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OCS Study
MMS 89-0006

Analysis and Ranking of the Acoustic Disturbance Potential of Petroleum Industry Activities and Other Sources of Noise in the Environment of Marine Mammals in Alaska

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ANALYSIS AND RANKING OF THE ACOUSTIC DISTURBANCE POTENTIAL OF PETROLEUM INDUSTRY ACTIVITIES AND OTHER SOURCES OF NOISE IN THE ENVIRONMENT OF MARINE MAMMALS IN ALASKA

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ABSTRACT

A better understanding of the numbers, locations, and acoustic intensities of the wide variety of man-made and natural noise sources in the Alaskan marine environment is needed in order to determine the normal levels of natural ambient noise and the "normal" levels of human noise to which marine mammals are exposed in their usual habitats. The purpose of this study is to provide an up-to-date compehensive synthesis of available information that compares the relative magnitudes and effects on marine mammals of noise from oil and gas industry activities with noise from other sources in Alaska OCS and coastal waters. The study procedure incorporates the receiver, source and path concepts generally used in acoustic analysis. The receiver characterization includes a review of marine mammal distribution in Alaska and a map of the distribution of each major species. (Scientific names of marine mammal species discussed in this report are presented in Appendix F.) Information on sound production, hearing sensitivity (when known), and observed responses to noise sources is also included. The analysis of noise sources found in the Alaskan marine environment considers natural, industrial, transportation, and cultural sources. Acoustic transmission loss characteristics obtained from measurements and model predictions are used to estimate the effective ranges of the noise sources using available source level information. Information on species distribution was combined with information on source distribution, source level, and transmission loss to determine the most significant sources in terms of their acoustic range and the numbers of mammals potentially affected. This was done by developing a Standardized Noise Contribution Model combined with a Standardized Exposure Rating Model for various specific species. This procedure provides an indication of which source - species combinations may have the highest potential for acoustic interaction in a given area. In terms of their potential effects on marine mammals, the loudest sound sources in the Alaskan marine environment are seismic arrays (both air gun and vibroseis), icebreakers, large ships, and dredges. Sound levels produced by smaller vessels and boats become significant when several of these sources are operating concurrently in a small area. Earthquake events produce high underwater sound levels sporadically in active seismic areas such as the Aleutian arc. Baleen whales are considered to have hearing sensitivity characteristics which include the frequency range of most of the man-made sources described above. As a result the exposure model showed that the gray, bowhead, fin, and humpback whales which frequent Alaskan waters are the species with the highest probability of acoustic interaction with most of the sound sources studied. The model predicted that killer whales, harbor porpoise, Dall's porpoise, harbor seals, and fur seals would be influenced primarily by the loudest sources since their hearing sensitivity does not extend to the low frequency range estimated for baleen whales. The other species studied, including walrus, white whale, and Steller sea lion, were all predicted to have medium to low probability of acoustic influence from the sources considered. This is primarily a result of the fact that their optimal hearing sensitivity is at frequencies above the dominant output frequencies of most man-made sources.

EXECUTIVE SUMMARY

Background

A number of studies have been made of the responses of marine mammals to various types of noise produced by the oil and gas industry. In these studies the existing ambient noise levels in the study areas have necessarily been used as a control stimulus. The noise exposure history of the subject mammals has not been known. The Alaskan marine environment contains a diverse variety of noise sources including marine biota, natural seismicity, vessel noise, and sources associated with the oil and gas industry. A better understanding of the numbers, locations, and intensities of these noise sources is needed in order to determine the normal levels of natural ambient noise and the "normal" levels of background noise, including extraneous human noise, to which marine mammals are exposed in their usual habitats. To that end, the purpose of this study is to provide an up-to-date comprehensive synthesis of available information about the relative magnitudes and anticipated effects on marine mammals of noise from oil and gas industry activities in relation to magnitudes and effects of noise from other sources in Alaska OCS and coastal waters.

Objectives

1. Identify the major sound sources in the Alaskan OCS and coastal marine environment and quantify their numbers, distributions (temporal and spatial), and acoustic characteristics.

2. Summarize the geographic zones of the potential acoustic influence on important marine mammal habitats and, for each noise source, postulate the magnitude of overall interactions with Alaskan marine mammals.

3. Quantify and rank the relative seasonal magnitude of sound "loading" of the Alaskan marine environment produced by each major sound source.

4. Depict the major sound sources and their geographic zone of influence as graphic overlays on displays of regional and temporal marine mammal distribution.

Study Description

The procedure followed to meet these requirements incorporates the source, path, and receiver concepts generally used in acoustic analysis. The receiver characterization includes a review of marine mammal distributions in Alaska and a map of the distribution of each major species. A total of 30 species known to occur in Alaska were considered in the study. Alaska is a significant part of the range of 18 of these species. Alaska is a relatively unimportant part of the range of eight of the species, and four of the species are rare or accidental in Alaskan waters. The report also reviews information on sound production by each species, hearing sensitivity (when known), and observed responses to noise sources.

The analysis of noise sources found in the Alaskan marine environment includes natural, industrial, transportation, and cultural sources. Information on their output spectra is presented in graphs and tables of 1/3 octave source level (dB re 1 μPa at 1 m). When available, information on the temporal characteristics of the sources is also included.

Acoustic transmission loss characteristics are obtained from measurements and model predictions. These characteristics, along with the above source level data, are used to estimate the effective acoustic ranges of sound sources. Both airborne and underwater transmission loss characteristics are required. However, empirical information on underwater acoustic transmission loss in Alaskan marine environments is sparse. As a result, it was necessary to use sound propagation models to obtain estimated transmission loss characteristics for several areas studied.

Information on species distribution was combined with information on source distribution, source level, and transmission loss to determine the most significant sources in terms of their acoustic ranges and the numbers of mammals potentially affected. This was done by developing a Standardized Noise Contribution Model which is based on the acoustic energy density contributed to the environment by a specific type of source in a defined reference area. The source rating is combined with a Standardized Exposure Rating Model for a specific species. The latter model takes into account the degree of matching between the source bandwidth and the species' hearing sensitivity, and the number of animals present in the reference area. The output of this procedure provides an indication of which source - species combinations have the highest potential for acoustic interaction in a given area. Zones of influence for the loudest and most widely distributed sound sources, as determined by the modeling procedure, are estimated for four selected OCS planning areas of high current interest - Chukchi Sea, Norton Basin, North Aleutian Basin, and Shumagin.

Study Results

The loudest sound sources in the Alaskan marine environment are seismic arrays (both air gun and vibroseis), icebreakers, large ships, and dredges. Sound levels produced by the smaller vessels used for cargo hauling, fishing, and recreation become significant when several vessels are operating in a relatively small area. Earthquake events produce high underwater sound levels sporadically in active seismic areas such as the Aleutian arc. Sound produced by aircraft is the loudest airborne noise component. The primary impact of this noise is near airports and landing strips and along routes where low level operations are prevalent.

Baleen whales are believed to have hearing sensitivity characteristics which include the frequency ranges of most of the man-made sources described above. As a result the exposure model showed that the gray, bowhead, fin, and humpback whales which frequent Alaskan waters are species with high probabilities of acoustic interaction with most of the sound sources studied. The model predicted that killer whales, harbor porpoise, Dall's porpoise, harbor seals, and fur seals would be influenced primarily by the loudest sources since their hearing sensitivity does not extend to the low frequency range believed to be important for baleen whales. The other species studied, including walrus, white whale, and Steller sea lion, were all predicted to have medium to low probability of acoustic influence from the sources considered. This is primarily a result of the fact that their optimal hearing sensitivity is at frequencies above the dominant output frequencies of most man-made sources.

Conclusions

The modeling procedure developed in the study provides a means of ranking source - species encounter situations using acoustic principles. The principles employed have been used in similar ways, and to some extent validated as meaningful, to predict human annoyance as a function of industrial noise exposure. These predictions should be useful as hypotheses about some of the species and situations where noise impacts are most and least likely. However, the application of these models to marine mammals has involved the use of several untested hypotheses. It has been necessary to use estimated and inferred values for many of the required model inputs where measured data are not presently available.

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1. INTRODUCTION

Noise sources can affect marine mammals in several ways including interference with acoustic communication (masking), production of unpleasant sounds (annoyance), and potential destruction of auditory function (hearing damage risk). The frequency ranges and sound levels at which these effects occur are not well known for most species. Some limited observations on whale behavior as related to quantified acoustic exposure levels have been obtained for a few species such as the gray, bowhead, humpback, and white whales. A number of general observations of the reactions of pinnipeds to aircraft noise have also been reported. Scientific names of marine mammal species mentioned in the report are listed in Appendix F.

The Alaskan marine environment contains a diverse variety of noise sources including marine biota, natural seismicity, vessel noise, and sources associated with the oil and gas industry. A better understanding of the numbers, locations, and intensities of these noise sources is needed in order to determine the normal levels of natural ambient noise and the "normal" levels of background noise including extraneous human noise to which marine mammals are exposed in their usual habitats. To that end, the purpose of this study is to provide an up-to-date compehensive synthesis of available information about the relative magnitudes and anticipated effects on marine mammals of noise from oil and gas industry activities in relation to magnitudes and effects of noise from other sources in Alaska OCS and coastal waters.

The requirements of the study are

1. Identify the major sound sources in the Alaskan OCS and coastal marine environment and quantify their numbers, distributions (temporal and spatial), and acoustic characteristics.

2. Summarize the geographic zones of the potential acoustic influence on important marine mammal habitats and, for each noise source, postulate the magnitude of overall interactions with Alaskan marine mammals.

3. Quantify and rank the relative seasonal magnitude of sound "loading" of the Alaskan marine environment produced by each major sound source.

4. Depict the major sound sources and their geographic zone of influence as graphic overlays on displays of regional and temporal marine mammal distribution.

The procedure followed to meet these requirements necessarily incorporated the receiver, source, and path elements needed for acoustic analysis. The receiver characterization includes a review of marine mammal distributions in Alaska and a map of the distribution of each major species. Information on sound production, hearing sensitivity (when known), and observed responses to noise sources is also reviewed. This information is presented in Section 2.

The analysis of noise sources includes natural, industrial, transportation, and cultural sources. Information on their output spectra is presented in Section 3 as graphs and tables of 1/3 octave source level. When available, information on the temporal characteristics of the sources is also included.

Knowledge of acoustic transmission loss characteristics is required to estimate the effective acoustic ranges of sound sources from given source level information. For the purpose of this study both airborne and underwater transmission loss characteristics are required. However, empirical information on underwater acoustic transmission loss in the Alaskan marine environment is sparse. As a result, it was necessary to use sound propagation models to obtain estimated transmission loss characteristics for several areas studied. The procedures employed and the results of the transmission loss analysis are presented in Section 4.

Information on species distribution was combined with information on source distribution, source level, and transmission loss to determine the most significant sources in terms of their acoustic ranges and the numbers of mammals potentially affected. This was done by developing a Standardized Noise Contribution Model, which is based on the acoustic energy density contributed to the environment by a specific type of source in a defined reference area. The source rating is combined with a Standardized Exposure Rating Model for a specific species. The latter model takes into account the degree of matching between the source bandwidth and the frequency band to which that species is most sensitive, the species hearing sensitivity, and the number of animals present in the reference area. The output of this procedure provides an indication of which source - species' combinations may have the highest potential for acoustic interaction in a given area. The development of this procedure and the results are described in Section 5. That section also includes estimated zones of influence for the major sound sources, as determined by the modeling procedure, in the four OCS planning areas selected for principal study concentration - Chukchi Sea, Norton Basin, North Aleutian Basin, and Shumagin. A Glossary of specialized terminology and an Index are provided following the conclusions and recommendations in Section 6.

The References Cited section contains all of the references cited in the preceding sections. Detailed information supplementing the discussion in Sections 1 - 5 is presented in the Appendices.

2. MARINE MAMMAL DISTRIBUTION AND ACOUSTIC CHARACTERISTICS

2.1 Summary of Marine Mammal Distribution in Alaska*

A review of the seasonal distributions of marine mammals in Alaskan waters was necessary in order to evaluate the degree of exposure of marine mammals to noise in various areas and seasons. Many other reviews of these distributional data have been prepared for various parts of Alaska, and it was not our intention to duplicate these. Instead, we restricted our review to the minimum effort necessary to provide the distributional data needed for present purposes.

2.1.1 Methods

To begin our limited review of the distribution of marine mammals in Alaska we compiled a list of 30 marine mammal species known to occur in Alaskan waters (Haley [ed.] 1978). We then examined the results of recent large-scale aerial and ship-based marine mammal surveys conducted in Alaskan waters (e.g., Rice and Wolman 1982; Brueggeman et al. 1983, 1987; Leatherwood et al. 1983; Brueggeman and Grotefendt 1984). Individual species accounts within these reports were frequently very well researched and in addition to describing the observed distribution of a particular species in the specific study area, the authors cited numerous other pertinent reports. These citations included such diverse documents as environmental synthesis reports and impact statements prepared for specific OCS planning areas, annual and final reports of studies sponsored by NOAA/OCSEAP and MMS, reports from the Alaska Department of Fish and Game and National Marine Fisheries Service, major published oceanographic reviews (e.g., Hood and Calder 1981; Hood and Zimmerman 1986), and monographs and other technical publications. Each of these reports was also searched for references to relevant reports that had not already been examined. The final step was to review relevant bibliographies (e.g., Severinghaus 1979; Braham 1986) to ensure that no major sources were missed.

After reviewing the literature to this extent, we divided the 30 marine mammal species into three categories (Table 2.1). The first category (18 species) included those marine mammals for which Alaska is a "significant" part of their range. We developed distribution maps for each of these species, using a common base map. These maps showed seasonal changes in range and distribution where possible. In addition to literature sources of the types mentioned above we utilized a pre-publication copy of the "Bering, Chukchi and Beaufort Seas Strategic Assessment: Data Atlas" (NOAA 1988) for determining the seasonal distribution of some species, and "Alaska's Wildlife and Habitat", Vol. 1 (ADFG 1973).

A second category of marine mammals consisted of eight widely distributed species for which Alaska is a relatively unimportant part of the range. We have shown the Alaskan distribution of these species with maps taken from other sources. The final category consisted of four species that are rare or

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*G.W. Miller, LGL Ltd.

Table 2.1. Common and Scientific Names of 30 Alaskan Marine Mammals.

		Category[1]		
		1	2	3
Baleen Whales				
Bowhead Whale	Balaena mysticetus	X		
Right Whale	Eubalaena glacialis			X
Gray Whale	Eschrichtius robustus	X		
Blue Whale	Balaenoptera musculus		X	
Fin Whale	Balaenoptera physalus	X		
Sei Whale	Balaenoptera borealis		X	
Minke Whale	Balaenoptera acutorostrata	X		
Humpback Whale	Megaptera novaeangliae	X		
Toothed Whales				
Sperm Whale	Physeter macrocephalus		X	
Narwhal	Monodon monoceros			X
White Whale	Delphinapterus leucas	X		
Baird's Beaked Whale	Berardius bairdii		X	
Cuvier's Beaked Whale	Ziphus cavirostris		X	
Stejneger's Beaked Whale	Mesoplodon stejnegeri		X	
Killer Whale	Orcinus orca	X		
Pilot Whale	Globicephala macrorhynchus			X
Pacific White-Sided Dolphin	Lagenorhynchus obliquidens		X	
Harbor Porpoise	Phocoena phocoena		X	
Dall's Porpoise	Phocoenoides dalli	X		
Pinnipeds				
Steller Sea Lion	Eumetopias jubata	X		
Northern Fur Seal	Callorhinus ursinus	X		
Walrus	Odobenus rosmarus	X		
Harbor Seal	Phoca vitulina	X		
Spotted Seal	Phoca largha	X		
Ringed Seal	Phoca hispida	X		
Ribbon Seal	Phoca fasciata	X		
Bearded Seal	Erignathus barbatus	X		
Northern Elephant Seal	Mirounga angustirostris			X
Other Marine Mammals				
Sea Otter	Enhydra lutris	X		
Polar Bear	Ursus maritimus	X		
		18	8	4

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[1] The categories shown indicate the level of discussion and mapping produced for each species; see text.

accidental in Alaskan waters. The distributions of these species are not mapped.

2.1.2 Marine mammal distribution

Baleen Whales

Bowhead Whale (Balaena mysticetus). The "Bering Sea" stock of bowhead whales moves seasonally among the Bering, Chukchi and Beaufort Seas (Fig. 2.1). These whales winter in the ice-covered waters of the northern and westcentral Bering Sea. In average ice years, bowheads occur from January to March in the pack ice from St. Lawrence Island south to St. Matthew Island, and in heavy ice years they can occur as far south as the Pribilof Islands (Braham et al. 1980). Leatherwood et al. (1983) indicated that wintering bowheads were most abundant near St. Matthew Island, and Ljungblad et al. (1986b) concluded that they seem to prefer the marginal ice zone during winter, regardless of where this zone is located. Ljungblad et al. (1986b) noted an association of wintering bowheads with the marginal ice front in ice coverage of from 10 to 90%. The actual wintering area probably varies from year to year, and within a season, as ice conditions change. Important areas of concentration appear to be recurrent polynyas near St. Lawrence and St. Matthew Islands, although there may be other important areas that have not yet been identified. The activities of bowheads during winter have not been studied.

The spring migration of the bowhead whale begins in the western part of the northern Bering Sea, when the pack ice begins to break up in March or April. Bowheads migrate from the areas west of St. Matthew Island and southwest of St. Lawrence Island past the west end of St. Lawrence Island. From there they pass through leads in the northwest Bering Sea and the western part of Bering Strait. After entering the Chukchi Sea they travel northeastward across outer Kotzebue Sound and on past Cape Thompson and Point Hope. From there they migrate northeastward along nearshore leads to Point Barrow. Bowheads usually begin travelling past Point Hope and Point Barrow in mid April. The main body of the migration past Barrow begins in the last week of April and continues through May. The spring migration period appears to be the primary season for calving and mating; occasional feeding also occurs.

From Barrow bowheads travel an offshore route to the eastern (Canadian) Beaufort Sea, the summer feeding grounds. Very few bowheads remain in Alaskan waters during summer. However, the western edge of the summer feeding grounds extends into the eastern Alaskan Beaufort Sea in some years (Ljungblad et al. 1986a; Richardson [ed.] 1987).

The autumn migration in Alaskan waters generally begins in early September as bowheads move into the Alaskan Beaufort Sea from Canadian waters. In some years, considerable feeding occurs during the autumn migration through the Alaskan Beaufort. Bowheads have usually left the Alaskan Beaufort Sea by mid-to-late October. This migration occurs over a fairly wide (100 km) corridor of coastal waters. Ljungblad et al. (1987) summarized the monthly changes in bowhead distribution in Alaskan waters during autumn, noting that they are generally found somewhat offshore in the eastern Alaskan Beaufort Sea in

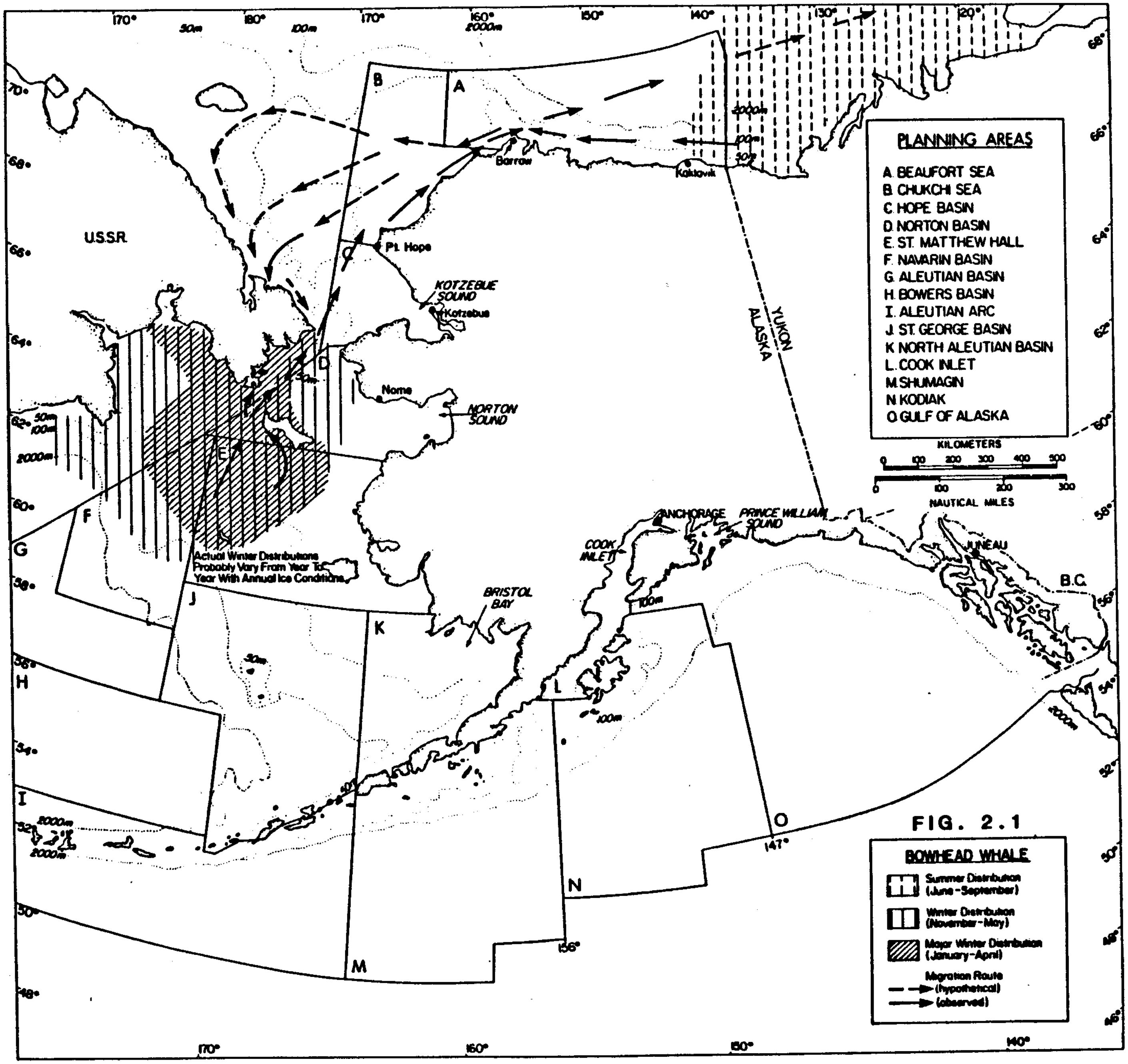

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
BOWHEAD WHALE
Summer Distribution (June-September)
Winter Distribution (November-May)
Major Winter Distribution (January-April)
Migration Route
(hypothetical)
(observed)
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
Actual Winter Distributions Probably Vary From Year To Year With Annual Ice Conditions.
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
170°
180°
170°
160°
150°
140°
130°
120°
50m
100m
2000m
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°
147°
156°
170°
160°
150°
140°

FIG. 2.1

August, in coastal waters across the Alaskan Beaufort Sea and northeastern Chukchi in September, and somewhat offshore in the central and western Alaskan Beaufort, and Chukchi Sea in October. Peak abundance indices in their Chukchi Sea study area were only 20% of indices calculated for the Alaskan Beaufort Sea. Headings of migrating bowheads sighted in the Chukchi Sea were clustered around a mean heading of 250°T. This heading suggests that at least some bowheads disperse across the Chukchi Sea en route to the Chukotka Peninsula, where numerous bowheads occur in late autumn (Miller et al. 1986). Braham et al. (1981) suggested that the primary route of autumn migrants is along the ice front west to Herald and Wrangel Islands and then south along the Chukotka Peninsula through Bering Strait. Bowheads generally enter the northern Bering Sea in November and December and arrive in their central Bering Sea wintering areas in December-February.

Right Whale (Eubalaena glacialis). The entire North Pacific population of right whales is presently estimated to number not more than 200 individuals. This species, which formerly occupied the northern Gulf of Alaska, the Aleutians, and the Bering Sea in the summer months, is now near extinction and there are few recent records for Alaskan waters (Braham 1986). Brueggeman et al. (1984) recorded two individuals in the Navarin Basin in 1982. Other recent extensive surveys in the right whale's former summering grounds have not produced any sightings (Rice and Wolman 1982; Leatherwood et al. 1983; Brueggeman et al. 1987).

Gray Whale (Eschrichtius robustus). Gray whales migrate to the Bering and Chukchi Seas to feed during the summer months. Because this migration occurs very close to shore, it has been extensively studied, and details of the migration pattern of this whale are relatively well-known.

The northward migration occurs in two pulses: the first consisting of adult males, immatures, and pregnant females; the second consisting primarily of lactating females and their calves. Northbound gray whales in Alaskan waters remain within 2 km of the outer coast of the mainland and/or barrier islands as far as the Kenai Peninsula. From there a majority migrate seaward of Kodiak Island, and then northward across the southwest end of Shelikof Strait to the Alaska Peninsula. Others head across the mouth of Cook Inlet and then close along the Alaska Peninsula. Gray whales pass through Unimak Pass (near its eastern shore) between March and June. Almost all of them continue an essentially coastal route around the perimeter of Bristol Bay to the southeast tip of Nunivak Island. From there they travel outside the island and fan out across the Bering Sea to St. Lawrence Island and beyond. A few individuals move north from Unimak Pass into offshore waters of the southeast Bering Sea, and small numbers remain along the north side of the Alaska Peninsula in summer (Braham 1984).

The southbound migration is also well understood. The migration is believed to be the reverse of the spring route; from the Bering Sea, around the perimeter of Bristol Bay, out Unimak Pass and along the coast of the Alaska Peninsula and the Gulf of Alaska, and south. Gray whales leave the Bering Sea through Unimak Pass from late October through early January, with peak numbers passing during late November and early December (Rugh 1984). It is possible that some gray whales move directly from feeding areas north of

St. Lawrence Island through offshore waters to Unimak Pass. Brueggeman (1984) recorded whales in his Navarin Basin study area only during autumn surveys. These southbound whales may have been migrating directly to Unimak Pass. However, Brueggeman et al. (1987) did not record any gray whales in the St. George Basin planning area during November and December despite substantial survey effort, and were therefore unable to substantiate a more direct route from the major summer feeding areas to Unimak Pass.

The distribution map indicates the major migration routes and summering areas. By far the most important feeding/summering area is in the northcentral Bering Sea between St. Lawrence Island and Bering Strait (Braham 1984; Moore and Ljungblad 1984). The major summer concentration area (Fig. 2.2) coincides with the distribution of a dense infaunal amphipod community upon which gray whales feed (Nerini 1984; Thomson [ed.] 1984). Gray whales reach St. Lawrence Island as early as May and concentrate near the southeast and west ends of the Island to feed. From these areas they disperse north, west and southwest. They enter the southern Chukchi Sea in summer and remain until autumn, but are scarce in the central and northern Chukchi except along the northwest Alaska coast to Pt. Barrow (Berzin 1984; Moore and Ljungblad 1984; Moore et al. 1986). In addition to the major summering area depicted, small numbers of gray whales summer at other locations along the migration route. Leatherwood et al. (1983) believed that grays summered in their study area in the North Aleutian planning area. Gill and Hall (1983) documented summer feeding at Nelson Lagoon along the north shore of the Alaska Peninsula during several years. Brueggeman et al. (1987) found small numbers of summering gray whales along the north shore of the Alaska Peninsula and a single summering whale near Popof Island, along the south side of the Alaska Peninsula. They concluded that almost every estuary on the north side of the Alaska Peninsula is important to summering gray whales, but that few gray whales summer in Alaskan waters south of the Peninsula.

Blue Whale (Balaenoptera musculus). The blue whale, the world's largest animal, is widely distributed in both the Northern and Southern hemispheres. In summer they can occasionally be found in the southern Bering Sea, and south of the Aleutians. Small numbers occur in July and August in the northern and eastern Gulf of Alaska, and southeast of the Aleutians (Fig. 2.3). They have not been sighted in recent studies conducted in the Navarin Basin (Brueggeman et al. 1984), southeast Bering Sea, or Gulf of Alaska (Rice and Wolman 1982; Leatherwood et al. 1983; Brueggeman et al. 1987). The lack of recent sightings suggests that the number of blue whales utilizing Alaskan waters is small.

Fin Whale (Balaenoptera physalus). The fin whale is an oceanic species with a world-wide distribution. Fin whales migrate north into Alaskan waters during the summer feeding season, entering the Bering, and less commonly the Chukchi Sea (Frost and Lowry 1981a) (Fig. 2.4).

Their primary Alaskan summer range, based on historical records and recent aerial surveys, appears to be Shelikof Strait and Kodiak Island waters, the shelf edge north and south of the Aleutians, and the southeast Bering Sea in the vicinity of the Pribilof Islands and north to 61° between St. Matthew and Nunivak Islands (Leatherwood et al. 1983). Data from Nasu (1974) show fin whale sightings in the Bering Sea concentrated along the shelf

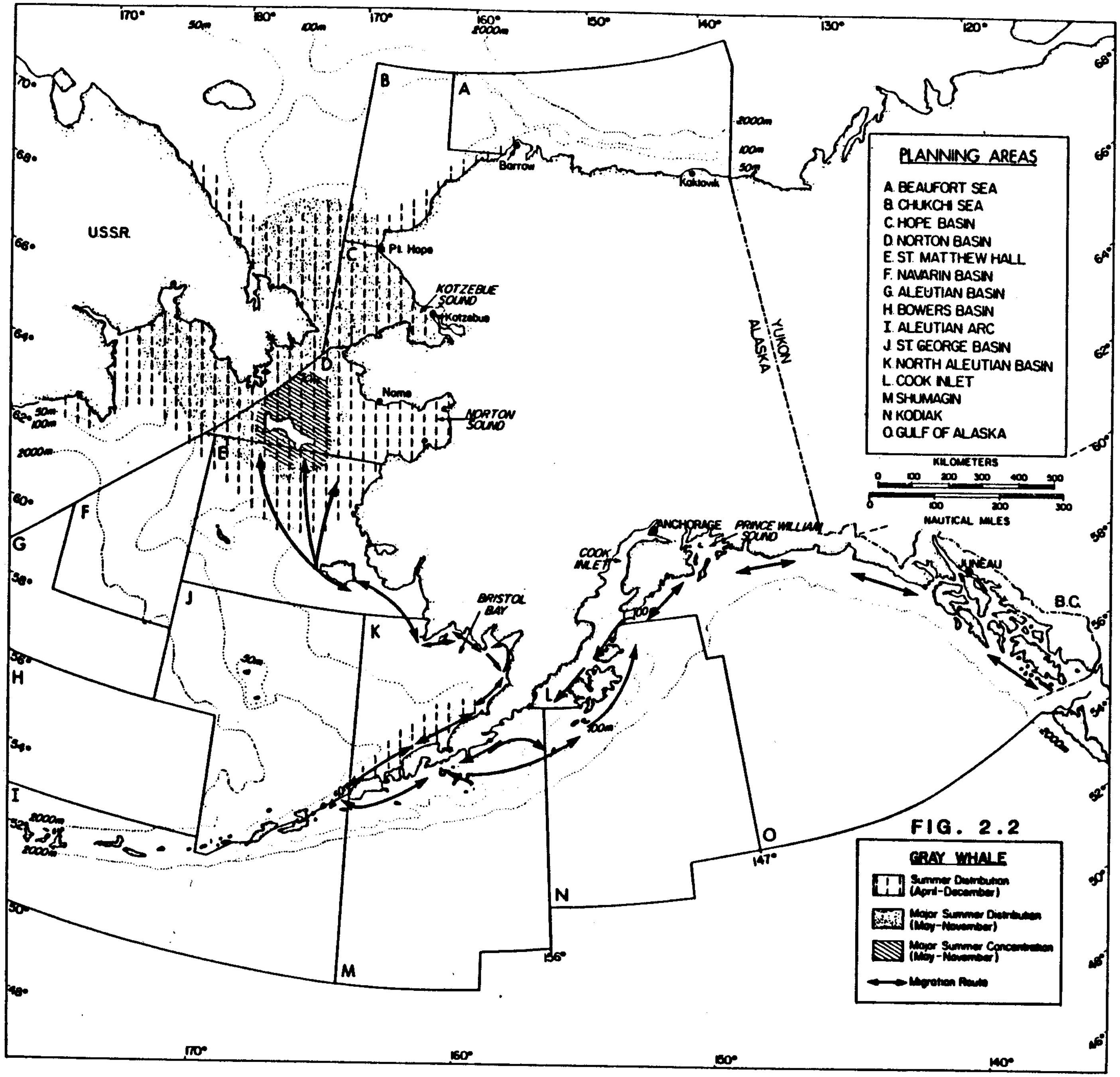


FIG. 2.2

PLANNING AREAS
A. BEAUFORT SEA
B. CHUKCHI SEA
C. HOPE BASIN
D. NORTON BASIN
E. ST. MATTHEW HALL
F. NAVARIN BASIN
G. ALEUTIAN BASIN
H. BOWERS BASIN
I. ALEUTIAN ARC
J. ST. GEORGE BASIN
K. NORTH ALEUTIAN BASIN
L. COOK INLET
M. SHUMAGIN
N. KODIAK
O. GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
GRAY WHALE
Summer Distribution (April-December)
Major Summer Distribution (May-November)
Major Summer Concentration (May-November)
Migration Route
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
170°
180°
170°
160°
150°
140°
130°
120°
160°
150°
140°
147°
156°
50m
100m
2000m
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°

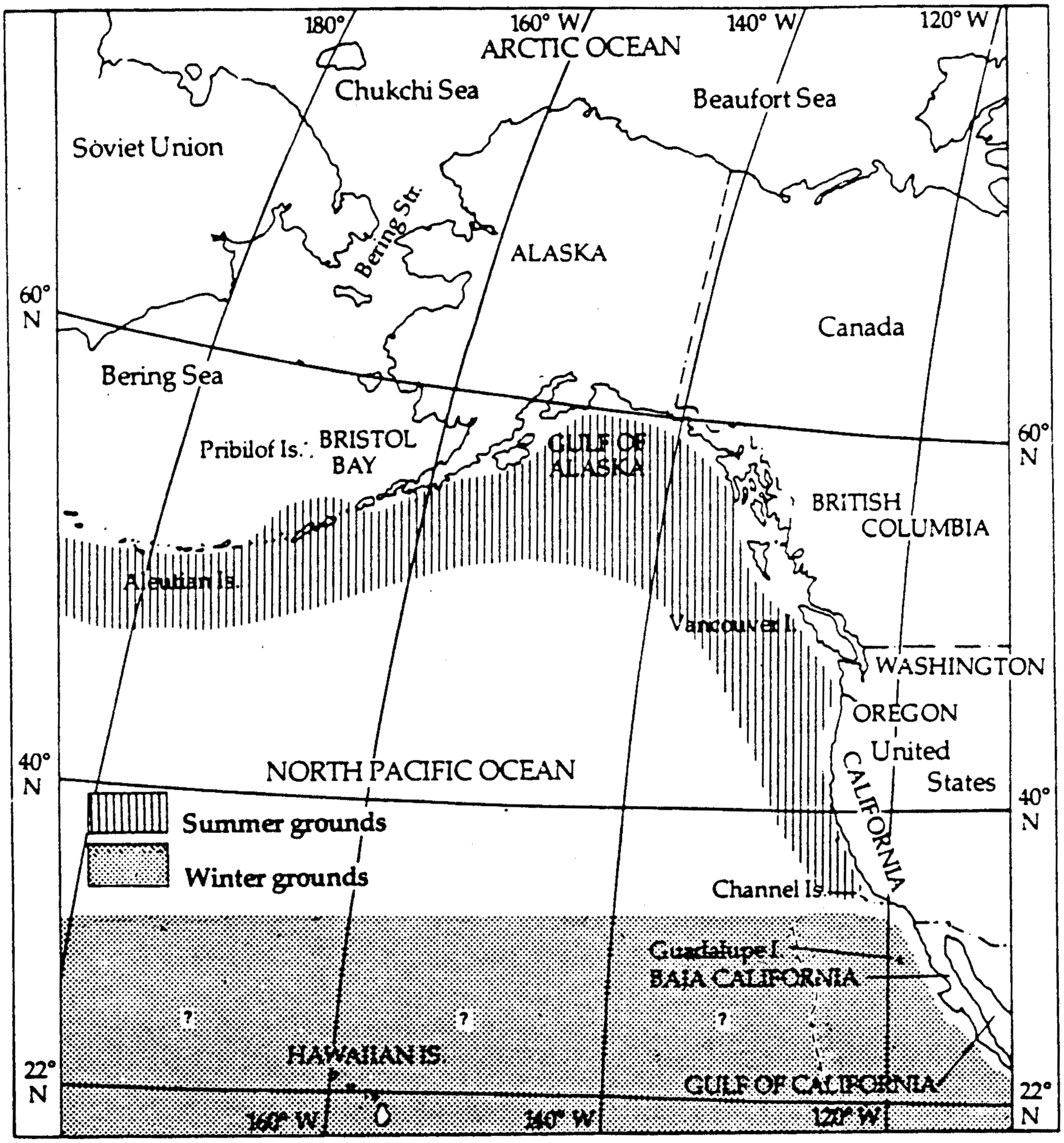


Figure 2.3. Blue Whale Distribution (Rice 1978a).

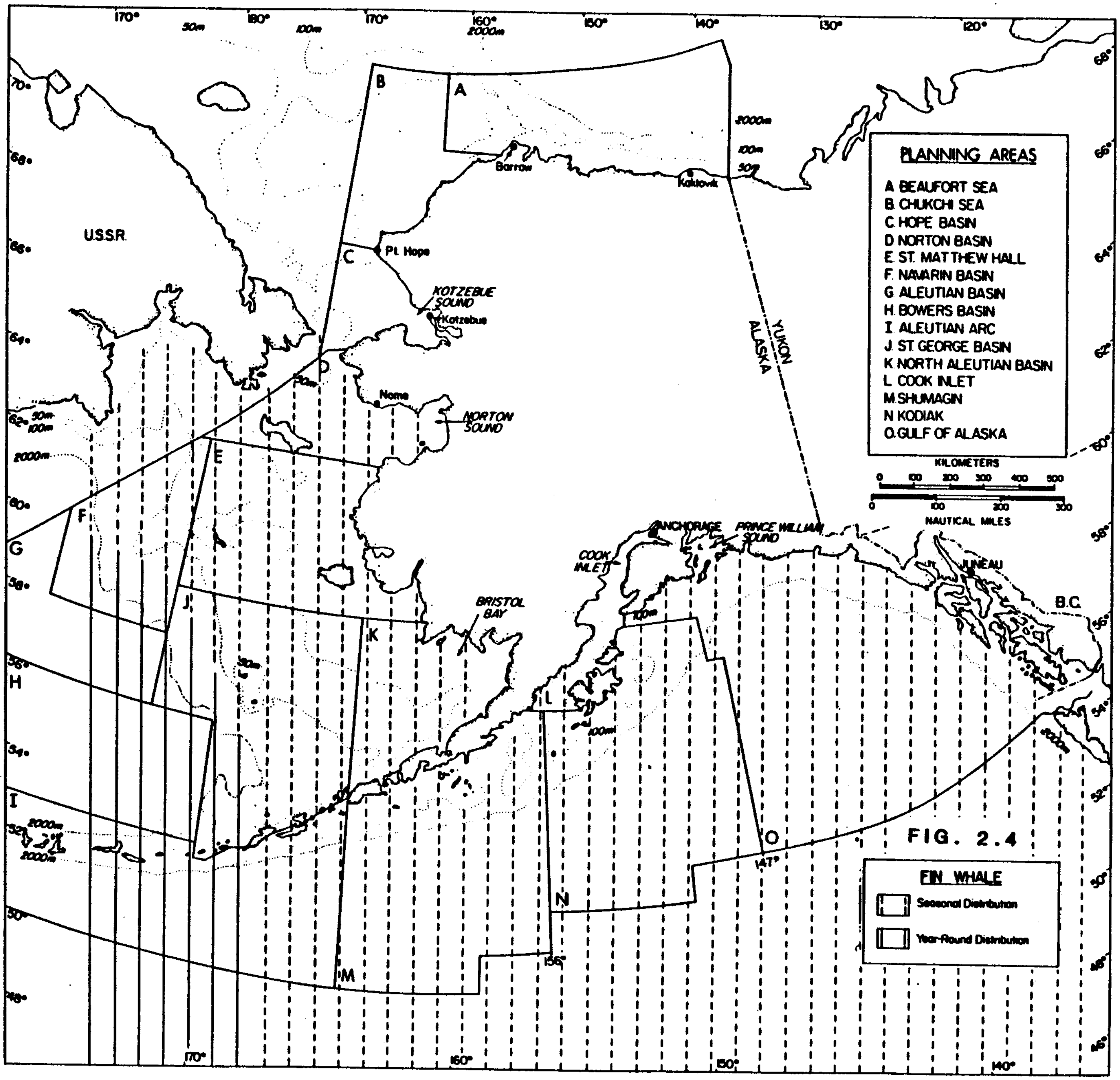

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
FIN WHALE
Seasonal Distribution
Year-Round Distribution
KILOMETERS
0
100
200
300
400
500
NAUTICAL MILES
0
100
200
300
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
50m
100m
2000m
170°
180°
160°
150°
140°
130°
120°
147°
156°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°

FIG. 2.4

break, but this distribution differs from that shown by Wada (1981) in which highest fin whale concentrations are shown well inside the shelf break in the eastcentral Bering Sea and the St. George Basin planning area south of Nunivak Island.

Brueggeman et al. (1987) found fin whales only in the Shumagin planning area, and only during July and August, in a study conducted from April-December in the North Aleutian Basin, St. George Basin and Shumagin planning areas. They found fin whales in areas of high bathymetric relief between 45 and 130 m deep. Brueggeman et al. (1988) conducted shipboard surveys in the Shumagin, Kodiak, and lower Cook Inlet planning areas. They found that fin whale distribution in their study area was not uniform and that greater than expected numbers of fin whales occurred between 156°W and 158°W longitude in the Shumagin Planning Area. During that study, fin whale sightings were most frequent in 50 to 150 fathoms (91 to 274 m) of water.

The northern limit of the fin whale's summer range is not clearly known. Although there are some records for the southern Chukchi Sea, Davis and Thomson (1984) considered the fin whale to be only an occasional visitor to the Chukchi Sea planning area. We have shown Bering Strait as the northern range limit, but recognize that fin whales may occasionally stray farther north.

Little is known about the wintering grounds of fin whales, although they are believed to winter largely in temperate to sub-tropical waters. Their migrations are not well understood--tagging studies have revealed large scale east-west as well as north-south movements (Leatherwood et al. 1983). Fin whales were found near the ice front during winter surveys conducted in the Navarin Basin planning area (Brueggeman et al. 1984). However, Leatherwood et al. (1983) found that fin whales were absent in autumn and winter from their study area in the Bering Sea, St. George Basin and North Aleutian Basin planning areas. Fin whales are considered "rare visitors" during winter in the Gulf of Alaska (Calkins 1986). Based on these scant data, the delineation between summer and year-round ranges shown on the range map is speculative. In summary, all of the planning areas south of Bering Strait are occupied by fin whales for at least part of the year, either as feeding areas or during migration.

Sei Whale (Balaenoptera borealis). The sei whale is widely distributed in many oceans. In Alaska it occurs in summer throughout the Gulf of Alaska and along the Aleutian Islands (Nasu 1984) (Fig. 2.5). Although there are records from the northern Bering Sea and even the southern Chukchi, this whale is seldom seen north of the Aleutians. They were not recorded by Rice and Wolman (1982) in the Gulf of Alaska, or by Brueggeman et al. (1984, 1987) in the Navarin Basin or in their study area in the St. George, North Aleutian and Shumagin planning areas. Although Leatherwood et al. (1983) recorded one in the southeast Bering Sea, they concluded that the southeast Bering Sea is not an important part of the sei whale's range. These whales migrate south in the winter months to warmer waters well south of Alaska.

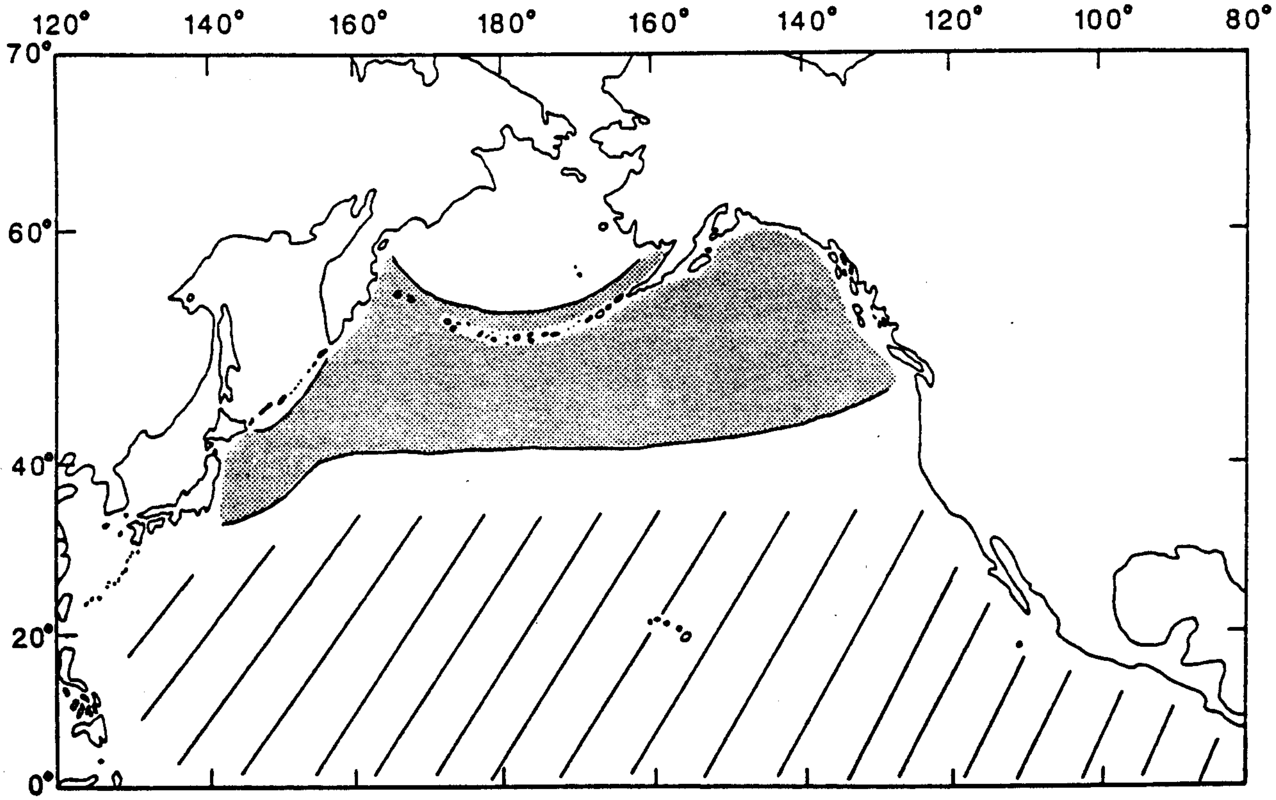


Figure 2.5. Schematic Seasonal Distribution of North Pacific Sei Whales. The Summer Distribution is Between the Bold Lines. The Striped Area is the Presumed Winter Distribution (Horwood 1987).

Minke Whale (Balaenoptera acutorostrata). The minke whale is a widely distributed whale, occurring in many oceans of the world in both the Northern and Southern hemispheres. In Alaska it is found in the Gulf of Alaska and the Bering Sea, occupying both shallow shelf and deep offshore waters (Fig. 2.6). It is common in shallow coastal waters of the Gulf of Alaska from April to October; there have been a few winter sightings in the Gulf of Alaska (Calkins 1986). In summer its range extends northward into the southern Chukchi Sea, where there are records from Kotzebue south (Frost et al. 1983). Davis and Thomson (1984) regarded the minke whale as rare or extremely uncommon in the Chukchi Sea planning area. In winter the population shifts southward, but the minke whale is believed to be a year-round resident in the Bering Sea. Minke whales were recorded during surveys conducted in the Navarin Basin planning area during all four seasons and were observed near the fringe of the ice front during winter surveys (Brueggeman 1984). Surveys in the Bering Sea (including the St. George and North Aleutian Basin planning areas) support the suggestion that some minke whales inhabit the Bering Sea year round. These results included winter and spring observations of minke whales near the pack ice edge (Leatherwood et al. 1983). In summary, minke whales may be expected to occur at least for a portion of the year in all planning areas south of, and including the Hope Basin area. The demarcation between the seasonal and year-round ranges shown on the distribution map is based on few data and is speculative.

North Pacific minke whales are thought to breed throughout the year, with calving peaks in December and June. Leatherwood et al. (1983) recorded one calf in May and another in August in the southeast Bering Sea.

Humpback Whale (Megaptera novaeangliae). The humpback whale is a cosmopolitan species found in all oceans. In general, it concentrates in coastal areas, but migrates through deep areas and also occurs regularly around shoals and offshore islands. It occupies Alaskan waters in spring, summer and fall, and some may occasionally venture as far north as the southern Chukchi Sea.

Important summering areas include the southeast Bering Sea, the Aleutians, Shelikof Strait, the Gulf of Alaska and southeast Alaska. Wada (1981) found highest densities of humpbacks in a region south of the Alaska Peninsula that corresponds to the Shumagin and Kodiak planning areas, and along the southeast Alaska coast in the Gulf of Alaska planning area. The numbers of humpbacks occupying Alaskan waters are not large. Rice and Wolman (1982) estimated that the total North Pacific population of humpbacks on the summer feeding grounds averaged only 1200 individuals. Morris (1981) estimated that 200 humpback whales were widely distributed during summer in the Bering Sea. In this area they are most numerous in the waters between the Pribilof Islands, Nunivak Island and Cape Newenham. Leatherwood et al. (1983) recorded only two individuals on surveys in this particular part of the Bering Sea and Brueggeman et al. (1984) did not record any humpback whales during their surveys in the Navarin Basin. Brueggeman et al. (1987) recorded humpback whales in the Shumagin, but not the North Aleutian and St. George planning areas. Brueggeman et al. (1988) conducted shipboard surveys during

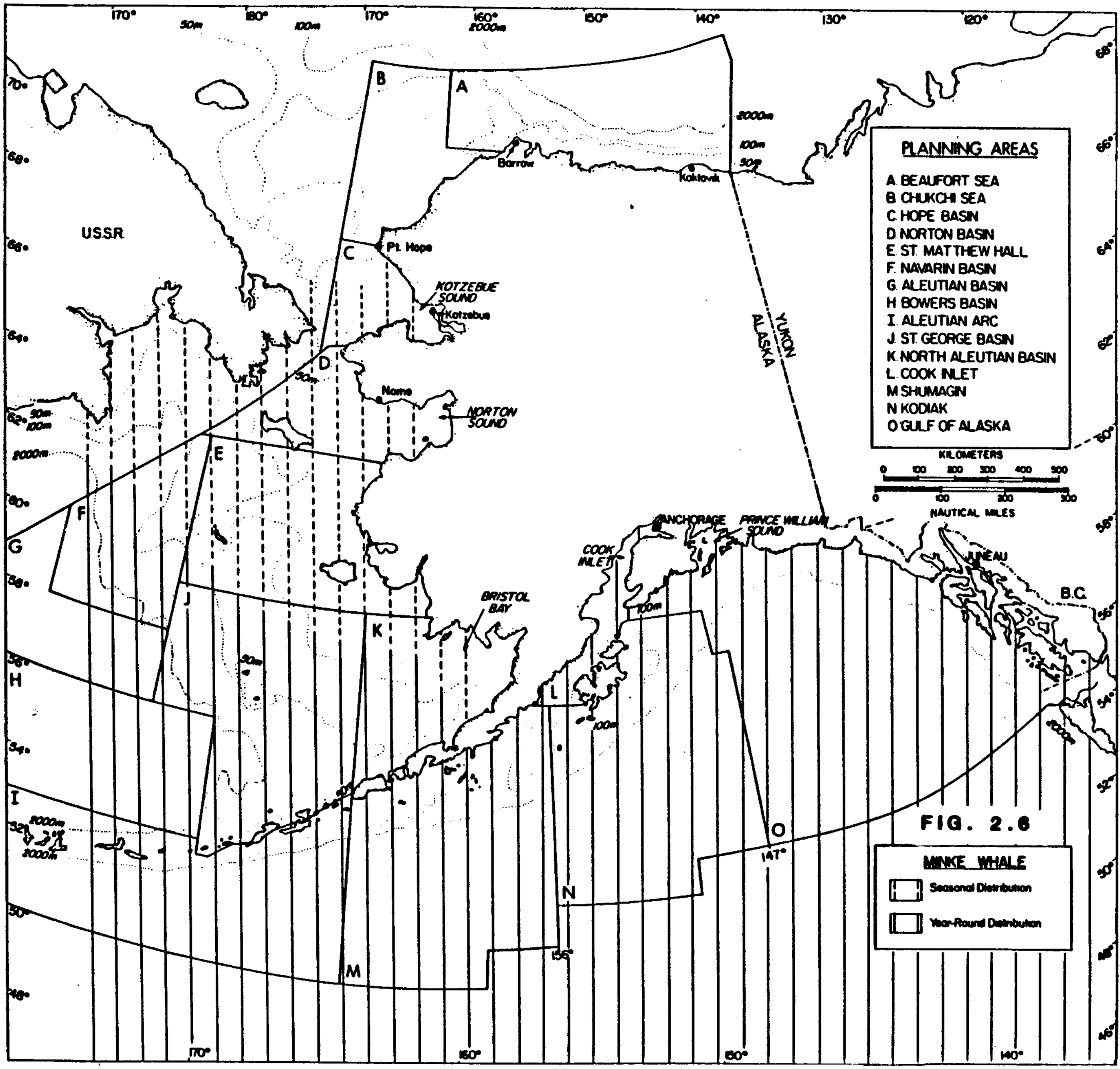

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
NAUTICAL MILES
MINKE WHALE
Seasonal Distribution
Year-Round Distribution
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
2000m
100m
50m
147°
156°

FIG. 2.6

June-July 1987 in the Shumagin, Kodiak, and lower Cook Inlet planning areas. They found unexpectedly high numbers of humbacks between 150°W and 154°W longitude (Kodiak/lower Cook Inlet area), especially in waters 25 to 50 fathoms deep. Most of these sightings were east or southeast of Kodiak Island.

Population estimates for Alaskan waters south of the Alaskan Peninsula (333, Brueggeman et al. 1987), the Gulf of Alaska east of Chirikof Island (364, Rice and Wolman 1982) and southeast Alaska (310, Baker et al. 1985) can be combined to provide a minimum abundance estimate of slightly more than 1000 humpbacks. Minimum abundance estimates calculated by Brueggeman et al. (1988) suggested that there were 220 (±127 SE) humpbacks in the Shumagin Planning Area and 1,027 (±387 SE) in the Kodiak lower Cook Inlet planning areas or a total of 1247 (±392 SE) humpbacks in the three planning areas. Some of the concentration areas within the Gulf of Alaska area are shown in Figure 2.7 and include areas around Sanak Bank and Shumagin Bank south of the Alaska Peninsula, waters east of Afognak Island, Prince William Sound, and coastal waters of southeast Alaska.

Darling and McSweeney (1985) photographically identified 420 individual humpbacks in southeast Alaska, and 54 in Prince William Sound in the years between 1975 and 1982. Fifty-one of the individuals identified in southeast Alaska and eight of the individuals identified in Prince William Sound were also identified in Hawaiian waters on their wintering grounds.

Wolman (1978) indicated that humpback whales spend about 5½ months on their feeding grounds and that their migrations north and south take about two months. They can generally be found in Alaskan waters from May to November, but some individuals have been recorded in southeast Alaska as late as early February. Despite these late sightings, overwintering in Alaskan waters is thought to be uncommon, if indeed it does occur at all (Baker et al. 1985). There is apparently temporal segregation during migration by age, sex, and reproductive state. Newly pregnant females and immatures are the first to begin the migration north to the feeding areas, and they are followed by mature males and lactating females. Lactating females are the first to begin migrating south to the breeding/wintering grounds and are followed by immatures, adult males, and non-lactating adult females. Southward migration begins in October and November, but the routes taken are poorly known.

Toothed Whales

Sperm Whale (Physeter macrocephalus). The sperm whale is an abundant species that inhabits all oceans of the world. Mature males migrate to higher latitudes than do females and immature males, which are rarely found north of 50° latitude. Adult males summer in deep waters off southeast Alaska, the Gulf of Alaska, the Aleutians, and into the central and western Bering Sea (Fig. 2.8). They arrive near the Aleutians in March and in the Bering Sea by April. Although sperm whales were not encountered during recent studies in the Bering Sea (Leatherwood et al. 1983; Brueggeman et al. 1984, 1987), recent Japanese sightings suggest that sperm whales are present in the eastcentral Bering Sea and the Navarin Basin planning area, as well as all planning areas south and east of these areas (Wada 1981). Recent surveys by Brueggeman

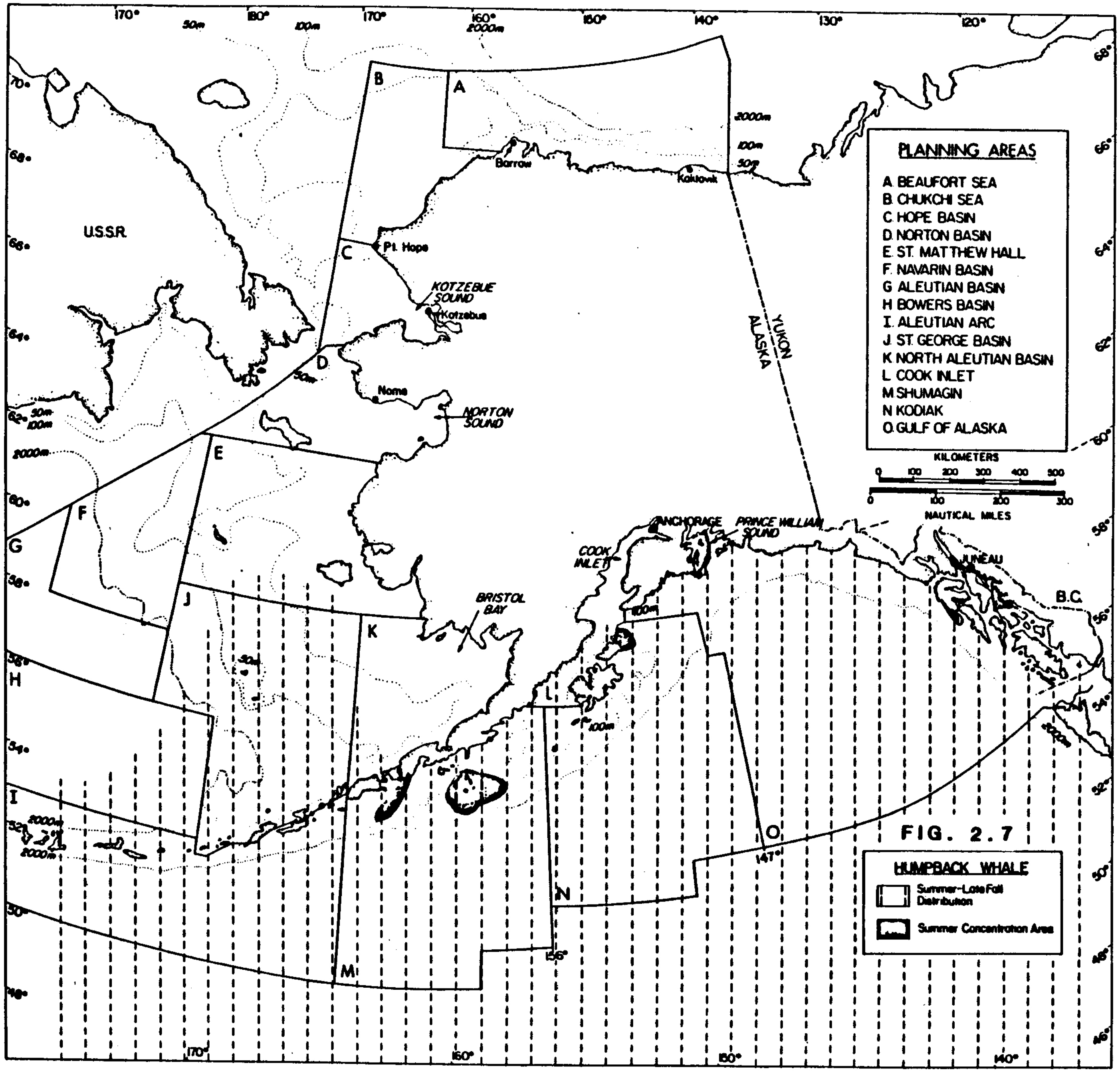

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
HUMPBACK WHALE
Summer-Late Fall Distribution
Summer Concentration Area
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
170°
180°
170°
160°
150°
140°
130°
120°
50m
100m
2000m
147°
156°
170°
160°
150°
140°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°

FIG. 2.7

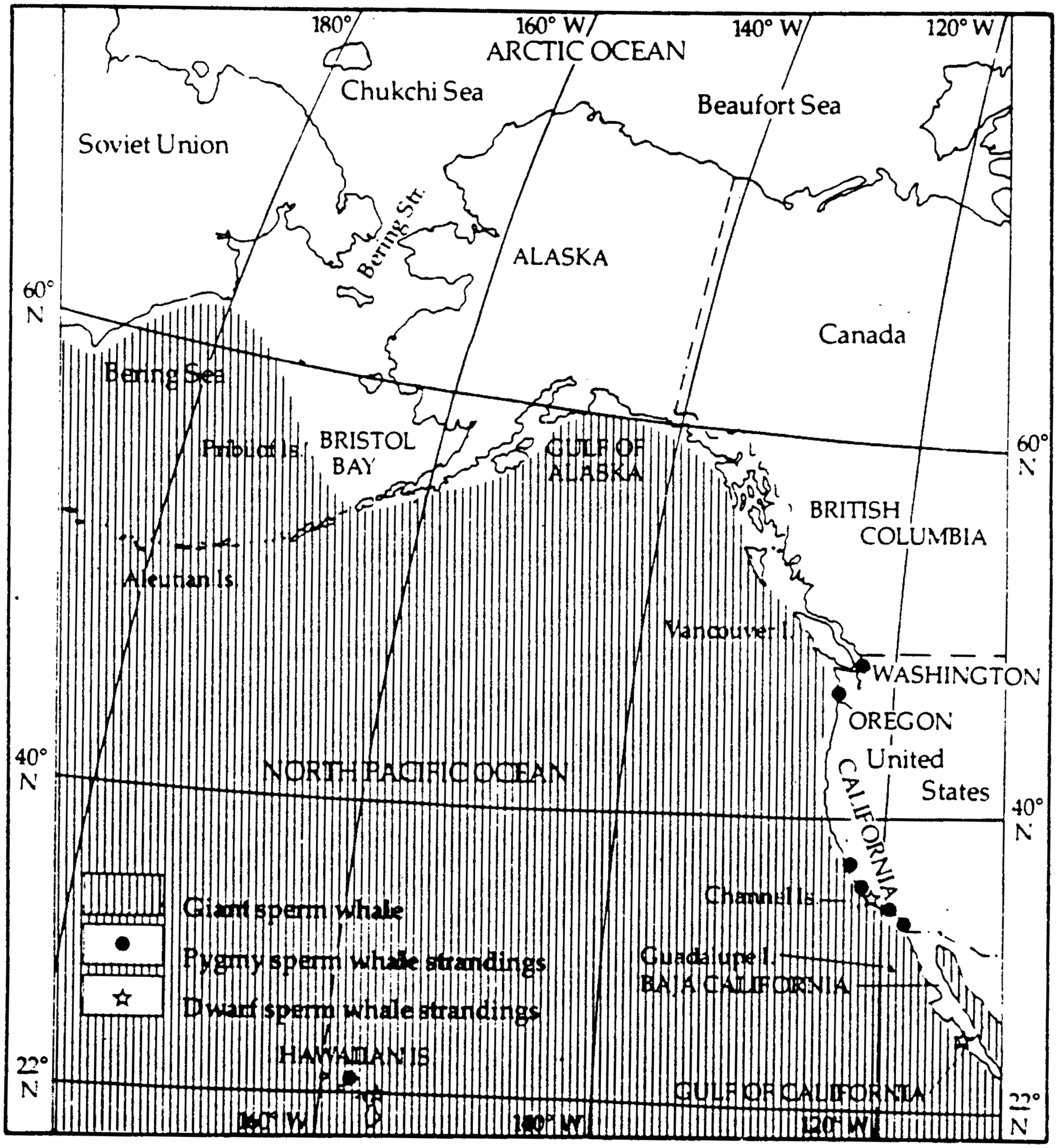


Figure 2.8. Sperm Whale Distribution (Rice 1978b).

(1987) recorded sperm whales in deep waters in the Shumagin planning area and Rice and Wolman (1982) found sperm whales far offshore in the Gulf of Alaska.

Narwhal (Monodon monoceros). The narwhal is found primarily in eastern Canadian and Greenland arctic waters. Narwhals rarely occur in Alaskan waters, although a small number of strandings and sightings of live individuals have been recorded.

White Whale (Delphinapterus leucas). The white whale (beluga) is an abundant and widespread circumpolar arctic and subarctic whale (Fig. 2.9). There are at least two stocks of white whales in Alaskan waters. The Cook Inlet stock is a small non-migratory stock occupying the northern Gulf of Alaska from Kodiak Island and the adjacent Alaska Peninsula in the west, to Yakutat Bay in the east (Harrison and Hall 1978). Estimates that this stock consists of from 300-500 individuals are based on uncorrected direct counts and may be 2-4 times too low (Calkins 1986).

White whales move seasonally in relation to the ice that forms over much of their range. In the Gulf of Alaska white whales move into upper Cook Inlet in the spring as the ice breaks up and concentrate near the mouths of rivers in the early summer. They can be found throughout Cook Inlet through late summer and then probably move to the lower Inlet in winter. White whales commonly concentrate in the mouths of rivers during calving, possibly because of a thermal advantage to newborns. Calving in Alaska occurs from mid May to early September with a peak in July (Seaman and Burns 1981). Another explanation for the concentration of white whales near river mouths in spring is that white whales are attracted by the large numbers of anadromous fish occurring there at that time of year.

The major Alaskan stock of white whales winters primarily in the ice covered waters of the Bering Sea, and their movements are affected by the seasonal cycle of ice distribution. During winter they are excluded from most of the coastal zone by the formation of shorefast ice. Most sightings of white whales during this season have been in the pack ice of the Bering and to a lesser extent the southern Chukchi Seas, and it is presumed that the majority of the population winters in those areas. A large portion of this stock migrates north in spring into the Chukchi and Beaufort Seas. Others migrate into Bristol Bay, Norton Sound or other coastal waters of the Bering Sea. The size of this Bering Sea "stock" is not well known. The portion of this population that migrates into the Beaufort Sea has been estimated to consist of at least 11,500 individuals (Davis and Evans 1982). An estimated 1000-1500 white whales are present in Bristol Bay and 1000-2000 occur in Norton Sound. The minimum size of this stock in Alaska waters is estimated to be 13,500-18,000 individuals (Frost et al. 1983; Seaman et al. 1985).

Spring migration occurs from March to early July (Braham et al. 1981). White whales leave the central Bering Sea in March and April, following inshore and offshore leads in the pack ice. Those summering in Canadian waters pass through the Chukchi Sea in mid-to-late April following nearshore leads along the west and northwest coasts of Alaska. East of Point Barrow white whales pursue an offshore route, following leads through the Beaufort Sea during May and June. Some of the white whales migrating through Bering

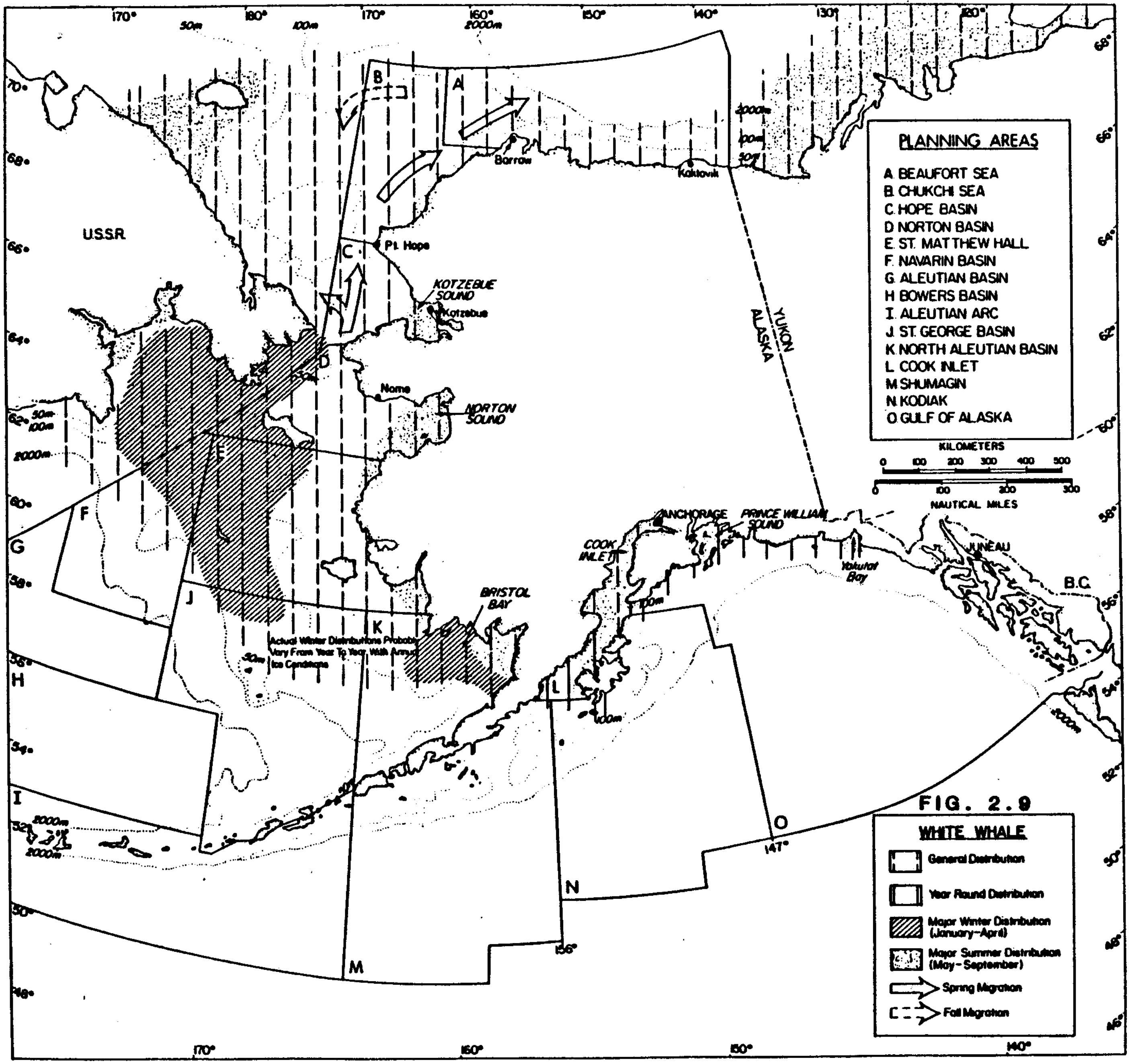

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
WHITE WHALE
General Distribution
Year Round Distribution
Major Winter Distribution (January-April)
Major Summer Distribution (May-September)
Spring Migration
Fall Migration
KILOMETERS
0 100 200 300 400 500
NAUTICAL MILES
0 100 200 300
U.S.S.R.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
YUKON
ALASKA
ANCHORAGE
PRINCE WILLIAM SOUND
COOK INLET
Yakutat Bay
JUNEAU
B.C.
BRISTOL BAY
Actual Winter Distributions Probably Vary From Year To Year With Annual Ice Conditions
50m
100m
2000m
170°
180°
160°
150°
140°
130°
120°
147°
156°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°

FIG. 2.9

Strait enter Soviet waters, migrating along the north coast of the Chukotka Peninsula.

The timing of the autumn migration west from Canada to U.S. and Soviet waters is not so well documented. Departure from the Canadian Beaufort Seas begins in August and September, with passage into the Bering Sea in December. The main route of westward migration through the Beaufort Sea is offshore (Ljungblad et al. 1987).

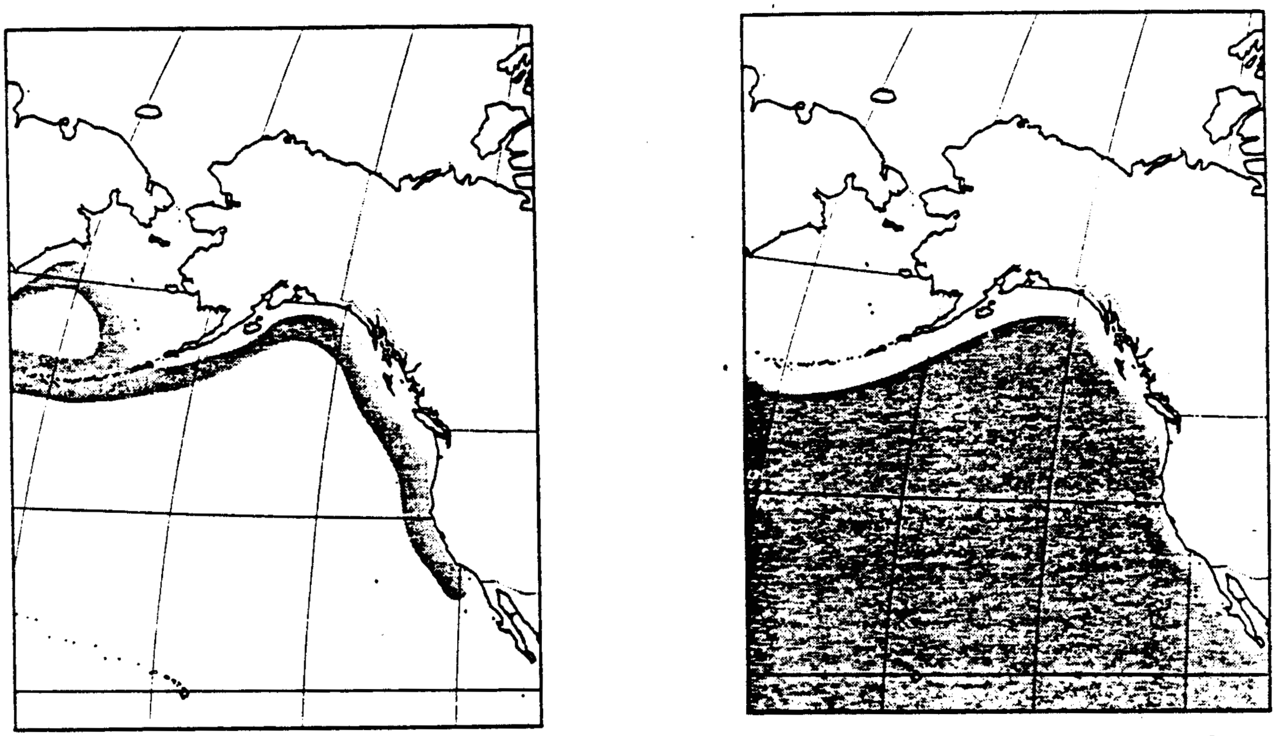
White whales begin to appear regularly near St. Lawrence Island in the Bering Sea from November to January.

The distribution map indicates only seasonal occupation of the Bering, Chukchi, and Beaufort Seas, although some parts of the Bering and southern Chukchi Sea may be occupied for most if not all of the year. Bristol Bay in particular is thought to support year-round populations of white whales (Leatherwood et al. 1983). White whales enter the rivers and inner bays of Bristol Bay in spring, as early as ice conditions permit, and remain until late summer. In winter months they move out with the advancing ice. This "population" may mix offshore during winter months with white whales that migrated northward in summer. Frost et al. (1983) investigated the impact of white whales on the red salmon run in inner Bristol Bay. The concluded that although 1983 consumption of adult salmon by white whales was an estimated 837,200 kg, this represented less than 1% of the commercial catch and just over 0.5% of the total salmon run.

Peak breeding activity is in mid April and early May. Gestation is about 14.5 months, and the calves, born mainly in July, nurse for 1-2 years. Females generally give birth every three years, and females with calves usually stay in herds separate from adult males (Fay 1978).

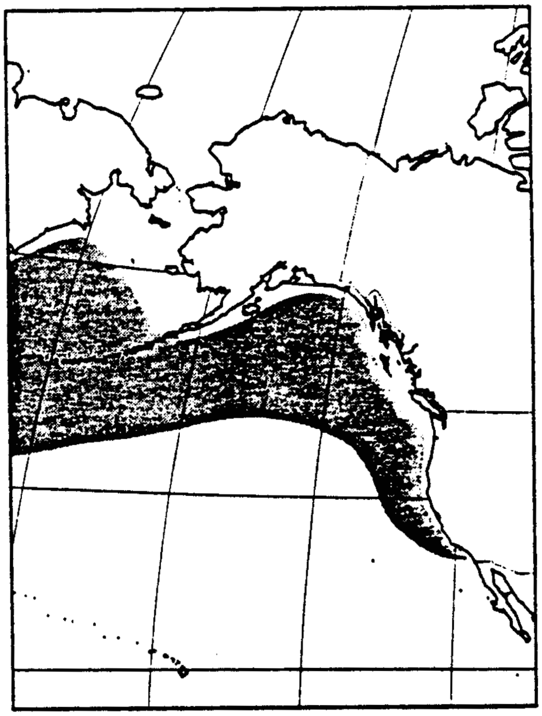
Baird's Beaked Whale (Berardius bairdii). Baird's beaked whale is found only in deep waters of the North Pacific. In Alaskan waters it is found in the Gulf of Alaska, and in summer it ranges north into the Bering Sea as far as the Pribilof and St. Matthew Islands. Much of the distributional evidence for this species in the Bering Sea is from a few stranded specimens. Recent summer sightings of small numbers of live individuals have been reported for the St. George Basin (Leatherwood et al. 1983) and Shumagin (Brueggeman et al. 1987) planning areas. Little is known about the life history of this species (Leatherwood and Reeves 1983) (Fig. 2.10a).

Cuvier's Beaked Whale (Ziphus cavirostris). Cuvier's beaked whale is the most cosmopolitan of the beaked whales and is widely distributed among the tropical and temperate oceans of the world. It is considered the most widely distributed and frequently sighted beaked whale in Alaskan waters, although knowledge of its distribution is based primarily on stranding records. In Alaska it is known to occur in southeast Alaska, and Aleutian Island waters. Its distribution in the Bering Sea is largely limited to waters near the Aleutian Islands, although a stranded specimen was found on St. Matthew Island in 1916. Recent summer sightings of small numbers of live individuals have been recorded in the Shumagin planning area (Brueggeman et al. 1987) and in the Gulf of Alaska (Rice and Wolman 1982) (Fig. 2.10b).



A. Baird's Beaked Whale

B. Cuvier's Beaked Whale



C. Stejneger's Beaked Whale

Figure 2.10. Beaked Whale Distributions (Rice 1978c).

Stejneger's Beaked Whale (Mesoplodon stejnegeri). Stejneger's beaked whales range in the North Pacific from subarctic waters north to Bristol Bay and the Pribilof Islands. This species is difficult to detect and identify at sea. They are rarely sighted and identified, and are known primarily from stranded specimens. Leatherwood et al. (1983) believed that most of five of their sightings (10 individuals) of beaked whales in the southeast Bering Sea and Shelikof Strait study areas were of this species (Fig. 2.10c)

Killer Whale (Orcinus orca). Killer whales are cosmopolitan in distribution. In the northeastern Pacific Ocean they occur in the eastern Bering Sea, and have been reported as far north as the Chukchi Sea. They are abundant in continental slope and shelf waters off the Pribilof Islands and the Aleutian Islands chain, and concentrations occur in Prince William Sound, off Kodiak Island, and in southeastern Alaskan waters (Dahlheim 1981; Calkins 1986). The concentration areas shown in Figure 2.11 are adapted from a figure in Braham and Dahlheim (1982) showing cumulative killer whale sightings (1958-1980) from NOAA's Platform of Opportunity Program.

The southern extent of heavy sea ice defines the northern limit of their Alaskan distribution. Morris (1981b) noted that they enter the Chukchi Sea during the open water season and are often sighted along the coast or at the edge of the pack ice. Frost et al. (1983) noted that killer whales are widely distributed in low numbers in the coastal zone of the Chukchi, and that they are seen every summer by residents of Shishmaref. Johnson et al. (1966) state that they are reported from the Eskimo villages north to Barrow, including Kivalina and Point Hope. Davis and Thomson (1984) concluded that killer whales are rare or extremely uncommon in the Chukchi Sea planning area.

In winter killer whales at the northern limits of their range shift southward with the advancing ice. Brueggeman et al. (1984) found killer whales along the fringe of the ice front during winter surveys in the Navarin Basin planning area, as well as during open water surveys in summer. Thus, they apparently inhabit the Bering Sea on a year-round basis.

In other recent surveys killer whales have been recorded in the St. George Basin, North Aleutian Shelf, Shumagin, Kodiak and Gulf of Alaska planning areas (Rice and Wolman 1982; Leatherwood et al. 1983; Brueggeman 1987). Killer whales were found in the St. George, North Aleutian Basin and Shumagin planning areas at least from summer through early winter and it is likely that at least some killer whales are found in these planning areas on a year round basis. Leatherwood et al. (1983) recorded eight calves in their southeast Bering Sea study area in the months of March, May and September.

Pilot Whale (Globicephala macrorhynchus). Pilot whales are found in temperate and tropical oceans of the world. They may be present but are not common in the Gulf of Alaska, which is far north of their population centers off the California and Mexico coasts. They have not been recorded in any recent major survey efforts in Alaskan waters (Rice and Wolman 1982; Leatherwood 1983; Brueggeman et al. 1984, 1987).

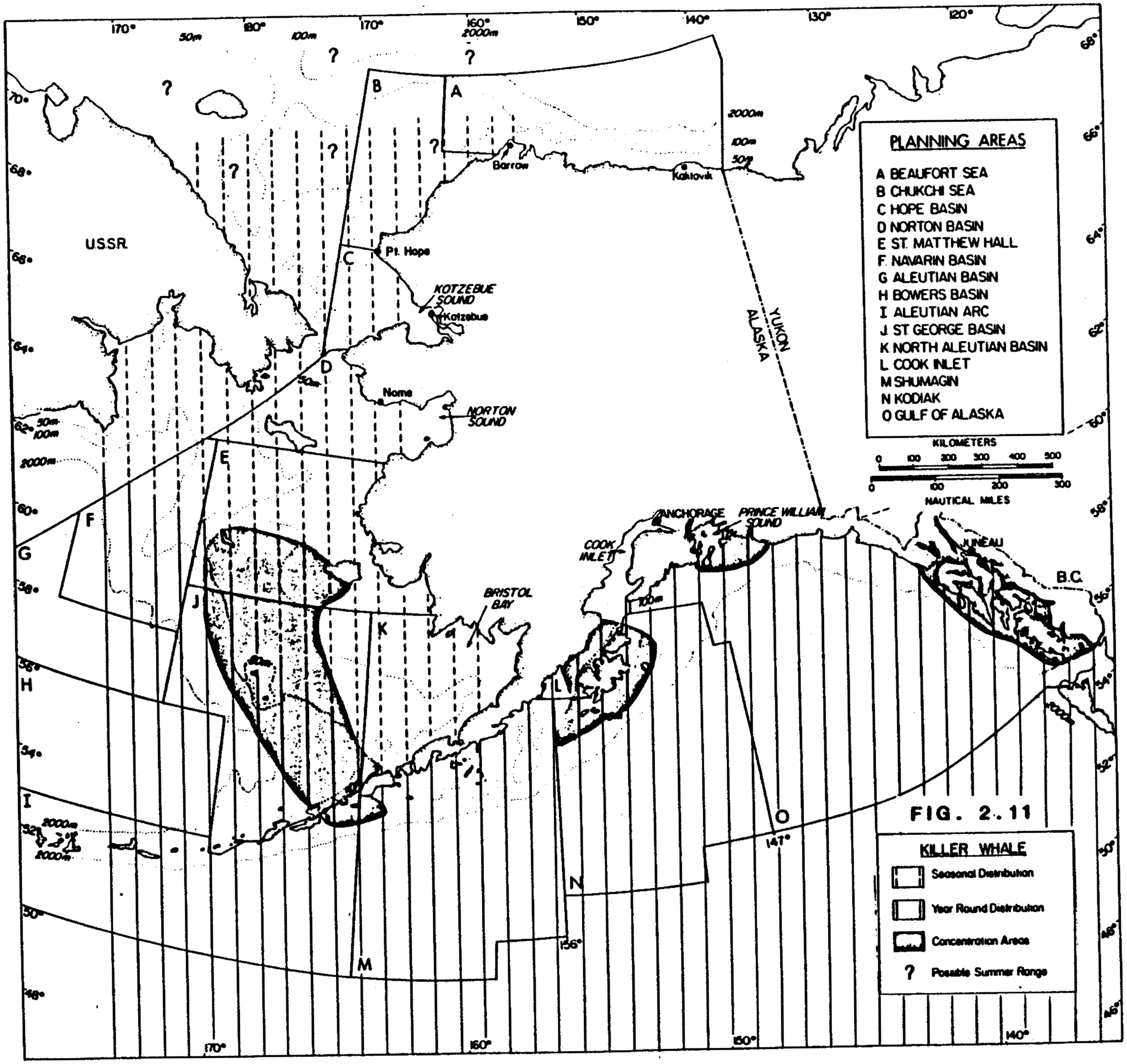

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
KILLER WHALE
Seasonal Distribution
Year Round Distribution
Concentration Areas
? Possible Summer Range
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
170°
180°
170°
160°
150°
140°
130°
120°
147°
156°
160°
150°
140°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°
50m
100m
2000m

FIG. 2.11

Pacific White-sided Dolphin (Lagenorhynchus obliquidens). This species is widely distributed in temperate waters of the North Pacific Ocean, and ranges in Alaskan waters from south of the Aleutians, eastward through the Gulf of Alaska. Records for the northern part of this range are seasonal, occurring during the warmer months. This dolphin inhabits coastal heads of deep canyons, and ranges offshore to the edge of the continental shelf. During recent large-scale survey efforts in Alaskan waters, white-sided dolphins have been recorded only by Rice and Wolman (1982) in the Gulf of Alaska (Fig. 2.12a).

Harbor Porpoise (Phocoena phocoena). The harbor porpoise is a boreal temperate species with a worldwide distribution. It is Alaska's smallest cetacean and occurs primarily in coastal waters of southeast Alaska, the Gulf of Alaska, the eastern Aleutians, Bristol Bay, and the eastern Bering Sea. Frost et al. (1983) suggest that this species probably occurs occasionally during summer along the entire Alaskan Chukchi coast. Prince William Sound is an area of particular abundance (Hall 1979; Calkins 1986).

Leatherwood et al. (1983) found harbor porpoises to be absent from their southeast Bering Sea study area in winter, but present in all seasons in Shelikof Strait. They recorded no sightings of harbor porpoises in or near sea ice at any season. Sightings occurred mostly within the 183 m contour (97.5%) and largely within the 128 m contour (79%). In southeast Alaska this species is believed to calve from April through September, with peak cow/calf sightings in August. Leatherwood et al. (1983) encountered a calf in each of June, July and August (Fig. 2.12b).

Dall's Porpoise (Phocoenoides dalli). Dall's porpoise is probably the most abundant small cetacean in the northern Pacific Ocean. Densities are highest in deep pelagic water and in areas along the continental shelf break, but the species occurs in all except the shallowest nearshore areas. They are found as far north as Bering Strait and the southern Chukchi Sea, but are generally more common south of 61°N latitude (Braham et al. 1977; Leatherwood et al. 1983) (Fig. 2.13).

Movements of this highly mobile species are poorly understood, but Leatherwood and Reeves (1978) suggest that the northern portion of the range is occupied only seasonally--the population shifts southward in winter. In support of this contention, this porpoise was not recorded during winter aerial and shipboard surveys conducted by Brueggeman et al. (1984) in the Navarin Basin, although it was the most abundant cetacean recorded during their spring, summer and autumn surveys. Leatherwood et al. (1983) found seasonal shifts in the range of this porpoise in the eastern Bering Sea. The range was most restricted in spring (when this species was absent from inner Bristol Bay) and widest in summer. Even in fall and winter Dall's porpoises were present to near 59°N latitude. Dall's porpoise is a year-round resident in the St. George Basin, North Aleutian Basin, Shumagin, Kodiak and Gulf of Alaska planning areas.

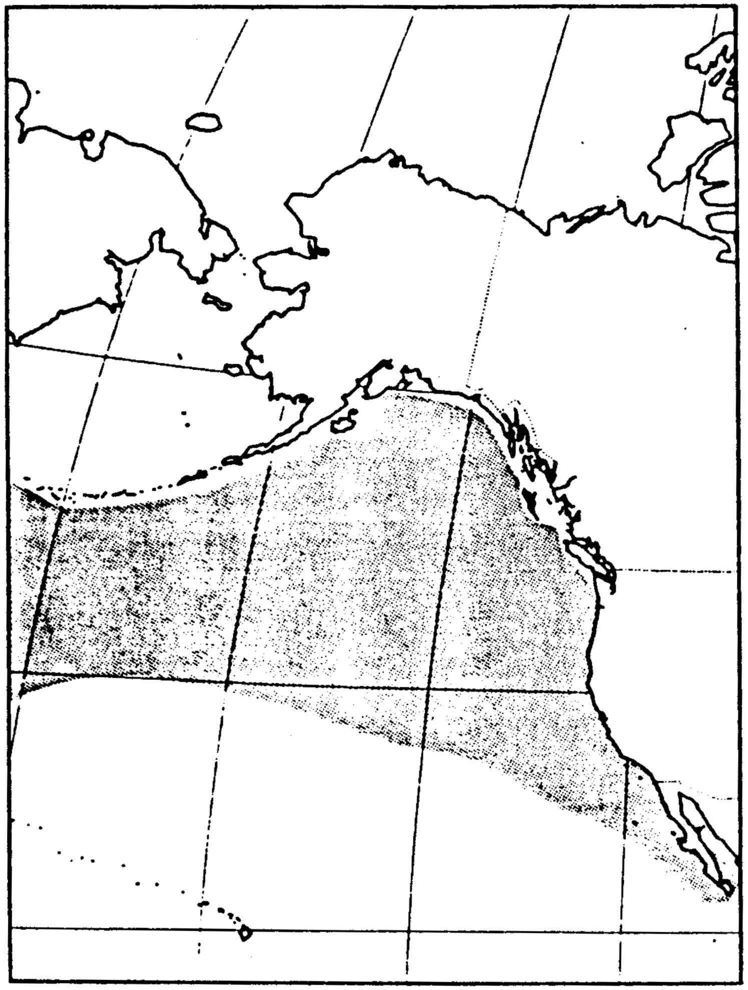


Figure 2.12a. Pacific white-sided dolphin distribution (Leatherwood and Reeves 1978).

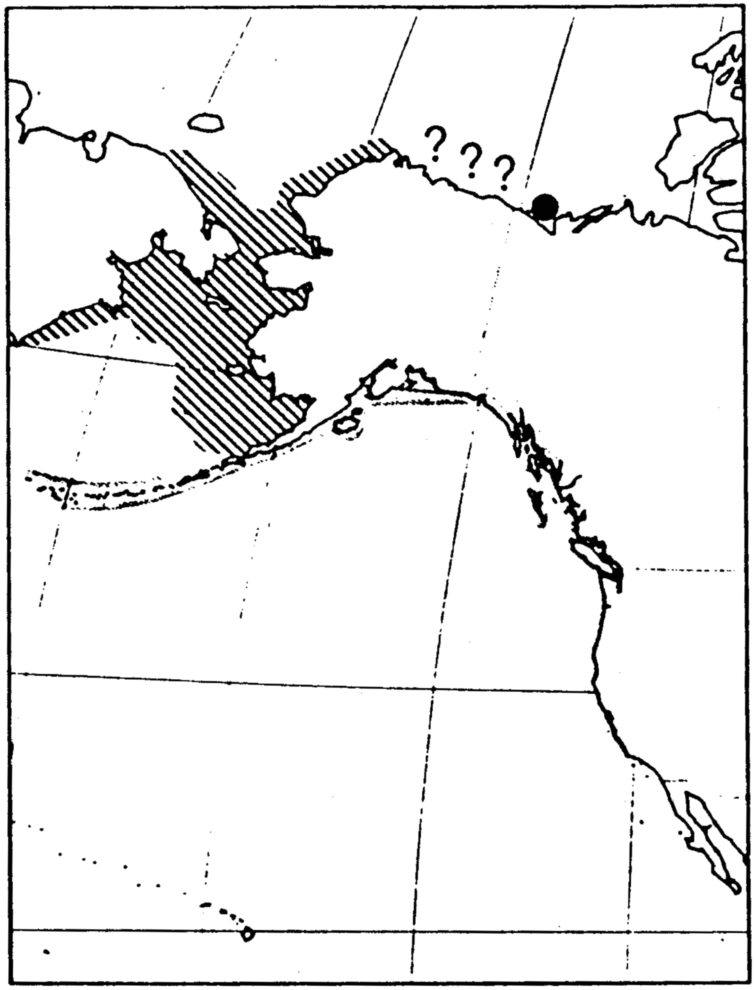


Figure 2.12b. Harbor porpoise distribution (Leatherwood and Reeves 1978). Solid circle denotes stranding; hatched lines show Bering and Chukchi distribution during ice-free periods.

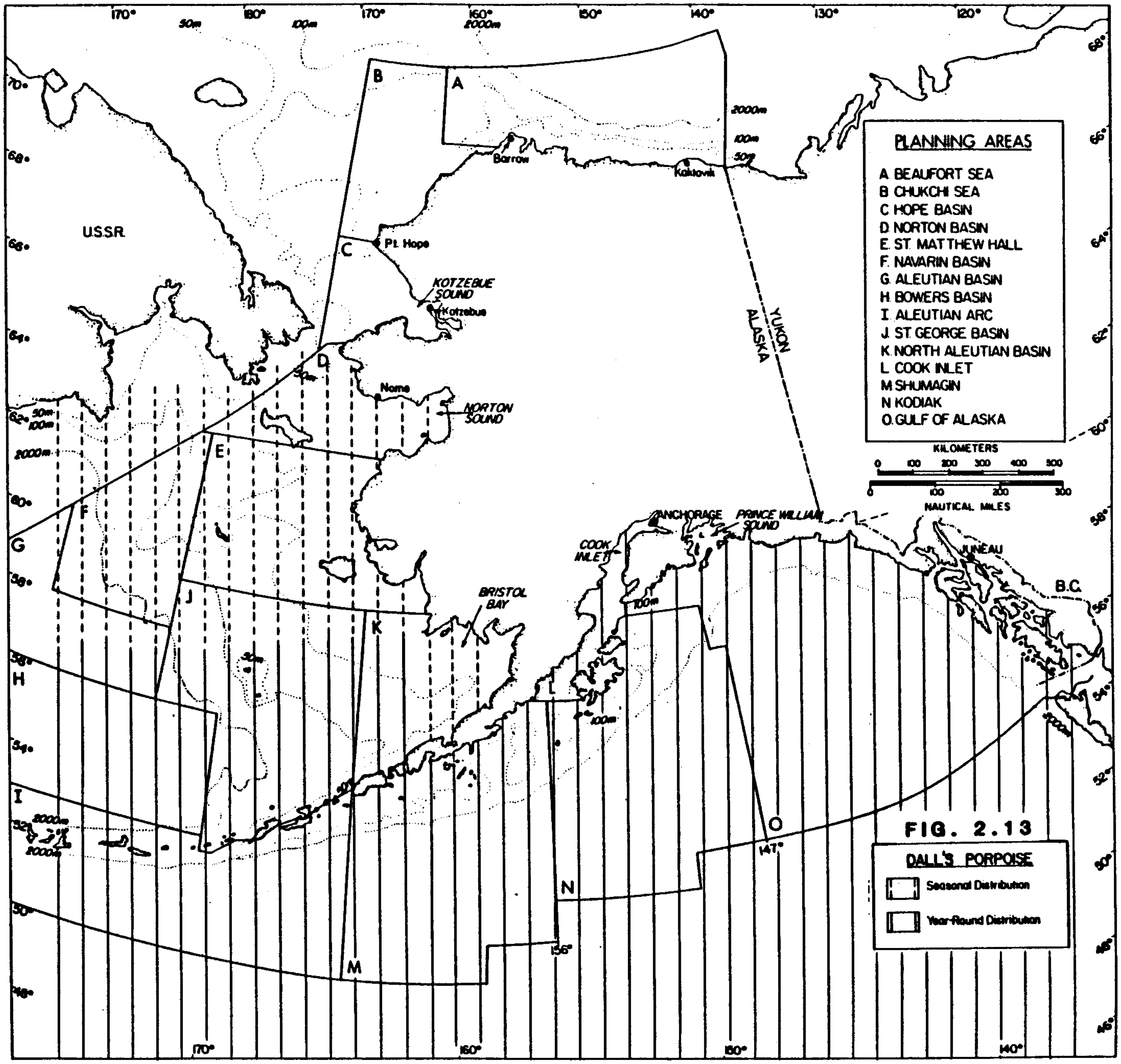


FIG. 2.13

DALL'S PORPOISE

Pinnipeds

Steller Sea Lion (Eumetopias jubatus). Steller sea lions breed along Alaska's coast from southeast Alaska, through the Gulf of Alaska, along the Alaska Peninsula and throughout the Aleutian and Pribilof Islands. This species thrives in remote rocky island regions. Sea lion rookery and haul-out sites are typically rocky headlands or islands (Fig. 2.14).

Male sea lions arrive at rookeries in early May and have established territories by the time pregnant females arrive. Bulls guard harems of about 14-17 females; pupping occurs from mid May through mid July. Mating occurs within two weeks of pupping, and most breeding is finished by mid July or early August. Molting follows mating and is usually completed by October. Pups usually enter the water at around one month of age but females continue to nurse their pups for up to one year.

Males and pupless females start to leave the rookeries in July; females with young remain at or near the rookeries. Although the Pribilofs represent their most northerly breeding areas in the Bering Sea, male and subadult sea lions disperse during the summer and forage and haul-out as far north as Fairway Rock and the Diomede Islands in Bering Strait on an irregular basis. Northerly sites where sea lions regularly haul-out include Cape Newenham, Nunivak island, and St. Matthew and Hall Islands.

Besides utilizing coastal areas, Steller sea lions forage at sea, mostly over the continental shelf in waters <90 m deep and within 25 km of shore. Some, however, have been sighted as much as 130 km from shore. Leatherwood et al. (1983) found that sea lions were the second most frequently encountered and abundant marine mammal in their southeast Bering Sea study area, and the most abundant in their Shelikof Strait study area. They noted that some components of the sea lion population are distributed on and seaward of the continental slope, in waters deeper than 900 m.

In the northern Bering Sea sea lions move south in winter with the advancing seasonal sea ice. In the late winter/early spring period they are found along the edge of the seasonal pack ice. Brueggeman et al. (1984) found that sea lions were narrowly distributed at the ice front in the western third of their Navarin Basin study area. Sea lions appeared to prefer areas of grease ice and small floes, and 0-60% ice cover.

In the accompanying distribution map, the indicated rookery/haul-out sites are the locations where biologists have recorded at least 1000 sea lions present at a particular time. As many as 10000 or more have been reported for five of the sites shown. These locations are all from ADFG (1973) except the Paule Bay and Cape Newenham locations, which are from Calkins (1979) and Frost et al. (1982). There is evidence that Alaskan sea lion populations have been in a decline for several decades (Merrick et al. 1987). Thus, the numbers of sea lions occurring at these rookery/haul-out sites may be lower today. However, the current general distribution of major rookery/haul-out sites is probably similar to that shown.

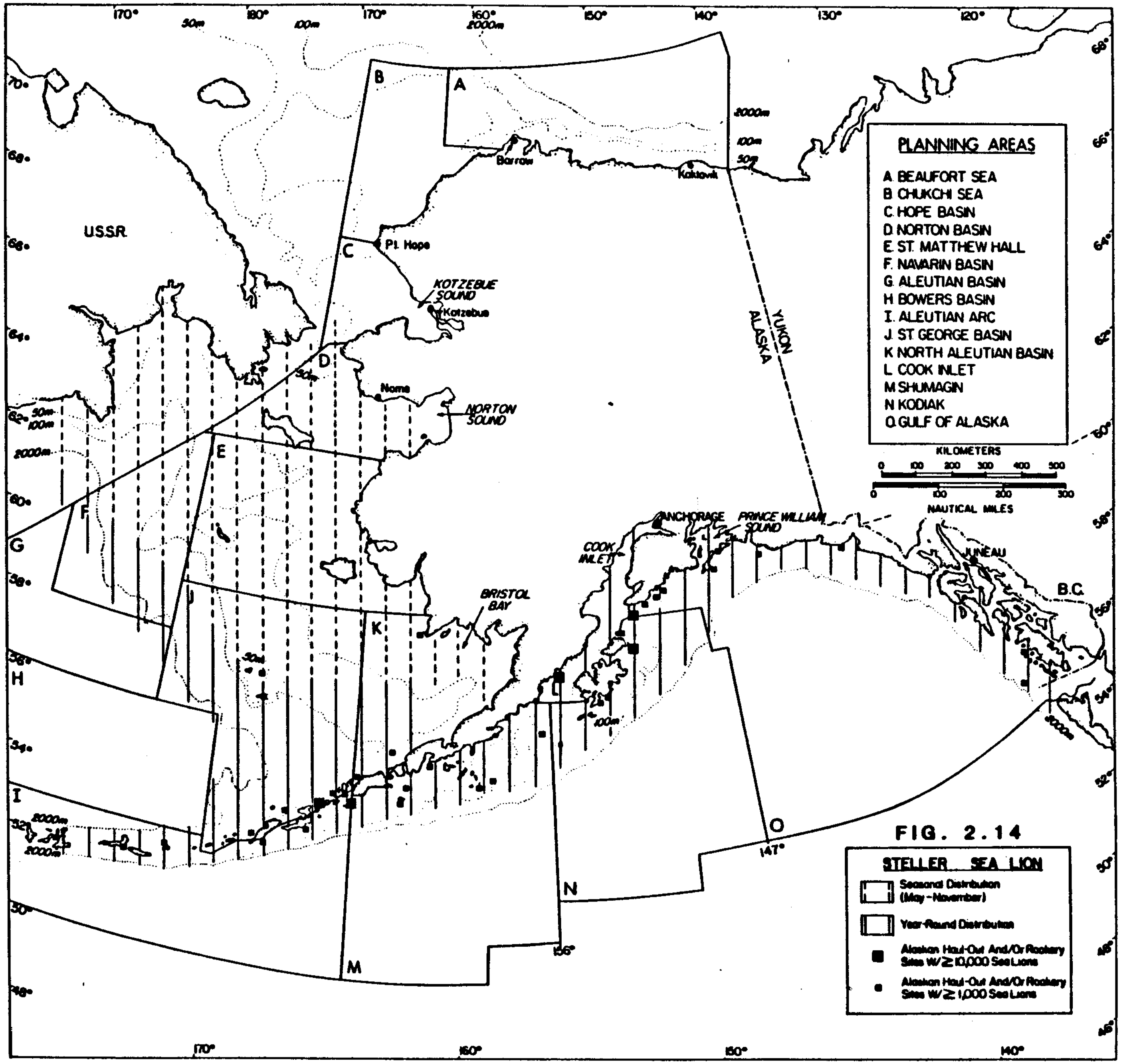

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F. NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I. ALEUTIAN ARC
J ST GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
STELLER SEA LION
Seasonal Distribution (May - November)
Year-Round Distribution
Alaskan Haul-Out And/Or Rookery Sites W/ ≥ 10,000 Sea Lions
Alaskan Haul-Out And/Or Rookery Sites W/ ≥ 1,000 Sea Lions
U.S.S.R.
ALASKA
YUKON
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
50m
100m
2000m
170°
180°
170°
160°
150°
140°
130°
120°
147°
156°
160°
150°
140°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°

FIG. 2.14

Northern Fur Seal (Callorhinus ursinus). The northern fur seal is the most abundant marine mammal in the Bering Sea. About 70% of the 1.2 million fur seals in the North Pacific breed on the Pribilof Islands. A very small rookery (five adults and two pups) discovered in 1980 on Bogoslov Island in the southeast Bering Sea is the only other known Alaskan rookery (Harry and Hartley 1981; Lloyd et al. 1981) (Fig. 2.15).

During the reproductive season (May-July) most fur seals in Alaskan waters are found in the eastern Bering Sea between the Aleutians and St. Matthew Island. A few immatures remain south of the Aleutians and in the Gulf of Alaska in this season (Gentry 1981). The Pribilof Island rookeries are first occupied in April or May by territorial adult males. Pregnant females arrive from mid June through July forming harems of from 1-100 females per bull. They usually bear pups within three days and breed within a week later (Gentry and Holt 1986). After 2-4 days lactating females depart to forage in a wide radius around the rookery for up to two weeks. This lactating/foraging cycle is repeated for 3-4 months. Foraging by lactating females and other fur seals that haul out near the rookeries occurs as far south and east as Unimak Pass, Akutan Pass, and the Unalaska Island area. Consequently, the shelf and slope areas within 150 km of the Pribilofs and a wide corridor extending southeastward to this forage/migration area are considered of major importance to the northern fur seal during the summer breeding season.

Numbers of fur seals at the Pribilofs increase throughout the summer as progressively younger animals return; one- and two-year-old age classes do not return until late August or September. However, by August adult males have begun leaving their territories and heading for sea. They do not return until the following May. Most of these males appear to winter in waters just south of the Aleutian Islands and eastward into the Gulf of Alaska. Some remain in the Bering Sea all winter. Adult females and juveniles begin to migrate south in October. They appear to fan out over the North Pacific Ocean at first, but soon they concentrate over the eastern and western edges, rather than the mid Pacific. By March some adult females have migrated as far south as the Mexican border. Pups are the last to leave the breeding islands. They first enter the sea at about four weeks of age and remain in the area, alternately hauling out and swimming until October or November. They reach the Aleutian passes by November and early December and reach southeast Alaska by late December. Little is known about the distribution and movements of young-of-the-years until they return to the breeding islands in large numbers as three-year-olds. In March adult fur seals begin their northward migrations back to the breeding grounds. However, some fur seals can be found in most parts of their range during any month of the year. Most fur seals wintering in the Bering Sea and the Gulf of Alaska are adult males. Younger males and females winter along the continental shelf, primarily south of Alaska waters (Gentry 1981; Harry and Hartley 1981).

Walrus (Odobenus rosmarus). The North Pacific stock of walruses constitutes 80% of the total world population of this species. In Alaska, an estimated 200,000 walruses inhabit the Bering and Chukchi Seas (Fay 1981).

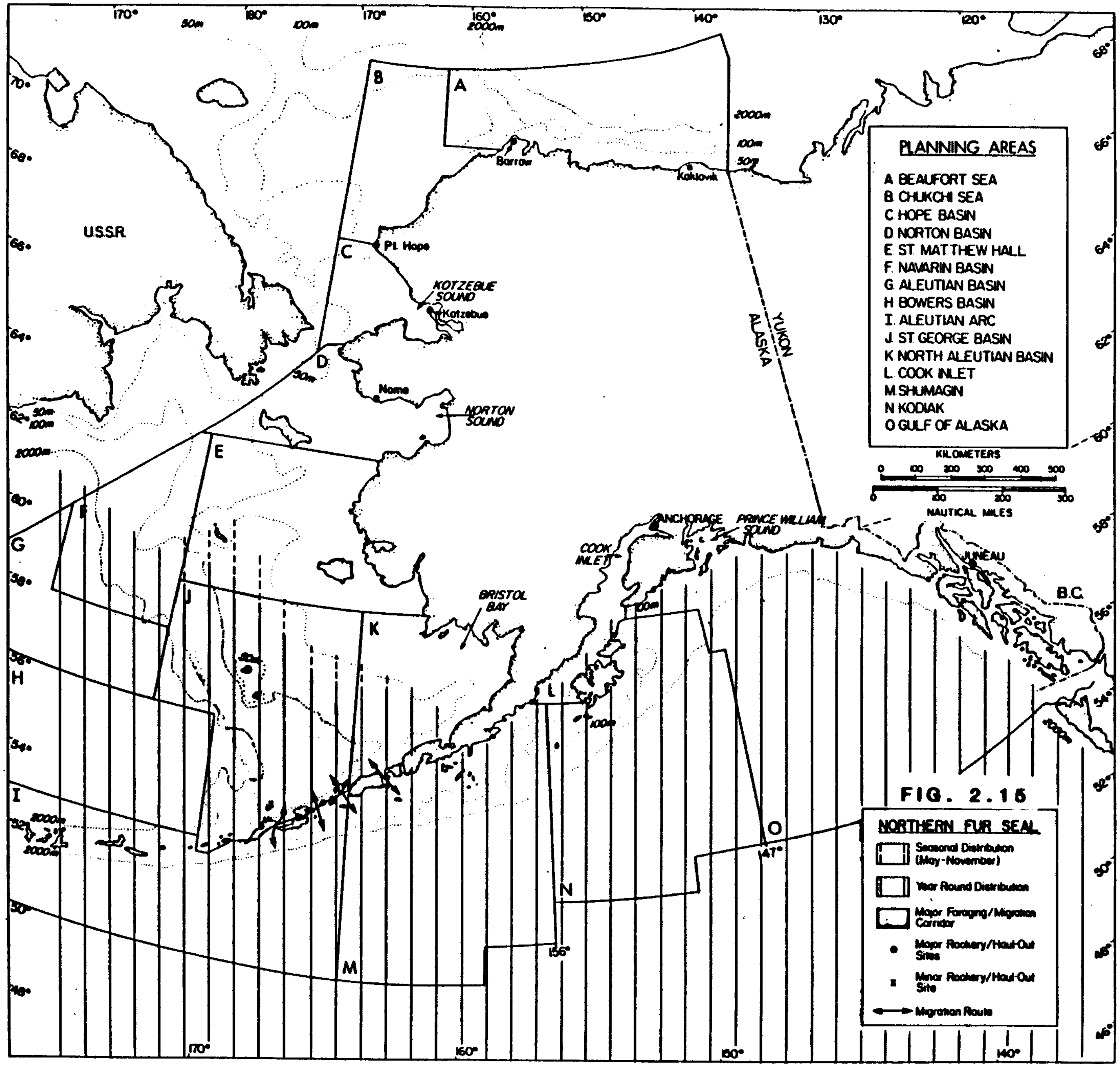


FIG. 2.15

NORTHERN FUR SEAL

A large portion of the population is migratory. Most walruses migrate northward through Bering Strait in spring, and summer along the ice edge in the Chukchi Sea. They leave the Chukchi Sea in advance of the forming sea ice in October. By November most of them are in or south of Bering Strait. Several thousand males do not participate in this migration, remaining instead in the Bering Sea throughout the summer (Fig. 2.16).

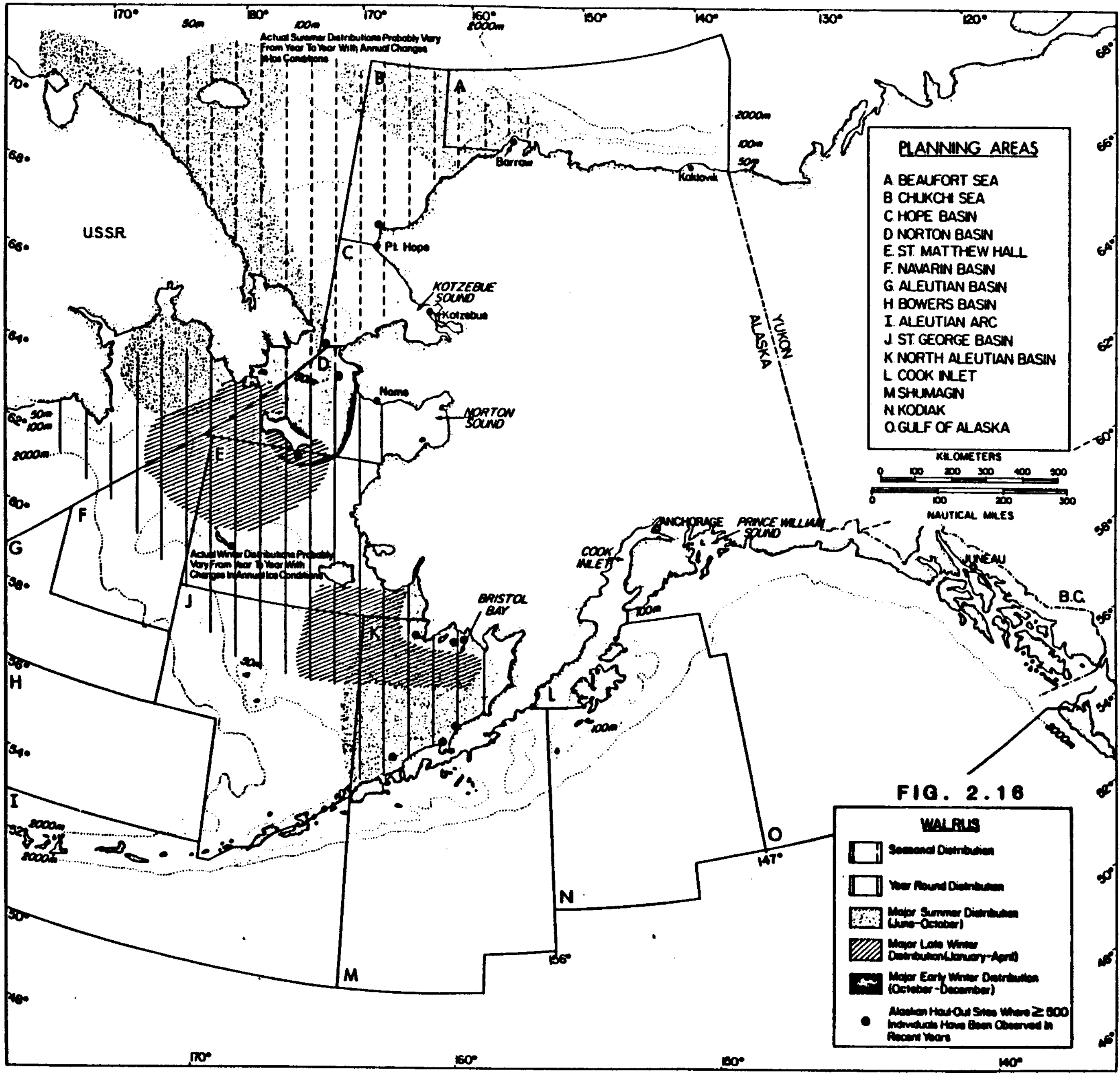
In summer about 90% of the North Pacific walruses are associated with the sea ice in the Chukchi Sea and the remainder are distributed in coastal waters south of the ice. The distribution of walruses in the Chukchi varies throughout the summer with changes in ice conditions and presumably also varies from year to year. Most of the individuals that inhabit ice-free waters in summer are bulls. They remain in the Bering Sea throughout the summer, utilizing small islands, or rocky or gravelly beaches at the base of promontories or headleads, as hauling grounds.

Most of the haul-out sites in the southeastern Bering Sea are used almost exclusively by adult male walruses in late spring and summer. In the northern Bering Sea haul-out sites are used during the summer feeding season mostly by adult males, but also by some females and juveniles that did not move into the Chukchi Sea. Haul-out sites in Bering Strait, which are on the main walrus migration route, are used by summering males as well as by females and juveniles during fall migration in October to December. On the distribution map we have plotted locations of terrestrial haul-out sites where large numbers (>500) of walruses have been observed in recent years. These sites are listed in Frost et al. (1982, 1983).

Although our distribution map shows the Bering Sea to be inhabited by walruses all year long, this is a simplification of the situation. There is a shift of the walrus residing in the Bering Sea to coastal areas in summer; few if any are found in offshore waters during summer. Brueggeman et al. (1984) found no walruses in the Navarin Basin during their summer and fall surveys. Overall, walruses were the most frequently encountered and abundant marine mammals recorded by Leatherwood et al. (1983) in their southeast Bering Sea study area, and summer sightings were restricted to coastal areas.

In winter the entire population is associated with the offshore pack ice, in areas where leads and polynyas are numerous and the ice is thick enough to support their weight. Brueggeman et al. (1984) found that walruses were widespread at the ice front but primarily occupied areas deep in the pack ice. They preferred areas of thin and grease-slush ice and avoided areas of thick ice and intermediate floe-size. Their occurrence deep in the pack probably reflects a preference for shallow waters where access to benthic invertebrates is easiest. Walrus are generally found in waters <100 m deep. The wintering areas shown in Figure 2.16 probably vary considerably from year to year with changes in annual ice conditions. Major shifts in year-to-year winter distribution have been noted and are assumed to be related to ice conditions (Fay 1982).

Mating takes place between December and April on the pack ice southwest of St. Lawrence Island and in the Bristol Bay region (January-April distribution shown in Fig. 2.16). Calving occurs mainly between 20 April and 10 May,



Actual Summer Distributions Probably Vary From Year To Year With Annual Changes In Ice Conditions
Actual Winter Distributions Probably Vary From Year To Year With Changes In Annual Ice Conditions
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
50m
100m
2000m
147°
156°
PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
WALRUS
Seasonal Distribution
Year Round Distribution
Major Summer Distribution (June-October)
Major Late Winter Distribution (January-April)
Major Early Winter Distribution (October-December)
Alaskan Haul-Out Sites Where ≥ 600 Individuals Have Been Observed In Recent Years
170°
180°
170°
160°
150°
140°
130°
120°
170°
160°
150°
140°

FIG. 2.16

on the ice. The single calves remain with their mothers for at least two years and are weaned during the second year (Kenyon 1978).

Harbor Seal (Phoca vitulina). Harbor seals inhabit temperate and subarctic waters of the North Atlantic and North Pacific, and have one of the largest distributions of any pinniped. In Alaska they have a littoral distribution and are largely non-migratory (Bigg 1981). They range from southeast Alaska, through the Gulf of Alaska, the Aleutian Islands, the Pribilof Islands and Bristol Bay (Fig. 2.17). The usual northern limit of their range is considered to be Nunivak Island (Frost et al. 1982), although there are recent records as far north as the mouth of the Yukon River (Leatherwood et al. 1983). The northern part of their range, south to about Cape Newenham, overlaps with the range of the closely related spotted seal.

Harbor seals haul-out on flat or gently-sloped beaches, offshore rocks, and sand or gravel bars. They breed, pup and molt on these sites. In many parts of their range harbor seals are widely distributed; small numbers of seals haul out on a large number of sites. However, most of the population occurs at a small number of sites where up to 10,000 individuals may haul out.

Harbor seals are present at coastal haul-out sites from late April to October. Pupping occurs from late May to mid July, but primarily in June. Nursing lasts for 3-5 weeks and mating occurs soon after weaning. Harbor seals molt from mid July to mid September and the peak of haul out usually occurs in June and July. Use of the sites decreases throughout September and October and is uncommon during the winter months. Leatherwood et al. (1983) found that in their southeast Bering Sea study area harbor seals were most widely distributed and abundant in spring and fall, and were concentrated in eastern Bristol Bay in summer. Although most of the individuals they recorded were in shallow water, some were encountered in depths of 90-110 m. The distribution map indicates haulout sites where more than 1000 harbor seals have been reported. The Bering Sea sites are from Frost et al. (1982) and the Gulf of Alaska sites are from ADFG (1973) and Pitcher and Calkins (1979).

Spotted Seal (Phoca largha). Spotted seals are closely related to harbor seals, but differ primarily in that they give birth and breed on ice-covered areas. They are found only in the North Pacific, primarily in the Okhotsk, Bering and Chukchi Seas (Burns 1978) (Fig. 2.18).

These seals are associated with sea ice from late fall to early summer (Fay 1974). During late winter and early spring when the sea ice reaches its maximum extent, the entire Alaskan spotted seal population is concentrated in or near the "ice front" in areas of small pans, usually <10 m wide. This ice zone extends from the southern ice margin north to heavier ice, and varies in width from less than 25, to more than 125 miles. Brueggeman et al. (1984) found that, in their Navarin Basin study area, spotted seals on average occurred 57 km in from the ice edge. They preferred areas of moderate ice coverage (20-60%) and thick first year ice, but used different sized floes indiscriminantly.

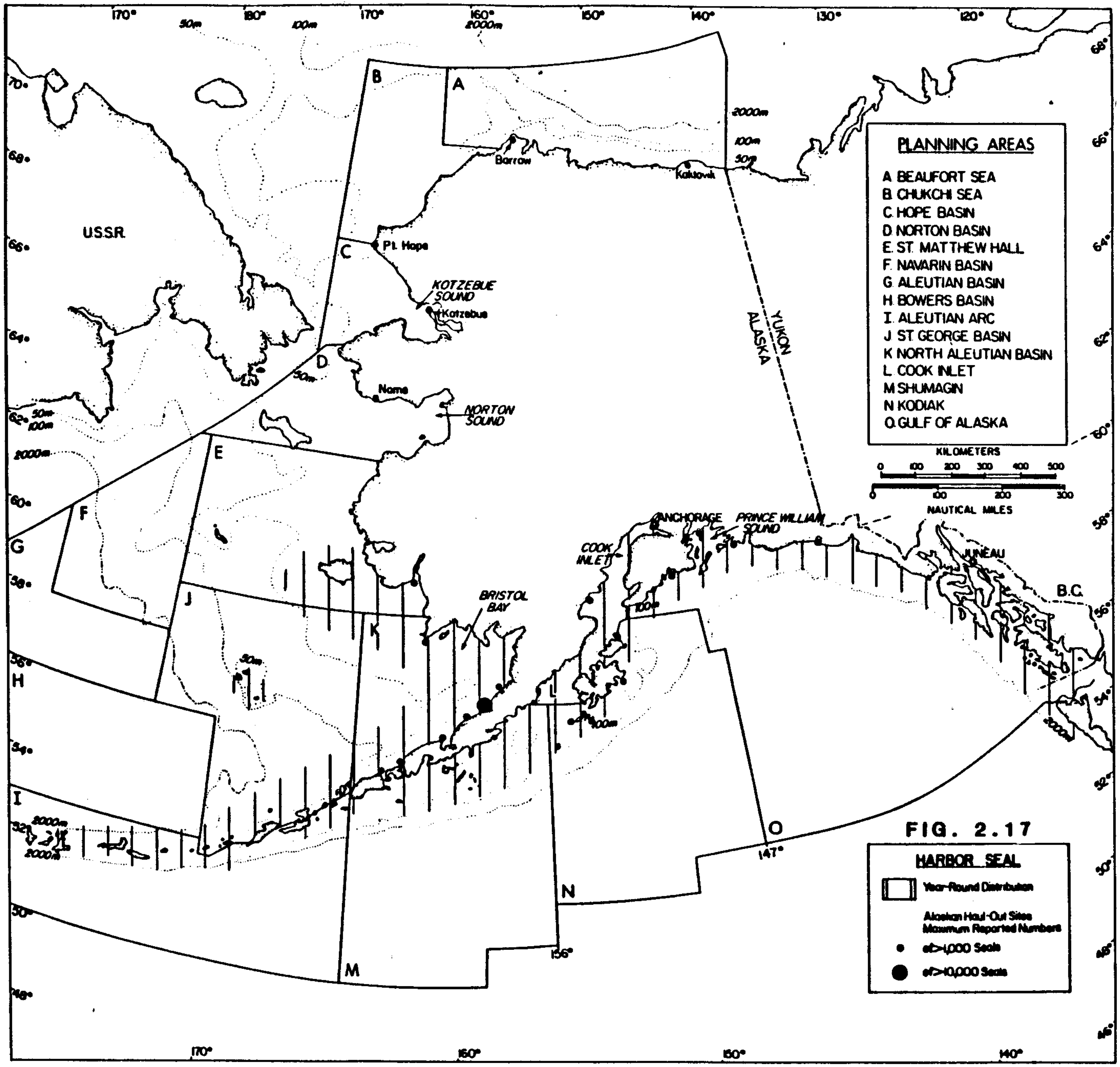

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
HARBOR SEAL
Year-Round Distribution
Alaskan Haul-Out Sites Maximum Reported Numbers
of >1,000 Seals
of >10,000 Seals
U.S.S.R.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
YUKON
ALASKA
ANCHORAGE
PRINCE WILLIAM SOUND
COOK INLET
BRISTOL BAY
JUNEAU
B.C.
147°
156°
170° 180° 170° 160° 150° 140° 130° 120°
170° 160° 150° 140°
50m 100m 2000m

FIG. 2.17

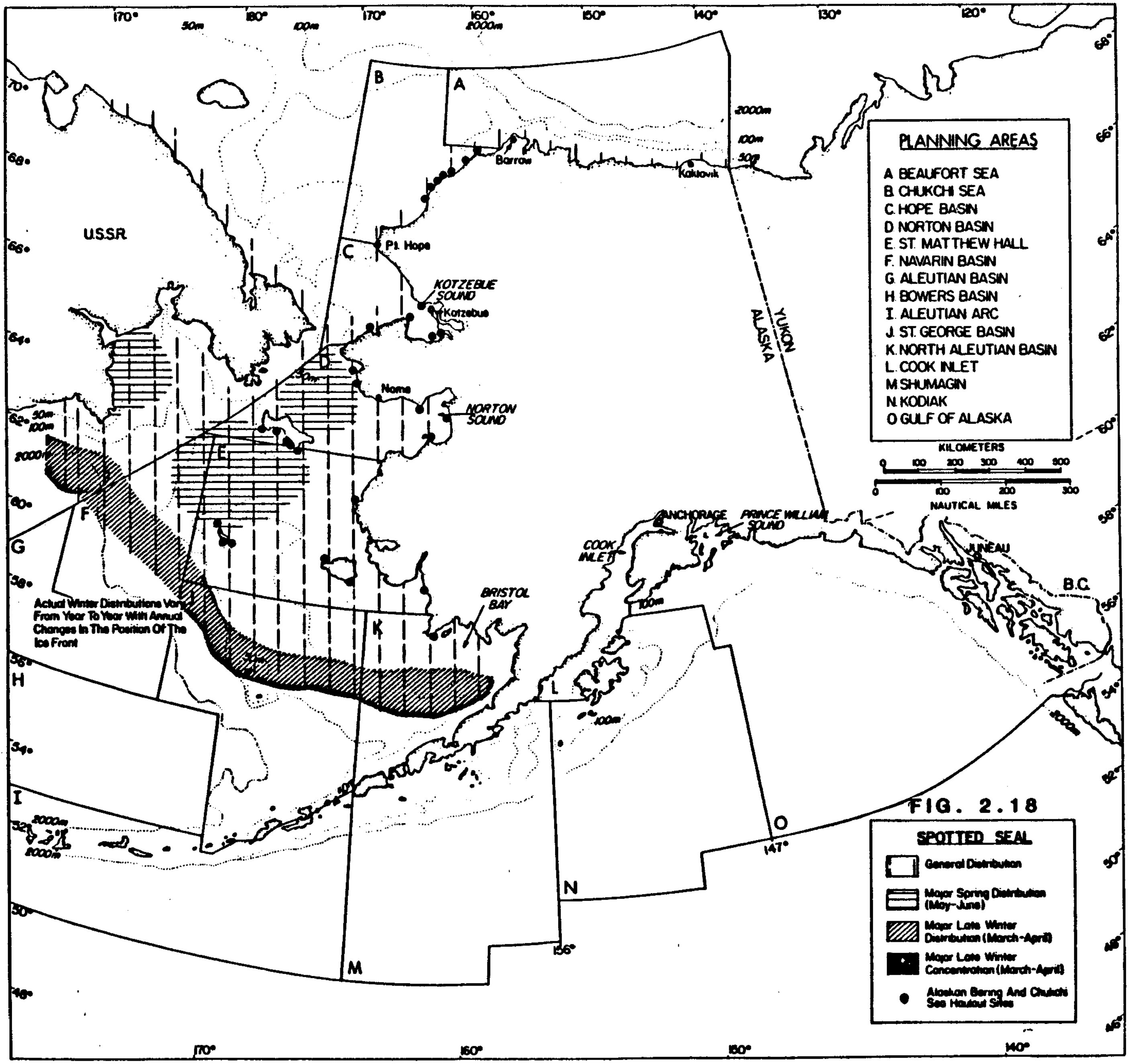

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F. NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I. ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
NAUTICAL MILES
U.S.S.R.
YUKON
ALASKA
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
B.C.
Actual Winter Distributions Vary From Year To Year With Annual Changes In The Position Of The Ice Front
SPOTTED SEAL
General Distribution
Major Spring Distribution (May-June)
Major Late Winter Distribution (March-April)
Major Late Winter Concentration (March-April)
Alaskan Bering And Chukchi Sea Haulout Sites

FIG. 2.18

As the sea ice retreats in late spring, spotted seals move north, and toward the coasts (Frost et al. 1983). During late summer and early fall they are widely distributed along coasts, entering bays and rivers and hauling out on land in any suitable location. The distribution map indicates locations where maximum numbers of 100 or more spotted seals have been recorded (Frost et al. 1982, 1983).

As the sea ice forms in late autumn spotted seals occupying the more northerly parts of their range move south into the Bering Sea. This process continues throughout the early winter. As the ice advances more spotted seals leave coastal sites and travel south with the advancing ice. This represents a critical period in the spotted seal's annual cycle because they pup, mate, nurse and molt on the ice. Pupping occurs on the ice floes in late March or April, in the shelter of ice hummocks and crevices if they are present. Mating occurs in late April and early May, after the pups have nursed for three to four weeks. Molt occurs on the Bering Sea ice remnants, primarily in the areas northeast and southwest of St. Lawrence Island, in May and June (see "major spring distribution", Fig. 2.18).

Ringed Seal (Phoca hispida). The ringed seal has a circumpolar distribution, with concentration areas being highly dependent on the presence of stable fast ice (Burns 1978). In winter highest densities occur near shore in the stable landfast ice. In other seasons ringed seals migrate at least locally with the annual advance and retreat of the pack ice. The total population in Alaskan waters is estimated to be 1-1.5 million, making it the most abundant ice-associated seal in Alaska (Fig. 2.19).

In winter the ringed seal is found throughout the ice-covered regions of the Bering Sea, and in the Chukchi and Beaufort Seas. It is the only seal to occupy landfast ice, and it does so by maintaining breathing holes through the ice with the strong claws of its foreflippers. Drift ice is a less desirable habitat, but is used by large numbers of ringed seals. During winter ringed seals excavate lairs in accumulated snow. The lairs are used for resting and pupping. Ringed seal pups are usually born in April, and are nursed for four to six weeks (Burns et al. 1981). Since destruction of a birth lair by early ice break-up can lead to premature weaning and abandoning of pups, stable fast ice is optimal pupping habitat. Mating occurs in late April and early May (Frost and Lowry 1981b). Ringed seals molt from late March until July, with a peak in June. During molt ringed seals haul out on ice and bask in the sun. Elevated skin temperatures may facilitate the molting process.

The broad-scale timing and magnitude of ringed seal migration is not well understood. Few ringed seals are present in the Bering and southern Chukchi Seas during the ice-free season. They arrive in the fall with the formation of the seasonal sea ice in November and leave when the ice is disintegrating in May and June (Johnson et al. 1966). They move into the Chukchi and Bering Seas where they spend the summer dispersed throughout ice covered areas. With the onset of winter and increased ice cover the area occupied by ringed seals expands southward accordingly. Small numbers of ringed seals were recorded in the Navarin Basin and North Aleutian planning areas (Leatherwood et al. 1983; Brueggeman et al. 1984). They probably reach their Alaskan southern limits in these areas and in the St. George planning areas.

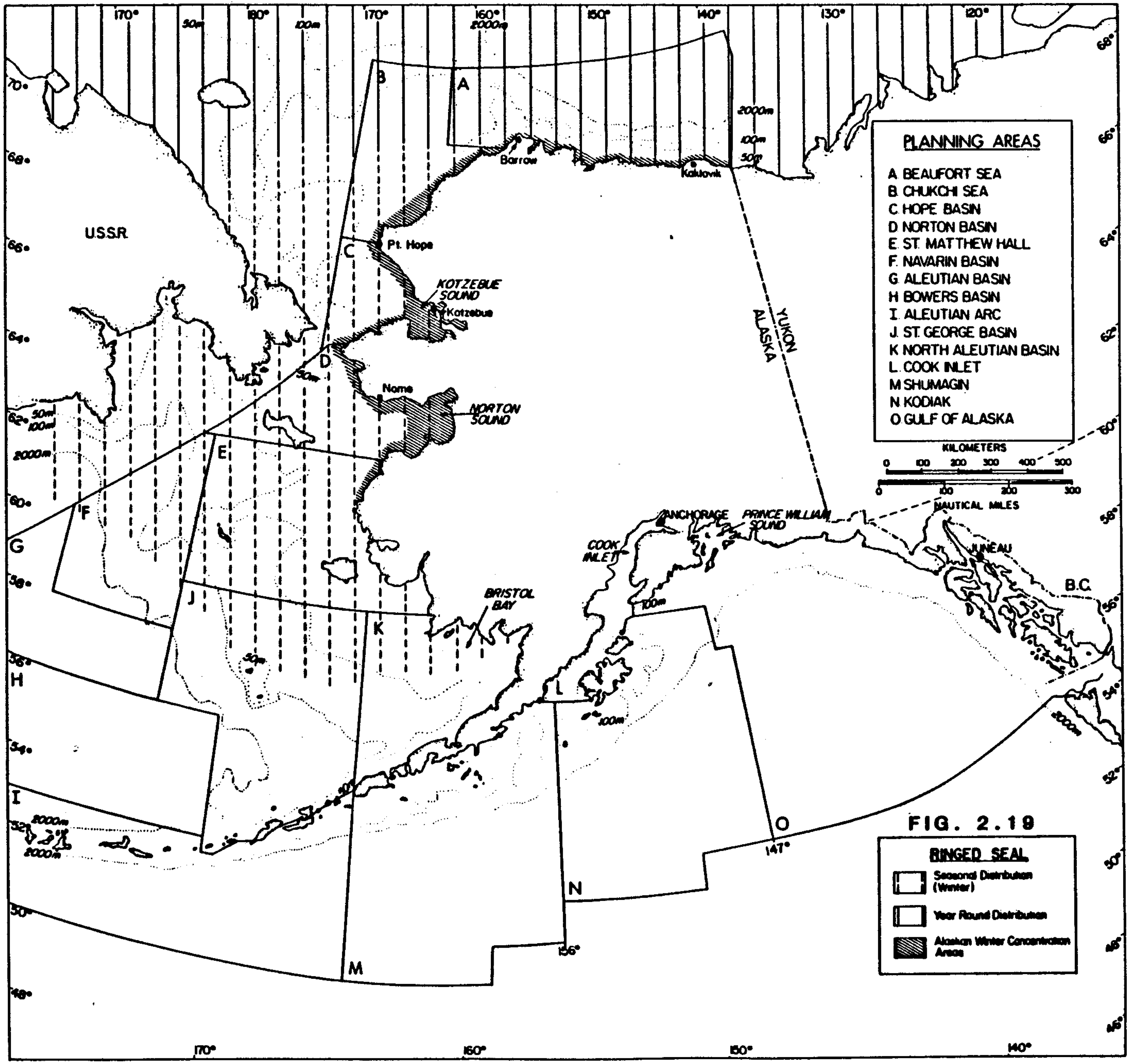

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F. NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
NAUTICAL MILES
RINGED SEAL
Seasonal Distribution (Winter)
Year Round Distribution
Alaskan Winter Concentration Areas
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
2000m
100m
50m
147°
156°

FIG. 2.19

Ribbon Seal (Phoca fasciata). The ribbon seal occurs only in the North Pacific region, with centers of abundance in the Okhotsk and Bering Seas (Burns 1978). In Alaskan waters they are concentrated during late winter and spring at the ice front in the Bering Sea. During this period ribbon seals pup, nurse, mate and molt on the ice. They breed from late April to mid May, and give birth 11 months later in early April. Pups are nursed for 3-4 weeks and females continue to feed during the lactation period. Mating occurs around the time of weaning. Pups and subadults have completed molting by early to mid May. Adults begin molting during the first half of May and completion of the molt coincides with the disappearance of the seasonal ice in the Bering Sea (Burns 1981a) (Fig. 2.20).

During ice-free periods ribbon seals are assumed to be pelagic because they are rarely found in nearshore environments and are not known to haul out on land. Their whereabouts during the open water season are not well known. Most individuals apparently move north into the Chukchi Sea, but some ribbon seals may remain in the Bering Sea.

During the winter season when ribbon seals are concentrated at the ice front, the entire Alaskan population is concentrated in the eastcentral Bering Sea and the Navarin, St. George and North Aleutian Basin planning areas, although the distribution among those planning areas would vary with annual and seasonal ice conditions. Burns and Harbo (1977) found that ribbon seals usually hauled out on relatively thick, clean, rough, snow-covered floes 20-50 miles north of the edge of the seasonal ice.

Bearded Seal (Erignathus barbatus). The bearded seal has a circumpolar distribution, and like the ringed seal, maintains a year-round association with sea ice. However, it is usually restricted to relatively shallow water, and to areas of pack ice, rather than fast ice. In winter most of the population is found amongst pack ice over the shallow waters of the Bering Sea, although some winter in the pack ice and shear zones of the Chukchi Sea (Burns 1978, 1981b) (Fig. 2.21).

In summer there is a northward movement of bearded seals into the Chukchi and Beaufort Seas. Only very low densities of bearded seals are found in open water south of the pack ice. Most of those that do occur in open water areas during the summer months are juveniles or subadults (Burns 1967). Periodically large numbers of subadults occur in Kotzebue Sound during the ice-free months. Northward movement through Bering Strait occurs primarily from late May to late June. Movement into and through the Alaskan Chukchi is thought to be primarily along the shear zone off the Alaska coast.

The southward fall migration is concurrent with the southward movement of the sea ice. This autumn movement occurs over a longer period of time than the spring migration. Young bearded seals may move south well before the advancing ice.

Bearded seals breed in May and pups are born on the ice the following April. The pups are nursed for less than three weeks. Molt occurs from April through August, with a peak in May-June. This peak coincides with the period of maximum hauling out.

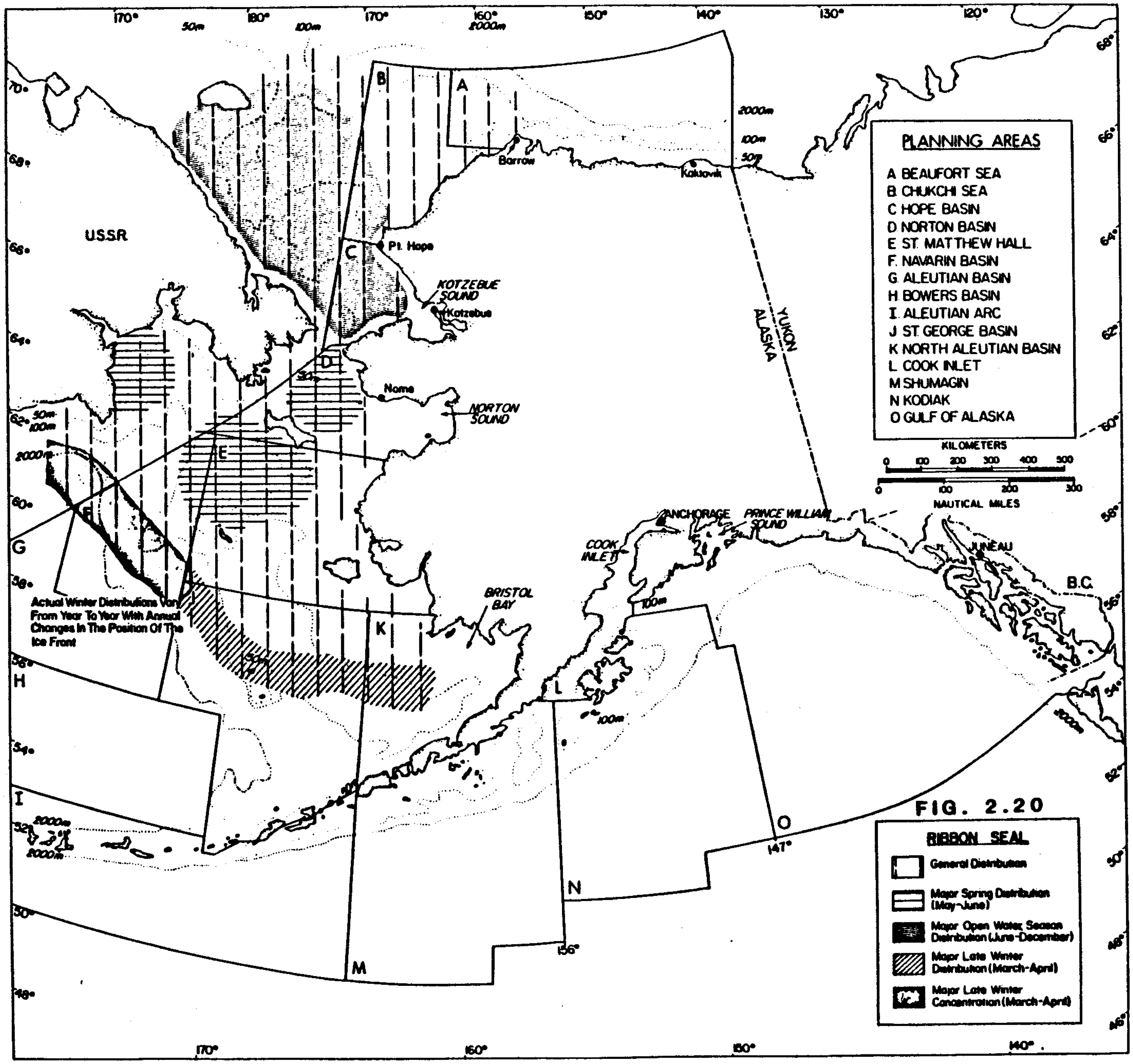

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F. NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I. ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
RIBBON SEAL
General Distribution
Major Spring Distribution (May-June)
Major Open Water Season Distribution (June-December)
Major Late Winter Distribution (March-April)
Major Late Winter Concentration (March-April)
Actual Winter Distributions Vary From Year To Year With Annual Changes In The Position Of The Ice Front
U.S.S.R.
YUKON
ALASKA
B.C.
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
170° 180° 170° 160° 150° 140° 130° 120°
170° 160° 150° 140°
156° 147°
70° 68° 66° 64° 62° 60° 58° 56° 54° 52° 50° 48°
50m 100m 2000m

FIG. 2.20

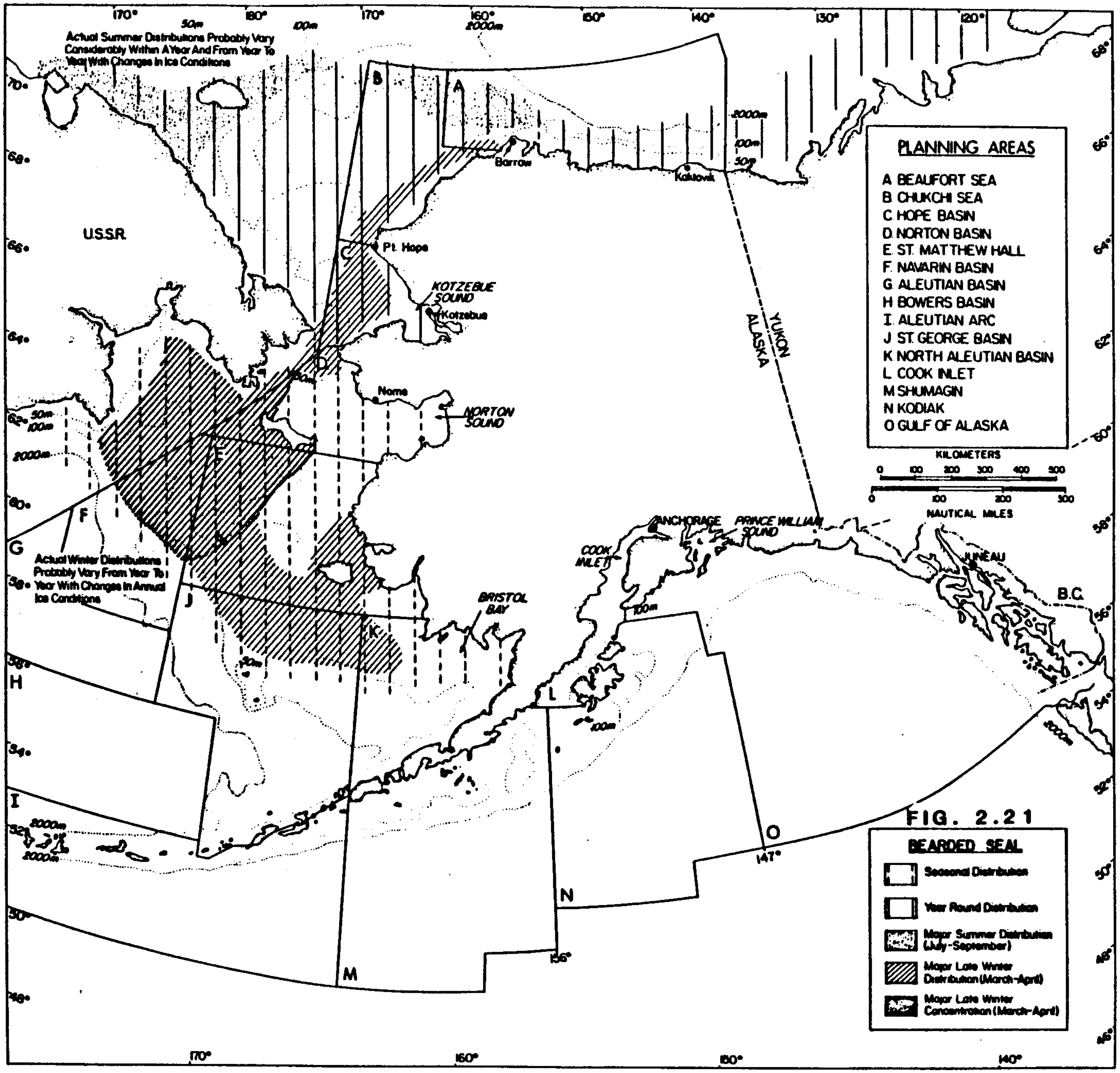

Actual Summer Distributions Probably Vary Considerably Within A Year And From Year To Year With Changes in Ice Conditions
Actual Winter Distributions Probably Vary From Year To Year With Changes In Annual Ice Conditions
U.S.S.R.
YUKON
ALASKA
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
B.C.
PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F. NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I. ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
50m
100m
2000m
170°
180°
170°
160°
150°
140°
130°
120°
147°
156°
160°
170°
140°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°
BEARDED SEAL
Seasonal Distribution
Year Round Distribution
Major Summer Distribution (July-September)
Major Late Winter Distribution (March-April)
Major Late Winter Concentration (March-April)

FIG. 2.21

The distribution map distinguishes between areas that bearded seals occupy seasonally (during the maximum extent of the winter ice) and year round. The demarcation between these two ranges is arbitrary and doubtless changes from year to year depending on ice conditions. Some of the areas shown as seasonally occupied may in fact be occupied year round, especially by juveniles and subadults. Also, it should be noted that much of the Beaufort and Chukchi Sea region shown to be inhabited year round is only marginal habitat in winter because of the great depth of the water and the heavy ice cover. This region is probably occupied by very low densities of bearded seals in winter. In some areas bearded seals reportedly maintain their own breathing holes in the ice in much the same manner as ringed seals (Stirling and Smith 1975).

Northern Elephant Seal (Mirounga angustirostris). The breeding range of northern elephant seals extends from islands off Baja California to the Farallon Islands off San Francisco, California. Non-breeding individuals occasionally stray into the Gulf of Alaska. None of the Alaska O.C.S. planning areas represent areas of importance to elephant seals. The northern elephant seal population is rapidly increasing and Leatherwood et al. (1983) speculated that the number of sightings in Alaskan waters may increase in the future.

Other Marine Mammals

Sea Otter (Enhydra lutris). In Alaskan waters the sea otter occurs in nearshore waters from the Prince William Sound region in the Gulf of Alaska, southwestward along the Alaska Peninsula and through the Aleutian Islands. They also occupy the north coast of the Alaska Peninsula (southwest Bristol Bay) and small numbers are found in waters near the Pribilof Islands (Schneider 1976). They have been reintroduced into their former habitat along portions of Alaska's southeast coast and these populations are expanding (Calkins 1986) (Fig. 2.22).

In the southeast Bering Sea study area surveyed by Leatherwood et al. (1983), the sea otter was the third most frequently sighted marine mammal. Sightings in winter were primarily nearshore. In spring, summer, and fall, sightings were more widely scattered, with sightings north of the Aleutians, near the Pribilof Islands, and between the Pribilofs and St. Matthew Island. They found that most sea otters were in very shallow water (<53 m), although some (including some large groups) were found over greater depths.

Sea otters sometimes stray north of their normal range, and have been reported at Nunivak and St. Lawrence Islands, and in Norton Sound. There is no evidence that populations have ever become established north of Bristol Bay and the Pribilof Islands (Schneider 1981). The annual formation of sea ice in winter apparently prevents them from becoming established north of their present range. Cimberg et al. (1984) reported that there was a winter exodus of sea otters from the North Aleutian Basin region, but this was not confirmed by Troy and Johnson (1987) who found that densities were not particularly low in this area in winter.

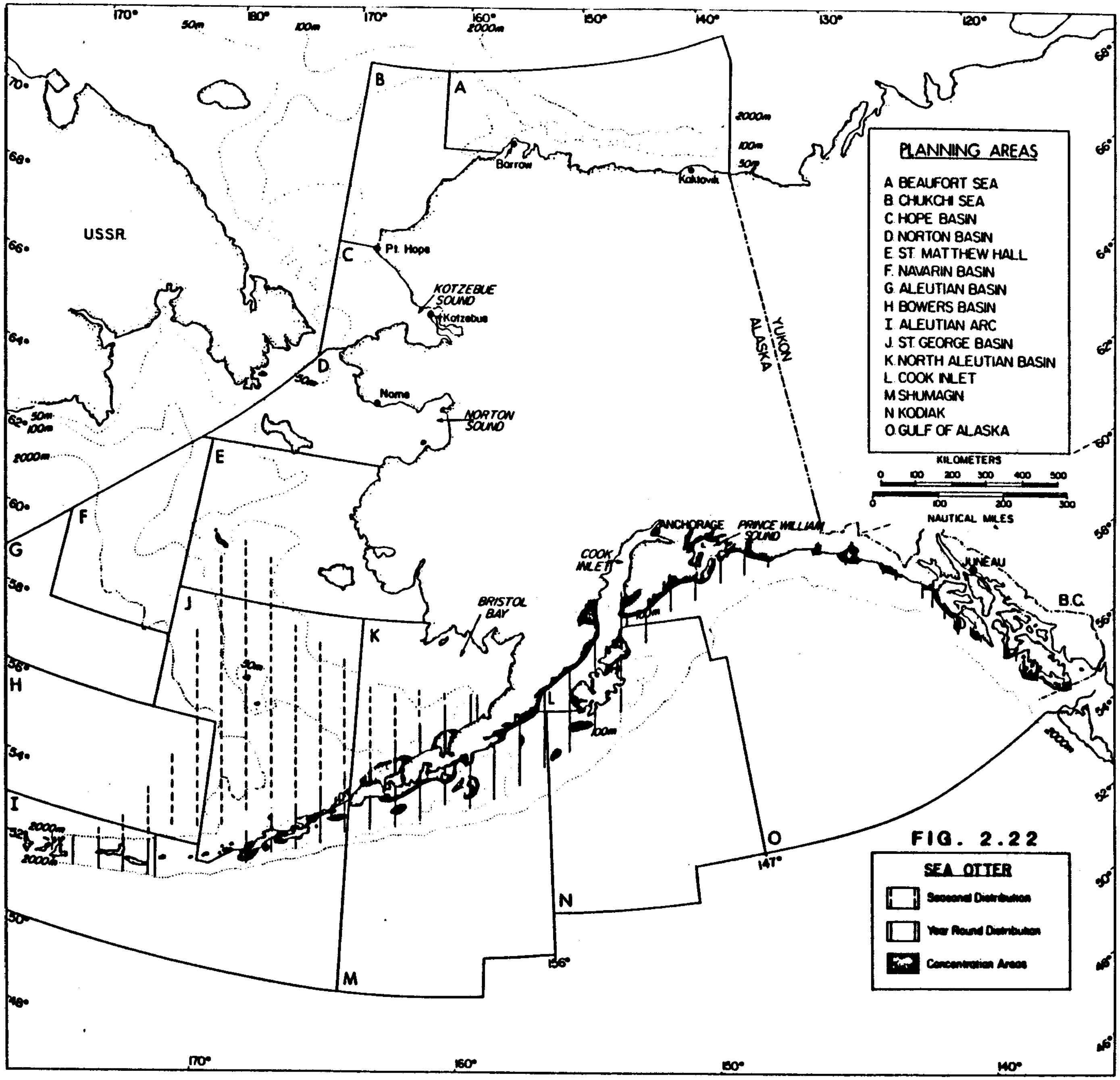

PLANNING AREAS
A BEAUFORT SEA
B CHUKCHI SEA
C HOPE BASIN
D NORTON BASIN
E ST. MATTHEW HALL
F. NAVARIN BASIN
G ALEUTIAN BASIN
H BOWERS BASIN
I ALEUTIAN ARC
J ST. GEORGE BASIN
K NORTH ALEUTIAN BASIN
L COOK INLET
M SHUMAGIN
N KODIAK
O GULF OF ALASKA
KILOMETERS
0 100 200 300 400 500
0 100 200 300
NAUTICAL MILES
SEA OTTER
Seasonal Distribution
Year Round Distribution
Concentration Areas
USSR
Barrow
Kaktovik
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
YUKON
ALASKA
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
B.C.
50m
100m
2000m
170°
180°
160°
150°
140°
130°
120°
147°
156°

FIG. 2.22

Sea otters may pup at any time of the year, but most births are in spring and summer (Kenyon 1981). Mating reaches a peak in September, October and November.

Polar Bear (Ursus maritimus). The polar bear can be considered a marine mammal because it spends a great portion of its life associated with the sea and sea ice, and subsists almost entirely on marine food chains. In Alaska, polar bears winter in the flaw zones of the Chukchi and Beaufort Seas, and in the northern Bering Sea in years when heavy pack ice has been driven southward through the Bering Strait. Polar bears are good swimmers but pack ice is important to bears as a solid substrate on which they can move about and hunt, and is an important determinant of their distribution (Fay 1974) (Fig. 2.23).

Some pregnant females go onshore in November and early December to make maternity dens in deep snow drifts (Burns et al. 1981). Off Alaska, however, most denning occurs on heavy drifting ice (Lentfer 1978; Amstrup 1987). Cubs are born in late December and early January and remain in the lair with the mother until late March or early April. Upon emerging from terrestrial dens, the mother and cubs move out onto the pack ice. Terrestrial Alaskan denning areas are found to be along the coasts of the Chukchi and Beaufort Seas from Point Hope to the Canadian border. There are few records of maternity dens in the Bering Sea, but some have been reported in the St. Lawrence Island and Cape Prince of Wales areas. Areas suitable for terrestrial maternal dens are determined by snowfall, ambient temperature, topography and wind, since successful denning requires snowdrifts that do not thaw during the denning period. Other important requirements are the presence of nearby seals, and ice conditions that enable bears to successfully hunt ringed seals during pre- and post-denning periods. Alaskan polar bears feed primarily on ringed seals, although some bearded seals are also taken. Both these prey species are associated with the sea ice throughout the year.

A recent study has documented the importance of pack ice as denning habitat for Beaufort Sea polar bears (Amstrup 1987). Seventy-one free ranging females were radio-tagged and tracked to their maternity dens. Only 13 of these dens were on land, four were on shore-fast ice and the remaining 54 (76%) were on pack ice. These marine maternity dens were found throughout the Beaufort Sea from sites just a few km from shore to as far as 550 km north of the coast. This study found that all terrestrial dens of radio-tagged polar bears were within or adjacent to the Alaska National Wildlife Refuge.

In general, the polar bear prefers areas where the sea ice is kept in motion by winds and current, and where open water and newly frozen ice facilitate seal hunting. These areas are found around the rim of the polar basin within 200 miles of land masses. In summer polar bears move north within this zone as ice recedes from coastal areas. 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. The one or two cubs remain with the mother for about 28 months.

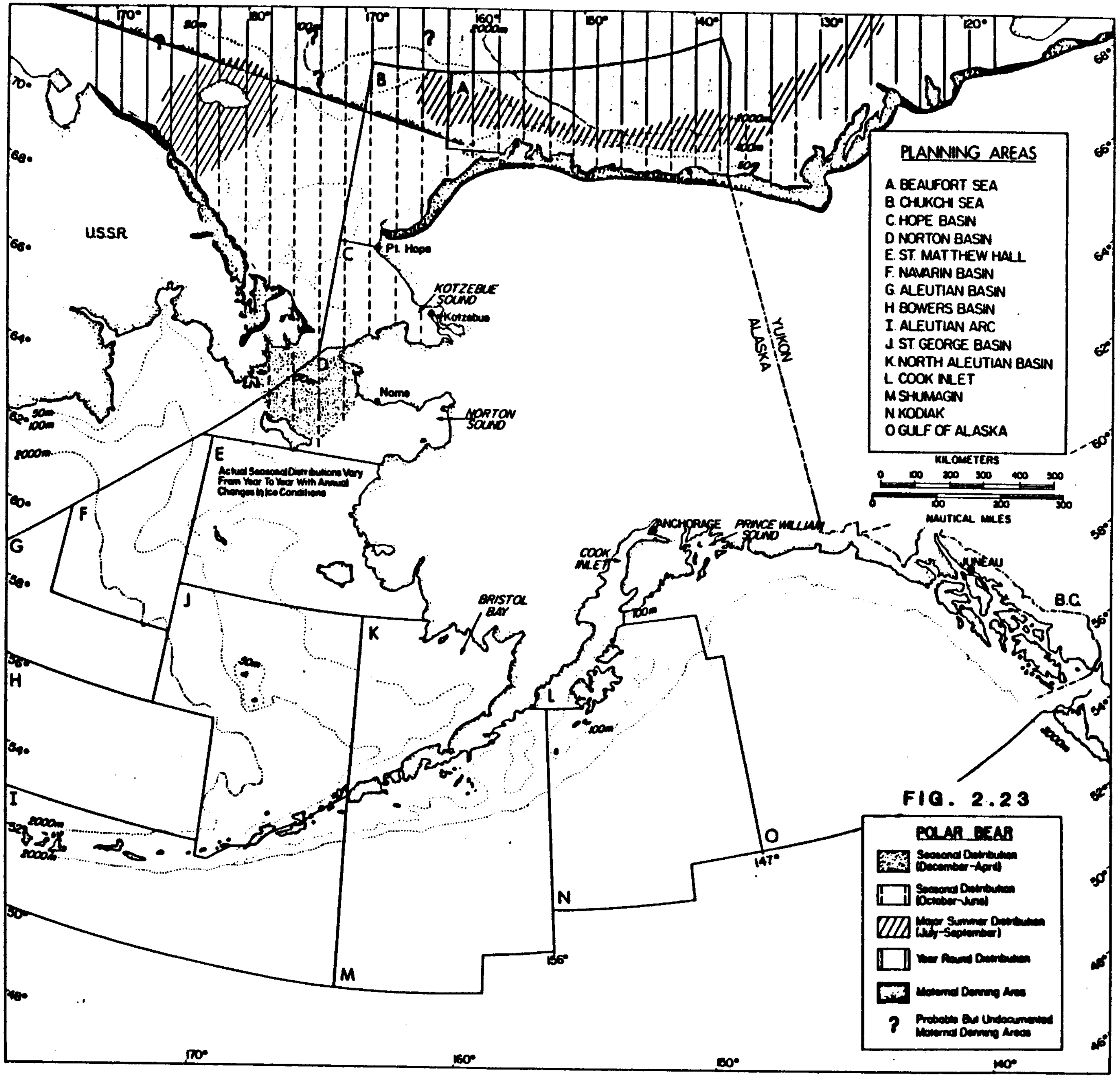

PLANNING AREAS
A. BEAUFORT SEA
B. CHUKCHI SEA
C. HOPE BASIN
D. NORTON BASIN
E. ST. MATTHEW HALL
F. NAVARIN BASIN
G. ALEUTIAN BASIN
H. BOWERS BASIN
I. ALEUTIAN ARC
J. ST. GEORGE BASIN
K. NORTH ALEUTIAN BASIN
L. COOK INLET
M. SHUMAGIN
N. KODIAK
O. GULF OF ALASKA
KILOMETERS
0
100
200
300
400
500
NAUTICAL MILES
0
100
200
300
POLAR BEAR
Seasonal Distribution (December-April)
Seasonal Distribution (October-June)
Major Summer Distribution (July-September)
Year Round Distribution
Maternal Denning Area
? Probable But Undocumented Maternal Denning Areas
Actual Seasonal Distributions Vary From Year To Year With Annual Changes In Ice Conditions
U.S.S.R.
YUKON
ALASKA
B.C.
Pt. Hope
KOTZEBUE SOUND
Kotzebue
Nome
NORTON SOUND
BRISTOL BAY
COOK INLET
ANCHORAGE
PRINCE WILLIAM SOUND
JUNEAU
170°
180°
170°
160°
150°
140°
130°
120°
147°
156°
160°
150°
140°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
50°
48°
46°
50m
100m
1000m
2000m

FIG. 2.23

2.1.3 Marine mammal numbers as related to OCS planning areas*

One of the purposes of this study is to develop a procedure for evaluating the disturbance potential of various noise sources with respect to the marine mammals in their vicinity. This model (described in Section 5.2) requires information on the population density of the species of concern in specific areas. Four OCS planning areas were selected to be studied in detail - Chukchi Sea, Shumagin, North Aleutian Basin, and Norton Basin. The population distribution information in Section 2.1.2 was used, together with other reference materials, to obtain population density estimates for these four planning areas for subsequent use in the "Standardized Exposure Rating" procedure.

Shumagin

Numerous marine mammal species occur in this area. This section refers only to the fin whale.

Fin whale sightings in the Shumagin Planning Area are concentrated both temporally and geographically. Brueggeman et al. (1987) recorded fin whales only in July and August in a series of aerial surveys conducted from April to December 1985. Sightings were clustered in an area extending roughly from the Shumagin Islands (160°W) east to 157°W. Approximately 90% of the fin whales they encountered were in waters <200 m deep (Fig. 2.24). However, analyses suggested that use of shallow (<200 m) and transition (200-2000 m) zones by fin whales was not statistically different. No fin whales were observed in the deep water (>2000 m) zone (Table 2.2).

Brueggeman et al. (1987) suggested that 166 (±93) to 184 (±90) fin whales occurred in the Shumagin Planning Area. These are minimum estimates, not accounting for whales that were submerged, or missed by observers. The observed density of fin whales in the shallow and transition zones was 0.0017 whales/km^2. This density is the average for those zones, but would clearly be higher in the area where sightings were concentrated (Fig. 2.24). Also,

Table 2.2. Densities[1] of Fin Whales (no./km^2) Estimated From Aerial Surveys in the Shumagin Planning Area.

	Spring Mar-May	Summer June-Aug	Fall Sept-Nov	Winter Dec-Feb
Fin whale				
Shallow	0	0.0017	0	0
Transition	0	0.0017	0	0
Deep	0	0	0	0

[1] Uncorrected for submerged whales or whales at the surface that were not seen by observers.

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*G.W. Miller, LGL Ltd.

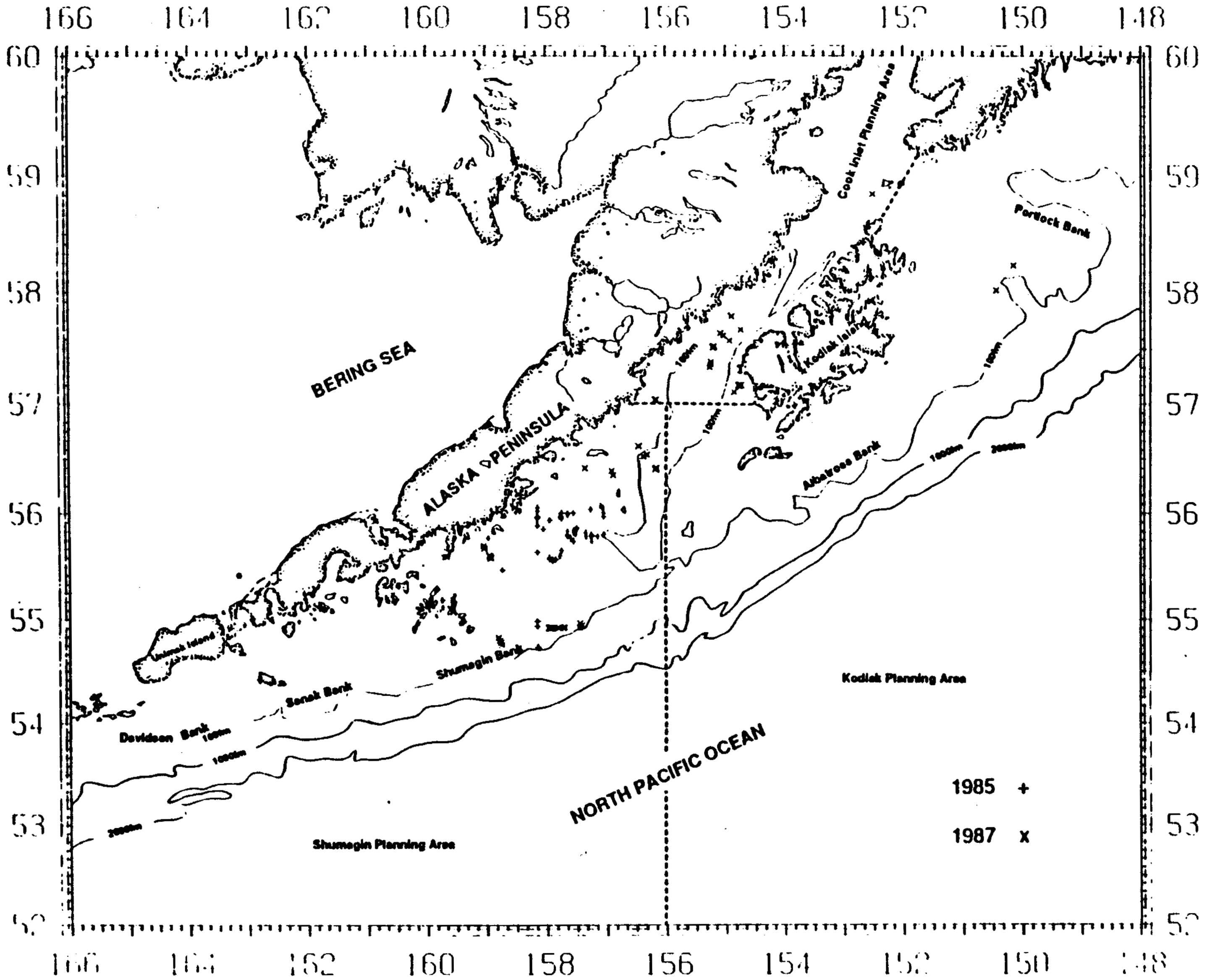

Figure 2.24. Finback Whale Locations Recorded During 1985 Aerial Surveys (Brueggeman et al. 1987) and 1987 Shipboard Surveys (Brueggeman et al. 1988).

although no sightings were recorded during the fall period, it should be noted that no surveys were conducted in September. October and November surveys resulted in no fin whale sightings, but it is probable that some fin whales are present in September. Leatherwood et al. (1983) recorded the fin whale in Shelikof Strait in early September.

Brueggeman et al. (1988) conducted shipboard surveys in the Shumagin, Kodiak, and lower Cook Inlet planning areas during June-July 1987. They recorded densities of fin whales in the Shumagin Planning Area about five times higher than those recorded by Brueggeman et al. (1987). Brueggeman et al. (1988) calculated minimum abundance estimates of 943 (±536 SE) fin whales for the Shumagin Planning Area. They concluded, based on the results of the 1985 and 1987 surveys, that "approximately 1000 finbacks or fewer summer in the Shumagin Planning Area.

Port Moller/Nelson Lagoon

Marine mammal populations near Port Moller were surveyed recently by Troy and Johnson (1987). These aerial and ship-board surveys covered the North Aleutian Shelf region from Unimak Pass to Cape Seniavin (about 45 km east of Port Moller) to depths of about 60 m. Common marine mammals in the area studied are Steller sea lion, harbor seal, sea otter, Dall's porpoise, harbor porpoise and gray whale (Table 2.3).

The sea otter is by far the most common marine mammal in this area. Otters are present year-round. They are relatively common to about the 50 m isobath and are generally most common in the 30-40 m depth range.

Gray whales migrate through the area in spring and fall and small numbers summer in the area. They are found in coastal waters, in the shallowest waters surveyed by aerial and ship-board observers.

Steller sea lions are found in the area year-round. Sea lions were found primarily in the shallowest waters surveyed, and most were seen well west of the Port Moller area, near Unimak Island.

Harbor seals were also found in shallow coastal waters. They are most common in the summer months. The winter decline may indicate a seasonal exodus from the study area, or reduced sightability during seasons when they do not haul out. The Port Moller/Nelson Lagoon area is a major haul out site and as many as 8000 harbor seals have been recorded there (Frost et al. 1982). Peak use of haul-out areas occurs during the molt in June and July and tapers off in September and October, after which harbor seals spend more time in the water.

The two species of porpoise occurred only seasonally in the study area, and in waters of variable depth. During a July 1985 cruise Dall's porpoise were found in fairly shallow (30-40 m) waters even though they are considered a deep-water species. Sightings of this species in May 1985 were in waters >60 m deep. Harbor porpoise recorded during shipboard surveys occurred in waters less than 30 m deep (July 1985) and in waters 40 to 50 m deep (May 1985).

Table 2.3. Densities[1] of Marine Mammals (No./km^2) Observed[2] on Aerial Survey Transects Along the Nearshore Zone of the North Aleutian Shelf, Including the Port Moller Area (Troy and Johnson 1987).

	Spring	Summer	Fall	Winter
	Mar-May	June-Aug	Sept-Nov	Dec-Feb
Sea otter	0.52	0.57	0.97	0.57
Steller sea lion	0.17	0.21	0.01	0.22
Harbor seal	0.20	0.44	0.01	0.02
Harbor porpoise	0.02	0.00	0.00	0.02
Dall's porpoise	0.00	0.02	0.00	0.00
Gray whale	0.02	0.02	0.01	0.00

[1] Highest monthly densities observed during each three-month period are shown.

[2] Actual densities may be considerably higher. During aerial surveys some marine mammals are submerged and therefore invisible to observers; others are present at the surface but not seen by the observers. Shipboard behavioral observations of gray whales in the Chirikof Basin indicated that in order to correct for submerged gray whales, raw density estimates derived from aerial surveys should be divided by 0.280 (July surveys from a Grumman Goose) and 0.358 (September surveys from a Twin Otter). Thus, the raw density estimates were 2.8 to 3.6 times too low. Also, these correction factors do not take into account animals present at the surface but not seen by the observers (Miller 1986). Davis et al. (1982) developed a correction factor for bowheads at the surface that were missed by the observers. They estimated that only 68.5% of the bowheads at the surface in their study were detected by the primary observers. Comparable correction factors are not available for the other species listed here.

Although there are records of up to 4000 walruses hauling out in the Port Moller area, their use of this area is apparently irregular, and may be declining. Frost et al. (1982) reported that walruses hauled-out in this area in 1968, 1969, 1979 and 1980. None were reported to be there in 1981 and only four in 1982. Records of hauled out walruses are more frequent from Amak Island and Cape Seniavin. Troy and Johnson (1987) recorded peak numbers of walruses in April, in the coastal zone of their North Aleutian Shelf study area.

Chirikof Basin

Several species of marine mammals occur in the Chirikof Basin of the northern Bering Sea. This area is one of the main feeding areas of gray whales, whose densities in the area are summarized in Table 2.4.

Table 2.4. Densities of Gray Whales (no./km^2) Estimated From Aerial Surveys in the Chirikof Basin.

	Spring Mar-May	Summer June-Aug	Fall Sept-Nov	Winter Dec-Feb
Gray whale	0.01[1]	0.04[2]	0.01[2,3]	0

[1] Northward migrating gray whales arrive at St. Lawrence Island in May and June. Here we have arbitrarily assumed that one quarter of the gray whales that are present in the summer in the Chirikof Basin have arrived by the end of May.

[2] From Miller (1986). Densities are corrected for submerged whales, but not for whales at the surface that were missed by the observer.

[3] From Miller (1986). Densities observed on aerial surveys in September were unexpectedly lower than summer densities. Migration out of the Bering Sea begins in October and is completed by the end of December.

The Bering Sea walrus population has been estimated to be as large as 200,000-300,000 individuals. There are two major breeding populations, one in the northcentral Bering Sea, the other in the southeastern Bering Sea. Most females and young migrate from April-June to the Chukchi Sea. During this period large numbers of walruses would be passing through the Chirikof Basin. These walruses would be returning through the area from October-December. Actual densities are not available for the Chirikof Basin, but would clearly be extremely variable depending on ice concentrations and movements. There would be few walruses in the Chirikof Basin in late winter, except in the immediate vicinity of St. Lawrence Island. In summer the walruses remaining in the Chirikof Basin would be present primarily at haul-out sites.

Alaskan Beaufort Sea/Corona Site

Several marine mammal species occur in this area. Table 2.5 summarizes information available on densities of bowheads and ringed seals, especially with regard to the "Corona" drillsite.

Chukchi Sea, Unimak Pass, Norton Sound

Observed numbers and estimated densities of selected marine mammal species are shown in Table 2.6 for selected seasons. Numbers of marine mammals in these areas are variable within seasons and between years and are difficult to summarize, being dependent on such factors as ice conditions. For example, gray whales generally migrate south through Unimak Pass from October to early January, but the exact timing of this migration varies from

Table 2.5. Densities (no./km^2) of Marine Mammals Estimated From Aerial Surveys in the Alaskan Beaufort Sea, Especially With Respect to the "Corona" Site.

	Spring Mar-May	Summer June-Aug	Fall Sept-Nov	Winter Dec-Feb
Bowhead whale	0	0-0.008[1]	0.006-0.0034[2]	0
Ringed seal	0.04[3]-0.41[4]	0.04-0.41[5]	few	0.04-0.41

[1] Densities shown indicate the maximum annual densities observed during August survey periods in 1985 and 1986 in the continental shelf stratum (Richardson et al. 1987). Densities are corrected for submerged whales, and whales at the surface that were not seen by the observers. The study area was centered about 100 km east of Corona; densities at Corona probably average somewhat lower.

[2] Densities shown indicate the maximum annual densities observed during September and October survey periods in 1985 and 1986 in the continental shelf stratum (Richardson et al. 1987). Densities are corrected for submerged whales, and whales at the surface that were not seen by the observers. The study area was centered about 100 km east of Corona.

[3] Ringed seal densities in areas of pack ice in the Alaskan Beaufort Sea range from 0.04 (Burns and Eley 1978) to 0.11 (Burns and Kelley 1982) (no./km^2, uncorrected for seals not hauled out or otherwise missed by observers) observed on aerial surveys. The 0.04 figure is a general figure for the Alaskan Beaufort, while the 0.11 figure was obtained on a brief (140 km) survey over pack ice between Flaxman Island and Barter Island on 29 May 1982.

[4] Average of six years data from 1970-1982 for fast ice (Burns and Kelley 1982). The study area extended from Flaxman Island to Barter Island. Surveys were conducted in late May and early June. Ringed seal densities near Corona might be expected to be comparable to densities shown for pack ice areas since landfast ice probably rarely extends as far offshore as the Corona site. However, the densities might be expected to be at the high end of the pack ice range discussed above, since the area would be fairly close to landfast ice and the pack ice might be heavy and consolidated, and therefore more desirable habitat.

[5] Although peak numbers of ringed seals would still occur in the Corona area in June, they probably begin to decline as the ringed seals move offshore with the retreating pack ice. Most of the population is thought to remain in the pack ice until freeze-up in the fall (Davis and Thomson 1984).

Table 2.6. **Observed Numbers and Estimated Densities (No./km^2) of Selected Marine Mammal Species in the Chukchi Sea, Unimak Pass, and Norton Sound.**

Location	Season	Numbers and Estimated Densities	Situation	Reference
Chukchi Sea				
Gray whales	summer, fall	(0 to 0.01/km^2)[1]	in offshore waters	Ljungblad et al. (1985); Davis and Thomson (1984)
	summer, fall	(0.02 to 0.06/km^2)[1]	in nearshore waters	" " "
Walrus	summer, fall	ƒ90,000[2]	offshore near ice edge, U.S. waters	Fay (1982); Davis and Thomson (1984)
	summer, fall	135,000[2]	offshore near ice edge, Soviet waters	" " " " " " " "
White whale	summer	1500-2500[2]	nearshore and in lagoons	Davis and Thomson (1984)
Unimak Pass				
Gray whales	spring, fall	16,000-17,000[2]	migrants passing through	Braham (1984); Rugh (1984)
Northern fur seal	spring, fall	800,000[2]	" "	Harry and Hartley (1981); Lloyd et al. (1981)
Steller sea lion	spring, fall	?	" "	Schusterman (1981)
Norton Sound				
Walrus	summer	>500[2]	nearshore off Nome	Fay (1982)

[1] Observed densities from aerial surveys.

[2] Estimated numbers.

year to year. Thus, during the fall (September-November) numbers of gray whales migrating through the Pass may range from 0 to peak rates of 52 whales/hr (Rugh 1984).

2.2 Marine Mammal Sounds*

All of the marine mammals that commonly inhabit Alaskan waters are known to produce sounds. Present knowledge about the frequencies and source levels of the underwater sounds that they make is summarized in Tables 2.7-2.9. The kinds and functions of these calls are summarized in the following paragraphs. This section concludes with a summary of the seasonal and geographical distributions of marine mammals in Alaskan waters, and expected seasonal variations in the rates and types of vocalizations. These types of data are relevant because marine mammal sounds contribute to the background noise, and because the types and levels of sounds made by animals give us clues about the frequencies that are important to those species.

Marine mammals use sounds for three basic functions: (1) long distance communication, (2) short distance social communication, and (3) echolocation. The use of sound for all three functions has not been demonstrated in all species. With the exception of echolocation, one species may use different kinds of sounds for different functions. Different species may use different kinds of sound for the same function.

Sounds produced for long distance communication may be associated with announcement of reproductive intentions, establishment of territory, coordination of foraging activities, maintenance or establishment of group structure, and coordination of activities at a distance. Over short distances, sounds are used in social interaction situations including agonism between individuals, establishment of dominance, play, identification of self and the group, identification of another individual, reproductive activities and establishment and maintenance of the mother/pup bond.

The echolocation capabilities of some odontocetes are very well developed. However, the exact functions of these capabilities in nature are not well demonstrated. It has recently been suggested that some odontocetes use echolocation clicks and sonic pulses not only to aid in locating potential food, but also to debilitate prey (Norris and Møhl 1983).

Marine mammals can produce vocalizations of different frequencies, durations, repetition rates, with or without amplitude or frequency modulation. Sounds can be continuous, segmented, or pulsed. Individual sounds are sometimes combined to form doublets, stereotyped phrases, songs or codas. These complex stereotyped sounds have certain characteristic qualities, but they often differ among areas, groups and individuals. The numbers of different sounds and combinations of sounds that can be produced is endless. Only a few species have been studied in detail. Sound production in some of these species has been studied in captivity and it is uncertain whether all the sounds produced in the wild are produced in captivity, and

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*D.H. Thomson, LGL Ltd.

Table 2.7. Characteristics of Underwater Sounds Produced by Alaskan Odontocete Whales.

Species	Signal Type	Frequency Range of Vocalizations (kHz)	Dominant Frequencies (kHz)	Source Level (dB re 1 μPa at 1 m)	References
White whale	whistles	0.26-20	2-5.9	-	Sjare and Smith 1986a,b
	pulsed tones	0.4-12	1-8	-	Sjare and Smith 1986a,b
	noisy vocalizations	0.5-16	4.2-8.3	-	Sjare and Smith 1986a,b
	echolocation	40-120	variable	160-222	Au et al. 1985, 1987
Killer whale	whistles	1.5-18	6-12	-	Steiner et al. 1979; Ford and Fisher 1983;
	pulsed tones	0.5-25	1-6	160	Awbrey et al. 1982; Ford and Fisher 1983; Schevill and Watkins 1966
	echolocation	0.1-35	12-25	180	Wood and Evans 1980
Pacific white-sided dolphin	whistles	7-16	-	-	Evans 1973; Caldwell and Caldwell 1977
	echolocation	0.2-150	60-80	170	Evans 1973
Dall's porpoise	clicks	0.04-12	-	-	Evans 1973
Harbor porpoise	clicks	100-160	130	132-149	Møhl and Andersen 1973
	clicks	2	-	100	Busnel and Dziedzic 1966; Schevill et al. 1969
Pilot whale	whistles	0.5-14+	14	180	Fish and Turl 1976
	echolocation	0.1-100	-	180	Evans 1973
Sperm whale	clicks	0.1-30	2-4, 10-16	160-180	Backus and Schevill 1966; Levenson 1974; Watkins 1980a
Beaked Whale	whistles	3-16	-	-	Winn et al. 1970a
	clicks	0.5-26+	-	-	Winn et al. 1970a

Table 2.8. Characteristics of Underwater Sounds Produced by Alaskan Baleen Whales.

Species	Signal type	Frequency Range of Vocalizations (Hz)	Dominant Frequencies (Hz)	Source Level (dB re 1 μPa at 1 m)	References
Fin whale	moans	17-25	20	160-186	Watkins 1981b; Watkins et al. 1987
	moans	30-750	-	155-165	Watkins 1981b; Cummings et al. 1986
	whistles?, chirps?	1,500-5,000	1,500-2,500	-	Thompson et al. 1979
	clicks?	16,000-28,000	-	-	Thompson et al. 1979
Blue whale	moans	12-390	20-30, 50-60	188	Cummings and Thompson 1971; Edds 1982
	clicks?	6,000-8000 21,000-31,000	6,000-8,000 25,000	130, 159	Beamish and Mitchell 1971; Beamish 1979
Minke whale	down sweeps	60-130	-	165	Schevill and Watkins 1972
	moans, grunts	60-140	60-140	151-175	Schevill and Watkins 1972; Winn and Perkins 1976
	ratchet	850-6,000	850	-	Winn and Perkins 1976
	clicks	3,300-20,000	<12,000	151	Beamish and Mitchell 1973; Winn and Perkins 1976
	thump trains	100-2,000	100-200	-	Winn and Perkins 1976
Sei whale	pulses	3,000	3,000	-	Thompson et al. 1979
Gray whale	moans	20-1,200	20-200, 700-1,200	185	Cummings et al. 1968; Fish et al. 1974; Swartz and Cummings 1978
	pulse modulated	600-1,800	200-600	-	Dahlheim et al. 1984
	FM up-down sweep	100-350	300	-	Dahlheim et al. 1984
	pulses	100-2,000	300-800	-	Dahlheim et al. 1984
	clicks (calves only)	100-20,000	3,400-4,000	-	Fish et al. 1974; Norris et al. 1977
Humpback whale	song components	40-8,000	100-4,000	144-174	Thompson et al. 1979
	shrieks (A)	-	750-1,800	179-181	Thompson et al. 1986
	horn blasts (A)	-	410-420	181-185	Thompson et al. 1986
	moans (A)	10-1,900	25-360	175	Thompson et al. 1986
	grunts (A)	25-1,900+	-	190	Thompson et al. 1986
	pulse trains (A)	25-1250	25-80	179-181	Thompson et al. 1986
	underwater blows	100-2,000	-	158	Beamish 1979
	fluke & flipper slap (A)	30-1,200	-	183-192	Thompson et al. 1986
	clicks	2,000-8,200	-	-	Winn et al. 1970b; Beamish 1979
Bowhead whale	tonal moans	25-900	100-400	129-178	Ljungblad et al. 1982; Cummings and Holliday 1987; Clark et al. 1986
	pulsive	25-3,500	-	152-185	Würsig et al. 1985; Clark and Johnson 1984; Cummings and Holliday 1987
	song	20-500	<4,000	158-189	Cummings and Holliday 1987
Right whale	tonal	30-1,250	160-500	-	Cummings et al. 1972; Clark 1983
	pulsive	30-2,200	50-500	172-187	Cummings et al. 1972; Clark 1983
				181-186	C. Clark (in Würsig et al. 1982)

(A) Humpback sounds recorded in Alaskan waters.

Table 2.9. Characteristics of Underwater Sounds Produced by Alaskan Pinnipeds.

Species	Signal type	Frequency Range of Vocalizations (kHz)	Dominant Frequencies (kHz)	Source Level (dB re 1 μPa at 1 m)	References
Bearded seal	song	0.02-6	1-2	-	Ray et al. 1969; Stirling et al. 1983
Ribbon seal	frequency sweeps	0.1-7.1	-	160	Watkins and Ray 1977 (estimated)
Ringed seal	barks, clicks, yelps	0.4-16	< 5	-	Stirling 1973; Cummings et al. 1984
Harbor seal and Spotted seal	social sounds	0.5-3.5	-	-	Beier and Wartzok 1979
	clicks	8-16	12	-	Schevill et al. 1963; Cummings and Fish 1971; Renouf et al. 1980
Northern fur seal	clicks, beats	-	-	-	Poulter 1968
Steller sea lion	clicks, growls	-	-	-	Poulter 1968
Walrus	bell tone	0.4-1.2	-	-	Schevill et al. 1966
	clicks	0.4-10	-	-	Ray and Watkins 1975

vice versa. Each successive research effort on most of these species expands knowledge to such an extent that it is reasonable to assume that their full repertoires have not yet been documented.

Nonvocal sounds made by marine mammals include tail and flipper slaps, breaching sounds, jaw claps, bubble noises and underwater blow noises (Pryor 1986). Some marine mammals produce sounds inadvertently when engaged in other activities. When baleen whales are feeding, the baleen may rattle as water passes through it (Watkins and Schevill 1976). Ringed seals produce noise when they scratch the ice to keep dive holes open (Cummings et al. 1984).

2.2.1 Toothed whales--calls and echolocation signals

The vocalizations made by toothed whales can be classified into two general groups: pure tone whistles and pulsed sounds. Pulsed sounds include the high frequency clicks used in echolocation, low frequency clicks used for communication, and complex grunts, screams, barks, quacks, squawks, blares and moans.

Basic whistle types include trills, and sounds that are unmodulated, ascending, descending, or wavering in frequency. A whistle can consist of one such call type uttered singly or as a continuous series of the same or mixed call types. Over the duration of a whistle, the amplitude of ascending and descending call types can vary. Wavering frequency calls can be superimposed on ascending/descending type whistles. Whistles can be continuous or have a variable number breaks and segments within one whistle. For any one species, initial, final and peak frequencies may vary, as can the duration and intensity. Whistles do not rise above 20 kHz and the lower frequency limit can be as low as 260 Hz (Table 2.7). Source levels for whistles have rarely been recorded. A sound pressure level of 180 dB re 1 μPa at 1 m has been measured for pilot whale whistles. They may serve as identification calls and for communication (Caldwell and Caldwell 1977; Herman and Tavolga 1980; Tyack 1986). The whistle repertoires of the white whale, pilot whale and Pacific white sided dolphin are well developed.

Pulsed tones have been recorded only from the white whale and killer whales. Most vocalizations made by the killer whale are pulsed tones (Ford and Fisher 1983). These are complex and are used for identification and coordination of group behavior (Ford and Fisher 1983; Hoelzel and Osborne 1986). Pulsed tones contain most of their energy below 8 kHz (Table 2.7). In the white whale, pulsed tones as well as some whistles were associated with social interaction situations (Sjare and Smith 1986b). Source levels of these pulsed calls are unknown.

Non-echolocation click type signals made by the sperm whale are used for social communication and the coordination of group behavior (Watkins and Schevill 1977; Watkins et al. 1985). They have the same functions as the whistles and pulsed tones of other species. The 2 kHz low frequency clicks uttered by the harbor porpoise also may be used for communication. Other species that do not whistle or make pulsed sounds may use moderate frequency clicks for communication. Sperm whale clicks have most of their energy below

16 kHz (Table 2.7). Low to moderate frequency click sounds made by other species have lower limits of 40 Hz to 2 kHz (Table 2.7).

Echolocation clicks from toothed whales are the highest frequency sounds produced by any marine mammals. In the white whale they range from 40 to 120 kHz (Au et al. 1985, 1987) and in the harbor porpoise they range from 100 to 160 kHz (Møhl and Anderson 1973). The sound intensity of echolocation clicks has been reported to range from 132 to 222 dB re 1 µPa at 1 m (Table 2.7). Moreover, these signals are highly directional and, at least in the white whale and bottlenose dolphin, have beamwidths (to the -3 dB points) of 5 to 12 degrees from the major axis (Au et al. 1986, 1987). Source levels and frequencies are variable within as well as between species; toothed whales apparently adjust their click frequencies and levels for optimum echolocation capabilities under varying environmental conditions (Au et al. 1985). When echolocating, the white whale usually emits a series of about 16 to 42 clicks (Au et al. 1985). In the white whale the typical interclick interval for the main echolocating clicks is 44 ms (Au et al. 1985). Typical click durations for odontocetes are less than 1 ms and can be as low as 35 µs (Popper 1980).

2.2.2 Baleen whales

Most sounds made by fin, blue, minke and sei whales (genus *Balaenoptera*) are low in frequency and of moderate intensity. Most vocalizations are below 3 kHz and have source levels of 151 to 188 dB re 1 µPa at 1 m (Table 2.8). The fin whale produces a repeated stereotyped 20 Hz call during winter that could be a display associated with reproduction (Watkins 1981; Watkins et al. 1987). These calls have been recorded from most ice free waters in winter, but not specifically from the Bering Sea (Watkins et al. 1987). The significance and uses of other calls are unknown.

Some moderate to high frequency click sounds have been recorded in the presence of blue, fin and minke whales (Beamish and Mitchell 1971, 1973; Beamish 1979; Thompson et al. 1979). Frequencies were 3.3 to 31 kHz and source levels were 130 to 159 dB re 1 µPa at 1 m (Table 2.8). Beamish and Mitchell (1973) raised the possibility that baleen whales use echolocation. However, other researchers have not recorded these click sounds and believe that there is no evidence to show that baleen whales use echolocation (Norris 1981; Watkins 1981).

Humpbacks are very vocal when on their southern wintering grounds. The songs and social sounds produced in late fall and winter have been well studied (Tyack 1981; Payne and Guinee 1983). Humpbacks do not sing and are less vocal when on their summering grounds in the Gulf of Alaska (Thompson et al. 1986). During summer, sounds are generally in the 20 to 2000 Hz range with intensities of 144 to 192 dB re 1 µPa at 1 m (Thompson et al. 1986).

Gray whales are vocal when migrating and when on their southern wintering grounds (Fish et al. 1974; Norris et al. 1977; Dahlheim et al. 1984). Sounds made on the summer feeding grounds in the Bering Sea are similar to those made while on the wintering grounds (Moore and Ljungblad 1984). The behavioral significance of the sounds is unknown (Dahlheim et al. 1984; Moore and Ljungblad 1984). On both the summering and wintering grounds, frequencies of most sounds were below 2 kHz (Dahlheim et al. 1984; Moore and Ljungblad 1984). Higher frequency clicks are produced by calves (Table 2.8; Fish et al. 1974; Norris et al. 1977).

Sounds of the northern right whale have not been studied. This species is now very rare in Alaskan waters. Sounds of southern right whales have most of their energy at frequencies between 50 and 1000 Hz (Clark 1983). Intensities are about 172 to 186 dB re 1 µPa at 1 m (Clark in Würsig et al. 1982). Simple sounds are used for long distance contact and complex sounds are associated with socializing whales (Clark 1983).

Most bowhead calls are brief moans in the frequency range of 25 to 900 Hz (Ljungblad et al. 1980; Würsig et al. 1985; Clark and Johnson 1984; Cummings and Holliday 1987). However, some complex sounds have components up to 4 or 5 kHz. Source levels of bowhead calls have been estimated to range from 129 to 189 dB re 1 µPa at 1 m (Clark et al. 1986; Cummings and Holliday 1987). The functions and behavioral significance of the sounds are, for the most part, unknown.

2.2.3 Pinnipeds

Most pinniped sounds (Table 2.9) are associated with agonistic displays, establishment of dominance and/or territory, and mating displays. In the northern fur seal, Steller sea lion, harbor seal and walrus, in-air vocal communications between mother and pup are established soon after birth and may be important in establishment of the mother/pup bond and for identification and location of the pup (Peterson 1968; Schusterman 1981; Miller 1985; Renouf 1984).

The underwater sounds of the Steller sea lion and of the northern fur seal are not well known. They consist of barks, clicks and bleating sounds (Schusterman et al. 1966; Poulter 1968; Schusterman and Balliet 1969; Cummings and Fish 1971). Frequency, source level information, and behavioral significance of these underwater sounds are unknown.

The bearded seal produces a distinctive musical trill, primarily in he spring. The trill generally begins at about 2.5 kHz, sweeps upward to 3 kHz, descends to 1 kHz with an upsweep to 2 kHz, and then descends below 1 kHz (Ray et al. 1969). A 0.5 to 1 kHz frequency modulation is superimposed on the center frequency. The trill ends with a pure tone descending from 500 to 200 Hz. The song is thought to be a territorial advertisement and/or mating call of the male (Ray et al. 1969). Source levels of bearded seal songs have not been reported but these songs are a prominent feature of the underwater acoustic environment of the arctic during spring.

The ribbon seal also produces a downward frequency sweep, but it does not waver and it exhibits several harmonics (Watkins and Ray 1977). Sounds are in the range of 100 to 7100 Hz with estimated source levels of 160 dB re 1 µPa at 1 m (Watkins and Ray 1977).

Ringed seals make low intensity clicks with a fundamental frequency of 4 kHz and barks, yelps, and growls with most energy below 5 kHz (Schevill et al. 1963; Stirling 1973; Cummings et al. 1984). Sound intensities are only 95-130 dB re 1 µPa at 1 m, which is low in comparison with other Alaskan marine mammals (Cummings et al. 1984; cf. Tables 2.7-2.9).

Walruses produce a stereotyped sequence of sounds consisting of clicks rasps and a bell-like tone. These sounds are in the frequency range 0.4 to 1.2 kHz with harmonics to 10 kHz (Schevill et al. 1966; Ray and Watkins 1975; Stirling et al. 1987). Source levels have not been reported.

2.2.4 Seasonal Aspects of Sound Production

In any given location, the contribution to ambient noise made by marine mammal sounds is strongly dependent on season. Season determines the locations of most of the marine mammals, and also determines their behavioral activities and hence the amounts and kinds of vocalizations that they produce. The seasonal distribution and seasonal influences on sound production of common Alaskan marine mammals are summarized below.

Spring: Fast ice and dense pack ice covers most of the Chukchi and Beaufort Seas in the early spring. The ringed seal is the only common inhabitant of these ice-covered waters. Ringed seal vocalizations become more common in April at the onset of the breeding season (Stirling et al. 1983; Cummings et al. 1984). Later in spring and during summer the ringed seal appears to be much less vocal (Stirling et al. 1983).

In spring, walruses, bowheads and white whales are widely distributed within the moving pack ice in the Bering Sea. Later in spring, bowheads and white whales aggregate while migrating in the system of opening leads in the Chukchi Sea. Bearded seals also follow the retreating ice edge into the Chukchi Sea. Ribbon seals are associated with the ice edge in spring; however, when the ice edge retreats, they remain in the Bering Sea. At the springtime ice edge in Lancaster Sound, N.W.T., a somewhat analogous situation, ambient noise was dominated by bearded seal, white whale and narwhal sounds (Finley et al. 1983, 1984). Walruses produce their stereotyped songs during the mating season in March and April (Stirling et al. 1983). However, it is not known if they vocalize during the remainder of the year as well. In the high arctic, bearded seal vocalization rates increased from late winter to early summer; however, it was not known if this was due to an increase in call rate or an increase in the numbers of seals present (Stirling et al. 1983). Spring migrating bowheads sometimes produce a stereotyped song in addition to the more common moans and other calls (Cummings and Holliday 1987; C.W. Clark pers. comm.). Thus, in spring, marine mammal sounds would probably contribute significantly to ambient noise levels near the ice edge in the northern Bering Sea and in the system of leads in the Chukchi Sea. This has been confirmed in the Barrow region during recent acoustic studies in spring.

In late spring, northern fur seals and Steller sea lion males come ashore to establish breeding territories. The in-air vocalizations associated with agonism among males have been documented. However, it is not known if similar vocalizations also occur at sea prior to hauling out. Spotted seals winter along the Bering Sea ice edge. At breakup, they migrate to nearshore areas in the northern Bering Sea and Chukchi Sea. Harbor seals use nearshore areas along the Alaska Peninsula, Aleutians and Pribilof Islands. Spotted seal males and females are vocal during the spring mating season (Beier and Wartzok 1979). In the spotted seal, this high rate of vocalization lasts about a month and the seals are relatively quiet for the remainder of the year (Beier and Wartzok 1979).

In late spring/early summer, gray whales migrate through Unimak Pass, across the North Aleutian Shelf, north to Nunivak Island, and from there directly to St. Lawrence Island, from whence they go to feeding grounds in the North Bering and Chukchi Seas. Migrating gray whales are vocal in the southern part of their range (Cummings et al. 1968); however, no attempt has been made to record the sounds of spring migrants.

Summer - During summer, most walruses are distributed along the ice edge in the northern Chukchi Sea. Smaller numbers are distributed at various locations in the Bering Sea. Harbor seals are found in nearshore areas, and spotted seals are found in nearshore areas of the Northern Bering Sea and in the Chukchi Sea. The ringed seal and bearded seal are widely distributed in the Chukchi and Beaufort Seas and the ribbon seal is found in offshore waters of the Bering Sea. Northern fur seals and Steller sea lion females forage at sea and return to the breeding islands to suckle young. The males leave their breeding territories and are foraging at sea by early August. Nothing is known about summer-time underwater sound production by these species.

In summer, gray whales feed in the northern Bering and Chukchi Seas. Gray whales vocalize when on their summer feeding grounds (Moore and Ljungblad 1984). Bogoslovskaya (1986) believes that gray whales feed in stable groups and that individuals within the group keep in acoustic contact with one another when feeding at distances greater than 800 m.

Most bowheads summer in the Canadian Beaufort Sea. Sounds made by bowheads on the summer feeding grounds are of the same type as those recorded during spring migration, with exception that songs have not been recorded in summer (Würsig et al. 1985).

Many white whales summer in the Canadian Beaufort Sea but others occur in Bristol Bay, Cook Inlet and Norton Sound. In summer, white whales are generally found in nearshore waters and make daily movements into estuaries. The white whale is very vocal when in its estuarine habitat (Ford 1977; Sjare and Smith 1986a,b). Its acoustic behavior during the time when it is not in estuaries is unknown.

The killer whale is widely distributed throughout the Bering Sea all year round and is found in the Chukchi Sea in summer. Killer whales appear to be vocal at all times (Ford and Fisher 1983; Hoelzel and Osborne 1986).

Humpback whales summer in southeast Alaska, the Gulf of Alaska, Bering Sea and occasionally in the Chukchi Sea. They are vocal in summer but the rate of vocalization is lower than when they are on the winter grounds (Thompson et al. 1986).

Sperm, right, fin, sei, and minke whales and Dall's and harbor porpoise are found in the Bering Sea in summer. Dall's and the harbor porpoise and minke whales range into the Chukchi Sea. Cuvier's beaked, Bering sea beaked and Baird's beaked whales summer in the Bering Sea. Cuvier's beaked and the Bering Sea beaked whale are year round residents. All of these species vocalize and can be expected to make some contribution to ambient noise levels.

Fall and Winter - In fall, Alaskan marine mammals migrate to their winter grounds. Because much of the spring time vocalization is related to reproductive activities, the contribution of marine mammal sounds to ambient noise would be expected to be lower in fall than in spring. Apart from bowhead and a few white whale recordings made in fall during several studies, there are no specific reports of sounds made by Alaskan marine mammals during fall. There is insufficient information from other areas to establish the nature and rates of vocalizations in fall.

Bowheads, walruses, white whales, bearded, ribbon, ringed, northern fur, harbor and spotted seals and Steller sea lions all winter in the Bering Sea near or south of the ice edge. Minke whales, Dall's porpoise and the harbor porpoise winter in the open water of the Bering sea. Winter distribution of walruses and other species depends on ice conditions. Ringed seals and a few bearded seals are the only inhabitants of the winter fast ice in the Chukchi and Beaufort Seas. Vocal behavior of Alaskan species in winter has not been studied.

2.3 Marine Mammal Hearing*

The hearing ability of a marine mammal is a complex function of several specific abilities or parameters:

1. The intensity of sound that is barely audible in the absence of ambient noise. This absolute hearing threshold varies with frequency, and the curve relating the threshold intensity to frequency is called the audiogram. Some species are more sensitive than others, and the frequency of peak hearing sensitivity varies among species.

2. The signal-to-noise (S/N) ratio that is required to detect a sound signal in the presence of background noise. This is called the "critical ratio" and is also a function of frequency.

3. The ability to localize the direction from which a sound is arriving. Animals with good localization abilities should be able to detect signals at a lower S/N ratio than animals with poor localization abilities, provided that the noise source masking the signal is not omnidirectional, and that signal and noise are not arriving from the same direction.

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*W.J. Richardson, LGL Ltd.

An understanding of these factors is necessary to evaluate the ability of a marine mammal to detect industrial sounds in various circumstances. This understanding is also needed to evaluate its ability to detect communication signals, echolocation sounds or other sounds of interest in the presence of "masking" by natural ambient noise and by industrial sounds.

Underwater hearing ability has been studied in a few odontocetes (toothed whales), phocids (hair seals), and otariids (eared seals). However, baleen whales and walruses have not been tested. In most of the marine mammal species that have been tested for hearing abilities, only one or two individuals have been examined. The low sample sizes prevent a detailed examination of variability among individuals of the same species. However, even the limited data presently available show that there are differences in hearing abilities between various species of toothed whales or of seals.

2.3.1 Frequency range and sensitivity

Sensitivities of marine mammals to sounds of different frequencies are best illustrated by means of audiograms. Audiograms are obtained by behavioral or electrophysiological techniques. In the behavioral method, tones of various intensities and frequencies are presented to a trained test animal. If the animal hears a sound stimulus, it responds positively; if the tone is not heard or if no sound was presented, as in a control trial, no such response occurs. The least intense tones detectable at various frequencies define an individual animal's audiogram.

2.3.2 Toothed whales

Behavioral audiograms have been determined for six species of toothed whales, including three Alaskan species--a harbor porpoise (Andersen 1970), a killer whale (Hall and Johnson 1972), and two white whales (White et al. 1978). Additional data on the sensitivity of three white whales to low frequencies were obtained by Awbrey et al. (1986, 1988). Figure 2.25a shows behavioral audiograms for these three species. Figure 2.25b shows corresponding data for non-Alaskan species including the bottlenose dolphin, the odontocete whose hearing has been studied in most detail. The other two non-Alaskan species for which behavioral audiograms are available are the false killer whale *Pseudorca cressidens* (Thomas et al. 1988) and the freshwater boutu *Inia geoffrensis* of South America (Jacobs and Hall 1972).

Most toothed whales can hear sounds over a very wide range of frequencies from as low as 75-125 Hz in the bottlenose dolphin and white whale (Johnson 1967; Awbrey et al. 1988) to 105-150 kHz in several species (Fig. 2.25). The killer whale differs from other odontocetes in that its upper hearing limit is about 31 kHz (Hall and Johnson 1972). Although the frequency range of the killer whale audiogram is narrower than that of other odontocetes that have been studied, its hearing at its "best" frequency is very sensitive. In the absence of noise, a killer whale can detect a signal of about 30 dB re 1 μPa if the sound is near 15 kHz (Hall and Johnson 1972) compared to about 39 dB at 30 kHz for a white whale (White et al. 1978), about 48 dB at 8 and 32 kHz for the harbor porpoise (Andersen 1970), and 41-42 dB at various frequencies for a bottlenose dolphin (Johnson 1967).

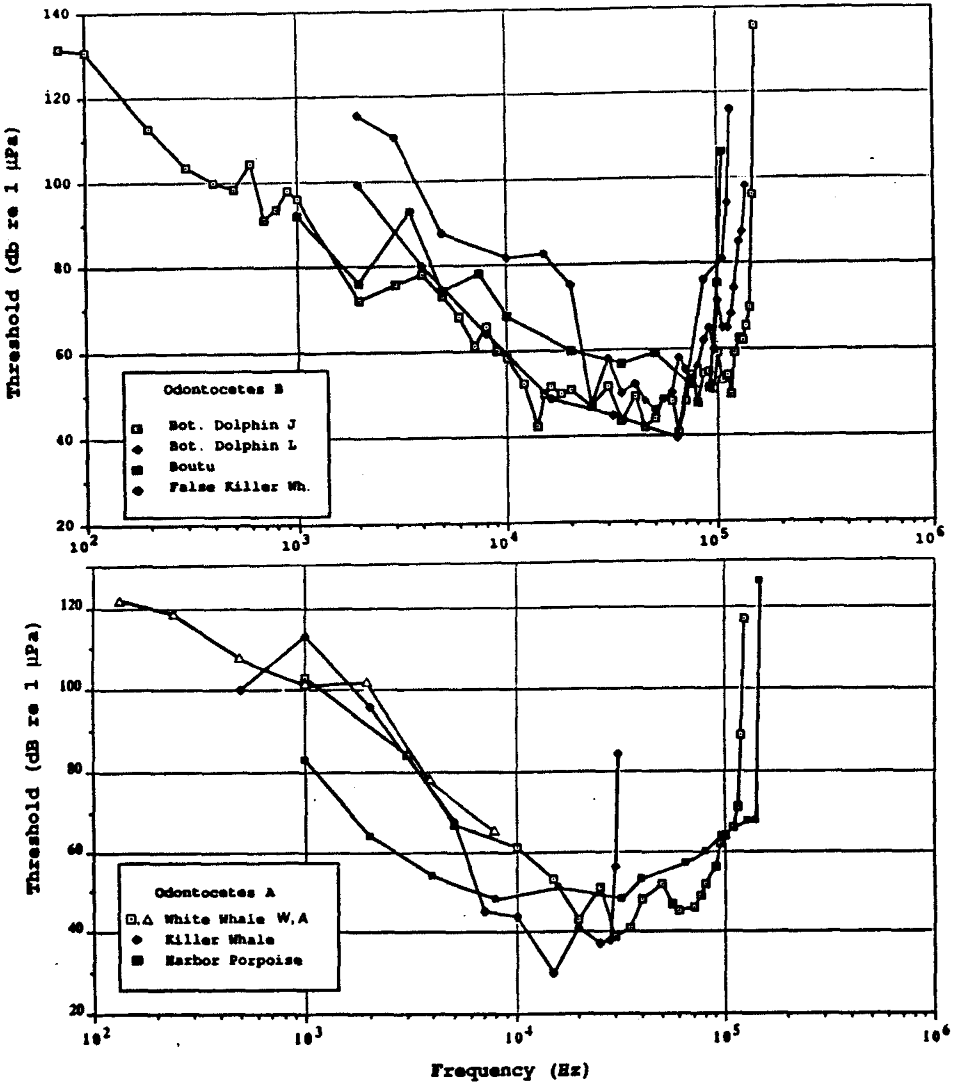

Figure 2.25. Underwater Audiograms of Several Odontocetes: (A) White Whale (White et al. 1978; Awbrey et al. 1988); Killer Whale (Hall and Johnson 1972); Harbor Porpoise (Andersen 1970); (B) Bottlenose Dolphin (Johnson 1968a; Ljungblad et al. 1982c); Amazon River Dolphin or Boutu (Jacobs and Hall 1972); False Killer Whale (Thomas et al. 1978).

For each species there is a range of frequencies where hearing thresholds are low. Below and above this range the hearing thresholds increase with decreasing or increasing frequency. The increase in thresholds is rather gradual at low frequencies. It is possible that estimated auditory thresholds for many species are too high for frequencies below 1-10 kHz, since the small tanks in which most audition tests have been done may have many echoes, standing waves and otherwise elevated noise levels. This problem was suspected in the studies by Hall and Johnson (1972), Jacobs and Hall (1972) and Ljungblad et al. (1982). The limited and questionable data on sensitivity at low frequencies (<1000 Hz) are a particular concern in the context of this review, since most industrial noise is primarily at low frequencies.

The increase in thresholds is more abrupt at high frequencies, at least when frequencies are shown on a logarithmic scale as in normal. This upper frequency cutoff was at about 31 kHz for the one killer whale tested, 120 kHz for white whales, and somewhere above 140 kHz for the harbor porpoise. Johnson (1980) has suggested that, above 50 kHz, the hearing of odontocetes may be limited by water molecule motion known as thermal noise (Urick 1975).

Bullock et al. (1968) and several subsequent investigations have obtained electrophysiological audiograms from several species of dolphins and porpoises. Electrophysiological audiograms are based on neural responses (evoked potentials) received from electrodes implanted in the animal's brain or, in some more recent studies, applied outside the skull. The shapes of the electrophysiological audiograms are generally comparable to those obtained behaviorally. In the case of the harbor porpoise, however, the lowest threshold determined by the evoked potential method was at a much higher frequency than that determined behaviorally (about 125 kHz vs. 8-32 kHz, Voronov and Stosman 1983; Popov et al. 1986 vs. Andersen 1970). Bullock et al. (1968) were not able to accurately record absolute intensities, but some of the subsequent electrophysiological studies may have provided absolute audiograms. Popper (1980) indicates, however, that thresholds obtained by these methods may be higher than those obtained behaviorally. In any case, invoked potential methods based on external electrodes hold particular promise for examining the hearing abilities of marine mammals such as baleen whales that are very difficult to hold in captivity (Ridgway et al. 1981; Ridgway and Carder 1983; Popov et al. 1986).

2.3.3 Pinnipeds

Behavioral audiograms have been obtained for three species of hair (phocid) seals--ringed, harbor and harp seals. Also, the grey seal has been studied by the evoked potential method. Ringed and harbor seals occur in Alaska. Phocid seals can apparently detect very high frequencies of underwater sound--up to 180 kHz in the case of the harbor seal (Fig. 2.26). However, above 60 kHz sensitivity is poor and different frequencies cannot be discriminated (Møhl 1968a,b). The functional high frequency cutoff is thus around 60 kHz for the species tested (Schusterman 1981). Below about 50 kHz, the hearing threshold of phocids is quite flat down at least to 1 kHz, ranging between 65 and 85 dB re 1 µPa (Møhl 1968a; Terhune 1981; Terhune and Ronald 1972, 1975a; Fig. 2.26). The lower limit of phocid hearing has not been clearly delineated since frequencies below 1 kHz have not been tested. The two species for which more than one individual has been tested (ringed and grey seals) exhibit some audiogram variability within species (Terhune and Ronald 1974; Ridgway and Joyce 1975).

The high frequency cutoff of eared seals (otariids) for underwater sound is lower than that of phocids (Schusterman 1981); however sensitivity in the range of best hearing is not substantially different from that of phocids (Fig. 2.26). The high frequency cutoff of both species of otariids that have been tested (California sea lion and northern fur seal) is between 36 and 40 kHz based on behavioral techniques (Schusterman 1981). The fur seal has a peak sensitivity of about 60 dB re 1 µPa between 4 and 28 kHz (Moore and Schusterman 1987), whereas the California sea lion has a peak sensitivity of

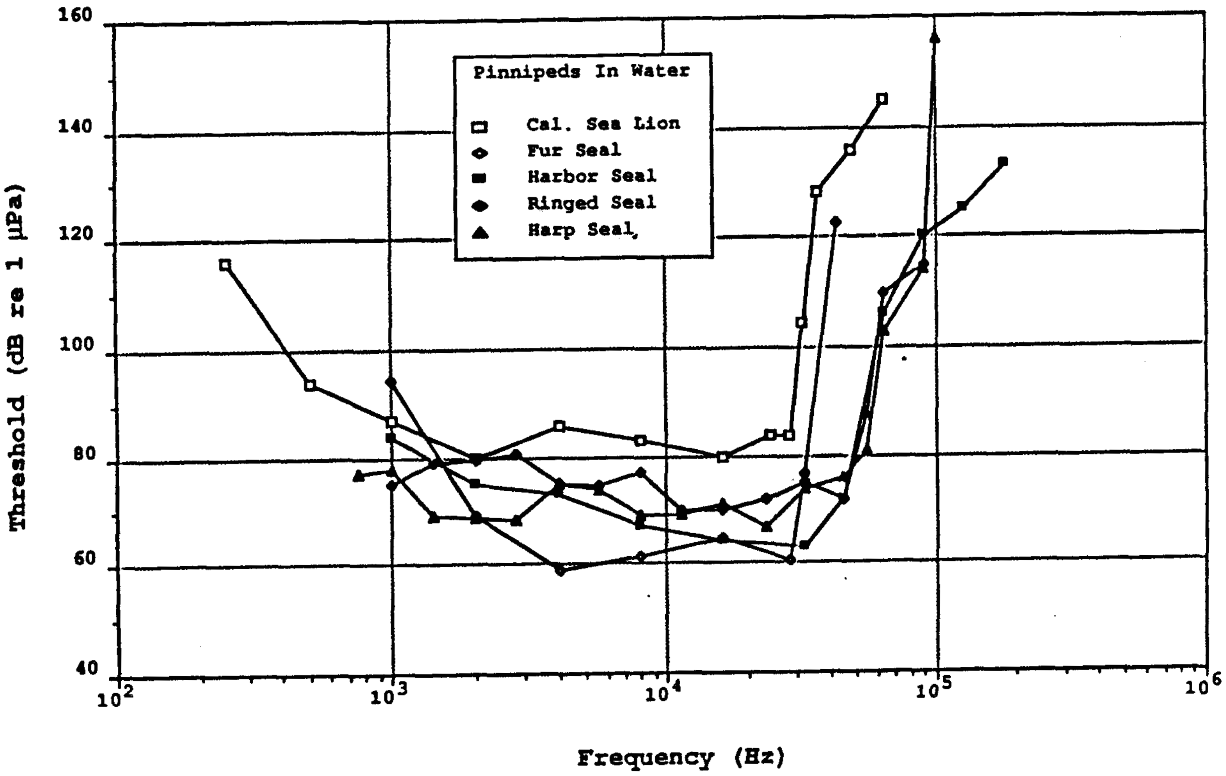

Figure 2.26. Underwater Audiograms of Several Pinnipeds: California Sea Lion (Schusterman et al. 1972); Average of Two Fur Seals (Moore and Schusterman 1987); Harbor Seal (Møhl 1968a); Average of Two Ringed Seals (Terhune and Ronald 1975a); Harp Seal (Terhune and Ronald 1972).

80 dB re 1 µPa at about 2 and 16 kHz (Schusterman et al. 1972). The hearing threshold of the California sea lion rises from about 87 dB re 1 µPa at 1 kHz to about 116 dB at 250 Hz. These low frequency hearing thresholds are probably valid since Schusterman et al. (1972) made very careful measurements of echoes and ambient noise in the test tank, and rigidly positioned the subject sea lion in a position where the signal level was measured at its maximum.

As amphibious animals, pinnipeds need to respond to in-air sound as well as to underwater sound. Aerial audiograms have been determined behaviorally for two fur seals and a California sea lion (Moore and Schusterman 1987), a harbor seal (Møhl 1968a), and a harp seal (Terhune and Ronald 1971). An earlier determination for another sea lion (Schusterman 1974) is now considered to be artefactual, and the reliability of the harp seal data for 1-8 kHz has also been questioned (Moore and Schusterman 1987). Besides these behaviorally-determined results, relative thresholds of in-air hearing at different frequencies have been determined by the evoked potential method for California sea lions and a harbor seal (Bullock et al. 1971). In air, otariids have slightly greater sensitivity and a more elevated high frequency cutoff than do phocids (Bullock et al. 1971; Schusterman 1981; Moore and Schusterman 1987; Fig. 2.27). The cutoff frequency of otariid hearing in air is about 32 to 36 kHz, not much lower than the underwater cutoff of 36-40 kHz (Schusterman 1981). In contrast, the in-air cutoff of the harbor seal is around 20 kHz, considerably lower than its underwater cutoff around 60 kHz. Based on behavioral experiments, both otariids and the harbor seal are most sensitive at 2 kHz and at 8-16 kHz and notably less sensitive at the intermediate 4 kHz frequency (Fig. 2.27). These animals are also similar to one another in that all suffer some loss of hearing sensitivity in air relative to water when results are expressed in directly comparable units, i.e., in dB re 1 μW/cm^2 (Møhl 1968a; Moore and Schusterman 1987).

2.3.4 Effects of sound duration

Signal duration influences the hearing threshold, at least under some circumstances. Almost all behavioral studies on hearing sensitivity have employed pure tones that were played to the test animals for at least 1/2 s, and in some cases the animals were allowed to control signal duration. However, Johnson (1968a) used tones of variable duration, including some that were much shorter than those generally employed. Frequencies ranged from

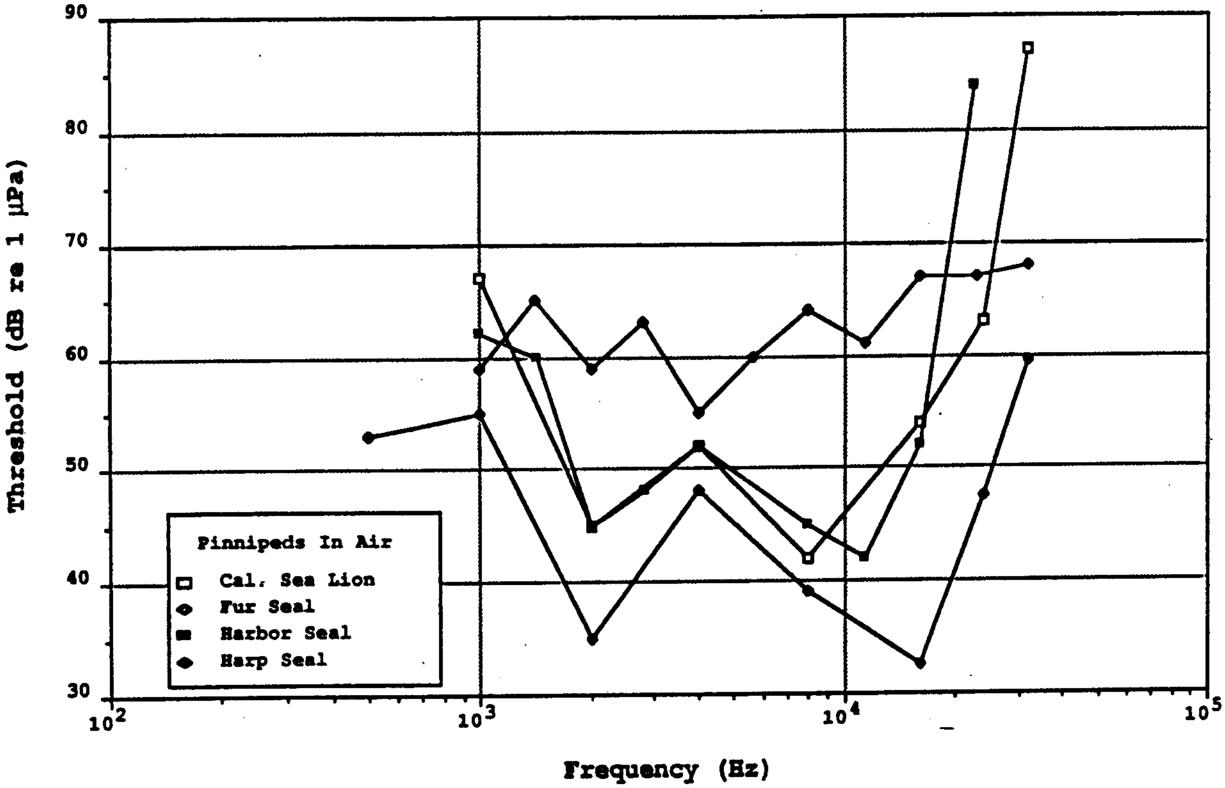

Figure 2.27. In-Air Audiograms of Several Pinnipeds: California Sea Lion (Moore and Schusterman 1987); Average of Two Fur Seals (Moore and Schusterman 1987); Harp Seal (Terhune and Ronald 1971); and Harbor Seal (Møhl 1968a).

250 Hz to 100 kHz in various tests. He found that the threshold for tones shorter than 0.1 to 0.2 s increased as the tone duration decreased. Tones longer in duration than 0.1 to 0.2 s elicited similar threshold values regardless of duration. For high-frequency single clicks of 0.2 ms duration, the threshold is about 20 dB higher than that for sounds longer than 0.1 to 0.2 s (Johnson 1968a). Likewise, Bullock and Ridgway (1972) found that evoked potentials recorded in the cerebrum of *Tursiops* increased in amplitude as tone duration increased. Also, evoked potentials recorded at the majority of locations (but not all) in the auditory cortex of the harbor porpoise increased in amplitude and decreased in threshold as tone duration increased (Popov et al. 1986).

Terhune (1988) recently performed a signal duration experiment on a harbor seal. At most frequencies tested, thresholds to pulses of various durations were similar as long as the duration was at least 50 ms. Thresholds increased as duration decreased from 50 ms.

These results might suggest that single short-duration signals, such as echolocation clicks or brief calls, will have higher thresholds than those indicated on the audiograms. However, Bullock and Ridgway (1972) found locations in the midbrain of *Tursiops* that appeared to be specialized for processing very brief (<2 ms), rapid-onset, rapidly-repeated, high-frequency (>30 kHz) clicks. These are all characteristics of *Tursiops* echolocation signals. Given the importance of echolocation to toothed whales, it can be assumed that neural processing is highly adapted for detection of echoes and integration of successive echoes. Pinnipeds seem far less responsive to click stimuli than are odontocetes (Bullock et al. 1971)

2.3.5 Auditory masking

Critical Ratios. The hearing threshold audiograms that have been presented (Figs. 2.25 and 2.26) represent the lowest intensities of sound that can be detected by an animal in the absence of noise. The sea is often a noisy environment, even in the absence of man-made sounds, and background ambient noise levels often mask the hearing thresholds of marine mammals. The intensity by which a signal must exceed the spectrum level background noise in order to be audible is termed the critical ratio (Hawkins and Stevens 1950; Popper 1980). Critical ratios for marine mammals have been determined by presenting a pure tone to a test animal while a background white noise* is present (Johnson 1968b; Terhune 1981; Fig. 2.28). A critical ratio of 20 dB at a particular frequency means that a tone at that frequency would have to have a level of at least 100 dB re 1 μPa to be heard over white noise with a spectrum level of 80 dB re $(1\ \mu\text{Pa})^2/\text{Hz}$.

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*White noise is simply broadband noise in which all frequencies in the noise spectrum are of equal intensity. In some masking experiments, the white noise has been filtered and limited to some range of frequencies above and below the test frequency. This should have little effect on the results as long as the bandwidth of the noise exceeds masking bandwidth.

Critical ratios tend to increase with increasing frequency. In the bottlenose dolphin, a pure tone signal at 6 kHz must exceed spectrum level noise by 22 dB to be detected, whereas a 70 kHz tone must exceed spectrum level noise by about 40 dB (Fig. 2.28). Critical ratios for the bottlenose dolphin have not been measured below 5 kHz. Burdin et al. (1973a) obtained some evidence that, at 1-10 kHz, critical ratios of dolphins are lower (better) than those of a human. Below 1 kHz though, the frequency discrimination abilities of the dolphin deteriorate rapidly (Thompson and Herman 1975), and bottlenose dolphin critical ratios may not closely resemble those of humans at low frequencies.

The critical ratios of the northern fur seal range from a low of 19 dB at 4 kHz to 27 dB at 32 kHz (Moore and Schusterman 1987). These values are a few decibels lower than the critical ratios of the bottlenose dolphin at corresponding frequencies (Fig. 2.28). In contrast, the ringed seal has critical ratios about 10 dB higher than those of the fur seal and several dB above the dolphin through the same frequency range (Terhune and Ronald 1975b; Fig. 2.28). However, Moore and Schusterman (1987) suggest that the ringed seal values are suspiciously high, and may be artefactual.

Critical ratios are not greatly different for underwater and aerial hearing, or across a wide range of vertebrates (Fig. 2.28, Moore and Schusterman 1987). The dolphin, fur seal and ringed seal data quoted above all represent underwater hearing. In-air critical ratios have been determined for the harp seal (Terhune and Ronald 1971) and the harbor seal (Renouf 1980). The validity of the harp seal data, at least for frequencies up to 8 kHz, has been questioned (Moore and Schusterman 1987). The in-air critical ratios for the harbor seal are generally consistent with the underwater values for the fur seal and bottlenose dolphin (Fig. 2.28).

Masking Bands. A pure tone is masked almost exclusively by noise at frequencies near the frequency of the tone. Noise at frequencies outside of this masking band has little influence on detection of the signal. The determination of the width of the masking band has been the subject of much effort. Fletcher (1940) proposed one method, based on the assumption that signal power must equal total noise power in the masking band in order to be audible. Since the spectrum level intensities of masking noise [dB re $(1\ \mu Pa)^2/Hz$] and the intensities of tones (dB re 1 μPa) are not compatible units, the spectrum level of the masking noise must be converted to a band level. The white noise often used in masking experiments has a flat spectrum, and therefore the energy in a masking band of noise is proportional to the masking bandwidth in Hz. Band level is computed from spectrum level by the formula

$$BL = SL + 10 \log BW \qquad (1)$$

where BL represents band level, SL represents spectrum level, and BW equals the bandwidth in Hz (Urick 1983). If it is assumed that signal power must equal or exceed noise power in the masking band in order to be detectable (Fletcher 1940), then the masking bandwidth is

$$BW = \text{antilog } CR/10 \qquad (2)$$

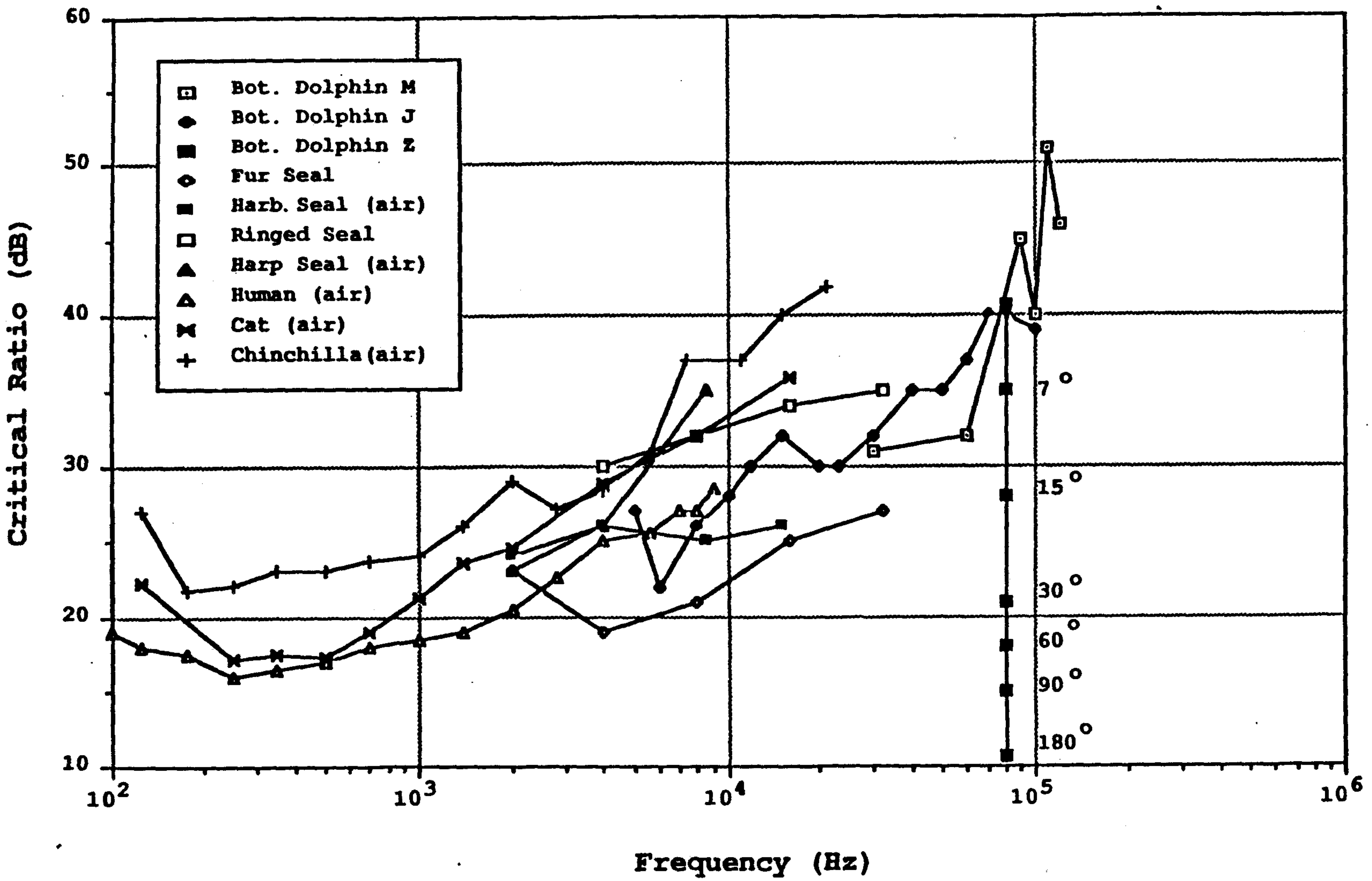

Figure 2.28. Critical ratios of several marine and terrestrial mammals. Critical ratios for the bottlenose dolphin are a function of signal and noise angular separation, as shown by the vertical line at 80 kHz. Underwater data: bottlenose (Johnson 1968b; Zaitseva et al. 1975; Moore and Au 1982); fur seal (Moore and Schusterman 1987); ringed seal (Terhune and Ronald 1975b). In-air data: harbor seal (Renouf 1980); harp seal (Terhune and Ronald 1971); human (Hawkins and Stevens 1950); cat (Watson 1963); chinchilla (J.D. Miller *in* Fay 1988).

where CR represents the critical ratio in terms of signal level relative to spectrum level noise. This gives the bandwidth in Hz of the band of masking noise that contains power equal to that of the signal tone (see Scharf 1970). Johnson (1968b), Terhune (1981) and others have used equation (2) to calculate masking bandwidths in Hz for marine mammals based on the assumption that signal power equals masking power. Figure 2.29 shows the results of such calculations, expressed as a percentage of the center frequency of the masking band.

Based on the available critical ratio data and the equal power assumption, masking bands often appear to be on the order of 1/6th to 1/3rd of an octave in width, i.e., bandwidth equals 11.6 to 23.2% of the center frequency (Fig. 2.29). If one of these "rules of the thumb" were strictly true, the critical ratios at several frequencies would be as follows:

	100 Hz	1 kHz	10 kHz	100 kHz
1/3 octave	13.6 dB	23.6 dB	33.6 dB	43.6 dB
1/6 octave	10.6	20.6	30.6	40.6

As evident from Figure 2.29, the critical ratios at low frequencies (human, cat) exceed those expected if the masking bandwidth is 1/3 octave. In contrast, critical ratios for marine mammals listening at most higher frequencies are somewhat lower than those expected if the masking bandwidth were 1/3 octave, or even 1/6 octave, particularly if one ignores the harp and ringed seal data that have been questioned by Moore and Schusterman (1987).

When attempting to calculate the radius of audibility of marine mammal calls or industrial noise in the presence of background noise, several workers have assumed that masking bands are 1/3 octave wide (e.g., Payne and Webb 1971; Gales 1982; Miles et al. 1987). Gales (1982) also considered the possibility that, at frequencies below 450 Hz, the masking bandwidth exceeds 1/3 octave. As evident from Fig. 2.29, masking bandwidth may indeed exceed 1/3 octave at low frequencies if marine mammals listening in water are similar to terrestrial mammals listening in air. If so, noise power in the masking band will be higher than calculated from the 1/3 octave assumption, and the radius of audibility of low frequency sound would be less than that calculated. Conversely, for higher frequencies where the masking bandwidth seems to be less than 1/3 octave based on critical ratio data for marine mammals, the radius of audibility could be somewhat greater than calculated assuming a masking bandwidth of 1/3 octave. All of these estimates depend on the validity of the equal power assumption, i.e., that a narrowband sound signal is masked when total noise power in the masking band equals or exceeds the power of the signal.

The equal-power assumption may not accurately represent the width of the masking band (Scharf 1970; Kryter 1985). Other methods, measure the masking band directly by manipulating the bandwidth of sounds masking a signal. The term "critical band" is used for direct empirical measures of the masking band (Scharf 1970). In humans, the critical band in Hz is about 2.5 times wider than the critical ratio equal-power band at the same center frequency. This means that humans can detect a signal whose level is somewhat less than the band level of

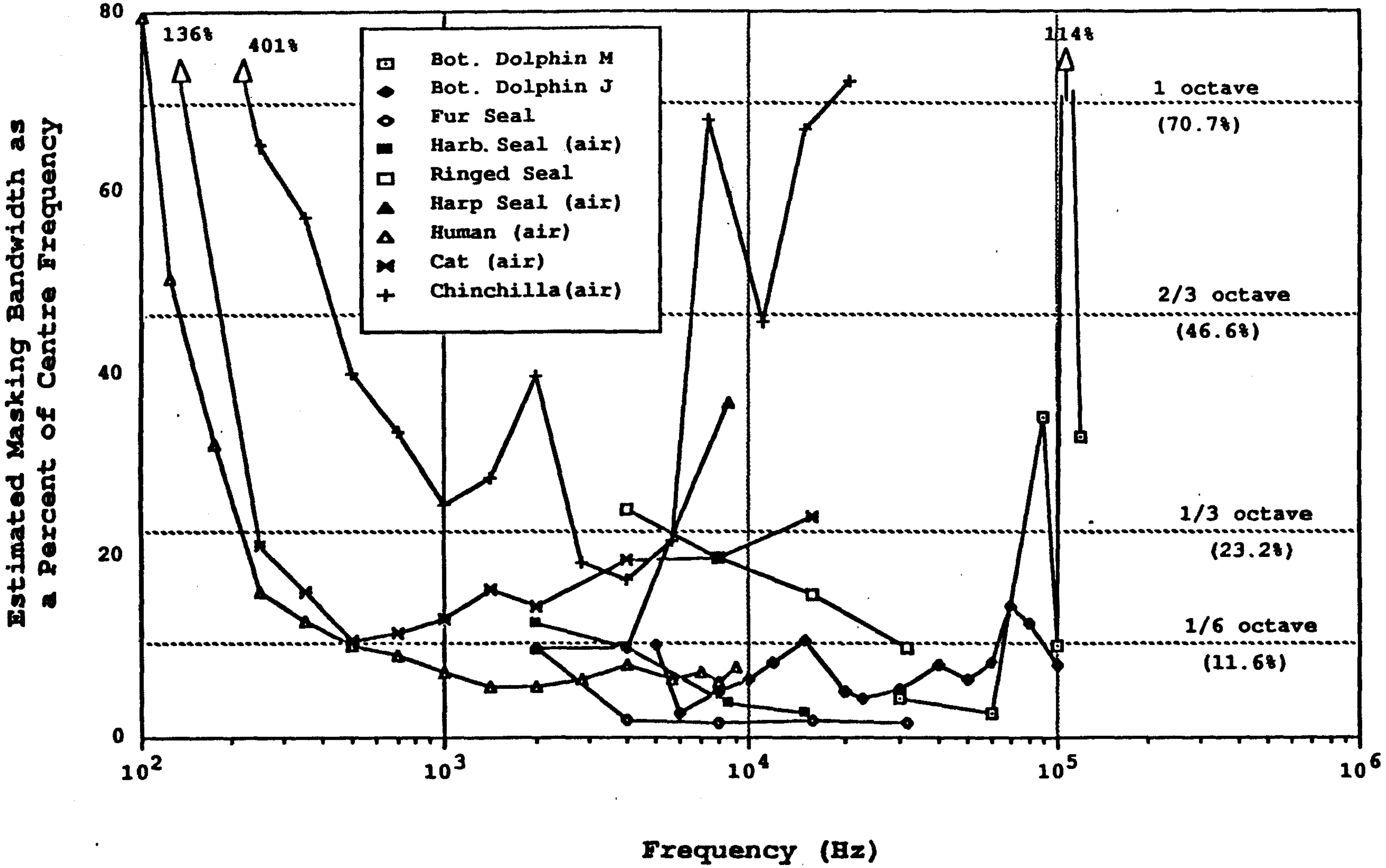

Figure 2.29. Estimated masking bandwidths of several marine and terrestrial mammals, expressed as a percentage of center frequency. Dashed horizontal lines show selected standard bandwidths. Assumes that signal power must equal or exceed noise power in masking band in order to be detected, i.e., masking bandwidth = (antilog Critical Ratio)/10. Based on same sources as previous figure.

noise in the masking band, contrary to the assumption of Fletcher (1940). In this instance, the threshold signal-to-noise ratio would be negative, i.e., < 0 dB.

Direct measurements of critical bandwidth in a marine mammal were obtained by Moore and Au (1983). They reported that a bottlenose dolphin's critical bandwidths at 30 and 60 kHz were, respectively, about 10 and 8 times wider than expected based on the equal power assumption. At 120 kHz the two methods gave similar results.

Threshold Signal/Noise Ratio. The above-mentioned results of Moore and Au (1983) show that, at 30 and 60 kHz, the bottlenose dolphin apparently can detect sounds 10 dB and 9 dB below the level of the noise in the corresponding critical band, i.e., at S/N = -10 and -9 dB. At 120 kHz the threshold S/N is near 0 dB.

Critical ratios of 20 dB or more are not incompatible with negative values of threshold S/N ratios; they are merely different ways of expressing the same phenomenon. Critical ratios relate total signal level in a narrow band to spectrum noise level on a "per Hz" basis. The negative S/N ratios represent signal level in a band to total noise level across that same band.

Though the conclusion that threshold S/N ratios may be negative is somewhat startling, it has been shown that human subjects can detect signals such as tones and speech at negative S/N ratios (Miller et al. 1951; Scharf 1970). Structured signals such as speech may be especially well detected due to differences between their frequency content and that of the noise, and also due to factors such as redundancy and context that give clues about the type of sound to expect next.

Payne and Webb (1971) discussed many of the human signal detection data in relation to the signals propagated by baleen whales, and suggested that baleen whales may also be capable of detecting sounds at negative S/N ratios. Hearing abilities of baleen whales are unknown, but some other groups of marine mammals (especially toothed whales) can discriminate intensities, frequencies and directions at levels comparable to those of humans. Bearing this in mind, the hypothesis of Payne and Webb (1971) on the hearing abilities of baleen whales is in line with data on marine mammal hearing abilities presented earlier in this section.

Laboratory tests of masking may really be tests of intensity discrimination, the task being to distinguish between the critical band of noise alone and the band of noise plus a signal. If a noise band has a certain intensity, there is a discrete increase in noise intensity that will cause the noise to be perceived as being more intense. Similarly, if a signal is added to noise, the signal will be perceived when the sum of the intensities of signal and noise cause a perceived increase in loudness over the noise alone.

Even in the absence of much detailed information about intensity discrimination by marine mammals, critical ratio data give valuable information, including an indication of the frequencies that are least prone to masking.

Critical ratio data also allow us to estimate the received level at which a narrow-band sound will be just detectable given a specified level of broad band background noise. However, some man-made noises have strong tonal components whose masking potential is not wholly predictable using critical ratio data. Limited data on masking of one high-frequency pure tone by another at various similar frequencies have been reported for *Tursiops* (Bullock et al. 1968; Johnson 1971). No such data are available for masking by low frequency tones, which are common components of industrial noise.

2.3.6 Adaptations for reduced masking

Most masking studies present the signal and the masking noise from the same direction. The sound localization abilities of marine mammals suggest that, if signal and noise come from different directions, masking may not be as severe as the existing critical ratio data suggest. In fish, the critical ratio at any given frequency decreases as the angle of separation between signal and masking noise increases (Chapman 1973). When the dominant background noise comes from a small number of specific sources such as ships or industrial sites, the background noise may be highly directional. Even some natural sources of background noise such as surf (Wilson et al. 1985) or ice may be strongly directional in the horizontal plane. Wind-induced ambient noise may exhibit significant variation in the vertical plane (Hamson 1985). In these situations, directional hearing abilities could, in theory, significantly reduce the masking effects of the noise. In the cases of the bottlenose dolphin (*Tursiops)* and the white whale, there is empirical evidence that masking effects of a particular noise are indeed strongly dependent on the relative directions of arrival of the sound signal of interest vs. the masking noise.

A study of directional masking at 80 kHz has been done using a bottlenose dolphin exposed to 0.6 sec tone pulses (Zaitseva et al. 1975). While the signal transducer was maintained at 0° relative to the animal's midline, a noise transducer playing 50 to 100 kHz white noise could be moved to any position around the dolphin in the horizontal plane. At 0° azimuthal separation the critical ratio was about 40.7 dB (Zaitseva et al. 1975), almost identical to the figure obtained by Johnson (1968b). Moving the masking signal away to angles of 7° to 180° separation caused decreases in critical ratios from about 35 to 11 dB, respectively (Fig. 2.28). Thus, the masking effect of background noise on *Tursiops* echolocation signals near 80 kHz will be much reduced if the noise is coming from directions other than that of the target of interest. This, coupled with the strongly directional nature of the echolocation pulses emitted by toothed whales (e.g., Norris and Evans 1967; Watkins 1980b; Au et al. 1986, 1987), is a very important adaptation for improving echolocation range and performance in the presence of noise.

It has been demonstrated that the white whale takes advantage of its directional sound emission and hearing capabilities while echolocating (Penner et al. 1986). When a noise source was placed in line between a white whale and the echolocation target, the whale echolocated by bouncing its beam off the water surface. This allowed the whale to concentrate its echolocation beam, and presumably its "receiving beam", in a direction slightly (~7°) different than that of the noise source. In this manner the white whale could detect the target when the noise level was too high to allow detection by conventional straight-line echolocation. No such capability was demonstrated in *Tursiops* (Penner et al. 1986).

In another experiment on *Tursiops,* Zaitseva et al. (1980) found that the angular separation between a sound source and a masking noise source has little effect on the degree of masking when the sound frequency is 18 kHz. Zaitseva et al. interpret this to mean that dolphin communication sounds will be more or less equally audible regardless of their direction of arrival, which is likely to be advantageous for purposes of social interactions. However, at these frequencies masking would be almost equally severe regardless of the direction of arrival of the masking noise.

Toothed whales, and probably other marine mammals as well, have additional capabilities besides directional hearing that can facilitate detection of sounds in the presence of background noise. Au et al. (1974) obtained indirect evidence that bottlenose dolphins may shift their peak echolocation signals to 120-130 kHz from the more typical 35-60 kHz signals in an area where there is a high level of ambient noise in the latter frequency range. Acoustic source levels of echolocation signals may also be greatly increased when necessary to circumvent noise (Au et al. 1974). Adaptation of the frequency and source levels of echolocation sounds to the prevailing noise environment was subsequently demonstrated in a more direct fashion in a white whale (Au et al. 1985).

Studies of masking at lower frequencies and in other marine mammal groups would be desirable. The demonstrated directional hearing abilities of some pinnipeds and baleen whales probably give them some improved capabilities. Whether most marine mammals can adjust the frequencies and source levels of their various call types to increase their communication ranges in the presence of noise has not been studied. However, the widely varying source levels of many marine mammal sounds are consistent with an ability to tailor the source level to the circumstances.

2.3.7 Audition in baleen whales

No work on auditory sensitivity has been performed on a live baleen whale. On the basis of anatomical and paleontological evidence, Fleischer (1976, 1978) has suggested that baleen whales are adapted for hearing low frequencies. Norris and Leatherwood (1981) examined the morphology of the hearing apparatus of the bowhead whale and several other species of cetaceans, and concluded that bowheads likely hear sounds ranging from "high infrasonic to low sonic to high sonic or low ultrasonic frequencies". Other authors (Evans 1973; Myrberg 1978; Turl 1980) suggest that marine mammals probably hear best in the frequency range of their calls. Most baleen whale sounds are concentrated at frequencies less than 1 kHz, though sounds up to 8 kHz are not uncommon (see Section 2.2.2). It is reasonable to suggest, then, that baleen whales are most sensitive to frequencies lower than 1 kHz. The morphology of the baleen whale cochlea is compatible with good low-frequency hearing and peak sensitivity between 1 and 2 kHz (G. Fleischer, Justus-Liebig University, pers. comm.).

There is behavioral evidence that at least some baleen whales detect faint calls from conspecifics many kilometers away, and head toward the calling animals (Watkins 1981b; Tyack and Whitehead 1983). Cummings and Thompson (1971) showed that gray whales swim rapidly away when killer whale sounds are projected into the water. Subsequently, Malme et al. (1983) found that gray whales detected killer whale sounds when their signal to noise ratio was about 0 dB. Various species of baleen whales have been found to move away from sources of industrial sounds. The directional responses to calling conspecifics, killer whale sounds, and industrial noise demonstrate that baleen whales have directional hearing capabilities.

The thresholds of other marine mammals range between 30 and 80 dB re 1 µPa at the frequencies to which they are most sensitive (see Figures 2.25 and 2.26). If baleen whales have similar sensitivities, but shifted to frequencies below 1 kHz, oceanic ambient noise--even in the absence of industrial activity--rather than absolute detection threshold would be the factor limiting hearing. Even in quiet conditions (sea state 1), average, ambient noise levels in the ocean are above 75 dB re 1 µPa in all 1/3 octave bands below 1000 Hz (Greene 1987, based on Knudsen et al. 1948). As noted earlier, masking bandwidths may exceed 1/3 octave at low frequencies, in which case ocean noise levels in masking bands would be even higher.

Though ambient noise probably limits low frequency hearing in baleen whales, the possible situation above 1 kHz is less clear. Ambient noise levels fall as frequency rises, and are, therefore, less likely to limit hearing. Cochlear structure suggests that the high frequency cutoff of baleen whales is about 20 kHz (G. Fleischer, pers. comm.).

Although audition data are totally lacking for baleen whales, auditory attributes such as critical ratio and sound localization ability may not be radically different than those of other mammals. This may be true even though low frequency sounds are probably the most important sounds for baleen whales. All vertebrates studied to date can localize sound, with humans and bottlenose dolphins having the most precise abilities of any species studied. Between 250 and 1000 Hz, humans have minimum audible angles below 2° (Gourevitch 1980). The baleen whale's ear is well isolated acoustically from the skull, a prerequisite for extremely accurate sound localization underwater (Fleischer 1978). The ears of pinnipeds are not perfectly isolated from the skull (Repenning 1972); thus the localization abilities of baleen whales may be superior to those of pinnipeds. The relatively great distance between the ears of large whales may greatly enhance their ability to localize sound cues (see Gourevitch 1980 for a detailed discussion of localization). Norris (1981) suggested that baleen whales may be able to find prey concentrations by localizing the sounds produced by swimming fish (e.g., Moulton 1960).

Critical ratio functions are similar among many vertebrates, and those of the baleen whales may be comparable. Baleen whales may also have lower critical ratios when signal and noise are angularly separated. Given the large size of baleen whales' heads, this improvement in critical ratio as a result of directional phenomena may extend to lower frequencies than in other mammals.

Although much speculation about some features of baleen whale hearing is possible, empirical measurements are highly desirable. It is technically feasible to obtain an audiogram from a beached or restrained baleen whale (Ridgway et al. 1981; Ridgway and Carder 1983). Empirical data are necessary before any confident predictions about mysticete auditory capabilities are possible.

2.4 Reactions of Marine Mammals to Man-Made Noise*

Reactions or lack of reactions of various marine mammals to different types of man-made sounds have been mentioned in many studies. Studies reported prior to 1983 were reviewed by Richardson et al. (1983). An updated version of that review considering studies done up to mid-1988 will soon be available (Richardson et al. 1989). Similarly, Johnson et al. (1989) reviewed literature and unpublished information about disturbance reactions of Alaskan pinnipeds. However, relatively few of the studies have provided specific information about the threshold sound levels, signal-to-noise ratios, or spectral characteristics at which marine mammals start to react. Some studies have provided information about reaction distances. In cases where sound attenuation rates can be estimated as a function of distance, these "distance threshold" data can provide approximate information about threshold sound levels at which reactions can be expected to begin.

This section summarizes selected studies of behavioral reactions of marine mammals to man-made noise, emphasizing the few studies in which the threshold of responsiveness was reported in terms of the received sound level at which behavioral reactions began. Studies in which the threshold reaction distance was reported are mentioned when the data may be specific enough to allow reasonably reliable estimates of sound levels as a function of distance. This is most likely to be true in the case of airborne sound propagation, e.g., from passing aircraft to pinnipeds hauled out on land or ice. For more details about all of the topics summarized below, the reader is referred to the more comprehensive reviews of Richardson et al. (1983, 1989) and Johnson et al. (1989).

2.4.1 Aircraft

Reactions of marine mammals to aircraft have been reported in many studies, but it was rarely documented whether the reaction was attributable to sound, vision or some other stimulus. Almost none of these reports have provided data on sound levels received by the mammals; some reports have provided estimates of the distances at which the mammals first react. These distances are quite variable, apparently depending on factors such as aircraft type, distance and altitude at closest approach, and flight pattern (straight line, circling, passing directly overhead vs. to the side, etc.).

Pinnipeds--Seals, sea lions and walruses that haul out on land or ice are probably the most sensitive marine mammals with respect to aircraft. These pinnipeds often rush into the water when disturbed by a passing aircraft.

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*W. John Richardson, LGL Ltd.

After such an incident, they may return to the haul out site within a few minutes, or may remain away for several hours or until the next day. In a small minority of the observations that have been reported, pups have been injured or killed by trampling when pinnipeds rushed into the sea, or as a result of abandonment after such incidents. In a study of harbor seals, Johnson (1977) found that light aircraft flying overhead at altitudes below 120 m (400 ft) nearly always caused seals to vacate the haul-out beaches; reactions to aircraft at 120-305 m altitude were more variable. Osborn (1985) found that aircraft flying below 150 m altitude over the same species caused alert reactions and, in a minority of cases, rapid movement into the water. California sea lions and elephant seals may be less sensitive than harbor seals (Bowles and Stewart 1980). The sensitivity of walruses to aircraft varies widely (e.g., Fay et al. 1986), but walruses that are hauled out often become alert or move into the water when aircraft approach within 1-1½ km at altitudes varying from 150 to 1500 m (Salter 1979). Among the other Alaskan species, Steller sea lions, fur seals, ringed seals, spotted seals and bearded seals often react to aircraft, but specific response thresholds have not been reported (Johnson et al. 1989; Richardson et al. 1989).

In general, pinnipeds hauled out on land or ice react to airborne sound from aircraft by becoming alert and, in many cases, by rushing into the water. They tend to be more sensitive to low-flying than to high-flying aircraft, to aircraft that are nearly overhead vs. those far to the side, and to abruptly changing sounds than to steady sounds. There are some indications that reactions to helicopters may be more severe than those to fixed-wing aircraft at similar distances. However, the lack of data on sound exposure levels makes these reports difficult to evaluate and impossible to quantify. Sensitivity apparently can vary according to stage of the breeding cycle. Partial habituation probably occurs under some conditions.

All available data on reactions of pinnipeds to aircraft involve animals that are hauled out. There are no specific data on reactions of pinnipeds at the surface of the water or underwater to noise from passing aircraft.

Toothed Whales--Toothed whales exposed to close approaches by aircraft sometimes dive abruptly or swim away from the aircraft track. Aside from the difficulty in being sure whether these behaviors were really attributable to the aircraft, we are not aware of any attempts to measure or estimate the received levels of aircraft noise that elicited these responses. Several workers have reported behavioral reactions of white whales to aircraft and helicopters flying overhead at altitudes ranging up to 500 m (e.g., Bel'kovich 1960). However, in other situations some workers have reported no detectable reaction to aircraft at altitudes as low as 150 m (Fraker and Fraker 1979). Data on reactions of other species of toothed whales to aircraft are even more meagre. Sperm whales reportedly showed no obvious reaction to a light twin engined aircraft circling overhead at 152 m altitude (Gambell 1968). Beaked whales seem to be especially sensitive to aircraft (Dohl et al. 1983).

Baleen Whales--Reactions of bowhead and gray whales to aircraft and/or certain aircraft noises have been examined more systematically, and additional anecdotal evidence is available for certain other species.

Bowhead whales circled by an Islander twin-engine aircraft often reacted when it was at or below 305 m altitude (1000 ft), infrequently reacted when it was at 457 m, and rarely did so when it was at or above 610 m (Richardson et al. 1985a,b). Underwater sound levels produced by this aircraft circling at various altitudes were reported by Greene (1985). Bowhead sensitivity to aircraft seemed to vary depending on the activity of the whales and on the water depth. Whales that were actively involved in feeding or social interactions were less sensitive to the aircraft than were those not actively engaged in one of these activities. For a given aircraft altitude, bowhead whales seemed to be more sensitive when the water depth was shallow than when it was deep, possibly because of the known tendency for underwater noise from an aircraft to propagate farther to the side in shallow than deep water (Urick 1972; Greene 1985).

The sensitivity of gray whales to aircraft noise also varies with whale activity (Ljungblad et al. 1983, 1987). Migrating gray whales approached by a UH-1N (Bell 212) helicopter have been reported to react to most approaches at altitudes below 250 m, some approaches at 305-365 m, and to none of the approaches at >425 m (SRA 1988). Underwater sounds produced by a Bell 212 passing overhead at various altitudes were recorded and measured by Greene (1985). Malme et al. (1983, 1984) tested the reactions of migrating gray whales to playbacks of that recording of Bell 212 sounds, repeated at an average rate of 3 simulated helicopter passes per minute. They found that 50% of the whales exhibited avoidance responses when the received helicopter noise level was 120 dB re 1 µPa.

Based on these studies of bowhead and gray whales, plus less detailed observations of other baleen whales, it is apparent that baleen whales often react to aircraft overflights by hasty dives, turns, or other behaviors. Sensitivity seems to depend on the activities and situations of the whales. There is no indication that single or occasional aircraft overflights cause long-term displacement of whales.

2.4.2 Ships and boats

Many authors have commented on the reactions or lack of reactions of marine mammals (especially cetaceans) to ships and boats (reviewed by Richardson et al. 1989). Most of these reports are anecdotal and lack both experimental control and measurements of received sound levels. Observations made from the disturbing vessel itself are difficult to interpret, since some animals react far enough away such that their detectability is affected by the presence of the ship. Also, as in the case of reactions to aircraft, it is usually uncertain whether the animals responded to the noise, sight, or other stimuli associated with the vessel. The following summary emphasizes the few studies where more specific information was obtained.

Pinnipeds--Very few quantitative data have been reported on sensitivity of pinnipeds to vessels. Reaction distances of walruses hauled out on ice or land to various types of boats have been reported. Reaction distances varied widely depending on vessel type, whether the direction of approach was upwind or downwind, group composition, and whether or not the animals had been subjected to hunting recently (Fay et al. 1986; Richardson et al. 1989).

Reaction distances of harbor seals hauled out on land seem to be at least as great for quiet unpowered vessels (kayaks, canoes) as for motorboats (Allen et al. 1984; Osborn 1985), suggesting that these seals may react more to the sight than to the sound of small vessels. Reactions of pinnipeds in the water to approaching vessels have rarely been reported. Fay et al. (1986) indicated that walruses tolerated closer approaches when they were in the water than when they were hauled out on ice pans.

Toothed Whales--Toothed whales show considerable tolerance of vessel traffic in many circumstances. However, they sometimes react at considerable distances when confined by ice or shallow water, or when they have learned to associate that vessel with harassment. Although received sound levels at which toothed whales do and do not react have not been reported, the threshold of responsiveness is likely to vary widely in parallel with the widely varying distance thresholds.

Dolphins often approach vessels and swim in their bow wakes, apparently unaffected by the high noise levels to which they must be exposed when within a few meters of the vessels. However, dolphins subject to harassment by tuna seining operations actively avoid tuna seiners and other vessels at distances of several kilometers (e.g. Norris et al. 1978; Au and Perryman 1982; Hewitt 1985). The avoidance reaction is suspected to be in response to underwater sound, in which case the animals must be reacting strongly to received noise levels far lower than those tolerated by dolphins that ride the bow waves of various vessels.

Similarly, white whales exhibit highly variable sensitivity to vessel noise. For example, in Bristol Bay, Alaska, white whales occur regularly amidst large fleets of fishing vessels. However, when these white whales move up a river they appear to be more sensitive to approaching outboard-powered boats (Stewart et al. 1982). Reactions of white whales to oil industry vessels operating in shallow coastal waters have been studied in the Mackenzie Delta area of the Canadian Beaufort Sea. There white whales sometimes avoid tugboats and similar vessels at distances as great as 2.4 km, but at other times occur within 0.2 km from such vessels (Fraker 1977a,b, 1978). Observations in that same area when ice was present in spring suggested that white whales are more sensitive to boats when ice restricts the animals to confined areas (Norton Fraker and Fraker 1982). White whales in leads consistently swam away from supply ships that were in motion at distances of 1 to several kilometers. White whales in the eastern Canadian high arctic have consistently shown very great sensitivity to noise from ships and from icebreaking. Strong avoidance reactions have been demonstrated repeatedly when the ship was several tens of kilometers away and when the ship noise was barely above the background ambient noise (LGL and Greeneridge 1986). Thus, no single noise threshold applies to all situations in which white whales occur. Their sensitivity varies widely with the circumstances.

Baleen Whales--There have been specific studies of the reactions of gray, humpback, and bowhead whales to vessels, and limited information, largely anecdotal, is available for some other species (Richardson et al. 1984). Watkins (1986) summarized some of the reactions of whales to boats based on his extensive experience near Cape Cod. Most low-amplitude vessel sounds seemed to be ignored. However, whales that had been exposed repeatedly to whale-watching vessels sometimes approached those vessels. On the other hand, whales often moved away in response to strong or rapidly-changing vessel noise. Avoidance reactions were especially strong when a boat was directly approaching (Watkins 1986). All of these phenomena have also been documented by other workers studying various species of baleen whales.

Reactions of gray whales to vessels have been described by several workers, but very little information has been reported (even indirectly) about the sound levels to which they do and do not react. Migrating gray whales have been reported to begin to exhibit avoidance when vessels approach within 200-300 m (Wyrick 1954). Summering gray whales may avoid ships that approach within 350-550 m (Bogoslovskaya et al. 1981). Jones and Swartz (1986) found that wintering gray whales tend to become less sensitive to boats as the winter progresses, presumably reflecting a habituation process. They and other workers also have documented an increasing tendency for gray whales to approach rather than flee from vessels in recent years. On the other hand, gray whales ceased using one wintering lagoon for a number of years when ship traffic was especially intense there, and returned in later years after ship traffic had abated (Bryant et al. 1984).

Humpback whales summering in waters of southeast Alaska often swim away when vessels approach within 2-4 km, and tend to dive when vessels are within 2 km (Baker et al. 1983). Sound levels received by the whales during those observations were determined by Malme et al. (1982) and Miles and Malme (1983). Dean et al. (1985) also found evidence that avoidance and other behavioral changes were common when vessels were underway within several kilometers of summering humpbacks. However, humpbacks sometimes show little or no obvious reaction even when vessels are much closer than the typical reaction distances reported by Baker et al. and Dean et al. Humpbacks are less likely to react overtly when actively feeding than when resting or engaged in other activities (Krieger and Wing 1986). Thus, no single "response threshold" can be defined that will apply to all humpbacks off southeast Alaska. Reactions of humpbacks wintering in Hawaiian waters to boats have been studied (e.g. Bauer and Herman 1986), but little information is available about the reaction distances or the sound levels that cause reactions in winter.

Reactions of bowhead whales to boats have been determined by experiments as well as opportunistic observations (Richardson et al. 1985a,b; Koski and Johnson 1987). Bowheads occasionally occur within a few hundred meters of oil industry and other vessels. However, experiments have shown that bowheads normally begin to swim rapidly away when vessels approach within 2-4 km. Reactions at even greater distances apparently occur in some situations (Koski and Johnson 1987). In one disturbance test where noise levels were measured directly, the noise level 4 km away from the vessel, the approximate distance at which bowheads began reacting, was only 84 dB re 1 µPa in the 1/3-octave band of strongest noise; that level was only 6 dB above the background ambient level in that band (Miles et al. 1987, p 225-231). However, bowheads tolerate higher vessel noise levels in some situations (Koski and Johnson 1987). They are especially sensitive to vessel noise when the vessel is heading directly toward the whale.

Generally similar although less detailed observations have been reported for a variety of other baleen whale species (Richardson et al. 1983, 1989).

2.4.3 Seismic exploration

Marine seismic exploration under open water conditions produces impulsive underwater sounds with source levels that greatly exceed those of other routine activities associated with offshore oil and gas exploration and development.

Pinnipeds--Reactions of pinnipeds to impulsive seismic noise have not been studied. Several species of pinnipeds are known to habituate to strong underwater noises, sometimes impulsive, that are often used in attempts to deter seals and sea lions from feeding on fish in nets or fish farms (e.g. Mate and Harvey 1987). More specific information is available about the reactions of ringed seals to on-ice seismic exploration via the Vibroseis technique, which uses strong frequency-sweeps rather than impulsive sounds. Vibroseis operations in winter and spring can cause localized movements of ringed seals away from seismic lines. However, this effect is detectable only within a short distance, possibly about 150 m (Kelly et al. 1986), even though Vibroseis noise can be measured in ringed seal lairs at distances up to about 2-6 km (Holliday et al. 1984).

Toothed Whales--Reactions of toothed whales to seismic noise also have not been studied systematically. The apparent ineffectiveness of small explosive charges in scaring white whales from an Alaskan salmon river (Fish and Vania 1971) may indicate a low degree of sensitivity to low-frequency impulsive noise. Hearing sensitivity of toothed whales is best at frequencies of several thousand Hertz (Awbrey et al. 1988), whereas almost all of the energy in seismic pulses is at frequencies below 500 Hz. Thus, it is possible that toothed whales are relatively insensitive to seismic pulses.

Baleen Whales--The behavior of several species of baleen whales exposed to seismic pulses has been observed opportunistically, and reactions of bowhead, gray and humpback whales to seismic pulses have been studied during controlled experiments.

Migrating gray whales showed definite avoidance reactions and other behavioral changes when exposed to seismic pulses with received levels exceeding about 160 dB re 1 µPa. The received levels at which 10%, 50% and 90% of the whales exhibited avoidance were estimated to be 164, 170 and 180 dB. Such levels were estimated to occur 3.6, 2.5 and 1.2 km broadside from an airgun array operating off the California coast. (Reaction distances could be greater in the Bering Sea and especially the Beaufort Sea because sound attenuates less rapidly with increasing distance in those areas than off California--Miles et al. 1987.) Less consistent and less dramatic reactions were suspected to occur at received levels of 140-160 dB, which would occur considerably farther away (Malme et al. 1983, 1984). Results of less extensive tests on gray whales summering in the Bering Sea gave results generally consistent with those on migrating gray whales (Malme et al. 1986). It is noteworthy that the threshold for distinct reactions to seismic pulses, about 164 dB, was about 50 dB higher than their reaction thresholds for continuous industrial noise such as that from drillships or production platforms. In this respect their behavior was consistent with that of humans, who are also more sensitive to continuous noise than to pulsed noise with an equivalent peak level (Fidell et al. 1970).

Similarly, experiments have shown that bowhead whales react to strong pulses of seismic noise by interrupting their normal activities and swimming away (Richardson et al. 1985a,b, 1986; Ljungblad et al. 1985, 1988). The first obvious behavioral reactions were typically detected when the approaching seismic ship was about 7-7.5 km away. In the Ljungblad et al. experiments, first reactions were evident when received noise levels were about 142-157 dB, and "total avoidance" (all whales moving away) was evident at 152-178 dB. (Note: Received levels of seismic pulses reported during studies of bowhead whales were instantaneous peak levels; those reported for gray and humpback whales were averaged over the duration of the pulse and thus would appear to be somewhat lower for the same actual level.)

Bowhead whales have frequently been observed engaged in seemingly normal activities when exposed to seismic pulses with received levels up to about at least 158 dB re 1 μPa at distances beyond about 6 km from seismic vessels. However, statistical analysis has found significant reductions in surfacing and dive durations and number of blows per surfacing when bowheads are exposed to noise from seismic vessels 6-99 km away (Richardson et al. 1986; Koski and Johnson 1987), consistent with changes observed when bowheads are strongly disturbed by closer seismic vessels. A similar pattern of change in surfacing, respiration and dive cycles has been noted in summering gray whales exposed to seismic noise (Malme et al. 1986, 1988). Thus, it is likely that bowheads are often subtly affected by seismic noise at distances well beyond those at which strong avoidance becomes evident, and at correspondingly lower received noise levels.

Humpback whale reactions to seismic noise have been studied in less detail. They, like bowhead and gray whales, tolerate noise pulses from distant sources, but exhibit startle responses at the onset of noise pulses with received levels of 150-169 dB (Malme et al. 1985).

In summary, baleen whales seem to be quite tolerant of noise pulses from marine seismic exploration. They usually continue their normal activities even when exposed to pulses with received levels as high as 150 dB, and sometimes higher. Such levels are 50 dB or more above typical ambient noise levels. However, subtle behavioral effects are suspected to occur at least some of the time at received levels less than this. At least in bowheads and gray whales, strong avoidance is common when received levels reach 160-170 dB. Such levels typically are found several kilometers from a vessel operating a full-scale array of airguns.

2.4.4 Dredging and marine construction

Dredges constitute some of major sources of underwater sound in certain nearshore areas. Fraker (1977a,b) observed that white whales reacted less to stationary dredges than to moving tug-barge combinations that emitted similar sound levels. White whales sometimes approached as close as 400 m from an operating dredge. Bowhead whales also were observed within 800 m of a suction dredge during aerial surveys, and industry personnel have reported that they sometimes were seen considerably closer than that (Richardson et al. 1985a,b, MS). Underwater noise from the dredge was clearly detectable out to distances of several kilometers, indicating that the white whales and bowheads may tolerate considerable dredge noise. However, underwater playback experiments using recorded sound from the same dredge showed that bowhead whales exhibited strong avoidance reactions when exposed to received broadband noise levels of 122-131 dB re 1 µPa, or 21-30 dB above the ambient noise levels at the times of the experiments (Richardson et al. 1985b, MS).

Insofar as we are aware, no quantitative data are available on reactions of other species of cetaceans or of pinnipeds to dredging and construction activities.

2.4.5 Offshore drilling and production facilities

Several anecdotal accounts have been published about the occurrence of various marine mammals (mainly cetaceans) near drilling and production sites (Richardson et al. 1989). In addition, controlled studies have been done to determine the sensitivity of white, gray, humpback and bowhead whales to underwater playbacks of drilling and (in some species) production sounds.

White whales have often been seen within 100 m of artificial islands that were "operational" and presumably drilling (Fraker 1977a,b; Fraker and Fraker 1979). Reactions of white whales to underwater playbacks of recorded sounds from a semisubmersible drillship have been tested in both the field (Stewart et al. 1983) and in captivity (Awbrey et al. 1986). Stewart et al. demonstrated avoidance reactions, but did not measure the sound levels that elicited avoidance. Awbrey et al. found that captive white whales were briefly startled by the onset of semisubmersible noise, but later swam within 1 m of the sound projector where the received noise level was at least 153 dB re 1 µPa. Overt behavior was not markedly affected by exposure to strong semisubmersible noise, and plasma catecholamine levels were not affected, suggesting that the animals were not stressed. These results may be another example of the degree to which white whales can adapt to repeated or ongoing man-made noise when it is not associated with negative consequences (see "Ships and Boats" section, above).

Bowhead whales whose behavior seemed normal have been seen within 10-20 km of drillships on several occasions, and on two occasions were as close as 8 and 4 km while the ship was drilling (Richardson et al. 1985a,b, MS). Industry personnel have reported closer sightings. Broadband sound levels 4 and 10 km from one of the drillships involved were 118 and 109 dB re 1 µPa, respectively, or 20 and 11 dB above the average background level in the same band (Greene 1985, 1987b). However, playback experiments using recorded sound from that same drillship showed that some bowheads initiate weak avoidance reactions when exposed to drillship sounds no stronger than those tolerated by the bowheads observed several kilometers from actual drillships. Taken together, results of drillship and dredge playback tests indicated that most bowheads do not react overtly unless the received noise levels are about 110-120 dB, or 20-30 dB above ambient levels in the corresponding band and 20-30 dB above the assumed threshold of hearing sensitivity (Miles et al. 1987; Richardson et al. MS). Thus, the radius of responsiveness around a drillsite is apparently considerably smaller than the radius of potential audibility.

Recently, migrating bowheads were monitored as they passed an operating drillship in the Alaskan Beaufort Sea. There was clear evidence that the whales avoided the area within 10 km of the ships, and some reactions were evident at greater ranges (Koski and Johnson 1987). The average level of broadband industrial noise 10 km from the drillship was 114 dB (Greene 1987a).

Reactions of migrating gray whales have been studied when the whales were exposed to underwater playbacks of drillship, semisubmersible, drilling platform, and production platform sounds (Malme et al. 1983, 1984). Avoidance reactions to all of these sounds were noticed. Received sound levels at which 50% of the whales exhibited avoidance ranged from 117 to 123 dB, depending on the type of noise. These sound levels corresponded to the received levels that one would expect to find 1100 m from the actual drillship if it were operating off the California coast, and 4-20 m from the other three sources (Malme et al. 1984). Larger radii of influence would be predicted if the same noise sources were operating in the Bering or Beaufort Sea, where sound attenuation rates are lower (Miles et al. 1987).

In summary, cetaceans exhibit avoidance reactions and other behavioral effects when exposed to moderately intense levels of drilling or production sounds. Whales seem most sensitive when the sound level is increasing or when a noise source first starts up. The limited available data suggest that stationary industrial activities producing continuous noise result in less dramatic reactions by cetaceans than do moving sound sources, particularly ships. There are indications that cetaceans may partially habituate to continuous noise. At least in the case of white whales, habituation may result in greatly reduced sensitivity. Cetaceans are often observed close enough to drillsites to be within the zone where they are expected to be able to hear industrial sounds emanating from those sites. Thus, the radius of avoidance by cetaceans appears to be considerably smaller than the radius of audibility.

Virtually no information is available about the reactions of pinnipeds to drilling or production operations.

3. NOISE SOURCE CHARACTERISTICS AND TYPES

This section contains a discussion of the various sources of sound in the Alaskan coastal environment. Procedures for describing the properties of sound are presented. Representative examples are given which show the characteristics of ambient noise and man-made sound sources.

3.1 Noise Source Descriptors

Noise has been described as unwanted sound. This subjective definition is appropriate since sound that may be disturbing to some listeners may contain useful information for others - a rock music concert being one example. The procedures outlined here for describing sound energy are therefore intended to provide physical measures which can be used to classify sound sources without requiring consideration of their potential effects on listeners. The issues of annoyance and disturbance are addressed separately in Section 5. Two major categories of descriptive parameters are considered - sound level spectra and temporal statistics.

3.1.1 Sound level spectra

The mammalian hearing process is capable of working over a very wide range of sound intensities and frequencies. Studies of the hearing processes of humans and of a limited number of other species, including some marine mammals, have shown that this wide range capability is obtained by having a logarithmic hearing sensitivity characteristic; i.e., the sensation of loudness has been found to increase as the logarithm of the sound pressure. Also, humans and several other species have a proportional bandwidth hearing selectivity; i.e., the selectivity of the hearing process becomes broader in the high frequency portion of the hearing range.

The logarithmic hearing sensitivity characteristic has resulted in the decibel scale of measuring sound intensity with a reference level (for airborne sound) set at the average threshold of (young) human hearing. Since sound intensity is proportional to the sound pressure squared, this results in the following definition of sound pressure level:

$$\text{SPL} = 10\ \text{Log}_{10}(P/P_{ref})^2 \quad \text{dB} \qquad (3)$$

or

$$\text{SPL} = 20\ \text{Log}(P/P_{ref}) \quad \text{dB} \qquad (4)$$

where, for airborne sounds,

$P_{ref} = 20\ \mu\text{Pascal}\ (20\ \mu\text{Newton/meter}^2)$ and

$\text{Log} = \text{Log}_{10}$

For underwater sound 1 μPa is used as the reference pressure to obtain a more convenient physical scale. Underwater sound levels using this reference will be specified using L_r or L_s rather than SPL to avoid confusion.

One of the principal means of distinguishing the sounds of various sources is by their distribution patterns of sound intensity with frequency. When this distribution has its intensity concentrated at discrete frequencies, the sound is tonal in character. When the distribution is spread over a broad frequency range the sound is rough and noisy. Sound spectrum analyzers are used to measure the distribution of sound intensity with frequency and thus classify various sources by their spectra. These analyzers may provide either a constant bandwidth analysis or a constant percentage bandwidth analysis. The constant bandwidth analysis provides sound level data in a sequential series of bands, each of constant bandwidth. The data are usually converted to an equivalent 1-Hz bandwidth to obtain standard comparison spectra. This type of "spectrum level" analysis is generally used for engineering and scientific purposes.

Constant percentage bandwidth analyzers have filter bandwidths which are a given percentage of the band center frequency. The bandwidth is usually specified as a fractional part of an octave. The 1/3 octave analyzer, which has a bandwidth of 23% of the center frequency, is often used in analyzing sounds of concern in human annoyance studies. This bandwidth has been found to approximate the selectivity characteristic of human hearing in the middle of the human hearing frequency range. It also approximates the hearing selectivity of some of the marine mammal species which have been studied. As a result, this type of spectrum characterization is used in this report to describe the various sources of concern.

3.1.2 Temporal features

Most natural and man-made sound sources do not produce sound at a constant output level. The temporal variation in level, and often in frequency spectrum, is an important descriptive parameter for sound from a given source. Output level fluctuations are particularly of concern for this study since the relationship between sound level and exposure duration in producing behavioral effects in non-human species is not well known. Some guidance can be obtained by review of studies of human annoyance reactions to time-varying industrial noise exposure.

To aid this review, relevant procedures and terminology used in the study of human response to fluctuating industrial noise sources are given below:

Exposure period - A reference period of time for calculating a behavioral response measure such as the equivalent sound level - one of the metrics used to predict annoyance (this period is generally considered to be eight hours for human response studies).

Source temporal characteristics -

Steady continuous source - A source with output level varying less than ±2.5 dB during an exposure period.

Fluctuating continuous source - A source with output level varying more than ±2.5 dB but not going below the ambient noise level during an exposure period.

Intermittent source - A source with more than one operating cycle during an exposure period.

Intermittent impulsive source - A source with more than one operating cycle during an exposure period where the output duration is less than 0.1 sec.

Equivalent sound level (L_{eq}) - The level of a continuous source that provides the same acoustic energy as a fluctuating or intermittent source for the same exposure period. The value of L_{eq} may be determined by a continuous integration of the energy output of the time-varying source using the following relationship:

$$L_{eq} = 10 \log \frac{1}{T_p} \int_o^{T_p} \left(\frac{p_r(t)}{P_o}\right)^2 dt \text{ (dB)} \qquad (5)$$

where T_p is the time duration of the exposure period

$p_r(t)$ is the time-varying sound pressure in a specified bandwidth

P_o is a referenced sound pressure (1 µPa).

It is often more convenient to do a statistical analysis using discrete logarithmic step increments instead of a continuous integration of the pressure signal. Steps with 5 dB intervals are recommended in Standard ISO/R 1996-1971 (Assessment of Noise With Respect to Community Response). The procedure is based on the following equation:

$$L_{eq} = 10 \log \left[\frac{1}{100} \sum T_i \; 10^{L_i/10}\right] \text{ (dB)} \qquad (6)$$

where T_i is the time interval (expressed as a percentage of the exposure period) for which the sound level is within the limits of class i (L_i ± 2.5 dB).

L_i is the sound level in a selected band corresponding to the midpoint of the class i.

Time Ratio or Duty-Cycle - The ratio of the total effective operating time in an exposure period to the length of the exposure period for a specific source. If an intermittent source produces identical output sequences during an exposure period, Eq. 6 may be simplified as follows:

$$L_{eq} = L_{eqs} + 10 \text{ Log}(nT_s/T_p) \text{ (dB)} \qquad (7)$$

where L_{eqs} is the equivalent sound level of a single output sequence

n is the number of sequences in an exposure period

T_s is the time duration of a single sequence

T_p is the time duration of the exposure period.

If a time-varying source produces most of its output within 5 dB of the maximum level, even though its output sequences are not identical, Eq. 7 may be simplified to the form:

$$L_{eq} = L_m + 10 \text{ Log } (T_m/T_p) \qquad (8)$$

where L_m is the median level of the highest exposure class

T_m is the total time during which the exposure level was within ±2.5 dB of L_m during the exposure period.

(Note that for this case, the time ratio $\approx T_m/T_p$.)

3.1.3 Source spatial characterization

Man-made noise is often produced by a moving source. A standard procedure has been established to determine the effective source output with respect to receiver locations which may be either fixed or moving. This is done by measuring the source output at a standard reference range. The resulting sound level spectrum is called the source level (L_s) and is usually specified at a range of 1 m. For many sources which are too large to measure accurately at a range of 1 m, the local transmission loss is calibrated so measurements made at greater ranges can be corrected to an effective range of 1 m. For aircraft noise measurements where atmospheric absorption is an important factor in addition to the geometric spreading loss, it is customary to use a flyover altitude of 1000 ft (300 m) as a reference range to avoid large potential errors in estimating atmospheric absorption loss corrections back to a range of 1 m.

From the viewpoint of a stationary listener, a moving source becomes a source with a fluctuating output level even though the actual output of the source may be constant. As a result the procedures developed in this report for application to fluctuating sources will also be relevant for use with moving sources. Source level spectra for sources which are usually moving are based on measurements made at the time of the closest point of approach (CPA) and range corrected using the CPA distance.

3.2 Natural Background Noise

There is a very large volume of literature on the subject of natural background noise (ambient noise) for both deep ocean and shallow water. Studies of ambient noise have ranged from treatments of specific environments (e.g., open ocean, island areas, harbors, near-shore or coastal regions and arctic regions) to concern with understanding specific source characteristics and physical mechanisms. Classical references on the subject are Knudsen et al. (1944), Wenz (1962) and Urick (1983). As one might expect, many causes of ambient noise exist in the ocean, particularly in the shallow waters* of continental shelf areas. Deep open ocean ambient noise levels are quite predictable above 500 Hz based on knowledge of wind and sea state conditions and below 500 Hz based on knowledge or assumptions regarding distant ship traffic conditions. On the other hand, in shallow water along the continental shelf and in near-shore areas, ambient noise is frequently highly variable from site-to-site and generally fluctuates considerably with time. Nevertheless, as presented in the literature (e.g., Wenz, 1962 and Urick, 1983) reasonable trends or estimates of shallow water ambient noise levels can be presented for known important sources of sound, with the associated levels varying as a function of definable parameters. Specific attention is given here to those non-biological sources of noise which are expected to be major contributors to ambient conditions along the Alaskan continental shelf. Emphasis has been placed on the four Department of the Interior (Minerals Management Service) Lease Sale areas of most interest to this study: Shumagin, North Aleutian Basin, Norton Basin and Chukchi Sea.

The major sources of ambient noise that need to be considered in order to understand the underwater acoustic environment of marine mammals inhabiting the Alaskan Continental Shelf regions are:

- wind, rain and sleet
- distant shipping
- surf
- turbulence effects due to tidal or other strong currents
- seismic noise (earthquakes, volcanic activity)
- ice cracking and pressure ridge activity
- glacial activity
- glacial ice effervescence.

Typical average noise spectra due to these sources are presented. Most of these exhibit a continuous but fluctuating time history and some are short term or nearly transient in character. A 1/3-octave band sound pressure level format has been selected for this study since it has been established for several marine mammals (as well as land mammals such as man) that background noise which has a significant effect on detection of a sound signal is the noise occurring within a band roughly 1/3 octave wide, centered at the frequency of the sound signal (see Section 3.1). Similarly, noise signatures

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*In the underwater sound and oceanographic scientific communities, shallow water is commonly defined as ocean depths of less than 100 fathoms (183 meters). The continental shelf break frequently occurs at about that depth, although in Alaska, particularly along the Beaufort Sea coast, the shelf break occurs at depths of about 50 to 70 m (27-38 fm).

of man-associated activities such as vessels and aircraft are presented in Section 3.3 on a 1/3 octave band basis.

3.2.1 Meteorological sources (wind, rain, sleet)

An early major summary of ocean ambient noise, published by Knudsen et al. (1944), has become a common baseline for comparison of ambient noise conditions in both the deep water and shallow water environment. However, the standard "Knudsen curves", which provide a means for estimating background noise levels to be expected for particular wind or sea state conditions, apply most reliably to deep ocean conditions, and then most effectively for frequencies between 500 Hz and 50 kHz. Shallow water ambient noise levels, the focus of this study, tend to agree with the Knudsen curves for frequencies above 1000 Hz but can vary considerably from site-to-site in continental shelf and near-shore areas. Wenz (1962) and Urick (1983) provide useful ambient noise summaries for the shallow water environment (as well as deep water). Figure 3.1 includes average shallow water spectra for typical wind and rain conditions obtained from their summaries.

Wind

On a 1/3-octave basis, wind-related ambient noise in shallow water (Fig. 3.1) tends to peak at about 1 kHz. Levels in 1/3 octave bands generally decrease at a rate of 3-4 dB per octave at progressively higher frequencies and at about 6 dB per octave at progressively lower frequencies. Sound levels increase at a rate of 5-6 dB per doubling of wind speed. Maximum 1/3-octave band levels of about 95 dB referenced to 1 μPa are frequently observed at about 1 kHz for sustained winds of 17-21 m/sec (34-40 knots) and about 82 dB also at 1 kHz when the winds are in the 3.4 - 5.4 m/s or 7-10 knot range. Since ambient noise related to wind is caused primarily by wave action and spray (and possibly to some extent to acoustic and pressure fluctuation coupling effects from air to water), the wind related noise component is strongly dependent on wind duration and fetch as well as water depth, bottom topography and proximity to topographic features such as islands and shore. A sea state scale which is related to sea surface conditions as a function of wind conditions is commonly used in categorizing wind-related ambient noise Table 3.1). The curves for wind-related ambient noise shown in Fig. 3.1 are reasonable averages, although relatively large departures from these curves can be experienced depending on site location and other factors such as bottom topography and proximity to island or land features. Statistical estimates of ambient noise conditions along the coast of the Alaskan Beaufort Sea (Miles et al. 1987) predict that the 95th percentile and 5th percentile levels of ambient noise (due primarily to wind) are 10 to 20 dB above and below the median level respectively. The median levels in the Beaufort Sea, as shown by the * and o symbols in Fig. 3.1 and by Greene (1987), are close to the Sea State 2 curve.

Rain

Water droplets impacting the ocean surface can be a major high frequency source of ambient noise in the ocean, depending on precipitation rate. As described by Wenz (1962) and Urick (1983) and based on their review of

FIG. 3.1 SHALLOW OPEN WATER NATURAL BACKGROUND NOISE SPECTRA
Due to Distant Shipping, Wind and Rain (Wenz 1962, Urick 1983)

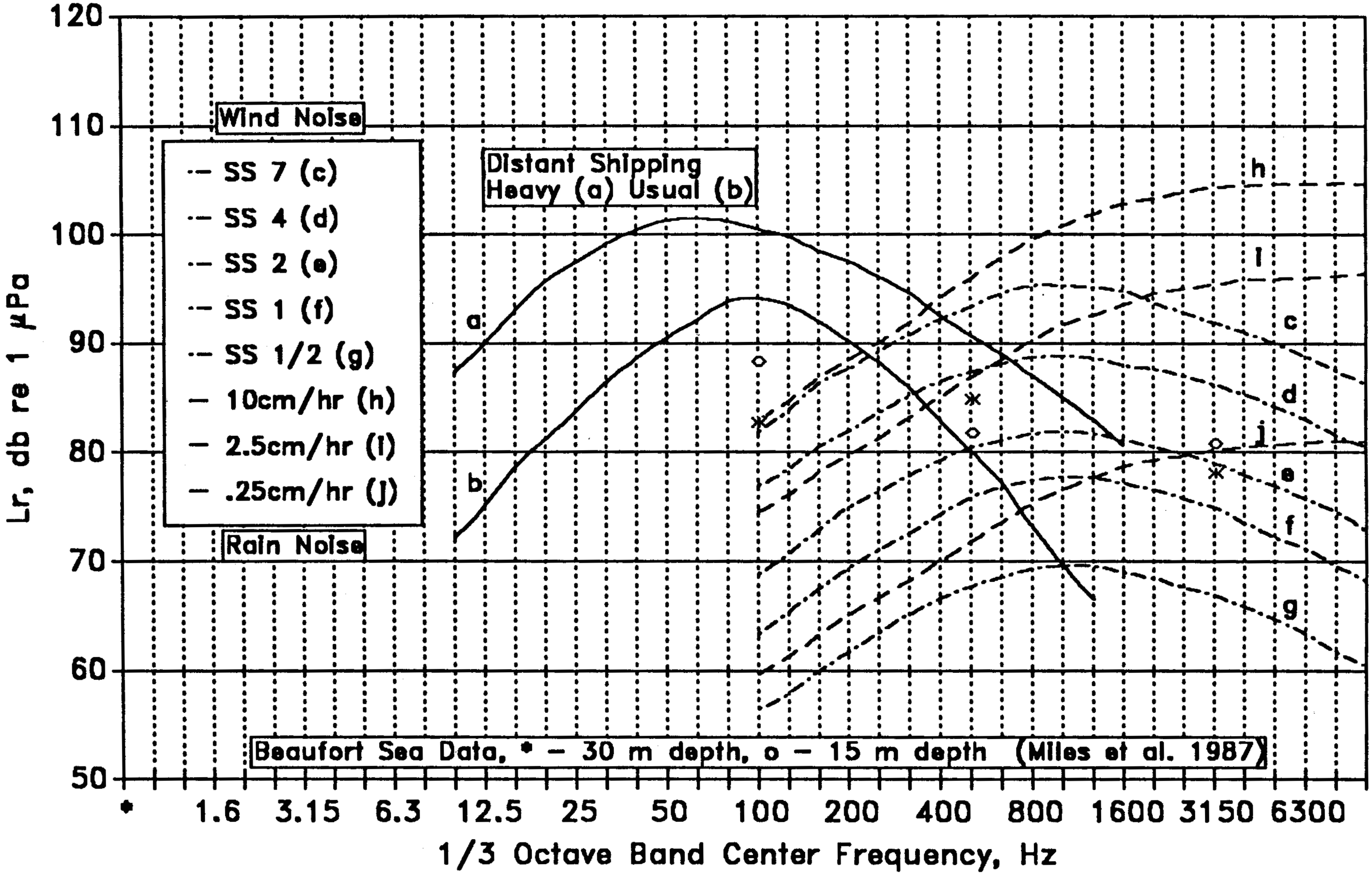


Table 3.1. Sea State Scale.

Sea State	Beaufort Wind Force	Wind Speed, m/sec	Wave Height meters (12-h wind)	Surface Character
0	0	<0.5	-	mirror-like
1/2	1	0.5 - 1.7	-	ripples
1	2	1.8 - 3.3	<0.3	small wavelets
2	3	3.4 - 5.4	0.3 - 0.6	large wavelets, scattered white caps
3	4	5.5 - 8.4	0.6 - 1.5	small waves, frequent white caps
4	5	8.5 - 11.1	1.5 - 2.4	moderate waves, many white caps
5	6	11.2 - 14.1	2.4 - 3.7	large waves, white caps everywhere
6	7	14.2 - 17.2	3.7 - 5.2	heaped-up sea, blown spray, streaks
7	8	17.3 - 20.8	5.2 - 7.3	high long waves, spindrift

theoretical and experimental work by Franz (1959), the underwater noise relates to impact velocity and droplet size. The dashed curves in Fig. 3.1 for rainfall rates of 0.25, 2.5 and 10 cm/hr demonstrate that noise levels from moderate to heavy rain dominate the wind-related ambient noise levels above 1 kHz, even for the most severe wind condition. One-third octave band ambient noise levels approaching 105 dB at 10 kHz can be expected for a rainfall rate of 10 cm/hr. Ambient noise levels due to rain vary as 15 log (rainfall rate). Using this algorithm, a light precipitation rate of 0.25 cm/hr would induce sound levels 24 dB below the 10 cm/hr curve. Even so, these levels would still be higher than the Sea State 2 curve at frequencies above 3 kHz.

Sleet or Hail

The impact of hard precipitation such as sleet or hail on the sea surface should result in ambient noise levels which are about the same as those shown for equivalent rainfall rates (Wenz, 1962).

3.2.2 Distant shipping

The presence of a relatively constant low frequency component in ambient noise within the 10-200 Hz band has been observed for many years and has been related to distant ship traffic as summarized by Wenz and Urick. Low frequency energy radiated primarily by cavitating propellers and by engine excitation of the ship hull is propagated efficiently in the deep ocean to distances of 2000 km or more. Higher frequencies do not propagate well to these distances due to acoustic absorption. Also, high frequency sounds radiated by relatively nearby vessels (e.g., 90 km) will frequently be masked by local wind-related noise. As an example 10 kHz acoustic energy is attenuated by absorption at a rate of 1 dB/km and 1 kHz energy at a rate of 0.1 dB/km. At a distance of 100 km, 10 kHz sounds would be attenuated by 100 dB due to absorption alone. Thus, distant shipping contributes little or no noise at high frequency. Their low frequency energy is a more significant factor, but such noise will be attenuated more rapidly when it propagates across continental shelf regions and into shallow near-shore areas than occurs in the deep ocean. Site location with respect to locations of shipping lanes is an important factor in causing changes in the level of the low frequency distant shipping component of ambient noise.

Figure 3.1 provides two curves which approximate the upper bounds of distant ship traffic noise. The upper curve represents noise at sites exposed to heavily used shipping lanes. The lower curve represents moderate or distant shipping noise as measured in shallow water. As shown, highest observed ambient noise levels for these two categories are 102 dB and 94 dB, respectively, in the 60-100 Hz frequency range. Not shown in this figure, but included in the Wenz paper, is the fact that in shallow water the received noise from distant ship traffic can be as much as 10 dB below the lower curve given in Fig. 3.1, depending on site location on the continental shelf. In fact, some near-shore areas can be effectively masked from this low frequency component of shipping noise due to sound propagation loss effects.

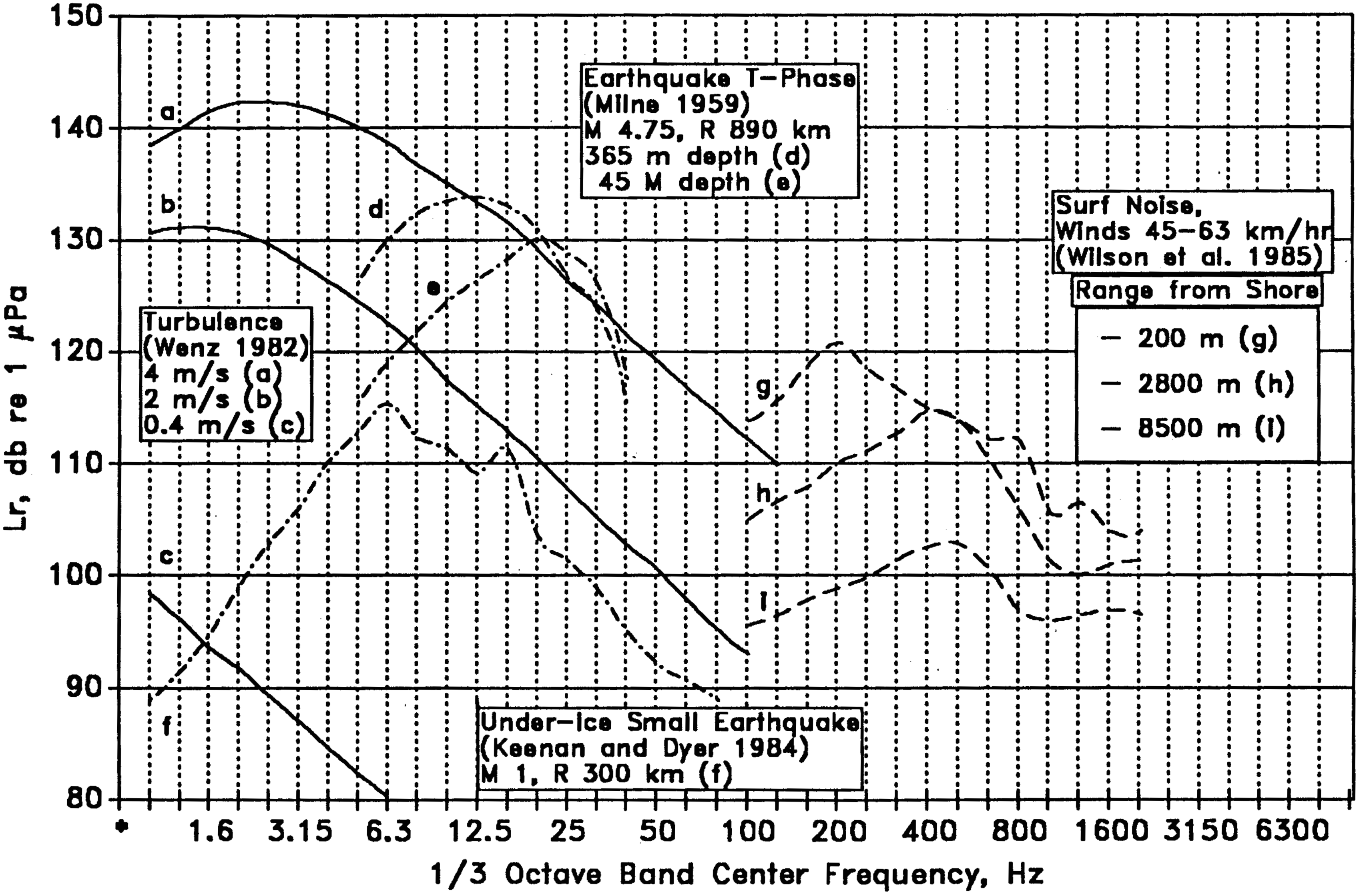
3.2.3 Surf noise

Very few data have been published relating specifically to local noise due to surf in near-shore areas along mainland and island coasts. Wilson et al. (1985) present noise levels for wind-driven surf along the exposed Monterey Bay coast, as measured at a variety of distances from the surf zone. Wind conditions varied from 12.9-18 m/s (25-35 kt). Those data, converted to 1/3 octave band levels, are shown in Fig. 3.2. They vary from 110-120 dB in the 100-1000 Hz band at a distance of 200 meters from the surf zone, down to levels of 96-103 dB in the same band 8500 meters from the surf zone. Assuming that these levels are representative for the Alaskan OCS, surf noise in the 100-500 Hz band will be 15-30 dB above that due to wind-related noise in the open ocean under similar wind speed conditions. Bardyshev et al. (1973) demonstrate that within 600 m of the surf zone, the ambient noise spectrum is skewed toward lower frequencies in the 100-8000 Hz band (they worked along a rocky, pebbly coast). Offshore, to distances of 20 km, the noise spectrum is nearly Gaussian, which is more characteristic of wind-generated ambient noise in the open ocean.

3.2.4 Turbulence noise

Turbulent flow occurs when tidal or oceanic currents interact with the ocean bottom or solid features such as islands and peninsulas, or when current speed is increased by a sudden constriction of the flow channel such as in straits or at a steep shoal. Turbulent flow causes pressure fluctuations in the fluid. This is a low frequency phenomenon which can be sensed by a pressure transducer and interpreted as sound. If a marine mammal is capable

FIG. 3.2 NOISE SPECTRA IN SHALLOW WATER FROM TIDAL TURBULENCE, EARTHQUAKES, AND SURF (Water depth less than 180 m)



of sensing infrasound pressure fluctuations, turbulent flow may contribute to the ambient noise sensed by the mammal. Figure 3.2 provides three curves for turbulence pressure fluctuations due to tidal and oceanic currents ranging from a low of 40 cm/s (0.8 kt) to a high of 400 cm/s (8 kt), based on an analysis presented by Wenz (1962). He shows that turbulence pressure ($\tilde{p}$) varies as:

$$\tilde{p} \approx \rho \tilde{u}^2 \tag{9a}$$

$$\tilde{u} \approx 0.05\ \bar{U} \tag{9b}$$

where ρ is the density of the ocean water and $\tilde{u}$ is the r.m.s. velocity of fluid within a turbulence cell. This turbulence velocity is about equal to 5% of the mean flow velocity (U) of the ocean current. Hence the turbulence pressure levels are proportional to the square of the turbulence velocity. The frequency of the pressure fluctuations is directly proportional to the mean flow velocity.

Tidal currents along the Alaskan coast can be extreme at narrow entrances to tidal bays. For instance, at Inian Pass at the entrance to Icy Strait in Southeast Alaska, and in Glacier Bay at Sitakaday Narrows, 7 knot (360 cm/s) tidal currents are common. The U.S. Department of Commerce Nautical Chart No. 17300 states that currents in Inian Pass may reach 8-10 knots (400-500 cm/s). Reed and Schumacher (1986) show that ocean currents driven by long term prevailing winds and geostrophic flow in the Alaska Coastal Current have prevailing rates during most of the year of 40-50 cm/s particularly along the Alaska Peninsula and in the Shumagin Island area. In the fall, the Alaska Coastal Current causes currents of greater than 100 cm/s in several areas of the Aleutian Islands. Pearson et al. (1981) report prevailing surface currents of 40-60 cm/s in the North Aleutian Basin and Norton Basin areas. Tidal currents in constricted areas of these regions can also reach the high rates seen in Southeast Alaska.

Thus, the three turbulence curves related to oceanic and tidal currents (Fig. 3.2) provide an indication of the very low frequency envelope or range of "sound" pressure levels which can be experienced along some parts of the Alaskan coastline.

3.2.5 Seismic noise (earthquakes and volcanic activity)

Since the southern coastal and continental shelf regions of Alaska represent one of the most seismically-active regions on earth, particularly from the Cook Inlet area west along the Alaska Peninsula and Aleutian Island chain, it is important here to consider underwater sound signals due to earthquakes as well as the seismicity of Alaska. The MMS lease sale areas which have the most potential of experiencing earthquakes and short-term underwater sounds due to them are those located in the Gulf of Alaska and Bering Sea regions.

Figure 3.2 provides representative underwater sound spectra associated with two earthquakes: a Magnitude 4.75 earthquake occurring at Cape Mendocino, California--890 km from the measurement system (Milne, 1959); and a small Magnitude 1.0 (or less) event in the Arctic that was measured under the ice at a distance of 300 km (Keenan and Dyer, 1984). These spectra are the only calibrated data (i.e., absolute levels) which could be located in this brief study. However, as will be seen, the sound pressure levels shown can be considered to be representative. Insofar as we know, all other published underwater sound data related to earthquakes and volcanic activity were uncalibrated and therefore could not be included in this comparison of sound levels due to natural causes. Spectrum shape and bandwidth shown here are consistent with those for the uncalibrated spectra, however.

The Milne curves for a T-Phase arrival lasting about 30 sec were obtained simultaneously on two hydrophones, one located in the deep sound channel at 365 m depth and one at 45 m. One-third octave band sound levels of 134 dB and 130 dB re 1 μPa, respectively, were reported. An earthquake T-phase (tertiary wave) is compressional wave energy which can propagate many thousands of kilometers in the deep sound channel and usually originates at the continental slope or mid-ocean ridge nearest an earthquake. The signature recorded at 45m by Milne was, in comparison to the 365 m signature, lower in level and peaked at a higher frequency (20 Hz vs. 10 Hz) since it represented acoustic energy that had "leaked" out of the deep sound channel.

The under-ice event (also T-phase) was one of a series of small earthquakes located by Keenan and Dyer through triangulation and correlation analysis to have occurred along the mid-Arctic ridge. This event was measured 300 km west of the ridge and about 320 km north of Greenland with an under-ice hydrophone array. The duration of the Arctic event was about 1-minute and it generated 1/3 octave band levels of 112-115 dB at about 10 Hz. These curves demonstrate that earthquakes can cause high levels of low frequency sound in the ocean.

The following discussion provides information on the seismicity, earthquake magnitudes, estimates of frequency of occurrence and estimates of overall sound pressure level which can be expected for typical earthquakes in the Gulf of Alaska and Bering Sea regions.

3.2.5.1 Seismicity

Earthquake and Volcanic Activity

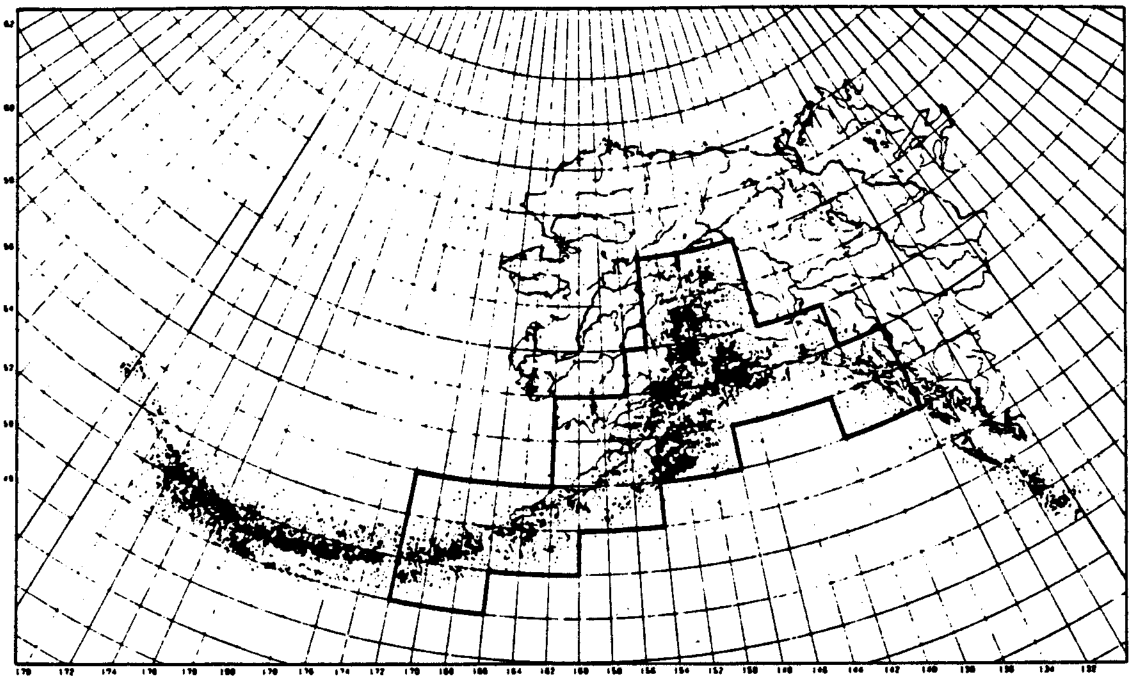
The seismicity of Alaska has been reported in detail by many authors, notably Meyers (1976), Meyers et al. (1976), Biswas et al. (1986), Jacob (1986), Sykes (1971), Davies et al. (1981), and Taber and Beavan (1986). In a concise treatment of seismicity, tectonics and geohazards of the Gulf of Alaska region, Jacob (1986) states that the Pacific Plate moves against and under the North American Plate in a north-northwest direction at a rate of about 5 cm/yr. In Alaska, the plate moves under the Chugach-St. Elias mountains, Prince-William Sound, Cook Inlet and the Alaska Peninsula generating subduction forces and heat which result in plate fracturing and volcanic activity. A high rate of occurrence of earthquakes results along the subduction zone at the rim of the Gulf of Alaska and out along the Aleutians as well as in some inland areas and in the Bering Sea coastal regions. Major fault zones have been generated: the Aleutian Trough, Chugach-St. Elias and

Fairweather faults, Lake Clark Fault (passing through Anchorage) and the Denali Fault which is further to the north and trending westerly to the Bering Sea. Figures 3.3 and 3.4, taken from Meyers et al. (1976) and Jacob (1986) respectively, provide an indication of earthquake epicenter and important volcano locations in Alaska. Earthquakes of Magnitudes 4-8.9 occurring between 1899 to 1974 have been plotted, where each earthquake is represented by a dot. The events are so numerous that the epicentral locations overlap on the scale map. Biswas et al. (1986) performed a seismicity study of Western Alaska concentrating on the Northern Bering Sea and Chukchi Sea areas (Norton Sound, Seward Peninsula and Kotzebue Sound); they demonstrated that many $M > 4$ events occur in that region as well. Twelve $M = 5.6$-7.3 earthquakes have occurred there between 1928 and 1965.

Most of the Alaskan volcanoes or volcanic areas are shown in Fig. 3.4. Many of these are or have been active in recent time. Coats (1950) stated that at least 76 major volcanoes had been identified in the Aleutian Arc by the time of his paper. Thirty-six of those had been active since 1760. There appears to be about a 20-yr periodicity of volcanic activity in the Aleutians. Eruptions are frequently explosive in nature. One of the most recent major events involved the St. Augustine volcano in Cook Inlet, which had a vent-clearing explosive phase in March 1986. That volcano erupted previously in 1976. Pavlov Volcano near the Shumagin Islands has a past history of activity, sometimes explosive, about every 10-15 years (Coats, 1950). In 1912, Novarupta on the Alaska Peninsula near Kodiak Island had the largest volcanic eruption ever witnessed in the Gulf of Alaska region. As noted by Jacob (1986), it was the world's largest eruption in this century and included frequent explosive activity. In terms of volume of ejecta, the Mt. St. Helens explosion in 1980 was ten times smaller than Novarupta. Seismic noise and, in the case of coastal events, underwater sound, results from volcanic eruptions, particularly those which are explosive. However, even without explosions, broadband high level underwater sound results when lava flows are emitted from the ocean floor or when they reach the ocean from land events are emitted from the ocean floor or when they reach the ocean from land vents. Snodgrass and Richards (1956) monitored sounds near a volcano in Mexico, where a lava flow entered the ocean from the coast. About 600 m from this lava flow, high level hissing and rumbling sounds dominated all other natural background, including high surf noise, with most energy in the 100 to 700 Hz band. For comparison, see Fig. 3.2 for typical surf noise sound level data.

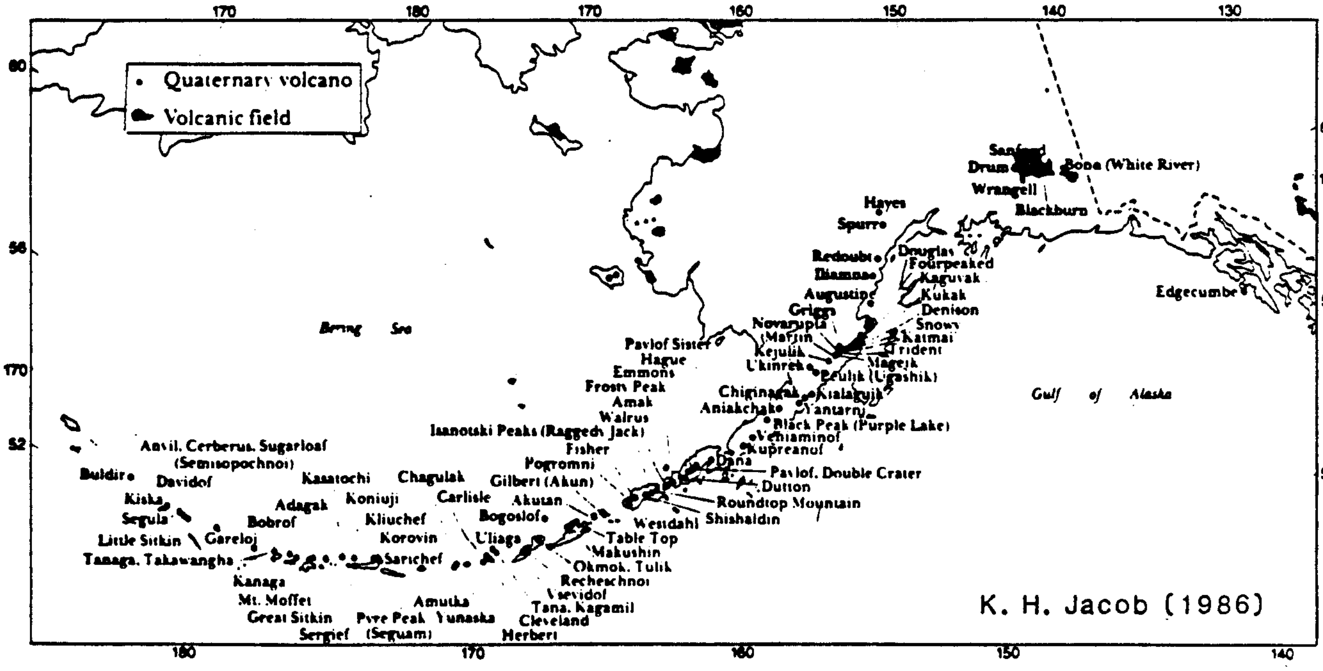
3.2.5.2 Earthquake Magnitude and Ground Motion

Meyers et al. (1976) performed a detailed historical analysis of earthquake activity in Alaska and concentrated on the boxed region shown in Fig. 3.3. They tabulated earthquakes as a function of magnitude and epicentral location and noted frequency of occurrence of events within a 75-km radius of 1-degree latitude/longitude intersection intervals throughout the boxed area and then plotted data to demonstrate trends. Figure 3.5 (from their Figs. 12 and 13) shows cumulative magnitude-frequency curves for the Shumagin and North Aleutian Basin areas. These data cover events in the Magnitude (M) = 4 to 6.8 range with a regression fit curve allowing for



H. Meyers et al. (1976)

Figure 3.3. Alaskan Earthquake Epicenters 1786-1974 (Approximately 10,000 Events).



K. H. Jacob (1986)

Figure 3.4. Major Volcanoes and Volcanic Centers in Alaska.

approximate extrapolation to lower magnitude events. Based on these curves, M = 6.8 or greater events can be expected to occur in either Shumagin or North Aleutian Basin once every 50 years (0.02 earthquakes per year). The curves predict one to two M = 4 or greater events per year and about ten M = 3 or greater events per year.

In studying data from many events in California, Alaska and Japan, Jacob (1986) demonstrated that the subduction zone thrust events in Alaska and Japan tend to cause higher acceleration ground motion than similar magnitude events in California which occur in a strike-slip zone. The trend curves in Fig. 3.6 (adapted from Fig. 6-30 in Jacobs, 1986), which have been added to this figure, do not represent a regression fit. They have been included to summarize Jacob's observations and for use in estimating underwater sound levels which could result from such events. Those estimates are provided below.

3.2.5.3 Seismic Exposure

Woodward-Clyde Consultants (1982) published a two volume report for the National Oceanic and Atmospheric Administration in which they developed a model for predicting ground motion due to earthquakes along the Gulf of Alaska coast. They developed a seismic exposure software package incorporating three other programs relating to (1) seismicity of the region, (2) ground motion levels for probability of exceedance, and (3) a contour plotting routine. The results of such an analysis are shown as a contour map of peak acceleration of ground motion in a selected region which can be expected from seismic events. Jacob (1986) used their method to compute a seismic-exposure map of the Shumagin Island region. Figure 3.7, taken from Jacob's report (his Fig. 6-32), shows peak acceleration ground motion contours having a 67% probability of non-exceedance within the 40 year period of 1982-2022. That figure represents a modification to the original Woodward-Clyde model, allowing for an update of the seismic attenuation law used for subduction zone sources.

3.2.5.4 Estimates of Underwater Sound Due to Earthquakes

Since the only absolute sound pressure level data due to earthquakes known by the authors are those shown in Fig. 3.2, it is worthwhile to estimate sound pressure levels based on given ground motion data and a series of assumptions. Figures 3.6 and 3.7 provide an indication of typical peak acceleration ground motion which can be expected for M = 6 to 6.8 earthquakes in the Alaskan subduction zone. Urick (1983) makes a calculation of sound pressure level in the ocean due to seismic noise vibrating the ocean bottom using the algorithm:

$$p = 2\pi f \rho c a \, , \tag{10}$$

where p is pressure (dynes/cm^2), f = frequency (Hz), ρ = density of sea water (g/cm^3) and a = ocean bottom displacement amplitude (cm/sec). He demonstrates that using this method, typical seismic background noise or microseismic r.m.s. displacement amplitudes of the ocean bottom can cause sound pressure levels consistent with those that are observed frequently at frequencies below 1 Hz (microseismic noise peaks at about 1/7 Hz). He assumes that 100% of the seismic energy is transferred into sound. Figure 3.8 provides overall r.m.s.

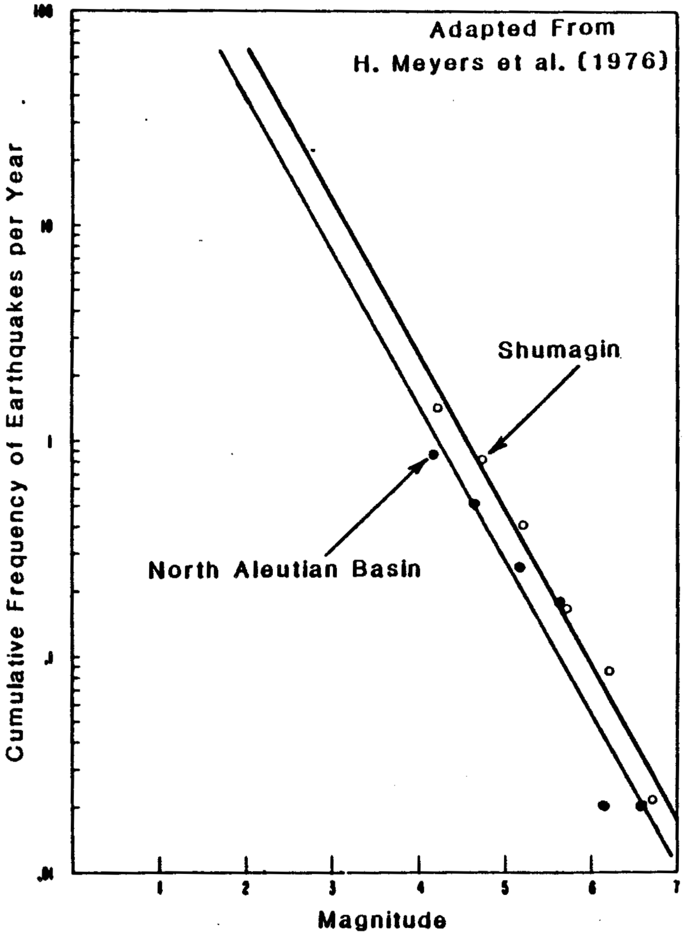


Figure 3.5. Cumulative Magnitude Frequency Relationships for the Shumagin and No. Aleutian Basin Regions.

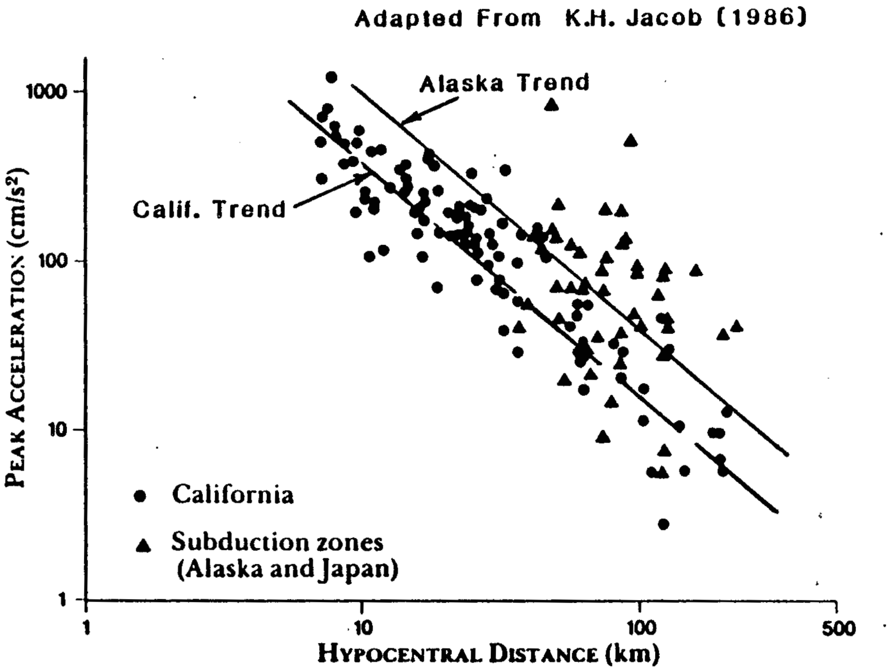
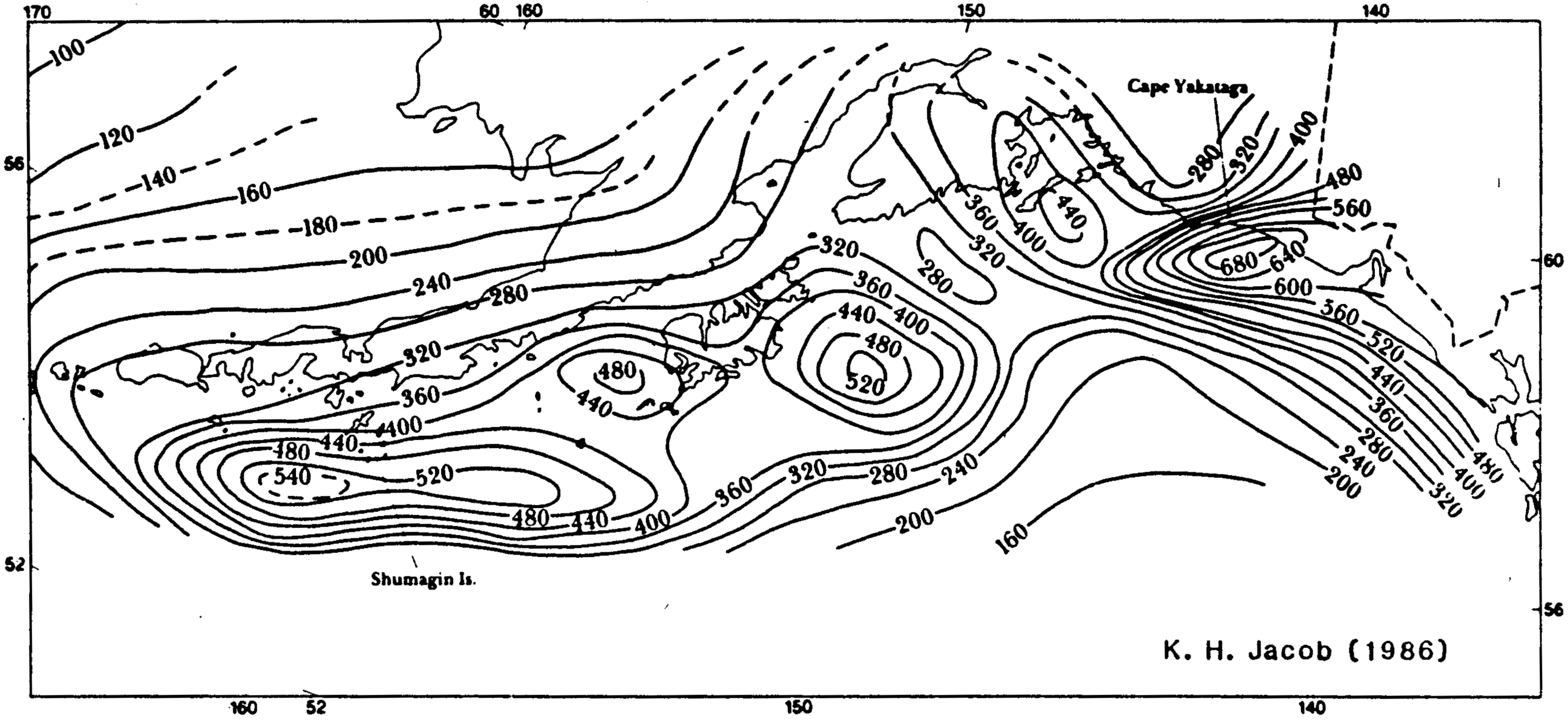


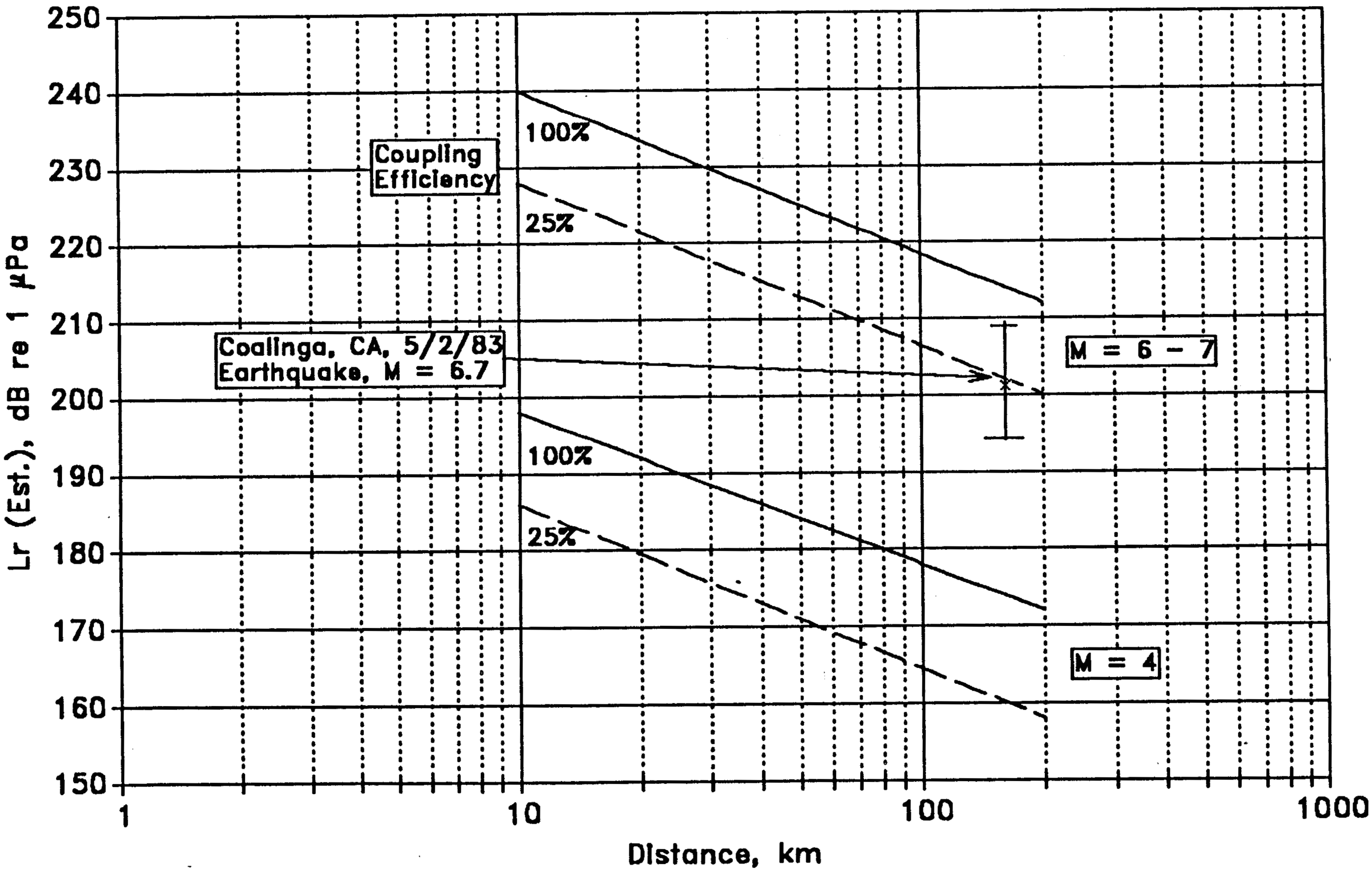
Figure 3.6. Comparison of Peak Ground Motion Acceleration Due to M = 6-7. Earthquakes in Alaska and California.



K. H. Jacob (1986)

Figure 3.7. Contour Map for Peak Ground Motion Acceleration (cm/sec^2) in the Southern Alaska and Gulf of Alaska Regions. (Values shown have a 67% probability of not being exeeeded within a 40-yr period from 1981-2021).

FIG. 3.8 ESTIMATED OVERALL SOUND LEVEL FOR SHORT TERM EARTHQUAKE EVENTS ALONG THE ALASKA PENINSULA



sound pressure level estimates for local earthquake events in the M = 6-7 magnitude range using that equation for a frequency of 10 Hz and the "trend" curve for ground motion in Alaska given in Fig. 3.6. The top curve in Fig. 3.8 assumes 100% coupling of seismic energy into water and the lower curve of the M = 6-7 envelope assumes 25% coupling. For 100% coupling, M = 6-7 earthquakes in the Alaska subduction zone should generate r.m.s. overall sound pressure levels from 240 dB down to 218 dB as distance from the event varies from 10 to 100 km. For 25% coupling efficiency, the sound levels will be about 12 dB lower. The data points for the M = 6.7 Coalinga, California earthquake were computed using the California ground motion trend curve in Fig. 3.6. In the context of the seismic exposure contours shown in Fig. 3.7, 500 cm/sec^2 peak acceleration at 10 Hz yields an r.m.s. sound pressure level of about 239 dB for 100% coupling of ocean bottom acceleration to ocean acoustic energy and 250 cm/sec^2 would generate about 233 dB.

Sound pressure levels for lower magnitude events (e.g., M = 4) have been estimated using an equation of Gutenberg's and reported by Richter (1958) for equating seismic energy (E) of body waves to local earthquake magnitude (M_L):

$$\log E = 9.9 + 1.9\, M_L - 0.024\, M_L^2 \qquad (11)$$

"Local" earthquakes are those detected less than 9 degrees away, or less than about 1000 km from the earthquake epicenter. The M = 6-7 event curves have been scaled as 10 log of the ratio of the energy for M = 6.5 and M = 4 events. Assuming that the Gutenberg scaling is valid for lower magnitudes, sound pressure level for M = 2 events would be 35 dB below the M = 4 curves. For M = 4 events, the overall r.m.s. sound pressure level should be about 199 dB at 10 km from the source and about 177 dB at a distance of 100 km.

Based on the curves in Fig. 3.8 (and accepting the assumptions used in deriving them) it is clear that local earthquake events occurring in Alaskan coastal regions have the potential to cause very high level sounds at low frequencies (e.g., 10 to 50 Hz). These sound levels would exceed those shown for earthquakes in Fig. 3.2 (e.g., 40 dB or more higher when a M = 4 event is about 50 km away from the receiver; compare the Milne 45-m curve in Fig. 3.2 with the Fig. 3.8 estimates. Recall, though, that these are short term events (~30 seconds) which are relatively infrequent except during the few days following a large earthquake when aftershocks can be expected.

3.2.5.5 Possible Gray Whale Response to Earthquake Noise

While the following account is anecdotal, it is included here as a limited observation of implied cetacean behavior during earthquake events.

During the latter part of April and early-May 1983, BBN was performing a field study regarding potential behavioral response of migrating gray whales (the mother/calf pair phase of migration) to controlled playback of underwater sound near Monterey, California. Details of that study were reported by Malme et al. (1983). Shore-based observation of gray whale mother/calf pairs migrating northward near and in the surf zone commenced on 16 April and continued for 20 days until 5 May. The experiments were performed near the beginning of the migration pulse and through the period of maximum passage of whales, which occurred in the 24-29 April time period. On 1 May the visual count was 20 whales during a 7 hour period. The count during the time of maximum passage had averaged 43 animals per day over a 3-day period. Some fluctuations in count were clearly due to poor visual conditions (fog, wind, rain), but these numbers indicate the trend in the whale count. On 2 May at 164300 toward the end of the observation period, seismic energy arrived from a $M = 6.7$ earthquake in Coalinga, California--144 km away. During the following 24 hours a series of 15 aftershocks in the $M = 3.5 - 5.1$ range were reported by seismic stations, on 4 May six shocks of $M \geq 3.4$ were reported, with nine events of $M \geq 3.4$ reported for the 5th of May. On 3 May only a single mother/calf pair was seen from the shore observation site (late in the afternoon), and three pairs each day were seen on 5/4 and 5/5. Observation conditions were good to fair on 5/2, excellent 5/3-5/4 and good to very good on 5/5 when the observation work was terminated.

The sound measurement system used by BBN was overloaded by the main shock on 5/2 and was not operating at the time of calculated aftershock arrival, hence we do not have sound pressure level data available for comparison with spectra in Fig. 3.2 or with predictions given in Fig. 3.8. Based on the known overload limit of the hydrophone preamplifier, a received sound pressure level of 176 dB will cause signal distortion; saturation should occur at a higher level of about 186 dB. The overall received sound pressure level from the main shock was expected to be about 195 - 206 dB (Fig. 3.8).

Obviously, we do not know whether the underwater sound (fluctuating compressional wave energy) from the main shock and from subsequent aftershocks caused the gray whales to move further from shore (beyond visual observation capability). Even though it is tempting to draw that conclusion, we may have been observing a natural rapid cessation of the migration pulse. Nevertheless, it is conceivable that marine mammals will change behavior temporarily during the onset of earthquake short term events. There have been many anecdotal observations of animal behavioral anomalies before and during seismic disturbances (see, for instance Lee et al., 1976 and Stierman, 1980).

3.2.6 Ice noise

There are several dynamic processes associated with ice in arctic and near-arctic regions which can contribute in a significant way to the natural underwater background noise. Under-ice noise studies, notably by Milne (1960), Milne and Ganton (1964), Greene and Buck (1964), and Buck and Wilson (1986), and summaries (e.g., Urick, 1983) have demonstrated the high variability of ambient noise levels in relation to such parameters as wind speed and changes in temperature and pressure ridge activity. During calm wind conditions and stable temperature, sound levels under a continuous ice sheet are frequently below those measured in the open ocean under sea state=0 conditions. Environmental changes such as a decrease in temperature (causing ice cracking) or an increase in wind speed can result in an increase in the background noise by as much as 40 dB. Rising temperatures tend to stabilize the ice and background noise levels drop. Wind-related effects have relatively little influence on under-ice noise when there is solid ice cover, but they become quite important when there are fractures in the ice with leads and floes and sharp ice/water discontinuities at the edge of the ice pack or ice floes. Greene and Buck (1964) demonstrated 10-15 dB fluctuations in under-ice 50 Hz noise levels; these were well correlated with changes in wind speed over the 2-28 knot range. As pointed out by Urick (1983), for a given wind condition, ambient noise levels are 12 dB or more higher near a sharp ice edge than in open water, and 20 dB higher than the levels measured under the ice sheet well away from the ice edge. In areas where tidal glaciers exist, icebergs and bergy bits generate very high levels of broadband noise due to an effervescence effect and glacial movement on bedrock causes high level seismic impulsive noise. The following brief summary discusses five of the more important sources of ice-related noise.

3.2.6.1 Pressure Ridge Noise and Ice Cracking

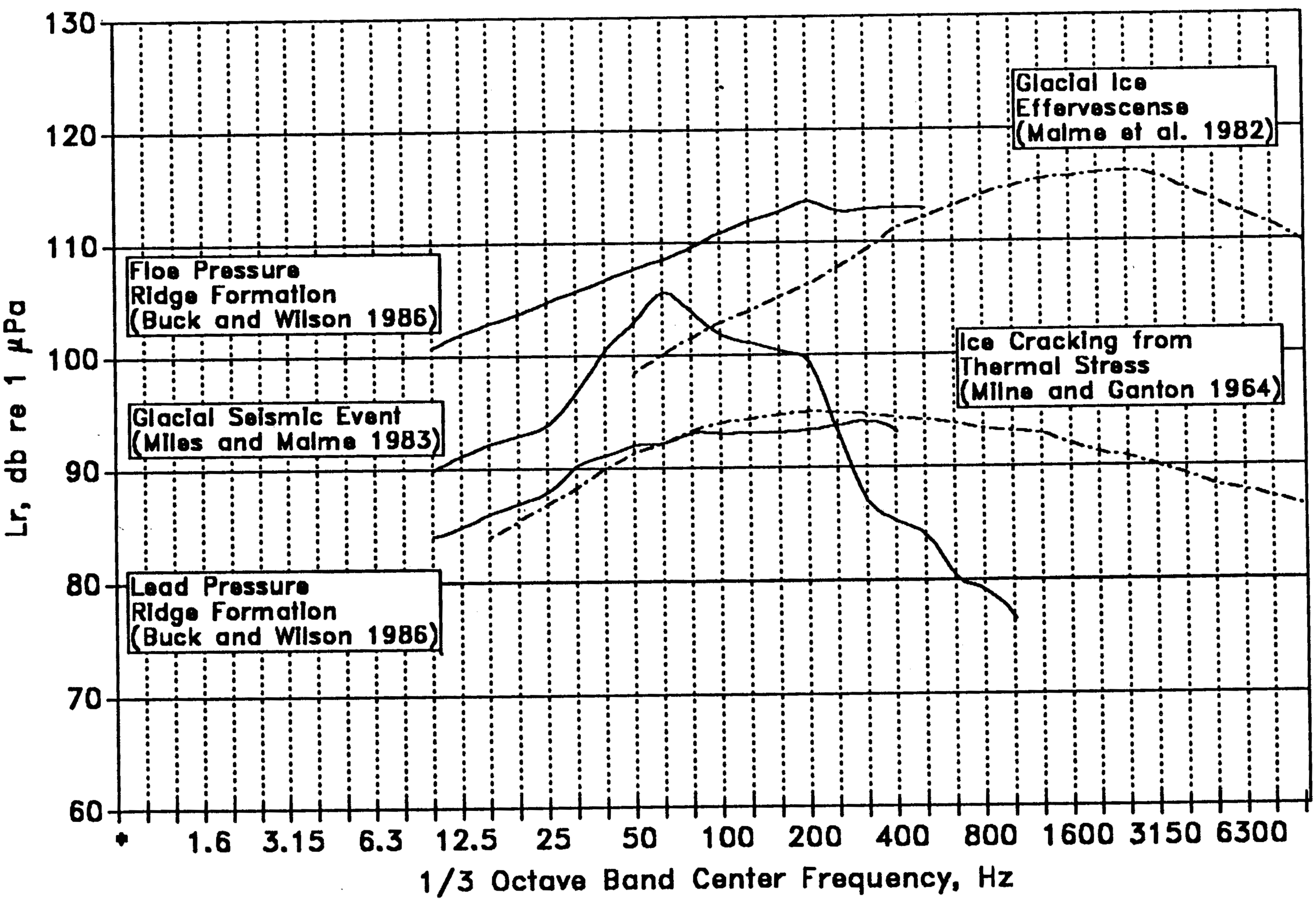
Buck and Wilson (1986) have reported data which they acquired in the Eurasian Basin of the Arctic Ocean during ice breakup and pressure ridge formation. They were able to deploy two hydrophones approximately 100 m from the ridge zone and at a depth of 30 m separated by 61 m to provide a two element array. A "lead pressure ridge" was formed when 1-m thick re-frozen lead ice fractured and started to build up due to horizontal forces. A "floe pressure ridge" was formed after the lead ice was forced onto the 4-m thick floe ice (where the camp was located) causing a build-up of ice load and fracturing of the floe ice. A pressure ridge and fractured keel were formed at the impact zone. Noise spectra acquired during the two stages of the pressure ridge formation are given in Fig. 3.9. Early in the pressure ridge formation (lead pressure ridge), 1/3 octave band sound pressure levels in the 100-400 Hz range were 93-94 dB. During the more forceful portion of the ridge formation (floe pressure ridge) the sound levels increased by about 19 dB to 111-113 dB.

Falling temperature causes ice fracturing which results in an increase in underice noise levels. Milne and Ganton (1964) provided data obtained while temperature dropped from -12°F to -38°F in February 1963 during underice experiments in the Canadian Archipelago. Their data converted to 1/3 octave band levels are shown in Fig. 3.9. Probably by coincidence, the low frequency portion of their ice-cracking data coincide very closely with the Buck and Wilson lead pressure ridge formation curve, with peak levels of about 95 dB occurring at 200-300 Hz.

3.2.6.2 Glacial Ice and Glacial Activity Noise

During BBN's field study in Glacier Bay National Park in 1981 (Malme et al. 1982), it was necessary to derive a quantitative description of the acoustic environment at various locations within the park, including sites near tidewater glaciers where a large quantity of broken glacier ice covered the water surface. Ambient noise levels in the vicinity of the glacial ice averaged 50 dB higher than ambients recorded in other areas of the region where no glacial ice was present. The sound spectrum shown in Fig. 3.9 is broadband in nature and is capable of totally dominating other sources of noise. Close inspection of ice specimens reveals myriads of bubbles frozen into the ice which have been compressed to an elliptical or flattened cross-section through increasing pressure during glacier formation. Ablation of the ice causes the compressed gas in the bubbles to vent when at the ice surface

FIG. 3.9 UNDERWATER NOISE SPECTRA FROM ICE-RELATED SOURCES



causing the broad effervescence sound spectrum. Urick (1971) also discusses this phenomenon in the context of Greenland icebergs. The other curve regarding glacier noise shown in Fig. 3.9 is the spectrum of a glacial seismic event, also recorded in Glacier Bay. Miles and Malme (1983) reported the results of an experiment in which a two element hydrophone array was used to obtain direction of arrival of a series of these events. That information, coupled with estimates of seismic path and water path travel times, showed that the source of these events was the upper portion of Reid Glacier (rather than the lower area where calving occurs). It has been hypothesized that the cause is stick-slip action at the ice/rock interface, generating enough energy in the rock to be equivalent to a M = 1-2 earthquake. Others (Weaver and Malone, 1979 and Van Wormer and Berg, 1973) have reported similar seismic events associated with Mt. Rainier and Mt. St. Helen's glaciers.

3.2.7 Summary of ambient noise components

Figures 3.1, 3.2, and 3.9 provide typical underwater and under-ice background noise spectra associated with a variety of sources likely to be encountered in the Alaskan outer continental shelf and near-shore regions. Any attempt to list them in order of importance would be misleading since the associated sound levels vary considerably with frequency as well as with such environmental conditions as wind, tide, ice cover, rainfall rate and proximity to glaciers. Sound sources considered in this study are:

- Wind and sea state conditions
- Rain and sleet
- Distant shipping
- Surf
- Turbulence due to tidal or other strong currents
- Seismic noise
- Ice cracking and pressure ridging
- Glacial activity
- Glacial ice effervescence.

Generally, if we accept that all of these sources can occur in or affect coastal areas, the dominant sources for various frequency ranges can be identified. In the very low frequency range of 1-10 Hz, tidal current turbulence effects and natural seismic events (which tend to be tens of seconds in duration) would dominate, frequently causing 1/3 octave band sound levels of 140 dB. In the 10-100 Hz band, the dominant sources of noise are earthquakes and other seismic events (135 dB or more depending on distance) and distant shipping (102 dB). From 100-1000 Hz, surf noise with peak levels of about 120 dB (depending on distance), ice pressure ridge noise (116 dB), glacial ice effervescence (115 dB), distant shipping (100 dB) and heavy wind and rain (90-100 dB) are important. Wind, rain and solid precipitation will dominate background noise at frequencies above 1000 Hz, with levels of 95-105 dB to be expected for heavy wind and precipitation conditions.

3.2.8 Airborne ambient noise

In a coastal area near the shoreline, surf noise is the dominant contributor to the airborne ambient. The overall airborne noise level and spectrum shape are related not only to the local wind speed but also to the height of the swell which may be influenced by distant storms at sea. Beyond 100 to 200 m offshore the airborne noise level is influenced primarily by local breaking wave crests and may become quite low during calm sea conditions. Some surf noise data reported for moderate wind speed conditions (about 10 kts) are shown in Fig. 3.10. The surf noise spectra reported for two different areas can be seen to be similar except at 50 Hz where the BBN data show a considerably higher level. This may be the result of higher swell conditions (swell height was not reported). The spectrum labeled "offshore" was measured for the same sea conditions as the surf noise spectrum but at a point about 200 m from the beach. The sea state was given as "choppy with some breaking crests". The band levels shown for the offshore spectrum correspond to those measured on land in rural areas and thus represent relatively quiet airborne noise conditions.

3.3 Man-Made Noise

This section contains a summary of the characteristics of man-made noise sources which are active in the Alaskan marine environment. The sources are organized into three general categories: industrial, transportation, and cultural. The information is presented in the form of tables of principal parameters and graphs showing selected source level spectra. The data base 1/3 octave spectra for all of the examples shown in this section is included in Appendix A.

The significant parameters selected for comparison in the tables are:

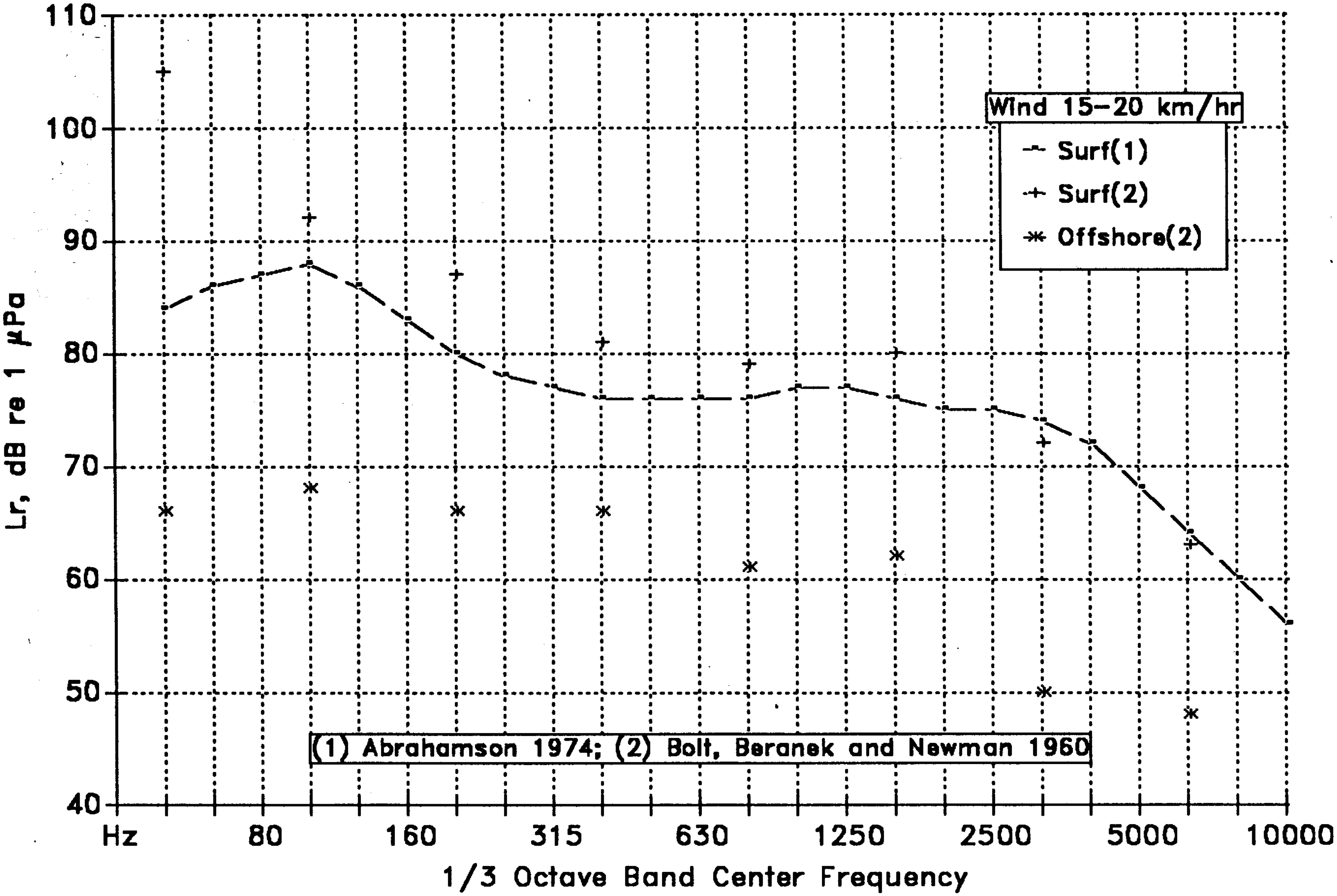
Type - Fixed, Local, or Moving. A "fixed" source remains stationary at one location, a "local" source is not fixed but moves at a slow rate of less than 0.3 km/hr, and a "moving" source travels at a higher rate of speed.

Dominant Bandwidth - The frequency band including the 1/3 octave band with the highest sound level and bounded by the 1/3 octave bands with levels within 10 dB of the maximum. The reported data spectra were sometimes truncated within the dominant bandwidth as defined here. This is noted by the statement "Bandwidth limited by available data".

Maximum 1/3 Octave Band - The band with the highest sound level.

Temporal Pattern - Continuous, Fluctuating, Intermittent, or Impulsive (see definitions in Sec. 3.1.2).

FIG. 3.10 AIRBORNE AMBIENT NOISE SPECTRA IN COASTAL AREA
(From Malme and Smith 1988)



(1) Abrahamson 1974; (2) Bolt, Beranek and Newman 1960

Time Ratio - The fraction of time that a source is within 5 dB of its maximum output level (see definitions in Sec. 3.1.2).

Measured/Estimated - "Measured" if the original reference included either source level data or transmission loss information to derive it, "Estimated" if the original reference included only received level and range information.

Reference - See the Sources Cited Section for the complete reference listing.

3.3.1 Industrial noise sources

This section includes representative source information from the petroleum industry and other types of Alaskan coastal industries as shown in Table 3.2. The table is arranged in decreasing order of source level in the dominant bandwidth. Information on the temporal characteristics of the sources is also included but this column is primarily based on estimates. Unfortunately many data references do not include information on the time pattern of sources.

The loudest industrial sources can be seen to be the seismic survey airgun array and the vibroseis system used for on-ice seismic exploration. The levels reported are peak 1/3 octave levels for the airgun array and average 1/3 octave, as converted from narrow-band data, for the vibroseis. The vibroseis data were measured by a hydrophone in water under the ice at a position to the side of the array (Cummings et al. 1981). Both sources deliver short bursts of energy. The loudest of the sources that produce much longer high level sound sequences is the icebreaker which is used in both petroleum and transportation industries. The high level sound from icebreaker operation is produced by propeller cavitation as the vessel pushes against the ice with very little forward motion. The underwater sound of breaking ice is not a significant factor in the sound output of the icebreaker.

The source level data shown in Table 3.2 for the icebreaker was obtained for operation of the Canadian icebreaking supply vessel ROBERT LEMEUR at the Corona drill site in the Alaskan Beaufort Sea. This vessel has a shaft horsepower rating of 9,600 BHP. The U.S. Polar Class icebreakers, which have a rated maximum horsepower of 60,000 BHP, and many of the other Canadian icebreakers are larger and are expected to have higher radiated noise levels. While no data were found for the Polar Class icebreakers operating in heavy ice, their predicted source levels are about 8 dB higher than that of the LEMEUR, on a horsepower scaling basis. A detailed analysis of icebreaker noise is given in Appendix B as an example of statistical procedures used for describing a time-varying source level spectrum.

Industrial source temporal characteristics

Figure 3.11 shows some of the results of a probability density analysis by Greeneridge Sciences of a continuous series of 1/3 octave pressure level spectra. This series was obtained from a 14 min. segment of radiated noise from the ROBERT LEMEUR operating in heavy ice at the Corona Site in the

TABLE 3.2 INDUSTRIAL NOISE SOURCES

Key: P - Petroleum Industry, O - Other Industries

Key	Source	Type	Dominant BW, Hz			Max 1/3 Oct,Hz		Temporal	Time		Source Level Data	
			fmin	fmax	Ls1,dB	freq.	Ls2,dB	Pattern	Ratio	TL	Meas/Est.	Reference
P	WESTERN POLARIS (Airgun Array)	moving	20	160	216	50	210	Impuls.	0.005		M	Miles et al. (1987)
P	Vibroseis (Vibration Pulse)	local	b 25	315	212	125	205	Inter.	e 0.01		E	Cummings et al. (1981)
P/O	ROBERT LEMEUR (Icebreaker)	local	40	6300	192	100	183	Inter.	0.8		M	Miles et al. (1987)
P/O	AQUARIUS (Transfer Dredge)	fixed	50	630	185	200	178	Contin.	1		E	Greene (1987)
P	KULLUK (Drilling Barge)	fixed	40	1250	185	400	177	Contin.	1		E	Greene (1987)
P	EXPLORER II ('86) (Drillship)	fixed	20	800	174	63	167	Contin.	1		M	Miles et al. (1987)
P	EXPLORER II ('81) (Drillship)	fixed	50	250	171	250	169	Contin.	1		E	Greene (1987)
P/O	BEAVER MACKENZIE (Trans.Dredge)	fixed	80	800	172	100	167	Contin.	1		E	Greene (1987)
O	Fishing Trawler (transit, 10kt)	moving	40	4000	169	160	158	Contin.	1		E	Urick (1983)
P	Caisson-Ret.Island (Drillrig)	fixed	31.5	b 800	167	63	159	Contin.	1		E	Greene (1987)
P/O	ARGILOPOTES (Clamshell Dredge)	fixed	b 250	1250	167	b 250	162	Inter.	e 0.3		M	Miles et al. (1987)
P	Vibroseis Convoy Moving	local	160	2000	167	500	160	Inter.	e 0.8		E	Cummings et al. (1981)
P/O	Bombardier (Tracked Vehicle)	moving	b 125	4000	158	1000	149	Fluct.	e 0.8		E	Heering and White (1984)
O	Fishing Trawler (trawling, 5kt)	moving	40	1000	157	100	147	Contin.	1		E	Urick (1983)

b - Bandwidth limited by available data (refers to number below)
e - Estimated value (refers to number below)

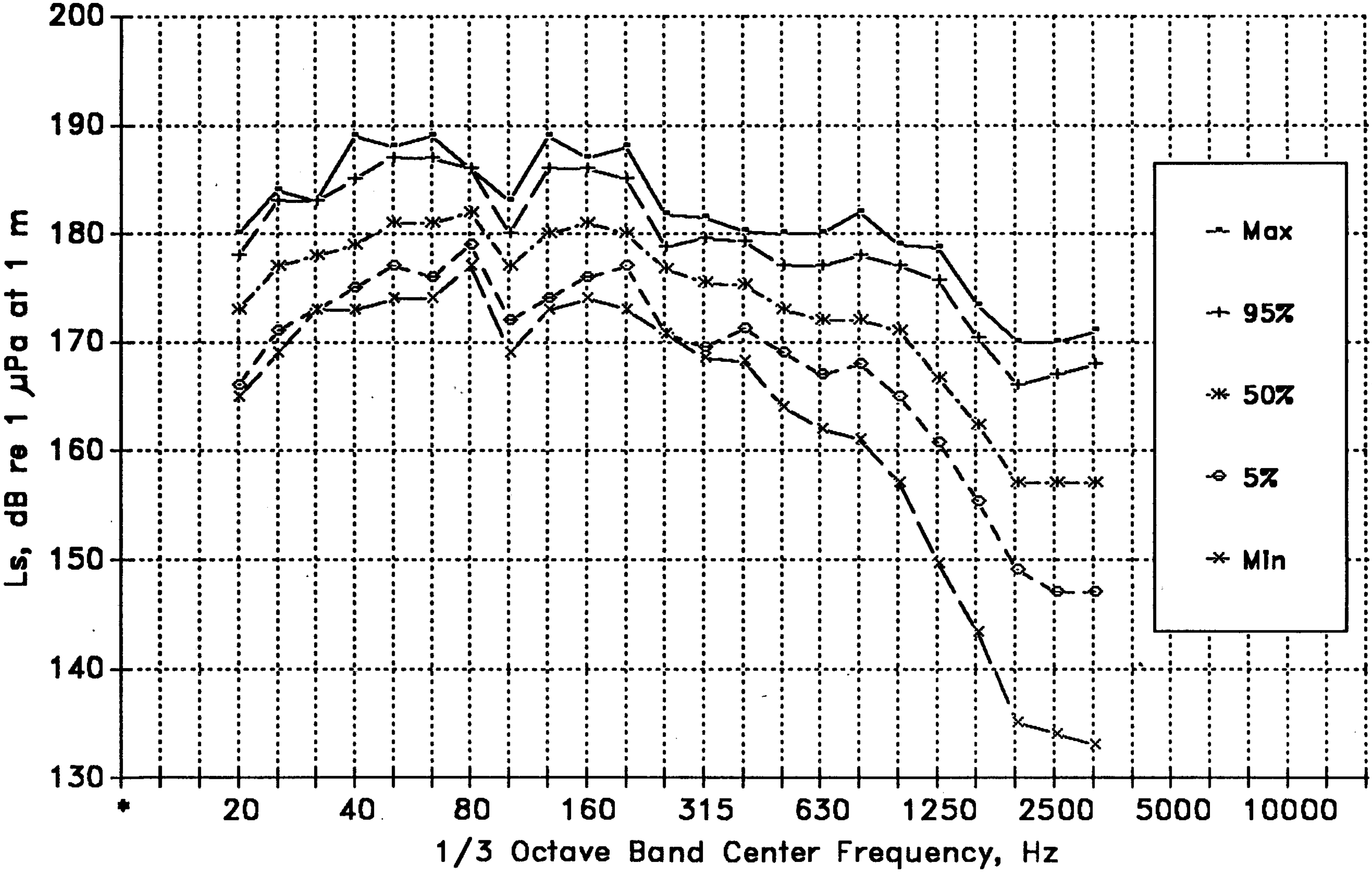


FIG. 3.11 STATISTICAL ANALYSIS OF ICEBREAKER NOISE SPECTRA
ROBERT LEMEUR at Corona Site, 1986 (Analysis by Greeneridge Sciences)

Alaskan Beaufort Sea. When working in ice the ship typically accelerates into an ice flow in attemping to break it. The ship often is stopped by the ice, resulting in heavy propeller cavitation and high noise output. When the ship reverses, the cavitation noise ceases momentarily until the propellers become loaded again. This results in a fluctuating noise output level and a changing source spectrum as the ship works in the ice.

Figure 3.11 shows the 1/3 octave maximum spectrum limits for a specified percentage of the 14 min. sample duration time. The estimated source levels of the icebreaker, considering the dominant band, were below 186 dB 5% of the time, below 191 dB 50% of the time, and below 196 dB 95% of the time. As a point of reference, these levels are slightly lower than the radiated noise from large supertankers at full power operation (Urick 1983). The correction of the Greeneridge data from received level at 0.46 km to a 1-m source level was performed using TL data obtained by BBN (Miles et al. 1987) at the Corona site during the same time period but at a somewhat different location than the Greeneridge measurements.

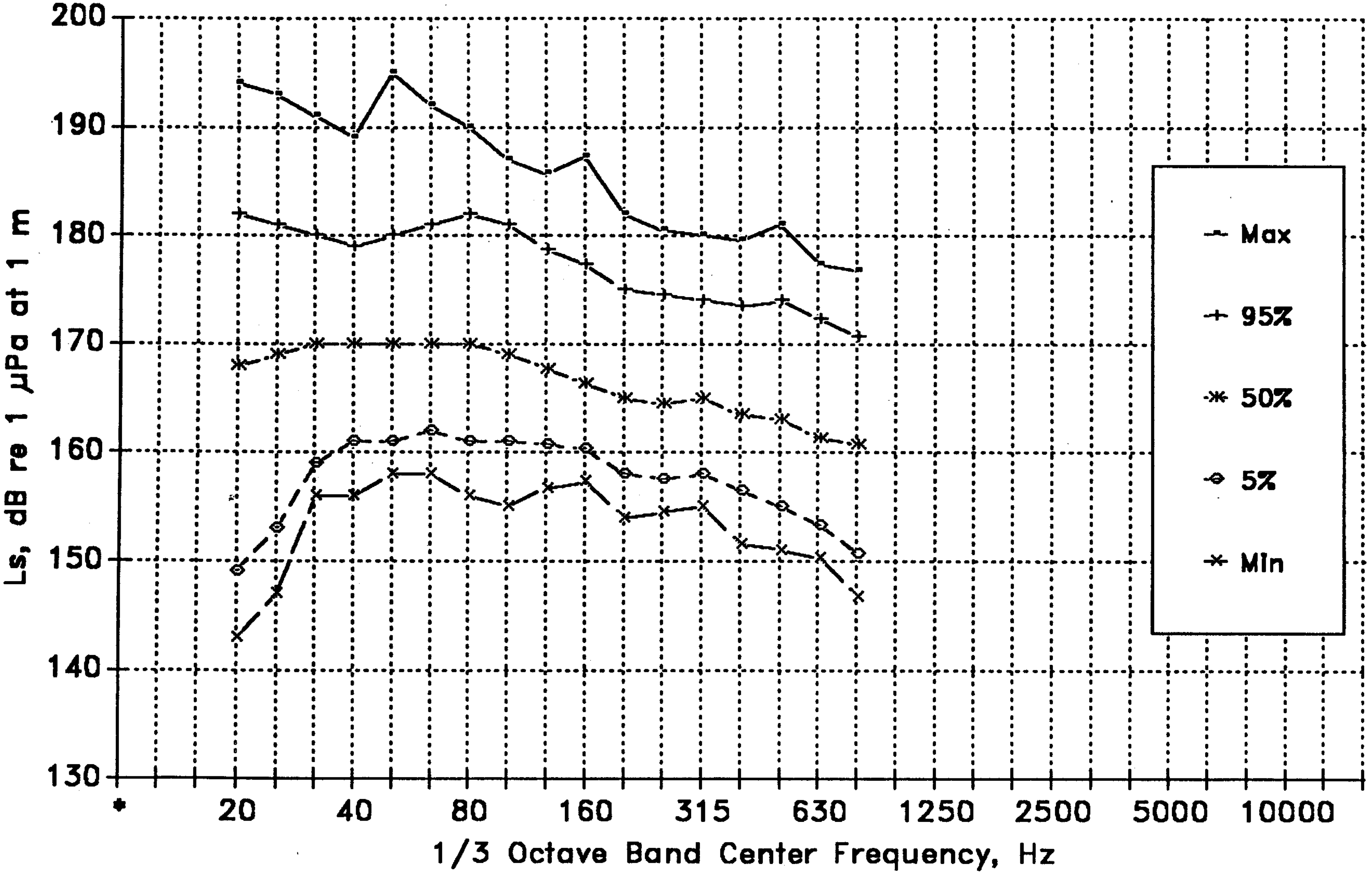
Measurements of the variation in radiated noise level from an operating drill site were made by Greene (1987a) during the same field period at the Corona site. The measurements were made using a moored telemetering array located 15 km east of the drillsite. This provided a means of measuring the composite signal from the site which was a representative mix of drillship sounds, supply vessel sounds, and icebreaker sound. A series of 170 hourly measurements were taken over a period of nine days. A statistical analysis of the data gave the results shown in Fig. 3.12. The TL correction to obtain estimated source level was made using the BBN data. The measurement period was described as one with little icebreaking activity, but some occasional vessel traffic was noted in the vicinity of the measurement array. This nearby vessel traffic probably caused an overestimation of source levels in Fig. 3.12. The 95%ile spectrum may be dominated by the short contributions from icebreaker operation whereas the 50%ile spectrum levels were controlled by drillship and supply vessel activity. The estimated source levels for the 95%, 50%, and 5%ile dominant bandwidths are 191 dB, 180 dB, and 171 dB, respectively.

The availability of the amplitude-time data for the icebreaker and for a representative drill site provided a means of estimating the effective time-fraction for these sources. For the relatively short period of 14 min of icebreaker operation that was analyzed the time-fraction is 0.5. This means that the L_{eq} is 10 Log T_f or 3 dB less than the effective maximum level. The time-fraction for the composite noise from the Corona Site is 0.2 which becomes a -7 dB correction to the maximum rms level (approximately the 95%ile level) to obtain the L_{eq}. Note that the L_{eq} levels are usually higher than the 50%ile levels so that Leq should not be assumed to approximately equal the median level in a fluctuating signal.

Non-petroleum industry sources

The major non-petroleum industry with highest number of sources in the Alaskan marine environment is the fishing industry. These sources range from large trawlers and fish processing vessels to small high speed outboard craft.

FIG. 3.12 STATISTICAL ANALYSIS OF CORONA SITE NOISE SPECTRA
Based on range-corrected data obtained 10-18 Sept. 1986 (Greene 1987)



The vessels of the fishing industry are widely distributed sources with a medium to low sound level output. As a result, the potential noise impact of individual fishing vessels on marine mammals is typically lower than that of large ships and many petroleum industry sources. However, when many trawlers are operating in a concentrated area, as occurs when the seasons first open for some specific species, the composite local noise level may be increased considerably. Sound levels have not been reported for these composite fishing operations but if 3 to 6 vessels are operating in close proximity, a 10 to 15 dB increase in local noise level over that expected from a single trawler is possible. Based on the source level data shown in Table 3.2 for trawling operations, this would increase the received levels in the immediate area of the concentrated fishing activity to values found near drillships and dredges.

The other major Alaskan industries, lumbering and mining, contribute noise to the marine environment primarily through their use of shipping for movement of materials. This is covered under the category of transportation. Some mining activities near coastal regions contribute indirectly to local noise levels by movement of materials across beaches using aircraft and landing barges. The recent movement of gold dredging activities offshore, primarily in the Nome area, is likely to increase local underwater noise levels. No specific acoustic source level data are available for gold dredges but data for several types of offshore dredges are presented in Table 3.2. The gold dredge operating off Nome is a large bucket type of dredge. It is possible that the noise levels of this dredge are more closely related to those of the transfer type of dredge than the clamshell dredge since the dredging operation is continuous rather than periodic.

Source level spectra for selected sources from Table 3.2 are shown in Fig. 3.13. The spectra for the seismic sources are seen to be similar in level and shape. The icebreaker spectrum has a large amount of energy at high frequencies which is typical of cavitation noise. The dredge noise output level can be seen to be higher than that of the drillship (Explorer II), particularly above 63 Hz. The dredge spectrum shown here is the loudest of the three available dredge examples. The trawler spectrum is representative of large trawlers (30 to 50 m) operating at 5 kts.

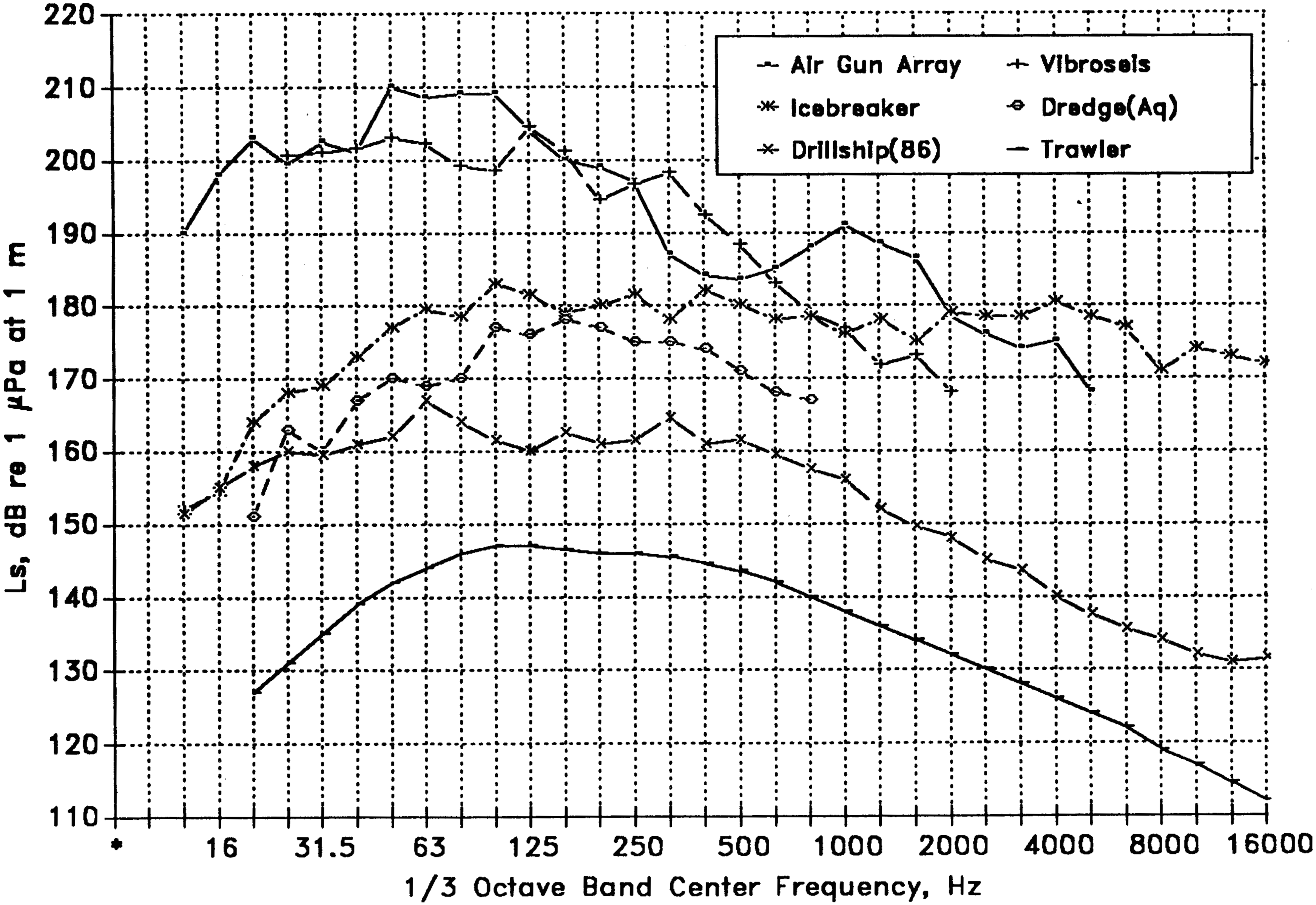
3.3.2 Transportation sources

Table 3.3 presents a compilation of relevant source information for the transportation industry. The general category of transportation sources has been subdivided into ships and boats, aircraft, and helicopters as shown in parts A., B., and C. of the table. The items selected are intended to be representative of the ships and aircraft used in Alaska. The format is identical to that used for Table 3.2.

<u>Boats and Ships</u>

Large oil tankers and cargo carriers of the type serving the Alaska pipeline at Valdez and passing through Alaskan waters on the route to Japan are the loudest water transportation source, often having dominant bandwidth source levels exceeding 185 dB when operating at full speed. In restricted waters when their speed is reduced to 10 kt or less, the source levels

FIG. 3.13 REPRESENTATIVE INDUSTRIAL NOISE SOURCES



generally drop about 10 dB. The majority of medium to large ships operating at full power have dominant bandwidth source levels in the 175 to 185 dB range as shown by the examples in the table. The source levels of small to medium sized ships and support vessels usually are in the 165 to 175 dB range, with vessels under 30 m (100 ft) long generally producing less than 165 dB source level. The example of the 20 m (65 ft) twin screw diesel shown in the table is quieter than the general class because of special design for use in Glacier Bay.

The frequency of the highest 1/3 octave band in the source level spectra can be seen in Fig. 3.14 to be related to the size of the vessel. Larger vessels usually have larger slower turning propellers than smaller ones and their source level spectra are dominated by frequency components related to the shaft RPM and the number of blades on the propellers. The icebreaker underway at 10 kts (CANMAR KIGORIAK) shown in the figure and table is the exception. It is only 90 m (300 ft) long, but has a 100 Hz maximum output band which is comparable to that of an 240 m (800 ft) long tanker. This is a result of the large power plant and large propellers required on icebreakers. The propellers on smaller vessels operate at high speed during normal cruise conditions and produce a large cavitation noise component in their source level spectrum. This broad-band noise component is usually louder than frequency components at blade rate harmonics and produces a maximum 1/3 octave band output in the 0.5 to 2 kHz frequency range as shown for the smaller vessels in the figure.

Aircraft

The source level characteristics for representative aircraft shown in Table 3.3b are based on measured data which have been corrected to a standard overflight altitude of 300 m (1000 ft) and to "Standard Day" conditions of 15 deg C and 70% relative humidity. To permit direct comparison with the output level of the underwater sources given in other tables, the source levels listed have been adjusted to be based on a 1 μPa reference rather than the 20 μPa reference pressure which is customary for airborne sound data. The data have been further adjusted to have a 1 m reference range by adding 50 dB (20 Log 300) as a spreading loss correction (no correction for atmospheric absorption was made).

As shown in the table, the F-4C military fighter with twin turbojet engines under afterburner power produces an effective bandwidth source level of 192 dB re 1 μPa at 1 m. This is seen to be comparable to the output source level of an icebreaker operating in ice as shown in Table 3.2. For a takeoff under normal power, the F-4C is similar to the Boeing 727 (three turbofan engines) in source level output. The 2-engine Learjet, while considerably smaller than the 727, can be seen to produce a source level within 5 dB of the larger aircraft on takeoff. The older design 4-engine propeller and turboprop aircraft such as the DC-6, Electra (P-3), and C-130 can be seen to have takeoff source levels which are about 175 dB, 10 dB lower than the 727 and F-4C. The 737-300 2-engine high bypass turbofan and the smaller 2-engine turboprop aircraft have takeoff source levels of about 165 dB, 20 dB less than that of the 727 and F4-C. The light 2-engine and 1-engine propeller aircraft such as the Piper Navajo and Cessna 185 have takeoff source levels which are

TABLE 3.3 TRANSPORTATION SOURCES

A. BOATS, SHIPS

Source	Type	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB (1)	Temporal Pattern	Time Ratio	TL	Source Level Data Meas/Est	Reference
800' Oil Tanker (16kt)	moving	b 2	4	205	2	203	Cont.	1		M/E	Cybulski (1977), and Heine and Gray (1977)
Icebreaker (transit at 10kt)	moving	63	1250	181	100	174	Cont.	1		M	Miles et al. (1987)
583' Diesel Ship (10kt)	moving	63	4000	177	315	168	Cont.	1		M	Malme et al. (1982)
352' Ferry (16kt)	moving	40	630	175	125	171	Cont.	1		M	Malme et al. (1982)
Tug and Barge (10kt)	moving	100	12500	171	630	162	Cont.	1		M	Malme et al. (1982)
110' Twin-screw diesel (10kt)	moving	315	b 16000	168	630	159	Cont.	1		M	Malme et al. (1982)
65' Twin-screw diesel (10kt)	moving	800	8000	156	1600	150	Cont.	1		M	Malme et al. (1982)

Notes: (1) From measurements by Cybulski and class averages reported by Heine and Gray for operations in deep water.
b Bandwidth limited by available data (refers to number below or to left)

B. AIRCRAFT

Source	Type	Dominant BW, Hz fmin	fmax	Ls1,dB (2)	Max 1/3 Oct,Hz freq.	Ls2,dB (2)	Temporal Pattern	Time Ratio	TL	Source Level Data Meas/Est	Reference
F-4C jet fighter (100% T/O,A/B)	moving	100	4000	192	160	183	Cont.	1		M	BBN archives
(100% Thrust, T/O)	moving	250	8000	186	630	178	Cont.	1		M	"
(87% Thrust, Appr.)	moving	125	3150	175	200	166	Cont.	1		M	"
Boeing 737-200, 2-eng. jet (T/O)	moving	100	800	185	125	180	Cont.	1		M	"
(Cruise)	moving	125	1600	161	160	154	Cont.	1		M	"
Learjet, 2-eng. jet (T/O)	moving	125	5000	182	630	173	Cont.	1		M	"
(Cruise)	moving	125	2000	177	500	169	Cont.	1		M	
C-130, 4-eng. turboprop (T/O)	moving	63	160	175	125	171	Cont.	1		M	"
also Lockheed Electra (Appr.)	moving	50	1600	158	160	152	Cont.	1		M	"
Douglas DC-6 4-eng. prop (T/O)	moving	b 50	1250	174	125	164	Cont.	1		M	"

TABLE 3.3 TRANSPORTATION SOURCES
C. HELICOPTERS (All turbine powered)

Source	Type	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Temporal Pattern	Time Ratio	TL	Source Level Data Meas/Est	Reference
Bell 205 (UH-1H) (Loaded)	moving	b 50	400	165	63	158	Cont.	1		M	BBN Archives
(Appr.)	moving	50b	400	161	200	155	Cont.	1		M	"
Bell 222 (T/O)	moving	b 50	800	152	125	146	Cont.	1		M	"
(Appr.)	moving	100	800	161	160	155	Cont.	1		M	"
Sikorsky S61 (HH-3F) (Cruise)	moving	31.5	250	156	40	152	Cont.	1		M	"
Bell 206B (OH-58) (Cruise)	moving	b 50	800	151	200	145	Cont.	1		M	"

Note:
b Bandwidth limited by available data (refers to number below or to left)

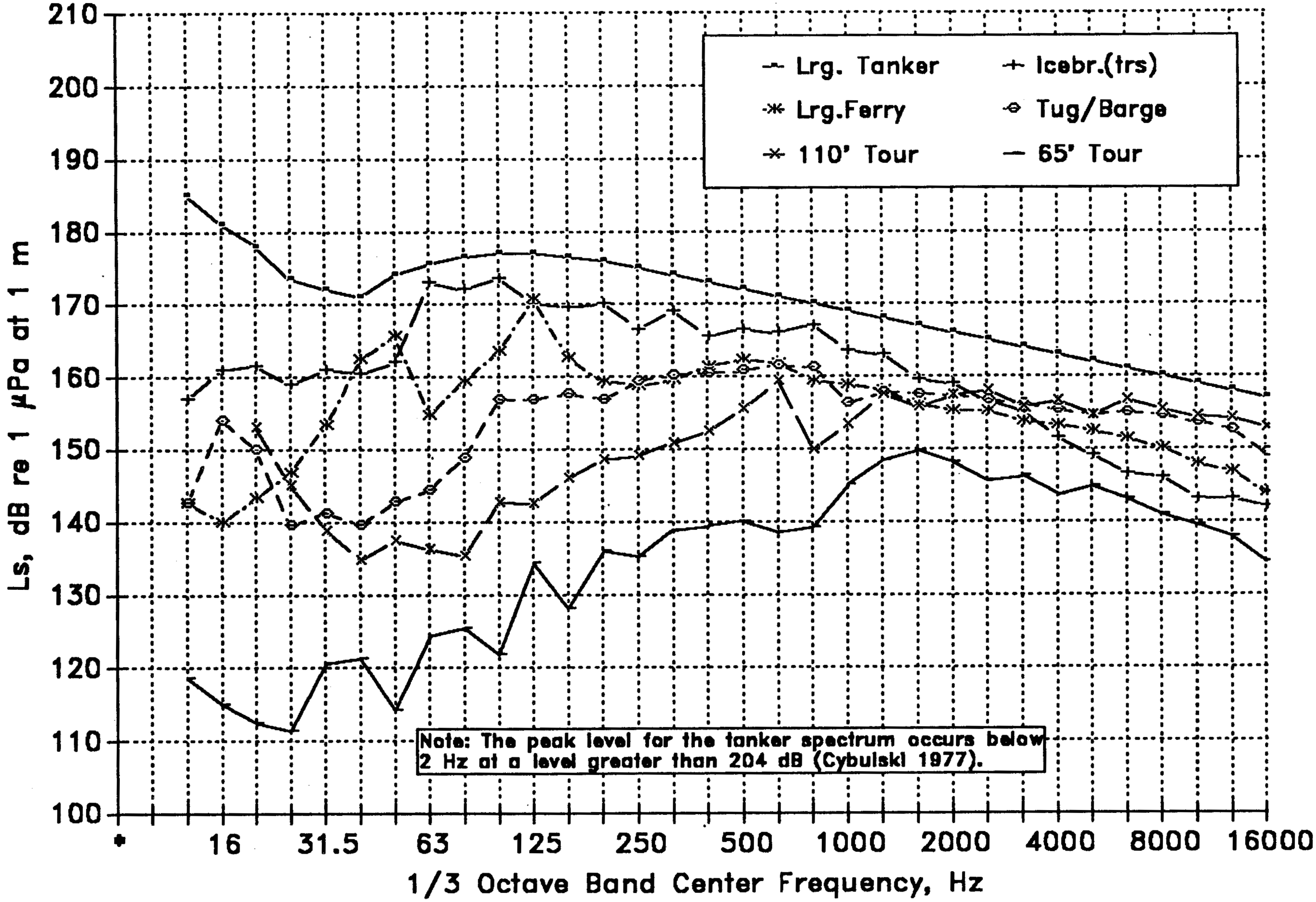
another 5 to 10 dB lower than that of the 2-engine turboprop, averaging about 155 to 160 dB. Cruise and approach power settings can be seen in the table to produce considerably lower source levels, ranging from 5 to 15 dB less than those measured for takeoff power. The takeoff power acoustic source level data is thus the most relevant for estimating the potential noise impact of aircraft operations.

Source level spectra for selected aircraft are shown in Fig. 3.15. The spectra shown have been adjusted for a 1 μPa reference pressure but are shown for the customary 300 m altitude measurement distance. The figure shows that the spectra fall into three groups based on average level and spectrum shape. The jet fighter and other jet transport aircraft have highest output levels and the broadest spectrum output. The large turboprop and modern turbofan aircraft have output spectra in the intermediate range with the turboprop showing low frequency spectrum peaks caused by propeller noise. The light 2-engine turboprop and single-engine propeller aircraft have the lowest noise output. While the low frequency noise output of the 2-engine turboprop can be seen to be higher than that of the single-engine propeller, as expected, the band levels above 400 Hz are lower for the 2-engine turboprop. This may be the result of the examples chosen and not necessarily true for general class averages.

Helicopters

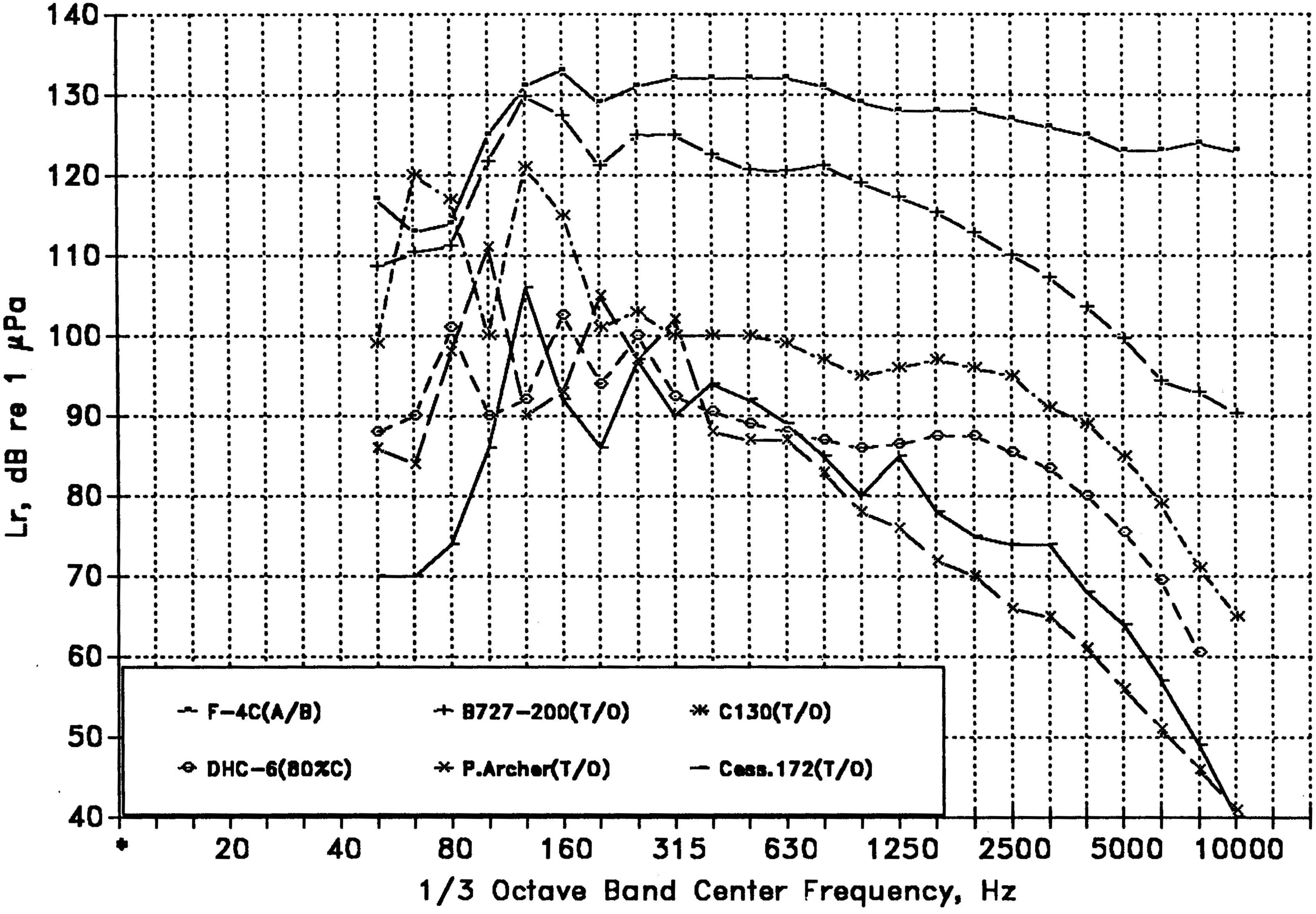
The helicopter source level data shown in Table 3.3C have also been adjusted to a 1 μPa pressure reference and a 1 m reference range to permit direct comparison of the data with those in the other tables. The group of helicopters shown in the table does not include the largest and smallest that

FIG. 3.14 REPRESENTATIVE SHIPS AND BOATS



Note: The peak level for the tanker spectrum occurs below 2 Hz at a level greater than 204 dB (Cybulski 1977).

FIG. 3.15 REPRESENTATIVE AIRCRAFT SPECTRA, STD DAY COND., 300 M ALT.



may be found operating in Alaska, but is thought to be representative of the prevalent sizes used in industrial and transportation applications.

The Bell 205 helicopter, used for both cargo and passenger carrying, can be seen from the table to produce a source level of 165 dB for the loaded cruise condition. This is comparable to the takeoff source level of the Boeing 737-300 as shown in Table 3.3B. The Bell 222, a newer and somewhat smaller helicopter, produces an approach source level of 161 dB. The takeoff source level of 152 dB shown in the table for this aircraft is undoubtedly too low as a result of the reported data not including the lower frequency noise components, e.g., from the main rotor, which are a significant part of the overall noise output. The Sikorsky S61, a larger model often used for search and rescue as well as oil industry operations, can be seen to produce a cruise source level of 156 dB which is comparable to the takeoff source level of the Cessna 172 single-engine propeller aircraft. This relatively low source level may be aided by the 5-bladed main and tail rotors used on the S61 helicopter. The Bell 206B, a 5-passenger light helicopter, is seen to produce a cruise source level of 151 dB which is similar to that of a Cessna 185 at cruise power, as shown in Table 3.3B.

The source level spectra for the selected helicopter examples are shown in Fig. 3.16. All of the spectra are similar with the exception of the Bell 205 and Bell 222 helicopters having band levels below 1.25 kHz which are 5 to 10 dB higher than those of the Bell 206B and the Sikorsky S61. Comparison of the general range of the helicopter spectra in Fig. 3.16 with the examples of fixed wing aircraft spectra in Fig. 3.15 shows that the group of helicopters selected produces source levels which are comparable to the lowest range of fixed wing aircraft spectra. With the probable exception of noise from the large two-bladed helicopters such as the Bell 205 and 212, the potential noise impact of helicopter operation is thus not expected to be much different from that for fixed wing aircraft operation for comparable aircraft sizes. However, since helicopters are typically operated at lower altitudes, there may be an increase in noise exposure at ground level for helicopters as a result of usual operating procedures.

3.3.3 Cultural and recreational sources

The acoustic source examples included in this category have been selected from vehicles and tools used for cultural and recreational fishing, hunting, camping, and other activities not performed for industrial or commercial purposes. Smaller boats have been included in this category rather than under industrial or transportation sources even though many small boats are used for commercial fishing. Table 3.4 contains source level data for the examples selected. The format is identical to that used previously in Tables 3.2 and 3.3. Representative estimated underwater source level spectra are shown in Fig. 3.17.

The most widely distributed recreation-related underwater acoustic sources in Alaskan waters are outboard motor powered boats. They produce a wide range of source levels depending on the motor horsepower and propeller type used. Outdrive and inboard power cruisers are also widely distributed. Examples of these sources are shown in Table 3.4. The dual 80 HP outdrive

FIG. 3.16 REPRESENTATIVE HELICOPTER SPECTRA, STD DAY COND., 300 M ALT.

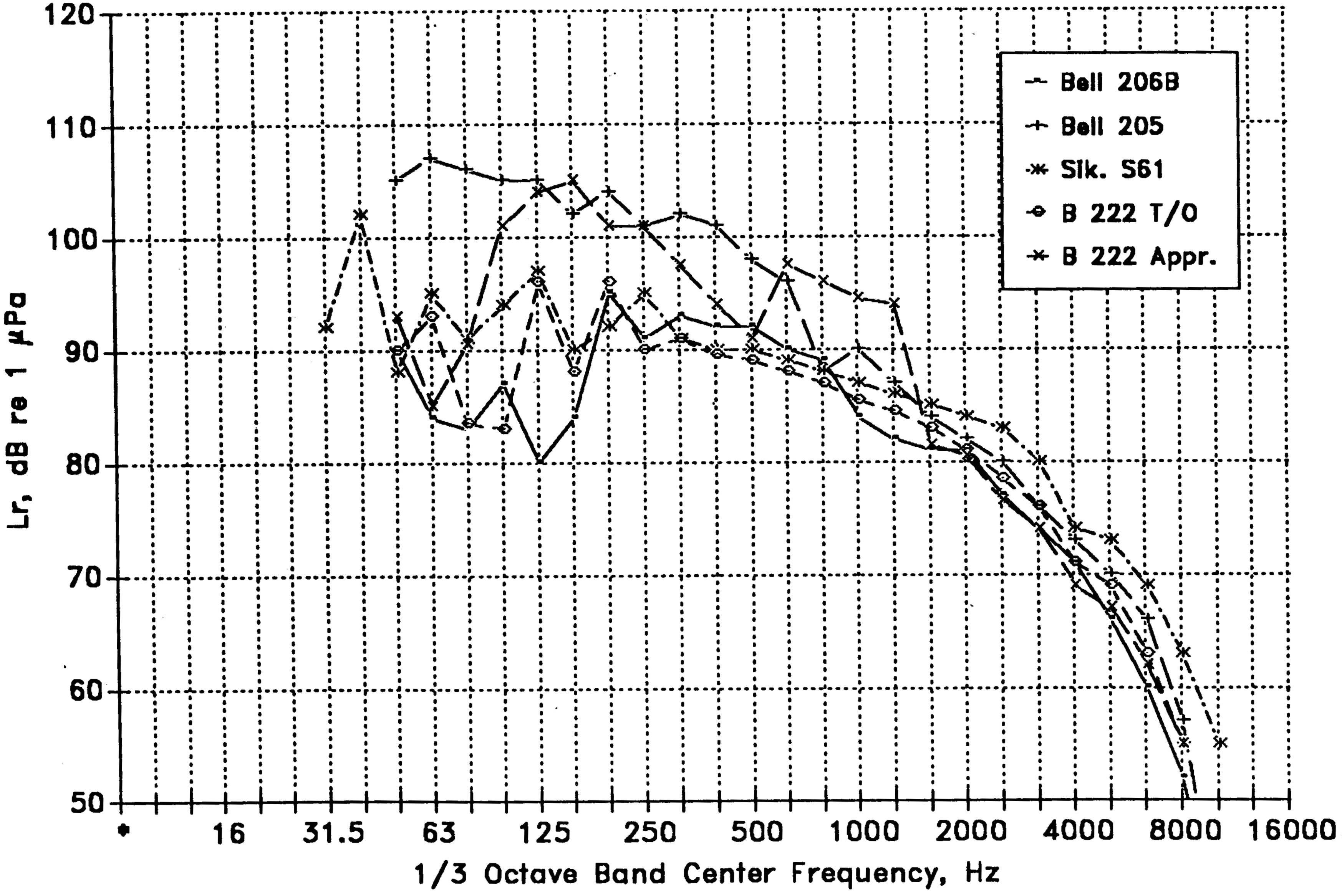


FIG. 3.17 REPRESENTATIVE RECREATIONAL SOURCES

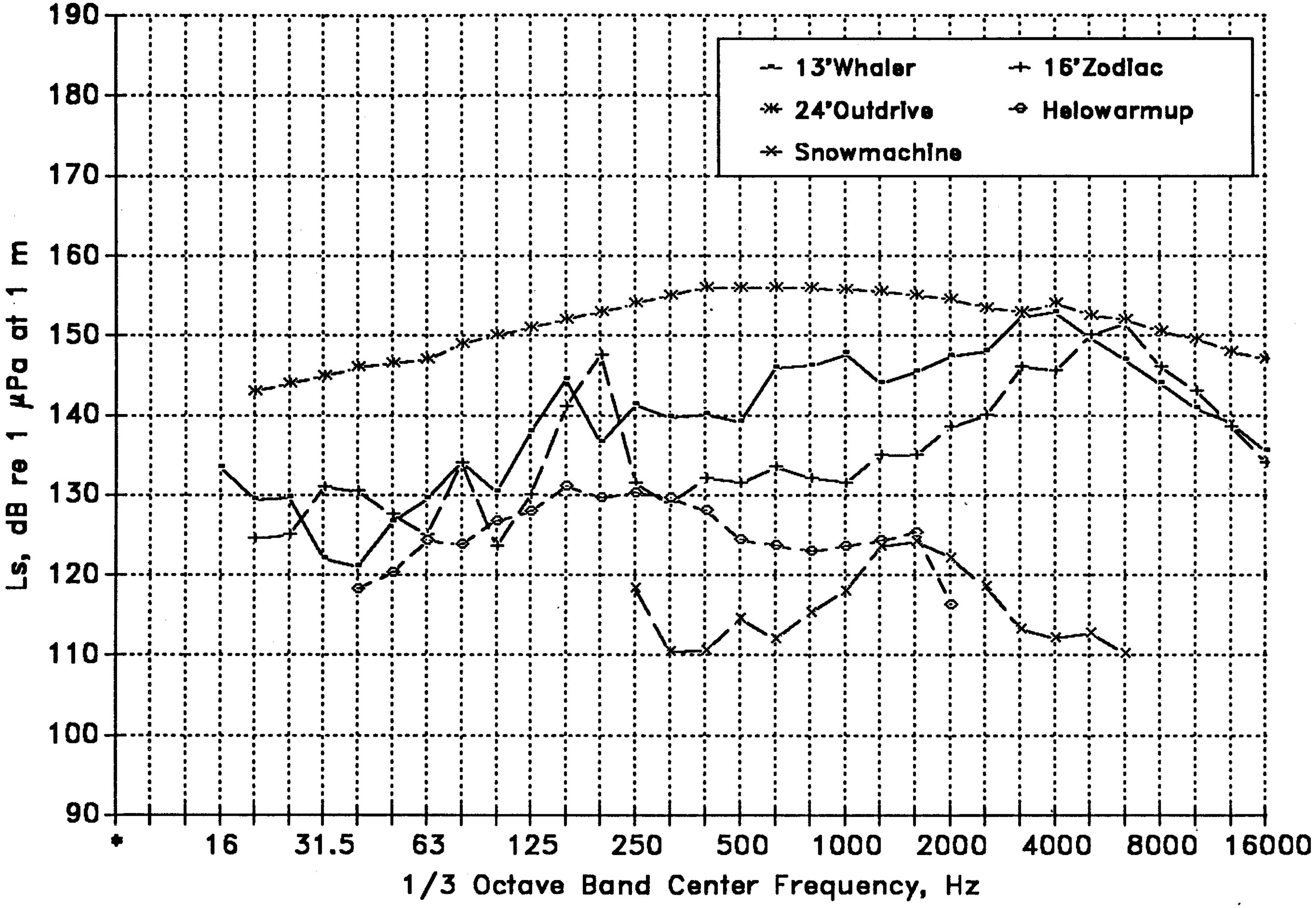


TABLE 3.4 CULTURAL AND RECREATIONAL SOURCES

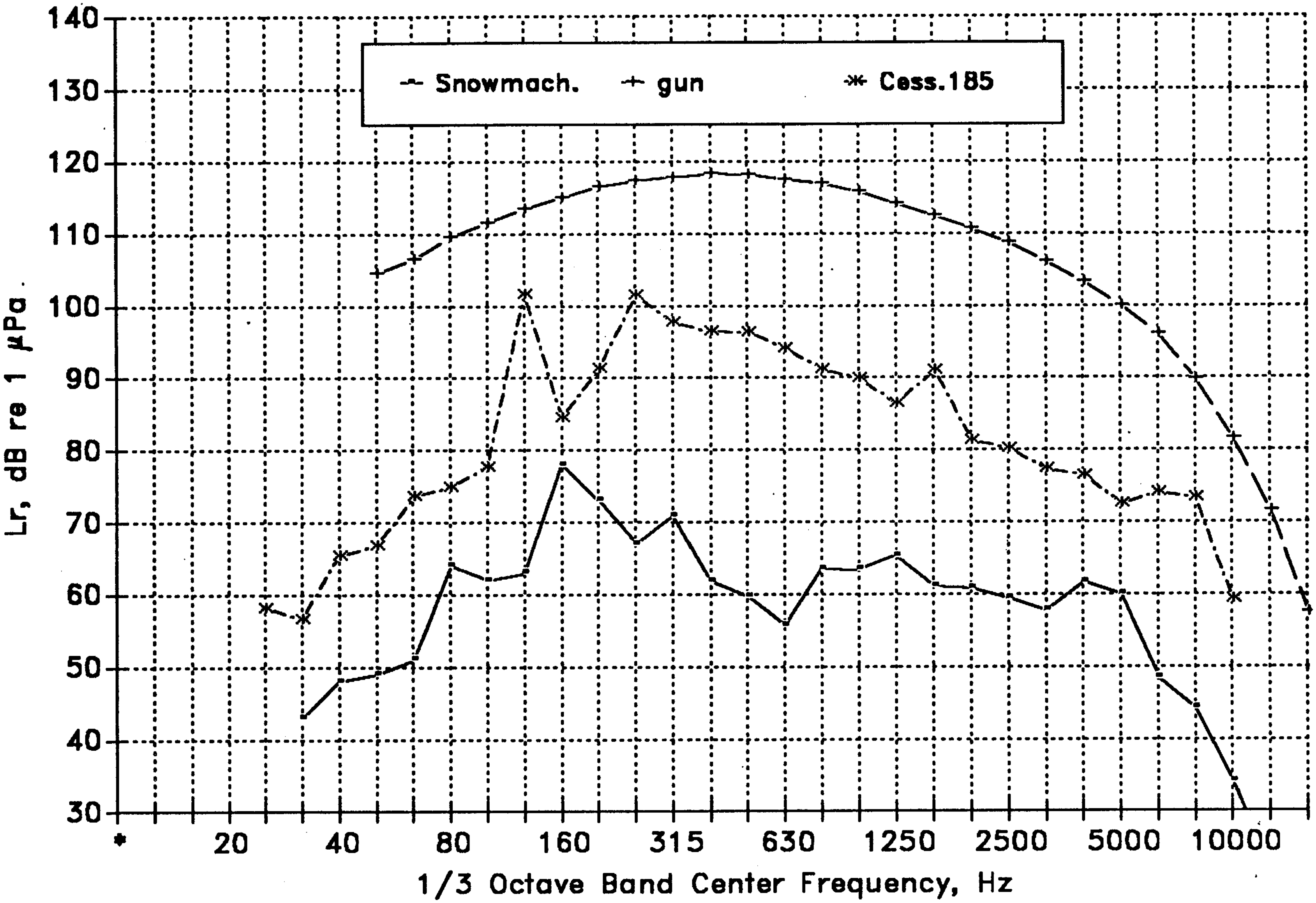
Source	Type	Dominant BW, Hz			Max 1/3 Oct,Hz		Temporal	Time	Source Level Data	
		fmin	fmax	Ls1,dB	freq.	Ls2,dB	Pattern	Ratio	Meas/Est,	Reference
24' Outdrive, 2-80HP (20kt) (1)	moving	40	16000b	167	500	156	Fluct.	0.8e	M	Malme et al. 1981
16' Zodiac, 20HP (20kt) (1)	moving	3150	10000	157	6300	152	Fluct.	0.8e	M	"
13' Whaler, 20HP (20kt) (1)	moving	630	8000	159	4000	153	Fluct.	0.8e	M	"
Snowmachine (16 km/hr) (2)	moving	250	2500	130	1600	124	Fluct.	0.8e	E	Holliday et al. 1980
Helicopter warmup on ice (2)	local	63	1600	139	160	131	Contin.	1	E	deHeering and White 1984
Shotgun, 10ga (3)	local	80	3150	172	500	162	Impulse	0.005	M	BBN Archives.
Snowmachine (40 km/hr) (4)	moving	160	315	125	160	122	Fluct.	0.8e	M	Cheney and McClain 1973

Notes:
b Bandwidth limited by available data
(1) Underwater sound
(2) Signatures obtained in water under ice cover
(3) Airborne sound

source level of 167 dB represents the upper range of source levels for most recreational sources. This level is comparable to that produced by a 35 m (110 ft) twin-screw diesel vessel as shown in Table 3.3A. When several vessels of this type are operating in close proximity the cumulative noise level can reach values similar to those that would be produced by a medium sized ship.

Example spectra for several of the more popular airborne sound sources are shown in Fig. 3.18. Note that these are radiated noise spectra for a range of 150 m, not source level spectra. The snowmobile spectrum is reresentative of older models and was obtained during acceleration of the machine while running at about 40 km/hr (25 mph). The spectrum for the 10 gauge shotgun shows peak 1/3 octave band levels. Since this is a highly sporadic and impulsive source it is difficult to estimate a representative time fraction to obtain an equivalent level. If a pressure pulse time constant of 2 msec and a shot repetition rate of 1/hr is assumed, the L_{eq} for the shotgun is estimated to be about 60 dB less than the spectrum levels shown in Fig. 3.18. The longer duration signal from the aircraft flyover thus is one of loudest recreational source signals.

FIG. 3.18 REPRESENTATIVE CULTURAL SOURCES
Airborne Sound at 150 m



4. SOUND TRANSMISSION CHARACTERISTICS

This section contains a brief summary of sound transmission theory relevent to the problem of predicting the effective ranges of the various sources discussed in the preceding section. A summary of sound transmission in air is presented as well as a discussion of shallow water sound propagation and transmission through the air-water interface. A discussion of sound transmission model development and application is presented along with examples of predicted transmission loss characteristics for the Alaskan environment.

4.1 Sound Transmission in Air

Sound transmission from a source in an unbounded atmosphere is attenuated only by geometrical spreading of the sound energy and by absorption of sound energy by air molecules. Sound transmission from a source near a non-rigid or permeable boundary is also influenced by reflection and refraction losses and by wave transmission along the boundary surface. Interference between these direct, reflected, and ground wave paths causes fluctuations in level and in frequency response for near ground transmission. In addition, the refraction caused by wind and temperature gradients produces shadow zones with very poor sound transmission in the upwind direction and often enhanced sound transmission downwind. These effects are very site and weather condition specific and hence it is not feasible to predict them on a general basis. As a result, for the purpose of predicting the average atmospheric sound transmission, gradient effects will be neglected and only spreading loss and atmospheric absorption will be considered in a simplified sound transmission model.

The loudest non-explosive airborne noise sources have been shown to be aircraft. The most significant mode of sound transmission to a point on the ground usually involves a direct path from the source to a receiver that is elevated well above the refracting and scattering effects of near-surface transmission. Because of this, by considering only spherical spreading, atmospheric absorption, and ground reflection effects, one can develop an adequate transmission loss (TL) equation for estimating the received level on the ground from an aircraft passing nearby. The relationship can be stated as:

$$L_r = L_s - 20\,\mathrm{Log}(R) - a\,R + R_g \quad \text{dB re 1 } \mu\text{Pa} \tag{12}$$

where: L_r = Received level spectrum near the ground

L_s = Source Level spectrum at 1 m from the source

R = Slant range in m

a = Atmospheric absorption spectrum in dB/m

R_g = Ground reflection factor, dB.

Since for most aircraft noise transmission calculations, a reference sound level at 300 m is used rather than a 1 m source level, Eq. (12) can be rewritten in a more convenient from as:

$$L_r = L_{ref} - 20 \text{ Log } (R/R_{ref}) - a\,R + a(SD)\,R_{ref} \quad \text{dB re 1 } \mu\text{Pa} \qquad (13)$$

where: L_{ref} = Reference source spectrum at 300 m for standard day conditions

R_{ref} = 300 m

a(SD) = Atmospheric absorption spectrum for standard day conditions.

The procedure for measuring L_{ref} utilizes microphones near the ground so the ground reflection effect is included in the measured level and is usually corrected for in published data. Equation (13) is to be applied successively to each spectrum band in calculation of the L_r spectrum; i.e., the 50 Hz band level of the L_{ref} spectrum would be used with the 50 Hz band levels of the absorption spectra to determine the 50 Hz band level of L_r, etc. Since the spreading loss term is not frequency dependent, it is calculated once and used repeatedly.

Atmospheric absorption at low frequencies below 30 kHz is produced by molecular absorption by oxygen and nitrogen molecules. The amount of absorption is dependent on frequency, temperature, relative humidity, and to a small degree on atmospheric pressure. The physical relationship between these parameters is not easily expressed in mathematical relationships, but an empirical computer algorithm has been developed for closed-form calculation of absorption coefficients from input of the four atmospheric parameters (ANSI S1.26-1978).

In a recent study, the transmission loss relationship given in Eq. (13) was used together with calculated absorption values tabulated in the ANSI standard to obtain estimates of aircraft noise in pinniped haulout areas in the Bering Sea (Johnson et al. 1988). The following example from that study is presented to illustrate the modeling procedure for airborne sound.

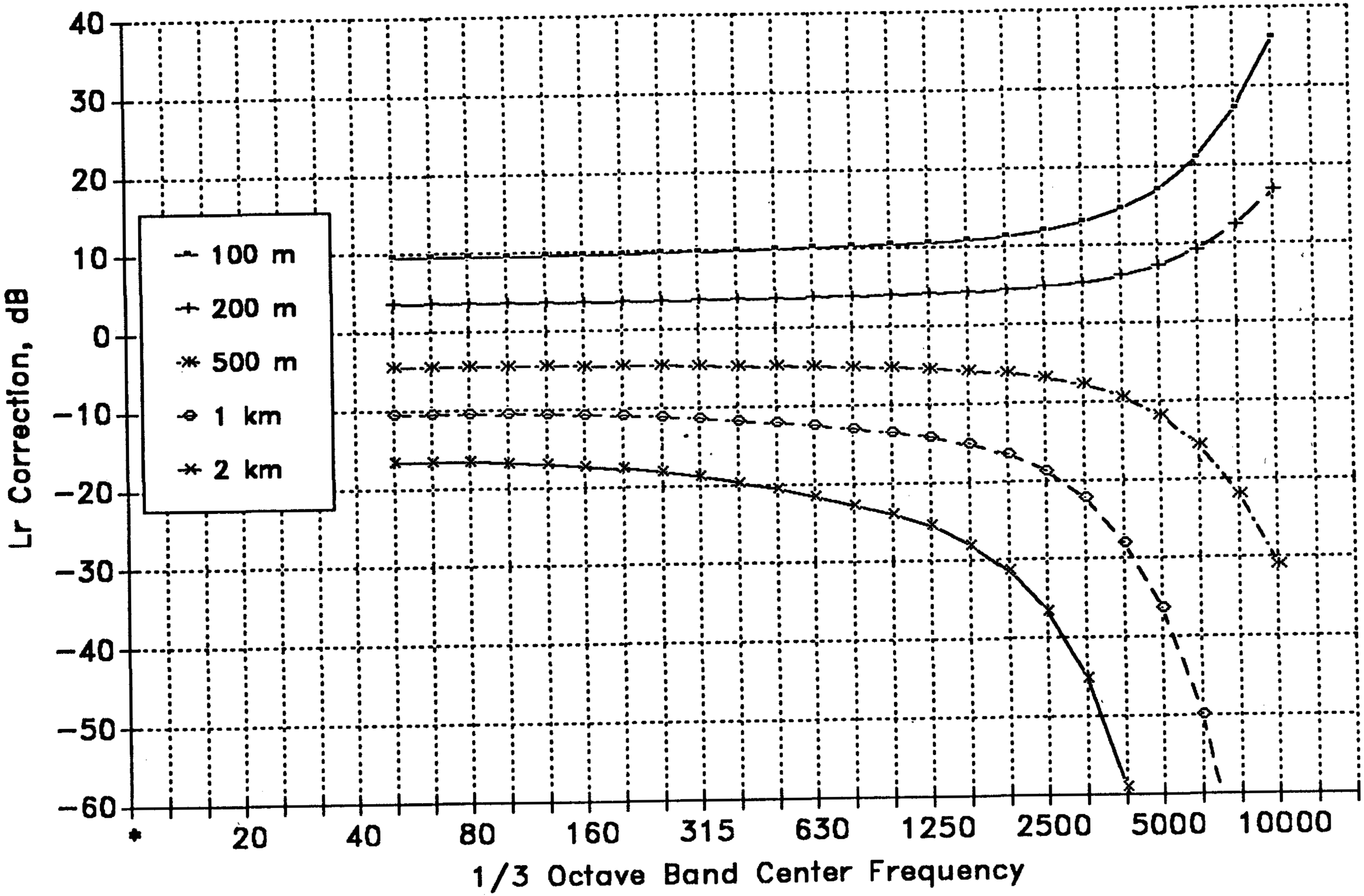
Examination of the climatic atlas data showing temperature and humidity values for the Bering Sea region of interest during the pinniped haulout season disclosed that the expected range of variation was not large. A table of absorption coefficients was prepared using excerpts from the ANSI Standard. The results are shown in Table 4.1 which presents atmospheric absorption coefficients estimated for spring and summer conditions. Values are presented showing attenuation per 100 m. Attenuation values over 150 m (500 ft) are also given to facilitate correction of reference spectra to 150 m and 450 m altitudes. For flyovers at 300 m the corrections to the standard day conditions can be used to estimate aircraft noise spectra at the Bering Sea sites.

The correction values shown in Table 4.1 for the 5 deg C, 80% RH condition in the Bering Sea were used with Eq. (13) to estimate direct path TL characteristics. Transmission loss spectra were calculated for estimating received levels near the ground from level overflights at 150 m, 300 m, and 450 m. Slant ranges of 1 km and 2 km were also considered in the estimations to represent offset passes. The resulting TL predictions are shown in Fig. 4.1. The aircraft radiated noise spectra shown in Fig. 3.12 and Fig. 3.13 can

Table 4.1. Atmospheric Attenuation for Representative Southern Bering Sea Conditions (Estimated Using ANSI S1.26-1978, Method for the Calculation of the Absorption of Sound by the Atmosphere).

Temp./Hum.	Freq.(Hz) Attenuation	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
0 Deg. C,	a, dB/100m	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.15	0.20	0.27	0.38	0.54	0.83	1.24	1.87	2.87	4.43	6.58	9.72	14.10	19.26
80% R.H.	a @ 150m (dB)	0.02	0.02	0.03	0.05	0.06	0.08	0.09	0.12	0.15	0.18	0.23	0.30	0.41	0.58	0.82	1.26	1.88	2.84	4.36	6.73	10.00	14.77	21.43	29.28
5 Deg. C,	a, dB/100m	0.01	0.01	0.02	0.02	0.04	0.05	0.07	0.09	0.11	0.14	0.17	0.21	0.27	0.34	0.46	0.67	0.97	1.44	2.18	3.39	5.12	7.82	11.97	17.48
80% R.H.	a @ 150m (dB)	0.02	0.02	0.03	0.03	0.06	0.08	0.11	0.14	0.17	0.21	0.26	0.32	0.41	0.52	0.70	1.02	1.47	2.19	3.31	5.15	7.78	11.89	18.19	26.57
10 Deg.C,	a, dB/100m	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.09	0.12	0.17	0.21	0.26	0.32	0.38	0.46	0.61	0.81	1.13	1.63	2.45	3.66	5.60	8.73	13.19
90% R.H.	a @ 150m (dB)	0.02	0.02	0.02	0.03	0.05	0.06	0.09	0.14	0.18	0.26	0.32	0.40	0.49	0.58	0.70	0.93	1.23	1.72	2.48	3.72	5.56	8.51	13.27	20.05
"Standard Day"																									
15 Deg.C	a, dB/100m	0.01	0.01	0.01	0.02	0.03	0.05	0.07	0.10	0.14	0.19	0.24	0.30	0.37	0.44	0.53	0.68	0.88	1.19	1.69	2.51	3.71	5.64	8.77	13.27
70% R.H.	a @ 150m (dB)	0.02	0.02	0.02	0.03	0.05	0.08	0.11	0.15	0.21	0.29	0.36	0.45	0.56	0.66	0.80	1.02	1.32	1.79	2.54	3.77	5.57	8.46	13.16	19.91
Corrections for Bering Sea Conditions																									
Add to data reported for "Standard Day" conditions																									
0 Deg. C,	c, dB/100m	0.00	0.00	-0.01	-0.01	-0.01	0.00	0.01	0.02	0.04	0.07	0.09	0.10	0.10	0.06	-0.01	-0.15	-0.36	-0.68	-1.18	-1.92	-2.87	-4.08	-5.33	-5.99
80% R.H.	c @ 150m (dB)	.00	.00	-0.02	-0.02	-0.02	.00	0.01	0.03	0.06	0.10	0.13	0.15	0.14	0.08	-0.03	-0.24	-0.56	-1.06	-1.83	-2.97	-4.44	-6.31	-8.28	-9.37
5 Deg. C,	c, dB/100m	0.00	0.00	-0.01	0.00	-0.01	0.00	0.00	0.01	0.03	0.05	0.07	0.09	0.10	0.10	0.07	0.01	-0.09	-0.25	-0.49	-0.88	-1.41	-2.18	-3.20	-4.21
80% R.H.	c @ 150m (dB)	.00	.00	-0.02	.00	-0.02	.00	.00	0.01	0.04	0.07	0.10	0.13	0.14	0.14	0.10	.00	-0.15	-0.40	-0.78	-1.39	-2.22	-3.43	-5.04	-6.66
10 Deg.C,	c, dB/100m	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.05	0.04	0.04	0.08
90% R.H.	c @ 150m (dB)	.00	.00	.00	.00	.00	0.01	0.01	0.01	0.03	0.03	0.04	0.05	0.07	0.08	0.10	0.09	0.09	0.07	0.06	0.04	.00	-0.05	-0.11	-0.14

FIG. 4.1 CORRECTION TO 300 M REFERENCE SPECTRA FOR AIRCRAFT FLYOVER AT OTHER ALTITUDES (Standard Day Conditions)



be used with the TL spectra in Fig. 4.1 to estimate received levels near the ground. Examples of this procedure are presented in Sec. 5.3.

4.2 Underwater Sound Transmission

In unbounded deep water sound transmission characteristics are determined by geometric spreading loss and molecular absorption of the sound energy in the same manner as in atmospheric transmission. Molecular absorption losses are much smaller underwater, however, and are not significant for frequencies less than 5 kHz and ranges less than 5 km. Sound transmission in shallow water is influenced by reflection losses from the bottom and surface, refraction from sound speed gradients, reflection and refraction from subbottom layers, and scattering from rough surfaces. All these effects must be considered along with geometric spreading loss to obtain estimates of the received level at some distance from a source.

The large variability in temperature and salinity characteristics of Alaskan coastal waters has a significant influence on sound propagation. Two representative sound speed profiles are shown in Fig. 4.2. The strong surface layer condition occurs in many areas during July - September when solar heating is high. The higher temperature region near the surface is associated with a lower salinity layer produced by runoff from rivers which floats on top of the denser ocean water. While the sound speed in fresh water is slower than that in ocean water, the temperature difference near the surface more than compensates for the effect of the lower salinity. Since sound travels faster in warm water than cold, the net effect is a downward refraction of horizontally traveling sound rays. This produces more bottom reflections per kilometer and higher transmission loss than would be the case if the high sound speed surface layer did not exist.

During the period of November - May when the surface is generally colder than the water at depth, the sound speed profile tends toward the neutral condition shown in Fig. 4.2. Under these conditions sound is not refracted downward and the influence of the bottom on the transmission loss is reduced. In ice-covered areas, the colder region near the surface produces upward refraction so that the ice layer roughness often becomes a more significant influence in sound transmission loss than the bottom properties (Milne 1967).

Several analysis techniques and computer-based models have been developed to aid in the prediction of acoustic transmission loss characteristics (Miles et al. 1987; Malme, Smith and Miles 1986). These procedures use measured sound speed profiles, bottom-loss parameters, and surface loss parameters in addition to spreading loss calculations to obtain their results. Several models have been developed for Navy applications such as the Generic Sonar Model (Weinberg 1985). Most of these are intended primarily for application to deep water areas. However, a recently developed model which is based on a procedure for solving the parabolic wave equation (Lee and Botseas 1982), can be applied to shallow water transmission. Moreover, it has provision for range-dependent parameters such a a sloping, non-uniform bottom, and range-varying sound speed profiles. This "Implicit Finite-Difference (IFD) Computer Model" developed at the Naval Underwater Systems Center was used to compute

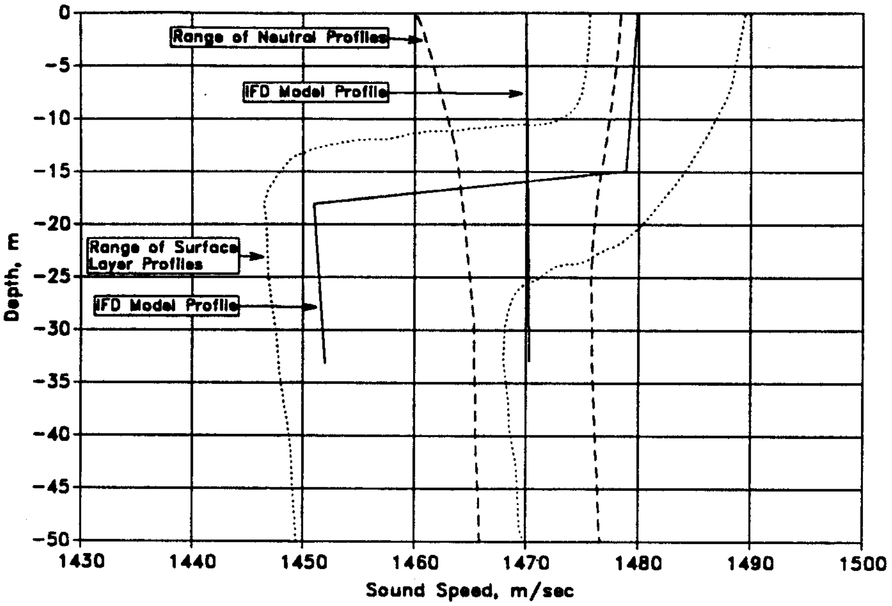


Figure 4.2. Range of Sound Speed Profiles for Study Areas.

transmission loss characteristics using published information on bottom characteristics and sound speed profiles.

The source and receiver depths used in the modeling work were 5 m and 10 m respectively to represent the average depth of ship and boat propellers and a representative depth of marine mammal habitat. It was necessary to perform both frequency and depth averaging of the model output to obtain transmission loss characteristics that were not overly influenced by single frequency interference patterns. For most of the analysis the model output for three frequencies was averaged, corresponding to the upper, middle, and lower frequencies of a 1/3 octave band. In this way, results for the 100, 315, and 1000 Hz 1/3 octave bands were obtained. In addition, the received levels were depth-averaged from 5 to 15 m.

An example of the output of the IFD Model is shown in Fig. 4.3. Here propagation in a region of the Norton Basin Planning Area with a depth of 33 m was considered. Figure 4.3A presents the predicted transmission loss at 3 frequencies for the strong surface layer profile shown in Fig. 4.2. Using information obtained from the literature (Mackenzie 1973), the model incorporated a bottom composition of silt-sand with a thickness of 2 m and a sub-bottom layer of basalt. The transmission loss for the same region under neutral gradient conditions is shown in Fig. 4.3B. The transmission loss characteristics can be seen to be similar out to a range of 3 km. Beyond this range the loss can be seen to be significantly less for the neutral gradient condition, with the greatest difference occurring at 1 kHz. These results indicate that the range of influence of the loudest industrial noise sources can be changed considerably by seasonal effects on the sound speed profile. Transmission loss data reported by Mackenzie (1961) for transmission at 200 Hz using a shallow source and receiver are also shown in Fig. 4.3B. Unfortunately no data are available at other frequencies for these conditions in this area.

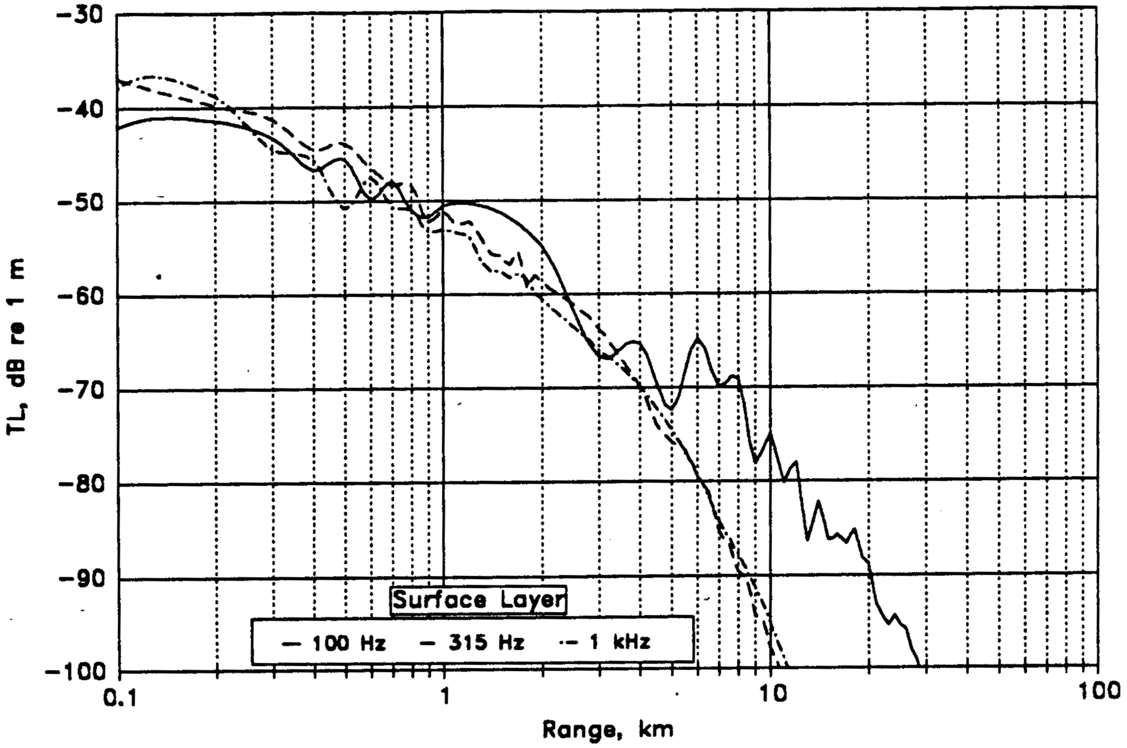


Figure 4.3A. Norton Basin Transmission Loss Surface Layer Conditions. Source Depth 5 m, Receiver depth 10 m.

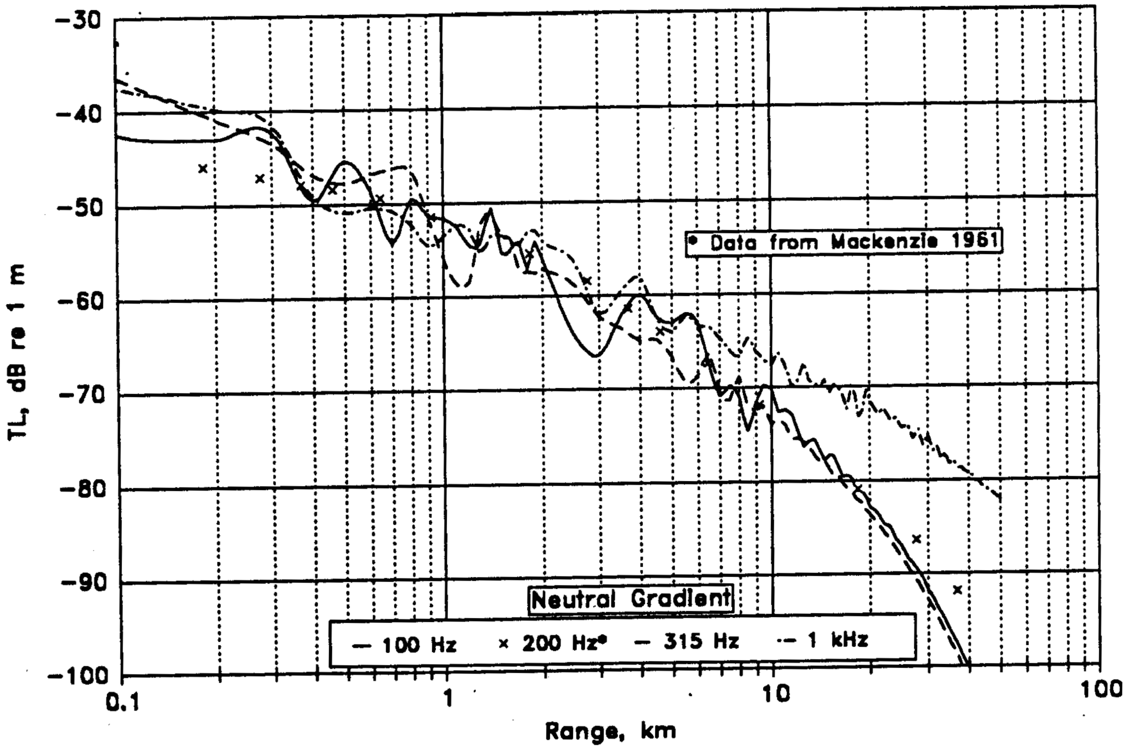


Figure 4.3B. Norton Basin Transmission Loss Neutral Gradient Conditions, Source Depth 5 m, Receiver Depth 10 m.

The IFD Model was also used to obtain transmission loss estimates for the North Aleutian Area and the Shumagin Area since only a limited number of empirical data are available for these areas also. Long range model estimates were not made for the Chukchi Area because data are available for both winter and summer conditions for this area (Greene 1981). The additional model results and the Greene data are presented in Appendix C.

4.2.1 The effect of a sloping bottom

The habitat of many species of marine mammals includes near shore and beach areas. Sound transmission is strongly influenced by the bottom slope present in most near-shore areas. When sound is transmitted upslope, as is the case for a source passing near a haulout area, two effects occur. If the bottom reflection loss is low, sound levels tend to be higher than those predicted by geometric spreading because the sound energy becomes concentrated in a smaller water volume as it travels upslope. However, if bottom loss is high, sound levels are reduced at a greater rate than expected from geometric spreading since sound undergoes more bottom contact than would occur for transmission over a constant depth bottom. These effects are further complicated by sound transmission and refraction in bottom material which often is an important means of sound transmission in very shallow water.

For a rigid, impermeable bottom theory predicts that sound transmission is not possible at frequencies for which the depth of water is less than 1/4 wavelength. Thus for sound transmission upslope from a broadband source, the low frequencies will be cut off or attenuated heavily at shorter ranges than the high frequencies. However, since most bottom material is not rigid and impermeable, this frequency-selective cutoff characteristic is not always observed. The presence of water-saturated sediments often permits significant sound transmission to occur up into the surf zone.

Because of the sloping bottom capability of the IFD Model, it was used to predict sound transmission characteristics for propagation toward shore in the Alaska Peninsula and Unimak Island areas. The profiles used for the model in this study are shown in Fig. 4.4. The geometry features a beach profile which has a constant slope connecting a flat region offshore with a flat region near shore. There are also two sloping bottom layers which have range-dependent thickness. Two types of potential sound impact situations were considered. An analysis of noise transmission from small craft offshore to a pinniped haulout area was made for a study conducted by LGL (Johnson et al. 1988). An analysis of an offshore vessel or oil rig noise transmission to whales near shore was made for this study. An example of the procedure and results for each analysis is presented here.

Table 4.2 lists the parameter values used in modeling the sound transmission for three different bottom types. Bottom Type 1 represents near-shore conditions at Port Moller and Cape Seniavin on the north shore of the Alaska Peninsula. It features a relatively thick layer of fine sand over a deep layer of coarser sand and gravel. Information for this model is based on data obtained from a NOAA survey made by Ertec Western Inc. (1983) and sand properties data reported by Stoll and Bryan (1970). Bottom Type 2 represents near-shore conditions at Pribilof Island sites and features a thin layer of

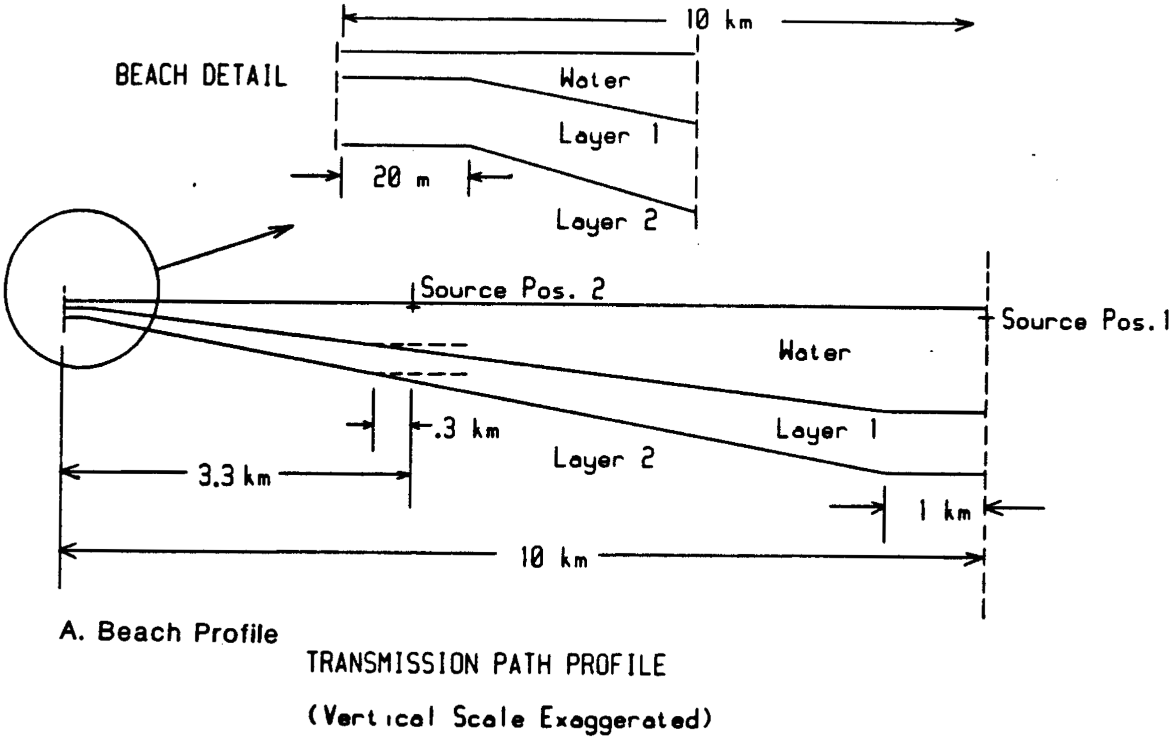


Figure 4.4A. IFD Model Geometry for Transmission from an Offshore Source to a Receiver Near the Beach.

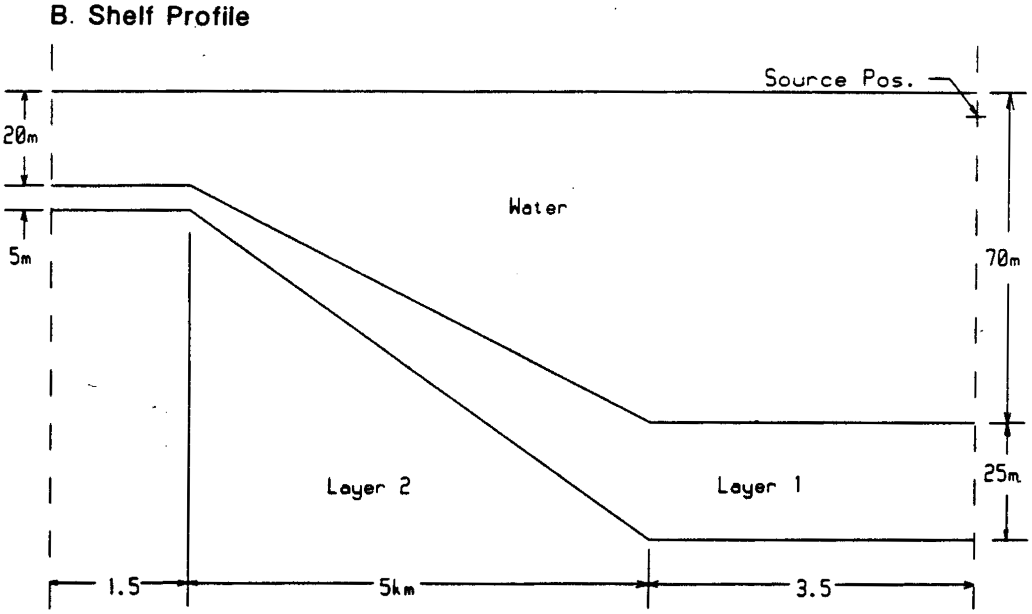


Figure 4.4B. IFD Model Geometry for Transmission From an Offshore Source to a Receiver Over a Coastal Shelf.

Table 4.2. Parameter Values for IFD Slope Model.

		Source Pos. 1 (10 km)			Source Pos. 2 (3.3 km)			Near-Shore (20 M)		
Type	**Slope**	**Water**	**Layer 1**	**Layer 2**	**Water**	**Layer 1**	**Layer 2**	**Water**	**Layer 1**	**Layer 2**
A. Bottom Layer Thickness, m (see Fig. 6)										
1	-0.004	37	25	>200	13	11.7	>200	1	5	>200
2	-0.01	91	2	>200	31	0.8	>200	1	0.1	>200
3	-0.01	70	25	>200				20	5	>200

B. Bottom Material Parameters

	Bottom Type 1			Bottom Type 2			Bottom Type 3		
	Water	Layer 1	Layer 2	Water	Layer 1	Layer 2	Water	Layer 1	Layer 2
Sound Speed (m/sec)*	1470.5	1700	1900	1471	1700	4000	1471	1700	1900
Density (kg/cu.m)	1000	1800	2200	1000	1800	2800	1000	1800	2200
Attenuation (dB/wavelength)	0	0.13	0.13	0	0.13	0.04	0	0.13	0.13
Layer 1 material	silt/fine sand			silt/fine sand			silt/fine sand		
Layer 2 material	sand/gravel			basalt			sand/gravel		

*Sound speed at surface 1470 m/sec, sound speed at 90 m, 1472 m/sec, linear gradient.

silty, very fine sand over a basalt rock sub-bottom. The model is based on data reported for Bering Sea regions by Mackenzie (1973). Bottom Type 3 represents conditions further off shore along the north shore of the Alaska Peninsula, Unimak Island and parts of the coastline near the Shumagin Islands. It features an initial depth of 70 m which shoals to 20 m over a distance of 5 km. The layer structure is similar to that of Bottom Type 1, with a different slope geometry as shown in Fig 4.4B.

The neutral gradient sound speed profile shown previously in Fig. 4.2 was used for the pinniped related model study. This is representative of Bering Sea conditions in spring before the warm summer surface layer has developed. For the gray whale related modeling, the surface layer profile typical of late summer conditions was also used.

The results of the IFD Model study using the Type 1 Bottom parameters are shown in Figures 4.5A through 4.5D. Figure 4.5D presents the TL characteristics for the two source positions plotted to show TL versus distance from the beach. This is presented as a more relevant format than the usual TL plot showing TL versus range from the source position.

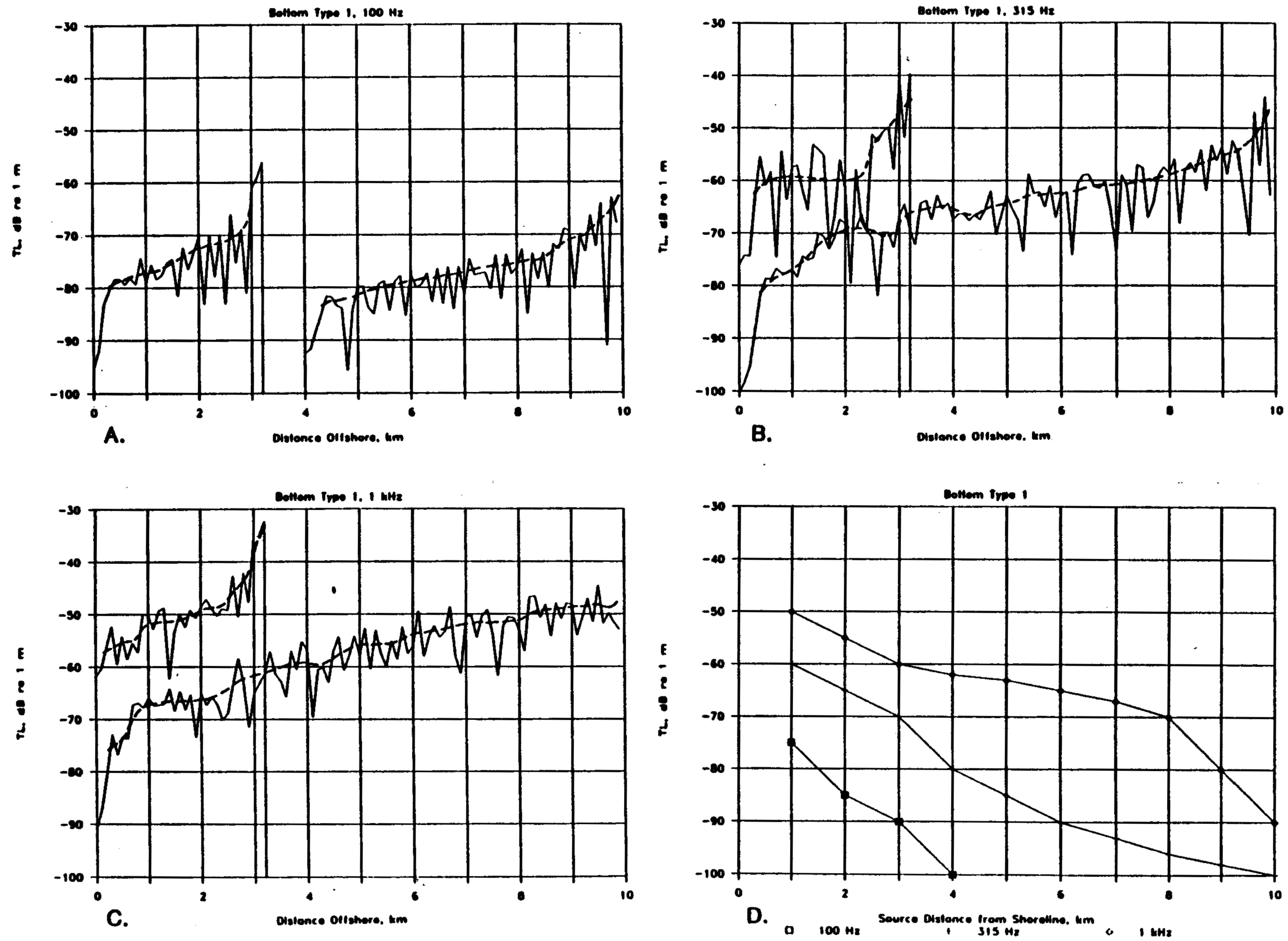


Figure 4.5. Offshore Transmission Loss for Sloping Bottom vs Distance Offshore
A. Bottom Type 1, 100 Hz; B. Bottom Type 1, 315 Hz;
C. Bottom Type 1, 1 kHz; D. Bottom Type 1, TL vs Source Range Offshore.

The model provides for transmission of only one frequency for each set of calculations. Consequently the calculated values shown in Fig. 4.5A for 100 Hz have fluctuations in level caused by multipath interference patterns. The results have been smoothed somewhat by averaging the TL values calculated at depths of 1, 2 and 3 m for each range increment to derive the solid curves shown in the figure. The dashed lines are estimated rms-averaged TL characteristics which would be obtained by averaging several model calculations using closely-spaced tones to smooth out the interference pattern.

Figure 4.5A shows that for a 100 Hz source located 10 km from the beach, the predicted TL becomes greater than 100 dB at range of 6 km from the source or 4 km from the beach. This is essentially the acoustic cutoff for sound at this frequency. For a source located 3.3 km from the beach the cutoff is reached within a few hundred meters of the beach. Note the TL at very short ranges from the source position is about 60 dB. This high value at short ranges is the result of the shallow source (1 m) and shallow receiver depths (2 m) selected for use in the study. This geometry was selected to represent the operating depth of the propellers of small and medium-sized vessels and the swimming depth of pinnipeds near the haul-out sites.

Figure 4.5B presents the predicted TL characteristics of the Type 1 bottom for 315 Hz. At this frequency the bottom losses are not as severe and transmission from a source at 10 km is not cut off until it gets very near the beach. For a source range of 3.3 km, transmission up to the beach region can be seen to occur. While attenuation rates near the source can be seen to be high as a result of the shallow geometry, a TL plateau is reached wherein a constant level is maintained or the level decreases slowly with increasing distance from the source. This is probably the result of sound transmission within the bottom layers and reflection and refraction out of the layers to reinforce sound in the water column. The TL characteristics shown in Fig 4.5C for 1 kHz are similar to those obtained at 315 Hz with somewhat lower values of loss being predicted.

The TL characteristics obtained from the model calculations for the Type 1 Bottom were interpolated to obtain a set of curves for predicting the TL from a shallow source to a shallow receiver near the beach as a function of the distance of the source from the shoreline. The results, shown in Fig. 4.5D, are presented to facilitate the estimation of received level near shore for a vessel operating directly offshore. The received level may be estimated as:

$$L_r = L_s - TL \quad \text{dB re } 1\ \mu\text{Pa} \tag{14}$$

where: L_r = Received level in a selected 1/3 octave band

L_s = Source level at 1 m in the selected 1/3 octave band for a specific source (from source level tables)

TL = The transmission loss from Fig. 4.5D for the 1/3 octave band at the range of interest (this may have to be interpolated).

The transmission loss characteristics calculated using the model with the Bottom Type 2 parameters are shown in Figs. 4.6A through 4.6C. When the TL characteristics at 100 Hz for the rocky bottom (Fig. 4.6A) are compared with those for the sandy bottom (Fig 4.5A), the propagation from the source at 10 km offshore can be seen to fall off more rapidly for the rocky bottom than for the sandy bottom. Normally sound transmission over a rocky bottom would be expected to be better than that over a sandy bottom. However in this case, because of the shallow source and receiver positions, most of the sound energy travels between the source and receiver by downward directed ray paths which incur a large number of bottom reflections in the case of the rocky bottom. For the sandy bottom much more sound energy is able to penetrate the bottom and eventually reflect and refract back out into the water layer to reinforce sound transmission at the longer ranges. The TL characteristics at 315 Hz (Fig. 4.6B) and at 1 kHz (Fig 4.6C) are similar to those at 100 Hz in that they all show a cutoff at a range offshore of 5 to 6 km for the 10 km source position. For the 3.3 km source position, the differences in TL characteristics between the Type 1 bottom and the Type 2 bottom are small. The TL near the beach is somewhat less for the rocky bottom than for the sandy bottom.

Figure 4.6D was developed by interpolation of the model results to obtain curves of TL versus source distance directly offshore for the Type 2 bottom. Comparison of the results for a rocky bottom (Fig. 4.6D) with those for a sandy bottom (Fig. 4.3D) shows that, while the TL is high at 100 Hz for both types of bottom, it is somewhat lower for the rocky bottom. At 315 Hz the TL for the rocky bottom is less than that for the sandy bottom for source distances less than 7 km offshore. For 1 kHz the TL values are similar for source distances less than 4 km, beyond which the TL for the sandy bottom condition is smaller. Thus the model results indicate that for the bottom geometries and parameter values used in the study, a rocky beach has less TL for nearby offshore sources than a sandy beach. While the transmission properties of a sandy beach provide less TL for the more distant offshore sources (>5 km) than a rocky beach, the relatively high losses for both types of beaches at these ranges probably make the difference academic for most sources of concern.

The TL characteristics shown in Figs. 4.7A and 4.7B were obtained using the IFD Model with a Type 3 Bottom and the layer geometry shown in Table 4.2 and Fig 4.4B. The source and receiver depths used were 5 m and 10 m respectively. Only one source position was used in this case and the figures show predicted TL versus range from the source toward shore. This analysis was directed at the situation of gray whales near shore in 20 m of water with a source offshore in 70 m. Because of deeper water, no acoustic cutoff is obtained within the the modeled range. For the neutral gradient condition (Fig. 4.7A), the TL from 1 km to 10 km for the 100 and 315 Hz bands can be seen to be about 15 dB. This is a normal value for propagation in shallow water over a flat bottom. However, the 1 kHz band shows a loss of only 3 dB over the same range. The upward sloping bottom seems to have the greatest effect on the higher frequencies for neutral SVP conditions.

For surface layer conditions (Fig. 4.7B) the predicted TL from 1 km to 10 km can be seen to be higher than in the previous case probably because of downward refraction and a greater number of bottom reflections per kilometer.

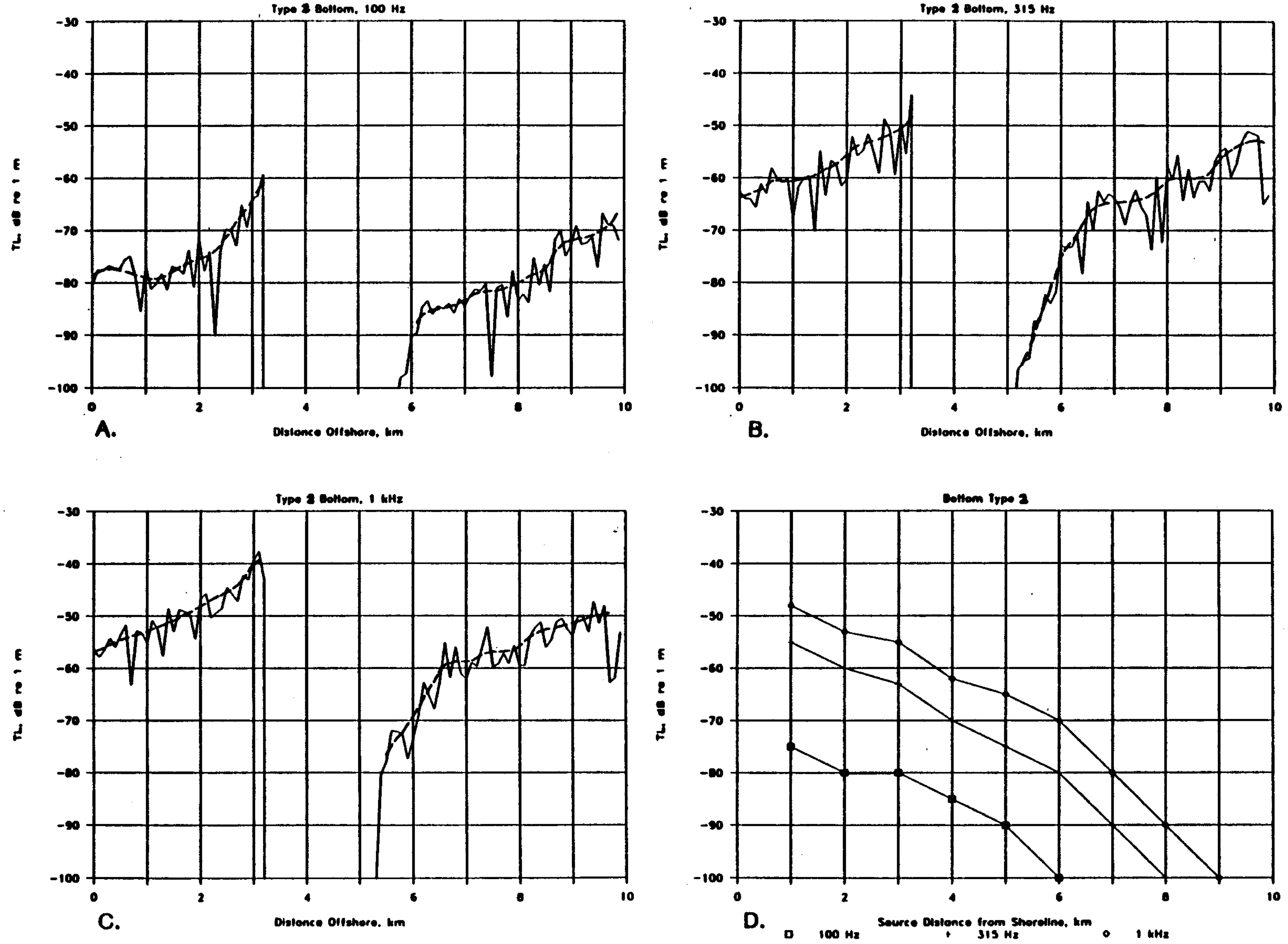


Figure 4.6. Offshore Transmission Loss for Sloping Bottom vs Distance Offshore
A. Bottom Type 2, 100 Hz; B. Bottom Type 2, 315 Hz;
C. Bottom Type 2, 1 kHz; D. Bottom Type 2, TL vs Source Range Offshore.

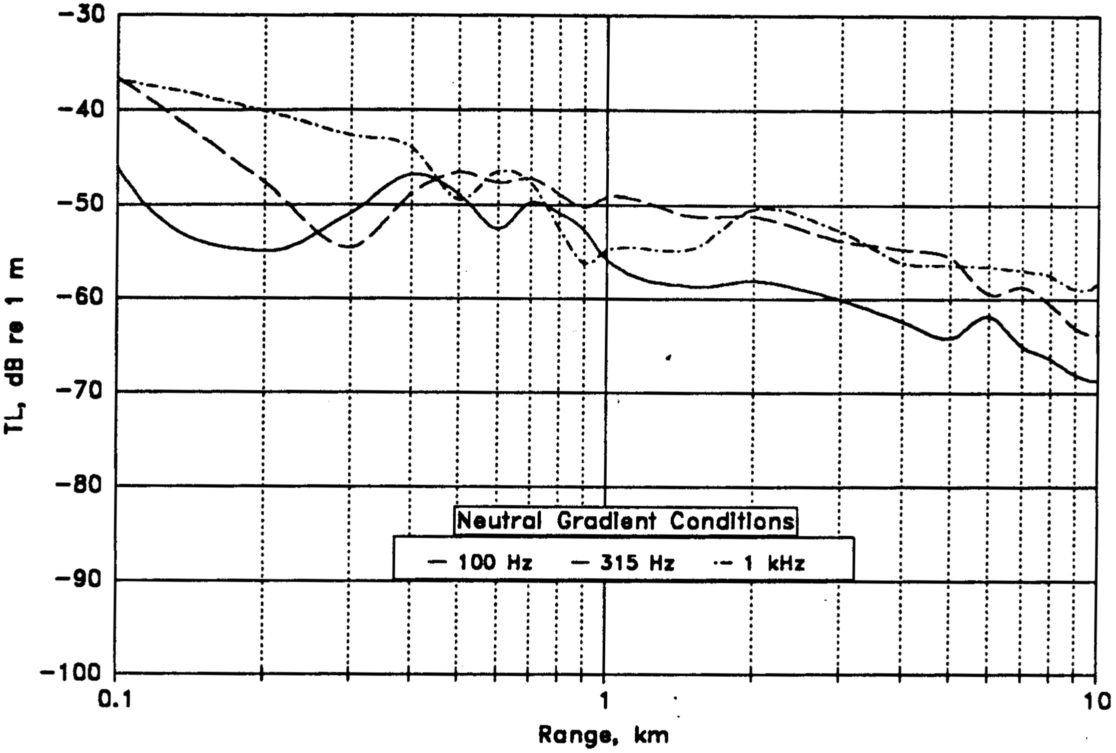


Figure 4.7A. Upslope Transmission Loss Characteristics for North Aleutian Area, Neutral Gradient Conditions, Source Depth 5m, Receiver Depth 10 m.

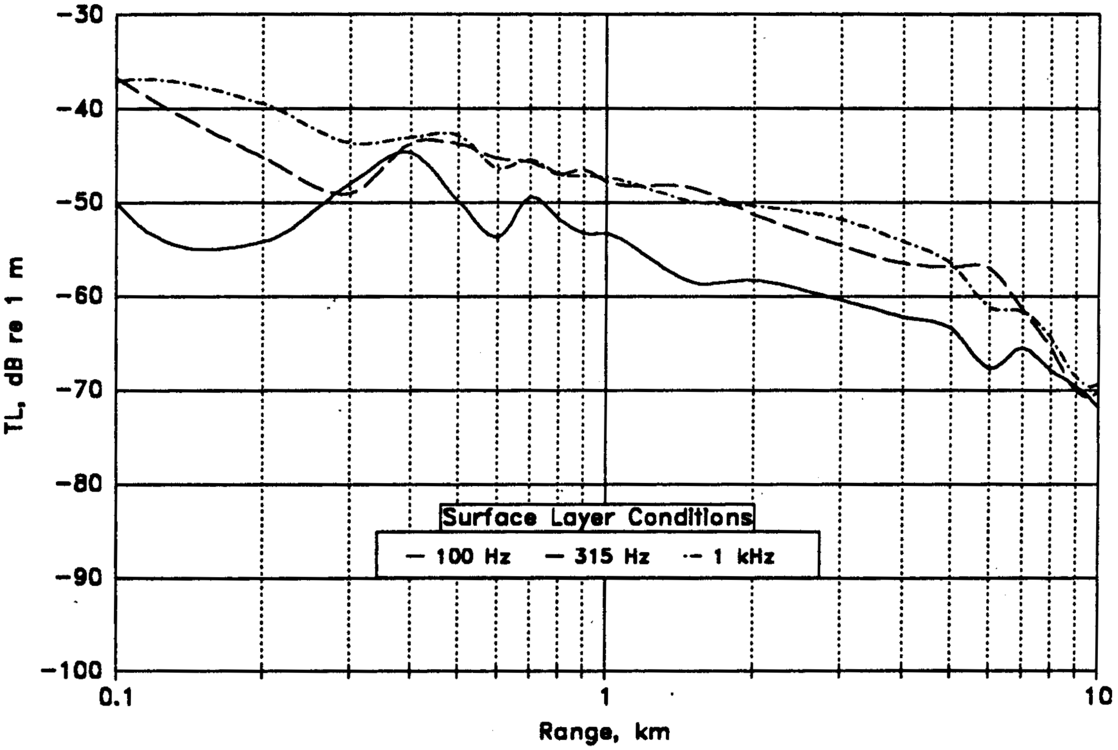


Figure 4.7B. Upslope Transmission Loss Characteristics for North Aleutian Area, Surface Layer Conditions, Source Depth 5m, Receiver Depth 10 m.

The greatest loss occurs at high frequencies and in the region near shore where the depth is reduced to 20 m. In this case a TL of 22 dB is observed for both the 315 Hz and 1 kHz bands, with a value of about 18 dB at 100 Hz. Since the propagation at 100 Hz is apparently not influenced very much by either the upward slope or by the change in SVP conditions over the 10 km range examined in the modeling procedure, it it likely that a significant amount of low frequency acoustic energy is reaching the near shore area by bottom refracted transmission in the water-saturated sediments. As shown by the model results for the very shallow Case 1 geometry, it is necessary for marine mammals to be very near shore to gain significant shielding from loud low frequency offshore sources.

4.3 Air-To-Water Transmission

Of the several papers available in the literature concerning transmission of sound from air into water, most do not consider the effect of shallow water conditions. Urick (1972) presents a discussion of the effect and reports data showing the difference in the underwater signature of an aircraft overflight for deep and shallow conditions. No analysis is presented which would permit estimation of the effective TL underwater for shallow water multipath transmission conditions. Young (1973) presents an analysis which, while directed at deep water applications, derives an equivalent underwater source for an aircraft overflight which can be used for direct path underwater received level estimates. Unfortunately, for the aircraft - marine mammal encounter geometry relevent to this study, the usual sound transmission involves both direct and bottom reflected paths. Because of this, it was necessary to develop an analytical model to help predict the total acoustic exposure level for marine mammals in shallow water near the path of an aircraft overflight (Malme and Smith 1988).

The model, which was developed for both this study and the related LGL study of pinniped response to aircraft noise (Johnson et al. 1988), provides for calculation of the acoustic energy at an underwater receiver contributed by both the direct sound field and a depth-averaged reverberant sound field. The direct sound field is produced by sound transmitted into the water along a direct refracted path from the airborne source to the underwater receiver. The reverberant sound field is produced by sound reflecting from the bottom and surface as it travels outward from the region directly under the aircraft. An analysis developed by P.W. Smith, Jr. based on an earlier study of shallow water sound propagation (Smith 1974) is used to predict the horizontally propagating sound field produced by the reflected sound energy.

Figure 4.8 shows the geometry and parameters used in developing the air-water transmission model. As depicted in the figure, sound from an elevated source in air is refracted upon transmission into water because of the difference in sound speeds in the two media. A virtual source location is formed which is the apparent location of the source for the sound path in water. Because of the large difference in sound speeds between air and water (a ratio of about 0.23) the direct sound path is totally reflected for grazing angles less than 77 degrees. For smaller grazing angles sound reaches an underwater observation point only by scattering from wave crests on the

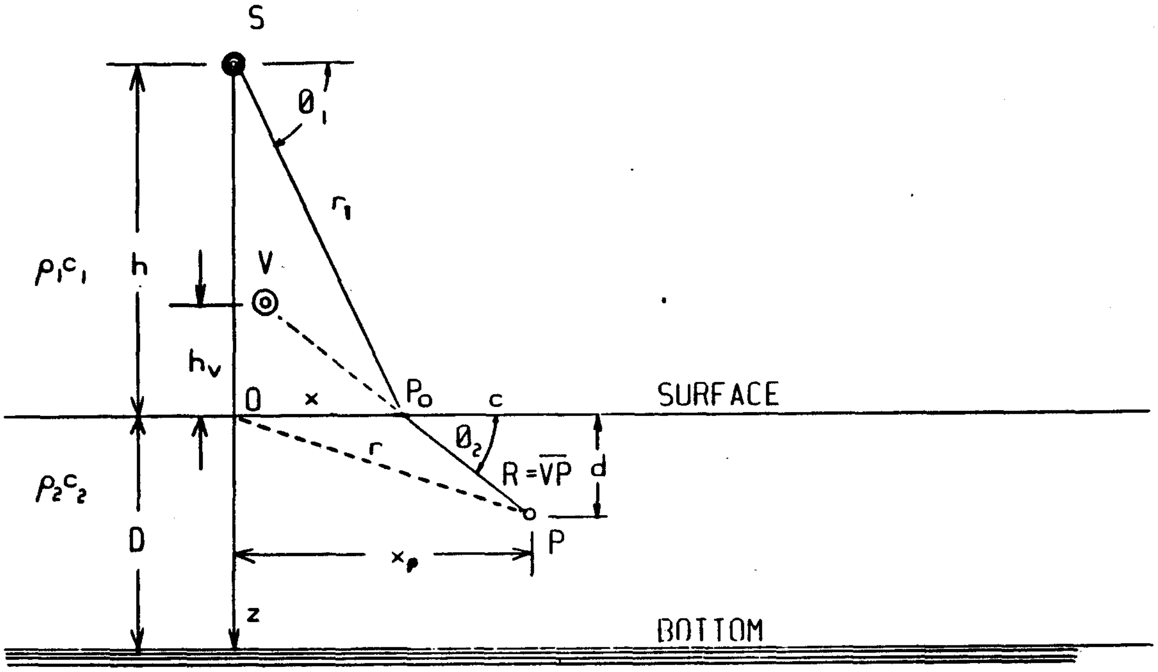


Figure 4.8. Geometry for Air-to-Water Sound Transmission.

surface, by non-acoustic (hydrostatic)* pressure transmission from the surface and from bottom reflections in shallow water.

As a result, most of the acoustic energy transmitted into the water from a source in air arrives through a cone with a 26 degree apex angle which intersects the surface and traces a "footprint" directly beneath the path of the source.

For underwater observation points in shallow water within this cone the directly transmitted sound energy is generally greater than the energy contribution from bottom reflected paths. At horizontal distances greater than 1 water depth from the boundary of the acoustic intercept cone on the surface, the energy transmitted by reflected paths becomes dominant and is an important feature of air-to-water transmission in shallow water. Thus two terms become necessary in the air - water transmission model to predict underwater received levels for the full range of expected source - receiver

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*This has been called "evanescent wave" transmission by Urick and others. It is important for transmission at low frequencies to receiver locations near the surface.

geometries. The analysis is described in Malme and Smith (1988), with the results summarized here in a logarithmic form for convenience in application to specific aircraft and overflight geometry.

Let $A = (h_v + d)$ where $h_v = nh$ and $n = c_1/c_2$, the effective source altitude.

x = the horizontal range.

L_r = the underwater sound level, dB re 1 μPa.

L_{inc} = the sound level in free air at a distance h from the source (excluding boundary effects), re 1 μPa.

[This may be measured or determined from Eq. (13)]

Then

$$L_r = L_{inc} + 20\text{Log}(h) - 7 + 10\text{Log}[T_d(A,x) + kT_a(b,x)] \qquad (15)$$

where $T_d(A,x) = [A/(A^2+x^2]^2$ (the direct field transmission factor) (16)

$T_a(b,x) = I/xD$ for Beta < 5 (17A)

$T_a(b,x) = (\pi D/2b^3x^5)^{1/2}$ for Beta => 5
(the channel transmission factor) (17B)

Beta = $bx/2D$, a depth-averaged sound field parameter
(Malme and Smith 1988) (18)

$k = 1/(A^2/x^2+1)$, a weighting factor for T_a

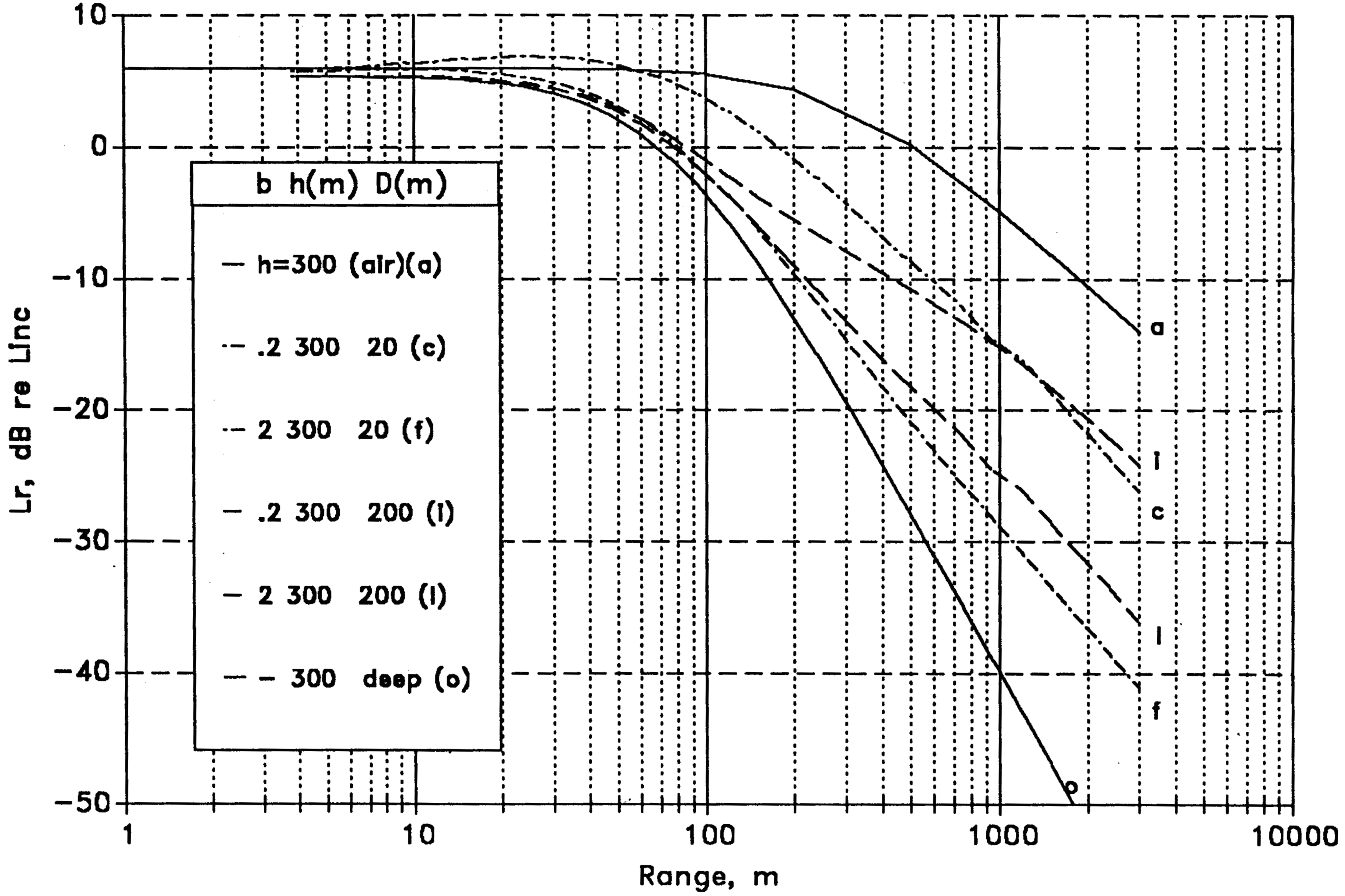
b = bottom loss factor

I = Reverberant energy summation (Malme and Smith 1988)

The relationship shown in Eq. (15) suggests that a 7 dB drop in level occurs as sound passes through the water surface, in addition to the spreading loss. This is correct for the radiated pressure component at some distance from the surface; however close to the surface, near-field effects occur which cause the underwater pressure to become equal to the pressure in air just above the surface (Urick 1972). This pressure is double that in the free field at the same range from the source because of the high acoustic impedance of water relative to that of air.

Several example figures were made using Eq. (15) to illustrate the interdependence of the various model parameters. Figure 4.9 shows the difference between the sound level underwater (L_r) and the "incident" sound level in air

FIG. 4.9 AIR TO SHALLOW WATER SOUND TRANSMISSION
Receiver Depth 5 m, Source Altitude 300 m



(L_{inc}). The incident sound level is defined as the level that would be measured at the surface directly under the source, if the surface were not there. This point on the surface is defined as the subsource point. A constant source altitude of 300 m and a constant receiver depth of 5 m have been used for all of the curves shown in the figure. The values chosen for the bottom loss parameter b are representative of soft mud (b = 2) and hard basalt (b = 0.2).

The highest curve in the figure shows the relative sound level in air just above the surface. When the source is overhead, the sound level is 6 dB higher than the free field incident pressure because of the boundary reflection. The lowest curve in the figure shows the relative sound level in deep water, where only the direct sound field is present. The curves in between show the influence of the bottom reflected sound in shallow water. For a hard bottom condition, the sound level near the subsource position can be seen to be influenced by the water depth; higher levels occuring in shallower water. However at distances greater than 500 m in this example, the water depth has a much smaller influence. Both the 20 m and the 200 m depth conditions show sound levels only 10 dB less than those in the air above the surface. This is to be compared with the levels at the same range in deep water which are 35 dB less than those in air.

For the soft, absorptive bottom condition, the water depth influence on the underwater sound level near the subsource point is not large, but at distances greater than 300 m the shallower depth can be seen to cause higher losses than the deeper since there are more reflections per kilometer. For ranges from the subsource point greater than 1000 m the sound levels can be seen to be more than 10 dB higher than those at the same range in deep water.

The effects of variation of source altitude, water depth and bottom loss for a hard bottom condition and a constant receiver depth are shown in Fig. 4.10. The altitudes selected are believed to be representative of those used by small aircraft flying over shoreline areas. The relative sound levels for deep water conditions are also shown for comparison purposes. At ranges of around 100 m from the subsource point both the bottom depth and source altitude can be seen to influence the relative sound levels, but at ranges beyond 500 m the altitude appears to have the greatest effect. However, the levels shown in the figure are relative to the "incident" sound level which is determined by the transmission loss in air. As an example, the transmission loss difference in air between source heights of 300 m and 1000 m would be about 10 dB, neglecting absorption losses. The figure shows that at a range of 1000 m the relative underwater level for an altitude of 1000 m is about 10 dB higher than that for an altitude of 300 m. Thus the total in-air and underwater transmission losses for source heights of 1000 m and 300 m are about equal and, as a result, the underwater sound level produced by an aircraft overflight is very nearly independent of the aircraft altitude for receiving locations at distances from the subsource point greater than the virtual source height (>0.23 h).

Figure 4.11 shows the results of the parameter comparison for soft bottom conditions. Here the relative levels are controlled by apparent altitude dependence out to ranges beyond about 500 m. Beyond this range bottom depth

FIG. 4.10 AIR TO SHALLOW WATER SOUND TRANSMISSION
Receiver depth 5 m, Hard Bottom

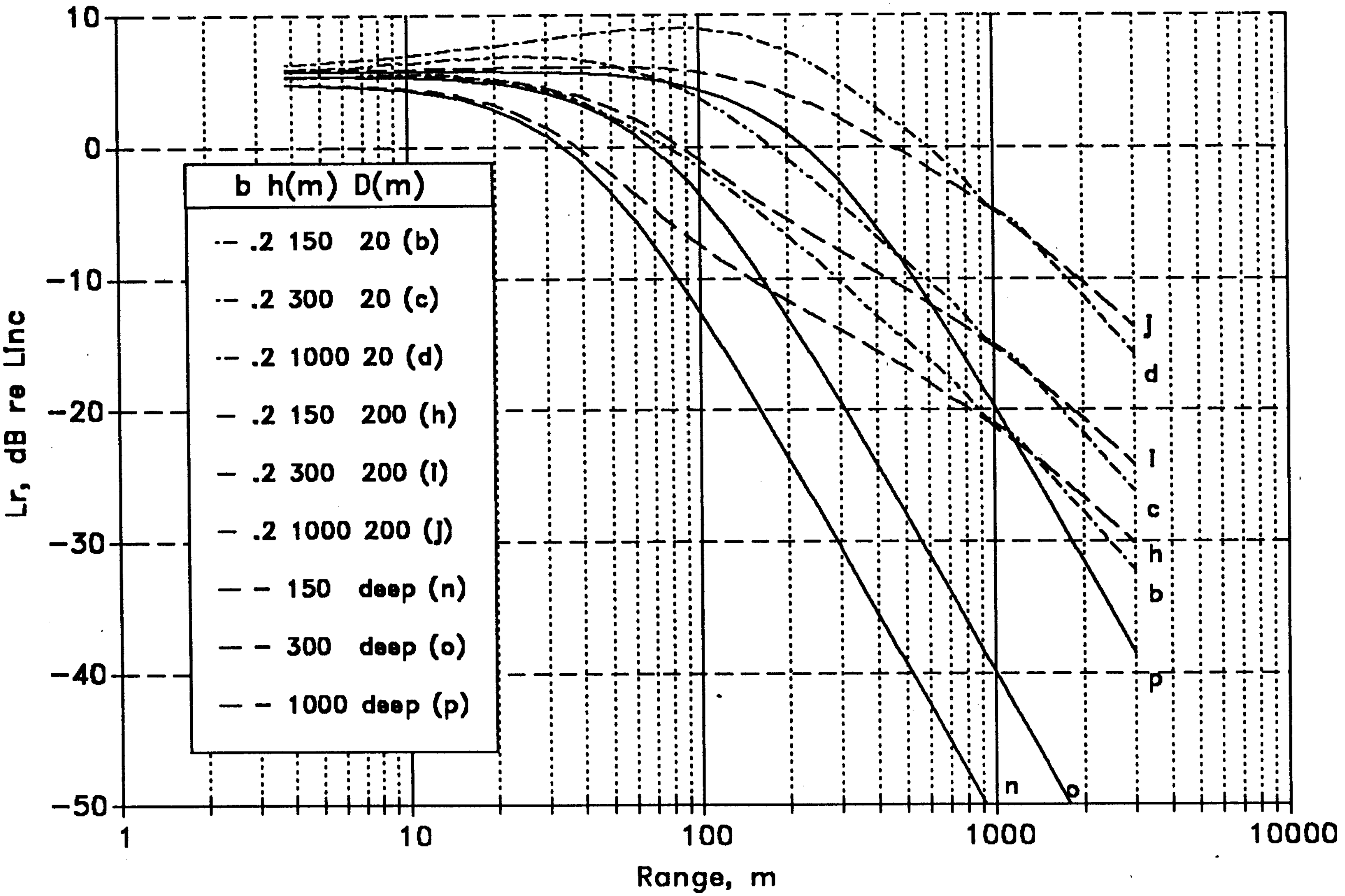
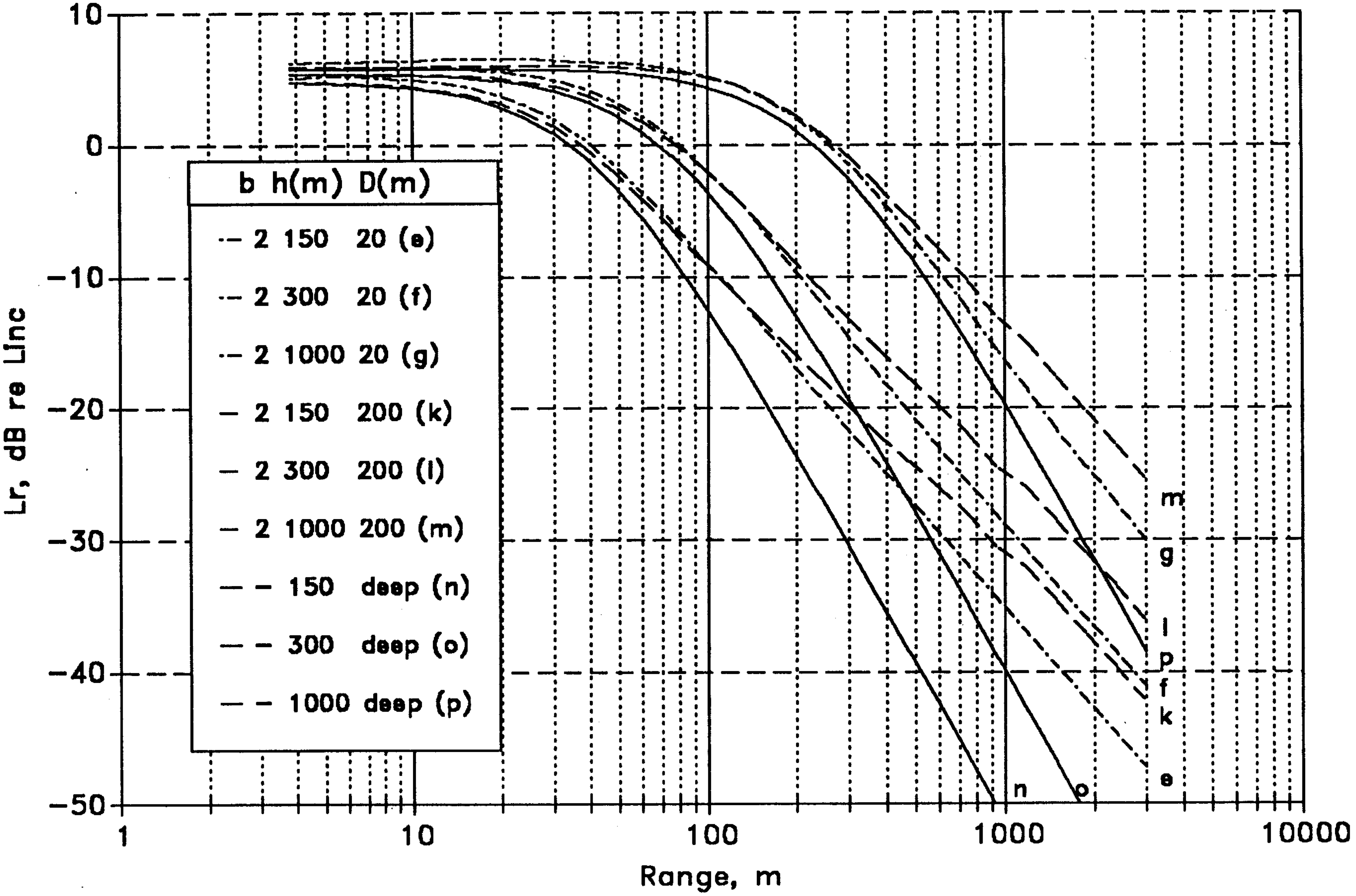


FIG. 4.11 AIR TO SHALLOW WATER SOUND TRANSMISSION
Receiver Depth 5 m, Soft Bottom



and bottom loss effects become more important. Again, as seen in Fig. 4.9, the losses for the 20 m bottom depth are greater than those for the 200 m depth because of the larger number of bottom reflections incurred in typical sound paths. Since, for a specific source altitude, the transmission loss for deep water is greater than that for either of the depths selected for the example, there is an optimum depth for a given type of lossy bottom which produces the lowest transmission loss.

The procedure for estimating the received level underwater using a calculated TL value or relative level values from Figs. 4.9 - 4.11 requires either measured aircraft signature information or published data from standard flyover tests. If standard flyover data (referred to a sound pressure of 20 μPa and a height of 300 m) are used, it is necessary to adjust these data to represent levels relative to 1 μPa (add 26 dB). If the temperature and relative humidity for the calculation conditions are greatly different from Standard Day conditions, the corrections given in Table 4.1 can be applied to the aircraft flyover spectrum to obtain better received level estimates at high frequency. These corrections are applied to obtain the correct sound level value for the high frequency bands at the water surface if the actual flyover altitude is greatly different from the standard test height. The molecular absorption loss incurred in the underwater path has not been included in the modeling procedure because generally short range applications are anticipated. This factor should be included for underwater transmission ranges greater than 5 km and/or frequencies higher than 10 kHz.

5. SOUND EXPOSURE PREDICTION PROCEDURES AND RESULTS

In this section the information on species distribution is combined with information on source distribution, source level and transmission loss to determine the most significant sources in terms of their effective range and numbers of mammals potentially affected. A procedure for rating the sources is presented which is based on the amount of sound energy contributed to the environment in a specific reference area. The source rating is combined with a receiver (species) rating procedure which includes the degree of matching between source bandwidth and species hearing response, the species hearing sensitivity, and the number of animals present in the reference area. The output of this exposure rating procedure provides a numerical indication of those source - species encounters which may have the highest potential for acoustic interaction in a given area. Estimated zones of influence based on probability of avoidance were determined for potentially high interaction encounters where response criteria were available.

While much of noise source level and species response rating procedure involves principles of physical acoustics, it must be emphasized that some of the rating procedures are based on human psychoacoustic research and incorporate hypotheses which have not been tested with marine mammals. Moreover, it has been necessary to infer and estimate many of the parameter values needed to develop ratings for several species where data gaps exist. The modeling procedure which has been developed in this study is offered as a means of identifying those areas where more information is needed. When the information becomes available it can be incorporated into the data base to replace presently inferred or estimated values and help provide better rating results. The modeling procedure itself can evolve with necessary changes and extensions when the needed information becomes available.

5.1 Noise Source Distribution*

The distribution of noise sources in the marine and coastal regions of Alaska was analyzed using the source classification format established in Section 3. Information on the distribution of petroleum industry sources was obtained from reports of the MMS OCS Office. Transportation industry source data were obtained from ship and ferry schedules, port records, and airline schedules. Fishing industry data bases and reports were reviewed to determine vessel operating areas. In most cases vessel numbers on specific fishing grounds were estimated because of a general lack of this type of information in available reports. Additional information on fishing vessel activity and on cultural and recreational sources was obtained from the environmental impact studies and the economic study series of the MMS. The series of final reports published by the NOAA Outer Continental Shelf Environment Assessment Program (OCSEAP) was also helpful in providing information on source locations and estimated numbers. The information obtained from review of documents was supplemented by telephone interviews when appropriate and by personal observations made on recent trips to Alaskan coastal areas while working on other projects.

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*D.G. Roseneau, LGL, Alaska, Fairbanks, and C.I. Malme, BBN.

In Section 2 the distribution of marine mammal species was described on a species-by-species basis. However, since the distributions of various sound sources in the Alaskan marine environment are very diverse and variable, it is more useful to discuss the source distribution on a planning area basis. A detailed description of the sources and their locations has been developed and is presented in the form of a summary table together with a narrative discussion focussed primarily on the Alaskan coastal OCS planning areas, including adjacent landward regions, with emphasis on the Chukchi Sea, Norton Basin, North Aleutian Basin, and Shumagin Areas.

Source distribution information for the most significant source types has also been used to produce two map overlays which can be used with the species distribution maps presented in Section 2. These overlays show estimated source distribution patterns for fishing vessel, commercial shipping, aircraft, and cultural activities. The overlays, which are self-explanatory, are located in an envelope inside the back cover of this report.

5.1.1 Beaufort Sea

This area has been the location of much oil exploration and offshore drilling activity in recent years and several specific studies of underwater noise have been completed in the region (Miles et al. 1987, Greene 1987a, Ljungblad et al. 1985). The seismic sources, icebreakers, drillships, supply vessels and helicopter traffic associated with this activity are the major sources of man-made noise in this area. Secondary sources are supply barge activity for the Prudhoe Bay complex, commercial air traffic into Prudhoe Bay and Barrow, and hunting from small motor-powered vessels. A listing of the major sources is given in Table 5.1.

5.1.2 Chukchi Sea

Little direct information is available on man-made noise in the Chukchi Sea. The seismic source activity required for oil and gas development is undoubtedly a dominant noise contributor for this region. The noise produced by icebreakers that occasionally pass through this region will be louder than that produced by locally operating sources. Supply barge and aircraft traffic are secondary contributors. Some observations for specific areas are as follows:

1) Point Lay: Some small boat traffic occurs along the coast in the vicinity of the summering whales when residents of Point Lay and Wainwright visit one another, or travel to coastal hunting and fishing camps, or go on other hunting forays. Also, some low-level aircraft traffic occurs along the coast between Point Lay, Wainwright and Barrow nearly every day. Single and twin-engine airtaxi aircraft often follow the beach below 150 m (500 ft) because of local weather conditions. An average of about one to two small aircraft land and take off low over the coast at Point Lay per day, and about one larger multi-engine cargo aircraft services the nearby DEW Line radar facility each month (D. Schmidt, pers. comm.).

TABLE 5.1 MAJOR NOISE SOURCE DISTRIBUTION IN ALASKA OCS PLANNING AREAS

				Avg.	Source Char.(2)		
Region	Location	Season	Source	No.(1)	Ls(dB)	BW(Hz)	Comments
Beaufort	Drill Site	Su, F	Icebreaker	1	192	40-6300	Assumes 1 site active
"	"	"	Drillship	1	174	20-800	"
"	"	"	Supp.Vessels	2	171	100-12500	"
"	General	Su, F	Air Gun Array	3	216	20-160	Based on prev. schedules
"	"	W, Sp	Vibroseis Array	1	212	25-315	"
"	"	Sp,Su,F	Helicopter Ops.	20/wke	168	16-400	Personnel and cargo transfer
"	Coastal	Su	Supply Barges	7	171	100-12500	Sea lift for Prudhoe Bay
"	Coastal	Su	Supply Barges	3	171	100-12500	Supplies for Barrow
"	Prudhoe Bay	All	Comm. Air Serv.	50/wk	185	100-800	B737-200, B727 aircraft mainly used
"	Barrow	All	Comm. Air Serv.	44/wk	185	100-800	B737-200, twin-eng prop aircraft
Chukchi	General	Su, F	Air Gun Array	1	216	20-160	Assumes planned survey activity
"	"	W,Sp	Vibroseis Array	1	212	25-315	"
"	"	Sp,S,F	Icebreaker	1	192	40-6300	Transient icebreaker passage
"	Wainwright	All	Air Service	27/wk	163	100-315	Twin-eng and single-eng planes used
"	Pt. Lay	All	Air cargo	1/mo	175	63-160	C-130 Aircraft used for DEW-Line supply
"	"	Su	Supply barge	1	171	100-12500	Supply barge for DEW-Line
"	Cape Lisburne	Su	Air Cargo	1/mo	175	63-160	C-130 Aircraft used for USAF radarbase supply
Hope Basin	General	Sp, F	Icebreaker	1	192	40-6300	Transient icebreaker passage
"	Kotzebue Sound	Su	Supply Barges	6e	171	100-12500	Supplies for Kotzebue, other towns
"	Kotzebue	All	Comm. Air Serv.	121/wk	187	100-800	B727, B737-200, twin-eng prop aircraft
"	"	All	Air freight	5/wk	175	63-160	C-130, DC-7, Electras used
"	Kotzebue Sound	Su, F	Small Craft	30e	167	40-16000	Single and twin outboard skiffs
Norton Basin	General	Sp, F	Icebreaker	1	192	40-6300	Transient icebreaker passage
"	Nome	Su, F	Dredge	1	172e	80-800e	Near shore gold dredge
"	"	Su, F	Ships,LgBarges	18	171	100-12500	Supplies for region
"	"	Su, F	Small Barges	200e	168e	315-16000e	Trans-shipment to other towns
"	"	All	Comm. Air Serv.	173/wk	187	100-800	B727, B737-200, twin-eng prop aircraft
"	Unalakleet	All	Comm. Air Serv.	28/wk	185	100-800	B737-200, twin-eng prop aircraft
St. Matthew Hall	General	Sp, F	Icebreaker	1	192	40-6300	Transient icebreaker passage
"	"	Su, F	Trawler	10e	157	40-1000	Offshore fishing
"	Bethel	Su, F	Supply barge	6e	171	100-12500	Supplies for region
"	"	All	Comm. Air Serv.	180/wke	185	100-800	B737-200, twin-eng prop aircraft
N. Aleutian Bas.	General	Su, F	Air Gun Array	1e	216	20-160	Assumes planned survey activities
"	Near AK Penin.	All	Seismic noise	1-10/yr	<240e	0.1-50	Sporadic seismic events at various levels
"	Bristol Bay	Su, F	Trawler	1000	157e	40-1000e	Includes all medium to large fishing vessels
"	"	Su, F	Small Craft	2000e	167e	40-16000e	Includes all 1 and 2 eng. skiffs and tenders
"	"	Su, F	Light Aircraft	100	157	125-250	Single-engine spotter aircraft
"	King Salmon	All	Mil. aircraft	12/wke	186e	250-8000	F-15 jet fighter operations
"	"	All	Comm. Air Serv.	140/wk	185	100-800	B737-200, Fairchild Metro, twin-eng prop
"	Dillingham	All	Comm. Air Serv.	122/wk	185	100-800	B737-200, Fairchild Metro, twin-enf prop
"	"	Su, F	Supply barge	1/wk	171	100-12500	Supplies for region
"	Nelson Lagoon	Su, F	Fish Proc. Ship	1	170e	20-1000e	Fish processing ship in lagoon periodically

Notes (1) Source numbers based on published information, local inquiry, or estimated (e) values.
(2) Source characteristics based on study results presented in Sect. 3.3 or on estimated (e) values.

TABLE 5.1 (CONT.) MAJOR NOISE SOURCE DISTRIBUTION IN ALASKA OCS PLANNING AREAS

				Avg.	Source Char.(2)		
Region	Location	Season	Source	No.(1)	Ls(dB)	BW(Hz)	Comments
St. George Basin	General	Su, F	Trawler	20e	157e	40-1000e	Distributed medium to large fishing vessels
"	Dutch Harbor	All	Comm. air serv.	36/wk	185	100-800	B737-200, Goose, Twin-eng prop aircraft
"	"	All	Cargo vessels	10/wk	180e	40-5000e	Dry cargo and container vessels
"	"	All	Oil tanker	1/wk	185e	40-5000e	Fuel resupply service
"	"	All	Tug/barges	2/wk	170	100-12500	Cargo transfer and reshipment
"	Akutan Harbor	Su,F	Fish processor	1	170	20-1000e	Fish processor with assoc. vessel activity
"	Unimak Pass(N)	All	Ship traffic	100/wk	175e	40-5000e	Avg. ship traffic, see Shumagin for details
Shumagin	Unimak Pass(S)	All	Large ships	30/wke	185e	40-5000e	Container, log, car carriers and tankers
"	"	All	Medium vessels	30/wke	175e	100-12500e	Dry cargo, tug/barges. large trawlers
"	"	Su, F	Fishing vessels	60/wke	165e	100-12500e	Transiting to fishing grounds
"	Near AK Penin.	All	Seismic noise	1-10/yr	<240e	0.1-50	Sporadic seismic events at various levels
"	Cold Bay	All	Comm. air serv.	27/wk	187	80-800	B727, Electra, Twin-eng prop aircraft
Cook Inlet	General	All	Seismic noise	<2/yr	<220e	0.1-50	Sporadic seismic events
"	Anchorage	All	Large ships	2/wk	185e	40-5000e	Container, tanker, misc. cargo
"	"	All	Tug/barges	5/wke	170	100-12500	Cargo transfer
"	"	All	Comm. air serv.	Cont.	180e	30-8000e	Essentially continuous traffic to 3 airports
"	Kenai	Su, F	Fishing vessels	Cont.	165e	100-12500e	Commercial and sports-fishing activity
"	"	All	Airport traffic	Cont.	165e	80-1600e	Mixed medium and small aircraft, some jets
"	Homer	Su, F	Fishing vessels	Cont.	165e	100-12500e	Fishing and pleasure craft activity
"	"	Su, F	Ferry	4/wk	175e	40-5000e	Alaska ferry service
"	"	All	Airport traffic	Cont.	165e	80-1600e	Medium and small aircraft, helicopter traffic
"	West side	All	Oil Platforms	Variable	160e	63-500e	Production platform noise (Malme et al. 1983)
Kodiak	Kodiak	All	Large ships	2/wk	185e	40-5000e	Container, tanker, and genral cargo
"	"	All	Tug/barges	5/wke	170	100-12500	Cargo shipment, transfer
"	"	Su, F	Ferry	4/wk	175e	40-5000e	Alaska ferry sevice
"	"	All	Fishing vessels	50/wke	165e	100-12500e	Commercial fishing activity
"	"	All	Comm. air serv.	195/wk	185	100-800	B737-200, med. turboprops, twin-eng. prop
Gulf of Alaska	Seward	All	Large ships	4/wk	185e	40-5000e	Container, general cargo
"	"	All	Tug/barges	10/wke	170	100-12500	Cargo shipment, transfer
"	"	Su, F	Ferry	4/wk	175e	40-5000e	Alaska ferry service
"	"	All	Fishing vessels	25/wke	165e	100-12500e	Commercial fishing activity
"	Valdez	All	Tankers	28/wk	185e	40-5000e	Pipeline tanker service
"	"	Su, F	Ferry	12/wk	175e	40-5000e	Alaska ferry service
"	"	All	Comm. air serv.	24/wk	165e	80-1600e	Convair TProp, twin-eng prop aircraft
"	Whittier	All	Large ships	2/wke	185e	40-5000e	Container, general cargo
"	"	Su, F	Ferry	12/wk	175e	40-5000e	Alaska ferry service
"	"	All	Tug/barges	5/wke	170	100-12500	Cargo shipment, transfer
"	P. Wm. Sound	Su, F	Cruise ships	2/wke	180e	40-5000e	Tourist sightseeing
"	S.E. Alaska	Su, F	Cruise ships	12/wke	180e	40-5000e	Tourist sightseeing
"	"	Su, F	Ferry	12/wke	175e	40-5000e	Alaska ferry service
"	"	All	Tug/barges	20/wke	170	100-12500	Cargo shipment, transfer
"	"	All	Fishing vessels	25/wke	165e	100-12500e	Commercial fishing activity
"	"	All	Comm. air serv.	50/wke	165e	80-1600e	Avg. for Sitka, Petersburg, Wrangell,Gustavus
"	Juneau	All	Comm. air serv.	182/wk	187	80-800	B737-200, B727-200, twin-eng. prop
"	Ketchikan	All	Comm. air serv.	268/wk	187	80-800	B737-200, B727-200, twin-eng. prop

Notes (1) Source numbers based on published information, local inquiry, or estimated (e) values.

(2) Source characteristics based on study results presented in Sect. 3.3 or on estimated (e) values.

Also, a large barge servicing the DEW Line site delivers equipment and supplies to a beach near the local entrance to Kasegaluk Lagoon every year (usually during early August -- D. G. Roseneau, pers. obs.). Typically, several pieces of heavy equipment (e.g., fork lifts, front-end loaders, caterpiller-type tractors) are put ashore to transport supplies across the barrier island. Boats then take the supplies across the lagoon to the road to the radar facility.

2) **Cape Beaufort, Chukchi Sea:** A pilot project to surface-mine coal has been operating near Cape Beaufort on the Chukchi Sea for about two years (1986-1987) (J. Trent, pers. comm.). The project, located on private lands, is being sponsored by the Arctic Slope Regional Corporation in an effort to test the feasibility of providing an alternate source of heating fuel to villages in the region (e.g., Point Lay, Wainwright, Barrow). The grounds being mined are located a few miles inland from an area of the Chukchi coast used by a summering population of 2,000-3,000 migrating, feeding and staging (and possibly calving) white whales (see comments on Point Lay above). Coastal mine-related activities have apparently been minimal (i.e., some aircraft traffic -- possibly some boat traffic). However, the development plan apparently includes a possible coal-staging/loading and barge landing area on the coast at or near Omalik Lagoon, about 12 km (7.5 mi) north of Cape Beaufort. Within a few years, the project may become a source of noisy activities that may be potentially disturbing to summering whales.

Several low-flying helicopters were seen flying to and from the general area of Capes Sabine and Beaufort during July - early August 1987 (D.G. Roseneau and A. Sowls, pers. obs.).

3) **Cape Lisburne:** Low flying aircraft often pass within about 0.8 km (0.5 mi) of the cape and nearby beaches every few days during June - September (D.G. Roseneau and A.M. Springer, pers. obs.). Most air traffic consists of medium and large-sized twin and multi-engined aircraft servicing the Air Force base.

Small boats also pass within 15-150 m (50-500 ft) of the cape and nearby beaches in varying numbers every summer (D.G. Roseneau and A.M. Springer, pers. obs.). Most boat traffic consists of a variety of single and twin-engined outboard-powered skiffs carrying subsistence hunters between traditional seabird egg-gathering sites on the cliffs and hunting areas east of the cape, and the village of Point Hope, about 65 km (40 mi) southwest of the cape. Also, outboard-powered inflatable rafts (usually one, occasionally two) have been used by seabird researchers traveling between study sites south and east of the cape and the Air Force base in every year but one (1982) since 1976 (usually every boatable day during intervals ranging from one to five weeks in July - August).

See Table 5.1 for estimates of source types and numbers for this area.

5.1.3 Hope Basin

The occasional operation of icebreakers in this area is expected to be the major noise source. During the open water season, boat and aircraft traffic near Kotzebue are secondary contributors. Some specific observations for the Kotzebue Sound region are presented in the following discussion.

1) **Kotzebue Sound:** A considerable amount of small boat traffic (generally consisting of large skiffs powered by single or twin outboard engines in the 40-100 hp class) and some diesel-powered tugboat/barge traffic has occurred in Kotzebue Sound for many years. Nearshore boat traffic has increased substantially near Kotzebue and along the northern shore of the sound (including Hotham Inlet) since a large July - August chum salmon (*Oncorhynchus keta*) fishery began expanding during the late 1970's. Tugboats and barges deliver supplies to Selawik in Selawik Lake, the Elephant Point - Buckland areas in Eschscholtz Bay, the village of Deering on the south shore of the sound, and several larger camps at other locations on the north and south shores of the sound several times each season. Many small boats also regularly frequent nearshore waters near Deering, clusters of summer camps in upper Eschscholtz Bay (e.g., Elephant Point), and many other traditional camps scattered around the perimeter of the sound.

A considerable amount of daily low-level air traffic has also occurred over the nearshore environments of the sound for many years, including single and twin-engine Kotzebue-based private and charter aircraft traveling between Kotzebue and outlying villages and fish camps (e.g., Piper Cubs; Cessna 180's, 185's, 206's, 207's 402's; Aero Commanders; British Islanders; Beechcraft 18's; DeHavilland Canada Otters; similar makes and models of other aircraft). Also, larger twin and multi-engine cargo and passenger aircraft (e.g., Douglas DC-3's, DC-4's, DC-6's, DC-7's; Lockheed Electras; Fairchild F-27's; Hercules C-130's; Boeing 727's, 737's) have used the Kotzebue airport every day for years. In general, volumes and kinds of air traffic have increased during the last ten years.

Although a "late-season" population of white whales has continued migrating past Point Hope and Cape Lisburne, and overall numbers appear to be about the same as they were during the 1970's (as suggested by some data obtained as recently as 1987), far fewer animals have apparently been entering the inner waters of Kotzebue Sound during recent years (J. Burns, pers. comm.). The apparent decline in numbers of whales using the inner sound (i.e., since about 1982) may be related to changing environmental conditions (e.g., silting-in of some estuaries, changes in water temperatures and salinities). It also may be related to increases in boat traffic and other noisy activities. However, direct correlations between increases in noise-producing activities and apparent decreases in whales in nearshore areas are difficult to formulate because the situation has been continually confounded by on-going and probably increasing subsistence hunting of animals in the inner sound. Direct harassment caused by hunting may be a more important form of disturbance than any recent increases in general boating, fishing, and flying activities. Hunting effort, particularly incidental hunting effort, probably began increasing during the early 1970's. The number and average affluence of people living in the Kotzebue area has risen markedly during the last 10-15 years, and Kotzebue recently surpassed Barrow in total population size.

See Table 5.1 for estimates of source types and numbers for this area.

5.1.4 Norton Sound

Gold dredging operations and any required winter icebreaking activities are expected to be the major noise sources in this region. Barge, supply vessel, and airport traffic in the Nome and Unalakleet areas are secondary sources during open water conditions. Specific observations for the Nome and northwestern Norton Sound area follow.

1) **Nome and northwestern Norton Sound:** A large mining vessel, the BIMA, has been dredging for placer gold several miles offshore of Nome in northwestern Norton Sound during ice-free months since spring 1986 (i.e., the second season of dredging was completed during fall 1987). This is a potential source of strong underwater sound. The dredge-vessel, managed by Inspiration Gold, Inc., is operated by about by 24 personnel and measures about 525 ft long, 140 ft wide and 112 ft high. The gold-recovery system includes a large suction system bringing large quantities of bottom materials aboard for sorting and screening (and possibly crushing). Screened and sorted waste materials are dumped overboard. Several small boats and barges visit the vessel to change crews and resupply the operation on a near-daily basis. Noise-levels produced by this specific dredging operation (i.e., lifting and dumping back bottom materials) are unknown, but some other marine dredges are known to be strong sources of noise (Greene 1985, 1987a; Section 3.3). However, concentrations of marine mammals rarely frequent the general area of the dredging operation in Norton Sound during ice-free months.

Specific source information is included in Table 5.1.

5.1.5 St. Matthew Hall

Any offshore icebreaking operations would be the major noise source in this region. Barge traffic to Bethel and offshore trawler operations are secondary sources. Source information is included in Table 5.1.

5.1.6 North Aleutian Basin

Commercial fishing operations are the major noise contributor in this area. While the source level of individual fishing vessels is considerably lower than that of the icebreakers that occasionally operate in the more northern areas, the distributed acoustic output of a large fishing fleet results in an insonified area larger than that around a single, more powerful source. Seismic exploration and potential subsequent drilling operations in this area will also provide major noise contributions. Sporadic natural seismic noise is generated along the southern boundary of this area by events along the Aleutian subduction zone. Occasional events may produce levels higher than man-made noise contributions for short durations. Zone of influence estimates for this area are included in Section 5.3. Specific observations for this region are given in the following discussion.

1) **Cape Peirce:** Single-engine floatplanes (e.g., Cessna 185's) and, less frequently, small amphibious aircraft (e.g., twin-engine Widgeons), land and take off near the beach about two to three times month (D. Herter, pers. comm.). The aircraft taxi to the beach to unload and pick up U. S. Fish and

Wildlife Service personnel and deliver supplies to a nearby cabin used during annual studies in the Cape Newenham National Wildlife Refuge. One or two other aircraft also occasionally visit the area during summer months (D. Herter, pers. comm.).

2) **Kvichak Bay and Nushagak Bays, Bristol Bay:** Upper Bristol Bay supports a world-class salmon fishery and large herring-roe fishery annually. In the order of 1,000 diesel-engine (and some gasoline-engine) fishing vessels supported by many high-powered tenders (e.g., powered by twin outboards in the 100-200 hp class), outboard-powered skiffs and single-engine floatplanes serving as spotter aircraft (e.g., Cessna 180's, 185's, 206's; Piper Super Cubs -- sometimes over 100 aircraft) operate out of Naknek, Dillingham, Togiak, Egegik and Pilot Point every summer. As many as 500 fishing vessels and associated tenders and aircraft often stage out of Naknek in upper Kvichak Bay, and a few hundred more operate out of Dillingham in Nushagak Bay. Several canneries are also located around the shores of the bays, including a few near the Snake River area. Also, many set-net fishing sites attended by small all-terrain vehicles (e.g., "three-wheelers") and skiffs are located around the shores of upper Bristol Bay, including in Kvichak and Nushagak bays.

In addition to fish-spotting aircraft operating offshore, many other aircraft fly along the coast and over portions of upper Bristol Bay every day. Air taxi operators regularly fly at low levels during trips to surrounding villages, canneries and fish camps. Also, larger aircraft, including multi-engine transports hauling fish and cargo, and commerial passenger aircraft, fly in and out of King Salmon and Dillingham. Several military aircraft also operate out of King Salmon, including a few U. S. Air Force F-15 fighters.

3) **Ugashik Bay:** Ugashik Bay in Bristol Bay supports a relatively large population of harbor seals annually (in the order of several hundred animals and probably larger) (R. Gill pers. comm.). The seals reside in the bay along with many diesel-powered commercial fishing boats and outboard-powered tenders delivering catches to a fish processor and seeking shelter from stormy weather. A variety of noises emanate from the processor, including noises from large compressors. Small outboard powered skiffs from Pilot Point also operate throughout the bay. Some subsistence hunting of seals and shooting from fishing vessels probably also occurs.

4) **Nelson Lagoon:** A large fish processor vessel is stationed offshore of the entrance to the lagoon for most of the summer during fishing seasons, and many fishing boats deliver catches to it nearly every day (R. Gill, pers. comm.). During these deliveries, the fishing boats, including outboard-powered skiffs and tenders, motor through the channel near hauled out seals.

Information on specific sources is included in Table 5.1.

5.1.7 St. George Basin

Ship traffic through Unimak Pass is the dominant noise source in this area. The traffic is most dense near the pass with several large vessels often passing through within an hour. This results in addition of noise contributions from several large sources and a resulting increase in the ensonified area beyond that normally expected for a single source. Zone of influence estimates which have been made for the North Aleutian Planning area in Section 5.3 would also generally apply in the St. George Basin area north and west of Unimak Pass since the ship traffic density and TL characteristics are expected to be comparable. Observations for specific locations in this area are given in the following discussion.

1) **Akutan Harbor, Akutan Island:** A large fish processor has been operating in this harbor. Numerous diesel and gasoline-powered fishing vessels deliver catches to the processor, and also seek shelter and drop anchor in the harbor. Noises from various engines, compressors and other activities also emanate from the fish processor. Many small outboard-powered boats from the village also regularly operate in the harbor.

The village is served by one amphibious twin-engine Gruman Goose landing and taking off from the water near the village almost every day (i.e., every day that weather permits). Also, other single-engine floatplanes frequently visit and use the harbor.

2) **Lost Harbor, Akun Island:** A situation very similar to that described for Akutan Harbor also exists at Lost Harbor on Akun Island in the eastern Aleutian Islands (D. Herter, pers. comm.). A major difference between the two harbors is the lack of a village in Lost Harbor. There is considerable local small boat and fishing vessel traffic and some floatplane traffic operating in the vicinity of a fish processor.

3) **Unimak Pass:** Unimak Pass in the eastern Aleutian Islands which is about 19 km (12 mi) wide, accommodates high volumes of international shipping traffic. This can include several large ocean-going vessels, including car and log-carriers, container ships and freighters, per day). Also, large numbers of foreign and domestic fishing vessels use the pass year-around. Shipping traffic is heavy, often including several vessels per hour, and generally spreads over a several mile-wide corridor when several vessels sail through the pass simultaneously. On one typical day in August 1982, ship traffic through Unimak Pass included four large commercial ships (one west-bound car-carrier, one west-bound log-carrier, one west-bound freighter and one east-bound freighter, all in excess of 500 ft long), one U.S. Coast Guard Cutter (west-bound and about 300 ft long), and two smaller fishing vessels (both west-bound and about 100 ft long). These vessels were seen passing within about four miles of a 200 ft long NOAA ship sailing through the pass during a two hour interval (D.G. Roseneau, pers. obs.). On occasion, major elements of large fishing fleets containing dozens of vessels may sail through the pass one after another in only a few hours or days time.

5.1.8 Shumagin

The north end of the Shumagin Planning Area is traversed by the ship and barge traffic using Unimak Pass. As a result the combined noise output from this traffic becomes the major noise contributor in this region. Small boat and aircraft traffic near shore are secondary noise sources. Oil exploration and drilling operations will become major sources when these activities increase. Natural seismic noise is also present in the northern end of this region which overlies the Aleutian subduction zone. The underwater sound levels produced by earthquake events are expected to be higher in this area than in any other Alaskan OCS planning area. Zone of influence estimates have been made for this area in Section 5.3. Information on the major sources is included in Table 5.1.

5.1.9 Cook Inlet

The major noise sources for this area are the ship traffic and aircraft operations near Anchorage and the fishing vessel and small craft operations in the Kenai and Kachemak Bay regions. Secondary sources are drilling and production platforms located primarily on the western side of the inlet. Volcanic and seismic activity on Augustine Island may be a significant sporadic source of noise. Observations for specific areas are presented in the following discussion.

1) Upper Cook Inlet: Many oil platforms (primarily producing platforms, but also some drilling platforms from time-to-time) are scattered offshore along the west side of Cook Inlet throughout the Beluga River - Trading Bay - Redoubt Bay areas. Also, several hundred diesel-powered commercial fishing vessels and outboard-powered skiffs operate in the inlet annually during summer fishing seasons (primarily in waters south of Turnagain Arm). Many larger vessels (e.g., large oil tankers, barges, container ships, freighters, and more recently, U.S. Navy warships) visit the Port of Anchorage and Kenai year-around.

Additionally, considerable air traffic occurs at relatively low-levels over the inlet every day [i.e., frequently below 1,000 m (3,300 ft) and often within only a few hundred meters of the surface]. Aircraft include dozens of single and twin-engine private and commercial fixed-wing airplanes and helicopters flying to and from small communities and oil rigs around the inlet, and dozens of twin and multi-engine military and commercial jet, turbine and piston-powered aircraft operating out of Elmendorf Air Force Base, Fort Richardson and Anchorage International Airport.

Heavy air traffic occurs regularly between Anchorage International Airport and the Kenai Peninsula over the entrance to Turnagain Arm. Also, considerable military and commercial jet traffic passes over the Susitna River estuary during approaches to and departures from Elmendorf Air Force Base and Anchorage International Airport. Many smaller private and commercial aircraft also fly across the inlet near the Susitna River delta, and shipping to and from the Port of Anchorage also passes the Susitna River estuary.

2) Kenai: Boats operating in this area often include several hundred diesel and gas-powered commercial fishing vessels and outboard-powered skiffs and small riverboats. Daily air traffic includes numerous small single-engine floatplanes landing and taking off on the river, and larger twin and multi-engine turbine and piston-powered aircraft and occasional corporate jets (e.g., DeHavilland Canada Twin Otters, Piper Navahos, Cessna 402's, Beechcraft 18's, twin-engine convairs, Lear Jets) arriving at and departing from the nearby Kenai airport. The south threshold of the runway is located just north of the river, and arriving and departing aircraft often pass directly over the water at an altitude of 150-300 m (500-1,000 ft).

3) **Kachemak Bay:** Kachemak Bay has a relatively high level of local boat traffic originating from Homer and the nearby fishing village of Kachemak Selo at the mouth of Swift River. Boat traffic includes a variety of diesel-powered commercial crab and salmon fishing vessels, and inboard and outboard-powered pleasure craft and sport-fishing boats (ranging from small skiffs to high-speed cabin cruisers and occasional air-boats).

Air traffic includes near-weekly U.S. Coast Guard Hercules C-130's flying below about 300 m (1,000 ft) and occasionally below about 150 m (500 ft) over the bay; one (often two) National Guard Bell UH-1 helicopters flying below 300 m (1,000 ft) and often below 150 m (500 ft) along the shores of the bay about once (sometimes two to three) times per week; numerous scheduled daily passenger aircraft (e.g., DHC Twin Otters, Piper Navahos, Cessna 402's, Beechcraft 18's, twin-engine Convairs) that often fly below about 300-600 m (1,000-2,000 ft) along or over the bay; and numerous private, charter and air taxi single-engine fixed-wing and light helicopter aircraft flying low over or along the shores of the bay (e.g., Cessna 185's, 206's, 207's; Piper Super Cubs; Bell 206B Jet Rangers).

During late June 1986 - early June 1987, construction activities for the Bradley Lake Hydroelectric Project along tideline on the east shore of the upper bay included construction of a temporary 200 man camp; construction of dock facilities and some channel dredging at Sheep Point. This involved considerable barge traffic and unloading of heavy equipment and supplies at the Martin River delta (summer 1986) and Sheep Point dock (late summer 1986 - spring 1987). Construction of about 9.5 km (6 mi) of road at tideline between the Martin River and a point about 3.2 km (2 mi) north of Sheep Point (included blasting at Sheep Point and the future powerhouse site about 3.2 km (2 mi) north of Sheep Point). There was also considerable large-scale blasting at a hillside quarry site about 1.6 km (1 mi) from the bay (including loud double and triple explosions that frequently echoed across the bay during July - August 1986). Demobilization of some camp facilities involving barge traffic occurred during April-June 1987.

5.1.10 Gulf of Alaska

The major noise sources in the Gulf of Alaska region are associated with the tanker traffic servicing the pipeline terminal in Valdez and the cruise ship activity in Southeast Alaska. Secondary sources are general fishing activity and ship traffic in the gulf and aircraft operations near airports and along beaches. The tanker traffic contribution is greatest in Prince William Sound where traffic lanes are more restricted than they are offshore. The noise contributions from smaller cargo vessels, cruise ships, and ferry traffic are also significant.

Cruise ship traffic in Southeast Alaska has been increasing in recent years. The major routes for these ships run from the Dixon Entrance up to Juneau through Stephens Passage and then through the Lynn Canal to Skagway and through Icy Strait to Glacier Bay. An average of 2 - 3 cruise ships per day plus about 8 - 10 ferries per week pass through most of the inside deep water routes. In addition to this traffic, barges and cargo vessels also use these routes between the major Southeast Alaska cities and Seattle. Specific source information is given in Table 5.1.

5.2 Sound Exposure Modeling

Computer-implemented models have been designed to help assess the potential environmental impact of diverse types of noise sources on the many species of marine mammals found in Alaskan waters. The Standardized Noise Contribution Model (SNC) has been developed to provide a means of comparing the acoustic energy contributions from all types of sources. The output of this SNC Model is a logarithmically-scaled number proportional to the acoustic energy density produced by a specific type of source operating in a defined reference area. This SNC value is used together with information on hearing characteristics and population density as an input to a Standardized Exposure Rating Model (SER) to rate potential response of a specific species to noise exposure. This SER Model is designed to evaluate the degree of potential impact of a specific source on a specific species by producing a logarithmically-scaled number proportional to the degree of matching between a noise source output bandwidth and a species hearing sensitivity characteristic.

The SNC values for the important sources in specific OCS reference areas were used in deriving SER ratings for the species within the areas. The resulting SER values serve as a means of ranking the potential for an acoustic interaction between specific sources and species. The procedure used in developing the SNC and SER models is summarized in the following discussion.

5.2.1 The standardized noise contribution model

The model uses a spreadsheet format to facilitate data entry, application of transmission loss information, and estimation of standardized noise spectra for a wide range of sources. The procedure involves selection of site-representative source types, transmission paths, source temporal patterns, and source spatial distributions - including those of moving sources. The basic concept for the procedure has been developed from industrial noise modeling procedures used for human population centers. It is based on the concept of the equivalent sound level for a time-varying or moving acoustic source. This concept was discussed in Section 3.1.2. The equivalent sound level, L_{eq}, is the constant sound level which produces the same acoustic energy exposure dose as the actual time-varying sound field.

For prediction of human response to noise, a total exposure period of eight hours is used to determine the average effective sound level of a fluctuating or intermittent noise source. This corresponds to the general period of working or sleeping activity. For marine mammals a shorter period of time is appropriate since they are not as constrained to a specific location as humans. The appropriate time period is difficult to determine. Few data are available on responses of marine mammals to repeated or ongoing exposure to sounds that, at least initially, cause behavioral responses. Moreover, the exposure period probably varies for different species and may depend on movement patterns in the course of normal feeding, migration or other activities. Movement patterns of the animals will have a strong influence on the duration on sound exposure, since many noise sources are either fixed or moving more slowly than the species exposed.

In the absence of specific evidence of an appropriate integration time for behavioral reaction to continued noise exposure it seems appropriate to assume a duration that is controllable by the species involved. Of the several species potentially impacted by the noise sources in the Alaskan marine environment, gray whales have been studied sufficiently to permit determination of noise response criteria for some types of industrial noise sources. In the course of these studies, it was observed that whales responded to loud sound fields by changing their swimming pattern to reduce the noise exposure. The swimming speed of gray whales when migrating was observed to be 5 to 10 km/hr (Malme et al. 1984). The radius within which behavioral reactions are expected is generally within 10 km of the source in most of the Alaskan OCS planning areas studied. Thus a two hour reference time is assumed to be appropriate in considering the average exposure interval for gray whales. For the purpose of this study, a two hour reference period is used for other species also, recognizing that changes may be needed when more specific behavioral response data become available. The impact of using an incorrect value for the reference exposure period (acoustic integration time) is not severe in its effect on the predicted L_{eq}. If the effective exposure period is as little as 40 min or as great as 6 hours, rather than the assumed 2 hours, this will result in a maximum error of 5 dB in the estimated L_{eq}.

The L_{eq} concept was developed for prediction of the response of relatively fixed human population centers to intrusive industrial noise sources that were either stationary or were moving in a defined spatial pattern. In order to apply this concept to the usual moving receiver - moving source situation applicable to marine mammals, it is necessary to devise a procedure which will standardize the conditions under which L_{eq} is estimated. This can be done by considering that an acoustic source near a specific site can influence an animal passing through the area by producing a behaviorally significant noise contribution that is proportional to the effective source level, inversely proportional to the transmission loss, and proportional to the probability of encounter. The effective source level is the constant level (referred to 1 m) that would produce the same acoustic energy over a 2 hr period as the actual time-varying source over the same interval. It can be specified in terms of the maximum source output level modified by a time duration correction factor.

The transmission loss can be standardized by considering a reference range which is representative of many actual exposure conditions. A practical reference range can be calculated by employing the concept of the effective source density per kilometer-squared (km^2). For a single sound source located in a region of horizontally uniform sound propagation conditions, it can be shown that the mean sound pressure level for a circular area of 1 km^2 is developed at an average range of 300 m when spreading losses alone are considered (10 Log, 15 Log, and 20 Log characteristics). Thus we propose to use 300 m as a reference distance for comparing various sound sources at a specific site. This distance is sufficient to provide for inclusion of site- and frequency-specific propagation effects for depths less than 50 m and is representative of distances for which behavioral influences have been observed in several species exposed to moderate source levels (Sec. 2.4).

The effective density of a given source type within a specific 1 km^2 region is determined by observation or by the use of statistical probability based on knowledge of source concentration locations and travel patterns for moving sources. The effective source density is used to determine the probability of encounter (Pe) for specific source - marine mammal situations. This can be applied to moving sources as well as fixed sources by recognizing that the probability of a marine mammal encountering a source (or vice-versa) is proportional to the number of sources per km^2 and to the number of mammals per km^2. It is also proportional to the speed of travel of both source and receiver if they are moving. This is a result of the model requiring an estimate of Pe over a 2 hour reference period rather than just an instantaneous value. This probability calculation requires estimates of both the number of sources and the number of mammals in a given area, as well as speed of travel information. In developing the physical acoustics portion of the model we have assumed that a subject mammal is present, so that this portion of the joint probability estimate is unity. Thus, for the present, we need to consider only the probability of this mammal encountering a source.

If a specific source type may be found with equal probability anywhere within a defined area, then the probability of encountering this source within a 1 km^2 zone surrounding a randomly selected receiver location is 1/A where A is the total area defined in the modeling procedure. If there are N sources in the total area, then Pe = N/A which is equal to the source density. This procedure is applicable to both fixed and moving sources since, for a fixed source, the receiver may be located anywhere in the model area with equal probability unless specific sites are being modeled. In this case, fixed sources in the area would have a Pe = 1.

If the source types being considered are not uniformly distributed because of geographic or operational constraints, then appropriate probability functions must be used to specify Pe in terms of receiver location. These specialized probability functions can be estimated by considering the areas of concentration associated with specific source types within a larger total region involved in a general analysis. This procedure is used in applying the SNC Model to specific OCS planning areas where source concentrations such as fishing areas, coastal shipping lanes, and airports are located. In these cases, the area used in estimating the Pe value for a given source type is determined by the size of the region(s) where these sources are located most of the time.

In the special case of airports, the region of highest sound concentration is located off the ends of runways. When the flight pattern from a runway is located over water, aircraft sound enters the water along a narrow track under the flight pattern and is propagated horizontally to a degree determined by the bottom conditions and water depth, as shown previously in Section 4.3. At some distance from the airport the sound in the water produced by larger aircraft usually drops below ambient levels as the aircraft reaches the cruising altitude. This is usually not true for smaller aircraft and helicopters which generally fly at lower altitudes. Thus the effective area of significant sound level near an airport is determined largely by the type of aircraft used. The model described in Section 4.3 was used as a guide in estimating the effective areas to be considered for aircraft sources. For aircraft travelling at low altitude the procedure used for moving sources is applied.

If a source is moving so as to change its average location within a period of two hours, the effective speed of advance must be considered since the value of Pe is increased. This occurs because the source has effectively occupied more than a 1 km^2 area in the two hour period, which is equivalent to having more than 1 source. It can be shown that the number of independent 1 km^2 areas occupied by the source in a two-hour period is equal to (1+1.77S) where S is the average speed of advance in km/hr. If the source is travelling along a straight path, S is equal to the actual speed. The Pe for a single moving source then becomes

$$Pe = (1+1.77S)/A \tag{19}$$

The basic formulation of the Standardized Noise Contribution Model can be summarized by the following equation:

$$SNC(S1) = L_s(S1) - TLr + 10\ \mathrm{Log}\{(T_f)(Pe)(N_s)\} \quad (\mathrm{dB\ re\ 1\ \mu Pa\ at\ 300\ m}) \tag{20}$$

where

SNC(S1) = The standardized noise contribution of source Type 1 at a specific site (1/3 octave band spectrum)

$L_s(S1)$ = Source Level of the Type 1 source (dB re 1 μPa, 1 m) (1/3 octave band spectrum)

TL_r = Transmission Loss in the area at a range of 300 m (dB) (1/3 octave band spectrum)

T_f = (Time Fraction) Source-on duration/Reference period

Pe = (Probability of Encounter) The probability that a specific type of source will be found in a 1 km^2 area surrounding the receiver location

N(S1) = Number of Type 1 sources in a specific area.

The SNC spectra of the significant sources in a specific area can be added together using a 1/3 octave power summation process to determine a composite standardized noise level.

The formulation of the SNC Model in Eq. (20) does not distinguish between fixed sources that fluctuate in level and moving sources that

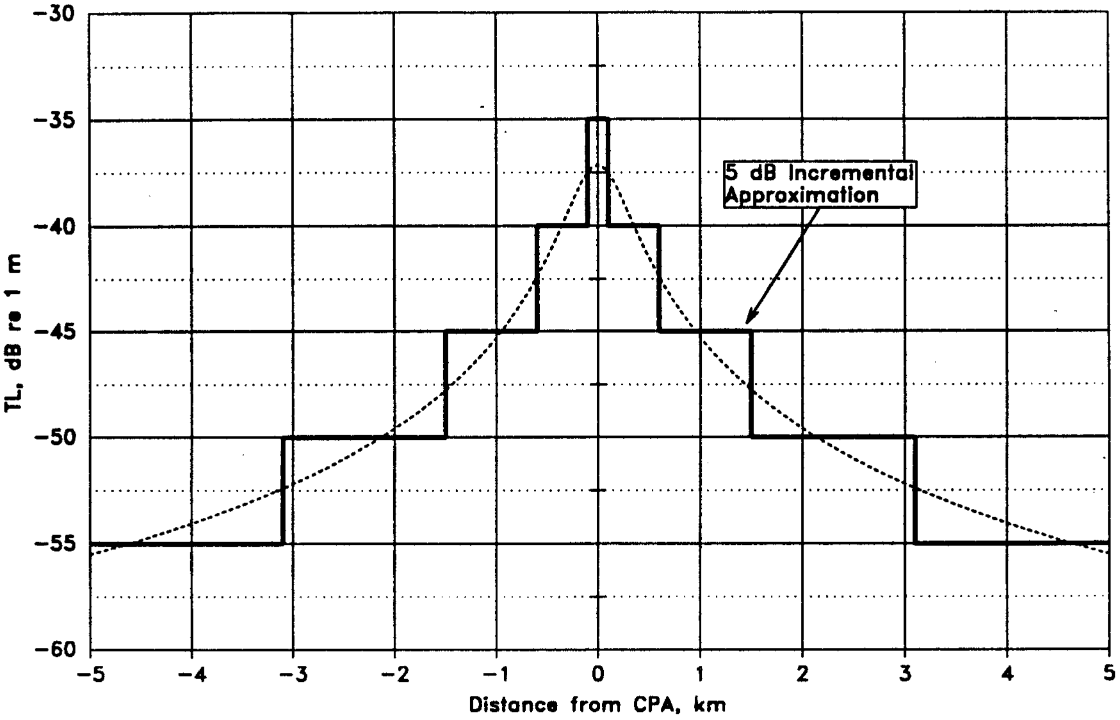


Fig. 5.1. Transmission Loss vs. Distance from CPA for a Moving Source. CPA 300 m from Receiver.

apparently fluctuate in level because of their motion, which causes the range and thus the TL to change with time. The effective received level from a moving source can be estimated using the same procedure used to determine Leq for a fixed source that fluctuates in time [see Eqs. (5) and (6) in Section 3.1.2]. Figure 5.1 shows the typical bell shaped curve that describes the change in transmission loss for sound from a source traveling along a straight line past a fixed receiver (a received level curve would have the same shape). A 15 Log R transmission loss characteristic was assumed in Fig. 5.1. The stepped curve shows the 5 dB incremental approximation used to estimate the effective TL for the entire closest point of approach (CPA) sequence. Since measured data (and some model outputs) often are not describable with an analytic function, an incremental integration process was used. This process, in effect, determined an equivalent constant sound level which contains the same acoustic energy during the time interval of the CPA sequence as the actual time-varying received level. The difference between the received level when the source is at CPA and the effective level for the entire CPA sequence is Cm, the moving source correction factor. The appropriate values for this factor were found by analyzing the TL information for each of the lease areas which were studied. The results showed that while this factor is area specific, it is not frequency dependent.

The time duration required for the CPA sequence must also be compared to the reference period. This is done as a separate correction process. Received levels significantly below the level at CPA do not contribute much to the total energy received during the CPA sequence. By neglecting contributions 20 dB or more below the level at CPA, it is possible to calculate a specific time required for completion of the sequence as determined by the speed of the source. The range from the receiver at which the received level is 20 dB below that at CPA is obtained using the measured or modeled TL characteristics. The effective time duration of the CPA sequence is approximately equal to the travel time required for the source to cover two of the 20 dB range intervals or:

$$T_t = 2\ (Rm/S) \quad \text{(sec)} \tag{21}$$

where

Rm = Maximum effective range where TL is 20 dB greater than at CPA (km)

S = Speed of the source (km/sec)

When these modifications are incorporated into the SNC Model, Eqn (20) can be rewritten as follows:

$$SNC = Ls - TLr - Cm + 10\ \text{Log}\{(Tt)(Tf)(Pe)(Ns)\}\ \text{dB re } 1\ \mu\text{Pa at } 300\ \text{m} \tag{22}$$

Eq. (22) was used to calculate the SNC ratings for the major sources identified in the study for each of four OCS planning areas - Chukchi, Norton Basin, North Aleutian and Shumagin. The effect of two different sound propagation conditions was also considered if appropriate. In order to simplify the analysis, the procedure followed previously in presenting a summary of source level characteristics is also used here in that the dominant bandwidths and maximum 1/3 octave band levels are used rather than the full 1/3 octave spectra. The SNC Model spreadsheet layout is shown in the example in Table 5.2. (Complete tabular SNC results for all of the areas studied are presented in the next section in combination with the SER Model results.)

The following description gives detailed information on the organization and terminology of the SNC tables.

Standardized Noise Contribution Model

(Description of terms and data entering procedure)

Source - Description of category or specific name of source.

Type - Fixed (remains stationary), Local (moves less than 600 m in 2 hours), Moving (moves more than 600 m in 2 hours)

Dominant Bandwidth - The frequency band including the 1/3 octave band with the highest level in the source level spectrum and bounded by the 1/3 octave bands with levels within 10 dB.

Table 5.2. Standardized Noise Contribution Model (Example).

STANDARDIZED NOISE CONTRIBUTION MODEL, North Aleutian Planning Area, Surface Layer Condition
Ref. areas used in model (km^2): Total overall, 149000 ; Coastal (c), 3600 ; Fishing (f), 34400 ; Airports (a), 78
Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 27 0.9

	(e - estimated)							Ref. 300 m		Mov.Srce.Corr.		Fluc.	Equiv.	Encntr.	Exp.	SNC ratings	
Source (area)	Type	Speed	Dominant BW, Hz			Max 1/3 Oct,Hz		D.Bnd.	Mx 1/3	Area	TravTime	Corr.	Level	Prob.	Num.	D.Bnd	Mx 1/3
		(kts)	fmin	fmax	Ls1,dB	freq.	Ls2,dB	Lr1,dB	Lr2,dB	Cm,dB	Tt/Tr	Tf/Tr	Leq.dB	Pe	N	SNC1,dB	SNC2
Tug/Barge (c)	movng	10	100	12500	171	630	162	129	120	-11	1	1	118	9.4E-03	e 5	105	96
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	125	114	-11	0.73	e 0.8	112	1.8E-02	e 15	106	95
13' Whaler (c)	movng	20	630	8000	159	4000	153	117	111	-11	0.73	e 0.8	104	1.8E-02	e 20	99	93
Trawler (f)	movng	5	40	1000	157	100	147	115	105	-11	1	e 1	104	5.1E-04	e 20	84	74
Trawler (f)	movng	10	40	4000	169	160	158	127	116	-11	1	1	116	9.8E-04	5	93	82
Drillship	fixed		20	800	174	63	167	132	125	0	1	1	132	6.7E-06	e 1	80	73
Dredge (AQ.)	fixed		50	630	185	160	178	143	136	0	1	e 0.8	142	6.7E-06	e 1	90	83
Seismic Array	movng	5	20	160	216 (300 m)	50	210	174	168	-11	1	e 0.005	140	1.2E-04	e 1	101	95
B. 737-200 (a)	movng	400	100	800	135	125	130	121	116	-10	0.0012	1	82	7.7E-02	3	75	70

f_{min} - the center frequency of the lowest frequency 1/3 octave within the 10 dB limit.

f_{max} - the center frequency of the highest frequency 1/3 octave within the 10 dB limit.

L_{s1} - the power sum of the 1/3 octave band levels in the dominant bandwidth expressed in dB re 1 μPa at 1 m.

Maximum 1/3 Octave Band - The 1/3 Octave Band with the highest level in the source level spectrum.

freq. - the center frequency of this band.

L_{s2} - the sound level in this band in dB re 1 μPa at 1 m.

Reference L_{r1} - The received level in the dominant band at a range of 300 m from the source in the area chosen for the model.

$$L_{r1} = L_{s1} - TL(300)$$

L_{r2} - The received level in the maximum 1/3 octave band at a range of 300 m from the source.

$$L_{r2} = L_{s2} - TL(300)$$

Moving Source Corrections - These are correction factors that provide spatial and temporal compensation for source motion.

Cm - a spatial correction factor that determines an average level for the typical bell-shaped L_r curve generated when a moving source passes by a fixed receiver. It is area specific but not frequency dependent.

T_t - the travel time required for a specific source to travel in a straight path past the receiver with a closest point of approach (CPA) of 300 m. The length of the path (Rm) is determined by the range at which L_r is 20 dB lower than at CPA.

T_t = 2(Rm/S), where S_s is the source speed.

Fluctuation Correction - This is a correction for fixed or moving sources which do not have a constant output level.

T_f - The total effective time during which a specific source is at or near maximum output during a time period covering a full operating cycle or a representative operating condition. For sources with a wide range of output levels, the approximate method of determining L_{eq} can be used to eliminate the need to determine T_f (discussed elsewhere).

T_r - The reference time interval used to determine the effective impact duration of a noise source - marine mammal encounter. An interval of 2 hrs is used as representing the average time interval that a moving source would be within acoustic range of a receiver or a moving mammal would be within acoustic range of a fixed source.

L_{eq} - The sound level of a fixed, constant amplitude source that would have the same acoustic energy as a fluctuating and/or moving source.

$$L_{eq} = L_{r1} - C_m + 10\ \mathrm{Log}(T_t/T_r) + 10\ \mathrm{Log}(T_f/T_r) \qquad (23)$$

Pe - (Probability of Encounter) The probability that a specific type of source will be found in a 1 km^2 area surrounding the receiver location.

From Eqn (19), Pe = $(1+1.77S)/A_t$, where S is the average speed of advance of the source in km/sec, if it is moving, and A_t is the total area included in the modeling procedure in km^2.

N - The number of sources of a specific type expected to be found in area A_t. This includes only the sources that are active at a given time.

SNC1 - The standard noise contribution rating for a specific source based on the effective bandwidth level, L_{s1}.

$$SNC1 = L_{eq} + 10 \, Log(Pe) + 10 \, Log \, (N) \tag{24}$$

SNC2 - The standard noise contribution rating for a specific source based on the maximum 1/3 octave band level, L_{s2}

$$SNC2 = SNC1 - L_{s1} + L_{s2} \tag{25}$$

5.2.2 The standardized exposure rating model

This model has been developed to provide a means of estimating the potential impact of the noise energy of a given type of source operating in a designated area on a single species found in that area. The model operates using the following measures at the reference range from a specified source (300 m):

- The acoustic energy density of the noise, since the potential for behavioral influence is considered to be proportional to the acoustic energy level. This is approximately equal to the value of SNC1.
- The population density of the species, since the encounter probability is proportional to the number of animals present.
- The amount of overlap between the output spectrum of a source and the hearing sensitivity curve of a given species.

The hearing response is a broad filter which when matched to the output spectrum of a source produces a higher loudness sensation than occurs when the dominant frequency range of the source is outside of the maximum hearing sensitivity region. As shown in Fig. 5.2, the model uses a measure of the bandwidth of the overlap region together with a measure of the maximum difference between the hearing threshold and the received level in the overlap region.

The SER Model is described by the equation:

$$SER = SNC1 + 10Log(D_s) + L_{r3} - S_s + 10Log(BW_{eff}) \text{ dB} \tag{26}$$

where:

D_s = Density of the species in the model area (N/km^2)

L_{r3} = The received level at the reference range (300 m) in the 1/3 octave band with the highest level above the hearing threshold (dB re 1 μPa) (see Fig. 5.2).

S_s = The level of hearing threshold at the center frequency of L_{r3} (dB re 1 μPa).

BW_{eff} = The audible bandwidth, i.e the frequency band where the received level at the reference range is above the hearing threshold of given species (kHz).

For the usual case where the high frequency limit of the band of audibility is more than a decade above the lower limit, the high frequency limit alone may be used in Eqn. (26) with less than 0.5 dB error. This is useful in applications where the lower limit of the range of audiblity is not easily defined because of lack of accurate hearing threshold data. The acoustic terms, L_{r3}-S_s and BW_{eff}, in the model are designed to provide an output approaching 0 for cases where the received level spectrum becomes equal to the hearing threshold and/or the audible bandwidth becomes very small. The bandwidth correction term is calculated using kiloHertz rather than Hertz, as in the usual application, in order to obtain more conveniently scaled values of SER.

An example of a spreadsheet layout for the SER Model is shown in Table 5.3. The table includes supplementary information on the effective bandwidth and highest 1/3 octave band of the source. It also shows comparable information for the region of maximum sensitivity on the hearing curve, defined as shown in Fig. 5.2. The following summary is given to explain the terminolgy used in applying the SER Model:

Standardized Exposure Rating Model

(Description of terms and data entering procedure)

Source - This is a summary of parameters from the SNC Model results which are used in the SER procedure; see Table 5.2 and its description for details.

Receiver (species) - Specific species name

D_s - Average density of the species in the model reference area (Number/km^2)

Hearing Bandwidth - The dominant hearing range of a species as defined by a 10 dB amplitude range centered on the frequency of maximum sensitivity.

Fr_l - The lowest frequency where the hearing sensitivity is within 10 dB of the maximum.

Fr_h - The highest frequency where the hearing sensitivity is within 10 dB of the maximum.

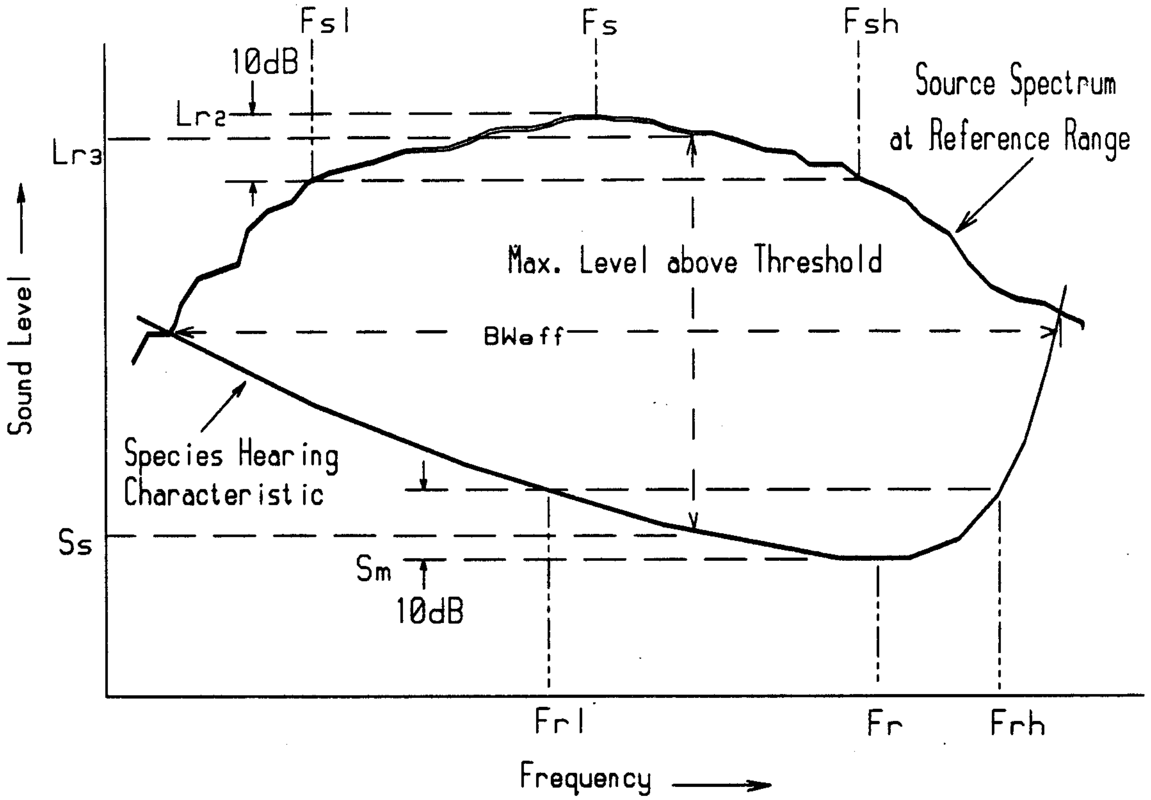


Figure 5.2. **Diagram of Source Spectrum and Hearing Characteristic Showing SER Model Parameters.**

Fr - The frequency where the hearing sensitivity is highest.

Sensitivity - The level of a pure tone which is detectable within the guidelines of established testing procedure.

Sm - The lowest detectable pure tone level (Highest sensitivity level).

Ss - The pure tone sensitivity level for a specific species at the center frequency with the highest 1/3 octave band level above the hearing threshold at the same frequency.

BW_{eff} - The audible bandwidth (see Fig. 5.2)

Ref SER - A reference value with $D_s = 1/km^2$, to permit comparison of species density independent SER values.

Area SER - The rating value when D_s is set to an appropriate value for a specific species.

SER-SNC1 - A measure of the potential acoustic influence of source on a species, independent of source density.

Table 5.3 Standardized Exposure Rating Model (Example).

STANDARDIZED EXPOSURE RATING MODEL, North Aleutian Planning Area, Surface Layer Condition
Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (c) - coastal area source (f) - fishing area source

SOURCE	Dominant BW,		Max 1/3 Oct		No.	SNC1	RECEIVER	Ds	Hearing BW, kHz			Sensitivity		Lr3	BWeff	SER, dB		SER-
	Fsl	Fsh	Fs,Hz	Lr2,dB	N	dB	Species	N/km^2	Frl	Frh	Fr	Sm,dB	Ss,dB	dB	kHz	Ref.	Area	SNC1
					e*			e	e	e	e	e	e	e	e	e	e	e
Seismic Array	20	160	50	168	1	101	Gray Whale	0.02	0.09	9	e	40	41	149	20	222	205	104
					e			e						e		e	e	e
Twin Outdrv.(c)	40	16000	500	114	20	106	Harbor Seal	0.44	3	50	33	63	63	101	60	162	158	52
					e			e						e		e	e	e
Twin Outdrv.(c)	40	16000	500	114	20	106	Harbor Porp.	0.02	3	80	15	48	48	109	130	188	171	65
					e		(1)	e	e	e	e	e	e	e	e	e	e	e
Twin Outdrv.(c)	40	16000	500	114	20	106	Stel.Sea Lion	0.21	0.7	30	15	80	80	113	30	154	147	41
					e			e	e	e	e	e	e	e	e	e	e	e
Twin Outdrv.(c)	40	16000	500	114	20	106	Gray Whale	0.02	0.09	9	0.7	40	40	116	20	195	178	72
					e			e								e	e	e
13' Whaler (c)	630	8000	4000	109	20	99	Harbor Seal	0.44	3	50	33	63	73	111	50	154	150	51
					e			e								e	e	e
13' Whaler (c)	630	8000	4000	109	20	99	Harbor Porp.	0.02	3	80	15	48	56	111	130	175	158	59
					e		(1)	e	e	e	e	e	e	e	e	e	e	e
13' Whaler (c)	630	8000	4000	109	20	99	Stel.Sea Lion	0.21	0.7	30	15	80	80	106	20	138	131	32
					e			e	e	e	e	e	e	e	e	e	e	e
13' Whaler (c)	630	8000	4000	109	20	99	Gray Whale	0.02	0.09	9	0.7	40	40	105	20	177	160	61
								e								e	e	e
Tug/Barge (c)	100	12500	630	120	5	105	Harbor Seal	0.44	3	50	33	63	63	104	63	164	160	55
					e											e	e	e
Trawler (f)	40	4000	160	116	5	93	Harbor Porp.	0.02	3	80	15	48	48	103	130	169	152	59

Note (1): Hearing characteristic for California sea lion used for Steller sea lion.

5.2.3 Results of model studies for selected planning areas

The SNC and SER Models have been set up in spreadsheet format to facilitate their use in developing predictions for noise ratings and mammal exposure ratings for specified area - source - species situations. Two seasonal conditions and four OCS planning areas of special interest - Chukchi Sea, Norton Basin, North Aleutian Basin, and Shumagin have been considered. For the Chukchi Sea, a summer condition of 50% ice cover and a winter condition of 100% ice cover have been used since these conditions are common and correspond to those for which TL data were available. For the remaining three areas, a late-spring/ summer condition and a late fall/early winter condition were considered. These are, respectively, the periods when (1) a strong surface layer is developed because of solar heating and high fresh water input, and (2) when the surface cools to produce a neutral or slightly negative temperature gradient and eventual ice formation in many areas. The ice cover conditions assumed for the non-Chukchi areas were 0% for spring/summer and 0 to 30% for late fall/early winter.

The results of the model analyses are presented here in tabular form with the SNC results presented first followed by the SER summary table. The SER analyses were made using the major source types identified in the SNC analyses together with some of the major species expected to be present based on the population distribution and density information presented in Section 2.1. An SER rating was obtained for both a reference condition of 1 animal/km^2 and a condition using the expected population density based on information from

Section 2.1.3 for each potential source - species encounter situation. Thus ratings are obtained for both the encounter sensitivity for a single animal and the specific potential for acoustic impact for the population within an area. The SER values obtained from the analysis are shown in bar graph format to supplement the data presented in the tables.

The SER Model is designed to show which species are potentially most influenced by a given noise source by developing high values when compared to the input SNC1 value. If the SER value is comparable to, or less than the SNC1 value, the species is likely to be minimaly influenced as a result of a mismatch between the source noise spectrum and the species hearing sensitivity and/or a low species population density in the area being considered. A procedure was devised for summarizing the results of the SER analysis using three general ratings of low, medium and high. These ratings were established by statistically analyzing the output of the SER Model for all of the source species encounters examined in the 4 planning areas. The average and the standard deviation of the area SER values were determined for a total of 75 data points. The values ranged between 111 and 207 dB with a mean value of 159 dB. The standard deviation was 20 dB. With these results as a guide the general ratings were defined as

Low - SER values 140 dB and lower

Medium - SER values between 141 and 179 dB

High - SER values 180 dB and higher.

These values are designed to provide a broad ranking of source audibility for the various source - species encounters considered under standardized conditions. These SER ratings are not based on behavioral observations and are intended only as a means of ranking encounter situations where potential behavioral responses may occur.

Only a limited number of behavioral studies are available to provide a means of calibrating this ranking scheme. Averaged results from gray whale disturbance studies using playback of several types of continuous noise from industrial sources (Malme et al. 1984) showed that 50% of the whales migrating through the test area avoided areas where sound levels were about 120 dB. Over 90% of the whales avoided the region near the source where sound levels were higher than 130 dB. Reviewing the results of the SER analysis for those areas where continuous source - gray whale encounters were considered provided the following results which show a comparison of the mean SER ratings with the mean of the received levels at the reference range of 300 m for the various sources considered (the number of samples and the standard deviation are also shown):

SER Rank	N	Mean SER(dB)	SD	Mean L_{r1}(dB)	SD
High	2	181	-	138	-
Medium	8	167	8	125	7

These results suggest that the SER ranking scheme is consistent with behavioral observations for at least one species. However, more acoustic disturbance response data are needed for other species before a broader based testing of the procedure can be performed.

Chukchi Sea

Table 5.4A shows the model results for the summer 50% ice cover condition. The sources considered were based on assumed oil exploration and drilling activity, together with representative commercial cargo barge and near-shore small craft activity. The dredge example used was the AQUARIUS, a transfer dredge which had the highest noise output of the examples obtained for the study. The two drill rigs considered were a drillship (EXPLORER II) and a drilling barge (KULLUK). The icebreaker example used was based on the ROBERT LEMEUR, an ice-breaking supply vessel, for which source level data are available. The noise level output of larger Polar-Class icebreakers is estimated to be significantly higher. (See Sec. 3.3.1 for details of noise characteristics from these sources.)

The loudest sources in terms of maximum level at the reference range (300 m) are the seismic array, icebreaker, dredge, and drilling barge. These sources are considered to found operating anywhere within the entire planning area with equal probability. The cargo barges operate primarily along the coast in a coastal zone which is assumed to extend offshore to a range of 4 km. An estimated coastal zone area is used in determining the Pe value for this source.

The sources selected for use with the SER Model because of their high SNC ratings were the seismic array, icebreaker, KULLUK, and the commercial tug/barge combination. Although the received level ratings for the tug/barge type of source are lower than those of several other sources such as the drillship, the SNC rating is high because of its high probability of encounter. The output level and spectrum for the dredge are similar to those of the KULLUK so the results of the model analysis for the KULLUK can also be considered to apply to the dredge. The review of mammal distribution in Section 2 indicated that three species to be found in the Chukchi during the summer season in relatively large numbers are gray whales, walruses, and white whales. The results of the SER Model analysis using the four dominant sources and these three species are shown in Table 5.4B.

The results of the SER analyses shown in Table 5.4B have been also plotted in bar graph form to illustrate the relationships between the SNC1, SER(ref), and SER(area) values. The resulting graph is shown in Fig. 5.3.

Figure 5.3 is an SER rating comparison for the Chukchi Sea area. It is based on values from Tables 5.4B and 5.5B for summer and winter seasons in this area. The information presented allows a comparison of the acoustic influence potential of the various major source and species interactions that are possible in this area. Only the dominant sources and the species of greatest population density and/or greatest importance are considered.

TABLE 5.4A

STANDARDIZED NOISE CONTRIBUTION MODEL, Chukchi Planning Area, Summer - 50% ice cover

Ref. areas used in model (km^2): total overall, 124000 ; Coastal (c), 1860

Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 3 0.5

(e - estimated value)

Source	Type	Speed (kts)	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Ref. 300 m D.Bnd Lr1,dB	Mx 1/3 Lr2,dB	Mov.Srce.Corr. Area Cm,dB	TravTime Tt/Tr	Fluc. Corr. Tf/Tr	Equiv. Level Leq.dB	Encntr. Prob. Pe	Exp. Num. N	SNC Ratings D.Bnd SNC1,dB	Mx 1/3 SNC2
Drillship	fixed		20	800	174	63	167	128	121	0	1.00	1	128	8.1E-06	1	77	70
Kulluk	fixed		40	1250	185	400	177	139	131	0	1.00	1	139	8.1E-06	1	88	80
Dredge (AQ.)	fixed		50	630	185	200	178	139	132	0	1.00	e 0.8	138	8.1E-06	1	87	80
Icebreaker	local		40	6300	192	100	183	146	137	0	1.00	0.5	143	8.1E-06	1	92	83
Seismic Array	movng	5	20	160	216	50	210	170	164	-9	0.32	e 0.005	133	1.4E-04	1	95	89
Tug/Barge (c)	movng	10	100	12500	171	630	162	125	116	-9	0.16	1	108	1.8E-02	e 1	91	82
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	121	110	-9	0.08	e 0.8	100	3.6E-02	e 2	89	78
13' Whaler (c)	movng	20	630	8000	159	4000	153	113	107	-9	0.08	e 0.8	92	3.6E-02	e 5	85	79
Bell 206B Helo	movng	80	50	800	(300 m) 101	200	(300 m) 95	101	95	-8	0.0034	1	68	2.1E-03	e 1	42	36
Bell 205 Helo	movng	80	50	500	(300 m) 114	63	(300 m) 107	114	107	-8	0.0034	1	81	2.1E-03	e 1	55	48

TABLE 5.4B

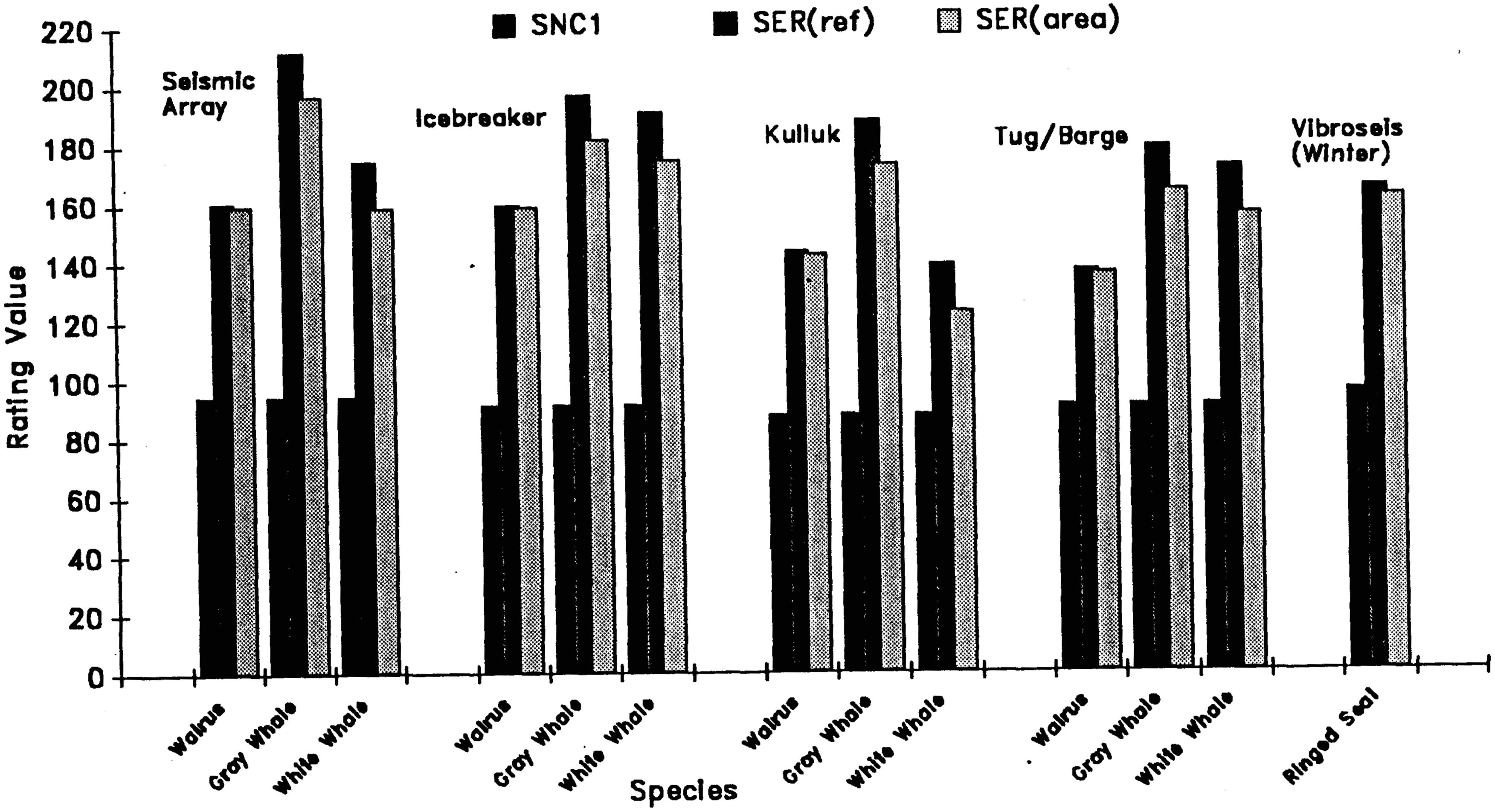
STANDARDIZED EXPOSURE RATING MODEL, Chukchi Sea Planning Area, 50% ice cover condition

*Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (c) - coastal area source*

SOURCE	Dominant BW, Fsl	Fsh	Max 1/3 Oct Fs,Hz	Lr2,dB	No. N	SNC1 dB	RECEIVER Species	Ds N/km^2	Hearing BW, kHz Frl	Frh	Fr	Sensitivity Sm,dB	Ss,dB	Lr3 dB	BWeff kHz	SER, dB Ref.	Area	SER-SNC1
					e*		(1)		e	e	e	e	e	e	e	e	e	e
Seismic Array	20	160	50	164	1	95	Pac. Walrus	0.8181	0.7	30	15	80	80	133	20	161	160	65
Seismic Array	20	160	50	164	e 1	95	Gray Whale	0.03	e 0.09	e 9	e 0.7	e 40	e 41	e 145	e 20	e 212	e 197	e 102
Seismic Array	20	160	50	164	e 1	95	White Whale	0.0227	18	80	30	38	38	e 98	100	175	159	64
Icebreaker	40	6300	100	137	e 1	92	Pac. Walrus	0.82	e 0.7	e 30	e 15	e 80	e 80	e 133	e 30	e 160	e 159	e 67
Icebreaker	40	6300	100	137	e 1	92	Gray Whale	0.03	e 0.09	e 9	e 0.7	e 40	e 40	e 132	e 20	e 197	e 182	e 90
Icebreaker	40	6300	100	137	e 1	92	White Whale	0.023	18	80	30	38	38	e 117	100	191	175	83
Kulluk	40	1250	400	131	e 1	88	Pac. Walrus	0.82	e 0.7	e 30	e 15	e 80	e 80	e 121	e 30	e 144	e 143	e 55
Kulluk	40	1250	400	131	e 1	88	Gray Whale	0.03	e 0.09	e 9	e 0.7	e 40	e 40	e 127	e 20	e 188	e 173	e 85
Kulluk	40	1250	400	131	e 1	88	White Whale	0.023	18	80	30	38	90	121	100	139	123	35
Tug/Barge (c)	100	12500	630	116	e 1	91	Pac. Walrus	0.82	e 0.7	e 30	e 15	e 80	e 80	e 111	e 30	e 137	e 136	e 45
Tug/Barge (c)	100	12500	630	116	e 1	91	Gray Whale	0.03	e 0.09	e 9	e 0.7	e 40	e 40	e 115	e 20	e 179	e 164	e 73
Tug/Barge (c)	100	12500	630	116	e 1	91	White Whale	0.023	18	80	30	38	38	e 99	100	e 172	e 156	e 65

Note (1): Hearing characteristic for California sea lion used for Pacific walrus.

FIG. 5.3 SER RATING COMPARISON, CHUKCHI SEA
Summer, 50% Ice Cover



Referring to Fig. 5.3, the black bars represent the SNC rating for the dominant bandwidth of a specific source. The height of a bar is proportional to the acoustic energy density level produced by a source type in the Chukchi Sea Planning Area. The dark gray bars represent the Reference SER rating which is proportional to degree of matching between the hearing response (known or assumed) of a species and the acoustic output bandwidth of a source. The Reference SER rating is based on the assumption that the species density in the area is $1/km^2$. It is necessary to include the actual species density in the SER rating since, if the density is zero, there is no probability of acoustic interaction. Therefore, an area SER rating is also determined which includes the species density value (observed or estimated) for the area. This is shown by the light gray bars in Fig. 5.3. If the species density is very low, the area SER values will be significantly lower than the reference values showing that, while a species sensitivity for a given source may be high, the probability for an acoustic interaction in a given area may be low because of a low probability of encounter.

In order to obtain SER values for gray whales it was necessary to derive an estimated hearing sensitivity characteristic since no measured data are available for any baleen whale (Sec. 2.3). This was done using a scaling procedure based on knowledge of their vocalization frequency range and an assumption that their maximum hearing sensitivity is comparable to that of the smaller whales and pinnipeds for which data are available. Since the vocalization range of gray whales extends to below 50 Hz, this implies that their hearing sensitivity is good in this range also. As a result they may be potentially more influenced by low frequency industrial noise than are species which have extended high frequency hearing sensitivity. The estimated hearing sensitivity characteristic and its derivation are discussed in Appendix D.

This estimated gray whale hearing response characteristic was used to enable SER values to be obtained for this important species. The hearing sensitivity characteristic for the walrus, which is also unknown, was assumed to be similar to that of the California sea lion. Hearing characteristics of the white whale have been measured and are given in Section 2.3.

The SER values from Table 5.4B which are used for the graphs in Fig. 5.3 show the ratings for source - species pairs which have a high potential for acoustic interaction in the Chukchi area during summer conditions. As indicated by the reference SER values, the gray whale is potentially the species most influenced by all of the sources. The SER rating for the seismic array - gray whale encounter is the highest in the table, followed closely by the icebreaker and KULLUK rating for the same species.

The SER value for the gray whale - tug/barge encounter is lower than the gray whale ratings with the other sources. While the maximum output 1/3 octave band for this type of source nearly coincides with the estimated maximum hearing sensitivity range of the gray whale, the maximum output level is more than 15 dB below that of the other sources. The small craft shown in the SNC model results would also have low SER values. Thus the potential impact of noise from commercial transport and small craft activities on gray whales in the Chukchi Sea area during summer conditions is predicted to be less than produced by the oil industry activities used in the modeling procedure. If large numbers of commercial vessels and small craft are in operation concurrently, their combined noise contribution will be larger than suggested by the SNC and SER values shown in Tables 5.4A and 5.4B. However, the modeling procedure suggests that it would require operation of more than 300 tugs or a combination of sources with comparable output to obtain SER values approaching those obtained for operation of one icebreaker.

For the other two species, the white whale Reference SER ratings are somewhat higher than those of the walrus for all of the sources except for the KULLUK. Since the hearing sensitivity for the walrus was assumed to be comparable to that of the California sea lion, no conclusions will be made based on the small species-to-species differences suggested by the model. The large difference between the SER ratings for the smaller mammals and those for the gray whale is due to the difference in hearing ranges, i.e. the likelihood that the gray whale is more sensitive in the low frequency range of most industrial sources. Therefore, even though the hearing sensitivity characteristic for the gray whale has been estimated, the trend shown in the SER ratings is probably valid. Note, however, that the SER value for the white whale and icebreaker is nearly as high as that of the gray whale - probably as a result of the high frequency content of the cavitation noise.

The results of the SNC Model analysis for the Chukchi area during winter conditions with 100% ice cover are given in Table 5.5A. The sources considered were limited to those that would operate under conditions of heavy ice cover. The vibroseis seismic exploration source can be seen to have the highest SNC rating with the vibroseis convoy and the tracked vehicle having considerably lower values. The vibroseis source level data are based on only one measurement with an estimated TL correction. As a result the SNC ratings for this source should be regarded as order of magnitude estimates. The values obtained for the snowmachine also should be considered order of magnitude estimates.

The SER model was used for analyzing a vibroseis - ringed seal encounter with the results presented in Table 5.5B and illustrated in Fig. 5.3. The reference SER rating of 165 is 69 dB higher than the SNC1 value of 96 indicating a significant acoustic interaction potential.

Norton Basin

The results of the model analysis for Norton Basin during late spring and summer are shown in Table 5.6A. Sources associated with hypothetical oil industry operations, together with existing gold dredging, transportation, and cultural activities, were used in the SNC Model. Noise data from a large transfer dredge, the BEAVER MACKENSIE, were used to approximate the noise output of the gold dredging operation in the Nome area, since specific measurements of noise from the BIMA (Sec. 5.1.4) were not available. The number of smaller sources considered to be operating concurrently represents an average value for a high-use period within the entire planning area.

TABLE 5.5A

STANDARDIZED NOISE CONTRIBUTION MODEL, Chukchi Planning Area, Winter - 100% ice cover
Ref. areas used in model (km^2): Total overall, 124000 ; Coastal (c), 1860
Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 3.5 0.3
e - estimated value

Source	Type	Speed km/hr	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Ref. 300 m D.Bnd Lr1,dB	Mx 1/3 Lr2,dB	Mov.Srce.Corr. Area Cm,dB	TravTime Tt/Tr	Fluc. Corr. Tf/Tr	Equiv. Level Leq.dB	Encntr. Prob. Pe	Exp. Num. N	SNC Ratings D.Bnd SNC1,db	Mx 1/3 SNC2
Vibroseis	local		25	315	205	125	205	159	159	0	1.00	e 0.05	146	8.1E-06	1	95	95
Vibros. Convoy	local		160	500	167	500	160	121	114	0	1.00	e 0.5	118	8.1E-06	1	67	60
Snowmachine (c)	movng	16	250	2500	130	1600	124	84	78	-8	0.22	e 0.8	68	1.6E-02	10	60	54
Tracked Veh.(c)	movng	15	125	16000	158	2500	149	112	103	-8	0.23	e 1	98	2.2E-04	1	61	52

TABLE 5.5B

STANDARDIZED EXPOSURE RATING MODEL, Chukchi Sea Planning Area, Winter - 100% ice cover condition
Source Information from SNC Model, Ref. Range - 300 m * e - estimated value

SOURCE	Dominant BW, Fsl	Fsh	Max 1/3 Oct Fs,Hz	Lr2,dB	No. N	SNC1 dB	RECEIVER Species	Ds N/km^2	Hearing BW, kHz Frl	Frh	Fr	Sensitivity Sm,dB	Ss,dB	Lr3 dB	BWeff kHz	SER, dB Ref.	Area	SER-SNC1
					e*			e					e	e	e	e	e	e
Vibroseis	25	315	125	159	1	96	Ringed Seal	0.5	3	50	16	70	76	130	32	165	162	66

The SNC ratings for the area show that the seismic array dredge, tug/barges and outdrives are the dominant sources with small craft, represented by the "whaler", and dredges rating as strong secondary sources. The review of marine mammal distribution in Section 2 showed that gray whales and walruses are important species in this area during the late spring and summer season. These species were used together with the five important sources determined above as the basis for the SER analysis shown in Table 5.6B, and illustrated by the graphs in Fig. 5.4A.

The results of the SER analysis show that, in this region as well as in the Chukchi, gray whales are potentially the species which may be most influenced by the noise sources. In this case the seismic source shows the most potential for causing reactions with tug/barge operations having the second highest SER rating. The SER ratings for the outdrives and the tugs are strongly influenced by assumptions about the number operating. The assumed values are based on general information from the region but are not derived from specific on-site data. The SER values for walrus while not as high as those for gray whales, show a moderate potential for acoustic influence since the SER values are generally more than 50 dB higher than the SNC values for the input sources. The seismic array again has the highest SER rating. This conclusion is subject to revision if hearing data for the walrus become available since it is based on the assumption that walrus hearing characteristics are similar to those for California sea lions.

The results of the model analysis for the late fall - early winter conditions in Norton Basin are shown in Table 5.7A. An icebreaker source has been added to the group of sources considered in the previous analysis. The numbers of the multiple sources operating have been reduced to reflect the probable seasonal effect. The resulting SNC ratings show that a seismic array retains its dominance followed by the icebreaker, coastal dredge, tug/barges, and outdrives. The estimated reduction in the number of outdrives and tugs operating has reduced their SNC ratings to less than that of the dredge.

Important species present in the area during the late fall - early winter season are ringed seal and walrus. These species have been used together with the dominant four sources listed previously as the basis for the SER analysis (the SER results for outdrives are expected to be similar to those for the tug/barges). The results, presented in Table 5.7B and in the graphs in Fig. 5.4B, show that the highest rating is for the ringed seal - seismic array encounter, with lower values occurring for the ringed seal - icebreaker and ringed seal - dredge encounters. The ringed seal - seismic array encounter may not occur very frequently in the real world because of the need for seismic vessels to operate well clear of ice covered areas as opposed to the propensity of ringed seals to seek out ice-covered areas. The ringed seal - icebreaker encounter, with a relatively high SER rating, is much more probable and the ringed seal - dredge encounter less likely. The SER results for walrus show a moderate interaction potential for the seismic array and icebreaker encounters which are lower than the ratings given the ringed seal encounters. The area SER ratings for all species are based on assumed density values and may be subject to revision when more information becomes available.

TABLE 5.6A

STANDARDIZED NOISE CONTRIBUTION MODEL, Norton Basin Planning Area, Surface Layer Condition

Ref. areas used in model (km^2): Total overall, 118000 ; Coastal (c), 3310 ; Fishing (f), 21600 ; Airports (a), 144

Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 4 0.5

	(e - estimated)							Ref. 300 m		Mov.Srce.Corr.		Fluc.	Equiv.	Encntr.	Exp.	SNC Ratings	
Source	Type	Speed	Dominant BW, Hz			Max 1/3 Oct,Hz		D.Bnd	Mx 1/3	Area	TravTime	Corr.	Level	Prob.	Num.	D.Bnd	Mx 1/3
		(kts)	fmin	fmax	Ls1,dB	freq.	Ls2,dB	Lr1,dB	Lr2,dB	Cm,dB	Tt/Tr	Tf/Tr	Leq.dB	Pe	N	SNC1,dB	SNC2
Tug/Barge (c)	movng	10	100	12500	171	630	162	128	119	-9	0.22	1	112	1.0E-02	3	97	88
												e			e		
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	124	113	-9	0.11	0.8	104	2.0E-02	10	97	86
												e			e		
13' Whaler (c)	movng	20	630	8000	159	4000	153	116	110	-9	0.11	0.8	96	2.0E-02	15	91	85
					(300 m)							e					
B 737-200 (a)	movgn	400	100	800	135	125	130	115	110	-8	0.0007	1	75	6.9E-02	1	64	59
					(300 m)							e			e		
Cessna 172 (a)	movng	100	50	125	96	80	95	76	75	-8	0.0027	1	42	6.9E-02	10	41	40
					(300 m)							e			e		
Cessna 172 (c)	movng	100	50	125	96	80	95	76	75	-8	0.0027	1	42	9.9E-02	10	42	41
												e					
Dredge (BM)(c)	fixed		80	800	172	100	167	129	124	0	1	0.8	128	3.0E-04	1	93	88
												e			e		
Dredge (AQ)	fixed		50	630	185	160	178	142	135	0	1	0.8	141	8.5E-06	1	90	83
Drillship	fixed		20	800	174	63	167	131	124	0	1	1	131	8.5E-06	1	80	73
												e					
Seismic Array	movng	5	20	160	216	50	210	173	167	-9	0.43	0.005	137	1.5E-04	1	99	93
Trawler (f)	movng	5	40	1000	157	100	147	114	104	-9	0.43	1	101	8.0E-04	5	77	67
Trawler (f)	movng	10	40	4000	169	160	158	126	115	-9	0.22	1	110	1.6E-03	2	85	74

TABLE 5.6B

STANDARDIZED EXPOSURE RATING MODEL, Norton Basin Planning Area, Surface Layer Condition

Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (c) - coastal area source

SOURCE	Dominant BW,		Max 1/3 Oct		No.	SNC1	RECEIVER	Ds	Hearing BW, kHz			Sensitivity		Lr3	BWeff	SER, dB		SER-
	Fsl	Fsh	Fs,Hz	Lr2,dB	N	dB	Species	N/km^2	Frl	Frh	Fr	Sm,dB	Ss,dB	dB	kHz	Ref.	Area	SNC1
					e*		(1)	(2)	e	e	e	e	e	e	e	e	e	
Seismic Array	20	160	50	167	1	99	Pac. Walrus	12.5	0.7	30	15	80	80	136	20	168	179	80
					e				e	e	e	e	e	e	e	e	e	
Seismic Array	20	160	50	167	1	99	Gray Whale	0.04	0.09	9	0.7	40	41	148	20	219	205	106
					e				e	e	e	e	e	e	e	e	e	
Twin Outdr.(c)	40	16000	500	113	10	97	Pac. Walrus	12.5	0.7	30	15	80	80	112	30	144	155	58
					e				e	e	e	e	e	e	e	e	e	
Twin Outdr.(c)	40	16000	500	113	10	97	Gray Whale	0.04	0.09	9	0.7	40	40	115	20	185	171	74
					e				e	e	e	e	e	e	e	e	e	
Tug/Barge (c)	100	12500	630	119	3	97	Pac. Walrus	12.5	0.7	30	15	80	80	114	30	146	157	60
									e	e	e	e	e	e	e	e	e	
Tug/Barge (c)	100	12500	630	119	3	97	Gray Whale	0.04	0.09	9	0.7	40	40	118	20	188	174	77
					e				e	e	e	e	e	e	e	e	e	
Dredge (BM)(c)	80	800	100	124	1	93	Pac. Walrus	12.5	0.7	30	15	80	80	109	10	132	143	50
					e				e	e	e	e	e	e	e	e	e	
Dredge (BM)(c)	80	800	100	124	1	93	Gray Whale	0.04	0.09	9	0.7	40	40	115	10	178	164	71
									e	e	e	e	e	e	e	e	e	
13' Whaler (c)	630	8000	4000	110	15	91	Pac. Walrus	12.5	0.7	30	15	80	80	105	20	129	140	49
					e				e	e	e	e	e	e	e	e	e	
13' Whaler (c)	630	8000	4000	110	15	91	Gray Whale	0.04	0.09	9	0.7	40	40	104	20	168	154	63

Note (1): Hearing characteristic for California sea lion used for Pacific walrus.

(2): Density value for walrus determined by observations for the Nome area (est. 40 km^2)

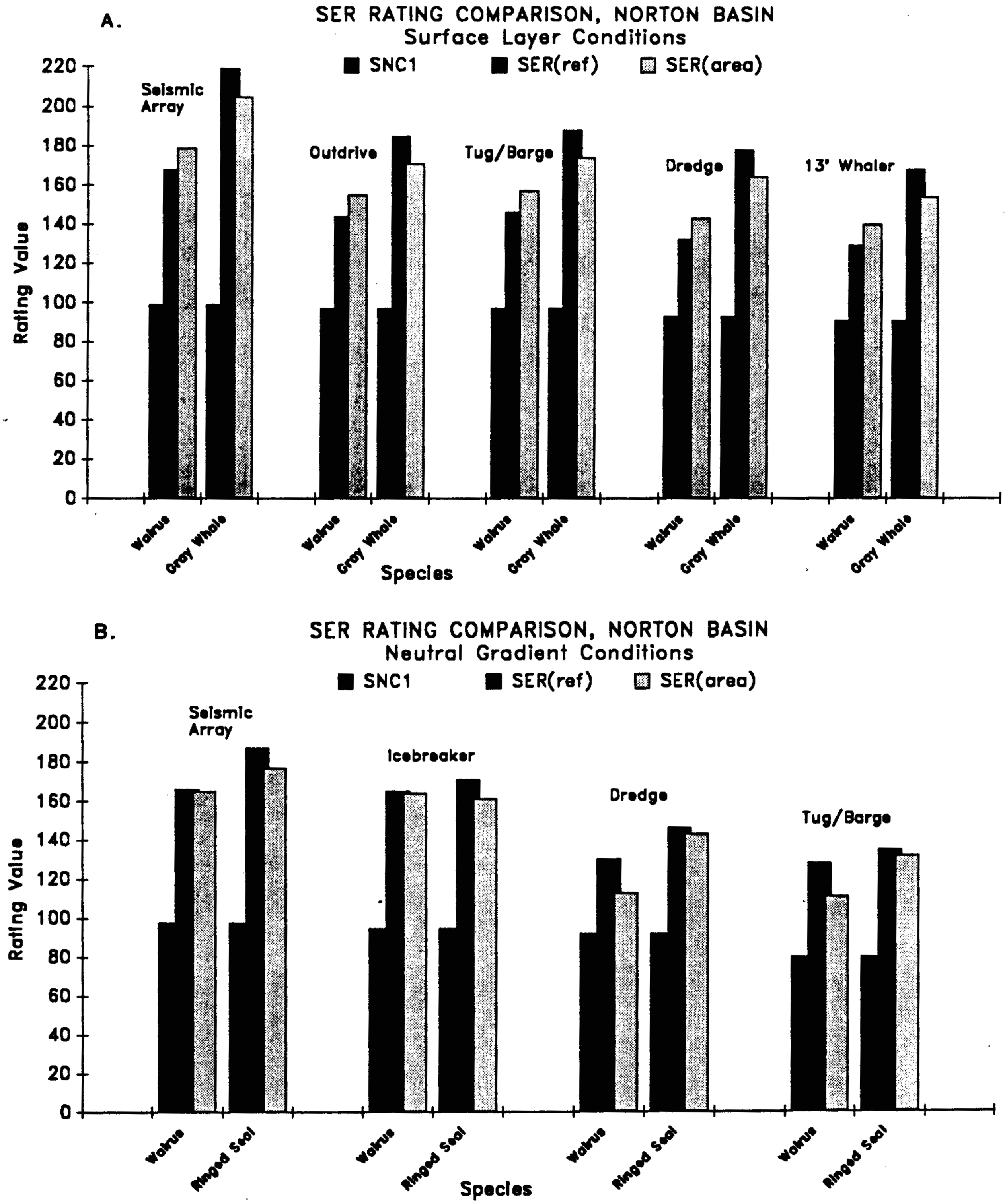


Figure 5.4. SER Rating Comparison, Norton Basin.
A. Surface Layer Conditions
B. Neutral Gradient Conditions

TABLE 5.7A

STANDARDIZED NOISE CONTRIBUTION MODEL, Norton Basin Planning Area, Neutral Gradient Condition
Ref. areas used in model (km^2): Total overall, 118000 ; Coastal (c), 3310 ; Fishing (f), 21600 ; Airports (a), 144
Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 4 0.5

	(e - estimated)							Ref. 300 m		Mov.Srce.Corr.		Fluc.	Equiv.	Encntr.	Exp.	SNC Ratings	
Source	Type	Speed	Dominant BW, Hz			Max 1/3 Oct,Hz		D.Bnd	Mx 1/3	Area	TravTime	Corr.	Level	Prob.	Num.	D.Bnd	Mx 1/3
		(kts)	fmin	fmax	Ls1,dB	freq.	Ls2,dB	Lr1,dB	Lr2,dB	Cm,dB	Tt/Tr	Tf/Tr	Leq.dB	Pe	N	SNC1,dB	SNC2
Tug/Barge (c)	movng	10	100	12500	171	630	162	127	118	-9	0.22	1	111	1.0E-02	1	91	82
												e			e		
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	123	112	-9	0.11	0.8	103	2.0E-02	3	91	80
												e			e		
13' Whaler (c)	movng	20	630	8000	159	4000	153	115	109	-9	0.11	0.8	95	2.0E-02	5	85	79
					(300 m)							e					
B. 737-200 (a)	movng	400	100	800	135	125	130	115	110	-8	0.0007	1	75	6.9E-02	1	64	59
					(300 m)							e			e		
Cessna 172 (a)	movng	100	50	125	96	80	95	76	75	-8	0.0027	1	42	6.9E-02	2	34	33
					(300 m)							e			e		
Cessna 172 (c)	movng	100	50	125	96	80	95	76	75	-8	0.0027	1	42	9.9E-02	2	35	34
Dredge (BM)(c)	fixed		80	800	172	100	167	128	123	0	1	0.8	127	3.0E-04	1	92	87
												e			e		
Dredge (AQ)	fixed		50	630	185	160	178	141	134	0	1	0.8	140	8.5E-06	1	89	82
Drillship	fixed		20	800	174	63	167	130	123	0	1	1	130	8.5E-06	1	79	72
												e					
Seismic Array	movng	5	20	160	216	50	210	172	166	-9	0.43	0.005	136	1.5E-04	1	98	92
Icebreaker	local		40	6300	192	100	183	148	139	0	1	0.5	145	8.5E-06	1	94	85

TABLE 5.7B

STANDARDIZED EXPOSURE RATING MODEL, Norton Basin Planning Area, Neutral Gradient Condition
Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (c) - coastal area source

SOURCE	Dominant B		Max 1/3 Oct		No.	SNC1	RECEIVER	Ds	Hearing BW, kHz			Sensitivity		Lr3	BWeff	SER, dB		SER-
	Fsl	Fsh	Fs,Hz	Lr2,dB	N	dB	Species	N/km^2	Frl	Frh	Fr	Sm,dB	Ss,dB	dB	kHz	Ref.	Area	SNC1
					e*		(1)		e	e	e	e	e	e	e	e	e	
Seismic Array	20	160	50	166	1	98	Pac. Walrus	0.85	0.7	30	15	80	80	135	20	166	165	67
					e			e							e	e	e	
Seismic Array	20	160	50	166	1	98	Ringed Seal	0.10	3	50	16	70	76	147	60	187	177	79
					e				e	e	e	e	e	e	e	e	e	
Icebreaker	40	6300	100	139	1	95	Pac. Walrus	0.85	0.7	30	15	80	80	135	30	165	164	69
					e			e							e	e	e	
Icebreaker	40	6300	100	139	1	95	Ringed Seal	0.10	3	50	16	70	76	134	60	171	161	66
					e				e	e	e	e	e	e	e	e	e	
Dredge (BM)(c)	80	800	100	123	1	92	Pac. Walrus	0.02	0.7	30	15	80	80	108	10	130	113	21
					e			e							e	e	e	
Dredge (BM)(c)	80	800	100	123	1	92	Ringed Seal	0.50	3	50	16	70	76	115	30	146	143	51
					e				e	e	e	e	e			e	e	
Tug/Barge (c)	100	12500	630	118	1	80	Pac. Walrus	0.02	0.7	30	15	80	80	113	30	128	111	31
					e			e					e			e	e	
Tug/Barge (c)	100	12500	630	118	1	80	Ringed Seal	0.50	3	50	16	70	76	113	60	135	132	52

Note (1): Hearing characteristic for California sea lion used for Pacific walrus.

North Aleutian Basin

The sources used in the SNC Model analysis for the North Aleutain Basin area are representative of existing fishing, transportation, and cultural activities plus hypothetical oil industry operations. As shown in Table 5.8A, the dominant sources in this area for the late spring - summer season are the tug/barges, outdrives, and hypothesized seismic array. Important secondary sources are small craft, trawlers (in transit) and hypothesized large dredge. Outdrives and other high-speed small craft are dominant sources, because of the large number in operation during peak fishing seasons. The larger tugs and fishing trawlers, while not as numerous, contribute significantly because they generally have relatively high RPM propellers which produce cavitation noise for most vessel operating conditions.

The southern portion of this area along the Alaska Peninsula is in an active volcanic zone (Sec. 3.2.5). As a result, sporadic low frequency noise is produced by bottom motion during earthquake events. During these events, the noise levels at frequencies below 50 Hz can be signicantly louder than the source levels of the industrial sources listed in Table 5.8A, with the possible exception of the seismic array. Sporadic seismic noise has not been given a rating in Table 5.8A because high level events are relatively infrequent, typically less than 1 per year of Magnitude 4 or greater (Fig. 3.5).

Four species - gray whale, harbor seal, harbor porpoise, and Steller sea lion - were considered, together with the five sources just discussed, in the SER model analysis for this area. The results in Table 5.8B and Fig. 5.5A show that the gray whale - seismic array encounter again has the highest SER rating, followed by the gray whales encountering the tug/barges and outdrives. The model was not run using the seismic array or trawler in relation to the other species since the pinnipeds and harbor porpoises were assumed to be generally located near shore during this season. As shown by the SER values, harbor porpoise have a higher potential for acoustic interaction than the other small marine mammals as a result of their more sensitive low frequency hearing.

There is a resident population of sea otters in the southern part of this area. No hearing sensitivity data are available for this species. It is expected that their hearing is optimized for airborne rather than underwater sound since they spend most of their time at or above the surface. Observations of the behavior of sea otters in the presence of an operating air gun and support vessel were made as part of an acoustic disturbance study of migrating gray whales (Malme et al. 1984). No significant changes in behavior were observed for operation as close as 900 m (Riedman 1984).

The SNC analysis for the late fall - early winter season in the North Aleutian Planning Area is shown in Table 5.9A. The group of sources used for the previous analysis was considered again after making changes in TL values and in the expected number of sources. The SNC ratings for all of the sources are reduced somewhat compared to those for the spring - summer season due to higher short-range TL and an estimated smaller number of operational vessels and small craft. The hypothesized seismic array along with tug/barges and outdrives are the dominant sources. The estimated smaller number of outdrives

TABLE 5.8A

STANDARDIZED NOISE CONTRIBUTION MODEL, North Aleutian Planning Area, Surface Layer Condition
Ref. areas used in model (km^2): Total overall, 149000 ; Coastal (c), 3600 ; Fishing (f), 34400 ; Airports (a), 78
Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 27 0.9

Source (area)	Type	(e - estimated) Speed (kts)	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Ref. 300 m D.Bnd. Lr1,dB	Mx 1/3 Lr2,dB	Mov.Srce.Corr. Area Cm,dB	TravTime Tt/Tr	Fluc. Corr. Tf/Tr	Equiv. Level Leq.dB	Encntr. Prob. Pe	Exp. Num. N	SNC ratings D.Bnd SNC1,dB	Mx 1/3 SNC2
Tug/Barge (c)	movng	10	100	12500	171	630	162	129	120	-11	1	1	118	9.4E-03	e 5	105	96
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	125	114	-11	0.73	e 0.8	112	1.8E-02	e 15	106	95
13' Whaler (c)	movng	20	630	8000	159	4000	153	117	111	-11	0.73	e 0.8	104	1.8E-02	e 20	99	93
Trawler (f)	movng	5	40	1000	157	100	147	115	105	-11	1	e 1	104	5.1E-04	e 20	84	74
Trawler (f)	movng	10	40	4000	169	160	158	127	116	-11	1	1	116	9.8E-04	5	93	82
Drillship	fixed		20	800	174	63	167	132	125	0	1	1	132	6.7E-06	e 1	80	73
Dredge (AQ.)	fixed		50	630	185	160	178	143	136	0	1	e 0.8	142	6.7E-06	e 1	90	83
Seismic Array	movng	5	20	160	216 (300 m)	50	210	174	168	-11	1	e 0.005	140	1.2E-04	e 1	101	95
B. 737-200 (a)	movng	400	100	800	135	125	130	121	116	-10	0.0012	1	82	7.7E-02	3	75	70

TABLE 5.8B

STANDARDIZED EXPOSURE RATING MODEL, North Aleutian Planning Area, Surface Layer Condition
Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (c) - coastal area source (f) - fishing area source

SOURCE	Dominant BW, Fsl	Fsh	Max 1/3 Oct Fs,Hz	Lr2,dB	No. N	SNC1 dB	RECEIVER Species	Ds N/km^2	Hearing BW, kHz Frl	Frh	Fr	Sensitivity Sm,dB	Ss,dB	Lr3 dB	BWeff kHz	SER, dB Ref.	Area	SER-SNC1
Seismic Array	20	160	50	168	e* 1	101	Gray Whale	e 0.02	e 0.09	e 9	e e	e 40	e 41	e 149	e 20	e 222	e 205	e 104
Twin Outdrv.(c)	40	16000	500	114	e 20	106	Harbor Seal	e 0.44	3	50	33	63	63	e 101	60	e 162	e 158	e 52
Twin Outdrv.(c)	40	16000	500	114	e 20	106	Harbor Porp. (1)	e 0.02	3	80	15	48	48	e 109	130	e 188	e 171	e 65
Twin Outdrv.(c)	40	16000	500	114	e 20	106	Stel.Sea Lion	e 0.21	e 0.7	e 30	e 15	e 80	e 80	e 113	e 30	e 154	e 147	e 41
Twin Outdrv.(c)	40	16000	500	114	e 20	106	Gray Whale	e 0.02	e 0.09	e 9	e 0.7	e 40	e 40	e 116	e 20	e 195	e 178	e 72
13' Whaler (c)	630	8000	4000	109	e 20	99	Harbor Seal	e 0.44	3	50	33	63	73	111	50	e 154	e 150	e 51
13' Whaler (c)	630	8000	4000	109	e 20	99	Harbor Porp. (1)	e 0.02	3	80	15	48	56	111	130	e 175	e 158	e 59
13' Whaler (c)	630	8000	4000	109	e 20	99	Stel.Sea Lion	e 0.21	e 0.7	e 30	e 15	e 80	e 80	e 106	e 20	e 138	e 131	e 32
13' Whaler (c)	630	8000	4000	109	e 20	99	Gray Whale	e 0.02	e 0.09	e 9	e 0.7	e 40	e 40	e 105	e 20	e 177	e 160	e 61
Tug/Barge (c)	100	12500	630	120	5	105	Harbor Seal	e 0.44	3	50	33	63	63	104	63	e 164	e 160	e 55
Tug/Barge (c)	100	12500	630	120	e 5	105	Harbor Porp. (1)	e 0.02	3	80	15	48	48	113	130	e 191	e 174	e 69
Tug/Barge (c)	100	12500	630	120	e 5	105	Stel.Sea Lion	e 0.21	e 0.7	e 30	e 15	e 80	e 80	e 115	e 30	e 155	e 148	e 43
Tug/Barge (c)	100	12500	630	120	e 5	105	Gray Whale	e 0.02	e 0.09	e 9	e 0.7	e 40	e 40	e 119	e 20	e 197	e 180	e 75
Trawler (f)	40	4000	160	116	e 5	93	Harbor Porp.	0.02	3	80	15	48	48	103	130	e 169	e 152	e 59

Note (1): Hearing characteristic for California sea lion used for Steller sea lion.

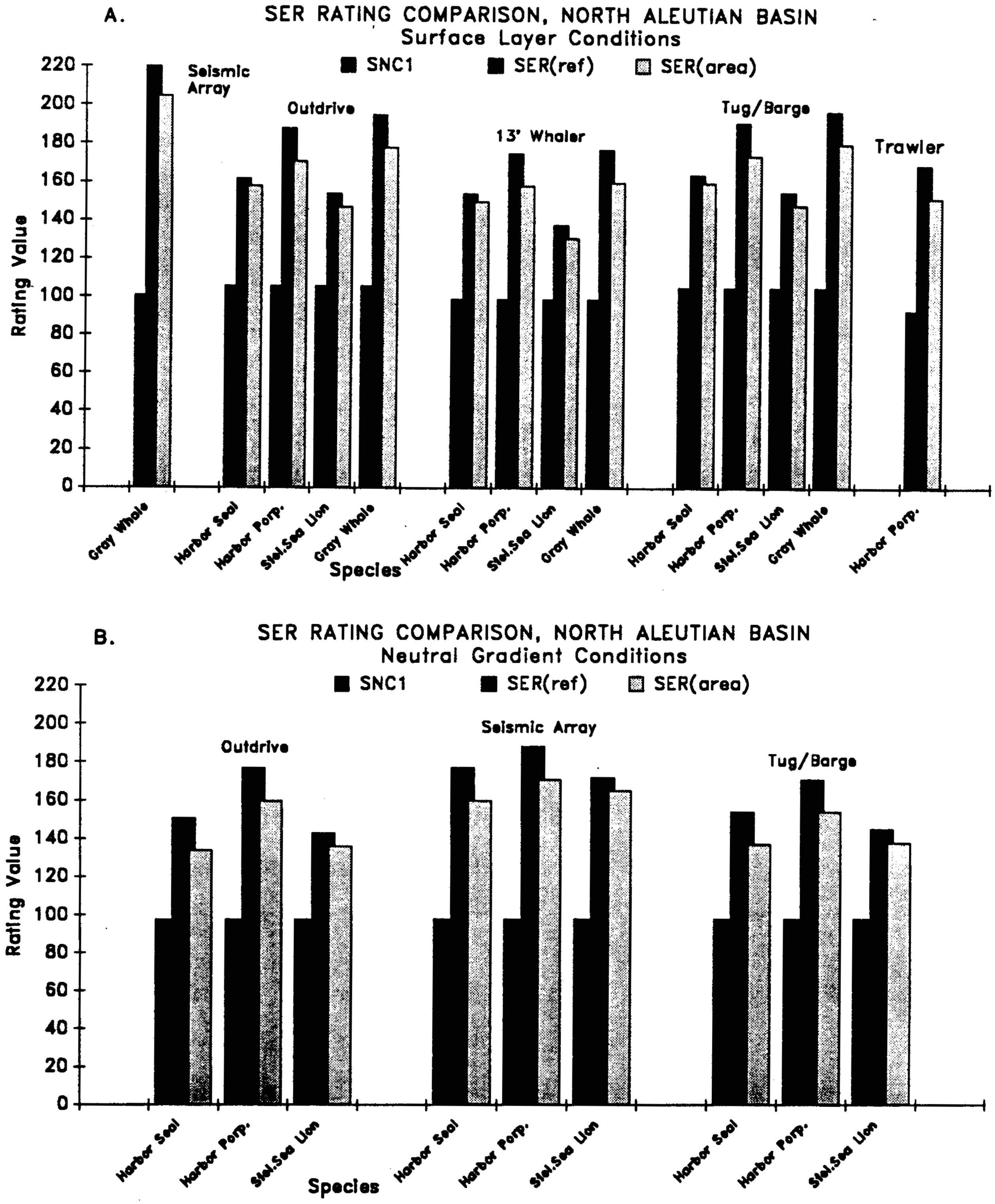


Figure 5.5 SER Rating Comparison, North Aleutian Basin.
A. Surface Layer Conditions
B. Neutral Gradient Conditions.

TABLE 5.9A

STANDARDIZED NOISE CONTRIBUTION MODEL, North Aleutian Planning Area, Neutral Gradient Condition

Ref. areas used in model (km^2): Total overall, 149000 ; Coastal (c), 3600 ; Fishing (f), 34400 ; Airports (a), 78

Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 23 0.9

(e - estimated)

Source (area)	Type	Speed (kts)	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Ref. 300 m D.Bnd Lr1,dB	Mx 1/3 Lr2,dB	Mov.Srce.Corr. Area Cm,dB	TravTime Tt/Tr	Fluc. Corr. Tf/Tr	Equiv. Level Leq.dB	Encntr. Prob. Pe	Exp. Num. N	SNC Ratings D.Bnd SNC1,dB	Mx 1/3 SNC2
Tug/Barge (c)	movng	10	100	12500	171	630	162	126	117	-11	1	1	115	9.4E-03	e 2	98	89
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	122	111	-11	0.62	e 0.8	108	1.8E-02	e 5	98	87
13' Whaler (c)	movng	20	630	8000	159	4000	153	114	108	-11	0.62	e 0.8	100	1.8E-02	e 10	93	87
Trawler (f)	movng	5	40	1000	157	100	147	112	102	-11	1	1	101	5.1E-04	e 3	73	63
Trawler (f)	movng	10	40	4000	169	160	158	124	113	-11	1	1	113	9.8E-04	e 1	83	72
Drillship	fixed		20	800	174	63	167	129	122	0	1	1	129	6.7E-06	e 1	77	70
Dredge (AQ.)	fixed		50	630	185	160	178	140	133	0	1	e 0.8	139	6.7E-06	e 1	87	80
Seismic Array	movng	5	20	160	216 (300 m)	50	210	171	165	-11	1	e 0.005	137	1.2E-04	e 1	98	92
B. 737-200 (a)	movng	400	100	800	135	125	130	121	116	-10	0.0012	1	82	7.7E-02	e 2	74	69

TABLE 5.9B

STANDARDIZED EXPOSURE RATING MODEL, North Aleutian Basin, Neutral Gradient Conditions

Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (c) - coastal area source

SOURCE	Dominant BW, Fsl	Fsh	Max 1/3 Oct Fs,Hz	Lr2,dB	No. N	SNC1 dB	RECEIVER Species	Ds N/km^2	Hearing BW, kHz Frl	Frh	Fr	Sensitivity Sm,dB	Ss,dB	Lr3 dB	BWeff kHz	SER, dB Ref.	Area	SER-SNC1
Twin Outdrv.(c)	40	16000	500	111	e 5	98	Harbor Seal	e 0.02	3	50	33	63	63	98	60	e 151	e 134	e 36
Twin Outdrv.(c)	40	16000	500	111	e 5	98	Harbor Porp. (1)	e 0.02	3	80	15	48	48	106	130	e 177	e 160	e 62
Twin Outdrv.(c)	40	16000	500	111	e 5	98	Stel.Sea Lion	e 0.22	e 0.7	e 30	e 15	e 80	e 80	e 110	e 30	e 143	e 136	e 38
Seismic Array	20	160	50	165	e 1	98	Harbor Seal	e 0.02	3	50	33	63	84	145	60	e 177	e 160	e 62
Seismic Array	20	160	50	165	e 1	98	Harbor Porp. (1)	e 0.02	3	80	15	48	48	117	130	e 188	e 171	e 73
Seismic Array	20	160	50	165	e 1	98	Stel.Sea Lion	e 0.22	e 0.7	e 30	e 15	e 80	e 86	e 145	e 30	e 172	e 165	e 67
Tug/Barge (c)	100	12500	630	117	e 2	98	Harbor Seal	e 0.02	3	50	33	63	63	101	60	e 154	e 137	e 39
Tug/Barge (c)	100	12500	630	117	e 2	98	Harbor Porp. (1)	e 0.02	3	80	15	48	e 56	108	130	171	154	56
Tug/Barge (c)	100	12500	630	117	e 2	98	Stel.Sea Lion	e 0.22	e 0.7	e 30	e 15	e 80	e 80	e 112	e 30	e 145	e 138	e 40

Note (1): Hearing characteristic for California sea lion used for Steller sea lion.

and similar high speed small craft during this season has reduced the SNC rating for this class from highest to a tie for the with seismic array. Small craft, the hypothesized large dredge, and trawlers are the secondary sources.

The pinniped species and harbor porpoise considered in the SER analysis for this area are the same as in the spring - summer period since they are generally resident throughout the year. The results of the SER analysis are shown in Table 5.9B and Fig. 5.5B. As a result of the lower SNC values for this season in the area, the SER values are also lower than those obtained for the spring - summer period. The harbor porpoise SER ratings show a moderate potential for acoustic influence by the sources considered with the highest rating for the seismic array. Ratings for the other two species are generally low.

The southbound gray whale migration is concluding during the early portion of this period. No analysis was done for gray whales since the SER results obtained for the whales present would be expected to be similar to those obtained for the spring - summer period. The values for the smaller sources would be somewhat reduced because of the smaller number operating. The SER values which would be obtained for gray whales would be high, suggesting that the transient gray whales are potentially more influenced by the local noise sources than the resident smaller mammals.

Shumagin

The southern region of the Shumagin Planning Area is in deep water off the edge of the continental shelf. Only the northern continental shelf region was included in the general SNC model area estimate. The north edge of the Shumagin Planning Area is traversed by ship and fishing vessel traffic using the Unimak Pass. This results in a significant noise input to this area. The sources used in the SNC analysis were selected to be representative of the Unimak Pass traffic and local small craft activity. In addition, sources associated with oil exploration and drilling operations were hypothesized to be present. The results of the SNC Model analysis are shown in Table 5.10A for the late spring - summer season in the Shumagin area. Large tankers are the dominant sources in this area because of their high sound levels at low frequencies. The seismic array, medium-sized cargo vessels (which compare with the large Alaska ferries in acoustic output), outdrives, and tug/barges are the secondary sources in this analysis. Three medium-sized cargo type vessels were considered to be operating concurrently.

The northern portion of the Shumagin Area is in the Aleutian arc volcanic zone and as a result the underwater ambient noise is influenced by sporadic volcanic and seismic activity. This activity is particularly intense in the Shumagin Island area (Fig. 3.7) where the probable ground acceleration levels are about twice as high as on the northern side of the Alaska Peninsula. As discussed previously for the North Aleutian Basin area, marine mammals are subjected to transient high level sounds at low frequencies when seismic events occur. While no rating has been made in Table 5.10A for the seismic noise in the Shumagin area, an estimation procedure is discussed in Sec. 6 as a basis for further study.

TABLE 5.10A

STANDARDIZED NOISE CONTRIBUTION MODEL, Shumagin Planning Area, Surface Layer Condition

Ref. areas used in model (km^2): Total overall, 85800 ; Shiplane (s),12200 ; Coastal (c), 8500 ; Airports (a), 9

Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 27 0.9

(e - estimated)

Source (area)	Type	Speed (kts)	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Ref. 300 m D.Bnd Lr1,dB	Mx 1/3 Lr2,dB	Mov.Srce.Corr. Area Cm,dB	TravTime Tt/Tr	Fluc. Corr. Tf/Tr	Equiv. Level Leq.dB	Encntr. Prob. Pe	Exp. Num. N	SNC Ratings D.Bnd SNC1,dB	Mx 1/3 SNC2
															e		
Lrg.Tanker (s)	movng	16	2	4	205	2	203	157	155	-11	0.91	1	146	4.4E-03	1	122	120
															e		
Ferry/Cargo(s)	movng	16	40	630	175	125	171	127	123	-11	0.91	1	116	4.4E-03	3	97	93
															e		
Tug/Barge (s)	movng	10	100	12500	171	630	162	123	114	-11	1	1	112	2.8E-03	5	93	84
												e			e		
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	119	108	-11	0.73	0.8	106	7.8E-03	10	95	84
															e		
Drillship	fixed		20	800	174	63	167	126	119	0	1	1	126	1.2E-05	1	77	70
												e			e		
Dredge (AQ.)	fixed		50	630	185	160	178	137	130	0	1	0.8	136	1.2E-05	1	87	80
												e			e		
Seismic Array	movng	5	20	160	216	50	210	168	162	-11	1	0.005	134	2.0E-04	1	97	91
					(300 m)							e			e		
Bell 205 Helo	movng	80	50	500	114	63	107	104	97	-10	0.0061	1	72	3.1E-03	1	47	40

TABLE 5.10B

STANDARDIZED EXPOSURE RATING MODEL, Shumagin Planning Area, Surface Layer Condition

Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (s) - shiplane source area (c) - coastal source area

SOURCE	Dominant BW, Fsl	Fsh	Max 1/3 Oct Fs,Hz	Lr2,dB	No. N	SNC1 dB	RECEIVER Species	Ds N/km^2	Hearing BW, kHz Frl	Frh	Fr	Sensitivity Sm,dB	Ss,dB	Lr3 dB	BWeff kHz	SER, dB Ref.	Area	SER-SNC1
					e*				e	e	e	e	e	e	e	e	e	e
Seismic Array	20	160	50	168	1	97	Fin Whale	0.0085	0.03	3	0.2	40	42	162	11	227	207	110
					e		(1)	e	e	e	e	e	e	e	e	e	e	e
Seismic Array	20	160	50	168	1	97	Stel.Sea Lion	0.1	0.7	30	15	80	80	132	20	162	152	55
					e			e							e	e	e	e
Seismic Array	20	160	50	168	1	97	Killer Whale	0.01	11	30	15	30	42	114	30	184	164	67
					e				e	e	e	e	e	e	e	e	e	e
Twin Outdrv.(c)	40	16000	500	108	1	95	Fin Whale	0.0085	0.03	3	0.2	40	41	109	20	176	155	60
					e		(1)	e	e	e	e	e	e	e	e	e	e	e
Twin Outdrv.(c)	40	16000	500	108	1	95	Stel.Sea Lion	0.1	0.7	30	15	80	80	107	30	137	127	32
					e			e							e	e	e	e
Twin Outdrv.(c)	40	16000	500	108	1	95	Killer Whale	0.01	11	30	15	30	30	100	30	180	160	65
					e				e	e	e	e	e	e	e	e	e	e
Lrg. Tanker (s)	2	4	2	155	1	122	Fin Whale	0.0085	0.03	3	0.2	40	42	129	20	222	201	79
					e		(1)	e	e	e	e	e	e	e	e	e	e	e
Lrg. Tanker (s)	2	4	2	155	1	122	Stel.Sea Lion	0.1	0.7	30	15	80	80	119	30	176	166	44
					e			e							e	e	e	e
Lrg. Tanker (s)	2	4	2	155	1	122	Killer Whale	0.01	11	30	15	30	30	109	30	216	196	74
					e				e	e	e	e	e	e	e	e	e	e
Ferry/Cargo (s)	40	630	125	129	3	97	Fin Whale	0.0085	0.03	3	0.2	40	42	122	20	190	169	72
					e		(1)	e	e	e	e	e	e	e	e	e	e	e
Ferry/Cargo (s)	40	630	125	129	3	97	Stel.Sea Lion	0.1	0.7	30	15	80	80	108	30	140	130	33
					e			e					e			e	e	e
Ferry/Cargo (s)	40	630	125	129	3	97	Killer Whale	0.01	11	30	15	30	30	95	30	177	157	60

Note (1): Hearing characteristic for California sea lion used for Steller sea lion.

A major species of concern for the spring - summer condition in the Shumagin area is the fin whale. Since no hearing sensitivity data are available for this species, an assumption was made that the fin whale hearing characteristic is similar to that of the gray whale. It is probable that their low frequency sensitivity is better that that of the gray whale since their vocalization range extends to below 20 Hz. With this information, a hearing sensitivity curve for this species was estimated by modifying the previously developed gray whale curve as shown in Appendix D. This permitted an SER analysis with results as shown in Table 5.10B and illustrated in Fig. 5.6A. The estimated SER ratings are somewhat higher than those obtained for the gray whale in the North Aleutian Basin. This is a result of the extended low frequency hearing range which was assumed to be appropriate for the fin whale. The highest SER rating is obtained for the seismic array with the large tanker somewhat lower. Though the SNC rating for the tanker is considerably higher than that of the seismic array, the dominant output of the tanker is at very low frequencies, estimated to be below the most sensitive region of the whales' hearing curve. While gray whales are present in this area during migration periods, no specific SER analysis was done since the values would be only slightly lower that those obtained for fin whales.

Other important species found in this region during the spring - summer season are humpback whales, killer whales, and Steller sea lions. The SER results for humpback whales are expected to be similar to those for fin whales so a specifc analysis was not made for this species. The SER ratings for killer whales and Steller sea lions show that killer whales have the higher potential response with SER ratings larger than those of the fin whale for outdrive sources. The ratings for the Steller sea lion are medium to low for all the sources considered.

The period for neutral gradient conditions in the Shumagin area would extend from late fall through winter and into early spring since no ice forms in this region. The SNC analysis for this period used the same sources as shown in Table 5.10A with the numbers adjusted for TL changes and a somewhat reduced vessel traffic during the winter period. The results of the SNC analyis shown in Table 5.11A are similar to those obtained for the spring - summer season with the large tanker being the dominant source and the hypothetical seismic array and ferry/cargo vessels secondary sources.

The principal species of concern in this area during the winter season include fur seals, Dall's porpoise, and Steller sea lion. No hearing sensitivity data are available for Dall's porpoise so data from the harbor porpoise were assumed to be similar. The results of the analysis, shown in Table 5.11B and Fig. 5.6B, suggest that the probability of acoustic interaction may be high for the fur seal and Dall's porpoise with the large tanker having the highest SER values. The Steller sea lion SER ratings are also relatively high for the tanker. For the other sources, the seismic array - fur seal encounter also has a relatively high SER value, but this encounter may not occur very often in survey operations.

TABLE 5.11A

STANDARDIZED NOISE CONTRIBUTION MODEL, Shumagin Planning Area, Neutral Gradient Condition

Ref. areas used in model (km^2): Total overall, 85800 ; Shiplane (s),12200 ; Coastal (c), 8500 ; Airports (a), 9

Ref. Range, 300 m; Max. Effective Range; ships, aircraft (km)- 23 0.9

(e - estimated)

Source (area)	Type	Speed (kts)	Dominant BW, Hz fmin	fmax	Ls1,dB	Max 1/3 Oct,Hz freq.	Ls2,dB	Ref. 300 m D.Bnd Lr1,dB	Mx 1/3 Lr2,dB	Mov.Srce.Corr. Area Cm,dB	TravTime Tt/Tr	Fluc. Corr. Tf/Tr	Equiv. Level Leq.dB	Encntr. Prob. Pe	Exp. Num. N	SNC Ratings D.Bnd SNC1,dB	Mx 1/3 SNC2
Lrg.Tanker (s)	movng	16	2	4	205	2	203	157	155	-11	0.78	1	145	4.4E-03	e 1	121	119
Ferry/Cargo(s)	movng	16	40	630	175	125	171	127	123	-11	0.78	1	115	4.4E-03	e 2	94	90
Tug/Barge (s)	movng	10	100	12500	171	630	162	123	114	-11	1	1	112	2.8E-03	e 2	89	80
Twin Outdrv.(c)	movng	20	40	16000	167	500	156	119	108	-11	0.62	e 0.8	105	7.8E-03	e 5	91	80
Drillship	fixed		20	800	174	63	167	126	119	0	1	1	126	1.2E-05	1	77	70
Dredge (AQ.)	fixed		50	630	185	160	178	137	130	0	1	e 0.8	136	1.2E-05	1	87	80
Seismic Array	movng	5	20	160	216 (300 m)	50	210	168	162	-11	1	e 0.005	134	2.0E-04	e 1	97	91
Bell 205 Helo	movin	80	50	500	114	63	107	104	97	-10	0.0061	e 1	72	3.1E-03	e 1	47	40

TABLE 5.11B

STANDARDIZED EXPOSURE RATING MODEL, Shumagin Planning Area, Neutral Gradient Conditions

Source Information from SNC Model, Ref. Range - 300 m * e - estimated value (s) - Shiplane area source (c) - coastal area source

SOURCE	Dominant BW, Fsl	Fsh	Max 1/3 Oct Fs,Hz	Lr2,dB	No. N	SNC1 dB	RECEIVER Species	Ds N/km^2	Hearing BW, kHz Frl	Frh	Fr	Sensitivity Sm,dB	Ss,dB	Lr3 dB	BWeff kHz	SER, dB Ref.	Area	SER-SNC1
Seismic Array	20	160	50	162	e 1	97	Fur Seal	e 0.1	2	28	4	58	58	127	e 25	e 180	e 170	73
Seismic Array	20	160	50	162	e 1	97	(1) Dall's Porp.	e 0.02	e 3	e 80	e 15	e 48	e 82	e 143	e 32	e 173	e 156	59
Seismic Array	20	160	50	162	e 1	97	(2) Stel.Sea Lion	e 0.2	e 0.7	e 30	e 15	e 80	e 80	e 132	e 16	e 161	e 154	57
Lrg.Tanker (s)	2	4	2	155	e 1	121	Fur Seal	e 0.1	2	28	4	58	58	115	e 40	e 194	e 184	63
Lrg.Tanker (s)	2	4	2	155	e 1	121	(1) Dall's Porp.	e 0.02	e 3	e 80	e 15	e 48	e 48	112	e 113	e 206	e 189	68
Lrg.Tanker (s)	2	4	2	155	e 1	121	(2) Stel.Sea Lion	e 0.2	e 0.7	e 30	e 15	e 80	e 80	118	e 30	e 174	e 167	46
Ferry/Cargo	40	630	125	123	e 2	94	Fur Seal	e 0.1	2	28	4	58	58	105	e 30	e 156	e 146	52
Ferry/Cargo	40	630	125	123	e 2	94	(1) Dall's Porp.	e 0.02	e 3	e 80	e 15	e 48	e 48	102	e 113	e 169	e 152	58
Ferry/Cargo	40	630	125	123	e 2	94	(2) Stel.Sea Lion	e 0.2	e 0.7	e 30	e 15	e 80	e 80	109	e 30	e 138	e 131	37

Notes (1): Hearing characteristic for harbor porpoise used for Dall's porpoise.
(2): Hearing characteristic for California sea lion used for Steller sea lion.

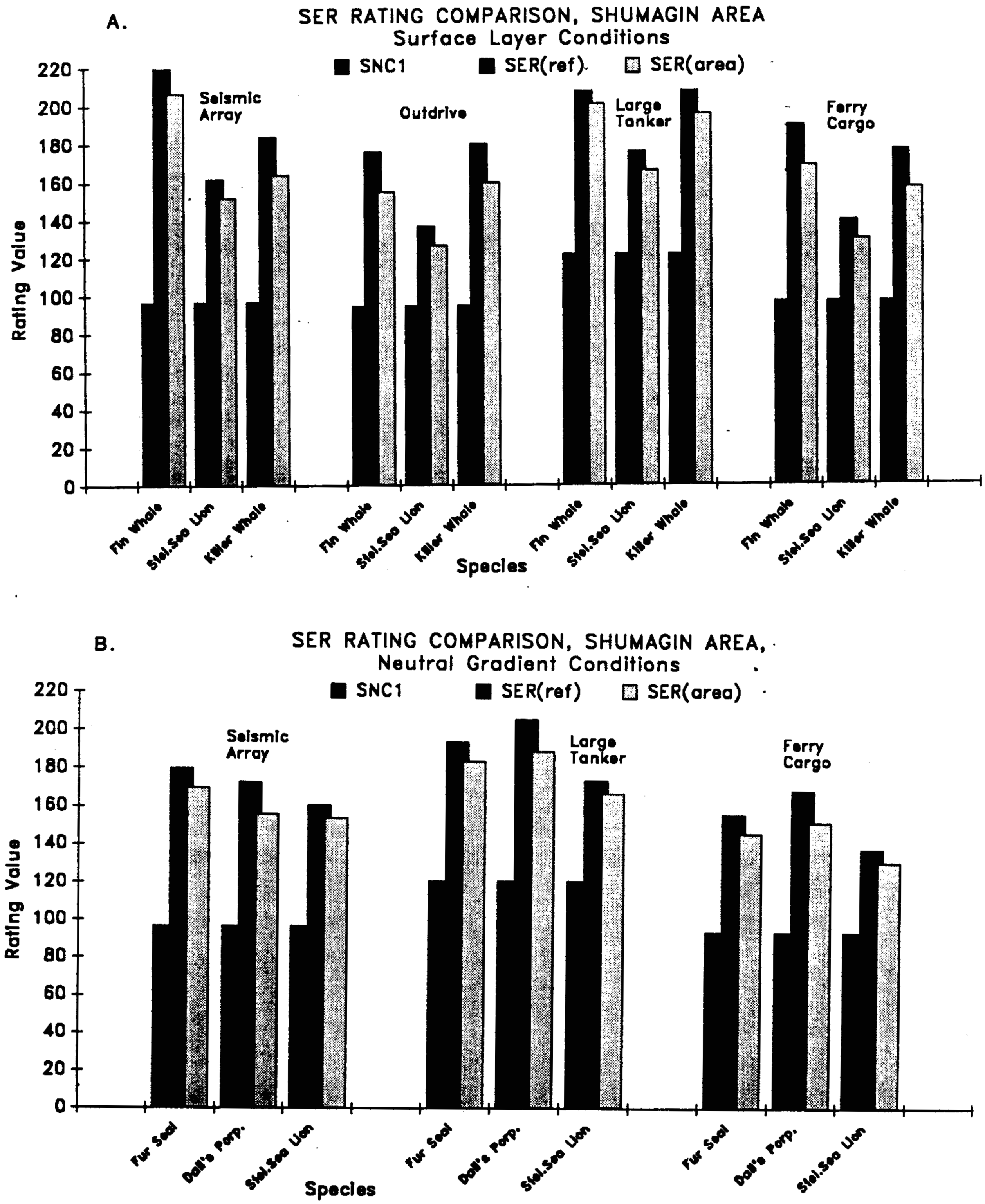


Figure 5.6. SER Rating Comparison, Shumagin Area.
A. Surface Layer Conditions
B. Neutral Gradient Conditions

An analysis was not performed for gray whales and fin whales which may be in this area during part of the winter. Because of their assumed good hearing sensitivity at low frequencies, the SER values which would be obtained for these species would be high and similar to those obtained for the spring - summer period, with some changes due to different population densities.

5.3 Zone of Influence Estimates for Major Noise Sources

Observations on whale behavior as related to quantified acoustic exposure levels have been obtained for a few species such as the gray (Malme et al. 1983, 1984); bowhead (Richardson et al. 1985; Ljungblad et al. 1989); humpback (Malme et al. 1985); and white whales (Aubrey et al. 1986). These studies have used movement away from a sound source (avoidance) as one of the main indicators of a desire to reduce sound exposure. Analyses of response data obtained from playback experiments and tests using air gun sources have provided estimates of the probability of avoidance for a limited set of industrial noise sources. The disturbance criteria are usually given in terms of the sound exposure level which will produce avoidance behavior in 50% of the animals exposed. For playback experiments with gray whales the sound level which produced a 50% probability of avoidance was found to vary within a range of 117 to 125 dB depending on the playback stimulus. The stimuli used were recordings of a drillship, drilling platform, semi-submersible platform, production platform and helicopter. The effective level of the playback signal was determined using the dominant bandwidth of the signal as defined previously in Section 3.

Studies of the behavioral responses of bowhead whales to playback of drillship and dredge noise and to noise from nearby boats have developed a somewhat different criterion (Richardson et al. 1985; Miles et al. 1987). In these studies the ratio of the received level in the strongest 1/3 octave band of the stimulus signal to the ambient noise in the same band was used as the primary measurement parameter. It was found that, while individual responses were highly variable, a S/N ratio of 30 dB caused about 50% of bowhead whales to exhibit avoidance behavior during drillship and dredge noise playbacks. Reactions to boats seemed to occur at lower S/N ratios.

In developing the estimates of the range at which a 50% probability of avoidance would occur for the major noise sources determined in this study, we have considered both the constant effective level criterion, using 120 dB as representing an average avoidance level for the various sources, and the 30 dB S/N criterion using the highest 1/3 octave band in the signal. As shown by the SER ratings determined in the previous section, the gray whale is the species that is potentially the most impacted by the major underwater sound sources considered. This is a result of the assumed high sensitivity of this species to low frequency sound and its high abundance relative to most other baleen whales in Alaskan waters. Presumably the hearing characteristics of the bowhead, humpback, and fin whales are comparable to the assumed characteristic of the gray whale, and as a result they also are potentially more influenced by the low frequency noise sources considered here than are the pinnipeds and odontocetes.

Studies of gray whale (Malme et al. 1983) and bowhead whale (Ljungblad et al. 1985) response to noise from air guns have shown that much higher effective peak pressure levels are tolerated before a 50% avoidance probability is reached when compared with the results from constant level playback studies. This is believed to be the result of mammalian hearing characteristics, as discussed earlier. The 50% avoidance probability has been found to occur for an average peak pressure level of 170 dB for gray whales and 160 dB for bowheads. These responses are for transient signals having a spectrum peak at about 100 Hz and a duration typically less than about 50 msec.

The 50% avoidance criterion for air guns has been determined as an average of the overall peak pressure levels for the pressure waveform. The air gun array and vibroseis array signals presented in the industrial noise data base are given in terms of peak level in a 1/3 octave band to be consistent with the other data sets. As a result, it is necessary to specify the overall peak pressure level of air gun signals in terms of the peak 1/3 octave band pressure spectrum to determine an equivalent criterion level for the zone of influence estimate. Measurements of the air gun array operation on the seismic survey vessel WESTERN POLARIS (Miles et al. 1987) showed that the ratio of the average peak pulse pressure to the pressure obtained from a power sum of the peak levels in the dominant 1/3 octave bands was 12 dB. Therefore, when using peak 1/3 octave spectra instead of the pulse pressure waveform, an effective received level of 158 dB is used as the gray whale 50% avoidance criterion for air gun array signals.

Moving sources may have a zone of influence which extends beyond the limits determined by the range at which the received level drops to the 50% probability of avoidance criterion. The behavioral response model incorporates a reference response time of 2 hours as the integration period in determining Leq. The total energy of all sounds received within a two hour period is considered as potentially influencing a behavioral response. As a result of this concept, moving sources can be considered to leave a trail or "footprint" which remains along the path of the source for a period of two hours. The effective zone of influence becomes elongated and has an area of:

$$A = \pi R_z^2 + 4\,S\,R_z \qquad (\mathrm{km}^2) \tag{28}$$

where R_z is the range at which the sound level is equal to 50% probability of avoidance criterion level (km)

S is the speed of advance of the source (km/hr).

On the other hand, as a result of the 2-hr averaging used in determining Leq, the estimated radius of influence around a moving source may be reduced from that expected if the same sound were present for the entire 2-hr period. In effect, the zone of influence would be determined by the range at which L_{eq} equals the criterion level rather than by the range at which the maximum received level (L_r) equals the criterion. Since the concepts of acoustic response time and equivalent level estimation as applied to marine mammal hearing and behavior need further study, for the present, maximum received level values are used to estimate zone of influence radii for both fixed and moving sources. Zone estimates include both range and area values. For moving sources the area values are determined using Eq. (28). Estimated zone radii are also given using L_{eq} values where appropriate.

5.3.1 Underwater sources

By using the measured or modeled TL data for each of the four selected planning areas together with source level spectra, it was possible to obtain plots showing average received level spectra versus range for each of the major industrial sources as determined by the SNC analysis. The zone of influence criteria for gray whales were applied to these plots to obtain estimated zone ranges for each of the planning areas and sources. The 30 dB S/N criterion developed for bowhead whales was also used since measured or estimated ambient noise spectra for the areas were available. This was done to obtain a comparison between this type of criterion and the constant received level criterion. Spectra were estimated at range intervals corresponding to approximately 10 dB decrements in received level in the mid-frequency bands. An example is shown in Fig. 5.7 for the Explorer II drillship hypothetically operating in the Chukchi Sea during summer conditions. In this example the statistical spread of ambient noise levels and the 30 dB S/N avoidance criteria are also shown to facilitate the zone of influence estimation procedure.

The information used to develop this figure was based on transmission loss data reported by Greene (1981). Computer assisted interpolation and extrapolation of the data were employed to obtain complete 1/3 octave transmission loss spectra for the range of 31.5 Hz to 1.6 kHz. These spectra were computed for 5 dB TL increments and applied to a measured source level spectrum for the drillship. Selected received level spectra obtained from this procedure are shown in the figure. For the other areas of interest where measured transmission loss data were not available, the results predicted by the IFD Transmission Loss Model (discussed in Section 4.2) were used as the basis for the transmission loss spectra synthesis. A complete set of received level plots for the major sound sources operating in the four selected study areas is included in Appendix E.

The zone of influence ranges and zone of influence areas were estimated using these plots and summarized in Table 5.12. The zone ranges were determined using both maximum source level and L_{eq} values, which consider the effective duty cycle of intermittent or fluctuating sources. The estimates concern potential gray whale response to underwater sound sources. Predicted responses of other species to airborne sound sources are discussed in the next section.

The icebreaker can be seen to have the largest estimated zone of influence in all of the areas where it may be operating. Although ice conditions in the North Aleutian area do not often require icebreaker operation, this area was also included in the zone of influence estimates. The sound transmission conditions in the North Aleutian area, which have relatively low losses at long ranges, provide the largest potential zone of influence. An effective range of 40 km is predicted if the maximum output level is considered. For the measured effective time fraction of 0.5, the L_{eq} is 3 dB

FIG. 5.7 DRILLSHIP (EXPLORER II) OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

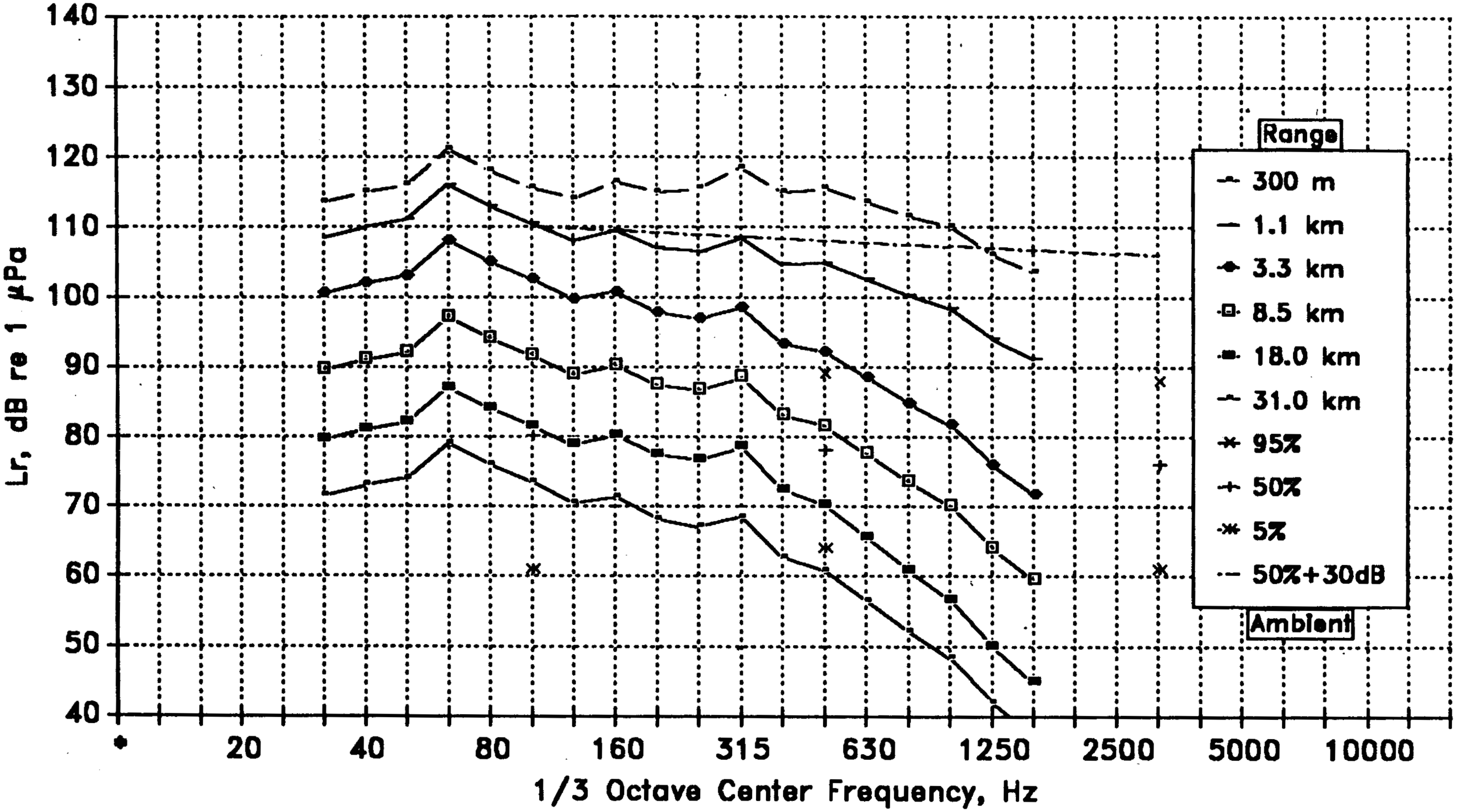


Table 5.12 Zone of Influence Estimates for Selected OCS Planning Areas

Species - Gray Whale
Zone - Range (km)/Effective area (km^2)
Criteria based on 50% Prob. Avoidance

Planning Area	Prop. Cond.	Source Type	Speed (km/hr)	(1) Lr=120	(2) Lr'=120	(3) S/N=30	(4) Lr=158
Chukchi	S	Icebreaker	-	8/200	6/115	10/315	
	N	"	-	5.4/92	4.3/58	11.7/430	
	S	Seismic Array	9.3			8.5/540	3.2/150
	S	Dredge(AQ)	-	5/79	4.5/64	6/110	
	S	Drillship	-	1.5/7.1	1.5/7.1	2/12.6	
	S	Tug/Barge (5)	18.5	0.7/53	-	0.8/61	
	S	Twin Outdrive (5)	37	0.45/67	-	0.6/90	
Norton	N	Icebreaker	-	12/450	9/250	10.5/350	
	S	Seismic Array	9.3		-	2.5/110	2.0/87
	S	Dredge(AQ)	-	4.0/50	3.5/38	2.5/20	
	N	"	-	5.5/95	4.8/72	3.5/38	
	S	Drillship	-	1.1/3.8	1.1/38	0.9/2.5	
	S	Tug/Barge (5)	18.5	0.8/61	-	0.7/53	
	S	Twin Outdrive (5)	37	0.5/75	-	0.4/60	
North Aleutian	N	Icebreaker	-	40/5030	30/2830	35/3850	
	S	Seismic Array	9.3		-	3.0/140	1.3/54
	S	Dredge(AQ)	-	20/1260	15/710	10/315	
	N	"	-	18/1020	14/620	12/450	
	S	Drillship	-	1.8/10	1.8/10.2	1.8/10	
	S	Tug/Barge (5)	18.5	1.5/120	-	1.5/120	
	S	Trawler (5)	18.5	1.1/85	-	0.3/22	
	S	Twin Outdrive (5)	37	0.8/118	-	0.3/45	
Shumagin	S	Large Tanker (5)	30	27/5530	-	6/545	
	N	"	30	18/3180	-	6/545	

Notes:
(1) Lr = Max. Source Level (Ls1) - TL at range Rz
(2) Lr' = Leq - TL at range Rz + TLref
(3) S/N = Signal in highest 1/3 octave band at range Rz - 50%ile ambient noise level
(4) Ls = 158, Criterion for air gun spectrum
(5) Zones of influence around moving vessels may be larger than suggested here if whales are more sensitive to noise from moving (in particular, approaching) vessels than from stationary sources (cf. Miles et al. 1987, Sect. 2.4).

lower than the maximum level. This has the effect of reducing the predicted average range to 30 km. When the 30 dB S/N criterion is applied using the maximum 1/3 octave band level, a predicted range of 35 km is obtained.

The smallest zone of influence for the icebreaker, within the areas studied, is expected to occur in the Chukchi Sea during winter 100% ice cover conditions where a radius of 5.4 km is predicted for the L_r = 120 dB criterion. This is a factor of 7.4 smaller than the zone radius predicted for the North Aleutian Basin. The 30 dB S/N criterion predicts a 11.7 km radius of influence for icebreaker operation during 100% ice cover conditions. The greater radius predicted by the latter criterion is a result of the low ambient noise levels observed during these conditions.

The predicted radius of influence for the seismic array can be seen to be largest for operation in the Chukchi area and smallest for operation in the North Aleutian Basin - opposite to the findings for the icebreaker. This results from propagation predictions for higher low frequency losses in the Norton Basin and in the North Aleutian areas than were indicated by transmission loss measurements in the Chukchi Sea. However the Chukchi transmission loss data (Greene 1981) did not cover the shorter ranges considered in the present modeling results. As a result extrapolation errors may be present and caution should be used in interpreting the zone of influence predictions for the low frequency seismic array signal.

The area of the zone potentially influenced by the icebreaker operating in the Chukchi Sea is shown in Table 5.12 to be 92 km^2 in the winter and 200 km^2 in the summer. While this can be seen to be larger than the area influenced by any other single source, if several smaller sources were operating concurrently the total area influenced by them may be greater than that for a single icebreaker. For example, if three outdrives or similar high speed fishing vessels were operating concurrently with non-overlapping zones of influence, the total area potentially influenced within a 2-hour period is estimated to be 201 km^2 - comparable to that of the icebreaker. In the other areas the zone of influence of the outdrive can be seen to be larger than in the Chukchi because of estimated better sound transmission conditions at high frequencies.

The zone of influence for the dredge can be seen to be comparable in the Chukchi and Norton Basin areas, with a somewhat smaller radius for the summer condition in Norton Basin. When the estimated zone areas are compared, tug/barge and small craft activities can be seen to have similar or greater potential influence areas than the dredge example, particularly if several sources are operating concurrently. Thus the ongoing gold dredging activity near Nome may not be the dominant noise source during active cargo shipping and fishing seasons. However, it is not known how similar the noise level from the gold dredge BIMA is with respect to the dredge noise levels used in this analysis. The dredge source can be seen to have a considerably larger predicted radius of influence in the North Aleutian Basin than in the other two areas because of the estimated better sound transmission conditions at high frequencies. In the North Aleutian Basin the estimated zone of influence area for the dredge during summer conditions is more than 10 times larger than the zone areas for the tug/barge, trawler, or outdrive.

The predicted radius of influence for the drillship example, which ranges from 1.1 km to 1.8 km, is larger than that of the smaller vessel examples in all of the area studies. However, when the potential areas of influence are considered, the smaller mobile sources have larger values. Thus in an active drill site area, the support vessels, which are generally moving around, provide the primary noise disturbance potential. The tug/barge source used here can be considered representative of a smaller supply vessel type.

The zone of influence estimates for the North Aleutian Basin area are likely about equally valid for the northern part of the Shumagin area where the water depth is less than 100 m. The IFD Model predicted similar sound transmission conditions for the two areas, except at low frequencies where the rocky bottom region in the Shumagin area showed somewhat less transmission loss (see Appendix C). As a result, only the large tanker source was considered explicitly for the Shumagin area zone estimates. The zone radius for the tanker operating at 16 kts (30 km/hr) was predicted to be 27 km for the summer propagation condition. This can be compared with the value of 20 km obtained for dredge operation (assumed to be the same as obtained in the North Aleutian Basin). These zone radii are the largest predicted in the study, considering that icebreaker operation in the North Aleutian Basin is not generally required. The area of influence for the tanker over a two-hour period is estimated to be over four times as large as that for the dredge. The probability is quite high that two or more large tankers or container ships of this size are operating concurrently in the Shumagin area because of the Unimak Pass ship traffic density. As a result noise levels due to commercial shipping in this area are expected to be comparable to or higher than those that may be produced by oil industry operations.

A map overlay showing the estimated zones of influence for the loudest sources in each of the four primary study areas is located in an envelope inside the back cover. This overlay can be used with the species distribution maps in Section 2 and with the two other overlays showing general source distributions.

5.3.2 Airborne sources

Airborne sound from land vehicles, vessels, and aircraft has been observed to cause disturbance reactions in marine mammals. Aircraft, because of their mobility and wide use in Alaskan marine regions, are the most dominant type of high level airborne source. Seals, walruses, and sea lions that haul out on beaches and ice are the most sensitive species to disturbance from aircraft sound (Sec. 2.4.1). No quantitative measurements of sound levels observed to cause disturbance to these species have been reported. As a result, it is difficult to define criterion sound levels for the onset of probable disturbance reactions. However, several observations, described in Sec. 2.4.1, have been made wherein estimates of aircraft type and slant range were obtained for observed disturbance reactions of harbor seals and walruses. These observations have been used to estimate a probable disturbance threshold level for these two species.

The results of this analysis are shown in Table 5.13. A level 110 dB in the dominant bandwidth of a "light aircraft" (assumed to be a Cessna 185 or similar single-engine airplane) was determined to cause hauled out harbor seals to vacate the beach most of the time. [This estimate was based on observations for flyovers at ranges of about 120 m (Johnson 1977).] The response of walruses varies widely but they were reported to become alert and move into the water when "aircraft" approach within 1-1.5 km at altitudes varying from 150 to 1500 m (Salter 1979). If the aircraft is assumed to be a twin engine turboprop, an estimated received level of 100 dB is obtained using a slant range of 1 km. The overall ambient noise level on beaches often exceeds this value because of surf noise (see Fig. 3.10). This suggests that walruses are reacting to visual stimuli rather than acoustic, or perhaps both. Alternatively, the observations may have been made on protected beaches with no surf and low ambient noise or for overflights with larger aircraft than that assumed in the analysis. Among the other Alaskan pinniped species that have been observed to react to aircraft, specific response thresholds have not been reported.

Table 5.13. Airborne Sound Zone of Influence Estimates for Pinnipeds.

Minimum slant range for probable disturbance by aircraft[1]

Species **L_r Criterion[2]**	**Harbor Seal** **110 dB**	**Pacific Walrus** **100 dB**
Light 1-eng Prop	120 m	300 m
Light 2-eng TProp	300 m	1.0 km
B737-200	400 m	1.1 km
B727	420 m	1.2 km
F-4C Military	1100 m	3.0 km

Notes: (1) Range estimated by using Eq. (13) for Standard Day Conditions together with aircraft radiated noise data from Table A-3.

(2) The L_r criterion for probable disturbance is determined by using observed response information from Sec. 2.4 and estimating the L_r in the dominant bandwidth for the aircraft type and range.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Major sound sources

Sound energy in the Alaskan marine environment was classified as originating from five categories of sources: natural, biological, industrial, transportation, and cultural. With the exception of specific types of source concentrations, the noise source distribution was found to be generally diffuse with a relatively sparse average density. Four types of source concentrations were found: industrial sources associated with seasonal oil exploration and drilling activities in the Alaskan Beaufort (and eventually in other OCS areas); high density shipping and fishing vessel activities in marine transportation lanes and popular fishing areas; aircraft, shipping and cultural sources contributing near cities and smaller population centers; and natural seismic activity contributing in active volcanic zones. The highly distributed and relatively local effects of these noise sources were not easily shown on a large scale overlay to be used with the mammal distribution maps. Consequently, the required source distribution information was presented in tabular form showing source types, locations, numbers, and acoustic characteristics. Table 6.1 shows the basic characteristics of examples of the major types of sources including both reported source levels as well as estimated equivalent source levels for those sources that have a time-varying output.

The estimated source levels for large earthquakes can be seen to be higher than those of all the other sources. The high levels are mitigated by the generally long interval between events and by the predominantly low frequency range of the acoustic energy. Much of the sound energy is below the hearing range of most marine mammals, with the probable exception of baleen whales.

The major area of volcanic and seismic activity in Alaska is the subduction zone along the Aleutian arc and the Alaska Peninsula. The North Aleutian and Shumagin Planning Areas include parts of this region. Seismic events of M6 to M7 are expected in this area at about a 2-year interval with production of loud underwater transients. Smaller scale events occur more frequently.

Baleen whales are capable of producing very loud vocalizations as shown by the representative value in Table 6.1. When several whales are interacting in an area their frequent vocalizations produce a very high average sound level. Pinnipeds, while not as loud as whales, are often more numerous in a given area and also provide a significant contribution to underwater noise levels.

The loudest man-made sound sources (excluding explosives) are air gun and vibroseis arrays. The source level shown for the air gun array is based on a power summation of the dominant bands in a 1/3 octave spectrum. The broadband pulse waveform peak is about 13 dB higher. The source level for the vibroseis is the maximum 1/3 octave band level obtained during the tone pulse sweep.

TABLE 6.1 SIGNIFICANT ACOUSTIC SOURCES IN THE ALASKAN MARINE ENVIRONMENT

Source	Type	Speed	Dominant BW, Hz			Max 1/3 Oct,Hz		Temporal	TravTime Corr.	Fluc. Corr.	Equiv. Level	Data	
		(kts)	fmin	fmax	Ls1,dB	freq.	Ls2,dB	Pattern	Tt/Tr	Tf/Tr	Leq.dB	Meas/Est.	Ref.
Earthquakes	fixed	-	<10	50	240	(varies)	(var.)	Interm.	1	3E-07 (1)	175	E	Sect. 3.2.5
Air Gun Array	movng	5	20	160	216	50	210	Impulse	1	5E-03	193	M	Miles et al. 1987
Vibroseis	local	-	25	315	205	125	205	Interm.	1	8E-02 (2)	194	M	Cummings et al. 1981
Large Tanker	movng	16	<2	4	205	4	203	Cont.	0.9	1E+00	205	M	Cybulski 1977 and Heine and Gray 1977
Icebreaker	local	-	40	6300	192	100	183	Fluct.	1	5E-01	189	M	Miles et al. 1987
F-4C Aircraft	movng	400	100	4000	192	160	183	Cont.	0.001	1E+00	162	M	BBN Archives
Baleen Whales	movng	2	20	500	185	(var.)	(var.)	Interm.	1	2E-01 (3)	177	M	Sect. 2.2.2

Notes: (1) The effective source level and time ratios shown are based on an M6-M7 event for 20 sec. at 2-year intervals.

(2) The maximum source level is based on a 4-unit array. The time faction is obtained from an assumed 10 sec pulse duration at 2-min. intervals

(3) The time ratio shown assumes an average 10 sec vocalization every minute.

The levels shown for both sources have been obtained from measurements made in shallow water at a horizontal aspect. The equivalent levels for these sources are estimated to be more than 20 dB lower than their maximum source level because of the short time duration of their signals relative to the pulse repetition rate.

The number of seismic arrays in operation has been quite variable, with a major exploration effort occurring in the Beaufort Sea area in some recent years. During the summer from 1 to 4 air gun arrays have been in operation there concurrently.

Icebreakers produce a significant amount of acoustic energy when operating in heavy ice. As a result of operating in a stalled condition at full power, icebreaker propellers cavitate heavily and radiate a very broadband acoustic spectrum. While instantaneous peak pressures and dominant bandwidth source levels are not as high as those of seismic sources, the long duration cavitation bursts of icebreakers have equivalent levels nearly as high as those of air gun arrays. The icebreaker data shown in Table 6.1 were obtained for operation of an icebreaking supply vessel. Operation of a U.S. Polar Class icebreaker at full power against heavy ice is estimated to produce an acoustic source level about 8 dB higher than shown in the table, or 200 dB re 1 μPa at 1 m. This is comparable to most supertankers at full speed.

Several medium-sized icebreakers and icebreaking supply vessels have been used at active drill sites in the Beaufort Sea to keep ice floes away from the drilling vessel. A limited operating budget has restricted the U.S. Coast

Guard icebreaking activities to one large Polar Class vessel in Alaskan waters and USCG icebreakers do not routinely support oil industry operation.

The F-4C fighter aircraft is included in the table as a representative loud jet aircraft. Most commercial aircraft are 10 to 20 dB quieter, and small civil aviation aircraft 20 to 30 dB quieter. On a sound pressure basis, the source level of the F-4C can be seen to be equal to that of the icebreaker. (The underwater sound reference level of 1 μPa has been used for both sources.)

Noise levels from large military and commercial aircraft are highest near airports. In other areas these aircraft usually fly at high altitude which considerably reduces their noise at ground level. Small aircraft and helicopters often fly at low level along shorelines and estuaries to aid navigation. This procedure produces sporadic high noise levels on the ground near the flight paths.

The large tanker example shown in the table is a steam turbine driven vessel which represents the upper range of large merchant vessels. Some supertankers may have up to 5 dB higher source levels depending on their propulsion plant and propeller design.

The major shipping industry sources in Alaska are the larger cargo, container, and tanker vessels that operate from the southern Alaska ports of Anchorage, Valdez, Seward and Kodiak to either the "lower 48" or to Japan. The route that is most important from the standpoint of potential marine mammal noise impact is the route to Japan which goes along the Alaska Peninsula and through Unimak Pass. This is also the route used by fishing vessels and cargo shipments, generally with tugs and barges, to the settlements along the Bering Sea coast and the Arctic.

The vessels operating for the tourist industry are also a significant part of the Alaskan marine environment. The cruise ships and ferries operating in Southeast Alaska, with acoustic source levels that range from 170 to 180 dB, maintain a schedule with typically more than 20 vessels per week along passages and channels frequented by humpback whales and other marine mammals.

The vessels used by the fishing industry are less powerful than the icebreakers and large tankers represented in Table 6.1. Their acoustic source levels are lower, typically ranging from about 170 dB for trawlers at full speed to 160 dB for smaller high speed sports-fishing vessels. When operating individually, these vessels do not have as much noise impact potential as the larger cargo vessels and tankers. While the source levels of individual boats are relatively modest, the combined effect of several vessels operating at high speed in the same area can produce a zone of high sound level which is comparable to that produced by a much larger vessel. This type of effect is likely to occur during openings of fishing for restricted species where concentrations of vessels are present. Vessel concentrations may persist through the season in areas where species do not disperse. The major fishing vessel locations are Homer in Kachemak Bay, Kodiak Island, Seward, Sand Point, Dutch Harbor, and the settlements along the east end of Bristol Bay.

Cultural noise sources associated with hunting, fishing, and transportation in coastal communities are also less powerful than the source examples shown in Table 6.1. While snowmachines are a popular, somewhat noisy form of winter transportation, they are generally less noisy than single-engine, light aircraft. Outboard powered skiffs, inboard and outdrive boats also provide sources of noise near communities during open water season. These sources contribute to the general airborne and underwater sound levels near communities in proportion to the number operating and their distribution density.

Assumptions used in this study

The development of the models used in the study required a number of assumptions to permit the use of results obtained from human psychoacoustic studies. While these assumptions were described previously in the discussion of the models, they are repeated here to provide a single reference point for their consideration.

Assumptions for SNC Model

1. The sound spectrum of most noise sources is not easily described by a simple analytic function. We assumed that it can be adequately characterized by the sound level of the dominant bandwidth (see glossary) and the sound level of the maximum 1/3 octave band.

2. The reference range of 300 m was assumed to represent many actual sound exposure situations. It also the distance at which the mean sound level is developed in a 1 km^2 circular area surrounding a source.

3. A time varying sound can be represented by an equivalent constant level sound (L_{eq}) that has the same acoustic energy exposure dose. We assume that L_{eq} will also have the same potential behavioral influence for a specific species as the time-varying sound.

4. Behavioral response to sound exposure is measured over an time interval that is representative of activity periods - typically 8 hours for humans. An exposure period of 2 hours was assumed for all of the species studied. This was based on gray whale swimming speed past a fixed source. This value can be made more species specific when more information becomes available.

5. The probability of encountering a given source type within a reference area was assumed to equal the number sources operating in the area at a given time divided by the area (km^2). The reference area is either the entire area being modeled if the sources may be found with equal probability over the entire area, or it is the area of the zone where they are usually found with equal probability.

6. Moving sources were assumed to have an enhanced probability of encounter (given by Eq. 19) because they effectively occupied more than one location during a 2-hour exposure period.

Assumptions for the SER Model

1. The SER values are obtained for species - source encounters which are assumed to occur regularly; i.e., no weighting factors are included for startle effects or for unusual source temporal patterns. These can be included when more data become available. Note however that normal source fluctuations are considered in the L_{eq} calculation which is part of determining SNC1.

2. The maximum sound level above hearing threshold, L_{r3}, does not consider any weighting factor based on apparent loudness. A value of 30 dB above threshold may be apparently louder if it occurs at a frequency near the maximum hearing sensivity range than if it occurs at a frequency much higher or lower than this range. In the present model this loudness dependence is assumed to be independent of frequency since data are not available to provide a better weighting factor.

3. Species density values which have been used in the SER Model have been assumed to apply over broad areas. In regions where high concentrations exist the SER values would be proportionally higher.

Ranking potential acoustic interaction

The Standardized Noise Contribution Model (SNC) and the Species Exposure Rating Model (SER) were developed during the study to rank the acoustic energy output of a wide variety of sources and provide a rating for the acoustic interaction potential of the various source - species encounters that are possible in a given area. The information developed using these models, presented previously in Tables 5.4 through 5.11, has been summarized in Table 6.2 for each of the four OCS Planning Areas that were studied in detail.

A simplified three level ranking system was used in summarizing the SER results. In this system a "High" ranking indicates a high probability of acoustic interaction because of a good match between species hearing and source output bandwidths together with a sufficient number of animals in the area. A "Low" ranking indicates a large mismatch between hearing and source bandwidths and/or a small number of animals in the area. The numerical criteria used in determining an assigned rank are given in Note (1) of the table. These criteria were developed from a statistical analysis of all of the SER results as discussed previously in Section 5.2.3.

The ranking order shown in Table 6.2 indicates that the baleen whales as represented in the study by the gray and fin whales have a high probability of being influenced by noise from most of the sources used in the analysis. This is a consequence of their assumed low frequency hearing sensitivity which is believed to overlap the output frequency range of most man-made sources (and also most natural sources). Some high rankings also occurred among the odontocetes and pinnipeds studied. These were for killer whales, harbor porpoise, Dall's Porpoise, fur seals, and harbor seals; all for tanker

TABLE 6.2 SUMMARY OF STANDARDIZED EXPOSURE RATING RESULTS FOR SELECTED OCS PLANNING AREAS

			Species											
Area	Seas./ Cond.	Source	Walrus	Gray Whale	Fin Whale	Humpback Whale	Killer Whale	White Whale	Ringed Seal	Harbor Seal	Fur Seal	Harbor Porpoise	Dall's Porpoise	Steller Sea Lion
Chukchi	Sum.	Seismic Array	(Med.)(1)	High(2)				Medium						
Sea	"	Icebreaker	(Medium)	High				Medium						
	"	Kulluk	(Medium)	Medium				Low						
	"	Tug/Barge	(Low)	Medium				Medium						
	Wint.	Vibroseis							Medium					
Norton	Surf.	Seismic Array	(Medium)	High										
Basin	"	Outdrive	(Medium)	Medium										
	"	Dredge	(Medium)	Medium										
	"	Tug/Barge	(Medium)	Medium										
	"	13' Whaler	(Low)	Medium										
	Neut.	Seismic Array	(Medium)						Medium					
	"	Icebreaker	(Medium)						Medium					
	"	Dredge	(Low)						Medium					
	"	Tug/Barge	(Low)						Low					
North	Surf.	Seismic Array		High						(Medium)		(Medium)		(Medium)
Aleutian	"	Outdrive		Medium						Medium		Medium		(Medium)
	"	13' Whaler		Medium						Medium		Medium		(Medium)
	"	Tug/Barge		High						Medium		Medium		(Medium)
	"	Trawler		(High)						(Low)		Low		(Low)
	Neut.	Outdrive		(Medium)						Low		Medium		(Low)
	"	Seismic Array		(High)						Medium		Medium		(Medium)
	"	Tug/Barge		(High)						Low		Medium		(Low)
	Surf.	Seismic Array		(High)	High	(High)	Medium			(Medium)		(Medium)		(Medium)
Shumagin	"	Outdrive		(Medium)	Medium	(Medium)	Medium			(Low)		(Low)		(Low)
	"	Large Tanker		(High)	High	(High)	High							(Medium)
	"	Ferry/Cargo		(Medium)	Medium	(Medium)	Medium							(Low)
	Neut.	Seismic Array		(High)	(High)		(Medium)			(Medium)	Medium	(Medium)	Medium	(Medium)
	"	Large Tanker		(High)	(High)		(High)			(High)	High	(High)	High	(Medium)
	"	Ferry/Cargo		(Medium)	(Medium)		(Medium)			(Medium)	Medium	(Medium)	Medium	(Low)

Notes:

(1) Ratings enclosed in parenthesis are inferred from ratings for similar species and source output spectra.

(2) The ratings are based on area SER values using the following criteria:
High, SER >= 180; Medium, SER = 179 to 141; Low, SER <= 140

encounters. All of the other sources studied gave a medium to low SER ranking for the odontocetes and pinnipeds. They all have hearing characteristics which are most sensitive at high frequencies above the dominant output bandwidth of most of the man-made sources in the marine environment. The results for walrus, Steller sea lion, and Dall's porpoise are based on the use of hearing characteristics for California sea lion and harbor porpoise and may be incorrect if the actual hearing sensitivities are greatly different from the values assumed.

It may be important that the low-frequency sensitivity of odontocetes and pinnipeds has not been determined as precisely as would be desirable. Measurement difficulties in small test tanks have made it impractical to measure the low frequency hearing of most species. Some of the estimates that have been published may underestimate the hearing abilities of pinnipeds and toothed whales at frequencies below a few kilohertz. Thus, they may be somewhat more sensitive to industrial noise than the model estimates suggest.

Predicted zones of influence

The range at which a 50% probability of avoidance would be expected for gray whales (the "zone of influence") was estimated for the major noise sources in each of the four OCS planning areas studied in detail. The predicted ranges were based on calculated acoustic propagation charcteristics in all of the areas except the Chukchi Sea, where a limited set of measured data are available.

The largest estimated zones of influence are produced by large tanker operation in the Shumagin area where a radius of 27 km is predicted and by dredge operation in the North Aleutian area which is predicted to have an effective zone radius of 20 km. Icebreaker operation in the North Aleutian area is probably infrequent, but if icebreakers are used in this area, a zone of influence radius of 40 km is estimated because of the predicted efficient mid-frequency sound transmission in this area. Sound transmission losses are estimated to be higher in the Norton Basin area. Because of this, the predicted zone of influence for icebreaker operation in Norton Sound is reduced to 12 km. The transmission loss data for the Chukchi Sea provide an estimated icebreaker zone of influence of 8 km during summer conditions and 5.4 km during winter conditions.

No quantitative measurements of sound levels observed to cause disturbance of marine mammals are available for airborne sound sources. Specific disturbance criteria are not therefore available. Some reported disturbance observations of harbor seals during aircraft overflights were used to obtain general estimates of minimum slant range distances for probable disturbance of this species. These overflight distances varied from 120 m for a light single engine propeller aircraft to about 420 m for a Boeing 727. Analysis of observations of walrus disturbance showed that these animals have highly variable response and may be disturbed by visual cues as well as acoustic noise levels. Their apparent sensitivity to intrusive sounds is considerably greater than harbor seals.

6.2 Recommendations

The modeling procedure developed in the study provides a means of ranking source - species encounter situations using acoustic principles. While the principles employed have been used in similar ways to predict human annoyance by industrial noise, their application here to marine mammals has involved the use of several untested assumptions. Moreover, it has been necessary to use estimated and inferred values for many of the required model inputs where measured data are not presently available. When appropriate data become available the procedures used in this study should be augmented and modified where required.

While humans have been found to respond as energy detectors with a fundamental stimulus integration time roughly equivalent to 8 hours, the hypothesis built into the SER model of a 2 hour integration time for marine mammals should be tested. This concept is useful for comparing different types of sources on an energy equivalent basis, but other procedures can be devised if it is found not to be appropriate for marine mammal psychoacoustics. Possible testing procedures could be devised which will allow the stimulus integration concept to be tested concurrently with testing for adaptation using repeated controlled noise exposures.

Appropriate weighting factors should be investigated for use in the SER modeling procedure which provide for the apparent increase in sensitivity of certain marine mammals during special situations. This increase in sensitivity occurs for the sudden onset of a new sound (startle effect), for a sound that is increasing in level (indicating approach), and for sounds indicating a known threat. The use of weighting factors in human response modeling has been found to provide the flexibility needed to accommodate the effects of special stimuli.

The accuracy and utility of the modeling procedures developed in this study need testing with field data. Ideally this testing would initially employ benchmark acoustic and biological data obtained from an area prior to the onset of development. This would be followed up using data obtained during the course of increasing industrial activity. The models would be run and the results compared with observations of mammal reactions in the area as the acoustic environment changed. The goal of this procedure is the refinement of the present preliminary and largely untested models into a marine mammal acoustic response model which would predict potentially significant acoustic impact situations during the course of environmental impact statement research and thereby allow time for assesment of the problem and determination of mitigation procedures.

GLOSSARY

1. GENERAL ACOUSTIC TERMINOLOGY

1/3 Octave Band Filter

A bandpass filter having a bandwidth equal to 23% of the center frequency.

Absorption Loss, A_V

The reduction in sound level caused by volumetric absorption of sound energy by the transmission medium.

Acoustic Normal Mode Theory

A solution to the acoustic wave equation which considers sound propagation as a series of acoustic standing waves (normal modes) which match the boundary and source conditions specified. The pressure contributions from a series of modes are added to give the total acoustic pressure at a selected observation point (similar to room acoustic theory); useful for shallow water and low frequencies.

Acoustic Ray Theory

A solution to the acoustic wave equation which considers sound propagating as uniform phase wavefronts along a path (ray) determined by the initial radiation direction from the source and the refractive properties of the medium; (similar to optical theory for light) useful for deep water and high frequencies.

Critical Angle

The reflection loss is 0 for grazing angles less than the critical angle.

Equivalent Sound Level, L_{eq}

The constant sound level which produces the same acoustic exposure dose as the actual time-varying sound field.

Exposure Period

A reference period of time for calculating a behavioral response measure such as the equivalent sound level. This period should be related to the activity cycle of a specific species (i.e., 8 hours for humans).

Grazing Angle

The angle between the sound propagation direction and a reflecting surface.

Reflection Loss (RL)

The reduction in sound level after reflection from an absorptive surface, expressed in logarithmic terms

$RL = L_{ref} - L_{inc}$ (dB)

where L_{ref} and L_{inc} are the reflected and incident sound levels at 1 m from the reflection point.

Sound Level or Received Level, L_r

The sound pressure at an observation position expressed in logarithmic terms

$L_R = 20 \log_{10} p/P_r$ (dB)

where the reference pressure, P_r = 1 microPascal (μPa)

Sound Speed Profile

The variation of the speed of sound as a function of water depth.

Sound Wavelength, λ (m)

$\lambda = c/f$, where c is the speed of sound (m/sec) and f is the frequency (Hz).

Source Directivity, D

The change in acoustic output of a source as a function of aspect angle in both the horizontal and vertical plane. Generally expressed as a logarithmic ratio

$D = 20 \log_{10} p/P_m$ dB

where p is the pressure in a given direction and P_m is the maximum source pressure in a reference direction.

Source Level, L_s

The sound pressure at an observation position 1 m from an acoustic source (dB re 1μPa at 1 m)

Spreading Loss

The reduction in sound level caused by geometric spreading of sound energy, generally expressed as cylindrical spreading (10 $\log_{10}$ range) or spherical spreading (20 $\log_{10}$ range).

Time Ratio or Duty Cycle

The ratio of the total effective operating time in an operating cycle or in an exposure period, whichever is shorter, to the length of the cycle or period for a specific source.

Transmission Loss, TL

The reduction in sound level with distance along a given acoustic path caused by spreading loss and absorption loss components

$TL = L_s - L_r$ dB re 1 m

2. BIOACOUSTIC TERMINOLOGY

Critical Bandwidth

The frequency band of noise surrounding a pure tone that is most effective in masking the tone. It is approximately equal to antilog (critical ratio)/10 but is often broader.

Critical Ratio

The signal-to-noise ratio that is required to detect a sound signal in the presence of ambient noise. This ratio varies with frequency and is usually lowest in the frequency range where the hearing threshold is also lowest.

Hearing Threshold

The intensity of sound that is barely audible in the absence of ambient noise. The absolute hearing threshold varies with frequency, and the curve relating the threshold intensity to frequency is called the audiogram.

3. SPECIAL TERMS USED IN THIS REPORT

Acoustic Interaction

The transmission and reception of sound during a specific source - species encounter at levels sufficiently loud to be at least 20 dB above the local ambient noise level in the dominant source bandwidth or 20 dB above the species hearing threshold in the same frequency range, whichever is highest.

Avoidance

A form of behavioral response to sound in which a species is observed to move away from the vicinity of the sound source or change normal movement patterns so as not to come as close to the source as would be expected in the absence of the sound.

Dominant Bandwidth

The portion of an acoustic source output spectrum including the 1/3 octave band with the maximum level and bounded by the 1/3 octave bands with levels within 10 dB of the maximum.

Effective Source Level

The rms sum of the pressure levels in the 1/3 octave bands within the dominant bandwidth referred to an equivalent 1 m range from the source (L_{s1}). This is determined for the maximum output level for fluctuating source outputs.

Probability of Encounter

The probablity of a specific species being in the same 1 km^2 area as a specific type of acoustic source.

Zone of Influence

The region within which received sound levels from a specific source are above a specified auditory criterion for a specific species. This criterion is usually considered to be avoidance behavior at the 50% probability level. Other possible criteria are audibility or masking.

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APPENDIX A:

ONE-THIRD OCTAVE BAND SPECTRA FOR SOURCE EXAMPLES USED IN THE STUDY

The 1/3 octave source level spectra for the source examples discussed in Section 3 are presented in the following set of tables:

Table A1.	Representative Industrial Sources
Table A2.	Representative Boat and Ship Source Level Data
Table A3.	Representative Aircraft Reference Level Spectra
Table A4.	Helicopter Radiated Noise Spectra
Table A5.	Recreational and Cultural Source Level Spectra
Table A6.	BBN Source Level Data
Table A7.	Greene (1987) Data.

Table A.1. Representative Industrial Sources
1/3 Octave Spectra, dB re 1 μPa at 1 m.

1/3 Oct. (Hz)	Air Gun Array (32 gun)	Vibroseis (4-unit)	Icebreaker (R.LEMEUR) (9600 HP)	Transfer Dredge (AQUARIUS)	Drillship (EXPL.II)	Trawler (5 kt)	(10 kt)
12.5	190		152		151.5		
16	198		154.5		155		
20	203		164	151	158	127	138
25	199.5	200.6	168	163	160	131	142
31.5	202.5	201	169	160	159.5	135	146
40	201	201.6	173	167	161	139	150
50	210	203.1	177	170	162	142	153
63	208.5	202.3	179.5	169	167	144	155
80	209	199.2	178.5	170	164	146	157
100	209	198.5	183	177	161.5	147	158
125	204	204.5	181.5	176	160	147	158
160	200	201.2	179	178	162.5	146.5	158
200	199	194.5	180	177	161	146	158
250	197	196.6	181.5	175	161.5	146	158
315	187	198.2	178	175	164.5	145.5	157.5
400	184	192.4	182	174	161	144.5	157
500	183.5	188.3	180	171	161.5	143.5	156.5
630	185	183	178	168	159.5	142	156
800	188	178.8	178.5	167	157.5	140	155
1000	191	176.8	176		156	138	154
1250	188.5	171.7	178		152	136	153
1600	186.5	173.1	175		149.5	134	152
2000	178.5	168	179		148	132	151
2500	176		178.5		145	130	150
3150	174		178.5		143.5	128	149
4000	175		180.5		140	126	148
5000	168		178.5		137.5	124	147
6300			177		135.5	122	146
8000			171		134	119	145
10000			174		132	117	144
12500			173		131	114.5	143
16000			172		131.5	112	142
Ref.	(1)	(2)	(3)	(4)	(5)	(6)	(7)

(1) Miles et al. 1987
(2) Cummings et al. 1981
(3) Miles et al. 1987
(4) Greene, Jr. 1987
(5) Miles et al. 1987
(6) Urick 1983
(7) Urick 1983

Table A.2. Representative Boat and Ship Source Level Data
1/3 Octave Spectra, dB re 1 μPa at 1 m.

1/3 Oct. (Hz)	>700 ft Tanker (16 kts)	Icebreaker (transit) (10 kts)	Alaska Ferry (16 kts)	Tug/Barge (2250 HP) (10 kts)	110 ft Tour Boat (10 kts)	65 ft Tour Boat (10 kts)
12.5	177	157	142.7	142.7		118.6
16	182	161	140	154		115
20	173	161.5	143.3	150	153.1	112.4
25	168	159	146.8	139.5	145	111.4
31.5	165	161	153.4	141.2	138.8	120.6
40	171	160.5	162.5	139.6	134.7	121.3
50	174	162	165.6	142.8	137.4	114.2
63	175.5	173	154.7	144.4	136.2	124.3
80	176.5	172	159.4	148.8	135.3	125.4
100	177	173.5	163.5	156.8	142.7	121.8
125	177	170	170.7	156.8	142.5	134.4
160	176.5	169.5	162.6	157.6	146	128.1
200	176	170	159.3	156.8	148.5	135.9
250	175	166.5	158.7	159.3	149.1	135.1
315	174	169	159.5	160.1	150.8	138.8
400	173	165.5	161.4	160.5	152.4	139.4
500	172	166.5	162.3	160.8	155.5	140
630	171	166	161.8	161.5	159.3	138.5
800	170	167	159.4	161.2	149.9	139.2
1000	169	163.5	158.8	156.3	153.4	145
1250	168	163	158	157.7	157.5	148.4
1600	167	159.5	156.1	157.5	155.8	149.7
2000	166	159	155.2	157.3	157.3	148.1
2500	165	156.5	155.2	156.7	158	145.6
3150	164	155	153.8	156.2	155.7	146.2
4000	163	151.5	153.2	155.3	156.5	143.6
5000	162	149	152.4	154.5	154.6	144.8
6300	161	146.5	151.3	155	156.7	143
8000	160	146	150	154.6	155.4	140.9
10000	159	143	147.8	153.6	154.4	139.4
12500	158	143	146.8	152.6	154.1	137.8
16000	157	142	143.8	149.3	152.8	134.4
Ref.	(1)(2)	(3)	(4)	(5)	(6)	(7)

*Supplemental Data for Tanker (1)

(Hz)	L_s
2	204
2.5	202
3.15	195
4	189
5	187
6.3	186
8	187
10	178

(1) Cybulski 1977
(2) Heine and Gray 1977
(3) Miles et al. 1987
(4)-(7) Malme et al. 1982

Table A.3. Representative Aircraft Reference Level Spectra
1/3 Octave Spectra, dB re 1 μPa, Range 300 m, 15 deg C, 70% Rel. Hum.

1/3 Oct. Hz	F-4C (Afterbrn)	B727 (Takeoff)	C130 (Takeoff)	B737-200 (Takeoff)	DHC-6 Twin Otter (80% crs)	Lt 1-eng. Prop. (Takeoff)
12.5						
16.0						
20.0						
25.0						
31.5						
40.0						
50.0	117.0	110.7	99.0	108.7	88.0	70.0
63.0	113.0	112.4	120.0	110.4	90.0	70.0
80.0	114.0	113.2	117.0	111.2	101.0	74.0
100.0	125.0	123.7	100.0	121.7	90.0	86.0
125.0	131.0	131.8	121.0	129.8	92.0	106.0
160.0	133.0	129.4	115.0	127.4	102.5	92.0
200.0	129.0	123.1	101.0	121.1	94.0	86.0
250.0	131.0	126.9	103.0	124.9	100.0	97.0
315.0	132.0	127.0	100.0	125.0	92.5	90.0
400.0	132.0	124.6	100.0	122.6	90.5	94.0
500.0	132.0	122.6	100.0	120.6	89.0	92.0
630.0	132.0	122.5	99.0	120.5	88.0	89.0
800.0	131.0	123.2	97.0	121.2	87.0	85.0
1000.0	129.0	121.0	95.0	119.0	86.0	80.0
1250.0	128.0	119.2	96.0	117.2	86.5	85.0
1600.0	128.0	117.4	97.0	115.4	87.5	78.0
2000.0	128.0	114.8	96.0	112.8	87.5	75.0
2500.0	127.0	112.0	95.0	110.0	85.5	74.0
3150.0	126.0	109.3	91.0	107.3	83.5	74.0
4000.0	125.0	105.6	89.0	103.6	80.0	68.0
5000.0	123.0	101.6	85.0	99.6	75.5	64.0
6300.0	123.0	96.4	79.0	94.4	69.5	57.0
8000.0	124.0	94.9	71.0	92.9	60.5	49.0
10000.0	123.0	92.3	65.0	90.3		40.0
12500.0						
16000.0						

Ref. BBN Archives

Table A.4. Helicopter Radiated Noise Spectra
1/3 Octave Spectra, dB re 1 µPa, 300 m alt., 20 deg C, 70 Rel. Hum.

1/3 Oct.	Bell 206B	Bell 205 (UH-1H)			Sikorsky	Bell 222	
Hz	(OH-58)	Cruise	Loaded	Approach	(S61)	Takeoff	Approach
12.5							
16.0							
20.0							
25.0							
31.5					92.0		
40.0					102.0		
50.0	90.0	105.0	107.0	100.0	88.0	90.0	93.0
63.0	84.0	107.0	108.0	101.0	95.0	93.0	85.0
80.0	83.0	106.0	107.0	89.0	91.0	83.5	90.5
100.0	87.0	105.0	106.0	90.0	94.0	83.0	101.0
125.0	80.0	105.0	106.0	100.0	97.0	96.0	104.0
160.0	84.0	102.0	101.0	104.0	90.0	88.0	105.0
200.0	95.0	104.0	102.0	105.0	92.0	96.0	101.0
250.0	91.0	101.0	101.0	101.0	95.0	90.0	101.0
315.0	93.0	102.0	100.0	100.0	91.0	91.0	97.5
400.0	92.0	101.0	99.0	98.0	90.0	89.5	94.0
500.0	92.0	98.0	97.0	91.0	90.0	89.0	91.0
630.0	90.0	96.0	95.0	90.0	89.0	88.0	97.5
800.0	89.0	88.0	87.0	88.0	88.0	87.0	96.0
1000.0	84.0	90.0	90.0	85.0	87.0	85.5	94.5
1250.0	82.0	87.0	86.0	85.0	86.0	84.5	94.0
1600.0	81.0	84.0	82.0	83.0	85.0	83.0	81.5
2000.0	81.0	82.0	79.0	82.0	84.0	81.0	80.5
2500.0	77.0	80.0	77.0	80.0	83.0	78.5	76.5
3150.0	74.0	76.0	74.0	76.0	80.0	76.0	74.0
4000.0	71.0	73.0	71.0	72.0	74.0	71.0	69.0
5000.0	66.0	70.0	68.0	68.0	73.0	69.0	67.0
6300.0	60.0	66.0	65.0	64.0	69.0	63.0	62.0
8000.0	52.0	57.0	57.0	60.0	63.0	55.0	55.0
10000.0	37.0	38.0	46.0	54.0	55.0		
12500.0							
16000.0							

Ref. BBN Archives

Table A.5. Recreational and Cultural Source Level Spectra
1/3 Octave Spectra, dB re 1 μPa at 1 m (except as noted).

	Underwater			Under Ice		Airborne	
1/3 Oct	13'Whaler 20 HP OB	16'Zodiac 20 HP OB	24'Outdrv 2-80 HP	Helo Warmup	Snowmach 16 km/hr	Shotgun 10 ga	Snowmach 40 km/hr*
12.5							
16	133.4						
20	129.4	124.5	143				
25	129.6	125	144				
31.5	122	131	145				63
40	121	130.5	146	118.2			68
50	126.6	127.5	146.5	120.3		148	69
63	129.5	125	147	124.3		150	71
80	134.1	134	149	123.8		153	84
100	130.3	123.5	150	126.7		155	82
125	137.9	130	151	127.9		157	83
160	144.5	141	152	131.1		158.5	98
200	136.5	147.5	153	129.6		160	93
250	141.3	131.5	154	130.2	118.3	161	87
315	139.7	129	155	129.6	110.4	161.5	91
400	140.1	132	156	128.0	110.5	162	82
500	139.1	131.5	156	124.4	114.5	162	80
630	145.9	133.5	156	123.7	112.0	161.5	76
800	146.2	132	156	123.0	115.3	161	84
1000	147.7	131.5	155.7	123.5	118.0	160	84
1250	143.9	135	155.5	124.2	123.5	158.5	86
1600	145.4	135	155	125.2	124.1	157	82
2000	147.4	138.5	154.5	116.2	122.1	155.5	82
2500	148	140	153.5		118.6	154	81
3150	152.2	146	153		113.2	152	80
4000	152.9	145.5	154		112.1	150.5	85
5000	149.7	150	152.5		112.7	149	85
6300	146.9	151.5	152		110.2	148	76
8000	143.9	146	150.5			146.5	76
10000	140.8	143	149.5			145	72
12500	139	138.5	148			144	67
16000	135.5	134	147			142	59
Ref.	(1)	(2)	(3)	(4)	(5)	(6)	(7)

(1) Malme et al. 1982
(2) "
(3) "
(4) deHeering and White 1984
(5) Holiday et al. 1980
(6) BBN Archives
(7) Cheney and McClain 1973
*(r = 15m)

Table A.6. BBN Source Level Data*
1/3 Octave Spectra, dB re 1 μPa at 1 m.

1/3 Oct. (Hz)	EXPLORER II (1986) Drilling L_s	R.LEMEUR Breaking Ice L_s	KIGORIAK Transit (10 kts) L_s	W.POLARIS Seismic (Peak) L_s	ARGILOPOTES Clamshell Dredge L_s	TUG/ BARGE (10 kts) L_s
12.5	151.5	152.0	157.0	190.0		142.7
16	155.0	154.5	161.0	198.0		154.0
20	158.0	164.0	161.5	203.0		150.0
25	160.0	168.0	159.0	199.5		139.5
31.5	159.5	169.0	161.0	202.5		141.2
40	161.0	173.0	160.5	201.0		139.6
50	162.0	177.0	162.0	210.0		142.8
63	167.0	179.5	173.0	208.5		144.4
80	164.0	178.5	172.0	209.0		148.8
100	161.5	183.0	173.5	209.0		156.8
125	160.0	181.5	170.0	204.0		156.8
160	162.5	179.0	169.5	200.0		157.6
200	161.0	180.0	170.0	199.0		156.8
250	161.5	181.5	166.5	197.0	162.0	159.3
315	164.5	178.0	169.0	187.0	159.0	160.1
400	161.0	182.0	165.5	184.0	158.0	160.5
500	161.5	180.0	166.5	183.5	156.0	160.8
630	159.5	178.0	166.0	185.0	147.0	161.5
800	157.5	178.5	167.0	188.0	158.0	161.2
1000	156.0	176.0	163.5	191.0	148.0	156.3
1250	152.0	178.0	163.0	188.5	158.0	157.7
1600	149.5	175.0	159.5	186.5	150.0	157.5
2000	148.0	179.0	159.0	178.5	141.0	157.3
2500	145.0	178.5	156.5	176.0	134.0	156.7
3150	143.5	178.5	155.0	174.0	130.0	156.2
4000	140.0	180.5	151.5	175.0		155.3
5000	137.5	178.5	149.0	168.0		154.5
6300	135.5	177.0	146.5			155.0
8000	134.0	171.0	146.0			154.6
10000	132.0	174.0	143.0			153.6
12500		173.0	143.0			152.6
16000		172.0	142.0			149.3

*BBN Data
EXPLORER II, drilling at Corona Site, Miles et al. 1987
ROBERT LEMEUR breaking ice at Corona Site, Miles et al. 1987
KIGORIAK transit at 10 kts, Corona Site, Miles et al. 1987
W. POLARIS seismic survey, 18 km N. of Corona Site, Miles et al. 1987
ARGILOPOTES, clam shell dredge at Erik Site, Miles et al. 1987
Tug (2250 HP) towing a loaded barge at 10 kts, Malme et al. 1982

Table A.7. Greene (1987) Data
1/3 Octave Spectra, dB re 1 μPa at 1 m*.

1/3 Oct. (Hz)	Caisson Island Drilling Est. L_s	EXPLORER II Drilling Est. L_s	KULLUK Drilling Est. L_s	BEAVER MACKENSIE Dredging Est. L_s	AQUARIUS Dredging Est. L_s
12.5					
16					
20	136.0	140.0	160.0	147.0	151.0
25	144.0	148.0	166.0	147.0	163.0
31.5	154.0	151.0	163.0	151.0	160.0
40	154.0	154.0	167.0	155.0	167.0
50	155.0	160.0	174.0	154.0	170.0
63	159.0	159.0	172.0	155.0	169.0
80	157.0	156.0	173.0	162.0	170.0
100	151.0	157.0	172.0	167.0	177.0
125	152.0	161.0	169.0	161.0	176.0
160	157.0	160.0	176.0	160.0	178.0
200	154.0	158.0	176.0	159.0	177.0
250	156.0	169.0	173.0	161.0	175.0
315	152.0	156.0	172.0	160.0	175.0
400	152.0	152.0	177.0	162.0	174.0
500	153.0	152.0	176.0	158.0	171.0
630	154.0	151.0	173.0	157.0	168.0
800	154.0	150.0	173.0	158.0	167.0
1000			168.0		
1250			167.0		
1600			166.0		
2000					
2500					
3150					
4000					
5000					
6300					
8000					
10000					
12500					
16000					

*Source level estimated using BBN TL data.

APPENDIX B:
ANALYSIS OF ICEBREAKING SOUNDS*

B.1 Introduction

The drillship CANMAR EXPLORER II was drilling an exploratory well at the Corona drillsite in early September 1986. Corona is in the Alaskan Beaufort Sea, north of Camden Bay, northwest of Barter Island, about 22 n mi offshore where the water depth is 35 m. As part of a planned, comprehensive sound monitoring effort, recordings were made of the underwater sounds from the support vessel ROBERT LEMEUR while it was icebreaking. In particular, sounds were recorded continuously for 14 minutes at range 0.25 n mi (0.46 km).

A detailed report of the sound monitoring results was published (Greene 1987), but not every interest in the recorded data was recognized during the original analysis. For instance, although the sound levels vs distance from the icebreaker were analyzed and reported, no extended time series of sound levels from icebreaking were investigated. In assessing the possible impact of such sounds of wildlife, knowledge of the variation in sound levels with time might be important. Hence, additional analysis has been performed on the 14 minute segment of icebreaking sounds, range 0.25 n mi.

B.2 Methods

The R/V JUDY ANN, a 43-ft fishing boat, had been chartered to serve as a sound boat for underwater acoustical measurements of the drillship and its support vessels. The boat's engines were shut down during recording. Hydrophones made by International Transducer Corporation (model 6050C) were suspended beneath a lightly-tethered sparbuoy at depths 9, 18, and 30 m. the hydrophones included a low-noise preamplifier and had a flat receiving response from below 20 Hz to above 8 kHz. The in-water cables were faired to prevent strumming. Signals from the three hydrophones were further amplified, if necessary, to obtain the best dynamic range on the tape recorder. the postamplifier gains could be set in steps of 10 dB from 0 to 40 dB. The audio cassette tape recorder was a four-channel Fostex model 250. The sound

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*Charles R. Greene, Jr., Greeneridge Sciences, Inc.

recording system and techniques had evolved over six years of making such recordings from small boats.

The analysis was performed using a Hewlett-Packard Vectra computer system (compatible with the IBM PC-AT). The technique was based on the weighted, overlapped segment averaging technique of Carter and Nuttall (1980). the signals were played back through a Krohn-Hite model 3342 filter to prevent aliasing. A 12-bit Metrabyte model DASH 16 analog-to-digital converter was used to digitize sections of signal each 16.5 s in duration. The sample rate was 8192 samples/second. The 16.5 s sections were analyzed separately and the results saved for comparison and statistical analyses. They were taken every 16 s. The results were sound pressure spectra with calibrated levels from 10 to 4000 Hz.

Each 16.5 s section was further divided into one-second segments for Fourier analysis using a fast Fourier transform routine. Segments were overlapped by 50% to permit extracting information from samples at the ends of each segment attenuated by "windowing" (Harris 1978); we used the Blackman-Harris minimum three-term window. The magnitudes squared (the "powers") in each transform cell, or bin, were computed. The results of analyzing each segment were averaged to obtain our estimates of the sound power spectrum for a 16.5 s section of sound.

The effective bandwidth of each spectrum analysis cell was 1.7 Hz, although the cells were spaced 1 Hz apart. The powers in the cells were added to obtain the sound power in selected frequency bands, in particular, the standard third-octave bands widely used in acoustical sound and noise measurements. All levels, both spectrum levels and band levels, were saved for statistical analysis, printing, and plotting.

There were two statistical analysis techniques. In one, each of the analysis cells (frequency bins) in the 53 resulting spectra were sorted from smallest to largest. Then, the minimum, fifth percentile, fiftieth percentile (median), ninety-fifth percentile and maximum levels for that bin were identified and saved until five statistical spectra were generated, corresponding to those levels. The five statistical spectra were plotted.

The other statistical analysis was to sort the third-octave levels from minimum to maximum and identify the same five levels; the results were tabulated.

In addition to the data analysis results just described, the third-octave levels were graphed as a time series spanning the 14-minute period analyzed. These graphs permitted observing the cyclical nature, if any, of the ice-breaking process and comparing the variations at different frequencies.

B.3 Results and Discussion

The results are presented in graphs and tables, which are discussed in this section. However, it may help to describe a qualitative model of the icebreaking noise process before looking at the data. Recall that the ship has two propellers (in nozzles) that turn at constant speed, and that the direction of travel (forward or backward) is controlled by reversing the pitch. Power changes are controlled by adjusting the propeller pitch; the shaft rotation speed stays constant. When high power is expected to be needed, as during icebreaking, the shaft on the ROBERT LEMEUR is set to turn at about 170 rpm. There are four blades on each propeller. Thus, the shaft rotational frequency is about 2.83 Hz and the blade rate is about 11.3 Hz. These frequencies may be expected to be the fundamental frequencies of harmonic families corresponding to the shaft and blade rates. The shaft rate harmonics fall on and between the blade rate harmonics and would not be expected to be prominent unless one blade on a shaft was damaged in some way to make more sound (it might cavitate at times when the other three were not, for example). Our narrowband analysis results span 20 to 4000 Hz, so only harmonics of the blade and shaft rates would be expected to be seen.

The ship accelerates into an ice floe when attempting to break it. The acceleration results in propeller cavitation, which creates high levels of broadband noise across a wide range of frequencies. When the ship hits the floe, it rides up on the ice and, with luck, breaks down through it. If the ice is heavy, as it was during the session recorded on 2 September, the ship will be stopped by the ice. At this time, the icebreaker is in the "bollard" condition with full power to the propellers but making no forward progress.

Cavitation is severe and the noise levels are high. Eventually, the "man at the wheel" (the duty officer) reduces the power to zero and into full reverse, which causes the propeller pitch to cycle from "full ahead" to "full astern." We expect the noiseto diminish to a low level, although the shafts continue to turn. As the pitch changes into reverse, the noise level will increase again, as the ship begins to accelerate. When the ship is 50 to 100 m away from the target floe, the duty officer changes the power setting from "full astern" to "full ahead" and the propeller pitch again rotates through the zero power position to full power. At this time, the ship may still be going backwards, and the noise caused by the acceleration may be considerable as the process begins over.

There will be variations on the above scenario. There are two propellers, and the officer conducting the icebreaking will need to change direction at some times. Then, he is likely to use power differently on the two propellers, even having one set for "full ahead" while the other is set for "full reverse".

During the recording session on JUDY ANN, we did not know how the duty officer was handling the controls for the two propellers. We could observe the ship motions and we could hear the sounds, and we have tried to reconstruct how the power was being controlled. Generally, the propeller blade rate was audible as a rapid series of impulses. At times the blade signal disappeared; we took those to be times when the pitch changed through zero power on both propellers. Seeing when the ship was going ahead and when it was going astern, we could generally relate the disappearance of the blade sound to a direction reversal. However, there were times when the ship reversed direction and the blade sounds persisted. We will return to these considerations, but first it will be beneficial to examine the results of the spectrum analyses.

Figure B.1 presents two unrepresentative spectra from the series of 53 computed. The spectrum in Figure B.1A was begun at time 13:12:24, when the icebreaker was in the "bollard" condition of being stopped by the ice but having full power applied. This spectrum had the highest overall band level (tied with four other spectra) and the highest levels for the 400 to 3150 Hz third-octave bands. The spectrum in Figure B.1B was begun at time 13:23:26, when the ship had been pushing ahead but reversed pitch to back away from the ice. This spectrum contained the highest third octave levels at 20 and 31.5 Hz, and the lowest third octave levels at the highest frequencies.

Figure B.2 contains five spectra composed by sorting the individual frequency analysis cells over the 53 spectra and determining the minimum, maximum, and the 5th, 50th (median) and 95th percentile levels. In one point of view, this figure presents five points on the cumulative distribution of spectrum levels for each frequency cell from 20 to 4000 Hz. Somewhat surprisingly, there is relatively little variation between the lowest and highest spectrum levels at low frequencies (about 20 dB). The sounds at those frequencies come mostly from the ship's machinery and propellers. Although the machinery operating speed is constant for all phases of the icebreaking, the power generated varies substantially. At the high frequencies, we expect considerable spread in the levels, as is shown, because of the effects of cavitation. The propellers cavitate most severely during the "bollard" condition and when changing direction from going astern to goind ahead. When changing the power setting from reverse to forward, the propellers pass through a condition where there is no cavitation at all. For comparison, the idealized spectrum for Knudsen et al. (1948) Sea State 6 is shown at the bottom of the figure.

Table B.1 presents the cumulative distribution information for each of the third-octave frequency bands. Consistent with the effect seen in the statistical spectra, the span of levels at low frequencies is only 15 dB at 20 Hz, 10 dB at 31.5 Hz, but at high frequencies it is 38 dB at 3150 Hz.

Figure B.3 presents the variation in sound level vs. time for four third-octave bands: 20, 50, 500, and 3150 Hz. During the 14 minutes recorded and analyzed, the ship went through about five cycles of "backing and ramming" a heavy ice floe in attempting to break it up. To depict these cycles, at the bottom of each graph we have drawn a "random square wave" representing the times the icebreaker was going forward and in reverse. Also shown are the instants of time when the ship's forward progress was seen to be stopped by the ice. The ship did not go into reverse immediately after being stopped, but continued to apply power for varying periods of time after being stopped. The "random square wave" cannot depict the variety of power settings and periods of propeller cavitation that existed during the 14 minute period, but some generalities may be stated. The ship usually cavitated severely after changing from "reverse" to "forward," as the ship reversed direction, and it usually cavitated severely after being stopped on a forward run by the ice. Also, propeller sounds usually faded away during a propulsion change from one direction to another.

In spite of these generalities, it is difficult to see any relationship at low frequencies between the ship activity or condition of cavitation and the sound level. At 20 Hz, it appears that the sound level decreased soon after the ship's forward progress was stopped each time. At the highest frequencies, the 3150 Hz third-octave band, the level was generally high while the ship was going forward and lower while the ship was in reverse. This observation is consistent with the theory that the ship propellers cavitate while the ship is accelerating forward to meet the ice, and that cavitation causes a general increase in level at higher frequencies. The effect does not appear to be present at 500 Hz or at the lower frequencies.

In summary, in 14 minutes there were about five cycles of accelerating into the ice followed by backing away to try again. Clear relationships between ship activity and sound level were difficult to find, but we did not have records of the power settings on the ship. The variations in sound level were different in the third octave frequency bands between 20 and 3150 Hz. At the highest frequencies, the levels were higher during the accelerating phase when the ship ran ahead to hit the ice than during the backing phase in preparation for another run.

REFERENCES FOR APPENDIX B

1. Greene, C.R., 1987. Acoustic studies of underwater noise and the localization of whale calls. In Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, Autmn 1986. Report by LGL Limited environmental research associates and Greeneridge Sciences, Inc., for Shell Western E&P Inc., 128 p.

2. Carter, G.C. and A.H. Nuttall. 1980. On the weighted overlapped segment averaging method for power spectral estimation. Proc. IEEE 68(10):1352-1353.

3. Harris, J. 1978. On the use of windows for harmonic analysis with the discrete Fourier transform. Proc. IEEE 66:51-83.

4. Knudsen, V.O., R.S. Alford and J.W. Emling. 1948. Underwater ambient noise. J. Mar. Res. 3:410-429.

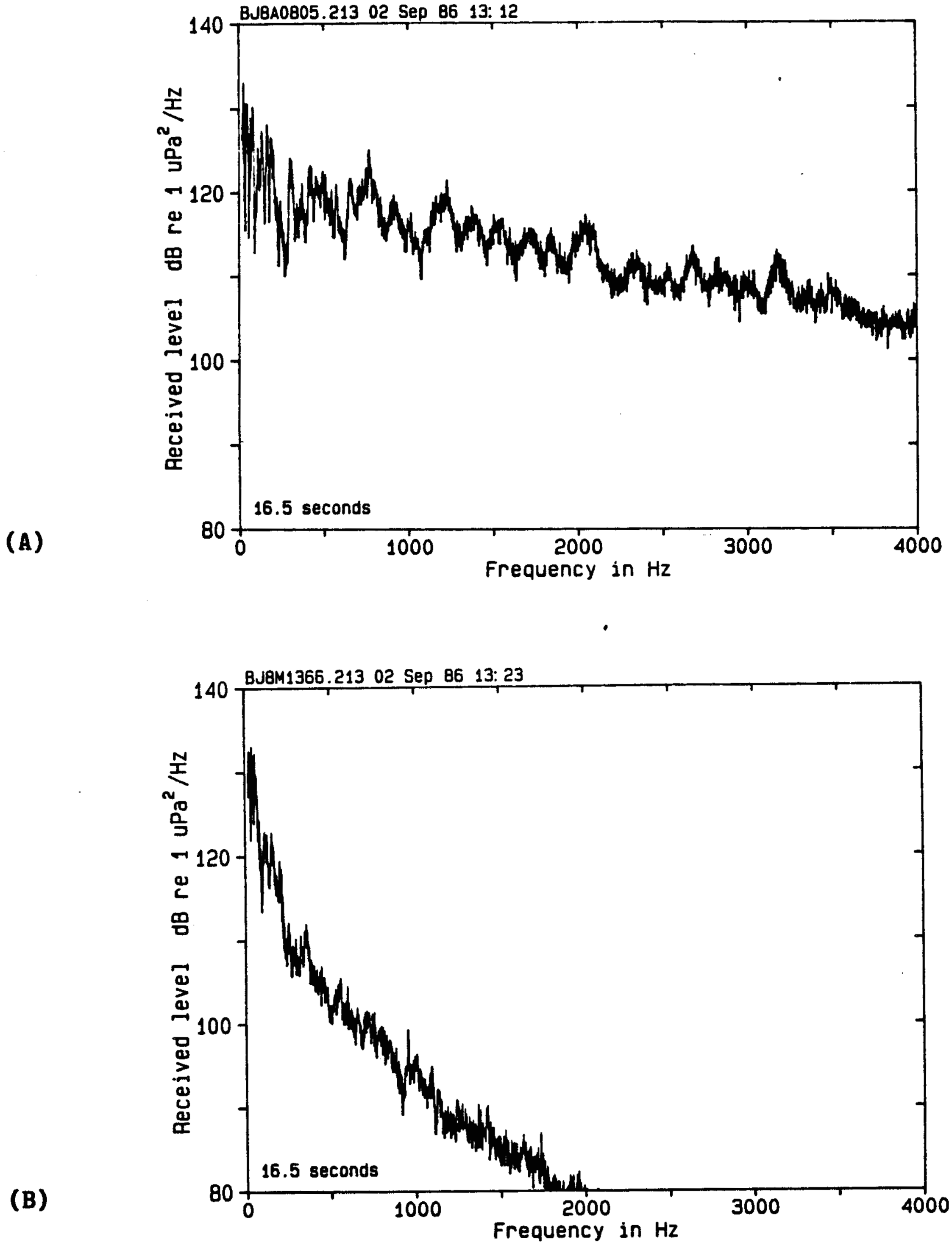


Figure B.1. Averaged Sound Pressure Spectra for the ROBERT LEMEUR Breaking Ice at Range 0.25 n.mi. (0.46 km). The Water Depth was 38 m, the Hydrophone Depth was 18 m. (A) is for the Ship Stopped by the Ice but Pushing Ahead with Full Power. (B) is for the Ship in Reverse Backing Away From the Ice.

Table B.1. Cumulative Distributions for Third-Octave Bands 20-3150 Hz. These Levels Were Derived by Sorting the Third-Octave Levels Computed in the 53 Analyses of Icebreaking Sounds.

53 records.

					Center frequency (Hz) of 1/3rd Octave Bands															Band level (Hz)								
	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	10-500	20-500	10-1000	20-1000
Minimum	120	124	128	128	129	129	132	124	128	129	128	127	126	127	124	122	121	117	113	110	105	102	99	142	141	142	142
5%	121	126	128	130	132	131	134	127	129	131	132	127	127	130	129	127	128	125	124	122	119	115	113	143	143	144	143
10%	122	127	128	130	133	132	134	127	130	131	132	128	127	130	130	128	128	125	125	123	120	118	114	144	144	144	144
50%	129	132	133	134	136	136	137	132	135	136	135	133	133	134	133	132	132	131	130	129	127	125	123	147	146	147	147
90%	132	137	137	139	142	141	141	135	140	140	140	135	137	138	136	136	137	134	135	133	133	131	130	150	150	151	150
95%	133	138	138	140	142	142	141	135	141	141	140	135	137	138	137	137	138	137	139	137	136	135	134	151	151	151	151
Maximum	135	139	138	144	143	144	141	138	144	142	143	138	139	139	140	140	142	139	142	140	140	136	137	151	151	152	151

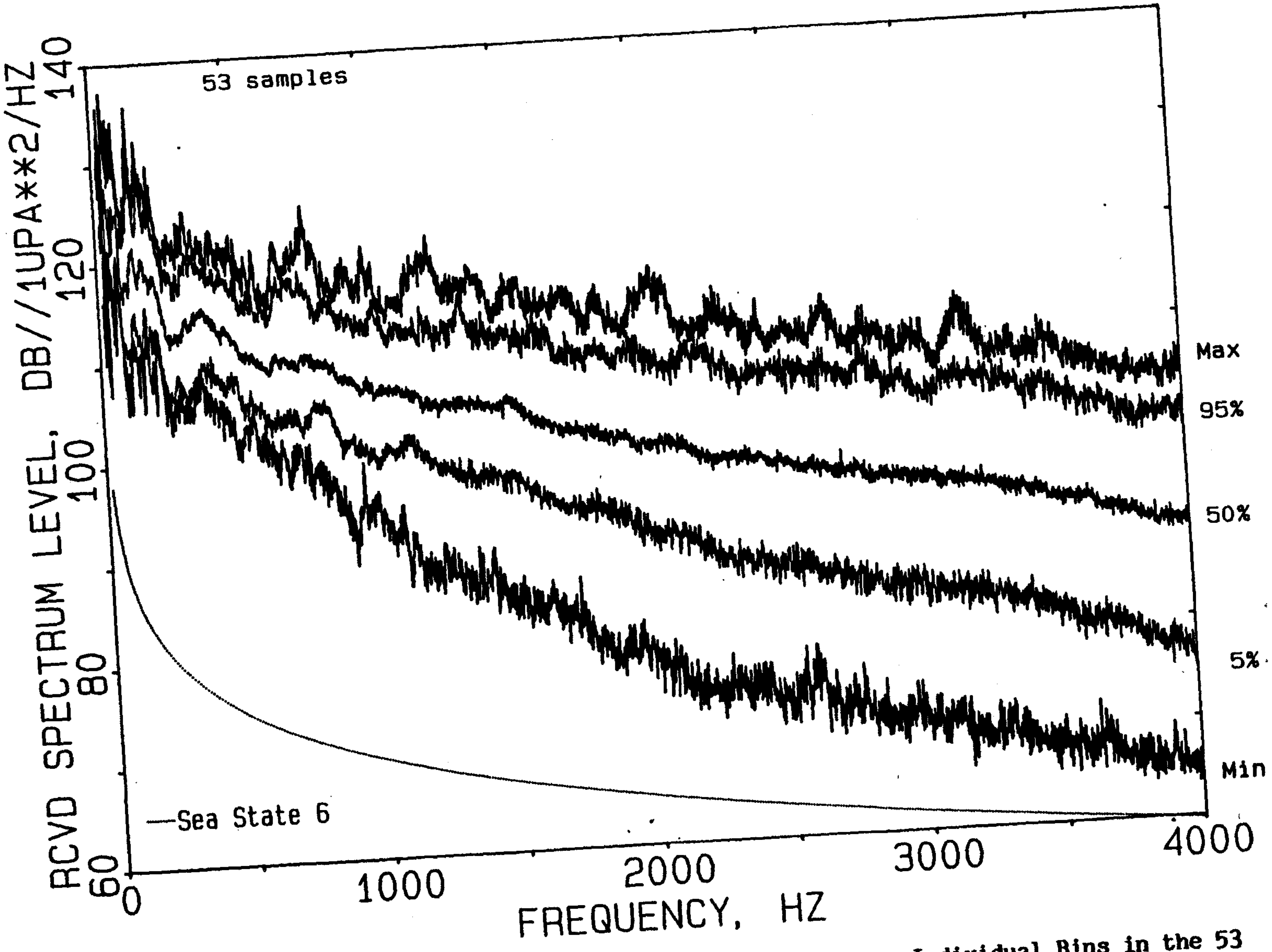
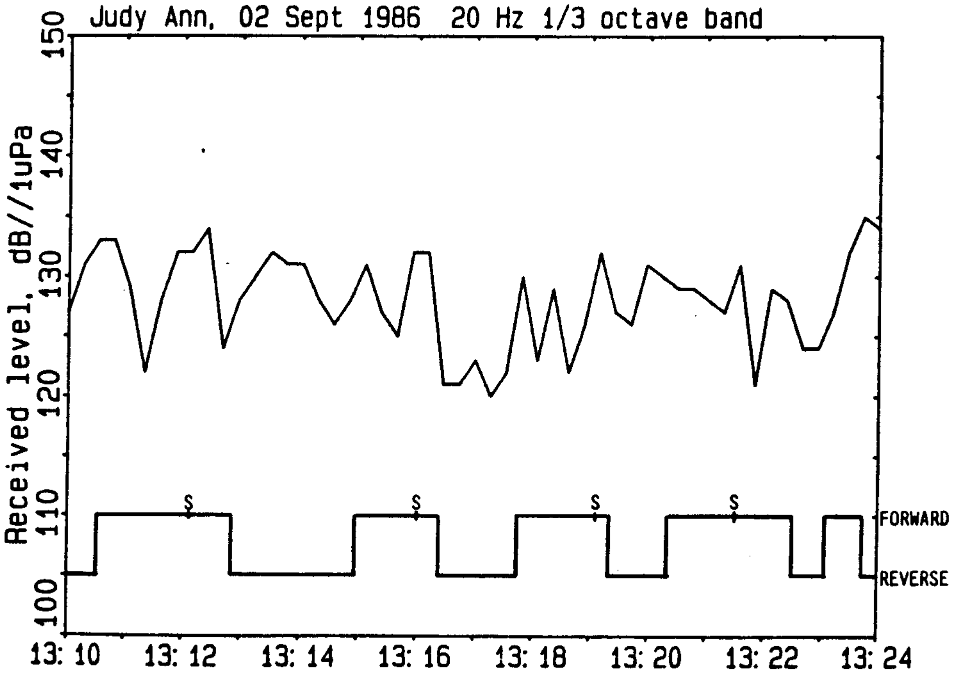
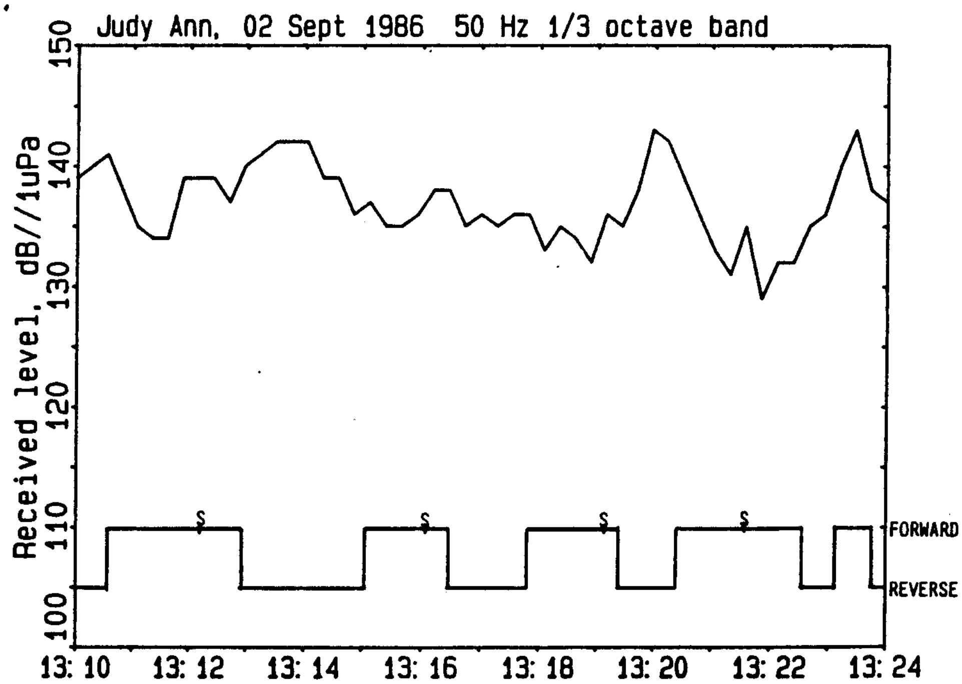


Figure B.2. Cumulative Distribution Spectra Derived by Sorting the Individual Bins in the 53 Spectra for ROBERT LEMEUR Icebreaking at Range 0.25 n.mi. (0.46 km). The Knudsen spectrum for sea state six, extrapolated to low frequencies, is included for comparison.

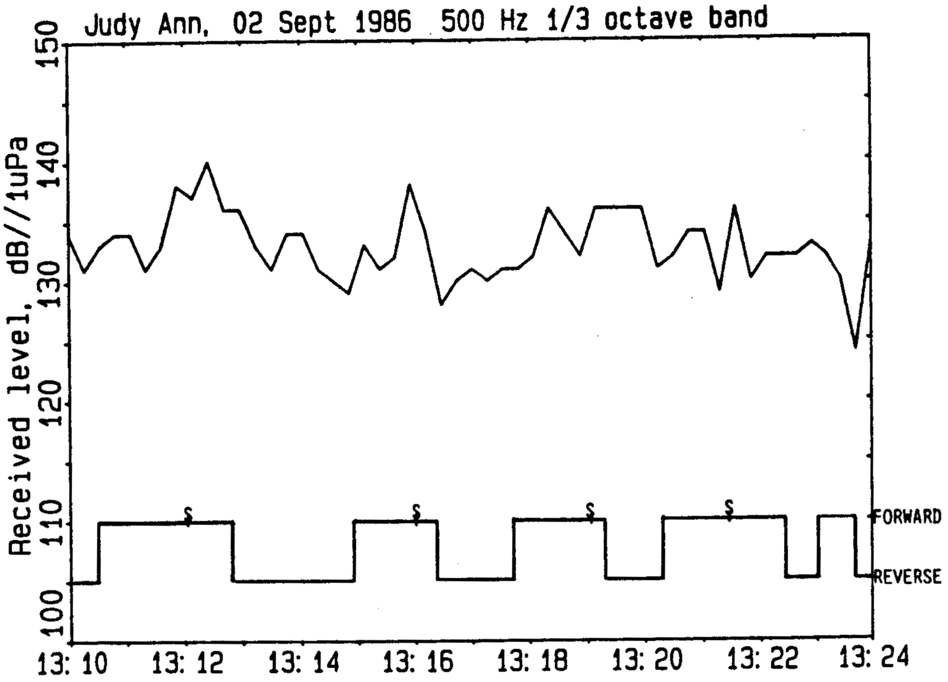


A. 20 Hz 1/3 Octave Band

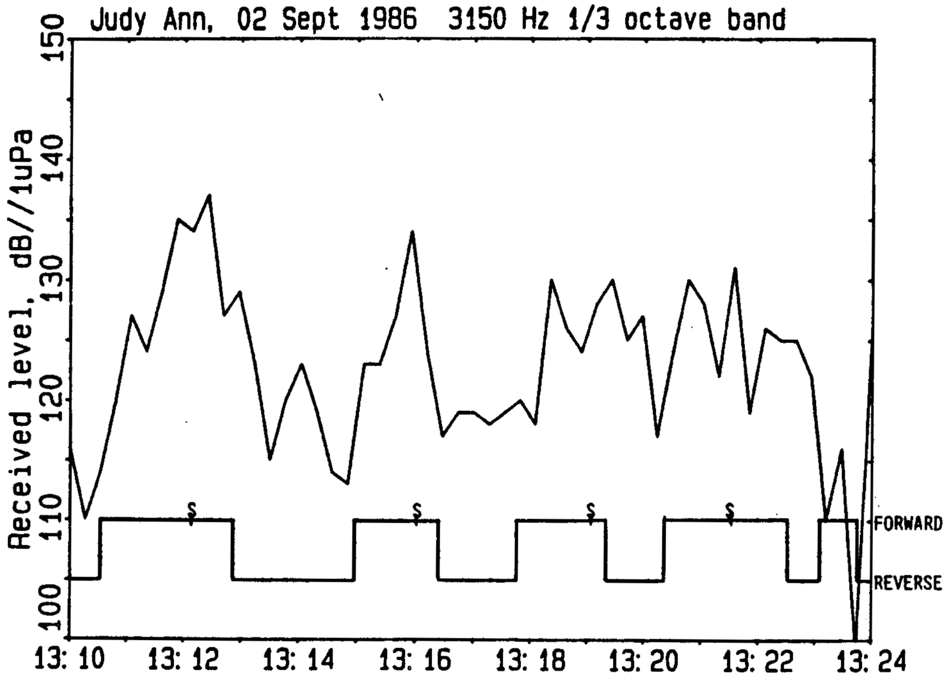


B. 50 Hz 1/3 Octave Band

Figure B.3. Time Series of the Icebreaking Sound Levels in Four Third-Octave Bands. The Center Frequencies are: (A) 20 Hz, (B) 50 Hz, (C) 500 Hz, and (D) 3150 Hz. The Travel Direction of the Icebreaker (Forward or Reverse) is Depicted at the Bottom of Each Graph. "S" Indicates When the Ship was Stopped by the Ice.



C. 500 Hz 1/3 Octave Band



D. 3150 Hz 1/3 Octave Band

Figure B.3. (Cont.)

APPENDIX C:

TRANSMISSION LOSS CHARACTERISTICS FOR SELECTED OCS PLANNING AREAS

The results obtained from the IFD sound transmission model for the Norton Basin, North Aleutian Basin and Shumagin OCS Planning Areas are presented here. Results are given for surface layer and neutral gradient conditions in these areas using the representative sound speed profiles shown in Fig. 4.2.

A summary of the propagation data reported by Greene 1981 for the Chukchi Sea area is also presented. The conditions represented are winter with 100% ice cover and summer with 50% ice cover.

The information is presented in the following figures:

FIG. C.1A TRANSMISSION LOSS CHARACTERISTICS
Chukchi Sea (Greene 1981)

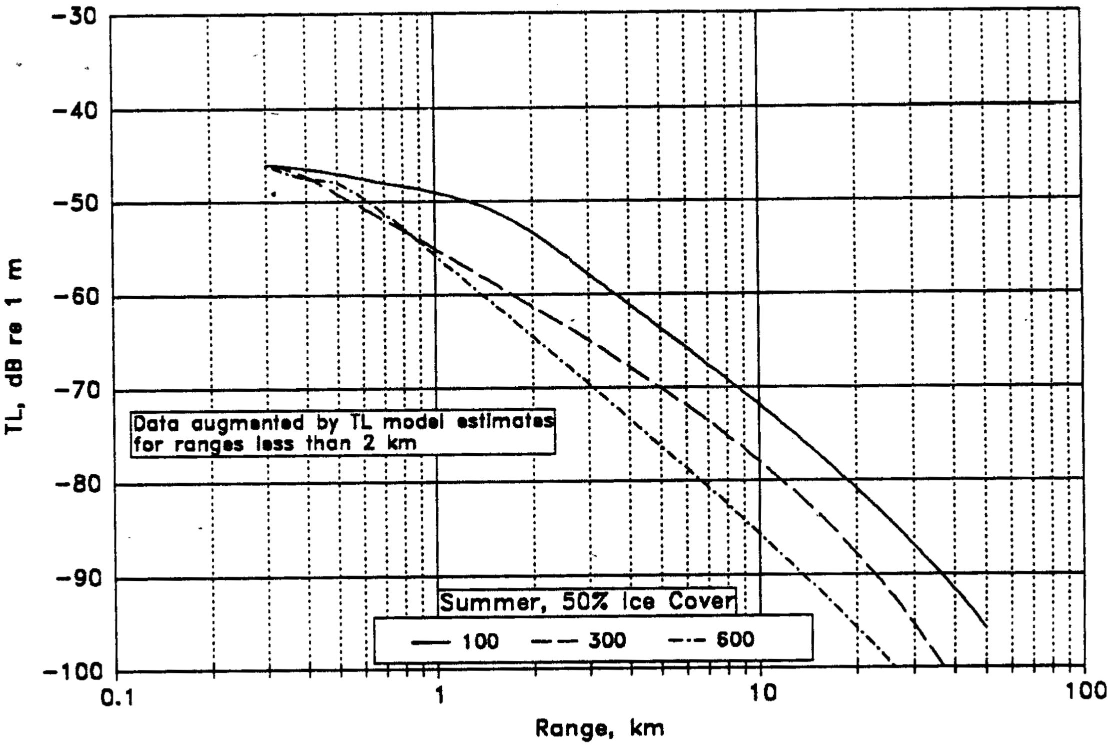


FIG. C.1B TRANSMISSION LOSS CHARACTERISTICS
Chukchi Sea (Greene 1981)

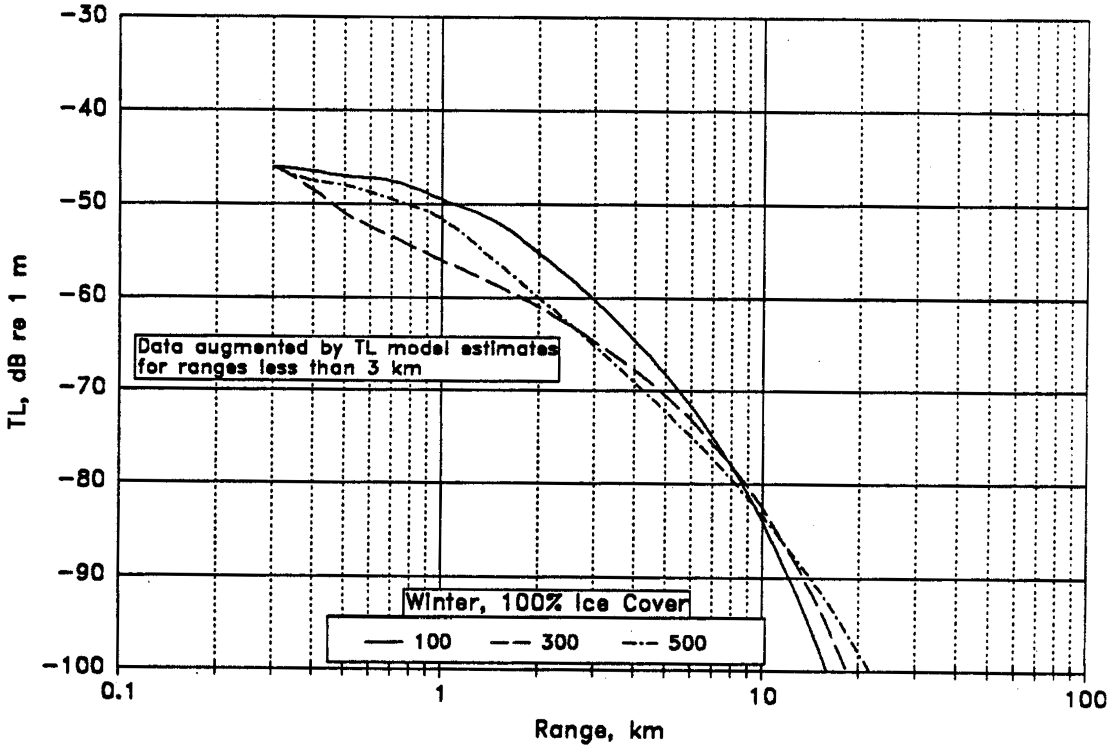


FIG. C.2A TRANSMISSION LOSS CHARACTERISTICS
Norton Basin

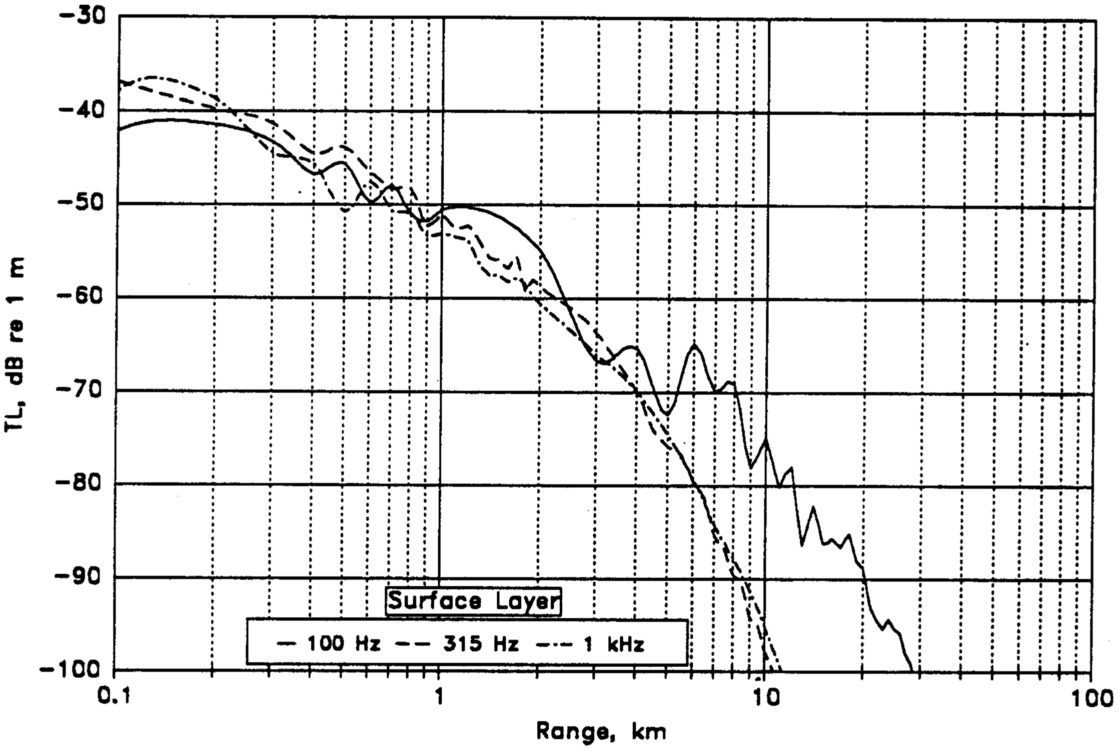


FIG. C.2B TRANSMISSION LOSS CHARACTERISTICS
Norton Basin

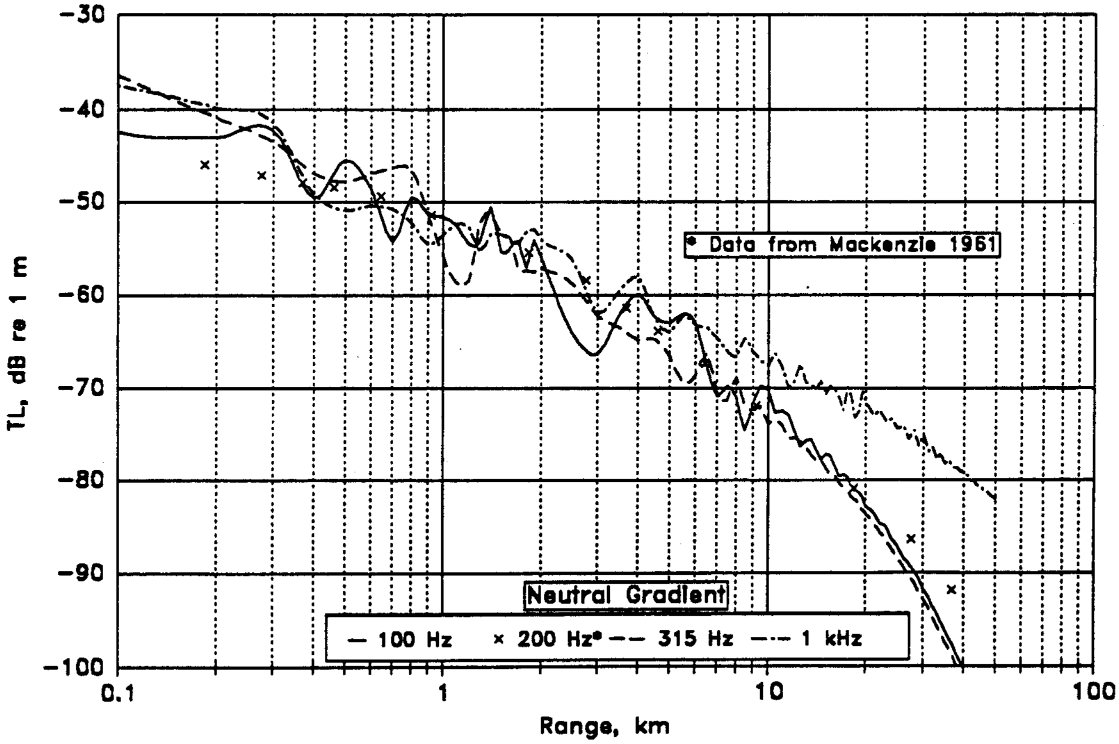


FIG. C3A TRANSMISSION LOSS CHARACTERISTICS
North Aleutian Area

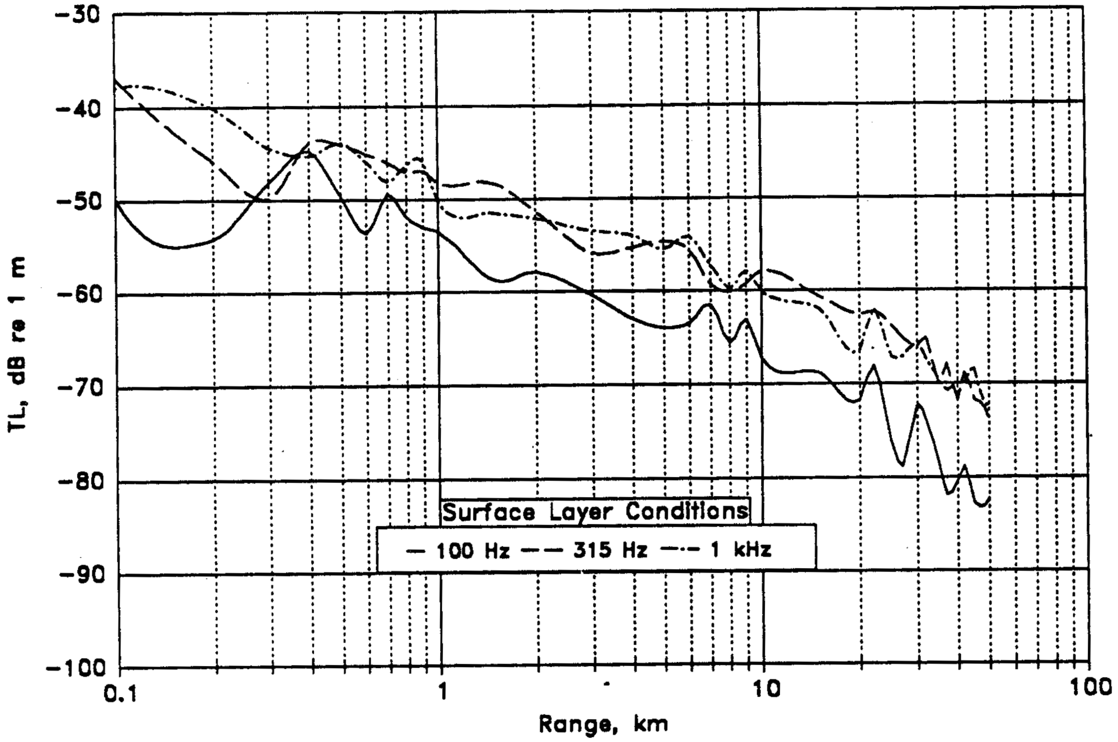


FIG. C3B TRANSMISSION LOSS CHARACTERISTICS
North Aleutian Area

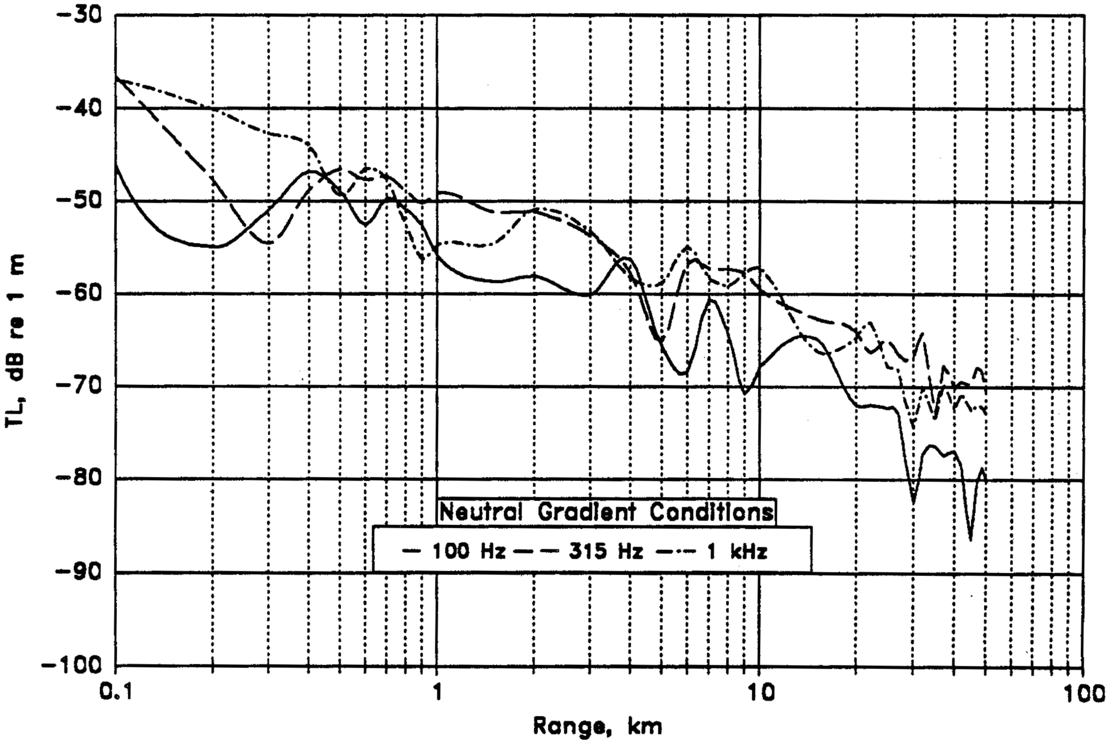


FIG. C4A TRANSMISSION LOSS CHARACTERISTICS
Shumagin Area (Rocky Bottom Region)

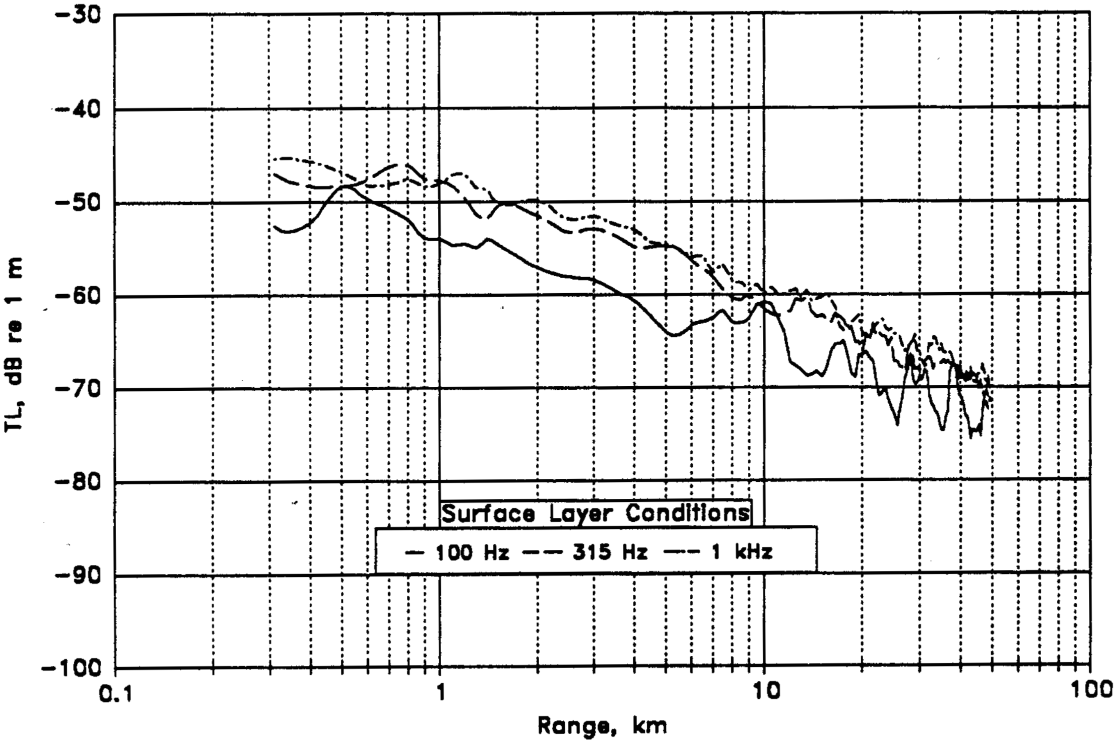
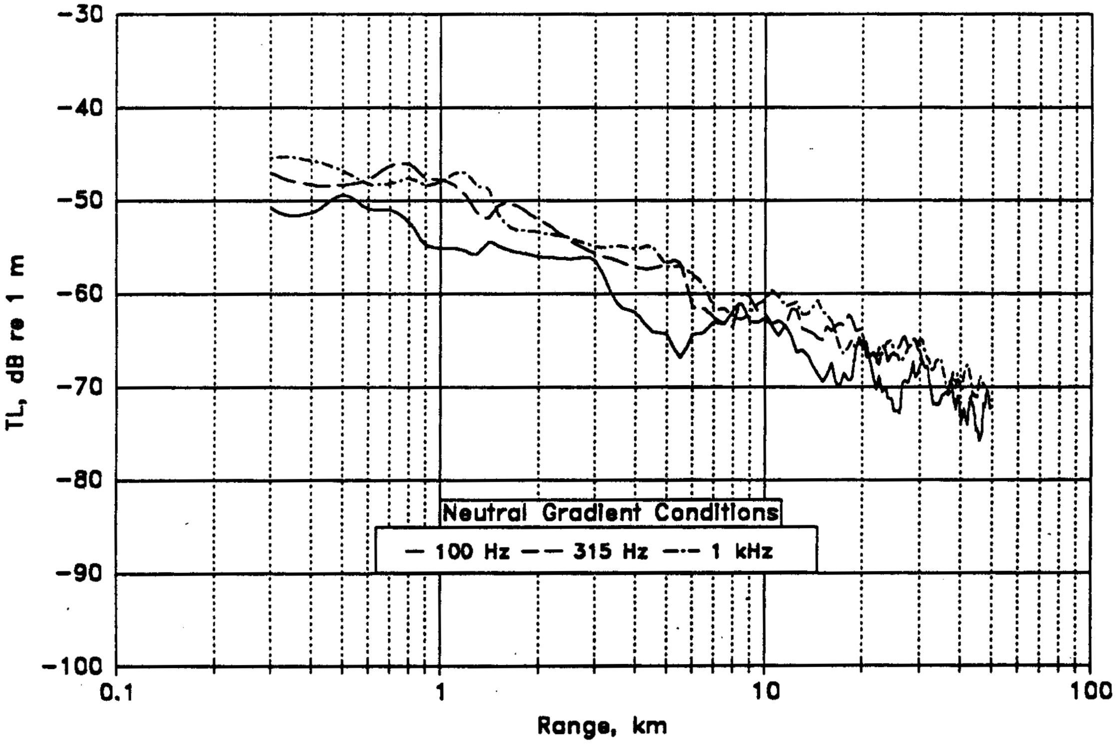


FIG. C4B TRANSMISSION LOSS CHARACTERISTICS
Shumagin Area (Rocky Bottom Region)



APPENDIX D:

ESTIMATION OF HEARING RESPONSE CHARACTERISTICS FOR GRAY AND FIN WHALES

Figure D.1 is presented as background information to help describe the proposed procedure. This figure shows the average human speech spectrum and hearing sensitivity characteristics as reported in the literature. One interesting feature is that the frequency range of maximum hearing sensitivity lies above the frequency range where the maximum speech level occurs. This is believed to have evolved to compensate for the higher attenuation of high frequencies in propagation through the air and for the need to maintain a nearly constant signal-to-noise ratio through the speech range for good speech intelligibility. Note that the upward slope of the hearing sensitivity curve is similar to the downward slope of the speech spectrum. For the human characteristics the frequency of maximum hearing sensitivity (Fma) is about 2 1/2 octaves above the frequency of maximum vocal output (for male speakers) (Fmv). It is possible that a similar difference exists in the frequency bands for marine mammal vocalization and hearing characteristics.

Two other curves are also shown in the figure which represent the sound levels at which a tone would become annoying or would become loud enough to cause permanent hearing damage. The pure tone amplitude range of normal hearing response for humans can be seen to cover a range of 60 to 90 dB on a logarithmic scale or a range of 1000 to 30,000 on linear scale, depending on frequency.

Figure D.2 illustrates the procedure used for estimating the hearing response of the gray whale. We assume that the characteristic will be similar in spectrum shape to that of other mammals (Myrberg 1978) but its location in frequency range will be determined by the acoustic requirements of the species. The vocalization output characteristic shown was estimated from a brief review of reported data. If a 2 1/2 octave difference exists between Fmv and Fma for gray whales, the range of maximum hearing sensitivity may occur around 700 Hz as shown. The maximum sensitivity level is estimated to be lower than the ambient noise spectrum level for Sea State 0 in this frequency range since gray whale hearing sensitivity has been observed to be ambient noise limited, not hearing sensitivity limited during quiet sea state conditions (Malme et al. 1984). A maximum hearing sensitivity of 40 dB was assumed since this corresponds to the value measured for orcas, the largest whale tested to date. It is possible that gray whale hearing is not this sensitive since the estimated frequency of maximum hearing sensitivity is 700 Hz versus the measured 12 kHz for orcas (see Fig. 2.24). Underwater ambient noise levels at 700 Hz are higher than at 12 kHz. Thus evolutionary processes may have resulted in reduced sensitivity at low frequency as an adaptation to the underwater ambient noise spectrum. Conversely, human hearing thresholds are below the level of general ambient noise so that human hearing is almost always noise limited. This is expected to be true for baleen whales also.

Figure D.3 shows the estimated hearing characteristics for gray and fin whales compared with the measured data for white whales (see Fig. 2.24). The hearing characteristic for fin whales was obtained from the gray whale characteristic by scaling the frequency range downward by a factor of 3. This was done because their dominant vocalization output occurs at lower frequencies than that for gray whales (see Table 2.7) and hence their hearing characteristic is expected to cover a lower frequency range. This procedure is highly speculative and the predicted characteristics are intended to be used only to provide preliminary estimates of potential acoustic sensivitity. Measured data must be used as soon as test results become available.

FIG. D.1 HUMAN VOCALIZATION AND AUDITION CHARACTERISTICS

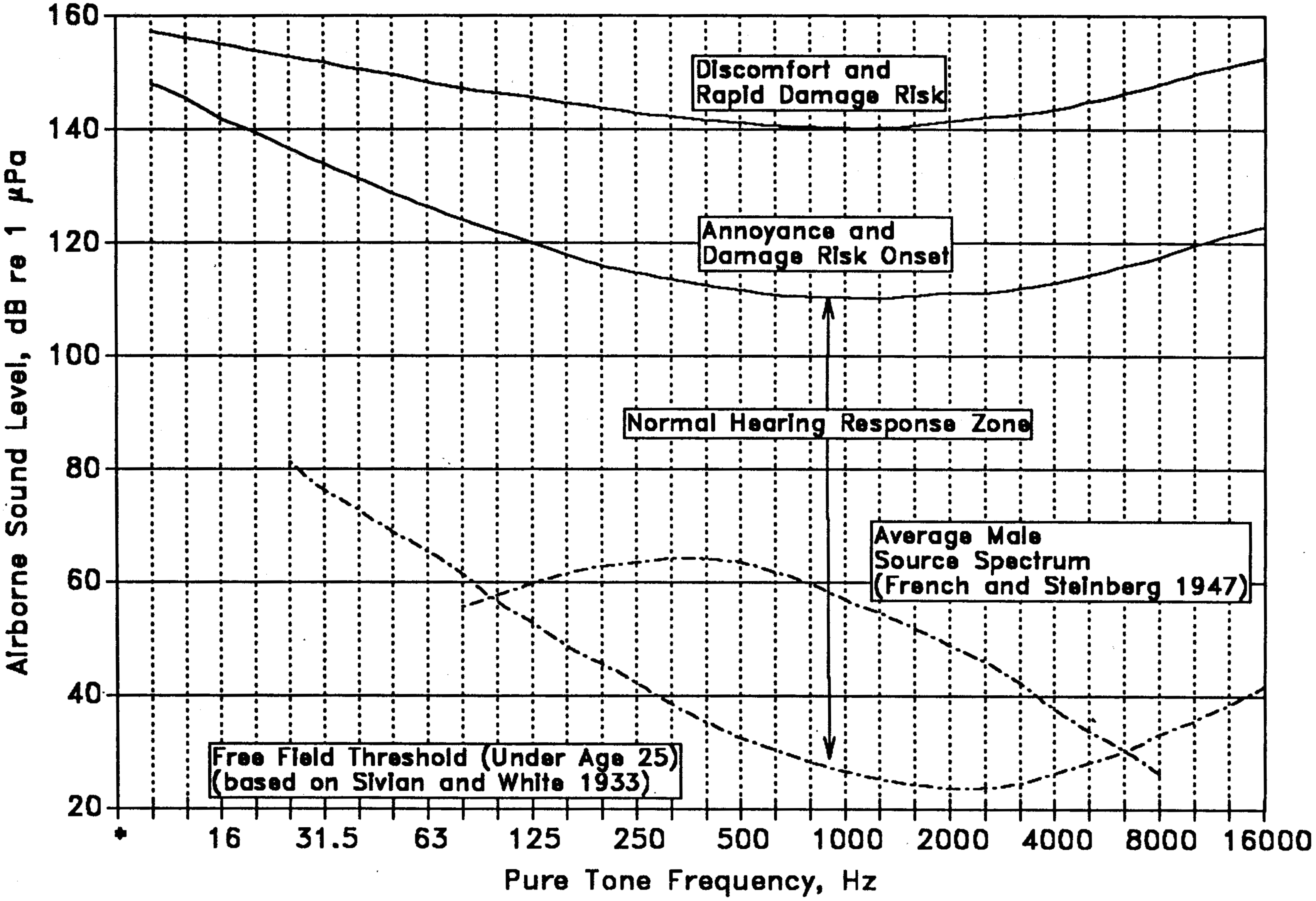


FIG. D.2 ESTIMATED GRAY WHALE VOCALIZATION AND AUDITION CHARACTERISTICS

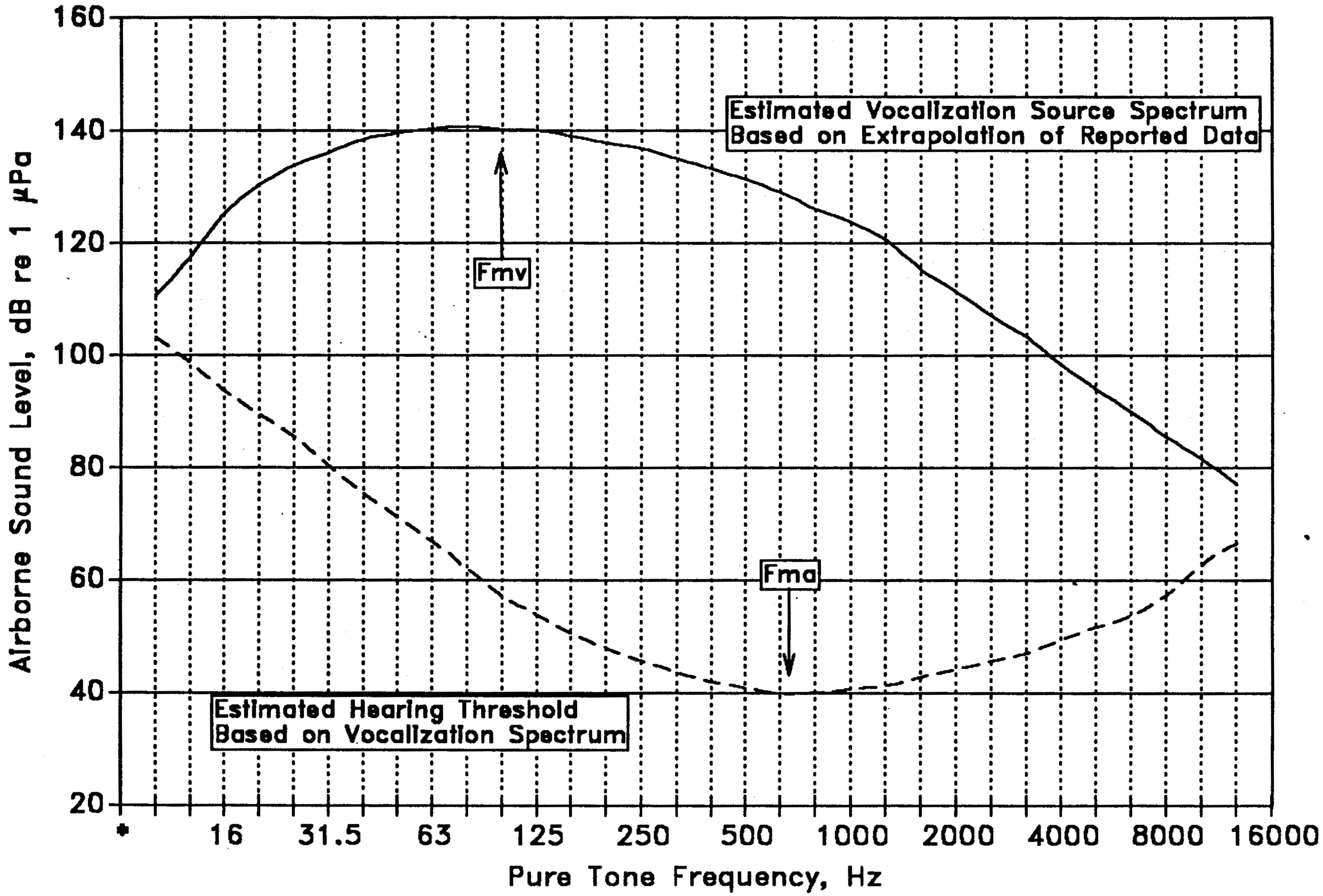
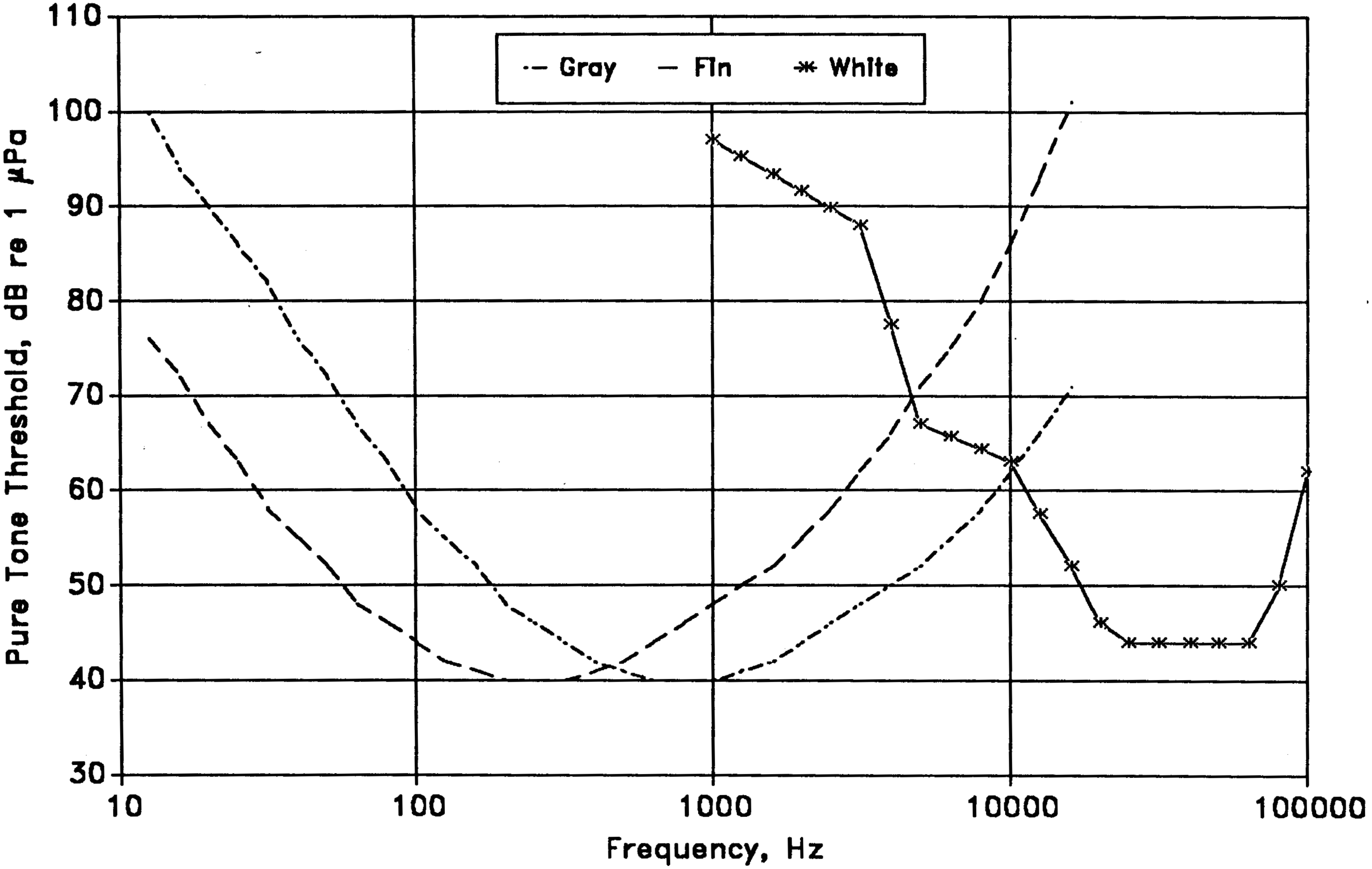


FIG. D.3 ESTIMATED HEARING CHARACTERISTICS FOR BALEEN WHALES
Measured curve for white whales shown for comparison



APPENDIX E:

ESTIMATED RECEIVED LEVEL SPECTRA FOR MAJOR NOISE SOURCES OPERATING IN SELECTED OCS PLANNING AREAS

Transmission loss data and IFD Model predictions were used together with source level spectra to obtain estimated received level spectra for operation of the major sound sources in the four selected OCS planning areas. The sources were determined by the results of the SNC model analysis (Sec. 5.3). Both actual and hypothetical sources are included. Range steps were selected to obtain approximate 10 dB decrements in received level spectra. The estimated statistical range of ambient noise levels for the areas are also included to show the ranges at which the received levels approach expected ambient levels. A criterion based on 1/3 octave band levels 30 dB above the 50%ile ambient noise spectrum is also shown. This criterion spectrum is intended to provide an indication of the range at which sound levels from the source may become significant with respect to potential behavioral response. Since data for establishing behavioral response criteria for specific noise sources are unavailable for most of the sources and species included in this study, the 30 dB criterion is intended to provide a common reference for all of the sources shown until more specific response data become available.

The following figures are presented to show received level spectra versus range for selected sources in the four planning areas:

FIG. E.1 VIBROSEIS ARRAY IN THE CHUKCHI SEA
Winter, 100% Ice Cover

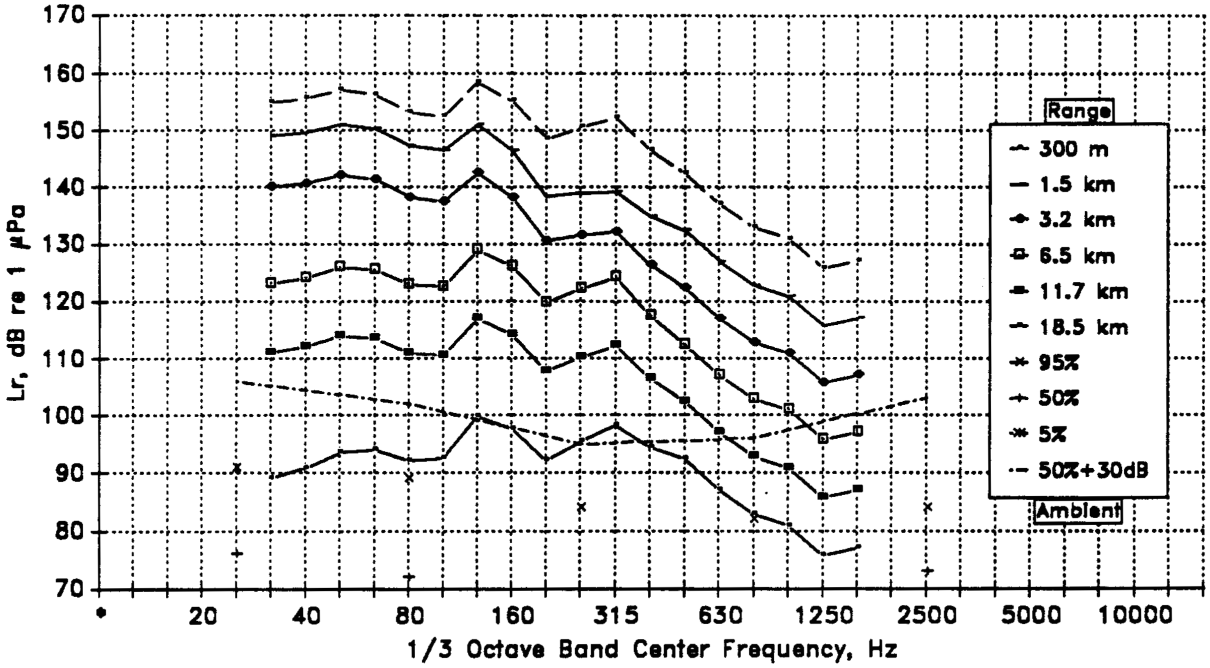


FIG. E.2 ICEBREAKER OPERATING IN THE CHUKCHI SEA
Winter, 100% Ice Cover

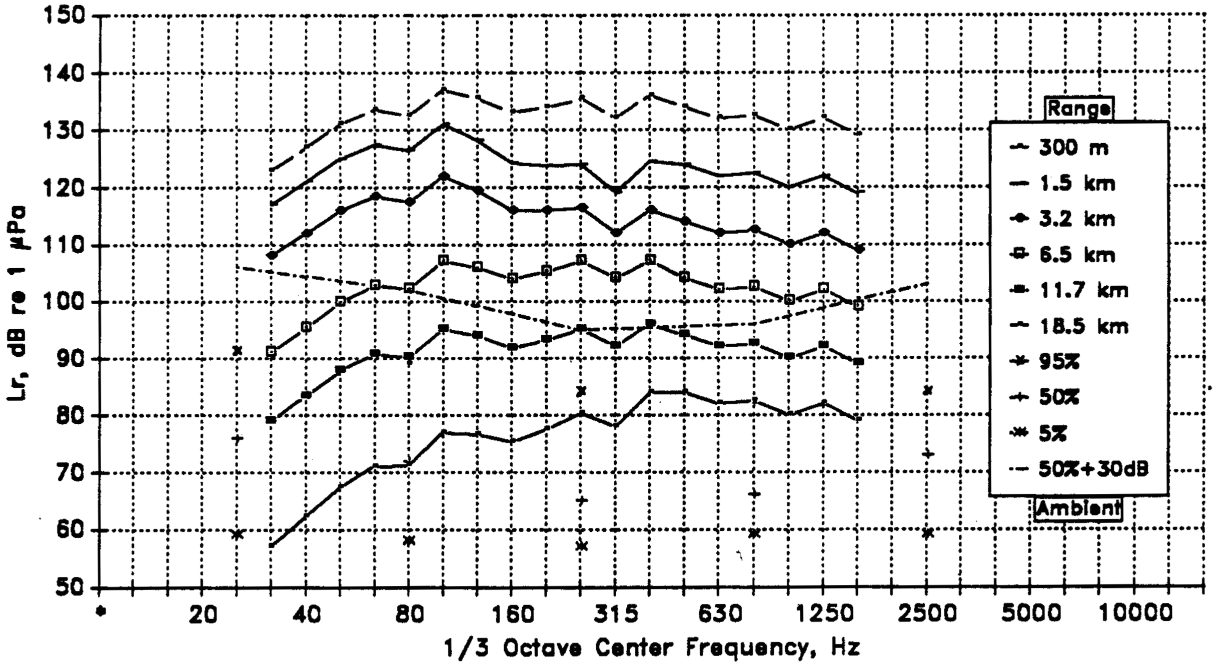


FIG. E.3 ICEBREAKER OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

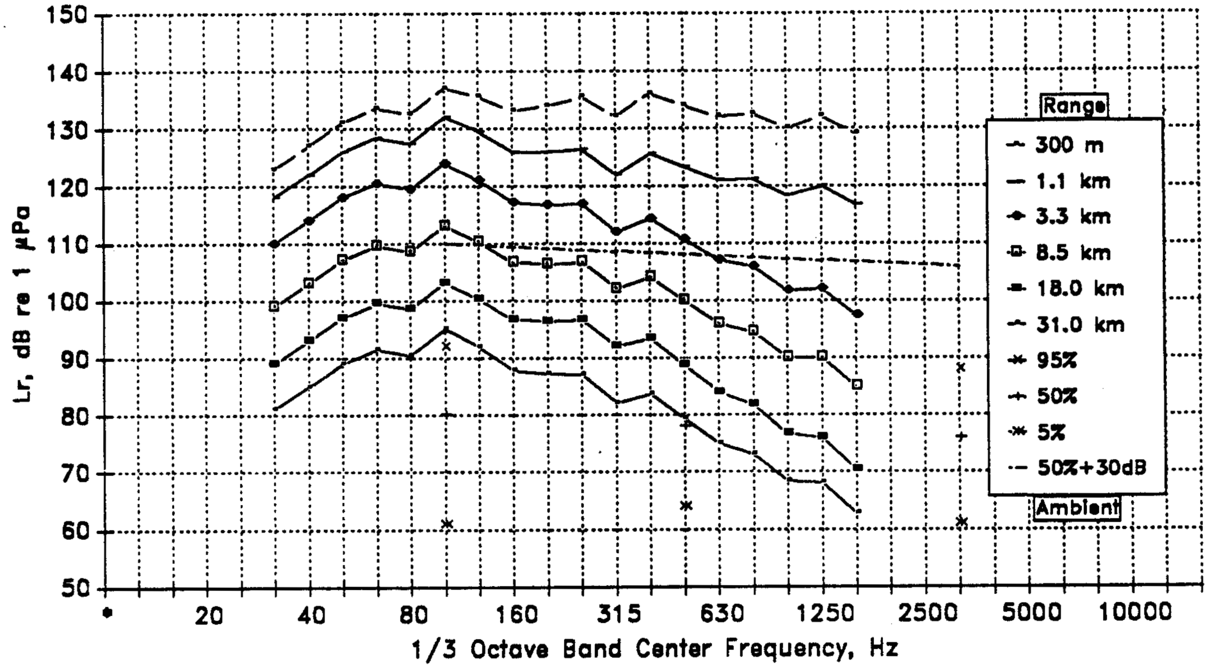


FIG. E.4 AIR GUN ARRAY (WESTERN POLARIS) OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

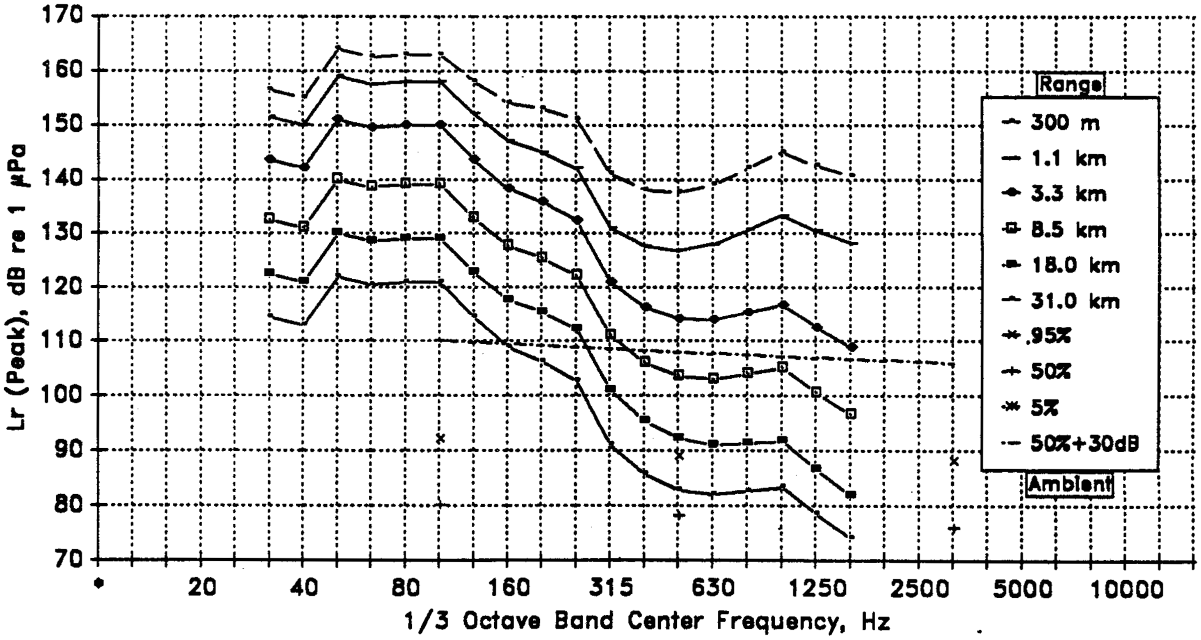


FIG. E.5 DRILLSHIP (EXPLORER II) OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

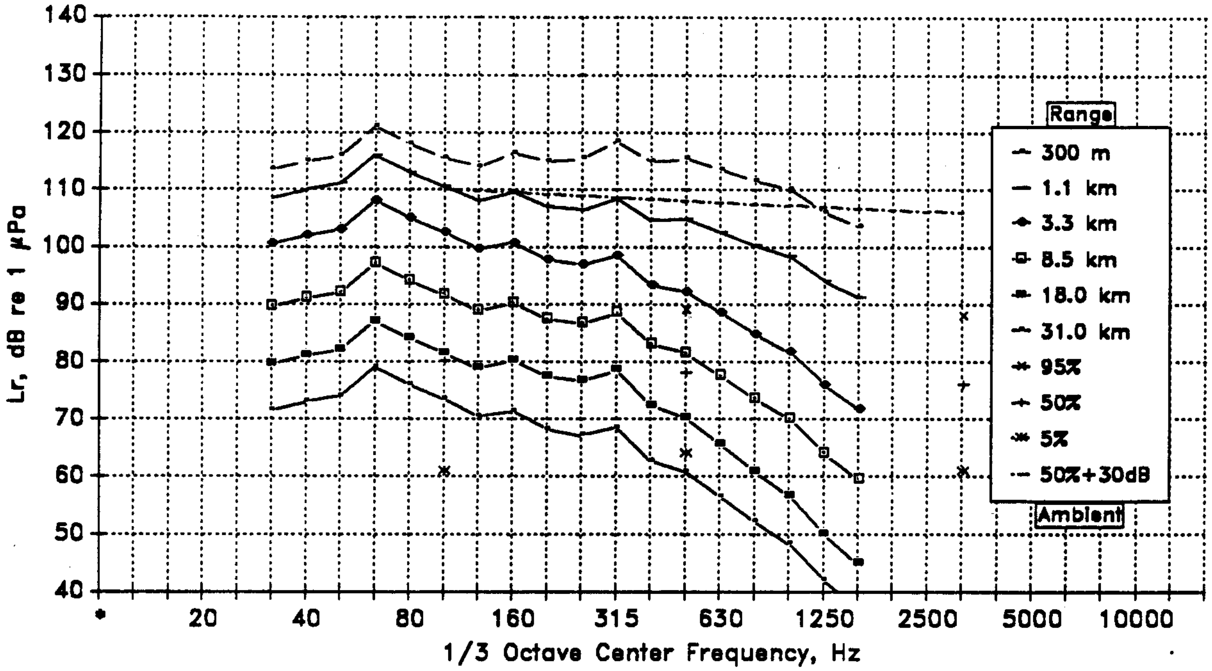


FIG. E.6 DREDGE (AQUARIUS) OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

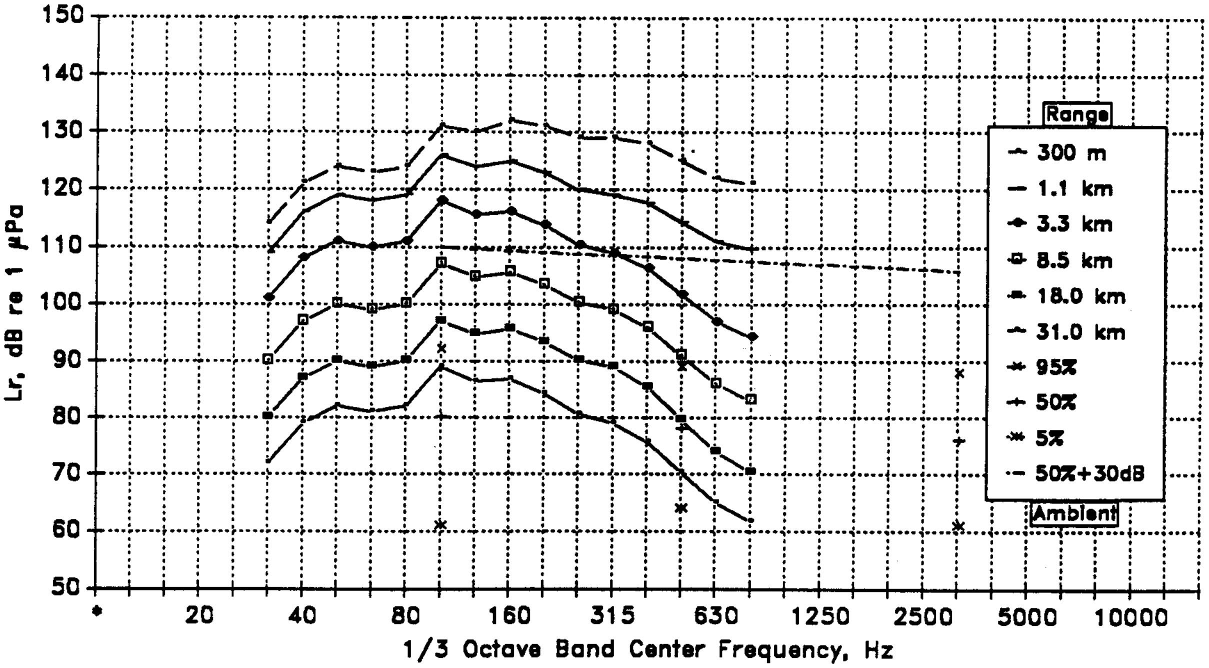


FIG. E.7 TUG/BARGE OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

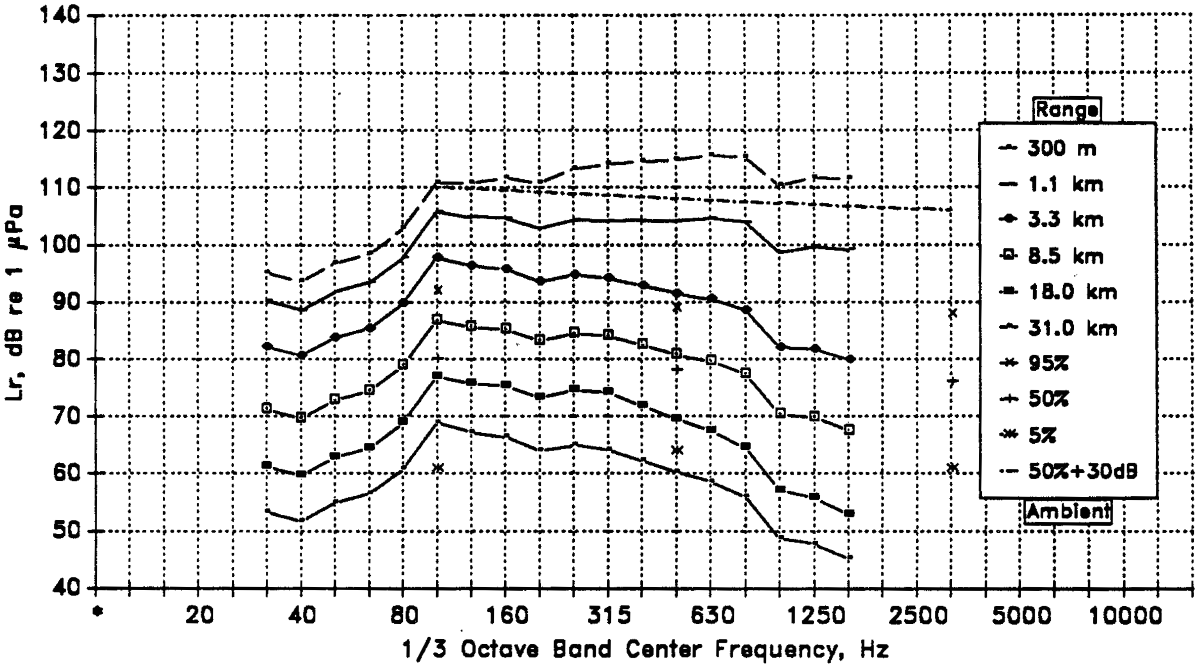


FIG. E.8 TWIN OUTDRIVE (20KT) OPERATING IN THE CHUKCHI SEA
Summer, 50% Ice Cover

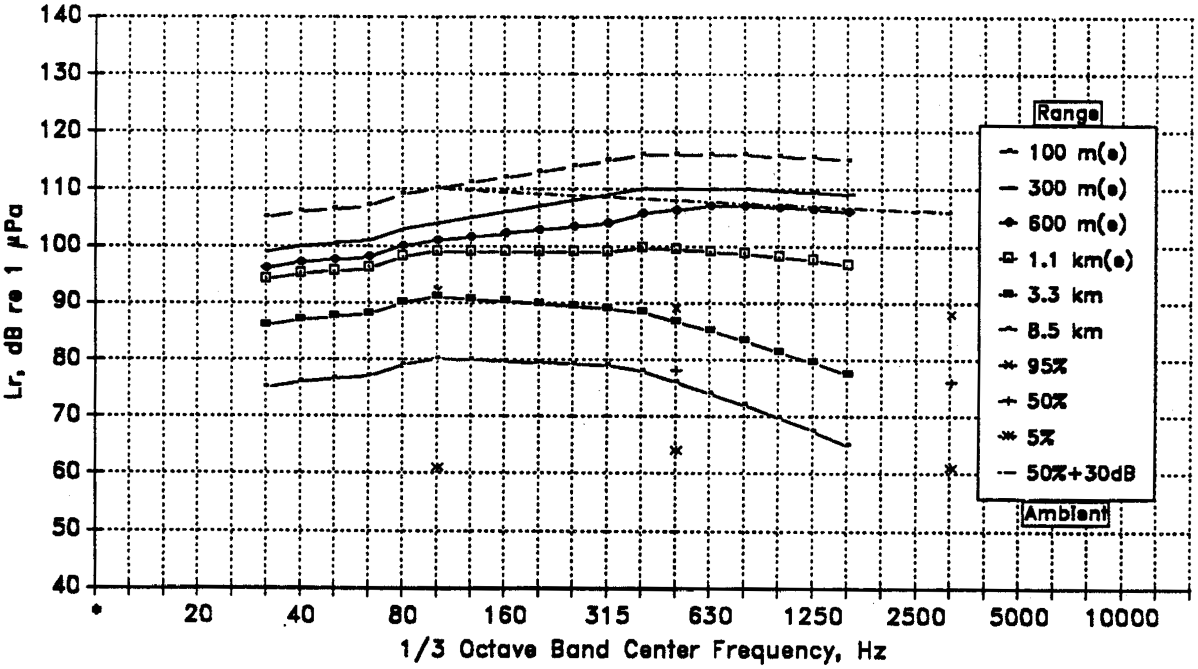


FIG. E.9 ICEBREAKER OPERATING IN NORTON BASIN
Neutral Gradient Conditions

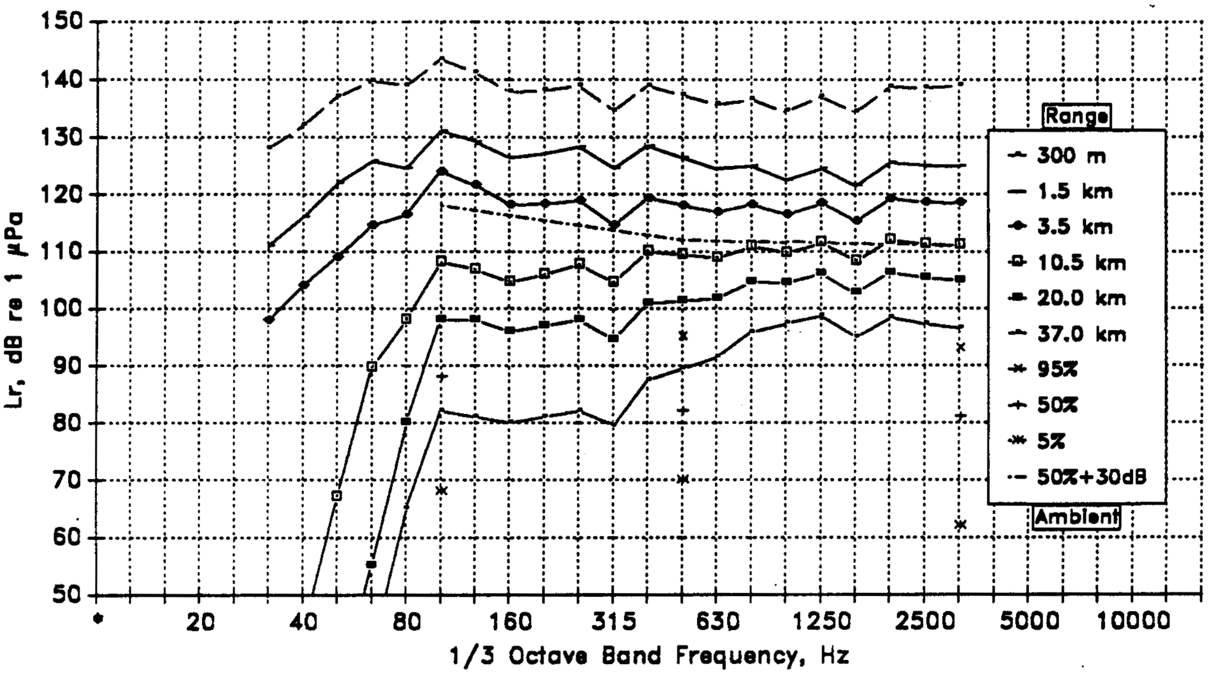


FIG. E.10 DREDGE (AQUARIUS) OPERATING IN NORTON BASIN
Neutral Gradient Conditions

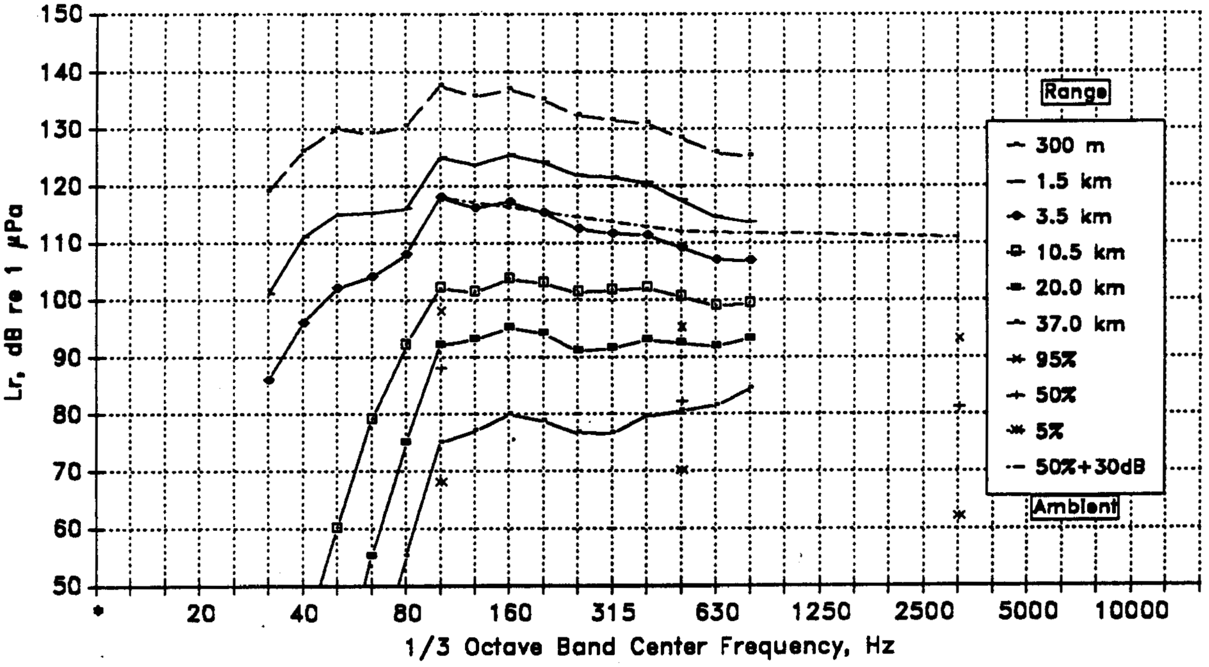


FIG. E.11 AIR GUN ARRAY (WESTERN POLARIS) OPERATING IN NORTON BASIN
Surface Layer Conditions

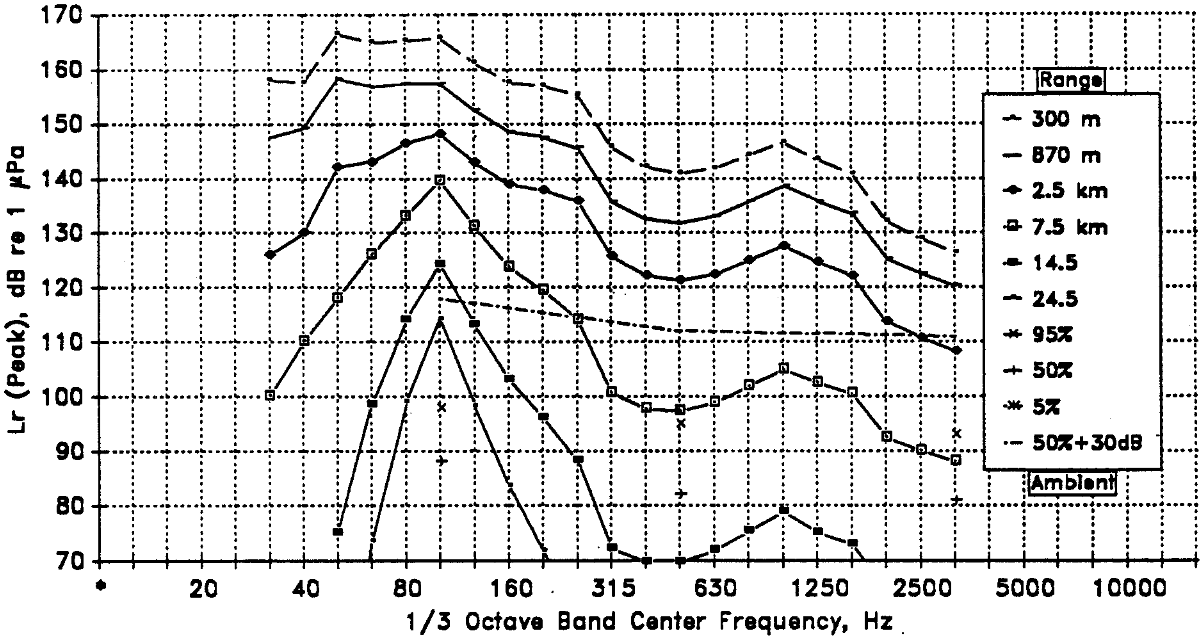


FIG. E.12 DRILLSHIP (EXPLORER II) OPERATING IN NORTON BASIN
Surface Layer Conditions

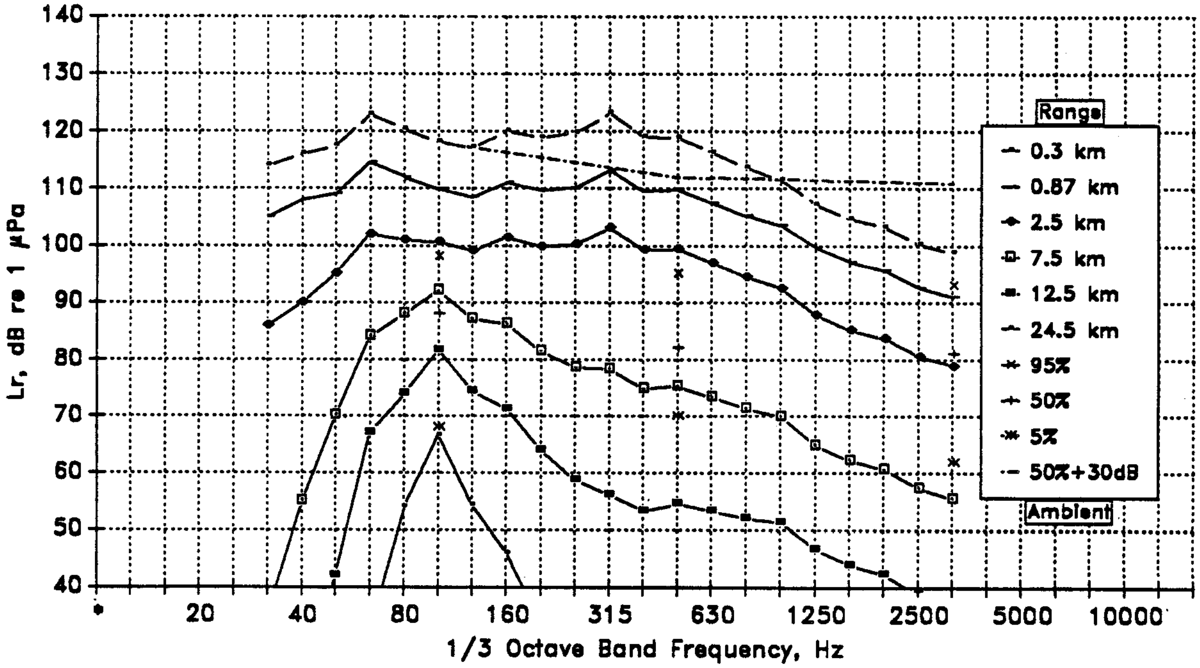


FIG. E13 DREDGE (AQUARIUS) OPERATING IN NORTON BASIN
Surface Layer Conditions

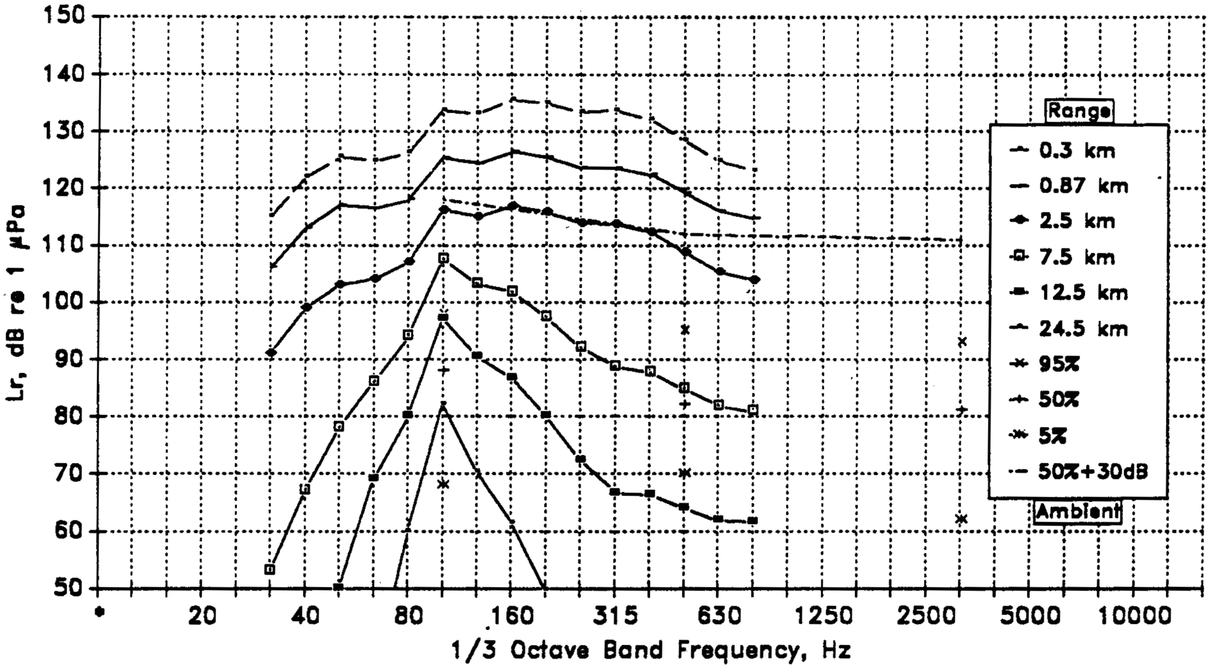


FIG. E.14 TUG/BARGE OPERATING IN NORTON BASIN
Surface Layer Conditions

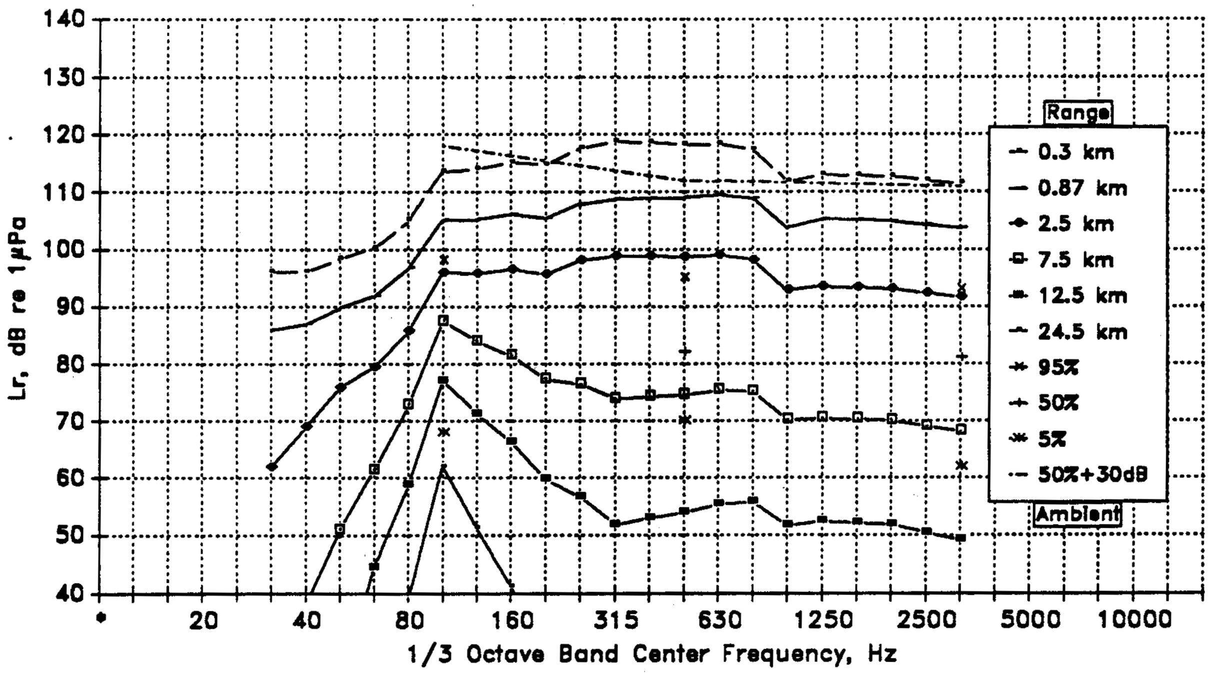


FIG. E.15 TWIN OUTDRIVE (20KT) OPERATING IN NORTON BASIN
Surface Layer Conditions

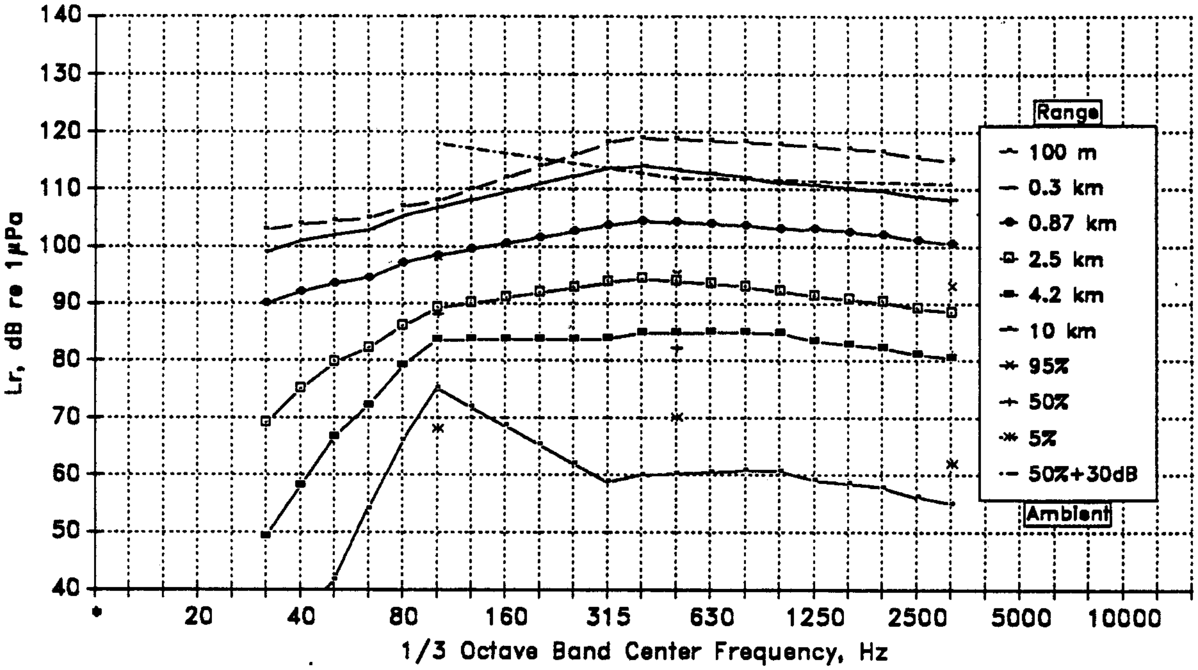


FIG. E16 ICEBREAKER OPERATING IN NORTH ALEUTIAN BASIN
Neutral Gradient Conditions

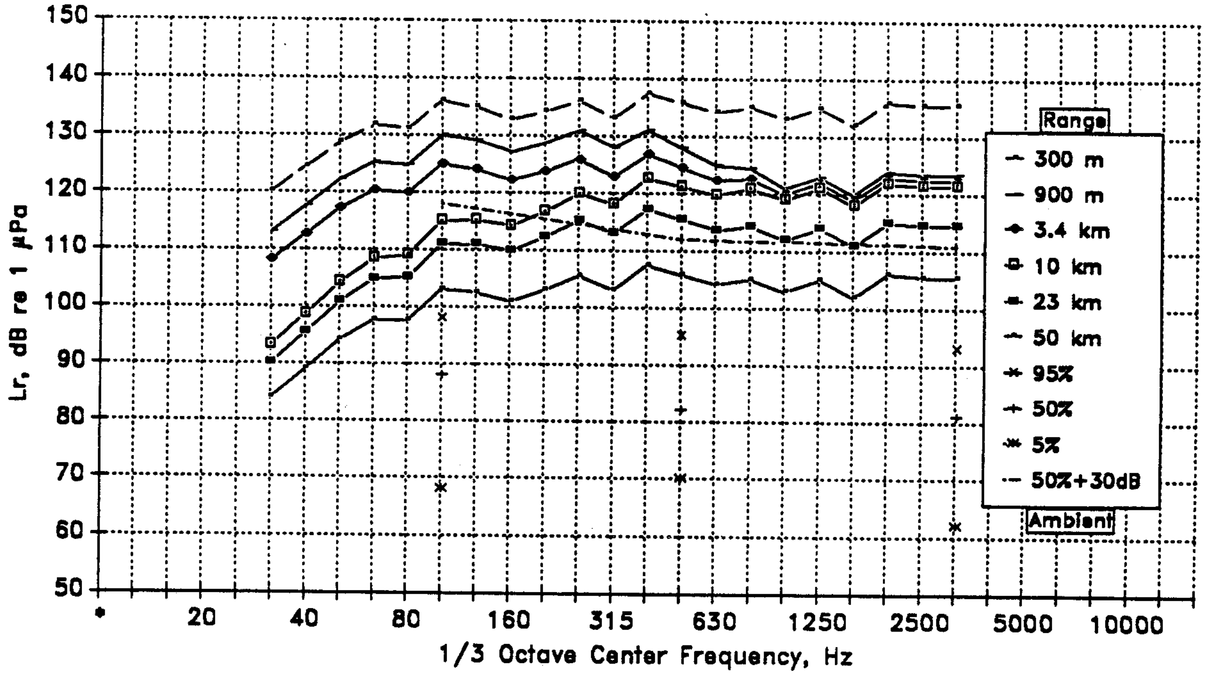


FIG. E.17 DREDGE (AQUARIUS) OPERATING IN NORTH ALEUTIAN BASIN
Neutral Gradient Conditions

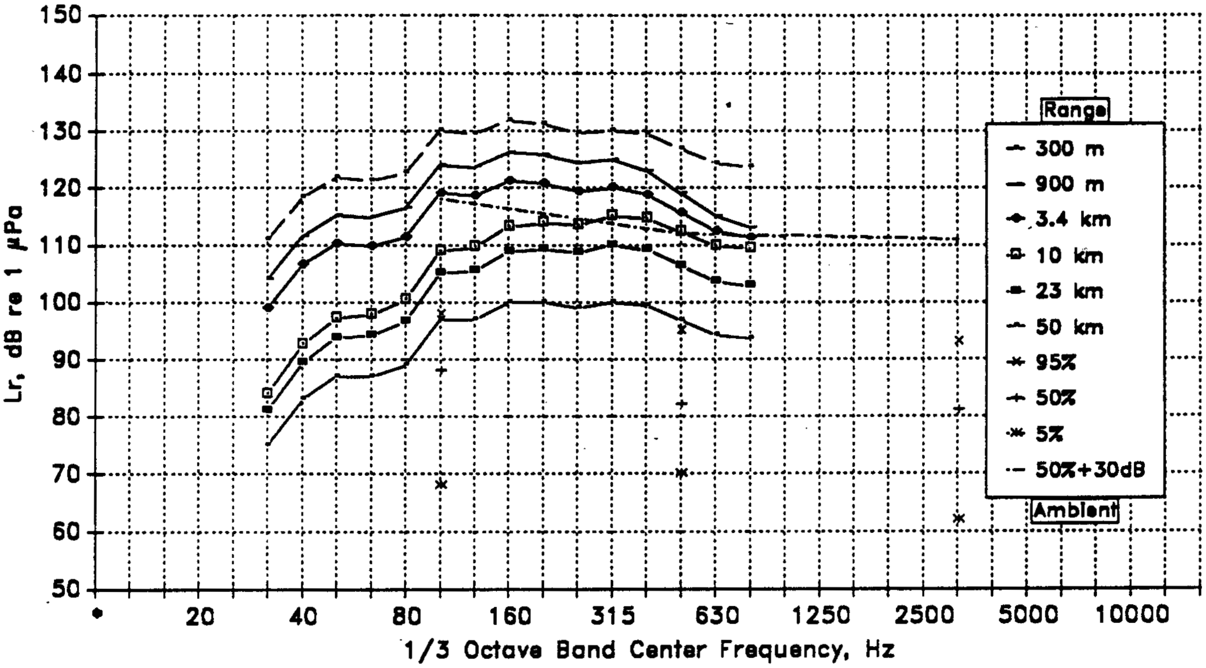


FIG. E.18 AIR GUN ARRAY (WESTERN POLARIS) OPERATING IN NORTH ALEUTIAN BASIN
Surface Layer Conditions

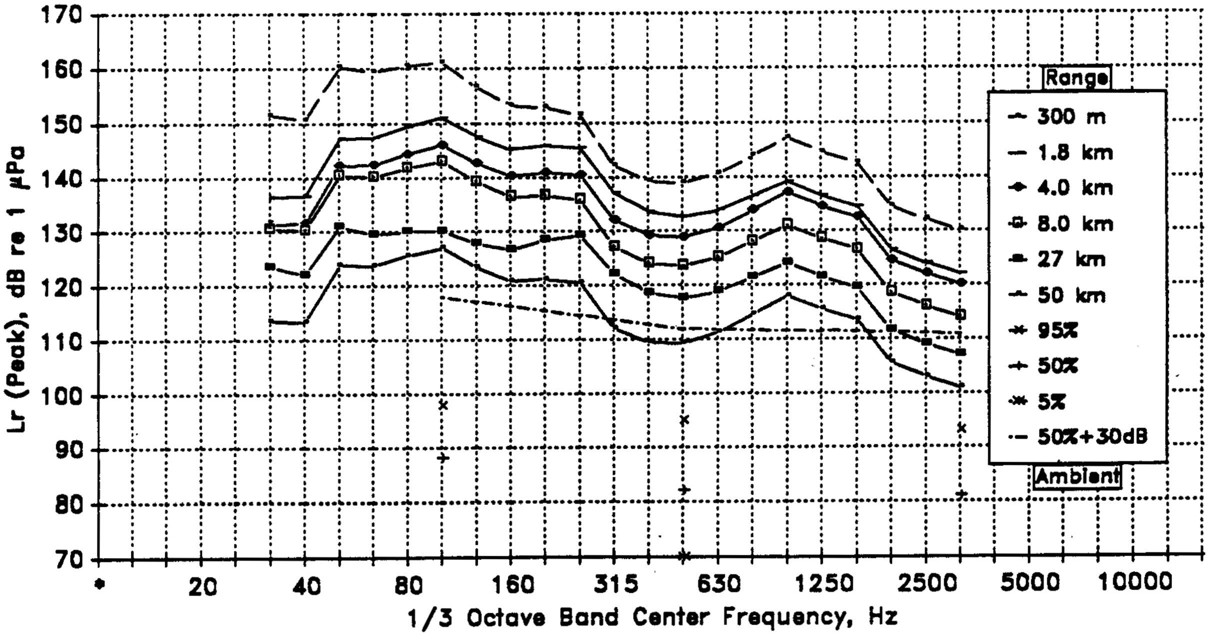


FIG. E.19 DRILLSHIP (EXPLORER II) OPERATING IN NORTH ALEUTIAN BASIN
Surface Layer Conditions

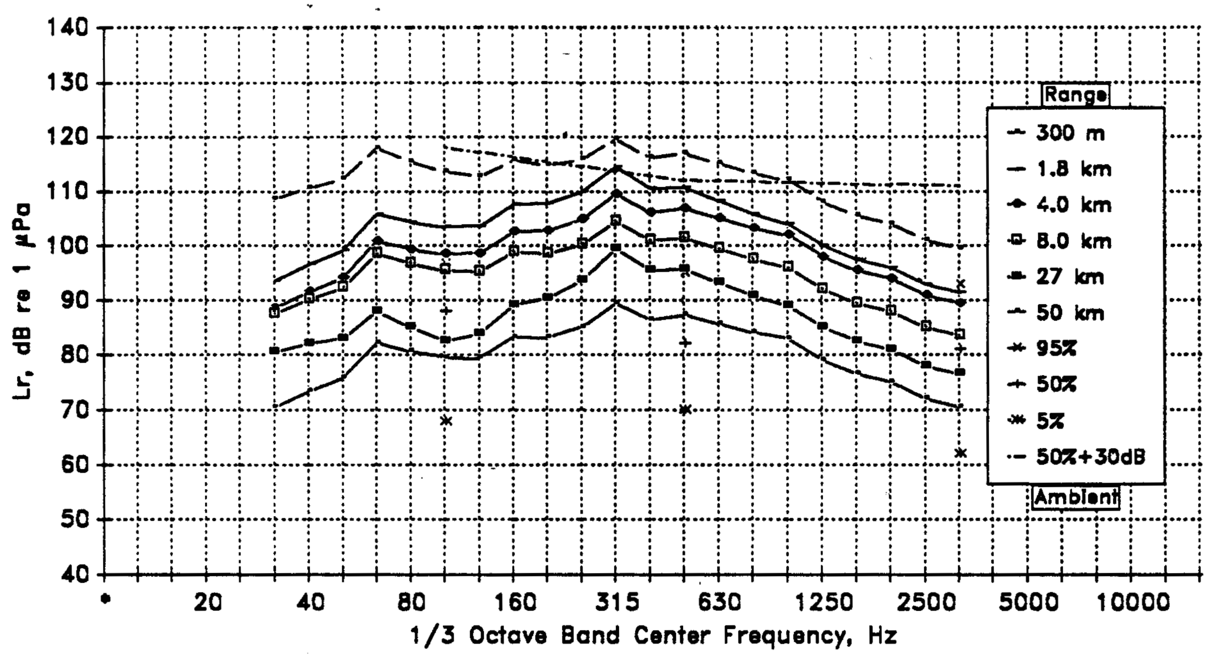


FIG. E.20 DREDGE (AQUARIUS) OPERATING IN NORTH ALEUTIAN BASIN
Surface Layer Conditions

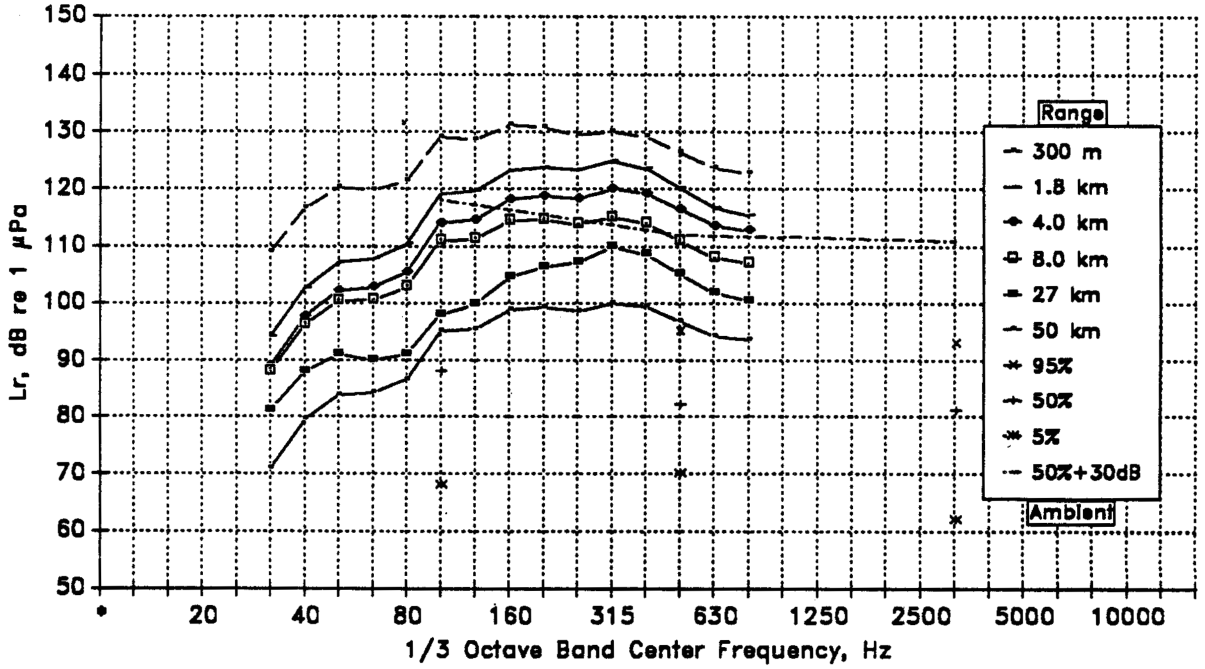


FIG. E.21 TUG/BARGE OPERATING IN NORTH ALEUTIAN BASIN
Surface Layer Conditions

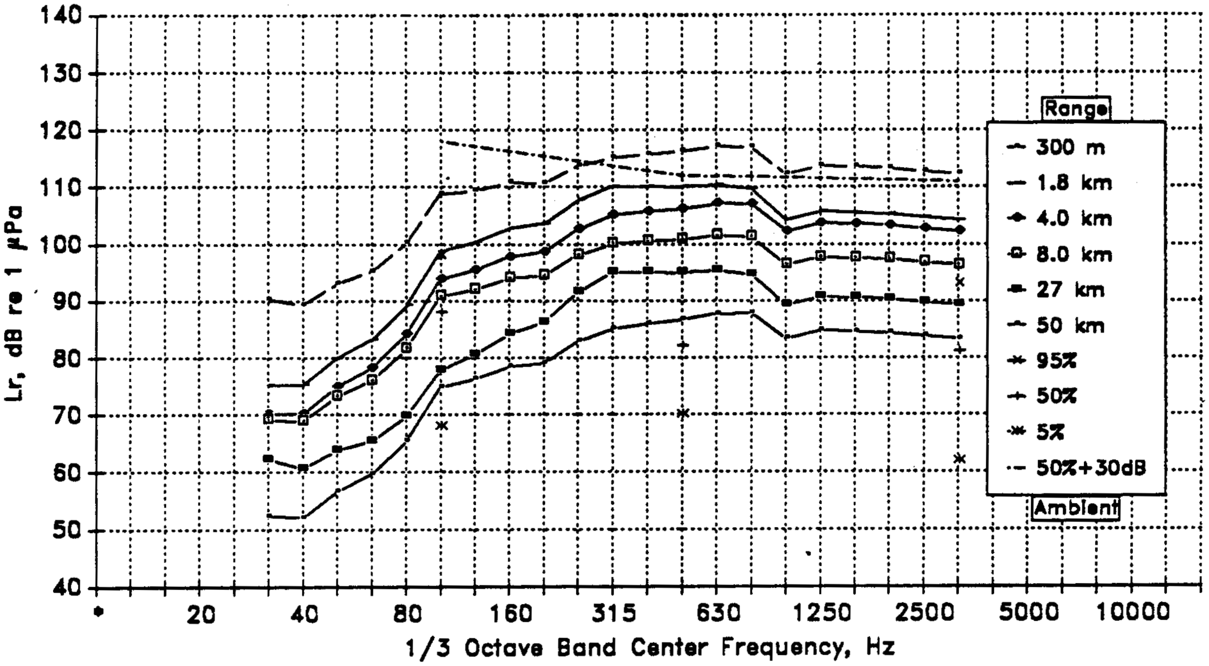


FIG. E.22 TWIN OUTDRIVE OPERATING IN NORTH ALEUTIAN BASIN (2–80hp)
Surface Layer Conditions

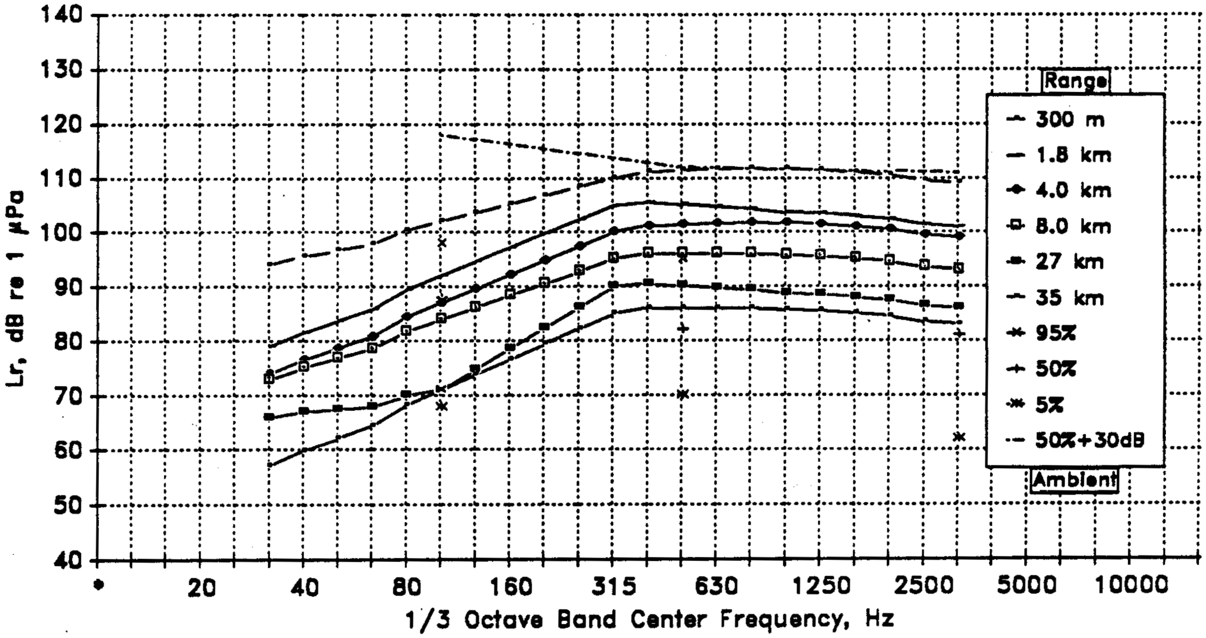


FIG. E.23 TRAWLER (10KT) OPERATING IN THE NORTH ALEUTIAN BASIN
Surface Layer Conditions

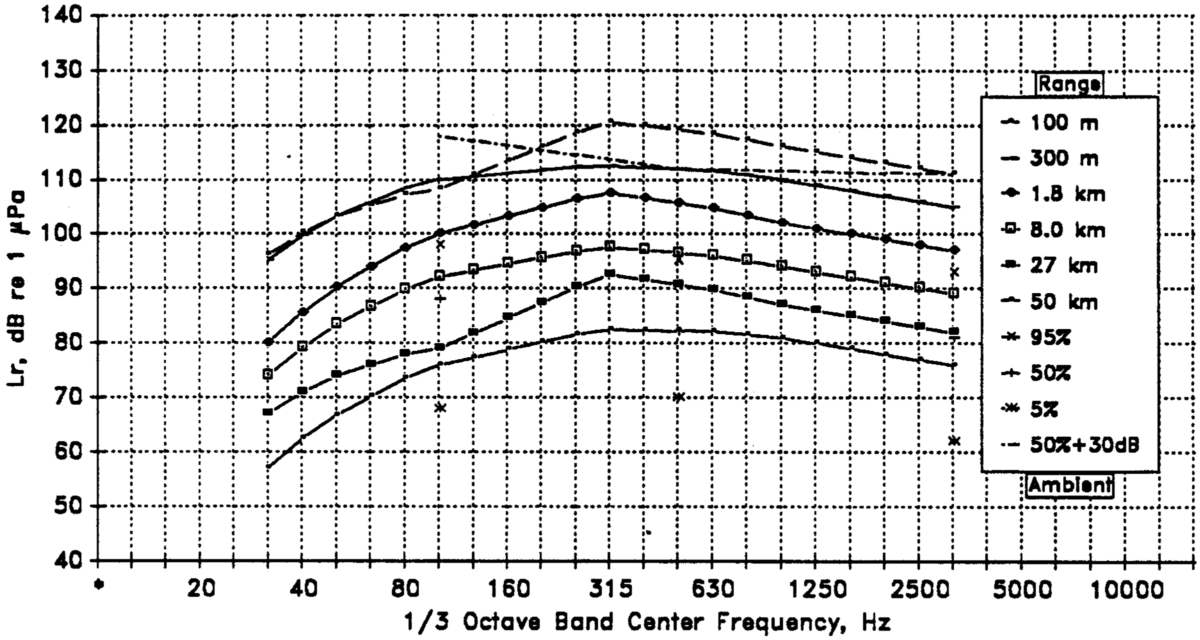


FIG. E.24 LARGE TANKER TRANSITING SHUMAGIN AREA
Neutral Gradient Conditions

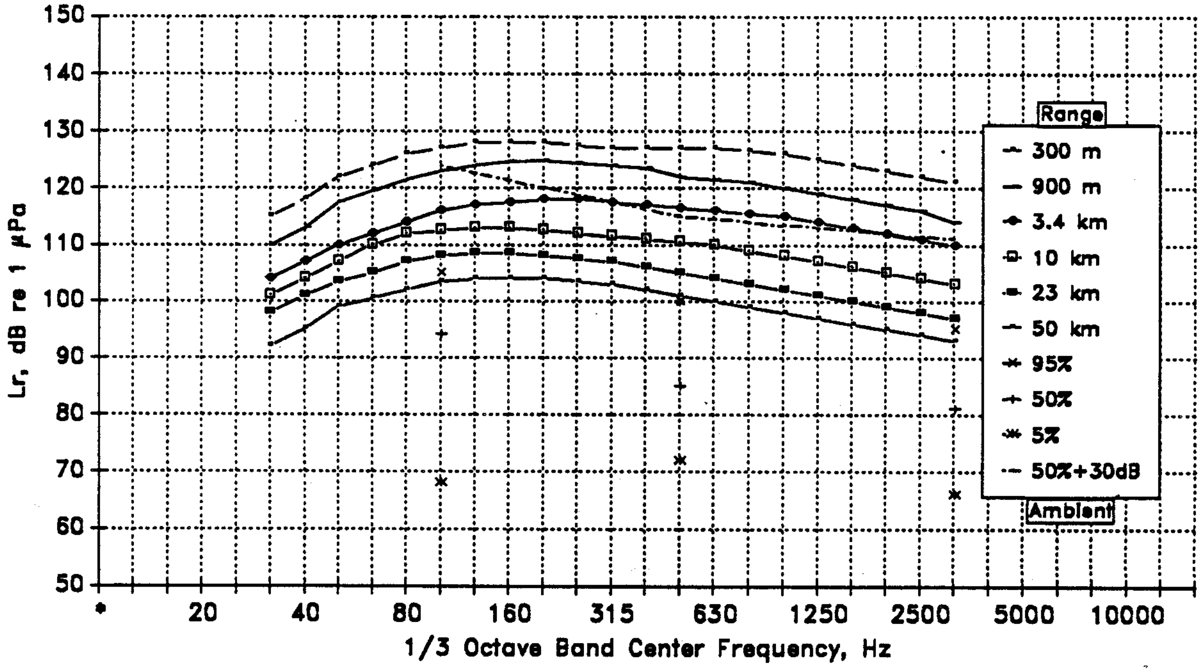


FIG. E.25 LARGE TANKER TRANSITING SHUMAGIN AREA
Surface Layer Conditions

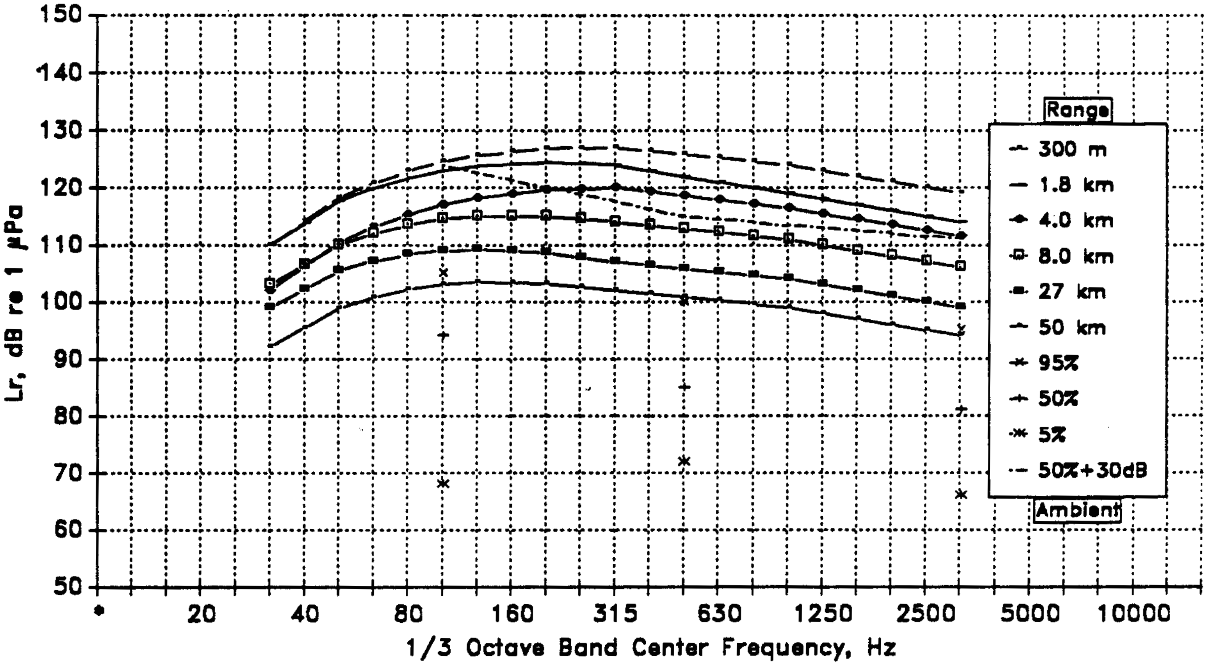
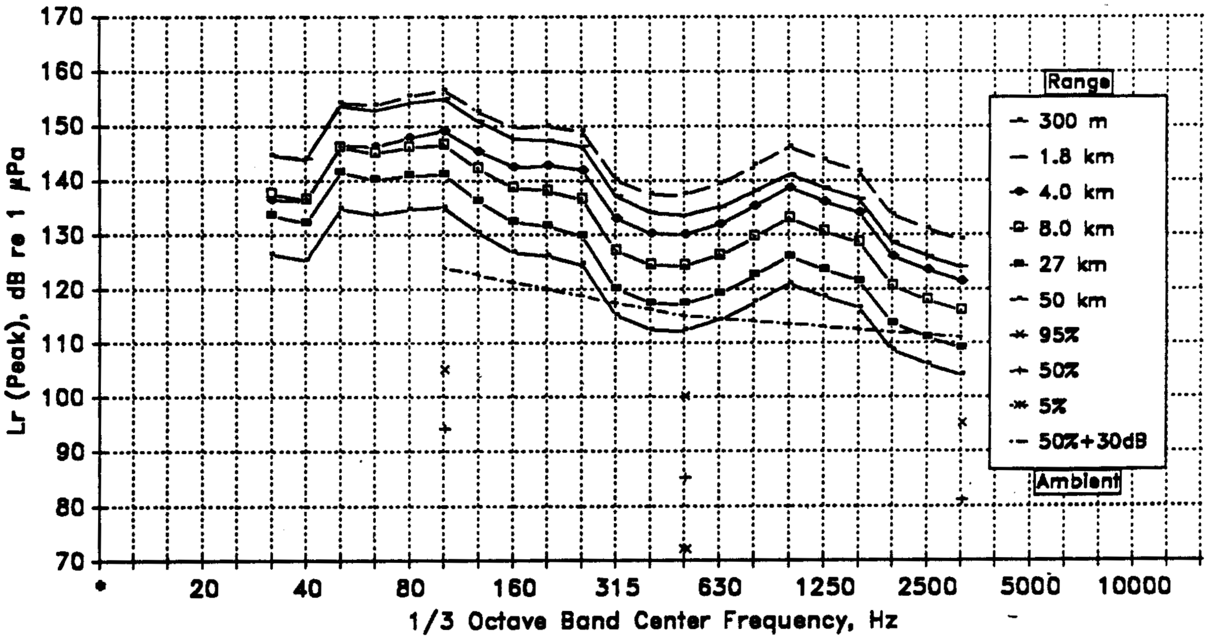


FIG. E.26 AIR GUN ARRAY (WESTERN POLARIS) OPERATING IN SHUMAGIN AREA
Surface Layer Conditions



APPENDIX F:

SCIENTIFIC NAMES OF MARINE MAMMALS MENTIONED IN THIS REPORT

Toothed Whales	*Odontocetes*
Narwhal	*Mondon monoceros*
White Whale	*Delphinapterus leucas*
Killer Whale	*Ocinus orca*
False Killer Whale	*Pseudorca crassidens*
Pacific White-Sided Dolphin	*Lagenorhynchus obliquidens*
Bottlenose Dolphin	*Tursiops truncatus*
Common Dolphin	*Delphinus delphis*
Risso's Dolphin	*Grampus griseus*
Boutu (Amazon River Dolphin)	*Inia geoffrensis*
Short-finned Pilot Whale	*Globicephala macrorhynchus*
Long-finned Pilot Whale	*Globicephala melaena*
Dall's Porpoise	*Phocoenoides dalli*
Harbor Porpoise	*Phocoena phocoena*
Sperm Whale	*Physeter catodon, P. Macrocephalus*
Baird's Beaked Whale (N. Pac. Bottlenosed)	*Berardius bairdii*
Goosebeak Whale (Cuvier's Beaked Whale)	*Ziphius cavirostris*
Stejneyer's Beaked Whale	*Mesoplodon stejnegeri*
Baleen Whales	*Mysticetes*
Fin Whale	*Balaenoptera physalus*
Blue Whale	*Balaenoptera musculus*
Minke Whale	*Balaenoptera acutorostrata*
Sei Whale	*Balaenoptera borealis*
Humpback Whale	*Megaptera novaeangliae*
Gray Whale	*Eschrichtius robustus*
Bowhead Whale	*Balaena mysticetus*
Northern Right Whale	*Eubalaena glacialis*
Southern Right Whale	*Eubalaena australis*
Hair or Earless Seals	*Phocids*
Ringed Seal	*Phoca hispida*
Bearded Seal	*Erignathus barbatus*
Ribbon Seal	*Phoca fasciata*
Harbor Seal	*Phoca vitulina*
Largha or Spotted Seal	*Phoca largha*
Harp Seal	*Pagophilus groenlandicus*
Elephant Seal	*Mirounga angustirostris*
Grey Seal	*Halichoerus grypus*
Fur Seals and Sea Lions (Eared Seals)	*Otariids*
Northern Fur Seal	*Callorhinus usinus*
Cape Fur Seal	*Arctocephalus pusillus*
Steller Sea Lion	*Eumetopias jubata*
California Sea Lion	*Zalophus californianus*
Walrus	*Odobenus rosmarus*
Sea Otter	*Enhydra lutris*
Polar Bear	*Ursus maritimus*