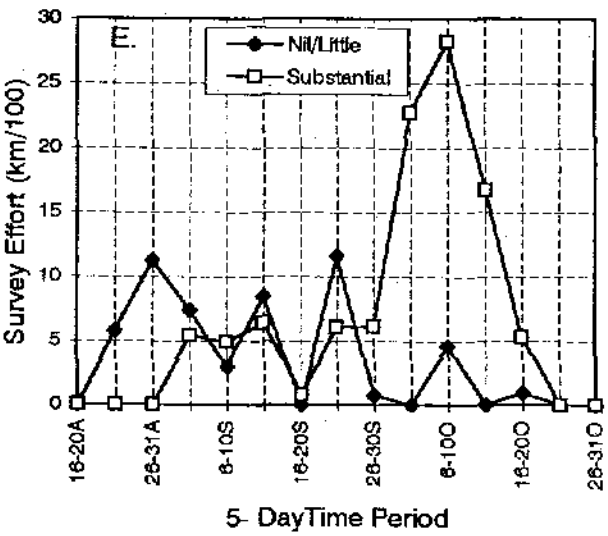


FIGURE 2.24. Seasonal pattern of bowheads in the Northstar region (147°-150°) during late summer and autumn of years with little or no industrial activity vs. substantial industrial activity. Includes (A,B) sightings and individuals by 5-day period, (C,D) sightings and individuals per 100 km of surveying, and (E) "Transect" survey effort, in 100s of kilometers. Based on MMS and LGL "Transect" surveys.

Based on these results, null hypothesis H_{01} as stated in the INTRODUCTION is rejected: there *was* a difference in bowhead distribution in the Northstar region in 1995 compared to previous years.

Movement Patterns.—The headings of bowheads that were engaged in active swimming when they were sighted were predominantly westward in both 1995 and 1979-94. There was no significant difference in headings among these two periods.

Of the large number of bowheads seen during "Transect" surveys in 1995, none were sighted after 25 September. The 1995 migration may have been early, but results on timing were inconclusive because of the poor weather late in the season.

Given the similar headings in 1995 vs. 1979-94, and the inconclusive data on migration timing, there is no basis for rejecting null hypothesis H_{02} regarding bowhead movement patterns relative to Northstar. However, in the absence of useable data on migration timing, no firm conclusion is possible.

Abundance.—Numbers of bowhead sightings and individual bowheads seen in the Northstar region (147°-150°W) were very high in 1995 as compared with earlier years, both on a "raw count" basis and after standardization relative to survey effort. Within the main migration corridor 10 to 60 km from shore, the abundance indices averaged 0.40 individual bowheads seen/100 km^2 in 1995 and 0.07 seen/100 km^2 in 1979-94. Neither of these values includes any allowance for the high proportion of bowheads that are missed during aerial surveys because the whales are below the surface as the aircraft passes.

Because 1995 was a light ice year, sightability of bowheads may have been higher in 1995 than in some earlier years with more ice. However, this does not fully explain the high apparent abundance in 1995, as bowheads were more commonly seen in 1995 than in all but one (1982) of the nine previous light ice years in the 1979-94 period. Whatever the reason, null hypothesis H_{03} must be rejected: apparent abundance indices and estimated numbers of bowheads in the Northstar region (147°-150°W) *were* higher in 1995 than in the 1979-94 period as a whole. However, abundance within 10 km of the planned Northstar seismic area in 1995 was apparently zero or near-zero, as it has been in most previous years.

Ice Effects.—"Median depth analyses" reported in Treacy (1995) and earlier reports suggested that the bowhead migration corridor tends to be farther offshore in heavy than in light ice years. Those analyses were restricted to sightings along formal transects, but did not allow for differences in survey effort vs. distance from shore and ice cover (*cf.* Fig. 2.21).

Our analysis is restricted to a smaller region (147°-150°W), and thus a smaller sample size, than considered by Treacy (1995). However, we have incorporated corrections for survey effort. For the 147°-150°W region, there was little difference in the position of the migration corridor between light and moderate ice years, but the corridor was significantly farther offshore in heavy than in light ice years even after allowance for the greater proportion of surveying in offshore waters during heavy ice years.

Industrial Activity Effects.—The bowhead migration corridor tended to be closer to shore in light ice years with little or no industrial activity in the central Alaska Beaufort Sea than in light ice years with substantial industrial activity within the Northstar region. The difference was statistically significant when individual bowheads were considered ($P<0.05$), but marginal for bowhead sightings ($0.1>P>0.05$).

General.—This analysis has provided some specific information about bowhead utilization of the Northstar region, and should be useful in establishing a baseline for comparisons with results obtained in future years when seismic exploration or other industrial activities occur in the area. The results show that sample sizes for the key area between 147° and 150°W longitude are small even after more than 15 years of broad-scale aerial surveys plus additional intensive, site-specific surveys during three autumns. The importance of intensive site-specific surveys is evident from the fact that 40% of the survey effort and 35% of the bowhead sightings in the 147°-150°W area were obtained during the site-specific surveys, mainly in 1982, 1984 and 1985.

This analysis is also noteworthy in demonstrating the need for correction of aerial survey results to allow for differences in aerial survey effort at different distances offshore. The approach used in this report shows promise as a practical method of allowing for variable survey effort at different distances offshore in different years.

2.3 Gray Whale

Introduction

Gray whales originally inhabited both the North Atlantic and North Pacific oceans (Brownell and Chun 1977; Mead and Mitchell 1984). The Atlantic Ocean populations are believed to have become extinct by the early 1700s. A relic population survives in the Western Pacific. The Eastern North Pacific stock of gray whales has recovered significantly over the past several decades; based on 1993-94 counts, this stock consists of about 23,100 individuals (Small and DeMaster 1995). The Eastern North Pacific stock of gray whales is not considered a strategic stock and it was recently (1994) removed from the List of Endangered and Threatened Wildlife.

Individuals in the Eastern North Pacific stock of gray whales breed and calve in the protected waters along the west coast of Baja California and the east coast of the Gulf of California from January to April (Swartz and Jones 1981; Jones and Swartz 1984). At the end of the breeding and calving season, the majority of the gray whale population begins an 8000 km coastal migration to summer feeding grounds in the northern Bering and southern Chukchi seas (Tomilin 1957; Rice and Wolman 1971; Nerini 1984).

Most summering gray whales congregate in the northern Bering Sea, especially off St. Lawrence Island, in the Chirikov Basin, and in the southern Chukchi Sea. Maher (1960) noted that they are scarce east of Barrow but have been reported at Foggy Island, the mouth of the Shaviovik River, Flaxman Island, and Barter Island. A few single gray whales have been seen in the far eastern portions of the Beaufort Sea (Rugh and Fraker 1981; W.J. Richardson, LGL Ltd., unpubl. data), indicating that small numbers must travel through Alaskan Beaufort waters during summer and autumn in some years. A single gray whale was reported taken by hunters at Cross Island in 1933 (Maher 1960).

Results and Discussion

A single dead gray whale was sighted by MMS on 3 September 1988 in Mikkelsen Bay near Tigvariak Island, about 60 km SE of the eastern edge of the Northstar seismic area (Treacy 1989). No other gray whales were sighted by MMS or LGL in the Northstar region during the 17 year period from 1979-95.

2.4 Beluga Whale

Introduction

The beluga whale is an arctic and subarctic species that has several subpopulations or stocks. The Beaufort Sea stock of beluga whales has recently been estimated at 41,610 individuals (Small and DeMaster 1995), based on applying a sightability correction factor of 2x to the most recent uncorrected estimate of 20,805 individuals (Duval 1993). The Beaufort Sea stock of beluga whales is not classified as a strategic stock (Small and DeMaster 1995).

The majority of whales in this stock migrate into the Beaufort Sea in April or May (Moore et al. 1993), although some whales may pass Point Barrow as early as late March or as late as July (Frost et al. 1988). The spring migration occurs through ice leads similar to those used by bowhead whales. A portion of the Beaufort Sea stock concentrates in the Mackenzie River estuary during July and August, but most of the population remains in offshore waters of the Beaufort Sea and Amundsen Gulf (Davis and Evans 1982). Some belugas are seen in the central Beaufort Sea during the summer, but sighting rates are an order of magnitude lower than during spring (Moore et al. 1993). Small numbers are sometimes seen along the Alaskan Beaufort coast during their fall migration in mid-to-late September (Johnson 1979). However, autumn surveys strongly indicate that most belugas migrate offshore, along routes that vary among years (Frost et al. 1988; Clarke et al. 1993).

Distribution and Migration Route

1995.—No belugas were recorded within the Northstar seismic area during 1995 aerial surveys (Fig. 2.25). Most sightings were well to the north or northeast of the seismic area's boundaries, with the closest sighting being about 60 km to the ENE. All but three of the sightings within the 146°-150°W area were in water depths ≥100 m. These three sightings

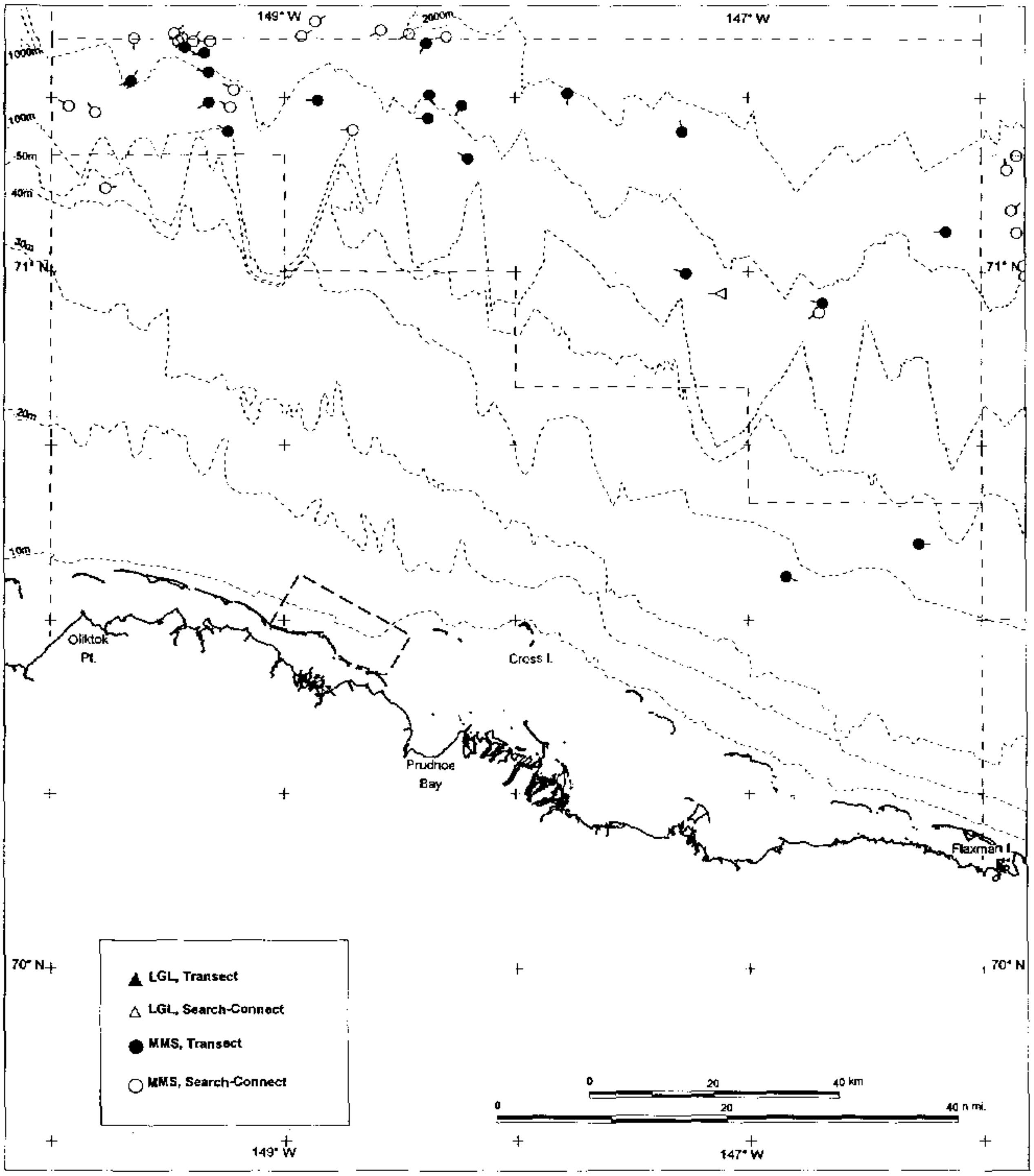


FIGURE 2.25. Beluga whale sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1995 based on MMS and LGL aerial surveys. Arrows on symbols show whale headings. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

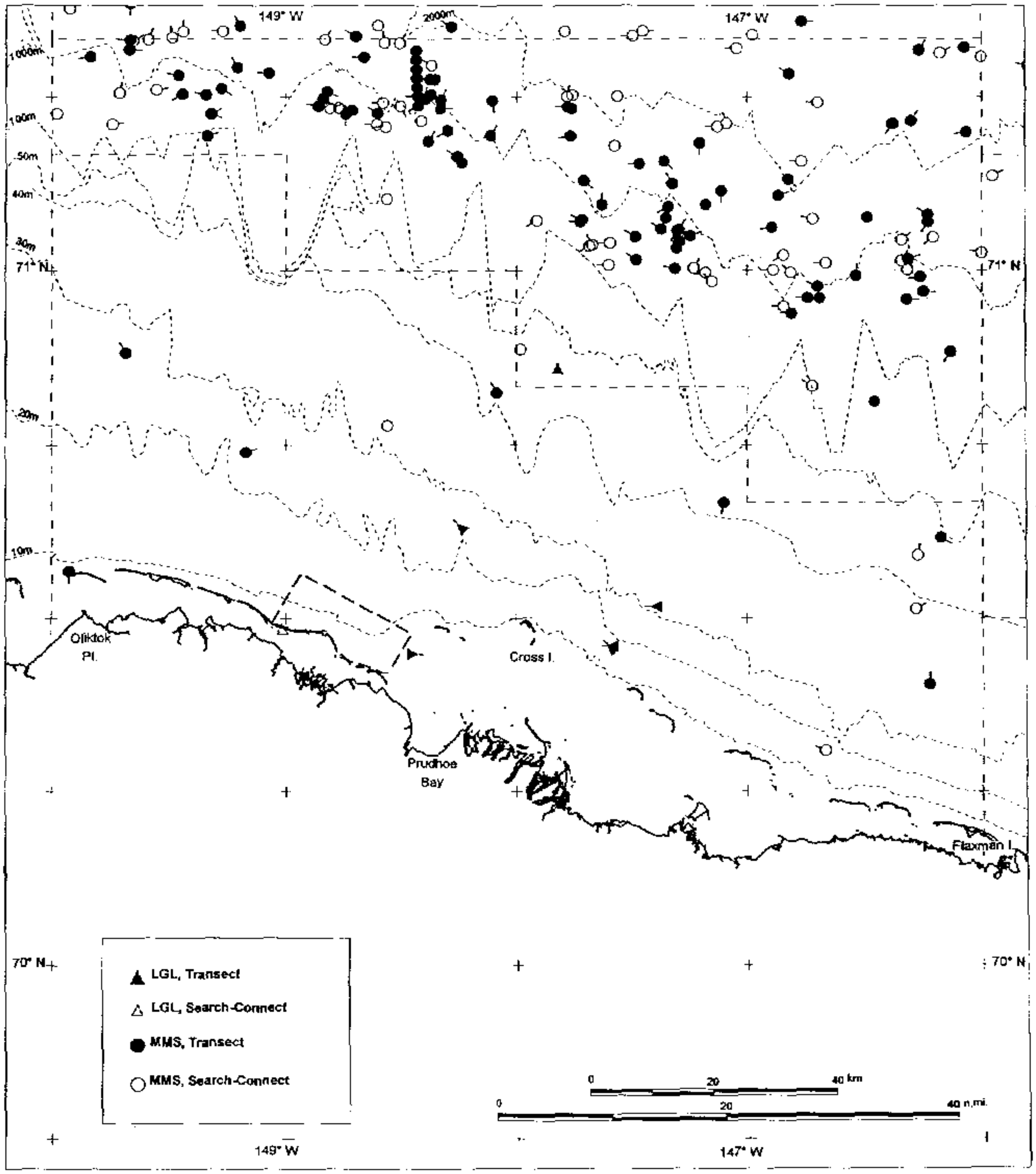


FIGURE 2.26. Beluga whale sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys. Plotted as in Fig. 2.25.

over the continental shelf consisted (from west to east) of 1, 2, and 1 belugas. All sightings in the 143°-146°W area were in water deeper than 100 m.

1979-94.—No belugas were sighted in the Northstar seismic area during aerial surveys conducted during the 1979-94 period, but two sightings occurred within about 1 km of Northstar (Fig. 2.26). Several other sightings of belugas were recorded at distances of 20-30 km from the Northstar seismic area. Apart from a relatively few scattered sightings in shallow (<10-50 m) waters, most sightings were in a SE-NW oriented band with its southern edge between the 100 and 1000 m depth contours. The map of MMS sightings in the broader study area (Fig. 2.27) shows numerous beluga sightings in continental slope waters deeper than 3000 m and includes some beyond 72°N where survey coverage was very sparse.

Distances from Shore.—The 1995 LGL and MMS beluga sightings recorded during late summer and autumn "Transect" surveys are plotted as a function of distance from shore for the Northstar region (147°-150°W) in Figure 2.28. Within that range of longitudes, the 18 beluga sightings during "Transect" surveys in 1995 were in 10-km zones ranging between 60 and 120 km from shore, with the largest number of sightings (9) in the 70-80 km from shore category (Fig. 2.28A). Of the 98 individual belugas represented in these 1995 data, more than half (59) were seen in the 70-80 km from shore category (Fig. 2.28C). When sightings and individuals per 100 km of survey effort are considered, the highest values were 110-120 km from shore (Fig. 2.28B,D), but these were based on a scant 12 km of surveys (Fig. 2.8).

During the 1979-94 period, MMS and LGL late summer and autumn beluga sightings in the Northstar region during "Transect" surveys ranged from inside the barrier islands to >130 km offshore (Fig. 2.27, 2.28A). The largest numbers of beluga sightings (33) and individuals (169) were seen in the 80-90 km from shore category. When standardized for survey effort, the highest sighting rate (1.6 sightings/100 km was 80-90 km from shore. The highest number of individuals (12.8/100 km) was recorded 110-120 km from shore.

The distribution of belugas extends beyond, and probably far beyond, the limits of the distance-from-shore analysis performed here. The limited survey coverage beyond the northern edge of the area we have considered here makes it impossible to adequately characterize the offshore distribution of this species. However, it is evident that the great majority of belugas passing the Northstar region are more than 60 km from shore. This is especially evident after the results are adjusted to allow for differences in survey effort vs. distance from shore (Fig. 2.28A vs. B, C vs. D).

Migration Timing.—When corrected for survey effort the 1979-94 data show that belugas are present in the Northstar region from August through late October (Fig. 2.29C,D). Peak numbers of sightings (0.47/100 km) and individuals (2.09/100 km) occurred during the 1-5 September period. Numbers declined gradually thereafter.

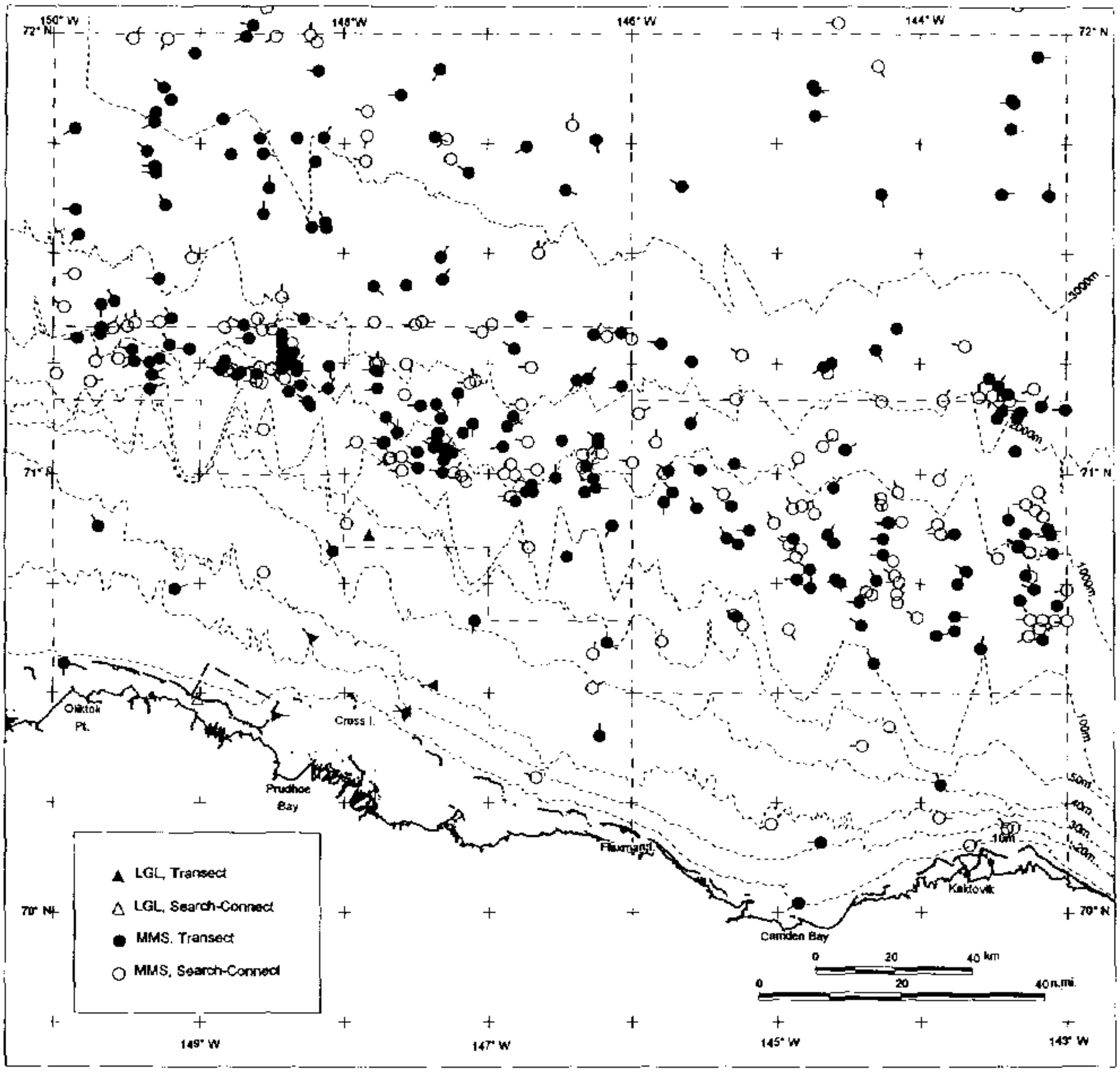


FIGURE 2.27. Beluga whale sightings in the central Alaskan Beaufort Sea (143°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys. Excludes LGL and other non-MMS aerial surveys east of 147°W. Dashed lines show boundaries of MMS survey blocks 1, 2, 10 and 4, 6, 9 (*cf.* Fig. 2.2). Otherwise as in Fig. 2.25.

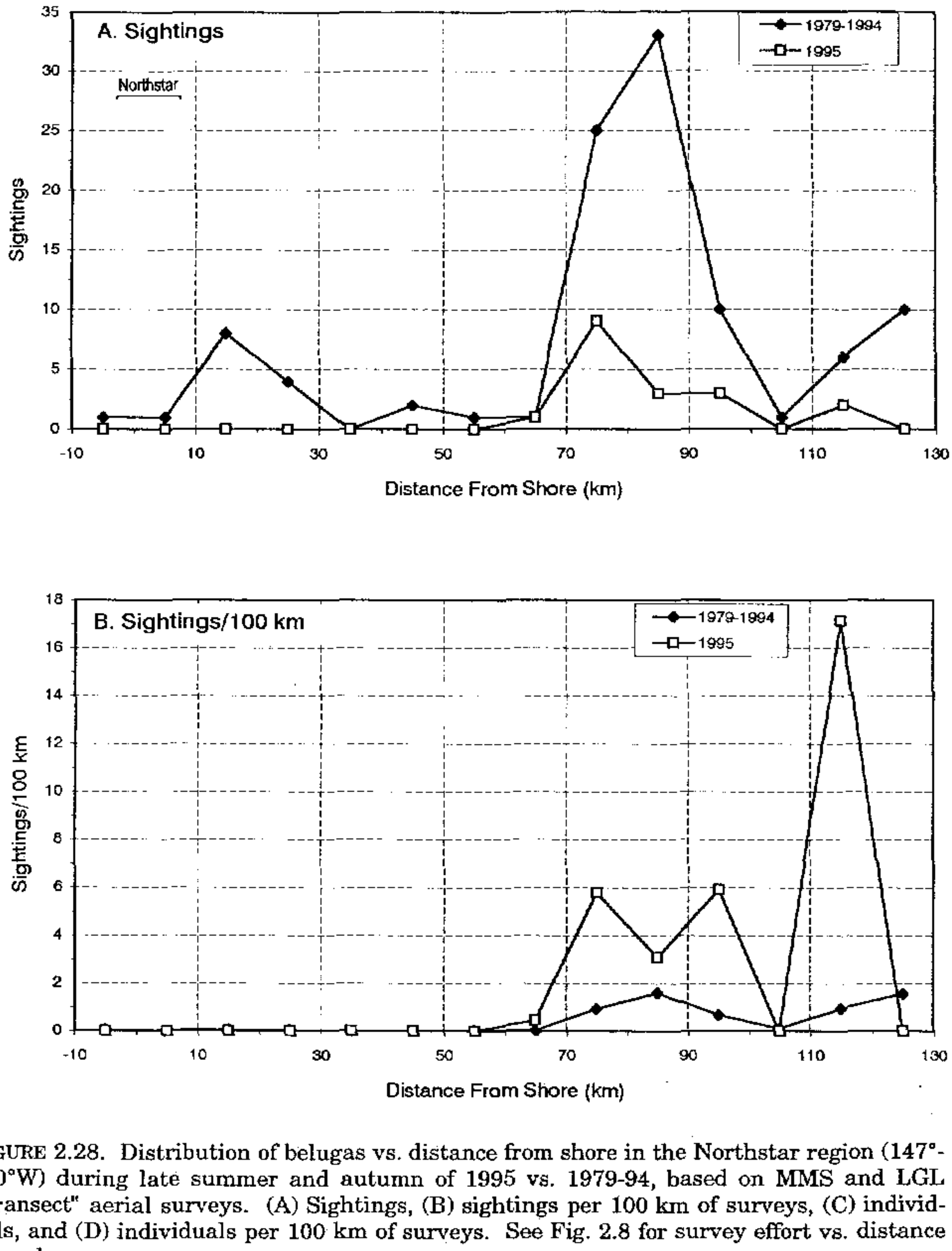


FIGURE 2.28. Distribution of belugas vs. distance from shore in the Northstar region (147°-150°W) during late summer and autumn of 1995 vs. 1979-94, based on MMS and LGL "Transect" aerial surveys. (A) Sightings, (B) sightings per 100 km of surveys, (C) individuals, and (D) individuals per 100 km of surveys. See Fig. 2.8 for survey effort vs. distance from shore.

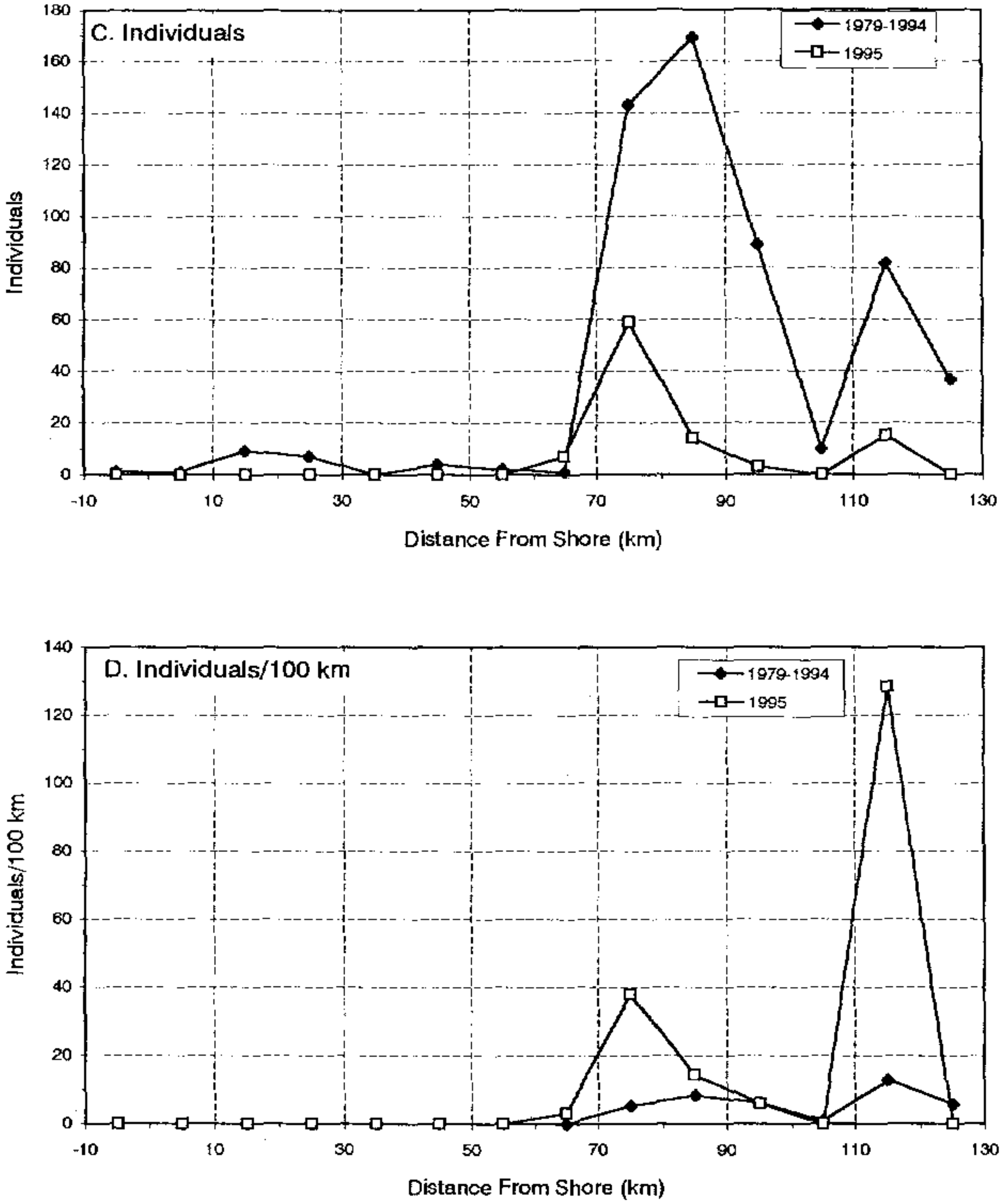
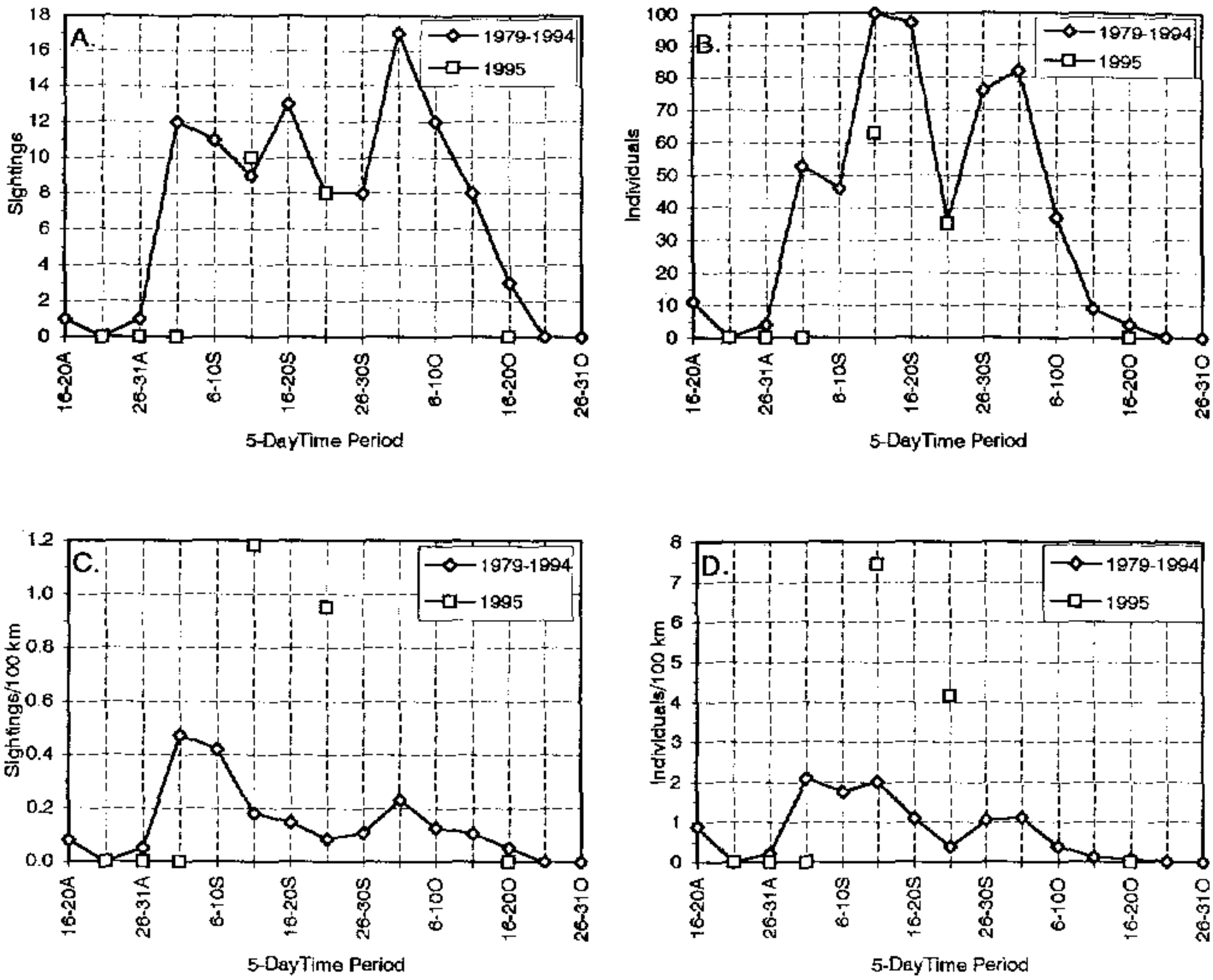


FIGURE 2.28. (continued)



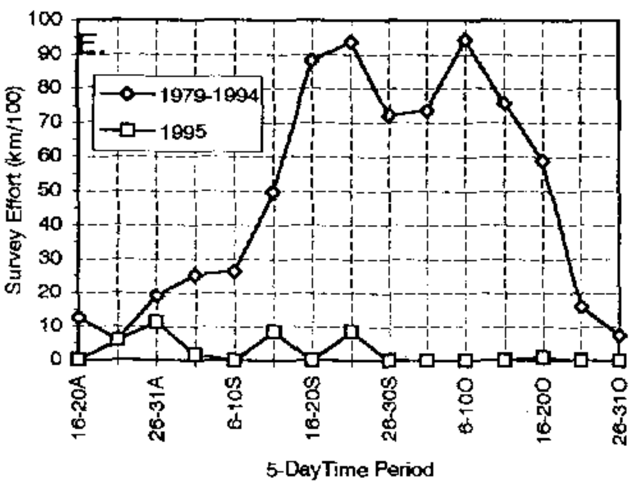


FIGURE 2.29. Seasonal pattern of belugas in the Northstar region (147°-150°) during late summer and autumn, 1979-94 vs. 1995. Includes (A,B) number of beluga sightings and individuals by 5-day period, (C,D) sightings and individuals per 100 km of surveying, and (E) "Transect" survey effort, in 100s of kilometers. Based on MMS and LGL "Transect" surveys.

Discussion

Belugas were not sighted within the Northstar seismic area during late summer and autumn surveys in 1995 or in 1979-94. However, small numbers of belugas have been sighted near Northstar. Most beluga sightings in the Northstar region are in offshore waters between the 100 and 1000 m depth contours >60 km offshore. Considering the 1979-94 data, and the 130 km distance-from-shore range that we examined, beluga sightings and individuals, corrected for survey effort, were most common in the 80-90 and 110-120 km from shore zones, respectively. When the data were corrected for survey effort, peak numbers of belugas were recorded in offshore waters during the 1-5 September period, and gradually declined through mid-late October.

2.5 Ringed Seal

Introduction

Ringed seals are year-round residents in the Beaufort Sea and the most abundant marine mammals in the region. The worldwide population of ringed seals is estimated at 6-7 million (Stirling and Calvert 1979). The estimated size of the Alaska stock, which occupies the Bering-Chukchi-Beaufort area, is 1-1.5 million (Kelly 1988; Small and DeMaster 1995), with an estimated 80,000 seals found in the Beaufort Sea during the summer, and 40,000 in the winter (Frost and Lowry 1981). The Alaska stock of ringed seals is not classified as a strategic stock by NMFS, and this classification is consistent with the recommendations of the Alaska Scientific Review Group (Small and DeMaster 1995).

During winter months, the ringed seal occupies the land-fast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas. As ice forms in the autumn, ringed seals maintain breathing holes by abrading the ice with their foreclaws. As snow accumulates they dig haul-out lairs in the drifts. In winter and spring, the highest densities of ringed seals are found on stable shorefast ice. However, in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice exceed those on shore-fast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). Females give birth to a single pup in birth lairs in early to mid-April; and nurse the pup for 4-6 weeks (Smith and Stirling 1975). Mating occurs in late April and May. From mid May on they haul out in the open air at holes or on the edges of narrow cracks to bask in the sun and molt.

As the ice breaks up and deteriorates ringed seals return to a pelagic existence. In the eastern Beaufort Sea and Amundsen Gulf, ringed seals concentrate in similar offshore areas from one year to the next and are often found in large groups in these areas (Harwood and Stirling 1992). It appears that these concentrations are found in areas of greater food abundance that may be related to oceanographic features. Similar summer concentrations have not been reported in the central and western Beaufort Sea. Ringed seals are significant predators of small fish and zooplankton. The ringed seal is also the principal food of polar bears (Stirling 1974; Kingsley 1990) and is important to other predators such as the arctic fox (Smith 1976).

In addition to local movements in response to seasonal changes in ice conditions, there may be a large scale movements of ringed seals into and out of the Beaufort Sea. Smith and Stirling (1978) described a westward migration of subadult seals in the eastern Beaufort Sea prior to autumn freeze-up and a small number of long distance movements of marked individuals have been documented. However, the nature and extent of these movements are not well understood (Smith 1987; Kelly 1988).

Aerial surveys for ringed seals are usually conducted during late winter and spring when the seals haul out on ice; quantitative surveys have not been possible during late summer. Only a very small proportion of the ringed seals present in open water are seen during high-altitude aerial surveys designed to search for whales.

Distribution

1995.—No ringed seals were observed within the Northstar seismic area during the 1995 aerial surveys conducted by LGL and MMS (Fig. 2.30). The sighting nearest the Northstar seismic area was about 10 km to the N. Except for two sightings located about 16 and 20 km NW of the Northstar seismic area in waters between 10 and 20 m deep, all of the ringed seal sightings were in waters deeper than 20 m. Most sightings were during the few surveys conducted by LGL in late August.

1979-94.—During earlier surveys by MMS (Fig. 2.31) and LGL (Fig. 2.32) there were 5 sightings of ringed seals within the Northstar seismic area, and numerous others within 10 km. The combined (MMS and LGL) results for the 1979-94 period indicate that ringed seal sightings outside the Northstar seismic area were widely distributed throughout most of the study area. However, relatively few sightings occurred in the shallow (<20 m) waters to the W and WNW of the Northstar seismic area (Fig. 2.33).

Seasonal Occurrence

During the 1979-95 period there were 304 sightings of a total of 727 ringed seals during late summer and autumn "Transect" surveys conducted in the Northstar region (147°-150°W) by MMS and LGL. Considering the five half-month periods from 16-31 August to 16-31 October, sighting rates/100 km ranged from 0.32 sightings/100 km (15-30 Sept) to 0.67 sightings/100 km during the 16-31 October period and 0.75 sightings/100 km (16-31 Aug). Considering the rather small seasonal differences in sighting rates, and the difficulty of sighting ringed seals from the relatively high altitudes used to survey cetaceans, the observed differences may be artifacts of seasonal and other variations in the sightability of ringed seals during late summer and autumn. The higher sighting rate in late August is almost entirely

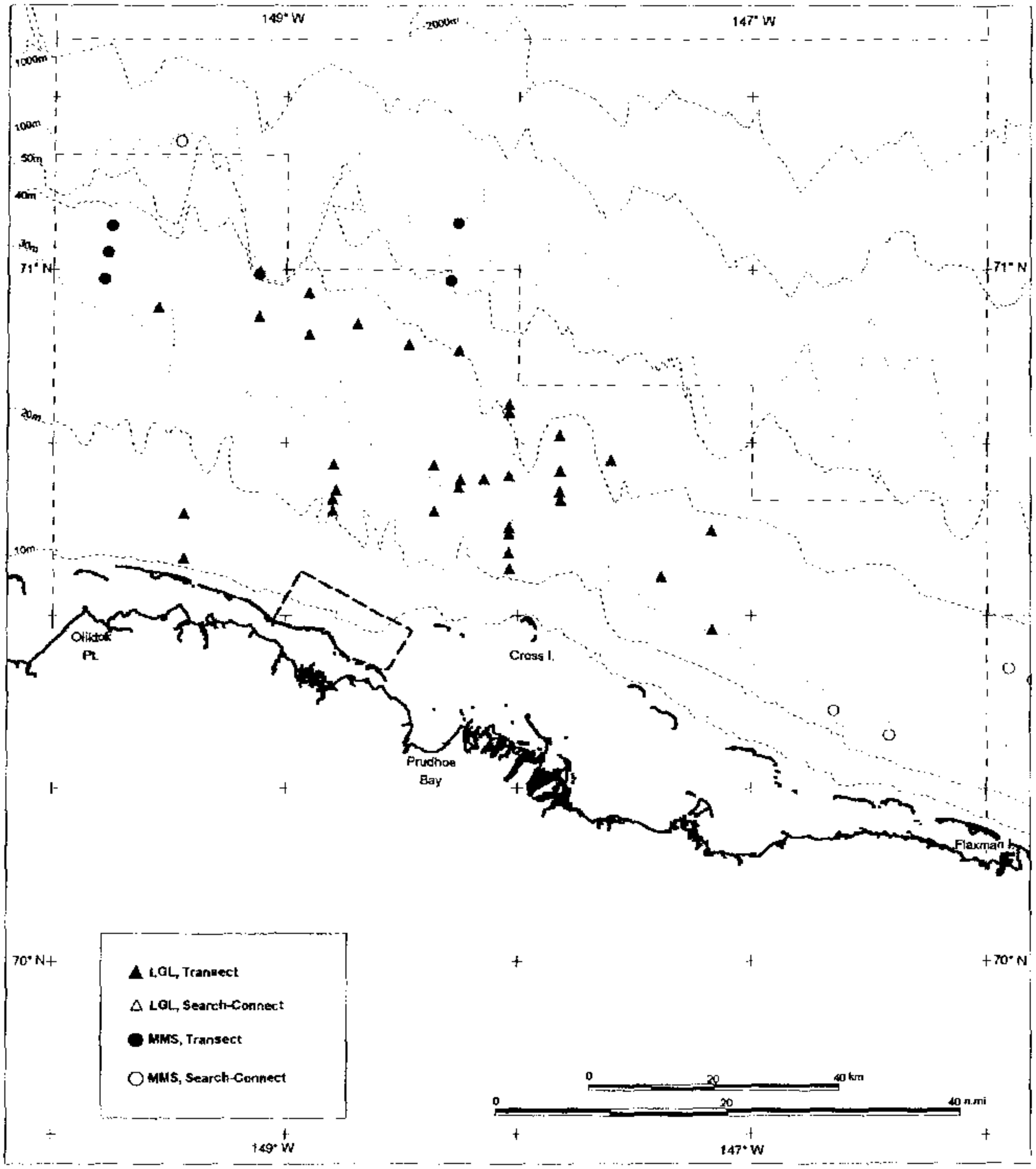


FIGURE 2.30. Ringed seal sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1995 based on MMS and LGL aerial surveys. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

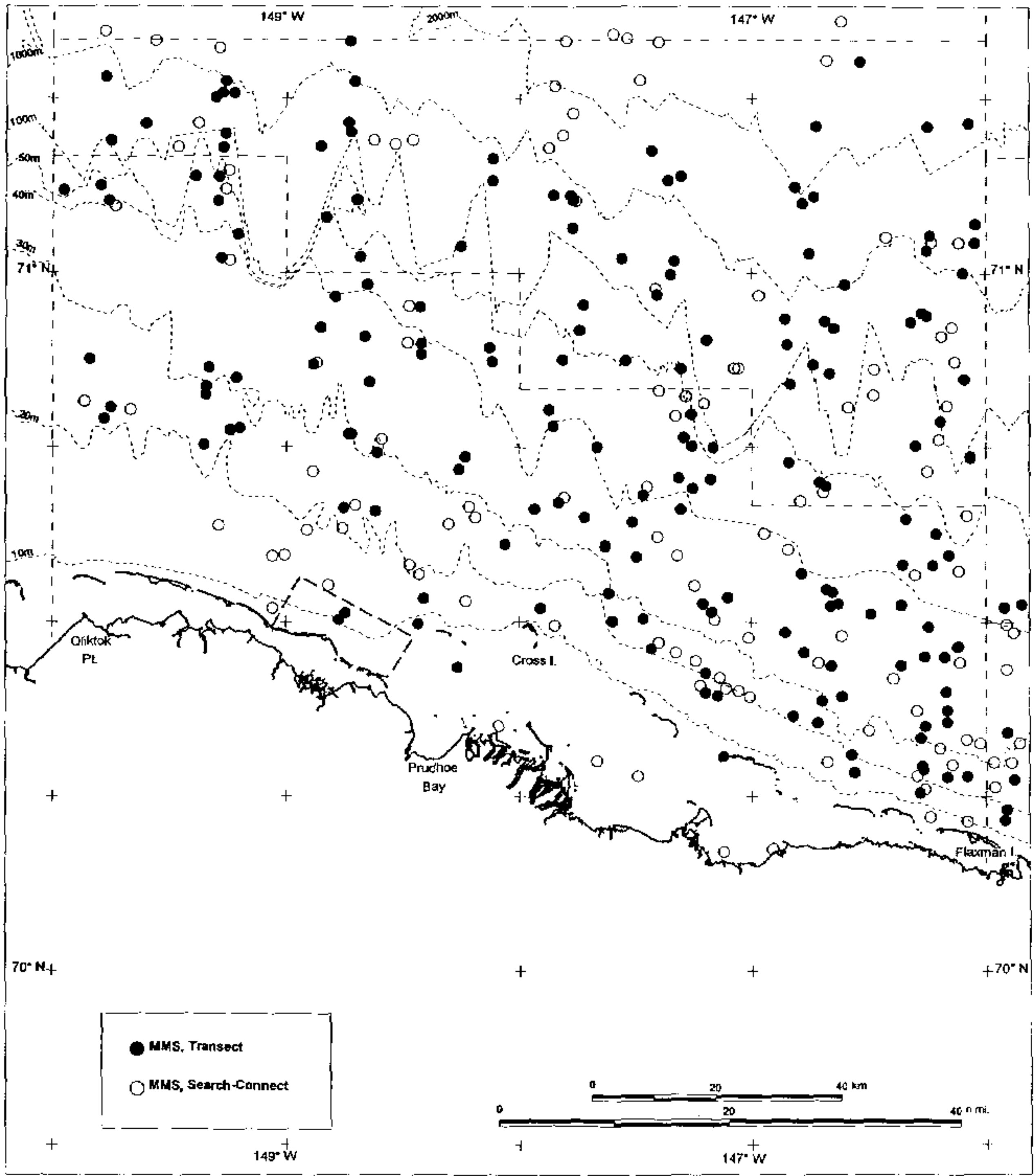


FIGURE 2.31. Ringed seal sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-94 based on MMS aerial surveys. Otherwise plotted as in Fig. 2.30.

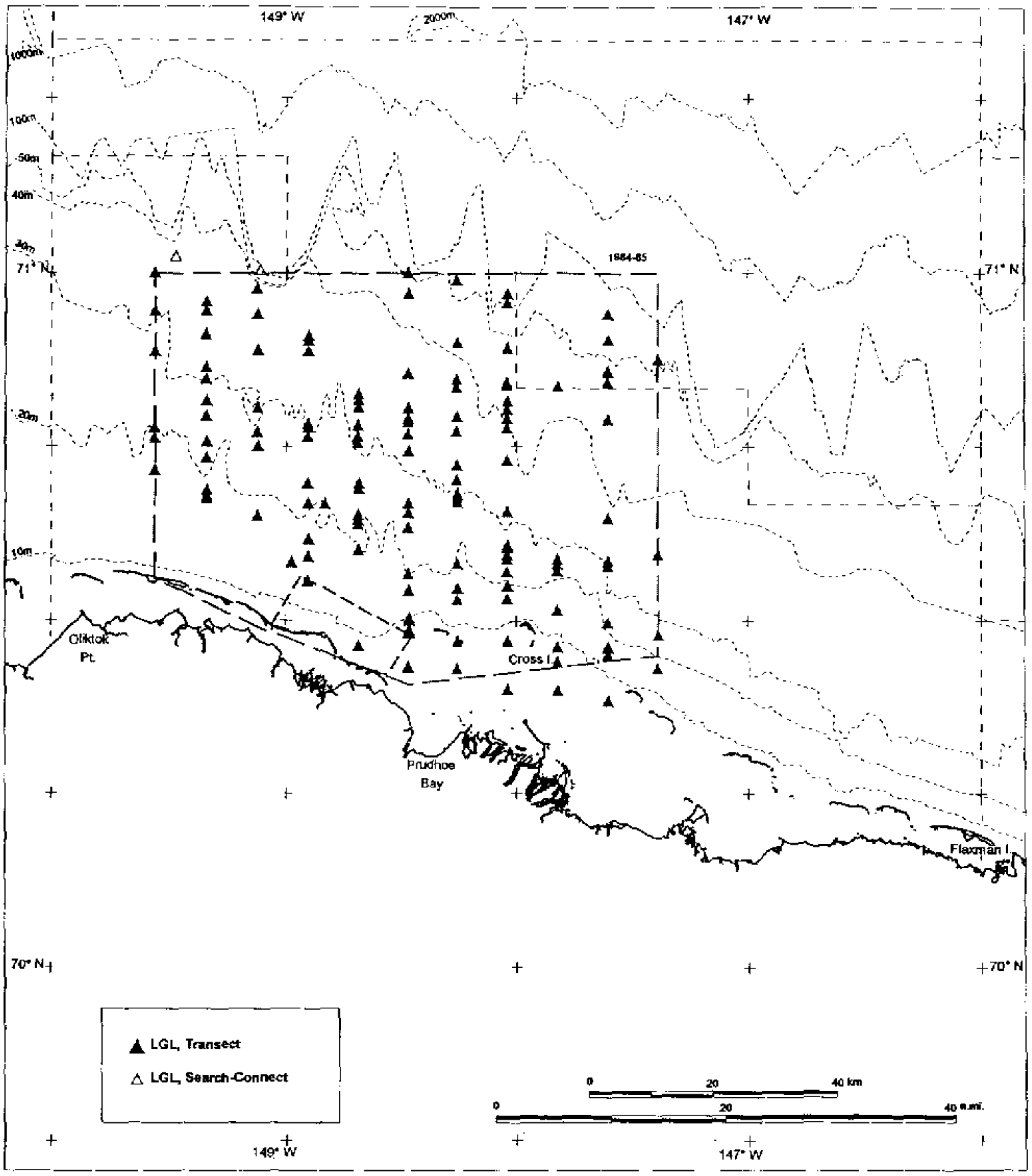


FIGURE 2.32. Ringed seal sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1984 and 1985 based on LGL aerial surveys. Dashed lines labeled 1984-85 show outlines of the areas surveyed by LGL in those years (see also Fig. 2.6). Otherwise plotted as in Fig. 2.30.

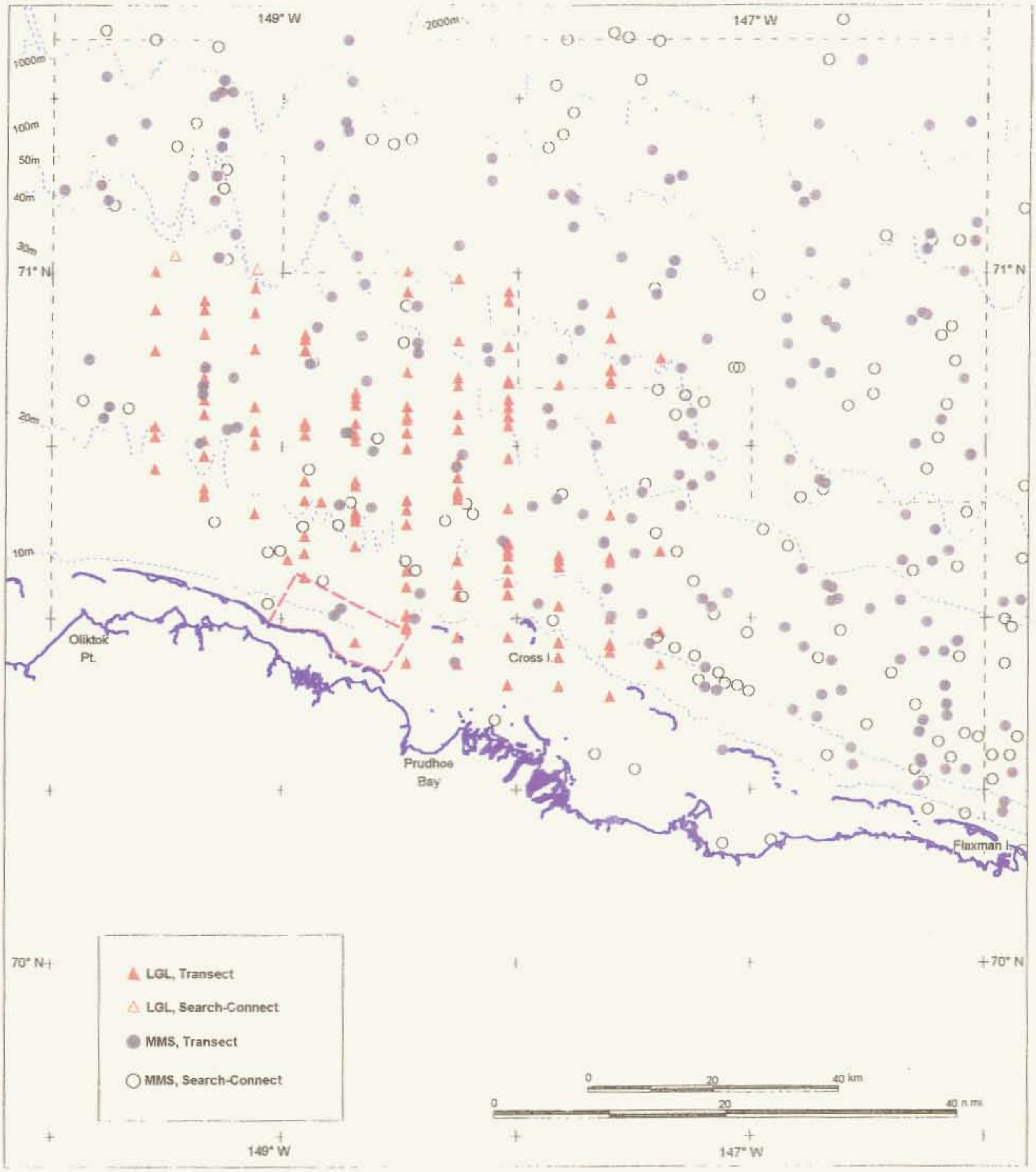


FIGURE 2.33. Ringed seal sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys (data of Fig. 2.31 and 2.32 combined).

attributable to seals recorded by LGL during 1995. Hickie and Davis (1983) noted that they saw few ringed seal during aerial surveys in the Seal Island area in 1982 (Fig. 2.5) until 9 October when seals began hauling out on new ice.

Discussion

During late summer and autumn ringed seals occur in the Northstar seismic area and are widely distributed throughout the surrounding area. Ringed seals in the water are difficult to detect from the altitudes at which most of the aerial surveys were flown. This is especially true when observers are searching primarily for whales. Ringed seals are undoubtedly more abundant in the region than these aerial survey data suggest.

2.6 Bearded Seal

Introduction

The Alaska stock of bearded seals, which occupies the Bering-Chukchi-Beaufort area of Alaska, has been estimated to consist of approximately 300,000 individuals (MMS 1996). Small and DeMaster (1995), on the other hand, indicate that "Until additional surveys are conducted, reliable estimates of abundance for the Alaska stock of bearded seals are considered unavailable". Nevertheless, the Alaska stock of bearded seals is not classified as a strategic stock by NMFS, and this classification is consistent with the recommendations of the Alaska Scientific Review Group (Small and DeMaster 1995).

The bearded seal is the largest of the northern phocids. It is primarily a bottom feeder and its preferred habitat is, therefore, areas with water depths less than 200 m. However, bearded seals apparently also feed on ice-associated organisms when they are present; a few bearded seals have been found associated with ice in water depths much greater than 200 m.

Seasonal movements of bearded seals are directly related to the advance and retreat of sea ice and to water depth. During the winter, most bearded seals in Alaskan waters are found in the Bering Sea. As the ice recedes in spring, bearded seals overwintering in the Bering Sea migrate northward during mid-April to June through the Bering Strait. During the summer most are found near the widely fragmented margin of multi-year ice covering the continental shelf of the Chukchi Sea and in nearshore areas of the central and western Beaufort Sea. In Alaska, bearded seals do not use coastal haul outs as they do in some other parts of their range.

In some areas, bearded seals are associated with the ice year-round; however, because bearded seals are primarily benthic feeders, they move into open water areas when the pack ice retreats to areas with water depths greater than 200 m. During the summer, when the Bering Sea is ice-free, the most favorable bearded seal habitat is found in the central or northern Chukchi Sea along the margin of the pack ice. Suitable habitat is limited in the

Beaufort Sea, where the continental shelf is comparatively narrow and the pack-ice edge frequently occurs seaward of the shelf and over water too deep for feeding (Nelson et al. n.d.).

Distribution

1995.—There were 5 sightings of bearded seals during the 1995 aerial surveys of the 146°-150°W area (Fig. 2.34). No bearded seals were observed in the Northstar seismic area—the nearest sighting was about 10 km to the N. All sightings were in shallow water between 10 and 40 m deep.

1979-94.—No bearded seals were sighted within the Northstar seismic area boundaries during aerial surveys conducted by MMS and LGL during the 1979-94 period (Fig. 2.35). However, several sightings occurred within a few kilometers of the northern edge of the Northstar seismic area (Fig. 2.35). Bearded seals were widely distributed in the region surrounding the Northstar seismic area. They were sighted in waters ranging from <10 m to >1000 m deep. Although bearded seals are known to prefer relatively shallow waters in which they can feed on benthic organisms, a few of the sightings recorded during the MMS surveys (which ranged farther north than the LGL surveys) were in waters north of the continental shelf. A few MMS sightings of bearded seals were in waters more than 3000 m deep and at latitudes north of 71°30'N (Fig. 2.36).

Seasonal Occurrence

During the 1979-95 period, there were 66 sightings for a total of 75 bearded seals in the Northstar region (147°-150°W) during late summer and autumn "Transect" surveys by MMS and LGL. Sightings of bearded seals declined steadily from a peak sighting rate of 0.27/100 km in the 16-31 August period to only 0.04/100 km during the 16-31 October period:

Aug.	September		October	
late	Early	Late	Early	Late
0.27	0.10	0.09	0.05	0.04

Some portion of the bearded seals that inhabit the Alaskan Beaufort Sea during the summer migrate into the Bering Sea to spend the winter months. The observed decline in bearded seal sightings over the late summer and autumn period is consistent with the departure of these individuals from the study area.

Discussion

Bearded seals were not sighted in the Northstar seismic area during the late summer and autumn aerial surveys conducted by MMS or LGL during 1979-95. However, bearded seals were sighted nearby, and were widely distributed throughout the surrounding area. Numbers declined as the season progressed.

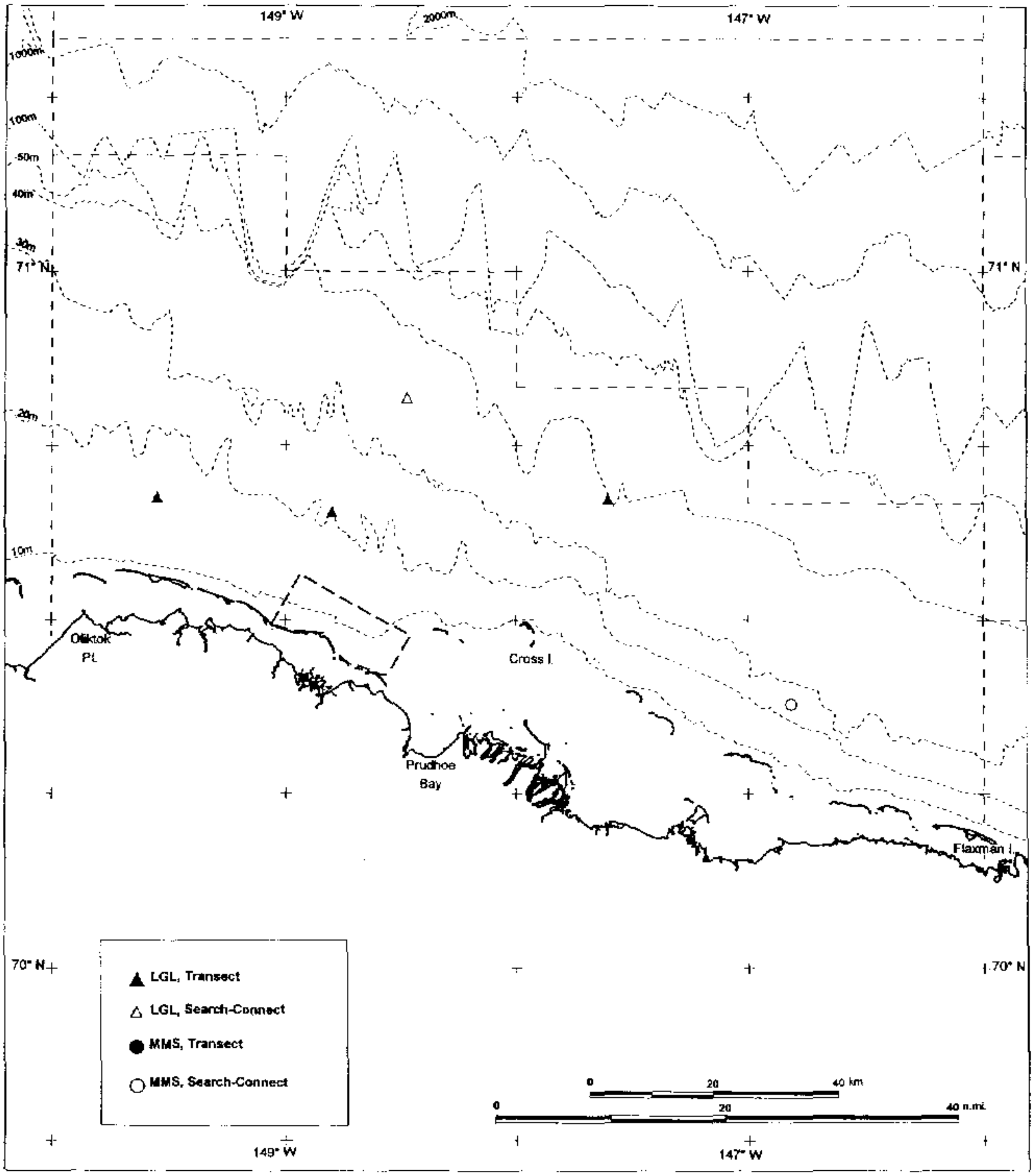


FIGURE 2.34. Bearded seal sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1995 based on MMS and LGL aerial surveys. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

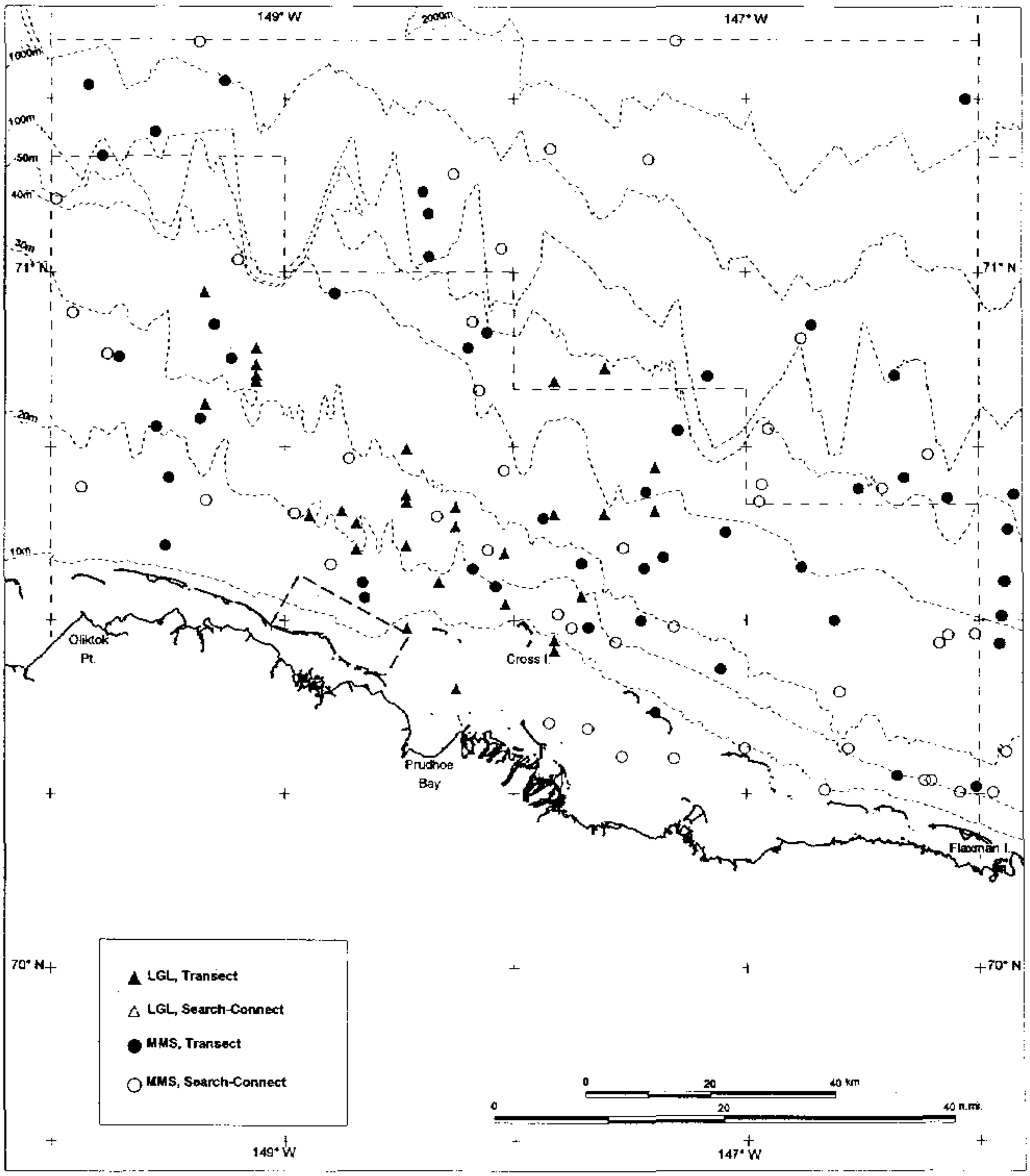


FIGURE 2.35. Bearded seal sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys. Otherwise plotted as in Fig. 2.34.

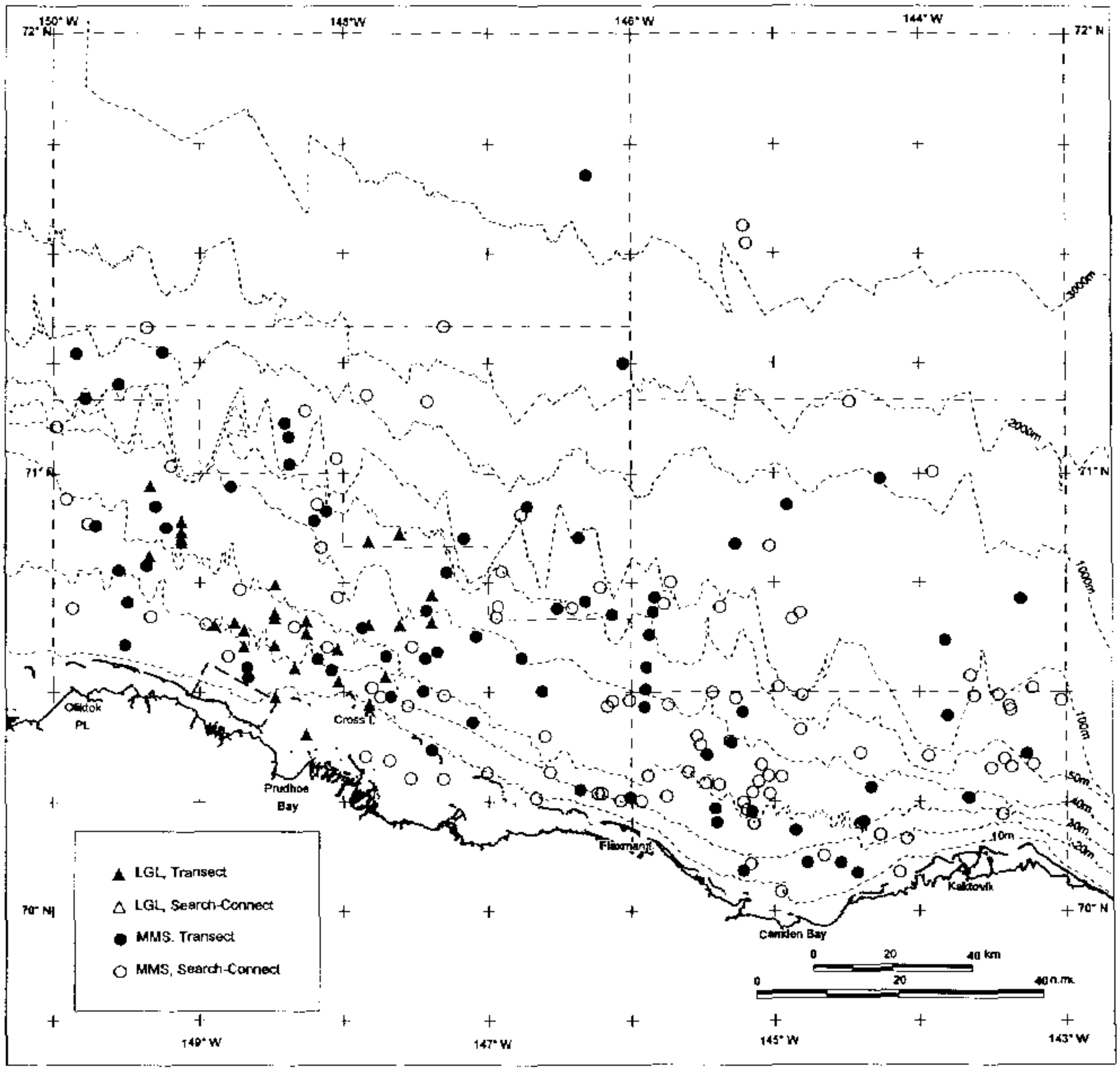


FIGURE 2.36. Bearded seal sightings in the central Alaskan Beaufort Sea (143°-150°W) during late summer and autumn of 1979-94 based on MMS and LGL aerial surveys, 1979-94. Excludes LGL and other non-MMS aerial surveys east of 147°W. Dashed lines show boundaries of MMS survey blocks 1, 2, 10 and 4, 6, 9 (*cf.* Fig. 2.2). Otherwise as in Fig. 2.34.

2.7 Spotted Seal

Introduction

An early estimate of the size of the world population of spotted seals was 370,000-420,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000-250,000 animals (Bigg 1981). An accurate estimate of the size of the entire Alaska stock of spotted seals is currently not available because of incomplete sampling (Small and DeMaster 1995). Nevertheless, the Alaska stock of spotted seals is not classified as a strategic stock by NMFS, and this classification is consistent with the recommendations of the Alaska Scientific Review Group (Small and DeMaster 1995).

During spring, when pupping, breeding, and molting occur, spotted seals are found along the southern edge of the sea ice in the Okhotsk and Bering seas. In late April and early May, adult spotted seals are often seen on the ice in female-pup or male-female pairs. Subadults may be seen in larger groups of up to 200 animals. During the summer, spotted seals are found primarily in the Bering and Chukchi seas, but some range into the Beaufort and perhaps into the East Siberian seas (Lowry n.d.). At this time of year, an unknown proportion haul out on mainland beaches and offshore islands and bars (Frost et al. 1993). Recent tagging studies during summer at Kasegaluk Lagoon, in the Chukchi Sea, indicate that spotted seals may travel long distances offshore to feed, and that a very small proportion (<10%) may be hauled out at any one time (Frost et al. 1993). In summer, they are rarely seen on the pack ice, except when the ice is very near to shore. The seals are commonly seen in bays, lagoons and estuaries, often in areas frequented by beluga whales. As the ice cover thickens with the onset of winter, spotted seals leave the northern portions of their range and move westward and southward into the Bering Sea.

A few spotted seal haul-outs occur in the central Beaufort Sea in the deltas of the Colville and Sagavanirktok rivers. Historically these sites supported as many as 400-600 seals, but in recent times <10 seals have been seen at any one site (J.W. Helmericks, pers. comm.; S.R. Johnson, LGL Ltd., unpubl. data). In total, there are probably no more than a few tens of spotted seals along the coast of the central Beaufort Sea during summer and early fall. They apparently feed in the lower reaches of the rivers or in the river deltas.

Results and Discussion

Spotted seals were not identified during the aerial surveys conducted by MMS and LGL during 1979-95. The Colville and Sagavanirktok river deltas are potential haul-out sites that may be used by small numbers of spotted seals during the summer and autumn. The Sagavanirktok river delta is within the Northstar region; the Colville river delta is west of 151°, at least 45 km west of the Northstar seismic area.

2.8 Walrus

Introduction

The Pacific walrus population, which includes about 80% of the world-wide walrus population, occurs primarily in the Bering and Chukchi seas. Approximately 250,000 walruses inhabited the Bering and Chukchi Seas in the early 1980s (Gilbert 1989; Fay et al. 1989). The population has undergone several cycles of reduction and recovery in the last century related to harvest pressures (Fay et al. 1989).

A large portion of the population is migratory. Females and young walruses, which are more migratory than adult males, travel northward from wintering areas in the Bering Sea, beginning in late March or April. This segment of the population spends the summer along the southern edge of the Chukchi Sea pack ice between Wrangel Island to the west and Point Barrow to the east (Sease and Chapman 1988). The main concentrations are near the coasts of Chukotka and Alaska rather than in central offshore portions of this range (Fay et al. 1984). The remainder of the population, primarily adult males, summers in the Bering Sea. When the pack ice begins to reform in autumn, the females and subadult males begin their southward migration toward the Bering Sea, swimming ahead of the pack ice in open water. By November most of them are in or south of Bering Strait.

Mating takes place from December to April on the pack ice southwest of St. Lawrence Island and in the Bristol Bay region. Calving occurs mainly from December to April on the ice, after a gestation period of about one year. The single calves remain with their mothers for about two years (Kenyon 1986).

Although the Alaskan Beaufort Sea is outside the principal range of the walrus, small numbers of walruses do occur in the Beaufort Sea in some years. The extent of these summer incursions probably varies with annual changes in ice conditions, and possibly with changes in the size of the population. Walruses feed on benthic organisms—primarily bivalves—and typically are found in waters <100 m deep.

Results

There have been five sightings of walruses between 146° and 150°W in the Northstar region during MMS and LGL aerial surveys conducted during the period from 1979 to 1995 (Fig. 2.37). The sightings ranged from about 8 to 38 km from the Northstar seismic area, in waters <40 m deep. The walrus sighted closest (8 km) to the Northstar seismic area was a dead individual. None of the sightings were within the Northstar seismic area, and all occurred before 1985.

The sightings occurred in the late 1970s and early 1980s. In 1979 Ljungblad et al. (1980) sighted four walruses on 31 August, two on 7 September, and one on 14 September. The sighting locations ranged from 12 to 31 km from the Northstar seismic area in waters

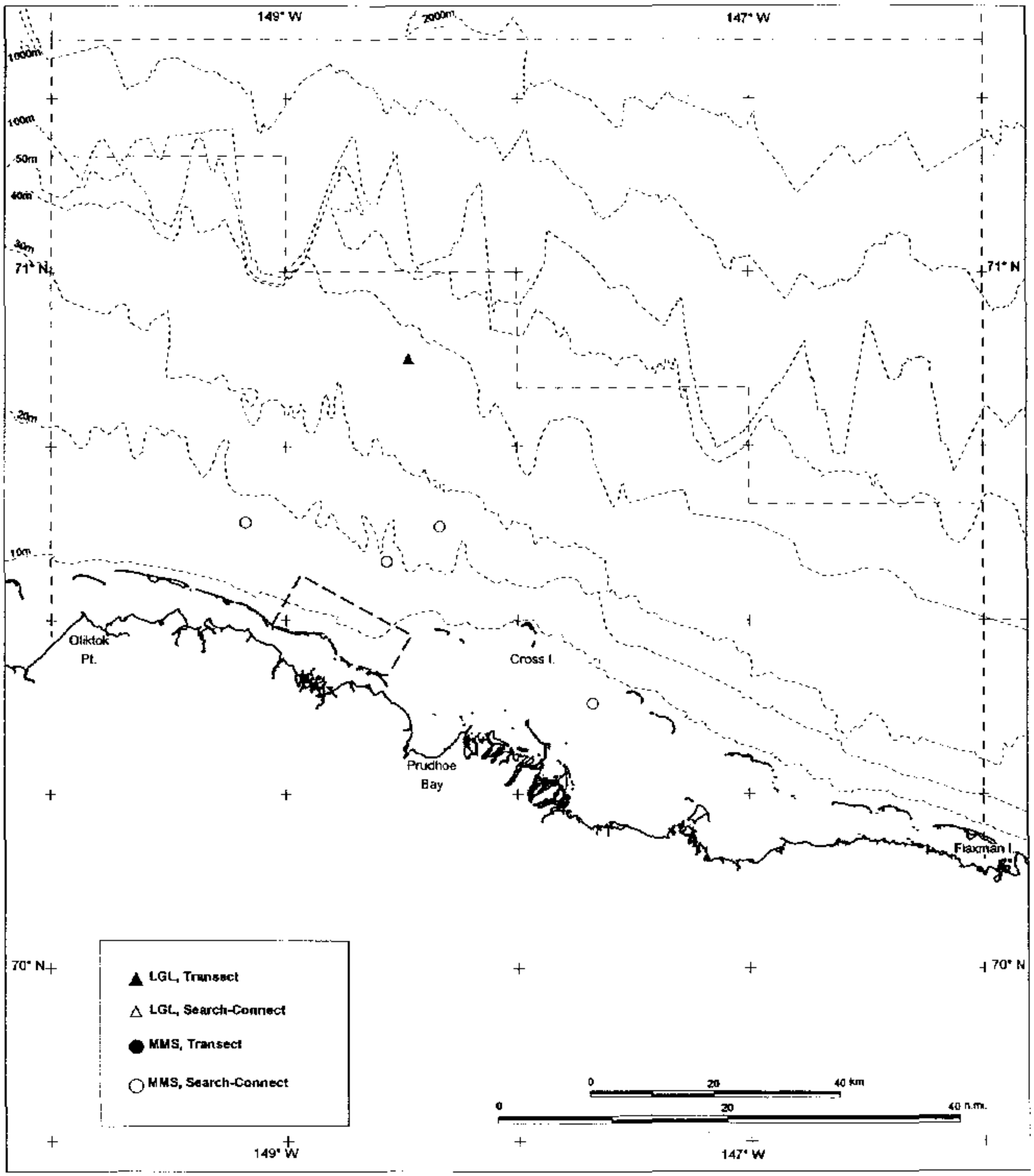


FIGURE 2.37. Walrus sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

<30 m deep. In 1981 a single dead walrus was sighted about 8 km north of the Northstar seismic area (<20 m depth) on 22 August. A single walrus was sighted during LGL surveys about 38 km north of the Northstar seismic area on 28 September 1984, in water <40 m deep.

Discussion

Walrus sightings are unusual in the area surrounding the Northstar seismic area, which is well to the east of the main summer range. During the 17-year study period, an average of 0.3 sightings and 0.5 individuals were recorded per year. The few sightings recorded were in shallow waters and relatively close to the Northstar seismic area. However, walruses have not been recorded in the general area during aerial surveys for over a decade.

2.9 Polar Bear

Introduction

Polar bears are long-lived carnivores that inhabit most ice-covered seas of the northern hemisphere. Their local distribution and numbers vary throughout the year, being strongly influenced by the distribution and abundance of their principal prey, the ringed seal, and by the presence or absence, distribution, and quality of sea ice. Along the Alaskan coast of the Beaufort Sea they are commonly found within about 280 km of shore (Amstrup and DeMaster 1988). There are an estimated 3000-5000 polar bears in Alaska (Amstrup and DeMaster 1988); the Beaufort Sea (Alaskan and Canadian) population for the 1972-83 period was estimated to be 1776 individuals (Amstrup et al. 1986).

During winter and spring, polar bears tend to concentrate in three types of ice: shorefast ice with deep drifted snow along pressure ridges, the floe edge, and areas of drifting ice with 7/8 or more ice cover (Stirling et al. 1975, 1981). Highest densities are recorded in the latter two categories, presumably because these habitats offer bears greater access to seals.

In spring and early summer polar bears move north with the ice as it recedes from coastal areas. They remain on the drifting pack ice during the summer months. Little has been published about their offshore distribution during this season.

In autumn when new ice begins to form, polar bears that summered on pack ice well north of the Alaskan coast begin moving south. Some pregnant females go onshore in November and early December to establish maternity dens in deep snow drifts. However, in the Alaskan Beaufort Sea region most females den on multiyear pack ice (Amstrup 1986). Cubs (one or two) are born in late December and early January and remain in the maternity den with the mother until late March or early April. Upon emerging from terrestrial dens the mother and cubs move out onto the pack ice. Cubs usually stay with their mothers until they are 1½ to 2½ years old, although some may remain with the female into their third or fourth year (Stirling et al. 1975). The breeding season is from April through June when both males and females are active on the sea ice, and gestation lasts about eight months.

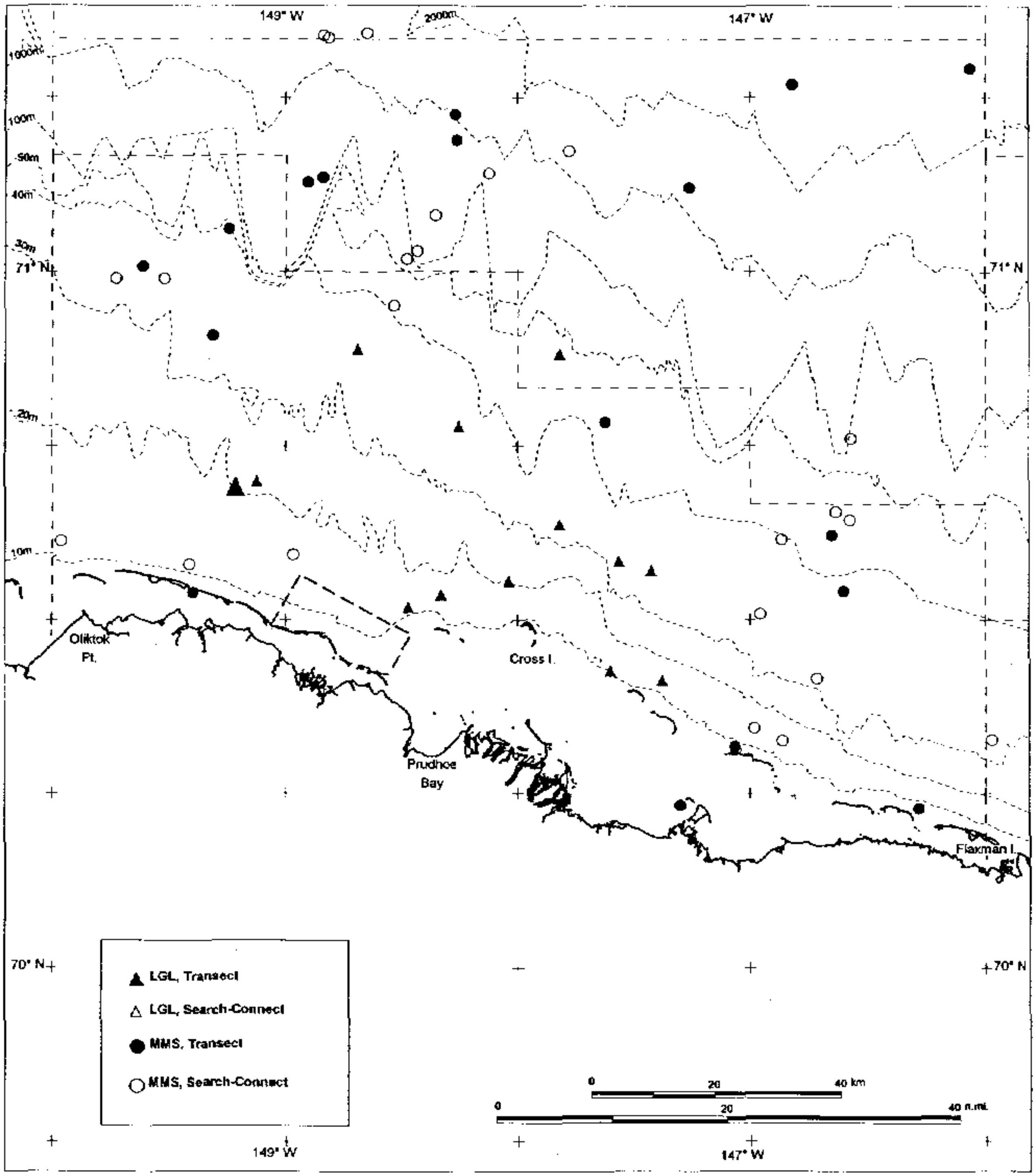


FIGURE 2.38. Polar bear sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. The large symbol represents the only 1995 sighting. Sightings of tracks or kills but no bear are excluded. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

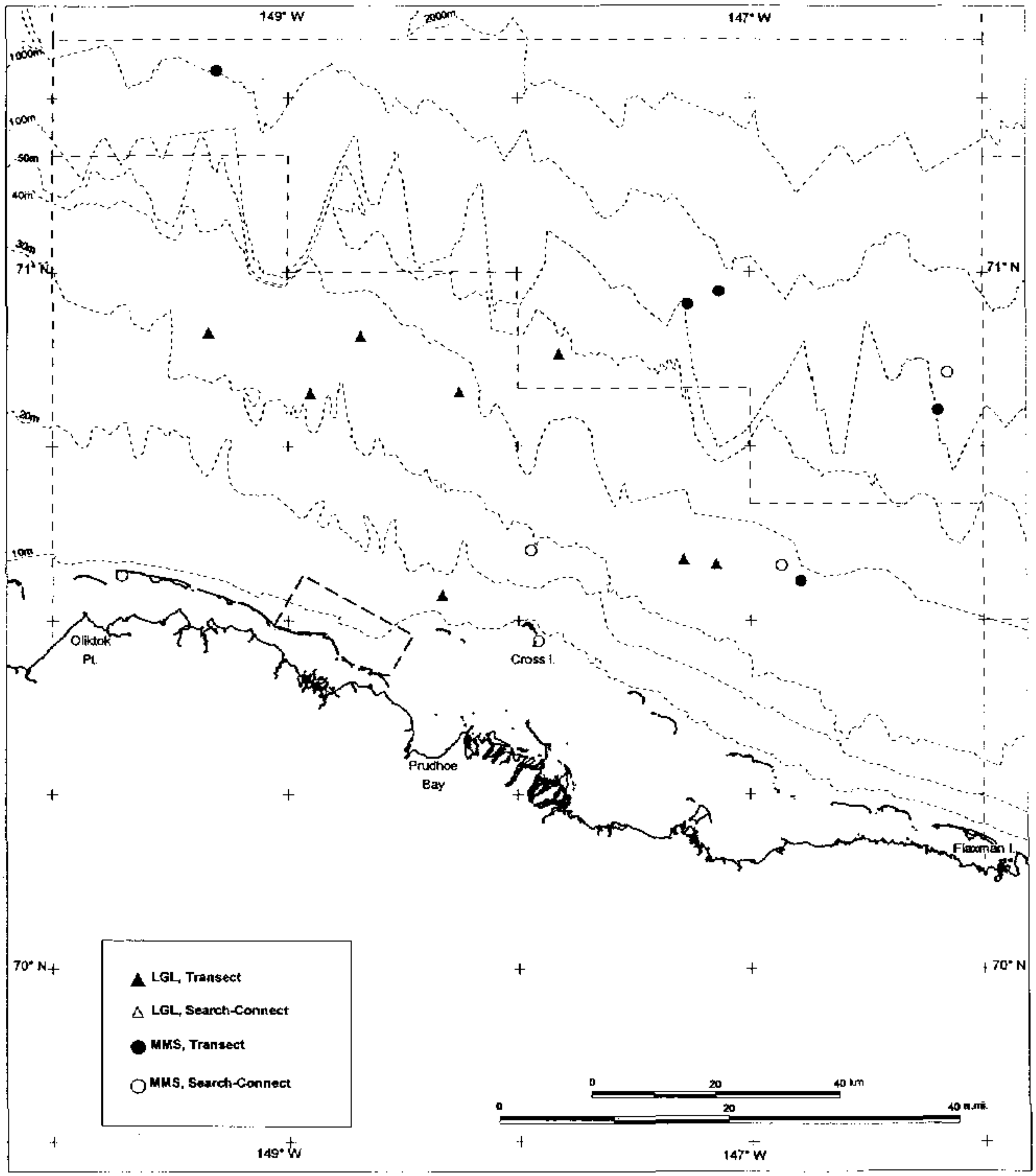


FIGURE 2.39. Polar bear kill sightings in the Northstar region of the central Alaskan Beaufort Sea (146°-150°W) during late summer and autumn of 1979-95 based on MMS and LGL aerial surveys. See METHODS for explanation of "Transect" vs. "Search-Connect" sightings. Heavy dashed lines show Northstar seismic area. Faint dashed lines show boundaries of MMS survey blocks 1 and 2 (*cf.* Fig. 2.2).

Seals are the primary prey of polar bears throughout their range. In the Alaskan arctic, polar bears prey primarily on ringed seals, and to a lesser extent on bearded seals. Walruses and belugas are occasionally taken by polar bears but are not considered an important part of their diet.

Distribution

1995.—One polar bear was recorded during the 1995 aerial surveys on 29 August (Fig. 2.38). This bear was sighted about 17 km NW of the Northstar seismic area, swimming amongst loose pack ice (30% ice cover) in water about 20 m deep. No polar bear kills (prey species killed by polar bears) were sighted during the 1995 aerial surveys.

1979-94.—There were no polar bear sightings within the Northstar seismic area boundaries during aerial surveys conducted by MMS or LGL during the 1979-94 period (Fig. 2.38). However, there were a few polar bear sightings within several kilometers to the NE, N and W of the Northstar seismic area (Fig. 2.38). Details are available for 2 of 3 sightings within 10 km of Northstar. The closest sighting was of a single adult polar bear swimming through slush ice ~3 km NE of the Northstar seismic area on 4 October 1982. A sighting 8 km NE of Northstar on 13 October 1982 involved three bears at a kill on new ice. Other polar bears were widely distributed in the region surrounding the Northstar seismic area, with sightings ranging from south of the barrier islands to as far north as 71°20'N. Polar bears were found in water depths ranging from <10 m to >1000 m.

No polar bear kills were observed within the Northstar seismic area during MMS and LGL surveys conducted during 1979-95 (Fig. 2.39). The nearest polar bear kill to the Northstar seismic area was about 8 km northeast. In the region around the Northstar seismic area polar bear kills were detected in an 80 km wide band paralleling the coast and extending from the barrier islands out to the 1000 m depth contour.

Seasonal Occurrence

A total of 26 sightings of 33 polar bears were recorded in the Northstar region (147°-150°W) during late summer and autumn "Transect" surveys by MMS and LGL during the 1979-95 period. The sighting rates ranged from 0.01/100 km during the 1-15 September period to 0.05/100 km during the 1-15 October period. No pattern in the timing of sightings was apparent for this rarely sighted (fewer than two "Transect" sightings per year) species.

Discussion

Polar bears were sighted near but not in the Northstar seismic area during late summer and autumn. Sightings were widespread throughout the region surrounding the Northstar seismic area during that season.

3. AMBIENT NOISE[2]

Ambient noise is the background sound excluding any specific sound sources that are being studied, and also excluding sound from any other sources not normally present (Richardson et al. 1995, Chap. 5). Ambient noise varies widely with location, season, time and numerous environmental parameters, especially shipping, wind and waves. Ambient noise is important in bioacoustics because it defines the background levels in which animals might receive sounds of interest. In particular, ambient noise will often mask the reception of industrial sounds (or mammal calls) by marine mammals beyond some distance from the source. This distance depends not only on ambient noise level but also on the initial strength of the industrial sound or call (its source level), the rate at which sound level diminishes during transmission (transmission or propagation loss), and the animals' hearing sensitivities. Other factors being equal, detection distance will be shorter when the ambient noise level is high and longer when it is low.

Sound characteristics are described by their sound pressures in micropascals (µPa), which are tiny variations in pressure. The hydrostatic pressure of a 10 m column of water is 1.01×10^{11} µPa (1 atmosphere), whereas the variations in pressure associated with a typical overall ambient noise level of 90 dB re 1 µPa are only 3.16×10^{4} µPa (rms). The rate of the pressure variations determines the frequency of the sound, which is measured in hertz (Hz, cycles per second). Random noise is distributed across a wide range of frequencies, in contrast to tones that are concentrated at single frequencies. To describe random noise, which is what most ambient noise is, requires examining sound pressures in specified frequency bands or as sound spectral densities. For example, an octave band spans a range of frequencies where the upper limit is twice the lower limit, so octave bands at higher frequencies cover more hertz than octave bands at lower frequencies. As a result, if a sound is uniformly distributed across all frequencies of interest, there will be higher sound power or sound level in higher octave bands. It is common practice to describe wideband and ambient sounds in 1/3-octave frequency bands, and we have followed that practice in this report. There are three 1/3-octave bands within each octave, with the boundary frequencies being spaced evenly on a logarithmic frequency scale. Adjacent boundary frequencies for 1/3-octave bands differ by factors of about 1.23x. Richardson et al. (1995, Chap. 2) describes acoustic concepts and terminology.

This section of the report presents ambient noise measurements from the Northstar region based on measurements in 1995 and earlier years. Using ambient noise statistics such as these, plus appropriate transmission loss models and estimates of the source levels of industrial sounds (or mammal calls), it would be possible to estimate the radii within which different species of marine mammals could potentially hear those industrial sounds or calls.

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[2] By Charles R. Greene, Jr., Greeneridge Sciences Inc.

One could also determine the differences between the industrial noise level and the ambient noise level at various distances from the industrial source, i.e. the "industrial-to-ambient ratios". The latter type of information is often important in estimating potential behavioral response radii around a source of man-made sound (Richardson et al. 1995, Chap. 10).

3.1 Sources of Data

Sonobuoys, August 1995

Aerial surveys for marine mammals were flown in the vicinity of the Northstar Unit (NSU) from 23 to 30 August 1995. Calibrated AN/SSQ-57A sonobuoys were dropped each day beginning 24 August. The sonobuoys, manufactured by Sparton Corporation, were modified so that the hydrophone depth was 10 m (33 ft) to permit their use in the shallow waters around NSU. These sonobuoys have omnidirectional hydrophones and frequency response from 10 to 20,000 Hz. However, the response is not constant with frequency: the low frequencies are de-emphasized (lower sensitivity) and the high frequencies are emphasized (higher sensitivity) for the purpose of increasing dynamic range (Richardson et al. 1995:38). This increasing sonobuoy sensitivity with increasing frequency counters the naturally-occurring decrease in ambient noise levels with increasing frequency.

Four sonobuoys were dropped during each flight. Four calibrated, wideband FM radio receivers were tuned to the respective sonobuoy radio channels. A TEAC model RD-101T digital audio tape (DAT) recorder was used to record the signals. The recorder band width was 0-10,000 Hz per channel, although the sonobuoy low frequency limit was effectively 10 Hz.

The sonobuoys were dropped at the locations shown in Figure 3.1. On most days, two sonobuoys were dropped at different distances offshore of Northstar, and two more were dropped farther west, near the west edge of the survey area. The signals were recorded continuously, but—as expected—the aircraft was not always sufficiently close to record adequate-quality signals. When the range was too great, radio static was present along with the underwater sounds. When the range was too short, the sounds from the aircraft engines and propellers were received underwater and were recorded; these appeared as tones at the propeller blade rate. Times when the recordings were contaminated by radio static or by aircraft sounds were excluded from the results reported below.

Seal Island Bottom Hydrophone, September 1984

Seal Island was an artificial gravel island built during the winter of 1982 about 5 km northeast of the barrier island system and about 22 km northwest of Prudhoe Bay. Shell Western Exploration and Production Inc. (SWEPI) installed a drillrig on Seal Island during the summer of 1984, intending to conduct exploratory drilling during the fall and winter. The rig was on standby during bowhead whale migration in September and early October—only a generator was operating to supply camp power. Staffing was minimal, and sounds from

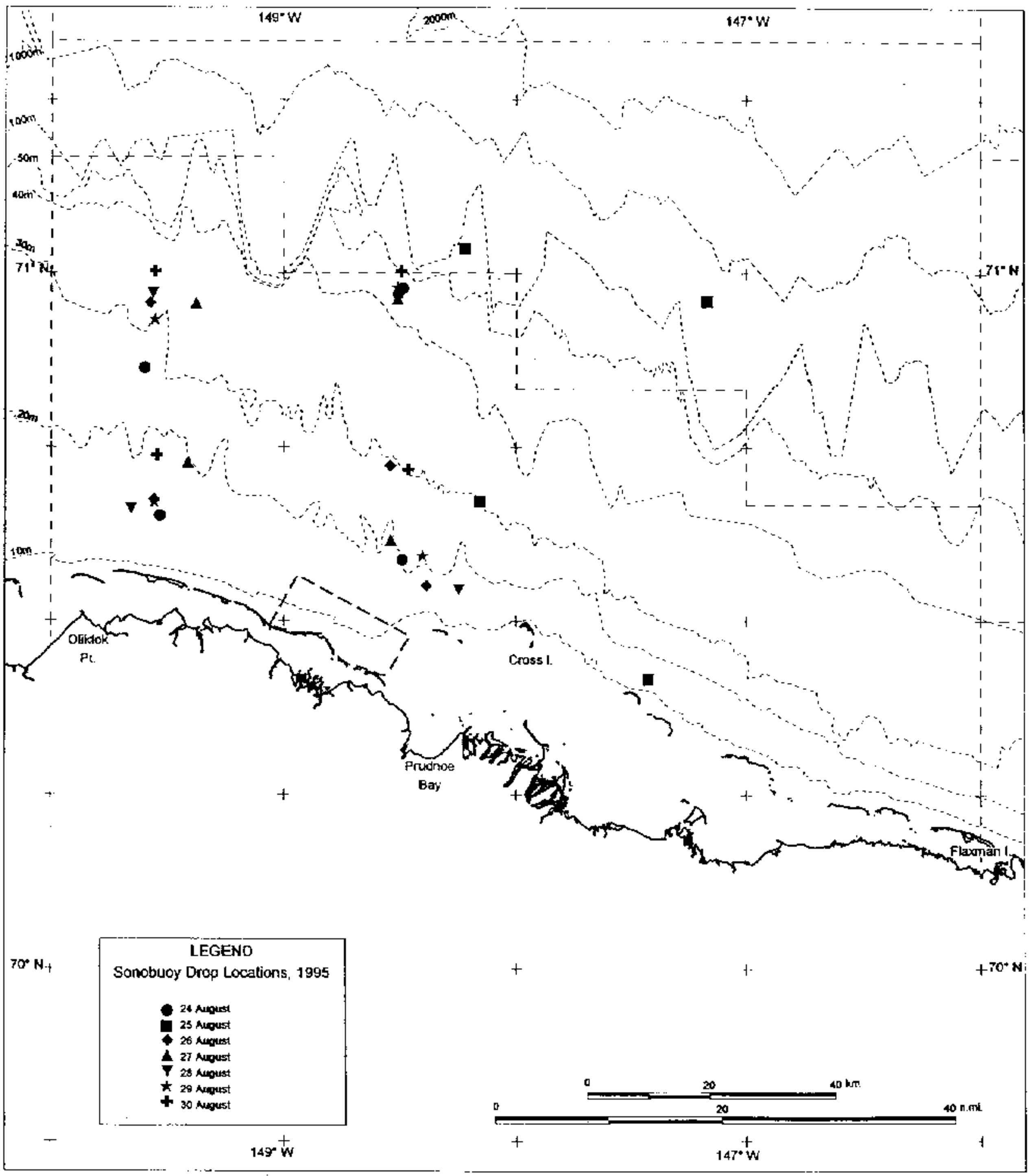

FIGURE 3.1. Map of August 1995 sonobuoy drop locations in relation to the planned Northstar seismic exploration area and the Alaska Coast.

the island were also minimal. Four hydrophones were installed north and east of Seal Island at distances 1.6-2.5 km and water depths 11.0-13.1 m. Their locations are indicated in Figure 3.2 (from Davis et al. 1985). Calibrated frequency response was flat from 5 to 1000 Hz. The hydrophone signals were recorded on a Fostex model 250 4-channel cassette tape recorder with calibrated frequency response from 10 to 15,000 Hz.

Hydrophone three malfunctioned and was not useful, but the other three hydrophones were monitored for bowhead whale calls and recorded hourly for ambient noise analyses on 21-29 September 1984. On the 29th, a storm moved ice floes that severed the hydrophone cables. The ambient noise levels from the three hydrophones were comparable, and hydrophone four was selected as a basis for measuring the ambient sounds reported here. It lasted the longest during the 29 September storm, providing more data than the other two hydrophones. Wind speed and direction at Seal Island were recorded hourly, corresponding to the times when ambient noise levels were measured.

At times barges and boats visited Seal Island or passed nearby. Those vessels had a major impact on the noise levels recorded. Noise recordings with boats and barges were excluded from these data—they did not represent ambient noise conditions.

Sandpiper Island Bottom Hydrophone, Sept - Oct 1985

SWEPI built another artificial gravel island named Sandpiper Island and installed a drillrig for exploratory drilling in the autumn of 1985 (Johnson et al. 1986). The water depth was 15 m. Figure 3.3 shows the location of Sandpiper Island on a map including Seal I., Northstar I., and Prudhoe Bay. The rig was on standby during whale migration, with low manning and only a generator running for camp power from 27 September through 11 October. A single hydrophone was installed 450 m NNW of the island. Its frequency response was flat from 5 to 1000 Hz. The hydrophone signals were recorded on a Sony TC-D5M cassette tape recorder with calibrated frequency response from 10 to 16,000 Hz. As at Seal I., wind speed and direction were recorded hourly, corresponding to the times when ambient noise levels were measured. Data that included vessel noises were excluded from this study.

3.2 Analysis

Analysis of the tape-recorded data was based on fast Fourier transforms (FFT) to compute acoustic pressure spectral densities. Raw analysis results were adjusted based on calibration data from hydrophones and tape recorders. Then, the resulting narrowband pressure densities were summed appropriately to compute 1/3-octave band levels. Examples of such narrowband and 1/3-octave band results are presented in Figure 3.4 for a sonobuoy signal recording from August 1995. The analysis parameters for these and other 1995 sonobuoy data were as follows: low-pass filtering at 8 kHz, 16,384 samples/second, FFT block length 8192 samples (0.5 s), Blackman-Harris windowed and 50% overlapped over a segment length of 8.25 s (averaging time), 2.0 Hz cell separation, and 3.4 Hz spectral resolution.

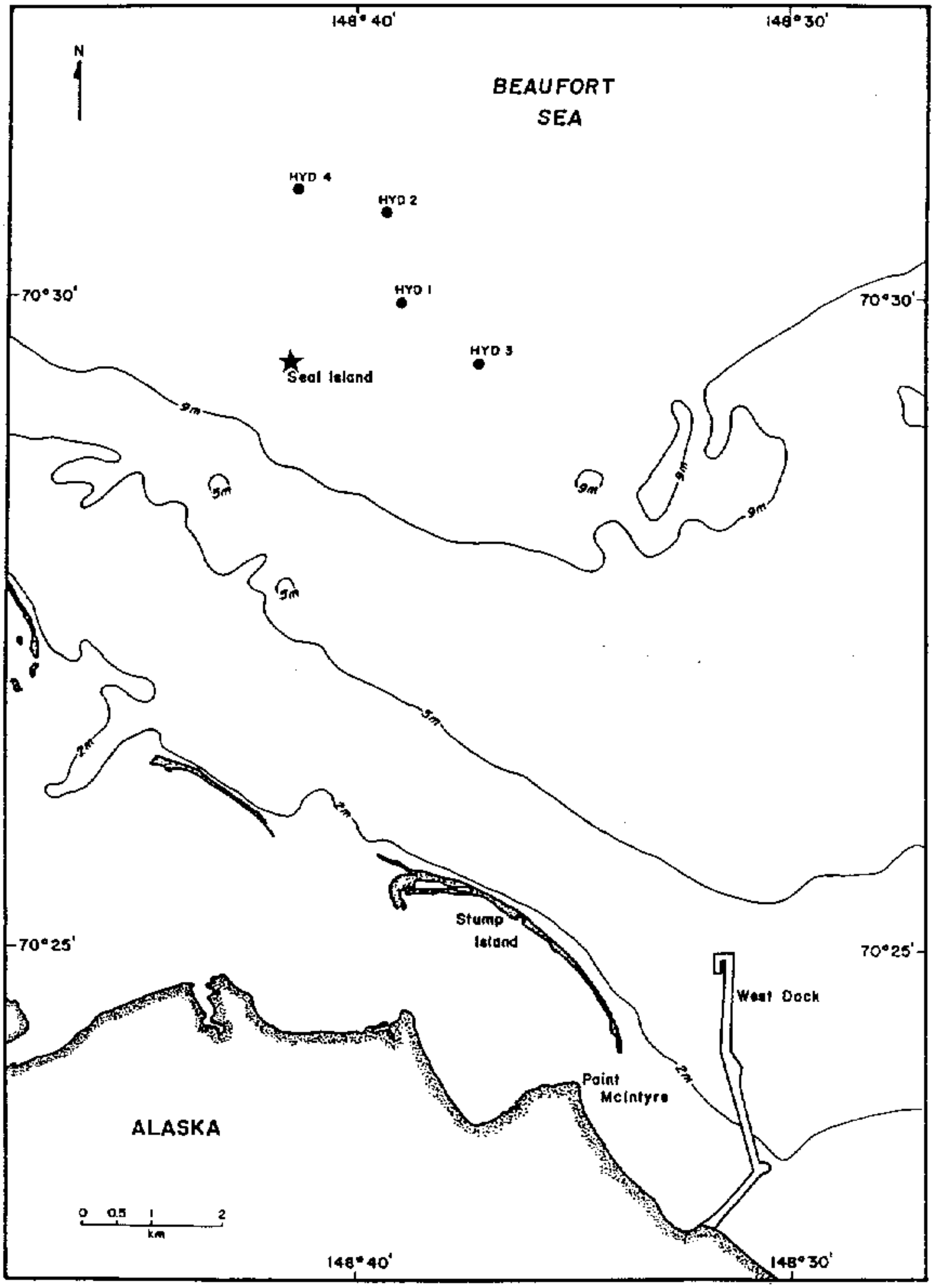

FIGURE 3.2. Location of Seal Island and hydrophones, also showing West Dock at Prudhoe Bay.

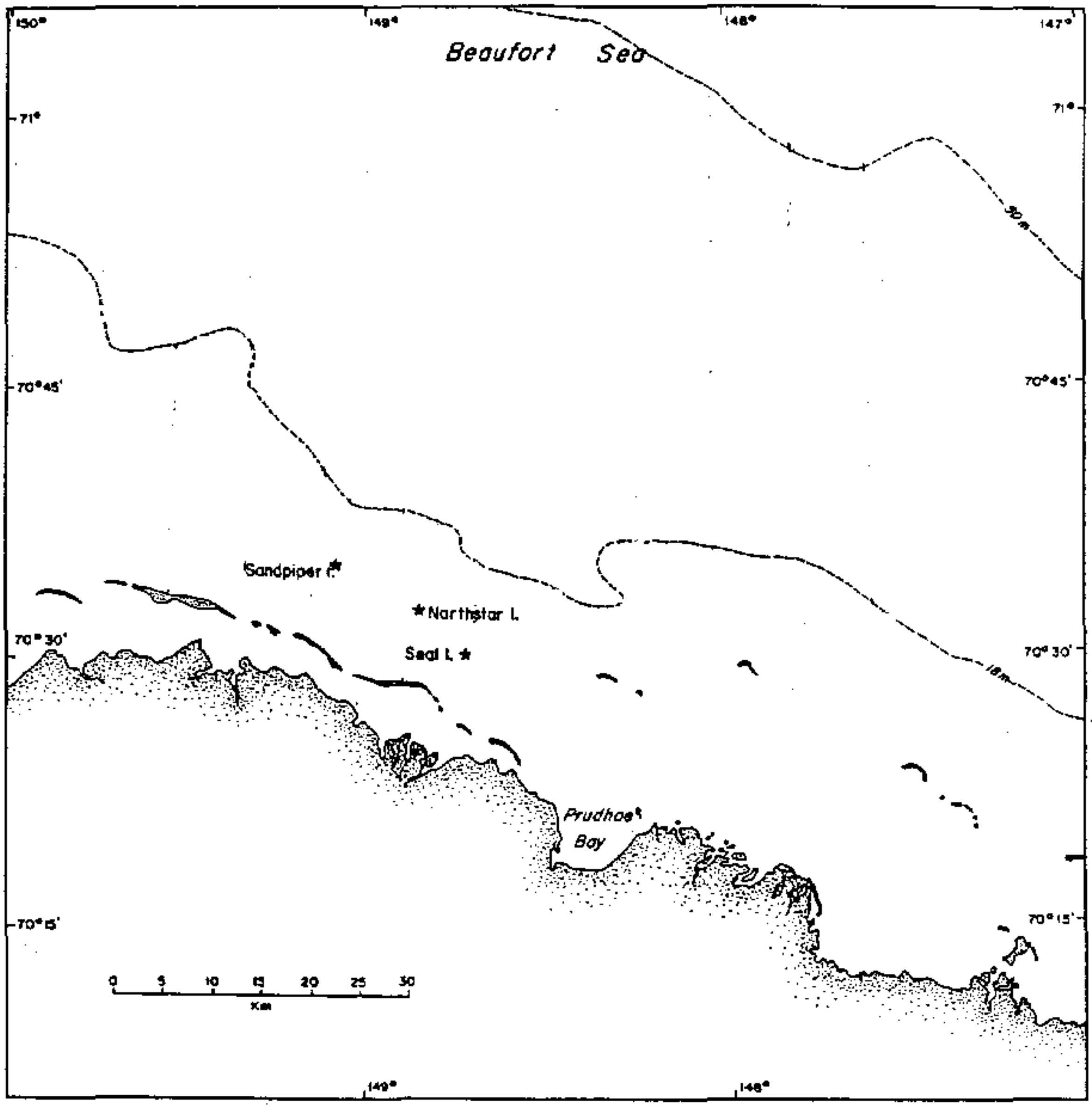

FIGURE 3.3. Location of Sandpiper Island in relation to Seal and Northstar Islands.

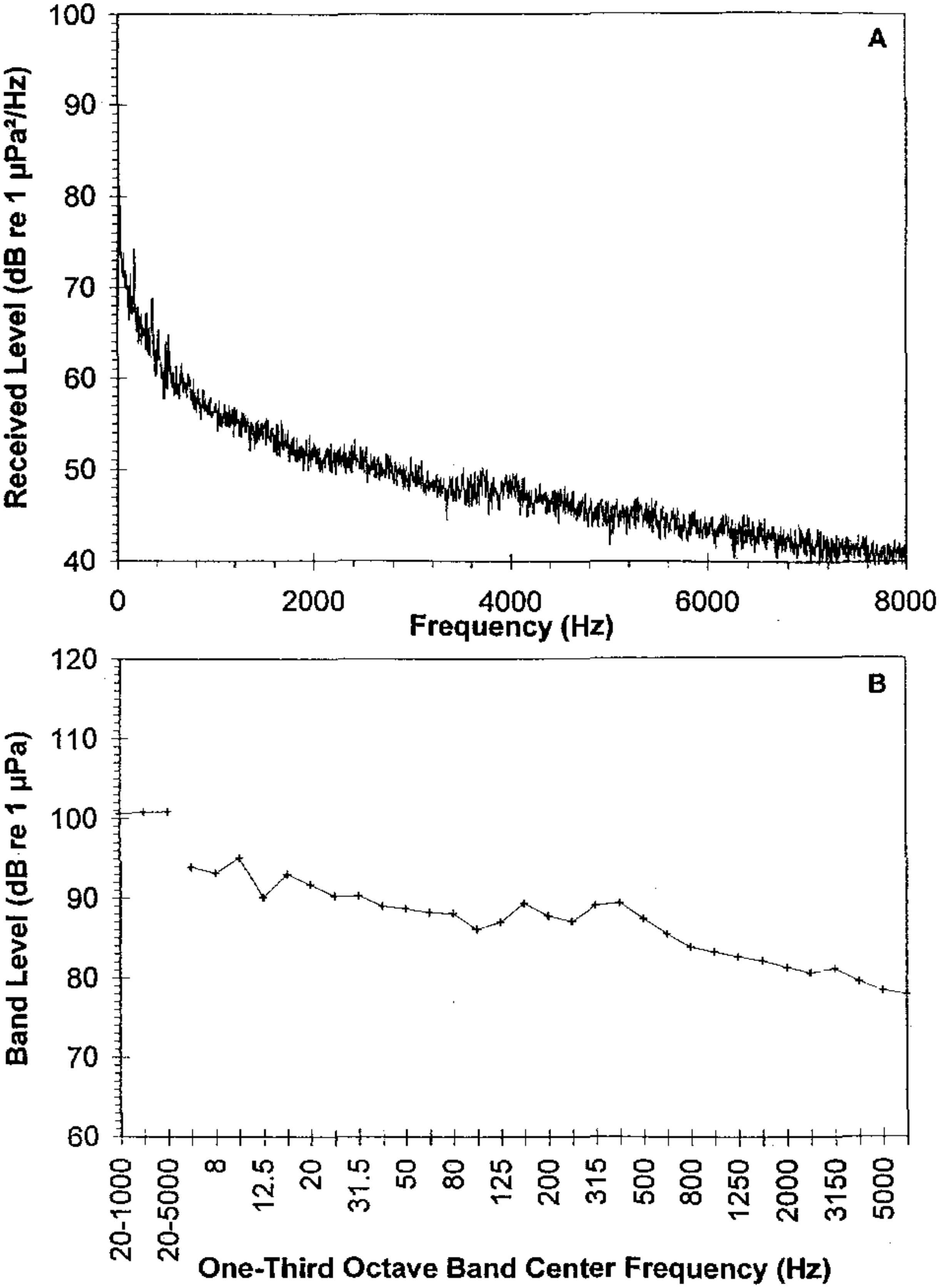

FIGURE 3.4. Examples of spectrum analysis results from a sonobuoy dropped near Northstar in August 1995. (A) Narrowband spectrum analysis. (B) Corresponding 1/3-octave band levels, also showing 20-1000, 20-2000 and 20-5000 Hz broadband levels.

Analysis parameters for the bottom hydrophone signals from Seal Island (1984) and Sandpiper Island (1985) were as follows: low-pass filtering at 1 kHz, sample frequency 2048 samples/second, FFT block length 2048 samples (1.0 s), Blackman-Harris windowed and 50% overlapped over a segment length of 8.5 s (averaging time), 1.0 Hz cell separation, and 1.7 Hz spectral resolution. For these bottom hydrophone signals, 1/3-octave band levels were computed for band center frequencies from 20 to 800 Hz. Analysis was done for every hour on the hour.

For all three years, broadband levels for the 20-1000 Hz band were computed and stored.

For each analysis time, the 1/3-octave band levels and the broadband level were saved in a spreadsheet with date and time, water depth, wind speed, wind direction, and ice cover observations. Samples containing boat, barge or other industrial sounds were flagged so they could be ignored in certain analyses. The spreadsheet data were examined statistically for relationships between ambient noise levels and environmental variables.

3.3 Results

Sonobuoys, August 1995

Analyses of each sonobuoy signal were attempted from recordings made shortly after drop time and on the hours thereafter during the flight, resulting in 98 analyses. However, the aircraft was not always within satisfactory radio range and 20 analyses were deleted due to excess radio static. All analyses were evaluated on a subjective scale of 100% for a clear signal to 0% for no underwater sounds heard. Some analyses contained components of the survey aircraft sounds, specifically, a propeller blade-rate tone at about 110 Hz, with the exact frequency depending on propeller rotation speed, and weaker harmonics. When present, the fundamental tone slightly increases the level of the 1/3-octave band centered at 100 Hz. Accepting only the analyses rated 70% or better, and deleting analyses for which wind speed or ice cover data were missing, 40 analyses were retained and entered into the spreadsheet.

Wind speed and direction were recorded at Deadhorse (Prudhoe Bay) but not always on the hour. The recorded observations were interpolated to obtain estimates at the times of the acoustic analyses.

Figure 3.5A presents the 20-1000 Hz band levels and wind speed vs. time of recording. The spread in levels observed each day arises from the geographical diversity of sonobuoy locations as well as the passage of a few hours. The correlation coefficients between the 1/3-octave band levels and wind speed were relatively low (Fig. 3.5B). The near-zero correlation for the 1/3-octave band centered at 100 Hz corresponds to the presence of the aircraft propeller tone. The low correlations for other frequency bands suggest that the wind speed observa-

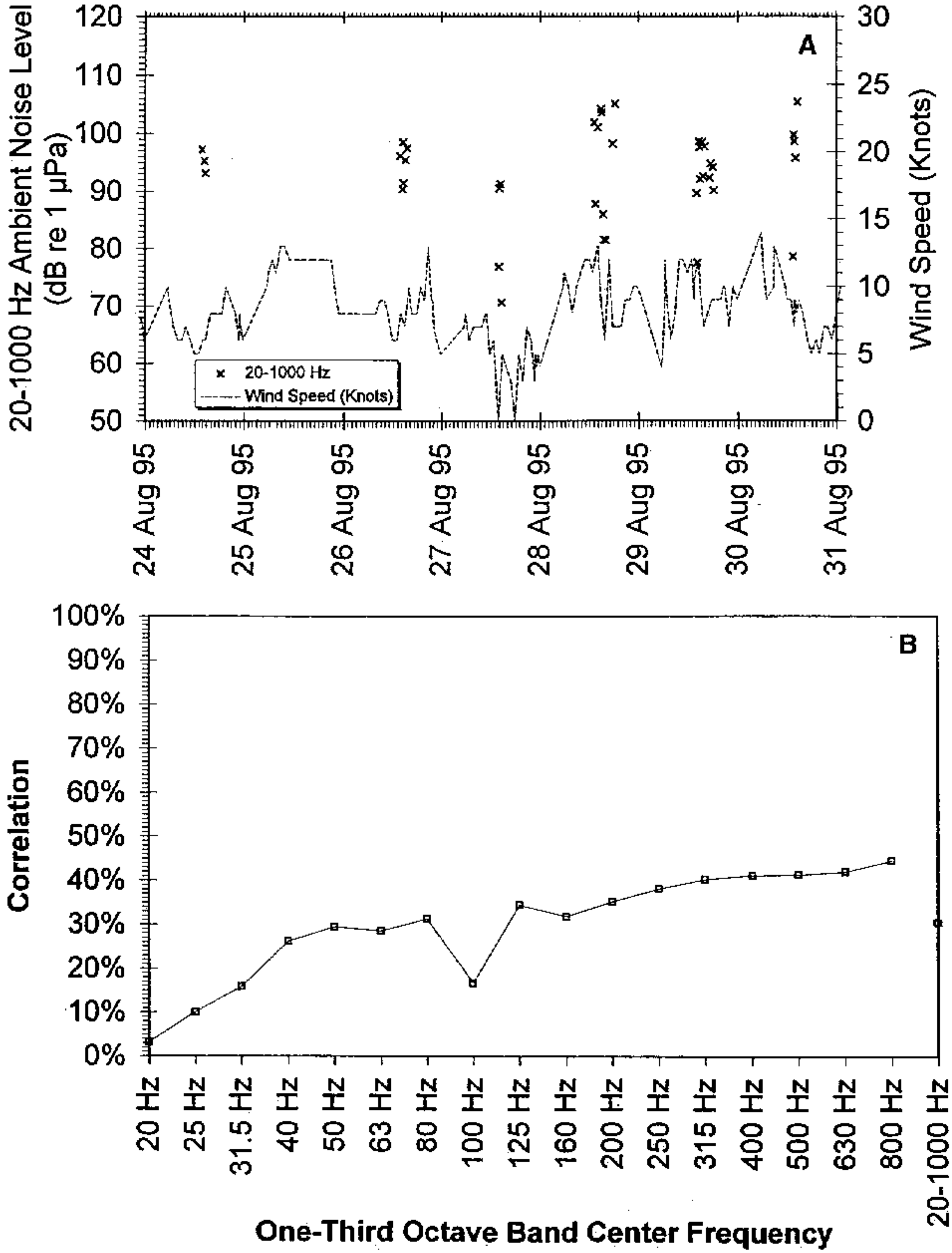

FIGURE 3.5. Ambient noise results from August 1995 sonobuoys: (A) 20-1000 Hz band levels and wind speed vs. time. (B) Percent correlation of the 1/3-octave band levels and the 20-1000 Hz broadband level with wind speed.

tions at Deadhorse are probably not appropriate for the sonobuoy locations seaward of the Northstar Unit (Fig. 3.1). It is not unusual for winds that far offshore to differ significantly from winds onshore.

Ambient noise levels were highly variable in all 1/3-octave bands and for various broader bands, based on the 40 acceptable analyses of ambient noise data from the August 1995 sonobuoys (Fig. 3.6).

Seal Island Bottom Hydrophone, September 1984

Figure 3.7A presents the hourly 20-1000 Hz band levels and wind speeds vs. measurement time. The symbols at the top signify possible man-made noise interference as explained in the key. Samples at those times were not included in the summaries and statistical analyses. The correlation coefficients between the 1/3-octave band levels and wind speed were generally 0.80 or higher (Fig. 3.7B), in contrast to the 1995 sonobuoy results (*cf.* Fig. 3.5B). At Seal Island, the level in the 1/3-octave band centered at 63 Hz (which included 60 Hz) was contaminated by pickup from the camp's 60 Hz electric power field; the high apparent correlation with wind speed is an artifact.

Again, the 1/3-octave band levels and 20-1000 Hz band levels were highly variable from time to time, based on 142 hourly analyses of ambient noise at Seal Island (Fig. 3.8). The high levels near 63 Hz during quiet conditions are artifactual, as noted above.

Sandpiper Island Bottom Hydrophone, Sept - Oct 1985

Figure 3.9A presents the hourly 20-1000 Hz wideband levels and wind speeds vs. observation time. The symbols at the top signify possible man-made noise interference as explained in the key. Samples at those times were not included in the summaries and statistical analyses. As at Seal I., there was a high degree of correlation between the 1/3-octave band levels and wind speed (Fig. 3.9B). The slight dips at 20 and 40 Hz are probably related to weak tones from the camp generator, which were present in the sounds at the hydrophone. (Those tone levels increased after the drillrig returned to operational status and more generators were activated, subsequent to the period considered in this report—Johnson et al. 1985.)

Figure 3.10 presents the distribution of 1/3-octave band levels, and the 20-1000 Hz band levels, based on 238 samples of ambient noise at Sandpiper Island. There was negligible electric field pickup at this installation, but there were weak acoustic signals at 20 and 40 Hz from the camp generator cylinder firing rate.

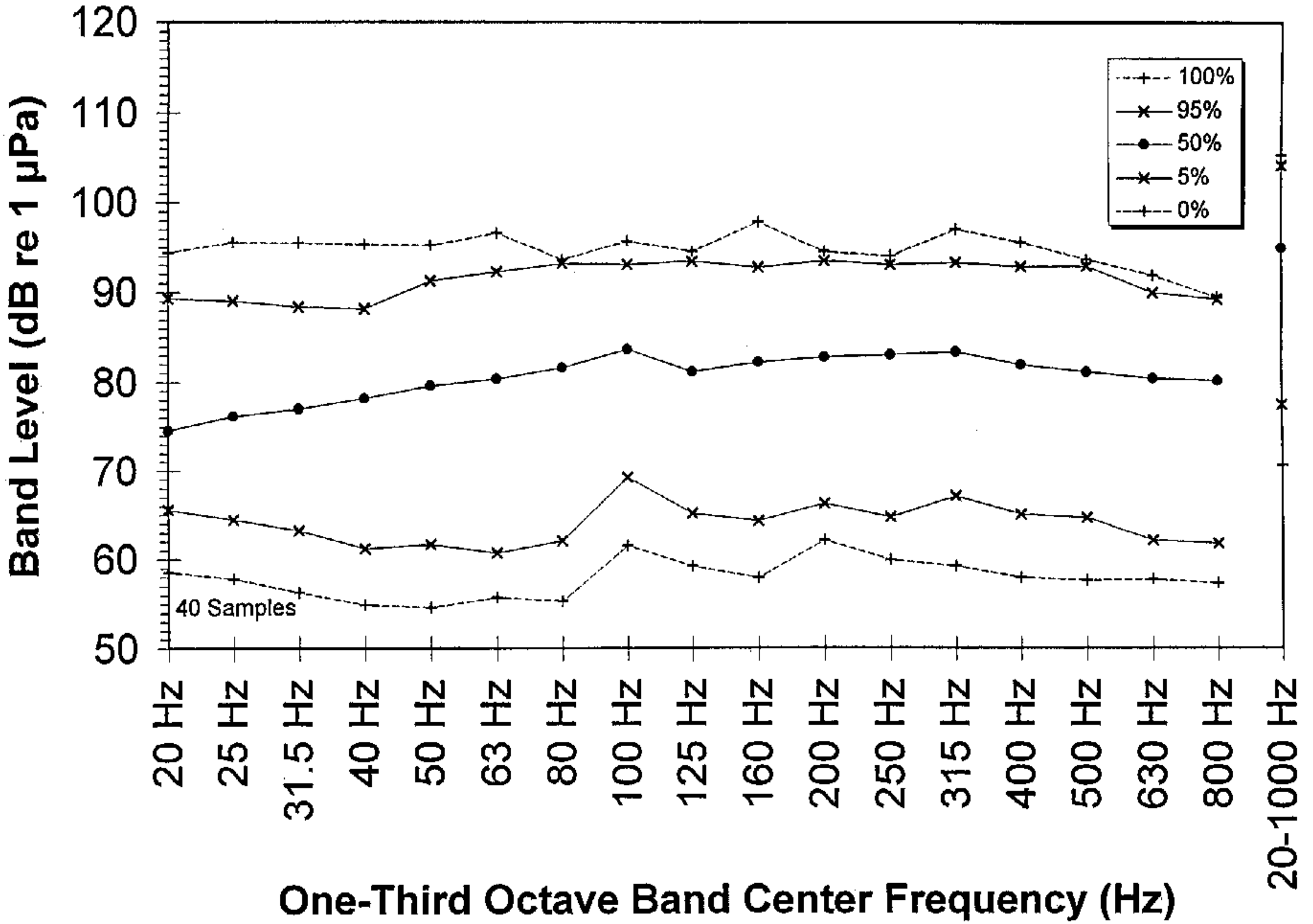

FIGURE 3.6. Distribution of 1/3-octave band levels vs. frequency for the ambient noise data from sonobuoys, August 1995. Curves show the minimum, 5th percentile, 50th percentile (median), 95th percentile, and maximum level for each 1/3-octave band and for the 20-1000 Hz broad band.

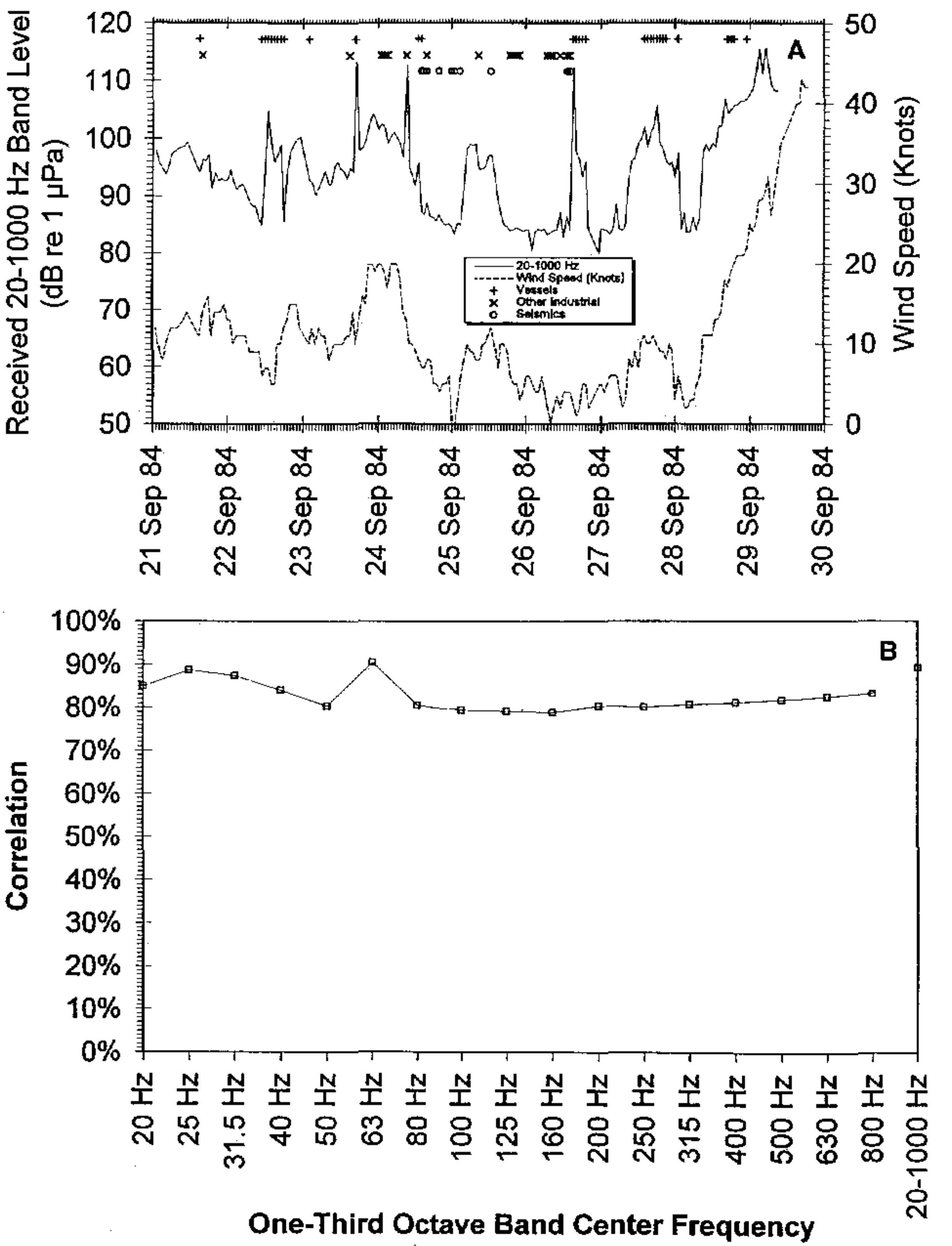

FIGURE 3.7. Ambient noise results from Seal Island, 1984: (A) 20-1000 Hz band levels and wind speed vs. time; symbols at the top show times when industrial sounds were present. (B) Percent correlation of the 1/3-octave band levels and the 20-1000 Hz broadband level with wind speed.

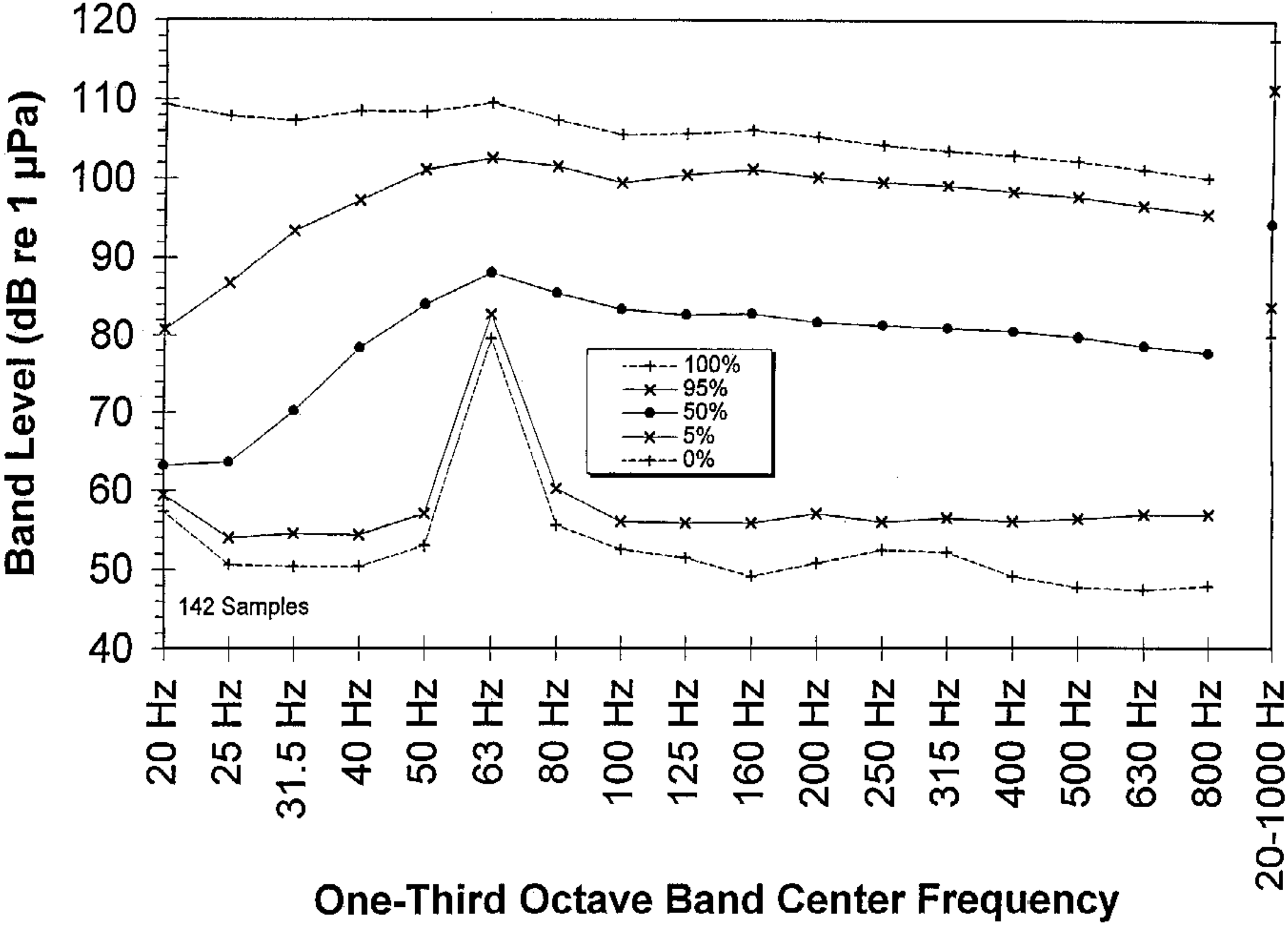

FIGURE 3.8. Distribution of 1/3-octave band levels vs. frequency for the Seal I. ambient noise data, September 1984. Curves show minimum and maximum levels, and the 5th, 50th and 95th percentiles, for each 1/3-octave band and for the 20-1000 Hz broad band.

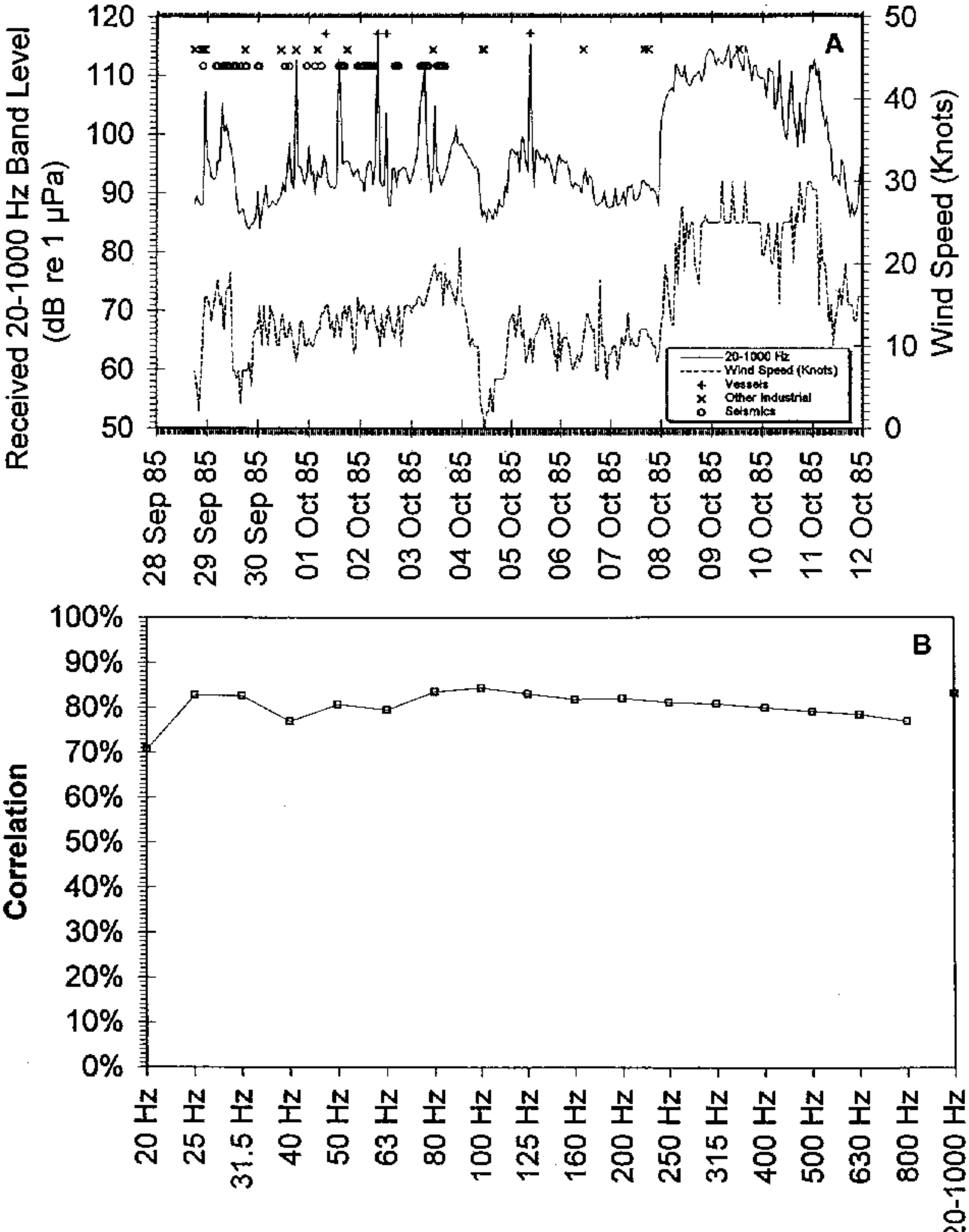

FIGURE 3.9. Ambient noise results from Sandpiper Island, 1985: (A) 20-1000 Hz band levels and wind speed vs. time; symbols at the top show times when industrial sounds were present. (B) Percent correlation of the 1/3-octave band levels and the 20-1000 Hz broadband level with wind speed.

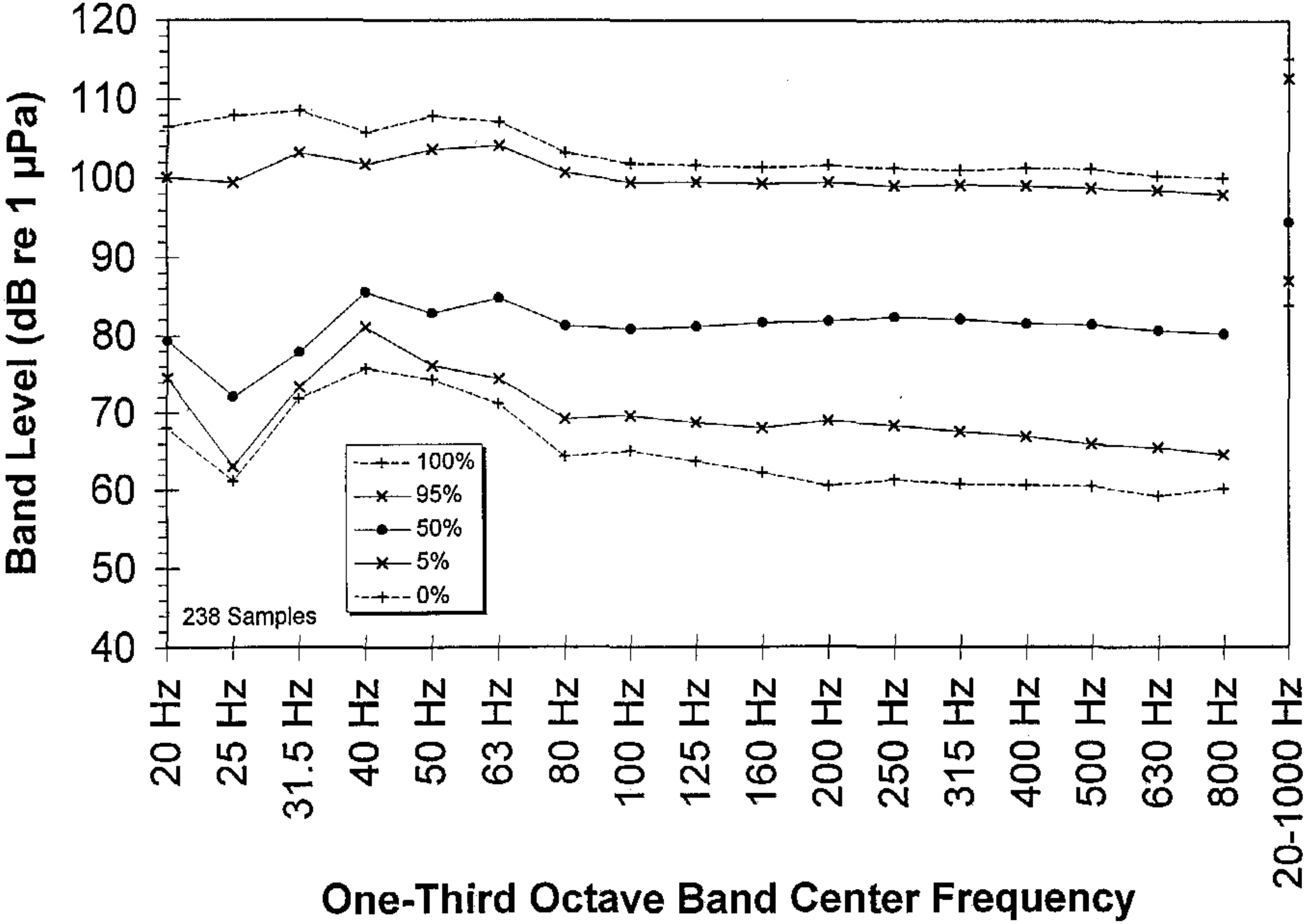

FIGURE 3.10. Distribution of 1/3-octave band levels vs. frequency for the Sandpiper I. ambient noise data, September-October 1985. Plotted as in Fig. 3.8.

Joint Results

The three sets of measurements (1984, 1985, 1995) were combined to form a set of 420 observations (Fig. 3.11). The median levels of the three annual datasets and the combined dataset are compared in Figure 3.12. At 100 Hz and above the spread in the medians is only about 4 dB. At 80 Hz and below, the median levels are more variable among years, probably reflecting the different water depths, propagation phenomena, and environmental conditions at each site. To review, the depth at Seal I. was 13 m, the depth at Sandpiper I. was 15 m, and the depths at sonobuoy locations varied. The hydrophone at Seal I. was 2.4 km from the island but the hydrophone at Sandpiper I. was 0.5 km away. The presence of the 20 and 40 Hz tones at Sandpiper I., where 238 of the 420 samples were obtained, skewed the results of the combined data to show higher 1/3-octave band levels at 20 Hz and 40 Hz than found either at Seal I. or via the 1995 sonobuoys.

Figure 3.13 shows the strength of correlation of 1/3-octave band levels and the 20-1000 Hz band levels with wind speed. The 1995 curve is clearly anomalous, indicating that the wind speed measurements at Deadhorse were not adequate as indicators of wind conditions at the offshore sonobuoy locations.

Environmental Influences on Ambient Noise

Ambient noise levels as a function of wind speed were examined by grouping the data based on the standard Beaufort Wind Force scale (Richardson et al. 1995:89). For each Wind Force scale value, the 1/3-octave band levels were sorted to obtain the ambient levels below which 5%, 50% and 95% of the measurements occurred. There was a strong tendency for increasing median ambient noise levels with increasing wind force both at Seal I. (Fig. 3.14A) and especially at Sandpiper I. (Fig. 3.14B). The 60 Hz artifact at Seal Island is apparent for the low wind speeds and the corresponding low median levels. Similarly, the 20 and 40 Hz tones at Sandpiper I. are manifest. The general decrease in levels at frequencies less than 40-60 Hz is probably a propagation effect related to the shallow water. Low-frequency components of ambient (or other) noises tend to be rapidly attenuated in shallow water.

Figure 3.15 shows the wind-dependence of the 5th and 95th percentile levels (as well as the medians) at Seal Island in 1984. Results are shown for each 1/3-octave band and for the 20-1000 Hz band, by Beaufort Wind Force. Figure 3.16 shows comparable data for Sandpiper Island in 1985.

Figure 3.17 compares the 5th, 50th and 95th percentile pressure spectral density levels (not the band levels previously presented)[3] with a standard summary of ambient noise in the

[3] Previously-presented values are levels for 1/3-octave bands, each of which has a bandwidth equaling 23% of its center frequency (e.g., 23 Hz for the band centered at 100 Hz). Wenz' curves show spectrum density levels, i.e. levels in 1 Hz bands. For all frequencies relevant here, spectrum density

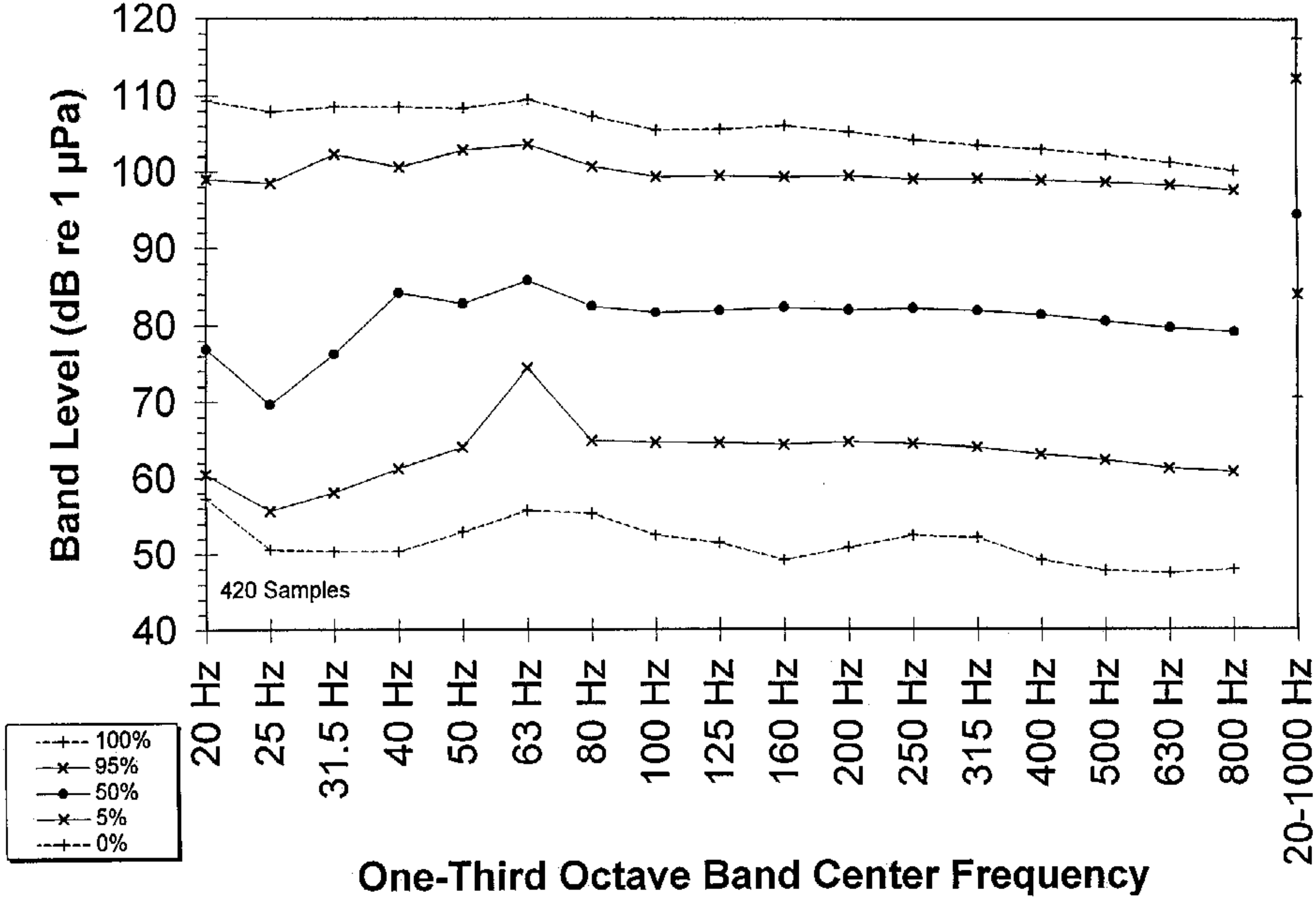

FIGURE 3.11. Distribution of the 1/3-octave band levels vs. frequency for the combined sonobuoys, Seal I., and Sandpiper I. measurements. Plotted as in Fig. 3.8.

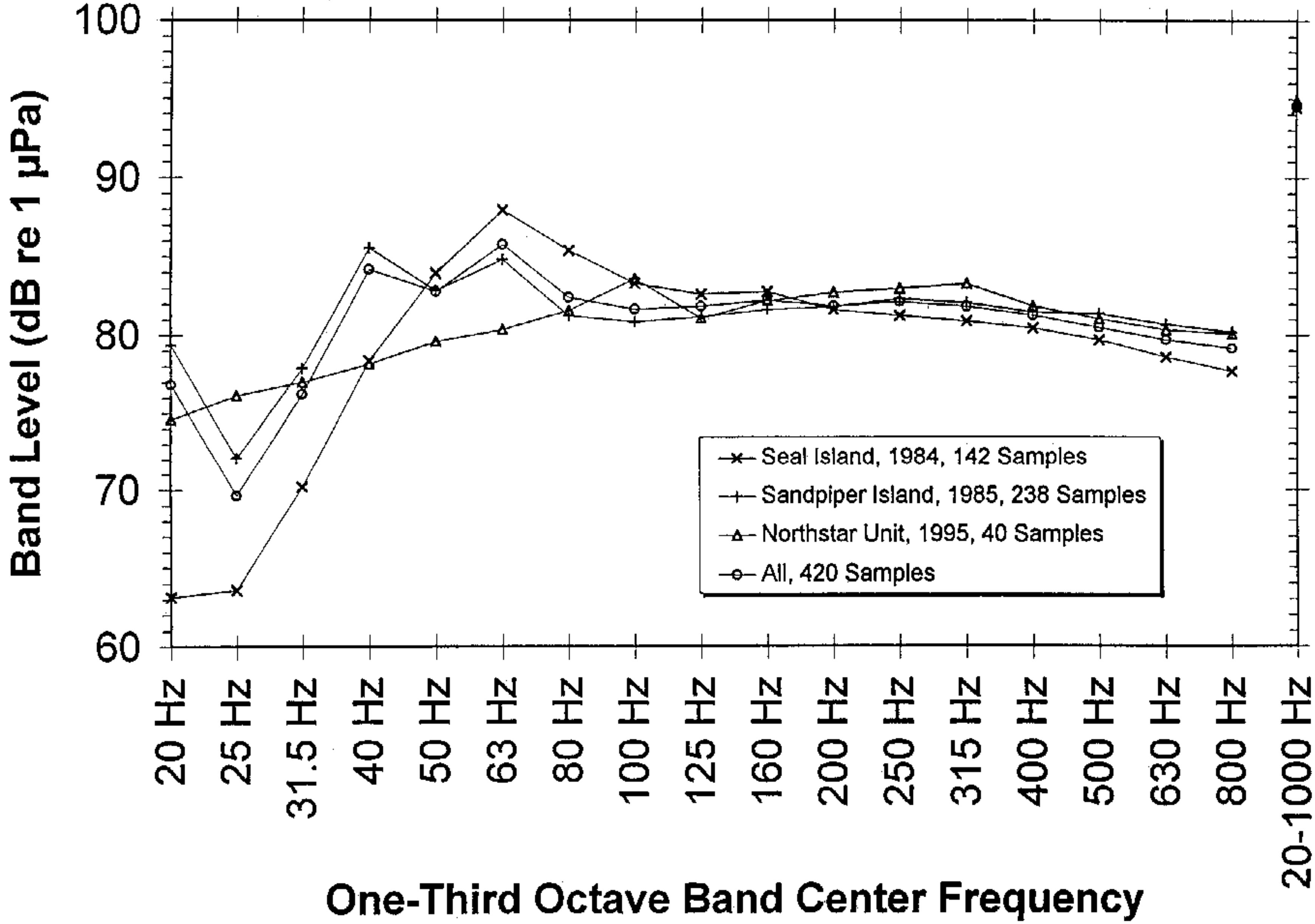

FIGURE 3.12. Comparison of the median 1/3-octave band levels vs. frequency for the three sets of measurements and their combination; 20-1000 Hz broadband levels are also shown at right.

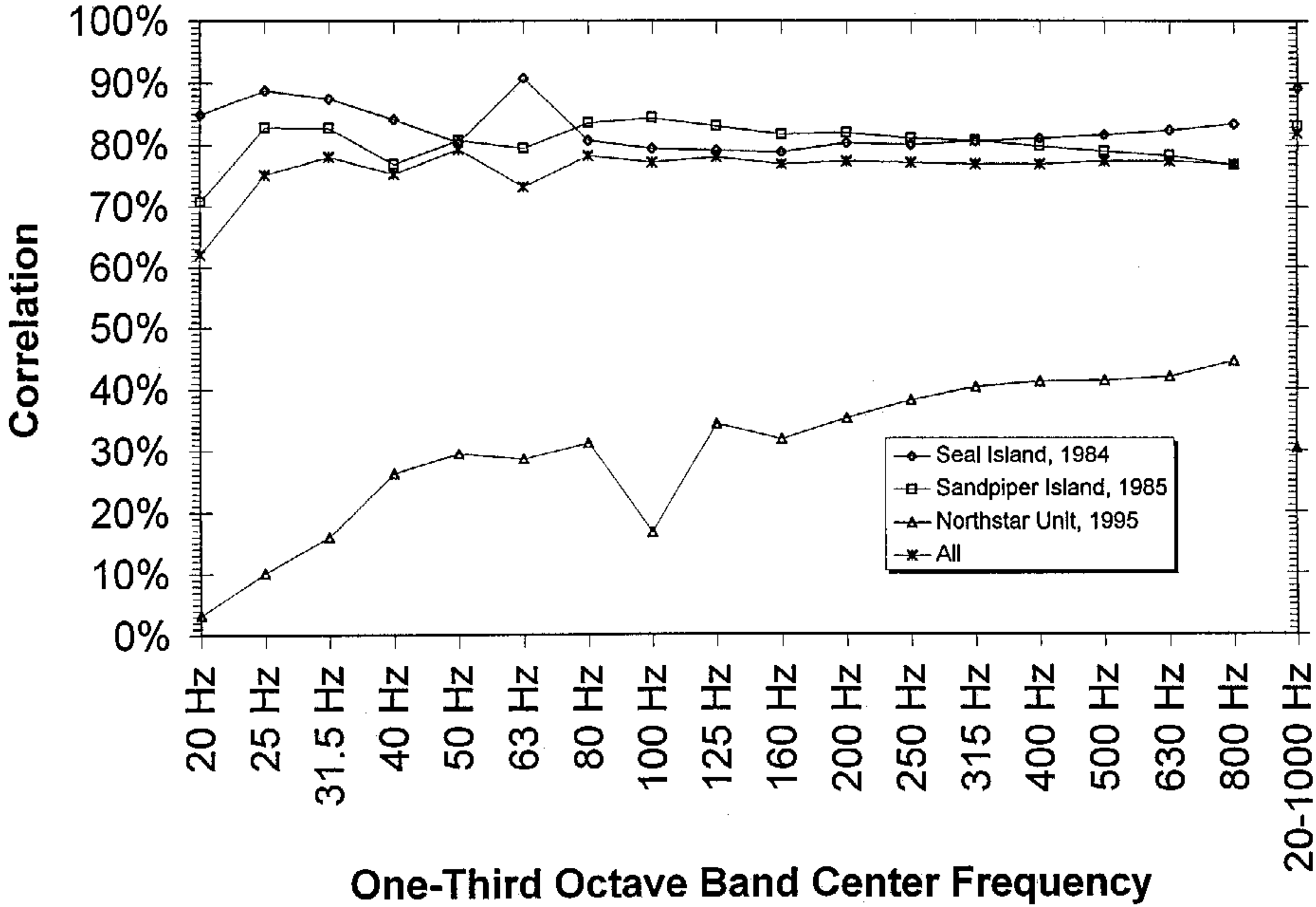

FIGURE 3.13. Comparison of the percent correlations of the 1/3-octave band levels with wind speed for the three sets of measurements and their combination; 20-1000 Hz broadband levels are also shown at right.

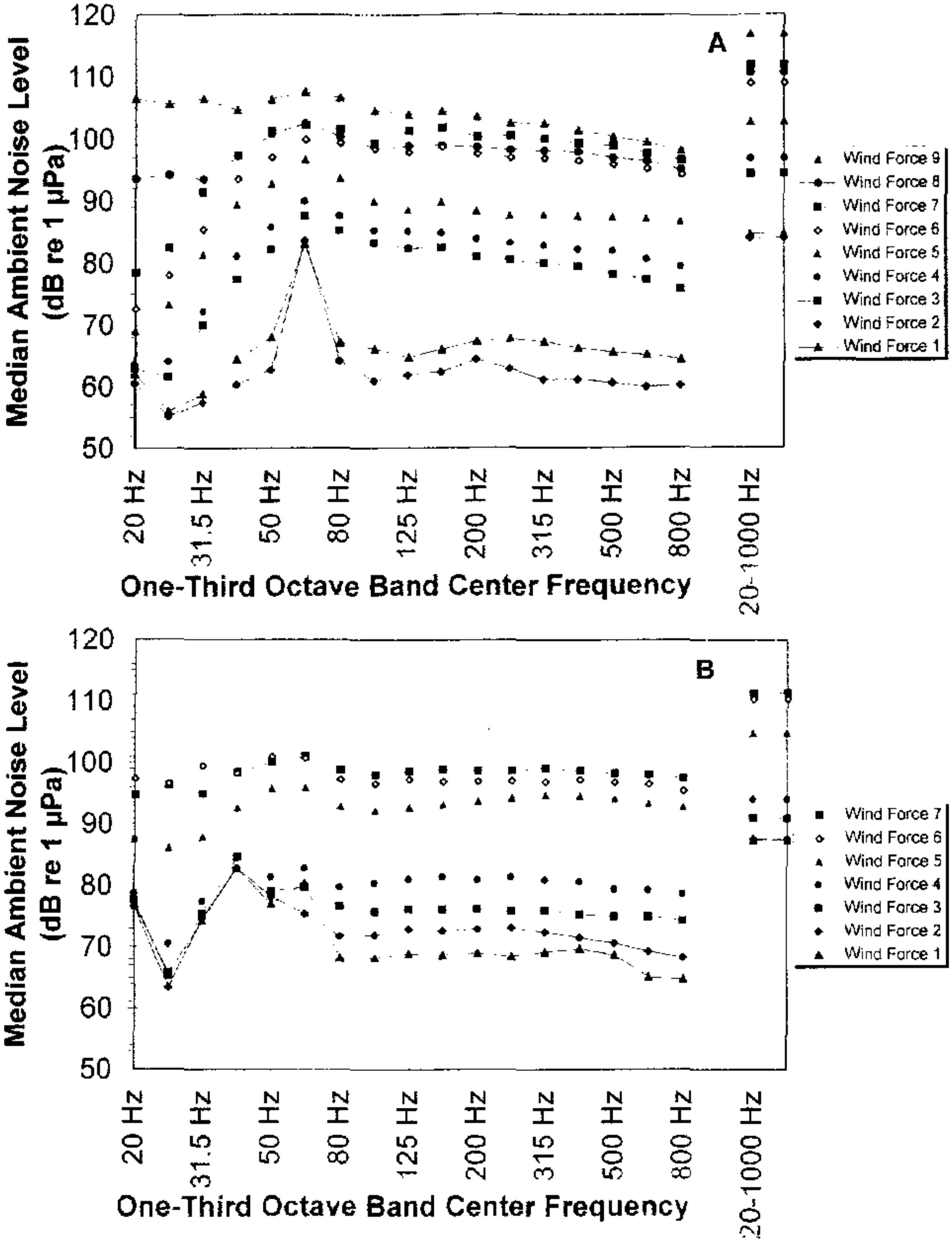

FIGURE 3.14. Wind dependence of median ambient noise levels: median levels in 1/3-octave bands and in the 20-1000 Hz broad band are categorized by Beaufort Wind Force. (A) Seal I. measurements. (B) Sandpiper I. measurements.

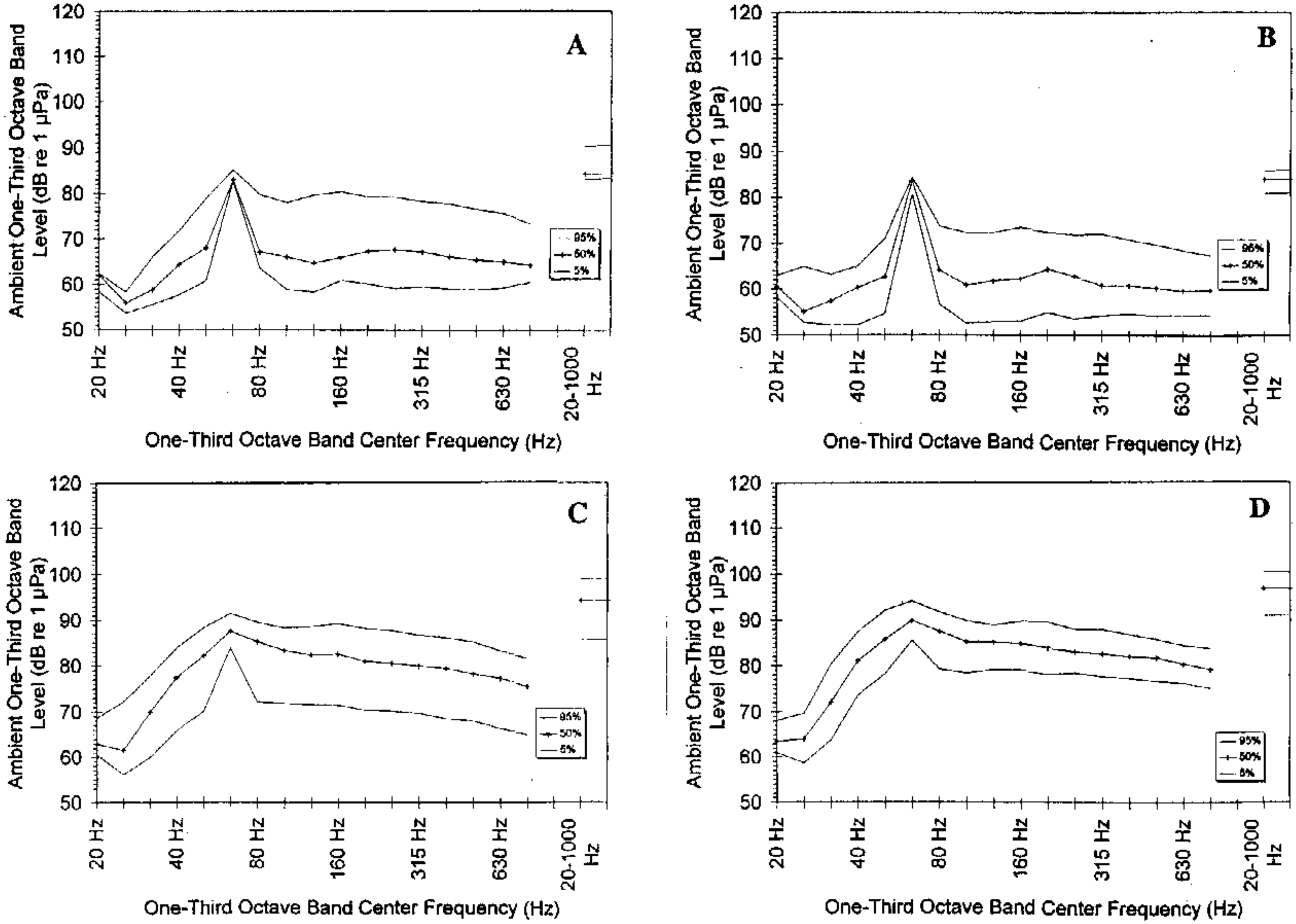

FIGURE 3.15. Wind dependence of 5th, 50th and 95th percentile ambient noise levels, Seal I., 1984. Levels in each 1/3-octave band and for the 20-1000 Hz band are shown, by wind force. (A) Force 1, 9 samples; (B) Force 2, 26 samples; (C) Force 3, 37 samples; (D) Force 4, 42 samples; (E) Force 5, 12 samples; (F) Force 6, 4 samples; (G) Force 7, 6 samples; (H) Force 8, 3 samples; (I) Force 9, 3 samples.

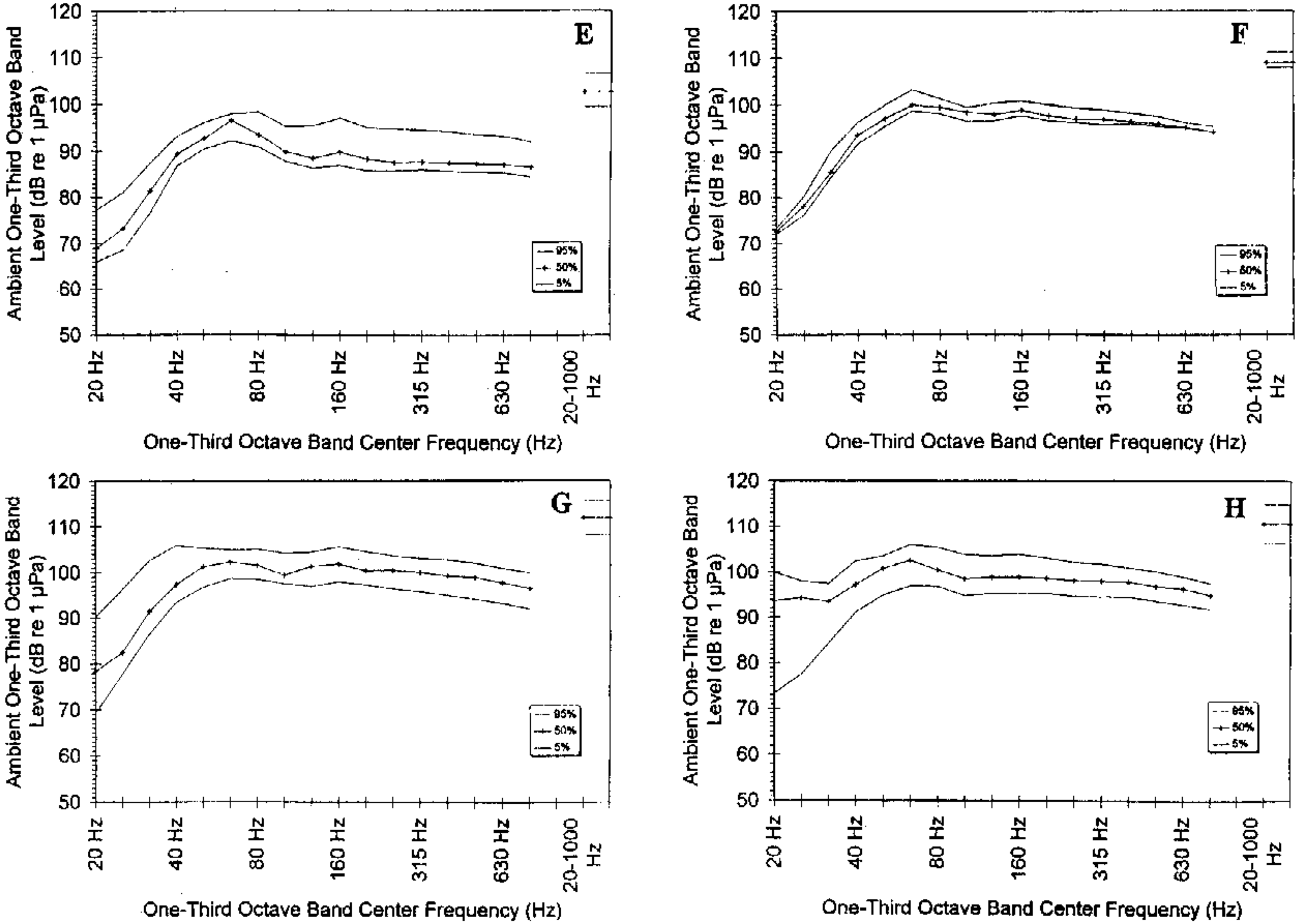

FIGURE 3.15. Continued.

world's oceans (from Wenz 1962). This superposition shows that the ambient noise in the Northstar area during late summer and autumn can vary over levels comparable to the variability of ambient sounds around the world. At higher frequencies (500 to 800 Hz), the 50th percentile (median) levels appear to align with levels falling between Wenz' Sea State One and Two. The 95th percentile levels correspond to levels exceeding Wenz' levels for sea state six; the 5th percentile levels correspond to levels on the order of Wenz' levels for sea state zero.

Data from the Northstar region do not follow the "rounding downward" of Wenz' sea state curves at frequencies less than about 500 Hz. Wenz's measurements were generally made in areas of the world with normal shipping traffic, and he may not have been able to separate traffic effects from wind effects (D. Cato, DSTO, Sydney, Australia, pers. comm.). The Northstar region is sufficiently isolated that, once the cases with nearby vessels are

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levels are numerically less than 1/3-octave band levels. The difference becomes progressively greater with increasing frequency as the 1/3-octave bands widen. For the comparison in Figure 3.17, our 1/3-octave levels have been converted to equivalent spectrum density levels by subtracting a "bandwidth correction" factor:

10 log (0.23 x center frequency in hertz).

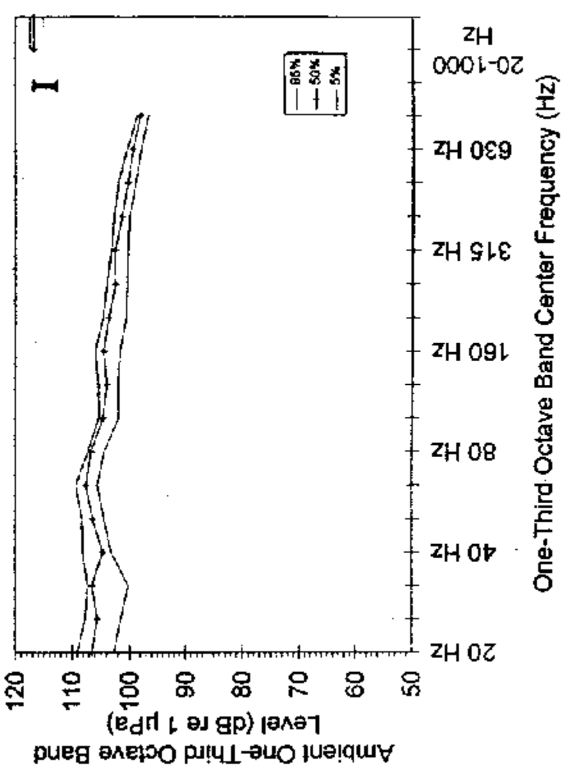

FIGURE 3.15. Continued.

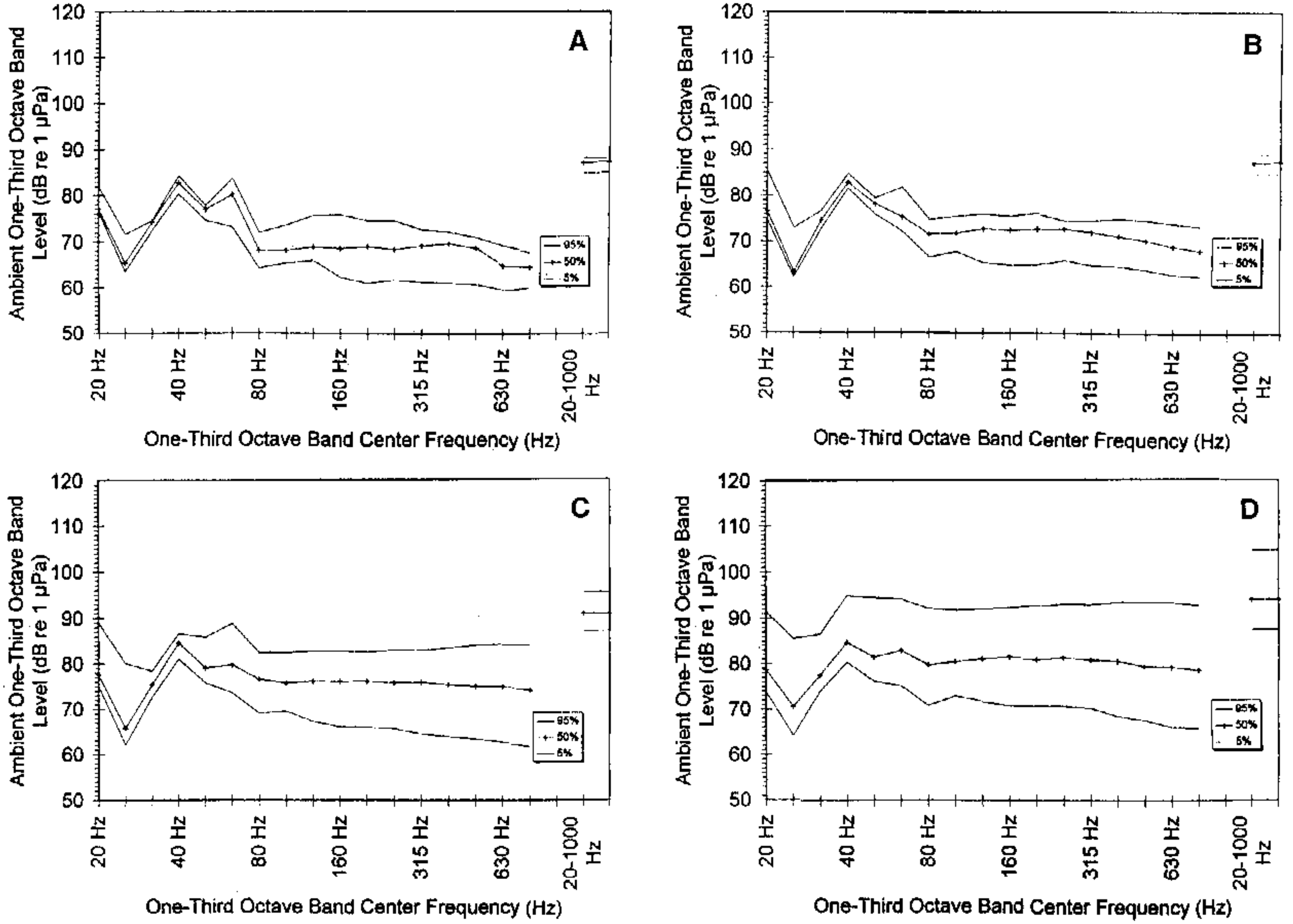

FIGURE 3.16. Wind dependence of 5th, 50th and 95th percentile ambient noise levels, Sandpiper I., 1985, plotted as in Fig. 3.15. (A) Force 1, 5 samples; (B) Force 2, 9 samples; (C) Force 3, 55 samples; (D) Force 4, 96 samples; (E) Force 5, 21 samples; (F) Force 6, 44 samples; (G) Force 7, 10 samples.

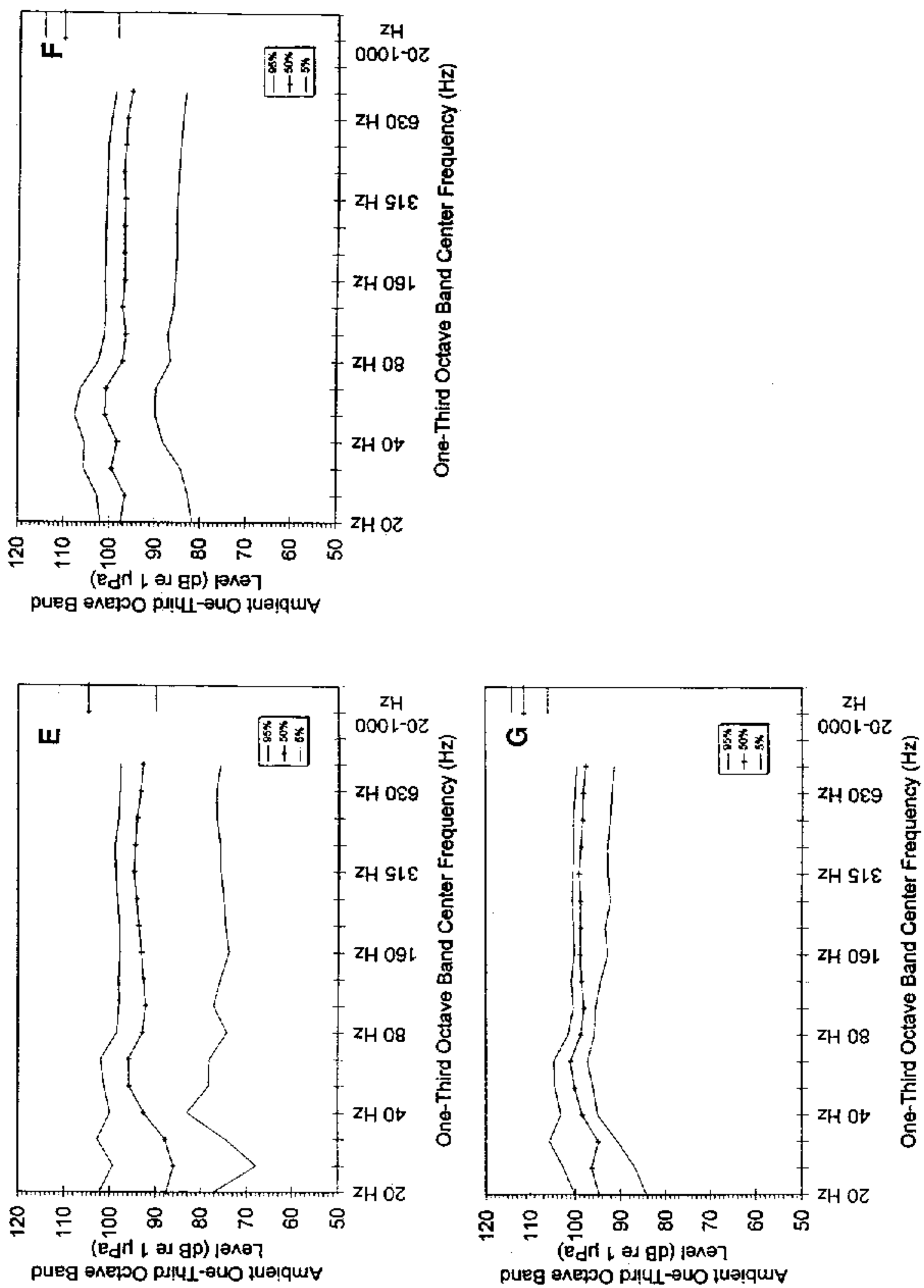

FIGURE 3.16. Continued.

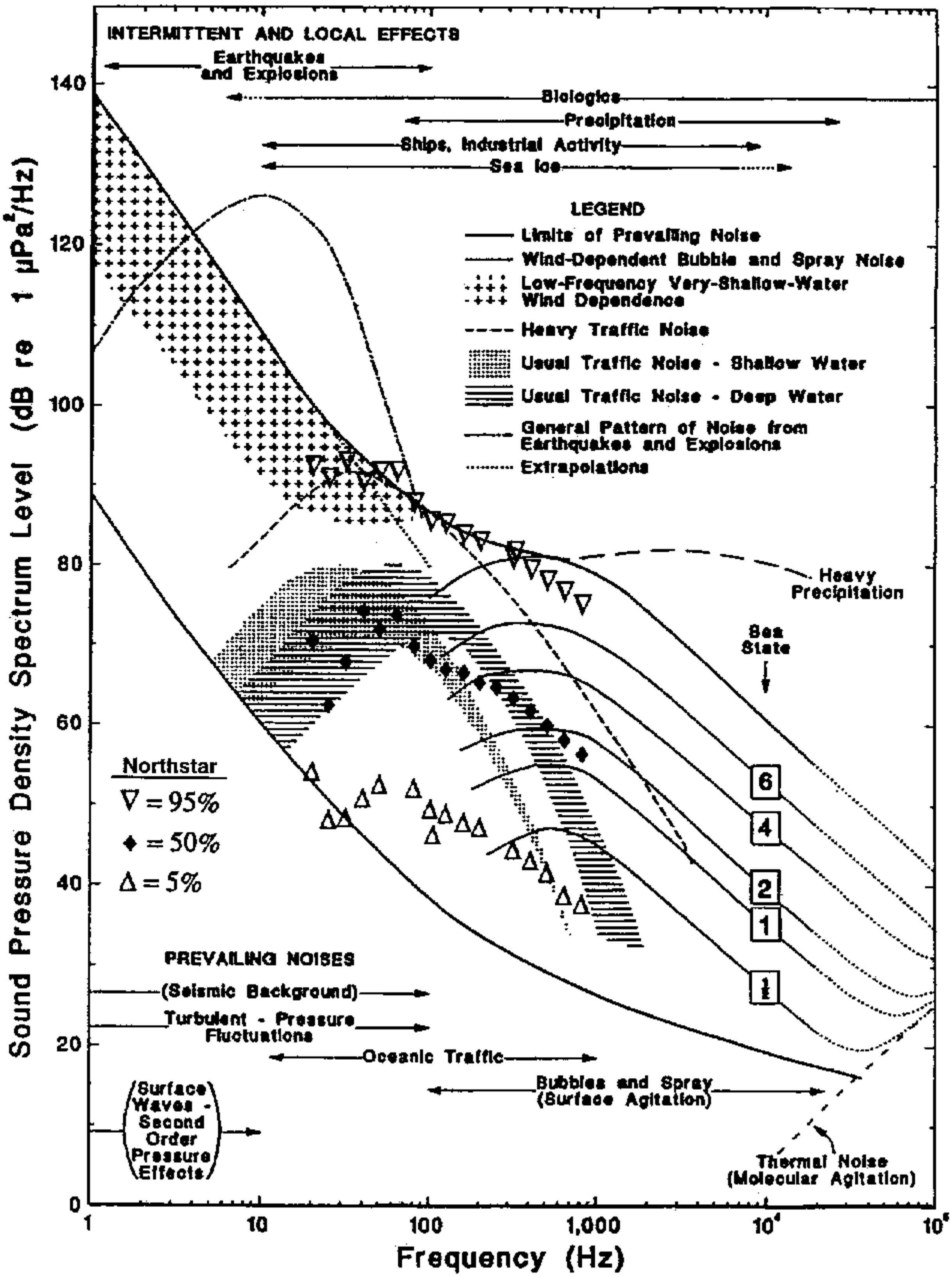

FIGURE 3.17. Wenz's summary of generalized ambient noise levels and sources with the 5th, 50th and 95th percentile data from the Northstar area superimposed for comparison. All levels are spectral density levels, i.e. representing sound levels on a "per hertz" basis.

eliminated (as was done with our data), there is little or no effect from "distant shipping". The results indicate that, under these conditions, wind speed influences sound levels down to frequencies at least as low as 60 Hz for the water depths observed in the Northstar region.

Multiple regression analyses of the Northstar ambient noise data were conducted to evaluate the simultaneous effects of wind speed and direction, ice cover, and year (1984 vs. 1985) on the ambient noise levels. Separate analyses were done for 1/3-octave bands centered at 25, 50, 100, 200, 400 and 800 Hz, and for the 20 to 1000 Hz broad band. The analyses were based on the 1984 and 1985 data only, as the wind data obtained for 1995 are not meaningful as a predictor of ambient noise levels at 1995 sonobuoy locations (Fig. 3.13).

These analyses showed that ambient noise levels in all frequency bands analyzed were positively and strongly correlated with wind speed (nominal $P \ll 0.001$ for each frequency). This was so both before and after allowance for other variables. There also was a significant positive relationship to the alongshore component of the wind[4], although the significance levels for this predictor variable varied widely among frequencies (from $P<0.05$ to $P<0.001$). After allowance for those two measures of wind, there was a significant negative partial correlation with ice cover for all frequencies analyzed; the nominal significance level was $P<0.001$ for all except the 25 Hz band, where $P<0.05$.

Thus, other factors being equal, the stronger the wind and the stronger its southeasterly alongshore component, the higher the ambient noise level. Also, the greater the ice cover, the lower the ambient noise level. These results are reasonable from physical considerations. Wind makes waves, which make noise, and the wind turbulence itself creates sound that is coupled to the water. Ice cover dampens waves.

In addition, for some frequencies ambient noise levels tended to be lower at Seal I. (1984 data) than at Sandpiper I. (1985 data) both before and after allowance for other variables.

Overall, the multiple regression models for specific 1/3-octave bands accounted for 68.3-79.5 percent of the variability in the 1984-85 ambient noise data. The model for the 20-1000 Hz broad band accounted for 78.9% of the variance.

3.4 Conclusions

Underwater ambient noise in and near the planned Northstar seismic area during late summer and early autumn is comparable to underwater ambient noise in the world at large, extending over similar ranges of levels. The median levels at frequencies from 500 to 800 Hz correspond to Wenz' levels for sea state one to two, which are moderately low. However, during periods of high ambient noise, the levels in the Northstar region correspond to Wenz'

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[4] ESE component taken as positive; WNW component taken as negative.

noise for sea states exceeding six (gale-force winds, 4-6 m wave heights). During periods of low ambient noise, the levels correspond to Wenz' noise for sea state near zero (calm wind, glassy surface). In the absence of human activities, wind speed is the primary factor influencing ambient noise level, but there is also a tendency for decreasing ambient noise levels with increasing ice cover.

Frequencies below 100 Hz are of interest here because the airguns used for seismic surveys emit most energy below 100 Hz. At those frequencies, the ambient noise in the Northstar region spans a broad range of levels corresponding to the high and low limits found in open oceans generally. Coincidentally, the median levels of ambient noise measured near Northstar at these low frequencies are similar to the levels expected in deep waters of the North Atlantic and North Pacific Oceans. In the latter areas, distant shipping is the main source of low-frequency sound (Fig. 3.17). In the Northstar data considered here, most of this low-frequency ambient noise was from natural sources.

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