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Outer Continental Shelf Environmental Assessment Program

Proceedings

Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting

February 7-8, 1989
Anchorage, Alaska

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Minerals Management Service
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OCS Study, MMS 89-0041

Proceedings of the

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Edited by

LAURIE E. JARVELA and LYMAN K. THORSTEINSON

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Preface

In 1974, in response to then President Nixon's order to gain self-sufficiency in meeting the Nation's energy needs, the Bureau of Land Management (BLM), U.S. Department of the Interior, announced an accelerated schedule that proposed 21 Outer Continental Shelf (OCS) oil and gas lease sales. At the time, the Alaskan continental shelf, comprising 74 % of the total area of U.S. continental shelves, was by far the Nation's largest unexplored, or "frontier," area. As a consequence, Alaskan sales were prominent in the schedule.

As part of the Alaska OC S leasing program, the BLM entered into a basic agreement with the National Oceanic and Atmospheric Administration (NOAA) to establish the Outer Continental Shelf Environmental Assessment Program (OCSEAP), whose role was to conduct environmental studies in areas identified for potential oil and gas development. OCSEAP was complemented later by BLM socioeconomic studies and endangered whales programs. The programs provide information used in preparation of environmental impact statements for leasing and post-sale decisions. OC SEAP's activities have included review of existing data, planning and management of original studies in all aspects of marine science, and transfer of information to users via a variety of meetings and workshops. The BLM-sponsored programs have played essentially the same role in its sphere of interest.

Considerable evolution of the Alaska OCS leasing program has occurred during the past 15 years. In 1982, the Minerals Management Service (MMS) was formed within the Department of the Interior and assumed responsibility for federal offshore leasing and related studies. Moreover, with the bulk of frontier area sales now having occurred and requirements for basic information on living resources having largely been met for leasing decisions, the MMS has assumed a progressively greater role in the direct management of selected portions of the Alaska environmental studies program, most notably with respect to endangered species and monitoring studies. The maturation of the Alaska studies program is also reflected in its diminished scope, resulting from the lack of commercially viable petroleum discoveries thus far in all but the Arctic region, and the aforementioned shift in programmatic emphasis from leasing to post-leasing activities. The Alaska OCS leasing program is presently administered by the MMS Alaska OCS Region Office, while OCSEAP is managed by the Ocean Assessments Division of the National Ocean Service. Both offices are located in Anchorage, Alaska.

The Gulf of Alaska/Cook Inlet/North Aleutian Basin Information Update Meeting took place at the Clarion Hotel, Anchorage, on 7-8 February 1989. The main purpose of the meeting was to bring invited experts together with the staffs of MMS and NOAA, as well as other interested parties, in order to present and discuss current information on selected topics relevant to the geographic areas of interest. The information will be used by MMS to prepare draft environmental impact statements and other decision documents for scheduled sales in the North Aleutian Basin and Gulf of Alaska region, which includes several planning areas. The meeting was organized into six technical sessions (Fisheries, Socioeconomic, Marine Mammals, Marine Birds, Coastal Ecosystems, and Oil Weathering and Effects), each of which was composed of formal presentations followed by question-and-answer periods.

Written summaries of the speaker's presentations form the body of this report. An introductory section (not part of the meeting) is included to develop a perspective for the emphases of the studies conducted in the planning areas under consideration. A background section that briefly describes OCS leasing activities in the area of interest and additional sources of information is appended for those readers unfamiliar with the Alaska OCS leasing program. A list of speakers and meeting attendees also is appended.

Acknowledgments

Many individuals contributed to the planning and conduct of the North Aleutian Shelf/Gulf of Alaska Information Update Meeting, as well as to the preparation of this document. Special thanks go to the invited speakers for their oral and written contributions. We also appreciated the lively and informative interchange generated by members of the audience, who responded to the speakers' presentations with many perceptive questions. From the Minerals Management Service, we thank Jerry Imm and Fred King for presenting introductory remarks and Dale Kenney for assistance in meeting planning and publicity. We greatly appreciate the efforts of Catherine and Anthony Mecklenburg of Point Stephens Press, who melded a packet of manuscripts into a coherent and attractive document. Finally from our office, we thank Jawed Hameedi, who offered advice throughout this project and presented introductory remarks at the meeting; Cheri Hendren, for her attention to numerous administrative details; Karella Gumppert, for handling numerous typing jobs; and Carrie Schoonmaker, for acting as meeting hostess.

Lyman K. Thorsteinson and Laurie E. Jarvela

Table of Contents

List of Figures

Figure		Page

List of Tables

Chapter 1

Introduction

LAURIE E. JARVELA and LYMAN K. THORSTEINSON
NOAA, National Ocean Service, Ocean Assessments Division, Alaska Office, 222 W. Eighth Avenue, #56, Anchorage, Alaska 99513-7.543

The Gulf of Alaska, Cook Inlet, and North Aleutian Basin (GOA/CI/ NAB; Fig. 1.1) are areas in which federally sponsored Outer Continental Shelf (OCS) oil and gas leasing has taken place over the past 12 years. Exploratory drilling has occurred in the former two planning areas and is anticipated shortly in the NAB area. Furthermore, additional leasing is anticipated in all of the areas. As part of the OCS leasing and development process the Minerals Management Service (MMS) identifies potential socioeconomic effects, ocean use conflicts. and environmental effects associated with planned oil and gas development, assesses such issues, prepares program documentation, applies preventive or mitigative measures to minimize adverse effects of oil and gas development, and monitors development activities.

A key requirement of the OCS oil and gas leasing process is the availability of the information needed for informed assessments. This has resulted in the conduct of a large number of studies addressing a variety of issues in the GOA/CI/NAB lease planning areas over more than a decade. These studies have addressed:

- natural hazards
- oil spill fate and effects on biota and habitats
- commercial fish and shellfish and associated fisheries
- important habitats
- marine birds and mammals
- endangered species
- socioeconomic effects of OCS-related development

Many information needs have been satisfied as a consequence of studies conducted for past sales. However, given the ongoing OCS oil and gas leasing and industry activity, there is a continuing need to update existing information (e. g., the present status of commercial fisheries) and to selectively acquire new information (e.g., in the Shumagin Planning Area, where little work had been done previously), Thus there have been—albeit at a reduced level—OCS-related studies under way in these planning areas in recent years. The GOA/CI/NAB Information Update Meeting was a forum to present the results of more recent MMS/OCSEAP-sponsored studies as well as relevant information acquired by state and federal management agencies. In the following paragraphs we attempt to lend a general perspective to the summaries of the meeting presentations that follow by relating them to current issues and federal OCS oil and gas program needs in the geographic areas of interest.

The salmon, crabs, groundfish, and herring in the Gulf of Alaska and southeastern Bering Sea are the basis for lucrative regional commercial fisheries supporting local communities and fishermen from more distant areas. Many species are also heavily used for subsistence. The importance of the fisheries and fishery-related issues is reflected both in the great emphasis given to them in past and ongoing studies by state and federal agencies and in the preponderance of fish and fishery-related presentations at the Information Update Meeting.

Until recently. little was known about fish use of shallow nearshore habitats along the north side of the Alaska Peninsula. The meager data— mainly from commercial fisheries catches and exploratory fishing conducted 20 years ago to study the seaward migration of sockeye salmon — suggested that this was an important seasonal habitat for many migratory finfish species and an area of juvenile residency for others. Data with better temporal-spatial resolution were needed to adequately assess potential effects of development from the nearby North Aleutian Basin planning area, so an intensive 2-Year survey of the coastal waters was implemented. This study provided considerable new information on the

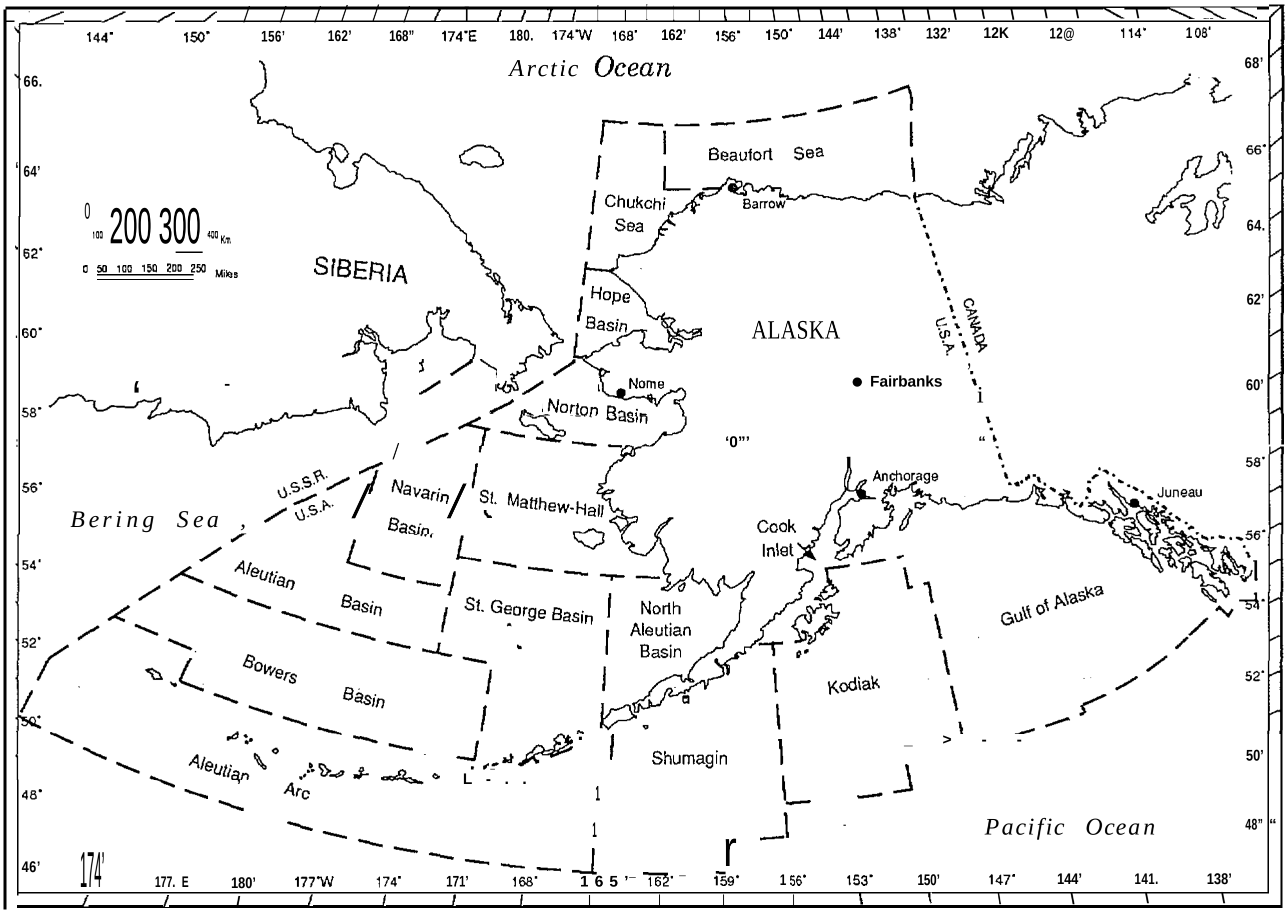

Figure 1.1 —Alaska OCS Region oil and gas lease planning areas.
(Adapted from OCS Information Report MMS 87-0016.)

timing and extent of use of the waters inside the 50-m isobath by outmigrant Pacific salmon, other commercially important species, and forage fish.

The Pacific herring roe fishery in the Togiak area of Bristol Bay presently is the richest such fishery in Alaska. The fishery occurs in the NAB northeast of the Sale 92 oil and gas lease blocks. Little is known about the early life history of herring in the Bering Sea. Thus it is difficult to assess their potential vulnerability to oil spills resulting from Sale 92 activities. In 1988 MMS/OCSEAP implemented a herring study in Auke Bay, southeastern Alaska, to evaluate habitat use and larval and juvenile herring growth and condition as a function of prey availability. This work, conducted in concert with APPRISE, a multiyear, multidisciplinary investigation of the association of primary production and subsequent recruitment of commercial fish, is described herein. It forms the basis for a herring study in the Port Moller area of Bristol Bay that will begin in 1989, That study is one element of a four-element fishery oceanography investigation, also including king crabs, Pacific salmon, and physical oceanography.

Field and laboratory studies of larval and juvenile king crabs conducted at Auke Bay during the past 2 years have provided a variety of insights about their behaviors and habitat preferences, complementing earlier work on king crab food habits and energetic performed in the field along the north side of the Alaska Peninsula. The OCSEAP-sponsored research on the food habits of king crabs in Bristol Bay is the only such Alaskan work we are aware of that incorporated an examination of clearance rates of various prey items as part of the food habits analysis and, in addition, immunological assays to identify crab prey not amenable to visual analysis. As with the herring study, the results of these and other studies not described at the Information Update Meeting will form the basis for site-specific investigations of the early life histories of the king crabs in the vicinity of Port holler.

Red king crab and *bairdi* Tanner crab stocks in the eastern Bering Sea are presently in a depleted condition. Recent crab fishing effort has been focused largely on *opilio* Tanner crabs and brown and blue king crabs. Management agencies have been conducting a variety o-f investigations to determine the causes of the precipitous drops in red king crab and *bairdi* Tanner crab abundances. Overfishing, disease. multiple crab pot lifts, and other factors have been implicated; however, the evidence is still equivocal. The burgeoning ground fishery in the southeastern Bering Sea may be a contributing factor, Large numbers of crabs are taken as bycatch when trawling for groundfish. Capture and handling mortalities of crabs of many age classes may be significant. The trawl fishery for Pacific cod in the shallow waters near Port Moller is of particular concern to Bering Sea crab fishermen. The area is suspected to be nursery habitat for juvenile red king crabs, and the fishermen fear that intensive trawling may adversely affect the habitat and resident crabs.

An ongoing MMS/OCSEAP study addresses the potential effects of oil spills on outmigrant salmon smelts in the Bristol Bay area. Information on the timing and migration routes of the various stocks of smelts transiting the bay during spring and summer is sparse. This is mainly due to difficulties associated with stock identification, varying freshwater residence periods of different stocks. environmental influences on the timing and rate of migration of stocks. and intermingling of stocks in marine waters. An oil spill's effects may be much different if, for example, it affects a single stock instead of a mixture of stocks. The former case is assumed to be more serious. as impact would be more concentrated; in the latter case it would be dispersed among several stocks. This issue is being addressed through a genetic stock identification study of Bristol Bay salmon, During the past 2 years tissues have been collected from adult fish in the major drainages around Bristol Bay. The results of ` 'genetic indexing" of chum and sockeye salmon populations were discussed at the meeting. This work is intended to lead to a capability to identify the river of origin of fish by their electrophoretic ' 'fingerprints." During 1989 some initial sampling of smelts in Bristol Bay is anticipated to test the approach. The genetic stock identification investigation is an element of the fishery oceanography study.

The Alaskan walleye pollock fishery is one of the richest in the world in terms of catch size and earnings, During the past few years it has evolved from a foreign-dominated fishery to one dominated by joint ventures between Americans, who catch the fish, and foreigners. who process the fish and transport and market the products. The management of the pollock fishery is hindered by the lack of information on the stock composition of populations fished, reliability of biomass estimates, and, in Shelikof Strait. the determinants of recruitment success. To address this need. NOAA's Environmental Research Laboratory and National Marine Fisheries Service and other collaborators have been conducting a multiyear, multidisciplinary study entitled Fishery Oceanography Coordinated Investigations (FOCI). FOCI is presently concentrating on the relationships between environmental conditions and the spawning success and survival of larval and juvenile pollock. Field work has been conducted mainly around the western end of Shelikof Strait. where the bulk of the Gulf of Alaska pollock population is thought to spawn. FOCI "s work is germane to OCS-related assessments due to the pollock's dominant position in regional ecosystems and the economic importance of the fishery.

MMS has sponsored numerous socioeconomic and sociocultural analyses in the GOA/CI/NAB area. One element of the program has been the analysis of regional fisheries and their impacts on local communities. The dynamic nature of the fisheries strongly influences regional employment and a host of other factors. Such effects must be understood in order to evaluate properly the incremental changes induced by OCS activities on local communities in the region adjacent to and beyond the GOA/CI/NAB planning areas, Similar] >-, other factors operate to influence the sociocultural and socioeconomic fabrics of regional communities and they must be known in order to fit OCS effects into the broader social context. Alaska is unique among the states experiencing OCS activity in the importance of subsistence as an economic force and one having a legal basis through the Alaska National Interest Lands Conservation Act, Subsistence hunting and fishing are important activities in virtually all coastal towns and villages in the GOA/CI/NAB region. As such. potential effects of OCS development on subsistence resources are routinely incorporated into the assessments prepared for leasing actions. Several presentations at the Information Update Meeting addressed the socioeconomic aspects of OCS development in the area of interest, Marine mammals are conspicuous inhabitants of the GOA/CI/NAB region. Therefore, they were the subject of numerous investigations by MMS/OCSEAP prior to initial lease sales in the region. However, much of that information is now dated (e.g., northern sea lion and sea otter censuses) and certain basic information needs remained, particularly those pertaining to endangered whales. Two recent OCSEAP-sponsored studies described at the Information Update Meeting address those shortcomings. In 1985 MMS/OCSEAP implemented a multiyear investigation of marine mammal abundance and habitat use in the waters along the north and south sides of the Alaska Peninsula. That study was complemented by an investigation of sea otter movements employing radio-tagged animals, The latter investigation was intended to supply information applicable to a sea otter-oil spill interaction model specifically tailored for assessments of effects of a spill on the large otter population residing along the north side of the peninsula, Both studies included evaluations of suspected seasonal movements of animals between the north and south sides of the Alaska Peninsula.

State of Alaska and NOAA resource management agencies are conducting marine mammal investigations that complement MMS/OC SEAP studies. Especially noteworthy are those concerned with northern fur seals and Steller sea lions. Both of these species, which are abundant in the GOA/CI/NAB region, are experiencing population declines, the causes of which are currently not known. Interactions with commercial fisheries are thought to play an important role in the declines. The depressed states of these populations likely will have major impacts on the management of both mammals and fisheries in the region for many years, especially if they are given threatened or endangered status under the Endangered Species Act. There is a belukha whale population in Cook Inlet that appears to be isolated from the larger population in the Bering Sea and Arctic Ocean. Relatively little is known about the Cook Inlet belukha population—its size, habitat use, or other attributes. Experts from the Alaska Department of Fish and Game and NOAA National Marine Mammal Laboratory presented overviews of the current status of these populations at the Information Update Meeting.

The coastal waters along the north side of the Alaska Peninsula and Unimak Pass are characterized by intensive seasonal use by numerous marine mammal, seabird, fish, and shellfish species. It had been hypothesized that observed patterns of utilization were related to enhanced primary productivity. In short, *in situ* productivity was thought to be augmented by particulate organic matter exported from nearby estuaries—most notably, eelgrass from Izembek Lagoon and, to a lesser extent, from Port Moller. The coastal habitats are potentially vulnerable to oil spills and other perturbations if OCS oil and gas production and transportation occur in the region. Therefore, two ecological investigations were conducted in the area during the past few years. This work, described at the Information Update Meeting, has resulted in a more refined knowledge of the dominant physical and biotic attributes, the dynamics of their interactions, and their roles in ecosystem structure and function of the coastal NAB and Unimak Pass.

"Effects" studies include laboratory and field experiments to ascertain the toxicological or behavioral effects of chemicals, noise, and other perturbing agents on biota. Two recently completed experiments that were discussed at the Information Update Meeting concerned black brant and salmon, animals that are seasonally abundant in the region under consideration. During summer 1988, a field experiment to determine the reactions of migrating salmon to a plume of dissolved petroleum was conducted. The results of this work have application to assessments of oil spill effects on salmon stocks in Bristol Bay and elsewhere. The second study involved controlled experiments on the responses of staging black brant to several types of aircraft flown at selected altitudes and distances from flocks of the birds. Information from studies such as this is used to develop stipulations for aircraft operations in the vicinity of important waterfowl concentration areas such as Izembek Lagoon and the large seabird colonies in the Gulf of Alaska. Each of the above efforts reflects the sophistication and innovation required to develop and implement experiments that can quantitatively determine the responses of free-ranging organisms to anthropogenic perturbations under field conditions in which the animals' responses maybe subtle, variable, or not directly observable.

Investigations ofoil spill fates form akeypart of the Alaska OCS leasing program. The results of these studies are heavily used in assessments of effects of hypothetical oil spills presented in environmental impact statements. Oil spill fate investigations have delved into the physical and chemical transformations of crude oil with time, its transport and dispersion by ocean currents, winds, and tides, and its interactions with ice and coastal beaches. The results of these studies have been incorporated into several progressively more refined. linked models that are used as predictive tools by MMS for assessments employing a suite of spill scenarios and launch points. The most recent refinement of the system was the development of a model linking a pelagic spill transport model to the beach-the coastal oil smear model. The field evaluation of the smear model in the North Aleutian Basin, described at the Information Update Meeting. is summarized in this report.

In certain circumstances, the effects of spilled oil on biota may be mitigated through use of dispersants. An example of such an application would be the dispersal of an oil slick approaching a seabird colony. To be effective, however, dispersant use must be timely because degradation processes acting on oil decrease the effectiveness of the dispersant. The Alaska Regional Response Team has developed guidelines for dispersant use in selected areas to facilitate quick decisions. The development of the guidelines for Prince William Sound and those proposed for lower Cook Inlet was described in the final presentation at the Information Update Meeting. a summary of which concludes the body of this document.

Chapter 2

Fish Use of Inshore Habitats Along the North Side of the Alaska Peninsula

JONATHAN P. HOUGHTON and JOHN S. ISAKSON*
Pacific Environmental Technologies, Inc., 170 West Dayton Street, Edmonds, Washington 98020

2.1 INTRODUCTION

Anticipation of oil and gas lease sales established a need for a greater understanding of the interrelationships of various components of the rich marine ecosystem of the eastern Bering Sea. The Outer Continental Shelf Environmental Assessment Program (OCSEAP) sponsored studies of many of these ecosystem components and identified a need for a greater understanding of the importance of the nearshore zone and embayments along the north side of the Alaska Peninsula for demersal and pelagic fish,

This research was designed to describe the species composition and abundance of demersal and pelagic fish assemblages in poorly studied nearshore. intertidal. and estuarine habitats of the North Aleutian Shelf (NAS) area. The 2-year study (Research Unit 659) was conducted by Dames & Moore in association with the Fisheries Research Institute (FRI), University of Washington (Isakson et al. 1986). A companion study (RU 658) explored the trophic relationships and processes of the nearshore ecosystem in the southern part of our study area. from Cape Seniavin to Cape Mordvinof (Truett 1987).

2.2 METHODS

The general approach of this study was to allocate the limited resources of sampling effort and time to maximize the collection of new information on the movement and abundance of commercially significant finfish in inshore habitats that are considered to be most vulnerable to perturbation from oil and gas development. The study area extended from False Pass to Ugashik Bay in waters to about 30 m deep. It encompassed three estuaries (Ugashik Bay, Port Heiden, and Port Moller) and a coastal lagoon (Izembek Lagoon), as well as exposed coastal and inshore habitats (Fig. 2.1).

In 1984, sampling was focused at depth-stratified stations (5, 10, 20, and 30 m) on six transects spaced throughout the study area to include three with associated embayments and three from exposed beaches. Depending on station characteristics. each was sampled by one or more of the following gear types: purse seine or tow net (targeting pelagic species); otter trawl and beam trawl (targeting demersal fish): beach seine (targeting littoral fish assemblages).

In 1985, only transects off of Ugashik, Port Heiden, Port Moller. and Izembek Lagoon were sampled, A new station was added at all transects and the three stations farthest offshore were stratified by distance offshore (8, 16, and 24 km; in contrast to the depth-stratified approach of 1984). To place more emphasis on pelagic species, only the beach seine, purse seine, and a new gear type (small purse seine) were used in 1985.

Three sampling cruises were undertaken in 1984 (late June to mid-July. late July to mid-August, late August to mid-September), In 1985, one 6-week cruise occurred from mid-June to the end of July. A total of 277 sets of all gear types was made in 1984, and 172 sets were made in 1985. All fish captured were either processed on board or preserved for later analysis.

2.3 RESULTS

Weather and surface sea temperatures were strikingly different in 1984 and 1985. During the three cruises in 1984, generally poor to harsh weather was experienced. while during the single extended cruise in 1985. the weather was generally much calmer. Sea surface temperatures for similar areas and times of

* In memorium

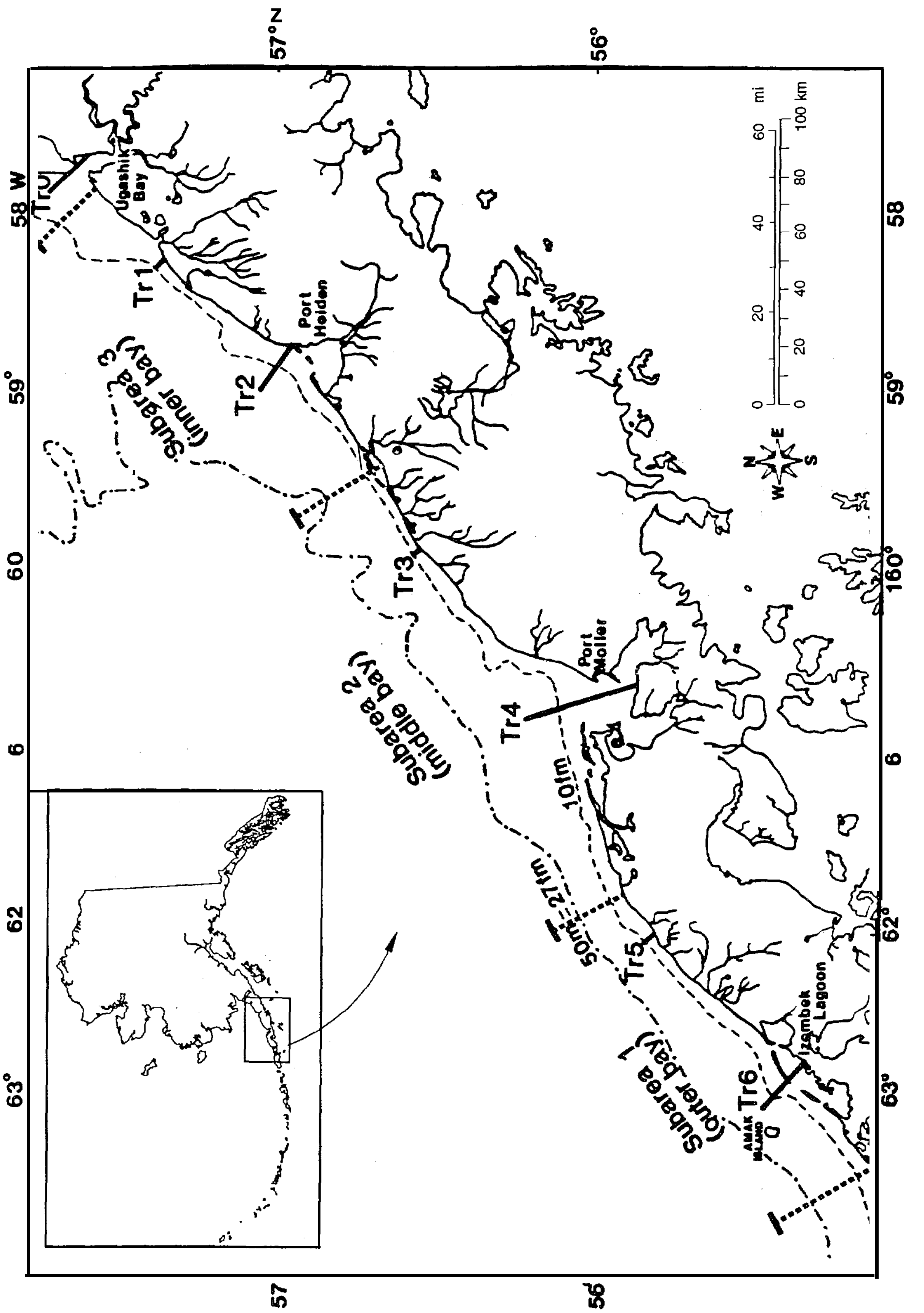

Figure 2.1—Study subareas and transect locations on the north side of the Alaska Peninsula, 1984 and 1985.

year were from 1 to 2 °C colder in 1985 than in 1984. Salinities were quite similar between the two years.

2.3.1 Demersal Fish

Demersal fish communities were dominated. in descending order of abundance. by yellowfin sole (*Limanda aspera*), Pacific cod (*Gadus macrocephalus*), rock sole (*Lepidopsetta bilineata*). Pacific sand lance (*Ammodytes hexapterus*), whitespotted greenling (*Hexagrammos stelleri*). and Alaska plaice (*Pleuronectes quadrituberculatus*; Table 2.1). These species dominants correspond to those reported to typify the demersal fish community of the middle Bering Shelf subarea closest to our study area (Walters and McPhail 1982, reported in Craig 1987) except that walleye pollock (*Theragra chalcogramma*) was not a dominant species in our area and sand lance and whitespotted greenling were not reported in abundance in the more offshore trawls. Yellowfin sole were widely distributed in the North Aleutian Shelf study area, as they are throughout the eastern Bering Sea. They showed no apparent trends except for lower catches (numbers) in Izembek Lagoon compared to Port Moller and a steady overall decline in catch through the sampling period (June-September 1984). Rock sole likewise showed little geographic pattern but had a generally declining capture rate (numbers) over the sampling period.

Otter trawl catches (mean fish weight per trawl) displayed no clear north-south or onshore-offshore trends. However, length-frequency plots from the catches of several species (Isakson et al. 1986) demonstrated patterns of recruitment. growth, and seasonal movement between habitats which correspond to the generalized patterns of spring onshore movement and recruitment suggested by Craig (1987).

2.3.2 Pelagic Forage Fish

By far the most dominant species present in the North Aleutian Shelf was Pacific sand lance. which comprised 62.5% of all fish taken (Table 2.1). Sand lance was the most abundant species in nearshore habitats, the second most abundant (to Pacific codj in the offshore pelagic habitat. and fourth in the demersal habitat. In the earlier 1985 sampling, sand lance appeared to be less abundant in the nearshore habitats of the study area. yet they still were the numerical dominant in beach seine catches and the second most abundant species (to juvenile sockeye salmon. *Oncorhynchus nerka*) in the offshore pelagic habitat (Table 2.2). Densities appeared to be greatest in the inshore waters (inside the 6-m isobath). In large purse seines there was also a general trend toward increased catches nearer shore. Sand lance were widely yet irregularly distributed throughout the study area, with significant concentrations in and outside of Port Moller and in Izembek Lagoon. Sand lance seemed to prefer relatively flat beaches. They were less abundant on inner bay (Ugashik and Port Heiden) transects. These results seem to confirm this species" role as one of, if not the most, important forage fish in this part of the Bering Sea (e.g.. Thomson 1987).

Several size classes of sand lance were evident in catches in 1984, with the smallest cohort recruiting to the beach seine in early August (Houghton 1987). Progressively larger fish were taken in more offshore gear. but this pattern may have been partially a result of gear selectivity.

The second most abundant pelagic nonsalmonid species in both 1984 and 1985 catches was the rainbow smelt (*Osmerus mordax*). Like the sand lance. rainbow smelt were most abundant in nearshore gear. Catch distribution was very patchy with respect to beach slope. substrate, and exposure. In contrast to sand lance. the highest catches were taken on the inner bay transects (inside Ugashik and Port Heiden). Several year-classes were present, with smaller fish more common in the littoral habitats.

The third most abundant fish taken in the pelagic habitat in 1984 was Pacific cod. which was also second in the demersal habitat. While often not considered to be a forage fish. per se. this species, by virtue of its abundance and distribution, is a significant food resource for higher trophic levels in the nearshore study area, Increasing numbers were taken in late summer of 1984. Pacific cod probably occupy a trophic niche in the NAS similar to that of walleye pollock in more offshore areas (e. g., Frost and Low-y 1987. Sanger 1987). In the earlier 1985 sampling, few cod were captured. Whitespotted greenling, Pacific herrring (*Clupea harengus pallasi*), and walleye pollock rounded out the most abundant nonsalmonids encountered in the pelagic habitat in 1984.

Pacific herring were taken in small numbers in all three gear types fished in 1985: however, it is likely that in neither year was sampling conducted early enough to cover periods of peak adult herring abundances in the study area. Recruitment of small herring (37–55 mm) to tow net catches in Port Moller late in 1984 suggested local rearing of herring from spring spawning in Port Moller. Only small numbers of capelin (*Mallotus villosus*) and pond smelt (*Hypomesus olidus*) were taken in these studies. primarily

Table 2. I —Total fish catch by species, North Aleutian Shelf, 1984.*

Species or group	Purse seine	Beach seine	20x9 townet	Otter trawl	Beam trawl	Total (all gears)
Alaska plaice	1	54 (8)	0	460 (6)	5	520 (9)
Arctic cod	1	0	0	1	0	2
Arctic flounder	0	7	3	0	0	10
Arctic lamprey	9	0	4	0	0	13
Bering poacher	2	19	0	357 (7)	2	380
Brightbelly sculpin	0	0	0	5	0	5
Butter sole	0	0	0	20	0	20
Capelin	0	1	0	0	0	1
Chinook salmon juvenile	21	2	3	0	0	26
Chum salmon adult	30	17	0	0	0	47
Chum salmon juvenile	288 (6)	22	32 (4)	0	0	342
Coho salmon adult	0	1	0	0	0	1
Coho salmon juvenile	195 (8)	27	0	0	0	222
Crescent gunnel	7	0	0	12	1	20
Crested sculpin	10	1	1	1	0	13
Dolly Varden adult	2	4	0	0	0	6
Eulachon	0	13	0	9	0	22
Flathead sole	0	0	1	4	0	5
Great sculpin	0	1	0	1	0	2
Kelp greenling	0	1	0	6	0	7
Liparis sp.	0	0	1	5	0	6
Longhead dab	0	2	0	164	1	167
Ninespine sticklebacks	19	3	24 (6)		0	46
Pacific cod	3,007 (1)	83 (6)	4	3,66: (2)	1	6,761 (4)
Pacific halibut	0	1	0	64	1	66
Pacific herring	4	3	742 (3)	1	0	750 (7)
Pacific sandfish	292 (5)	5	28 (5)	44	0	369
Pacific sand lance	1,102 (2)	33,177 (1)	20,043 (1)	954 (4)	0	55,277 (1)
Padded sculpin	0	0	0	3	0	3
Pink salmon adult	6	0	0	0	0	6
Pink salmon juvenile	5	0	0	0	0	5
Plain sculpin	0	4	1	2	0	7
Pleuronectidae	2	0	1	0	0	3
Pond smelt	0	27		0	0	27
Rainbow smelt	34	949 (2)	7,02: (2)	285 (10)	5	8,292 (3)
Ribbed sculpin	0	0	0	11	0	11
Rock sole	5	29	0	1,487 (3)	26 (3)	1,546 (6)
Sail fin sculpin	0	0	0	2	0	2
Sculpin D	0	3	0	5	0	8
Silverspotted sculpin	6	0	0	2	0	8
Snake prickleback	3	4	5 (9)	356 (8)	40 (2)	408 (lo)
Sockeye salmon adult	87 (10)	1	0	0	0	88
Sockeye salmon juvenile	262 (7)	33 (lo)	8	0	0	303
Staghorn sculpin	0	159 (4)	0	40	0	199
Starry flounder	5	106 (5)	15 (8)	77	2	205
Sturgeon poacher	1	1	0	39	0	41
Surf smelt	1	216 (3)	0	1	0	218
Threaded sculpin	0	7	0	318 (9)	7	332
Threespine sticklebacks	3	4	0	0	0	7
Tidepool sculpin	0	0	0	1	0	1
Tubenose poacher	0	14	1	174	3	192
Unidentified cods	163 (9)	0	0	0	0	163
Unidentified smelt	31	14	15 (8)	2	0	62
Walleye pollock	557 (4)	0	0	31	0	588 (8)
Whitespotted greenling	1,090 (3)	35 (9)	7 (lo)	615 (5)	3	1,750 (5)
Wolf eel	6	0	0	0	0	6
Yellowfin sole	19	74 (7)	20 (7)	8,657 (1)	79 (1)	8,849 (2)
Total	7,276	35,122	27,979	17,882	177	88,436
All juvenile salmonids	771	84	43	0	0	898
Number of hauls	71	47	40	117	2	277

* Numbers in parentheses represent ranking of catches

Table 2,2—Total fish catch by species. North Aleutian Shelf. 1985.*

Species or group	Small seine	Purse seine	Beach seine	Total (all gears)
Alaska plaice	0	0	52	52
Arctic flounder	10	0	84	94
Arctic lamprey	2	7	0	9
Capelin	3	106	0	109
Chinook salmon juvenile	2	2	2	6
Chum salmon adult	0	23	2	25
Chum salmon juvenile	758 (2)	403 (3)	3,970 (2)	5,131 (3)
Coho salmon juvenile	52	178 (5)	62	291 (8)
Dolly Varden adult	0	7	2	9
Dolly Varden juvenile	0	40	0	40
Great sculpin	0	1	3	4
Ninespine sticklebacks	0	0	2	2
Pacific cod	0	10	2	12
Pacific herring	15	27	13	55
Pacific sandfish	1	81	0	82
Pacific sand lance	336 (4)	1,006 (2)	8.308 (1)	9,650 (1)
Pink salmon adult	0	4	0	4
Pink salmon juvenile	115 (5)	5	832 (4)	952 (5)
Pond smelt	0	0	96	96
Rainbow smelt	700 (3)	13	2,033 (3)	2,746 (4)
Rock sole	0	0	13	13
Saddleback gunnel	0	0	3	3
Snake prickleback	1	0	77	78
Sockeye salmon adult	0	386 (4)	0	386 (7)
Sockeye salmon juvenile	738 (1)	8,498 (1)	5	9,241 (2)
Staghorn sculpin	2	1	49	52
Starry flounder	0	6	610 (5)	616 (6)
Sturgeon poacher	0	1	3	4
Threaded sculpin	0	0	1	1
Threespine stickleback	2	3	3	38
Unidentified cod	0	0	4	4
Unidentified greenling	0	1	0	1
Unidentified sculpin	0	0	1	1
Unidentified smelt	0	6	0	6
Walleye pollock	0	15	2	17
Whitespotted greenling	4	121	3	128 (9)
Yellowfin sole	0	7	20	27
Total	2,732	10.988	16.266	29.986

*Numbers in parentheses represent ranking of catches.

near shore and on the northern transects. Reported large spawning populations of capelin in the area (Barton et al. 1977) were apparently missed by our sampling.

2.3.3 Salmon

1984—Cruises 1, 2, and 3.—Despite the fact that over half of the 1984 effort (158 of 277 sets; Table 2.1) was with gear types selected to catch juvenile salmon, this group represented only about 1% of all fish captured. The average catch of juvenile salmon in purse seines was only 8.21/set. Catches were very patchy and the conclusions regarding catch patterns are correspondingly weak. During Cruise 1 (late June to mid-July), the purse seine catch of salmon (8.60/set) was dominated numerically by coho (*Oncorhynchus kisutch*)(78%; primarily because of one large catch off Port Heiden), followed by sockeye (23'%) and chum (O. *keta*; Fig. 2.2). The Cruise 2 (late July to mid-August) purse seine catch (9.86/set) was dominated by sockeye (54%) and chum (34%). Juvenile coho and chinook (O. *tschawytsha*) were also common: pink salmon juveniles (O. *gorbuscha*) were only taken during Cruise 2. The purse seine catch rate

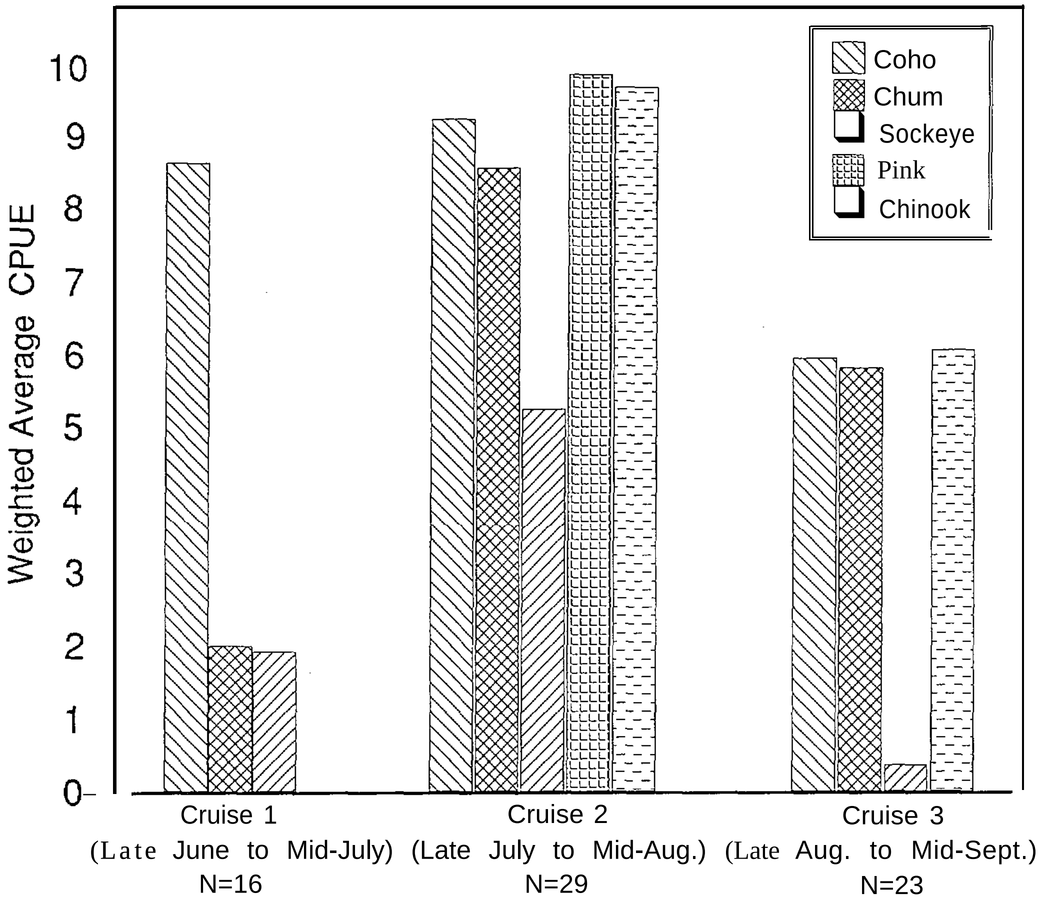

Figure 2.2 — Purse seine catch of juvenile salmon by cruise, all transects and stations combined, 1984.

during Cruise 3 (5.82/set) was substantially lower than during Cruise 2, despite one very large catch of chum salmon juveniles.

During Cruise 2, when the most complete purse seining coverage was achieved (three stations on each of five transects), there was a steady increase in the numbers of sockeye and total juvenile salmon with distance offshore. The overall purse seine catch rate (all species and stations combined) generally declined with distance down the Alaska Peninsula.

Our low catch rate for juvenile salmon in 1984 (compared to that of earlier studies; e.g., Straty 1974, Hartt and Dell 1978) was attributed to smaller seine size and to our late start which likely missed peak sockeye migrations. Calculations of the location of the migrations from various river systems at probable speeds of ocean migration indicated that the majority would not have been in the study area at the time of sampling (Isakson et al. 1986). It was also thought that our catch rates (e. g., Cruise 2 purse seine results) might reflect less preference for shoreline areas (which are extremely dynamic in the Bering Sea) than is the case for other areas (e.g., Simenstad et al. 1982).

1985—Cruises 4a and 4b.—Systematic coverage of the study area from mid-June through July 1985 revealed that large numbers of juvenile salmon seasonally occupy the nearshore waters of the North Aleutian Shelf. A total of 15,619 juvenile salmon was caught in 97 large purse seine sets, 34 small seine sets, and 41 beach seine sets (Table 2.2). Approximately 59 % were sockeye, 331% were chum, 6% were pink, 29Z0 were coho, and <0.1 % were chinook.

Strong trends in relative abundance were apparent in the sockeye catch data. High mean purse seine CPUEs (88.5 fish/set in the large seine and 22.4 fish/set in the small seine) compared to those for the beach seine (0.1) describe a coastal distribution for sockeye with relatively little use of littoral habitats (Fig. 2.3). Purse seine CPUE declined with distance

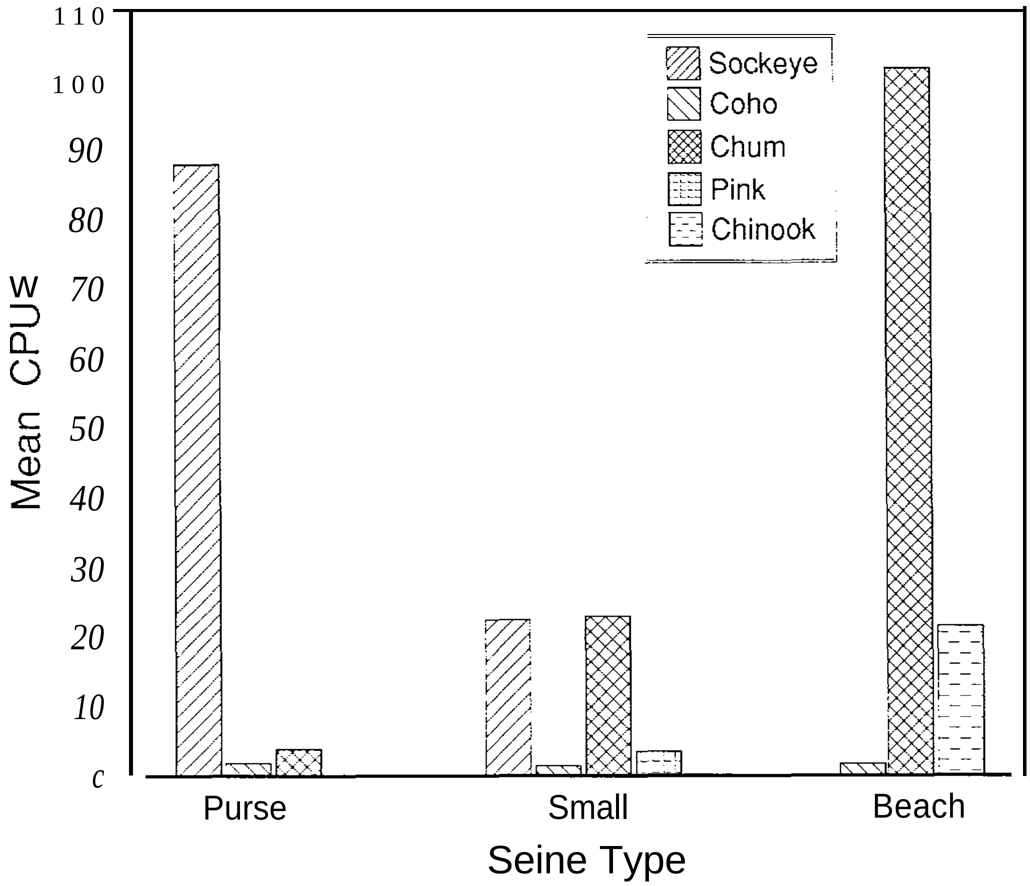

Figure 2.3 —Juvenile salmon mean catch by gear type.1985.

down the Alaska Peninsula. distance offshore. and time (Fig. 2.4). Comparatively larger catches of sockeye juveniles at inner bay transects (off Ugashik and Port Heiden j suggested a migration corridor less than about 15 nmi wide. whereas smaller catches at outer bay transects indicated that the migrating fish had either dispersed or were displaced offshore between Port Heiden and Izembek Lagoon,

A series of paired purse seine sets indicated that sockeye catches were g-eater when the set was made facing toward Bristol Bay (northeast] than away (southwest), and on ebb tides than flood. This suggests a constant orientation of' the juveniles. and perhaps a movement offshore on ebb tides and onshore during flood tides.

Small numbers of juvenile coho salmon were taken routinely, but not consistently, at all locations in 1985. The mean CPUE for the survey (all gears combined) was 1.7 fish/set. Abundance generally increased over time and with distance out of Bristol Bay. Coho were rare 01- absent in beach seine and small seine catches at Ugashik and Port Heiden at all times. but were common in all gears and at all times at Port Moller. suggesting that this is an important secondary rearing area for juvenile coho salmon.

Juvenile chum salmon were present only in intertidal habitats inside Port Moller during the first half of the 1985 survey period (16 June–7 July), but became relatively abundant throughout the study area in the second half (8–28 July; Fig. 2.5). The mean CPUE for chum salmon was 30.5 fish/set (all gears combined), although much of this was due to a single beach seine catch of nearly 3.300 fish. A shift from intertidal to subtidal and offshore habitats was evident from changes in the CPUE of each gear type over time. The pattern of habitat use in Port Moller clearly shows this estuary to be a seasonally important nursery area for local chum salmon stocks.

Pink salmon were not widely distributed in the study area in 1985. The mean CPUE for this species was 5.7 fish/set (all gears combined). Juvenile pink salmon were taken only at Port Moller and Ugashik on the last days of the survey. The low incidence of migrating juvenile pink salmon in purse seine catches

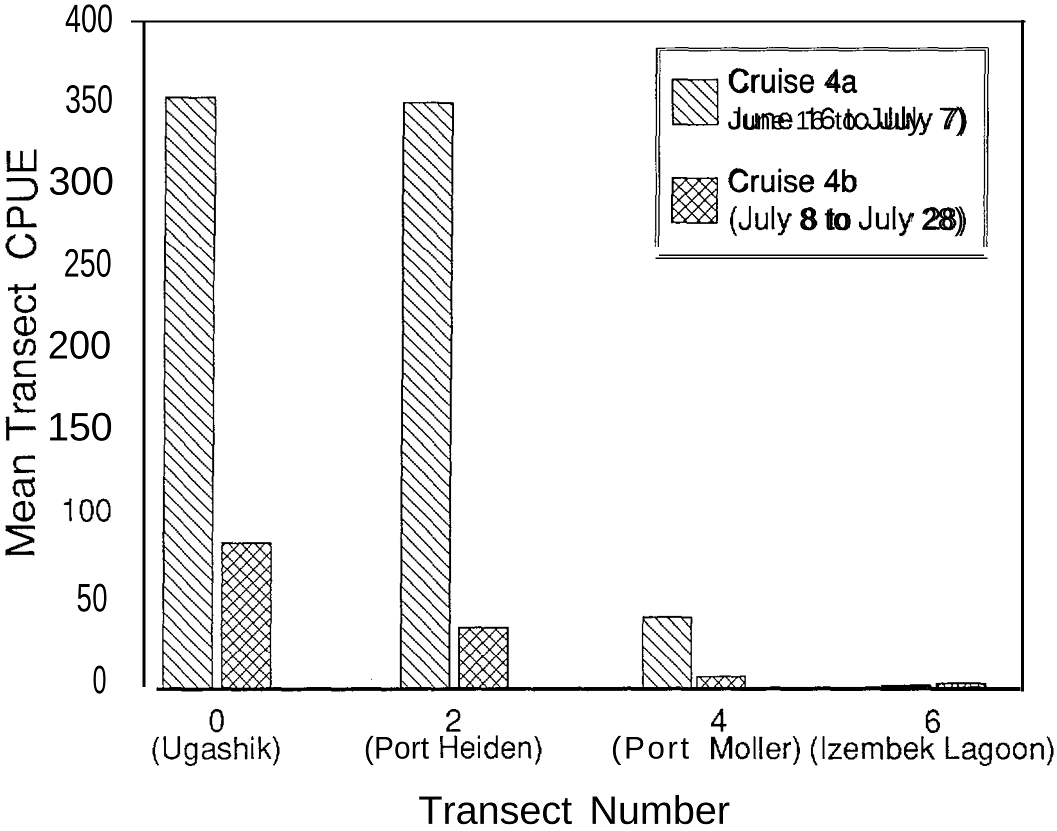

Figure 2.4 —Juvenile sockeye salmon catch by transect and period, 1985.

probably was due to the termination of sampling early in summer before Bristol Bay pinks had arrived in the study area.

Only six juvenile chinook were taken by all gears during the 1985 survey. Four of the six were taken near Ugashik Bay, which is known to support a run of adults. It is possible that juvenile chinook migrated out of the study area earlier, perhaps at depths inaccessible to the purse seine, so that small catches do not accurately reflect the relative abundance of this species along the north side of the Alaska Peninsula.

Statistical evaluation of differences in fish growth by analysis of scale patterns was used to attempt to distinguish individual stocks from mixed stock samples from the Ugashik and Port Heiden transects. A linear discriminant function analysis of scale measurement data revealed that differences in scale growth patterns were not as distinct in 1985 as had been expected: Ugashik, Naknek, and Wood River scales were virtually indistinguishable. Poor reliability of parent stock separation precluded any conclusive statements regarding stock composition of catches at Ugashik and Port Heiden.

Adult salmon. —Adult salmon were not specifically targeted in this survey. However, adult sockeye salmon captured off Ugashik Bay on 20 June and 12 July 1985 were found to be aggressively feeding on euphausiids. Evidence of feeding within the influence of fresh water was unexpected, although the ultimate destination of feeding fish could not be determined.

2.4 DISCUSSION

Virtually all of the 1985 sampling was completed in water temperatures lower than those recorded at the beginning of Cruise 1 in 1984. Thus, it is more appropriate to view the results of 1984 sampling as an extension of 1985 activities rather than to compare results across years. The relative climatological (and, presumably, biological) timing of 1984 and 1985 sampling periods was almost without overlap. Therefore, the results of the 1985 survey should be viewed as representative of conditions that may have existed in 1984 prior to our sampling. Similarly, the 1984 results may represent biological patterns that existed in 1985 after the termination of sampling.

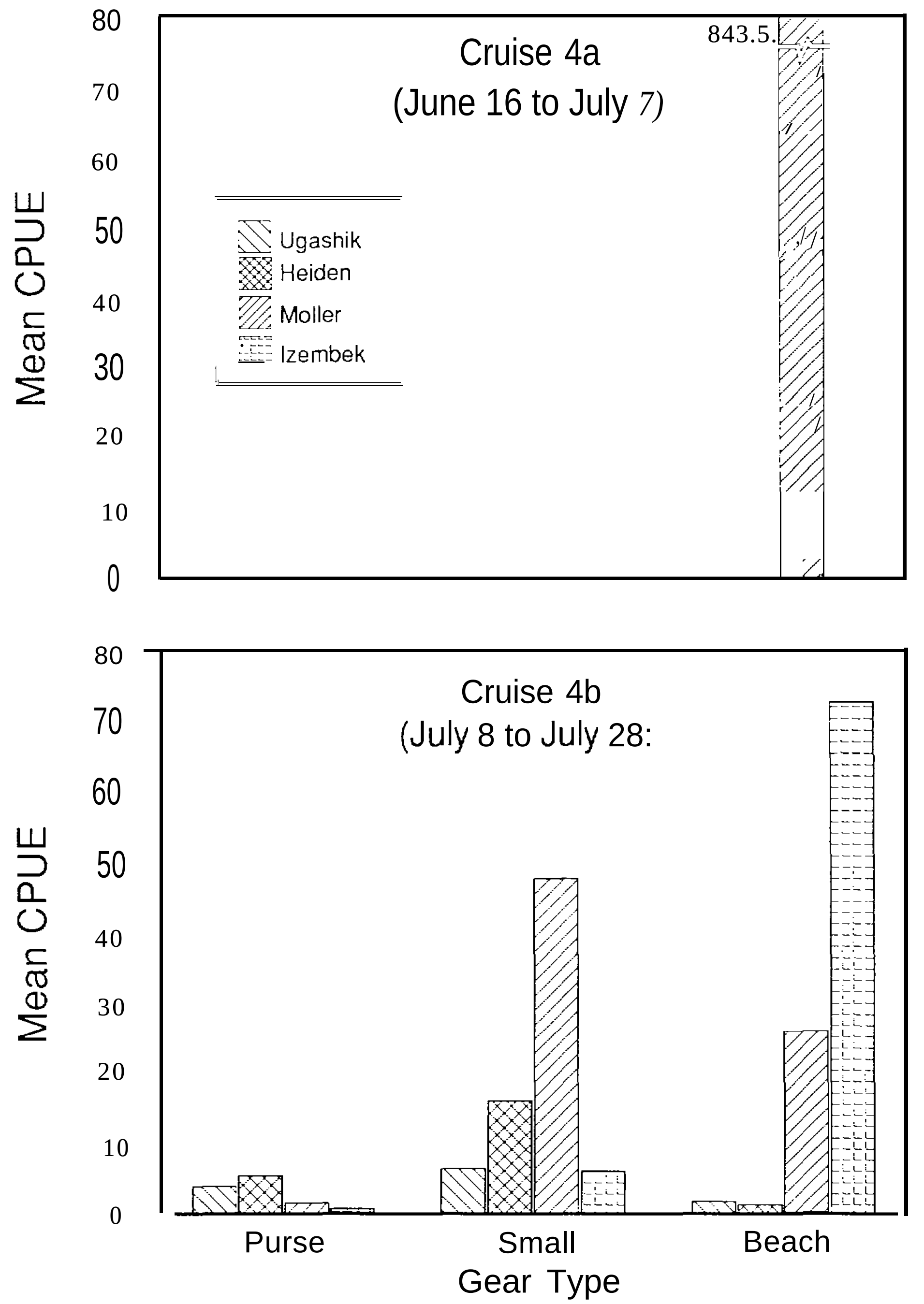

Figure 2.5 — Juvenile chum salmon catch by gear type, 1985.

The results of the 1984 sampling raised some doubts about the capabilities of the gear to catch fish and/or the importance of the nearshore zone to juvenile salmon. Alternatively, the low catches could have indicated that the sampling was begun after peak periods of sockeye juvenile abundance in the area. Since sampling began much earlier in 1985 relative to peak migratory activity of juvenile sockeye salmon, it confirmed that peak abundances of sockeye undoubtedly had occurred in the study area in 1984 prior to the start of survey activities. Furthermore, comparatively large catches of salmon in 1985 demonstrated that nearshore and estuarine waters are very important rearing and migration routes for juveniles, especially sockeye and chum.

The model of sockeye salmon migration proposed by Straty (1974) is largely supported by our results, to the extent that the surveys overlap. The intensive inshore coverage in the 1985 sampling complemented the intensive offshore sampling in the earlier survey. Major trends in the migration patterns of juvenile sockeye in 1984 and 1985 were nearly identical in many cases to those documented by Straty; for example, the strong shoreward bias of catches in the northern part of our study area. This tended to break down farther to the southwest wherein Cruise 2 catches increased with distance offshore. Chum salmon were shown to be more shoreline oriented than sockeye, coho, and chinook salmon early in their marine residency but also move offshore with size and as they move down the peninsula.

We would amend the Straty model only to point out that the interannual variation in the factors influencing the time/space patterns of migration can be quite pronounced; thus they may substantially modify details of the general migration patterns concluded from a short-term (1- or 2-year) survey.

Coastal embayments adjacent to the North Aleutian Shelf were shown to be highly important seasonally for juvenile chum, pink, and coho salmon. Data for chinook salmon are inconclusive on this point, but we know that locally important runs of adults return to both the Nushagak and Ugashik systems. Port Moller supports impressive numbers ofjuvenile salmon, especially pinks and chums, and appears to be more important in this respect than other embayments along the north side of the Alaska Peninsula.

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Chapter 3

Relationships of Growth and Survival of Pacific Herring to Environmental Factors

MICHAEL D. MCGURK
Triton Environmental Consultants Limited,
205-2250 Boundary Road, Burnaby, B. C., Canada V5M 3Z3

3.1 INTRODUCTION

Stocks of Pacific herring. *Clupea harengus pallasi*, in Alaska have fluctuated considerably in size due to exploitation and to variation in recruitment (Reid 1971; Fried and Wespestad 1985). Environmental factors are presumed to be the ultimate causes of variation in recruitment. The question of how closely the recruitment of Alaska herring and environmental factors are related is important because the development of the oil and gas reserves on Alaska's continental shelf has the potential to reduce the quality of inshore habitat. thereby reducing herring recruitment or at least increasing its variability. Pacific herring are expected to be vulnerable to changes in inshore habitat because they spawn in the intertidal zone and their larvae and juveniles feed and grow in estuaries and embayments.

This study was designed to identify the biological factors that are responsible for variations in the survival of herring larvae. The primary objective was to measure the relationships between growth and survival of herring larvae in Auke Bay, Alaska. and environmental factors. particularly the concentrations of prey. the concentrations of predators. and water temperature.

3.2 STUDY AREA

Auke Bay (58°22′N, 134°40′W) is a small bay of 11 km² located 20 km north of Juneau (Fig. 3.1). It is part of the home range of the Lynn Canal-Auke Bay herring stock. one of five separate stocks in southeast Alaska (Carlson 1980). The water column in Auke Bay is unstratified from November to March. Stratification begins in April and is complete by July. Surface temperatures rise from 3-5°C in March to 14°C in July; surface salinities fall from 31 ppt to 10-15 ppt. The pycnocline is at 20 m; temperatures and salinities below this depth average 4-5°C and 31 ppt. respectively (Shirley and Coyle 1986). During summer the upper water layer of the bay moves in a counterclockwise gyre; water flows into the bay along the eastern shore between Spuhn Island and the Mendenhall Peninsula and exits between Coghlan and Spuhn islands.

3.3 MATERIALS AND METHODS

Five stations were sampled every 3-7 days from 15 May to 27 July 1988. At each station, three tows were made with a 3-m-long bongo net in a double oblique pattern from the surface to 30 m and back (Fig. 3.2). The first two tows collected herring larvae using a 333- or 505-μm-diameter mesh and the third tow collected zooplankton using a 165-pm-diameter mesh.

Herring larvae from the first tow were preserved in 5% seawater formalin and then counted and measured for length. dry weight, and morphometry. These data were used to calculate age-specific rates of total mortality. population rates of growth in length and weight, and condition factor (McGurk 1985). Condition factor was used to estimate the rate of mortality of herring larvae due to starvation, using the assumption that all starving larvae died within 6.5 days of entering that category,

Larvae from the second tow were stored in 37% isopropyl alcohol in order to preserve the two sagittal otoliths. They were then counted. measured for length. and measured for the radii of each otolith, the number of rings in each otolith. and the width of the outermost ring with an optical pattern recognition system (Biosonics Ltd.). These data were used to calculate specific growth rates.

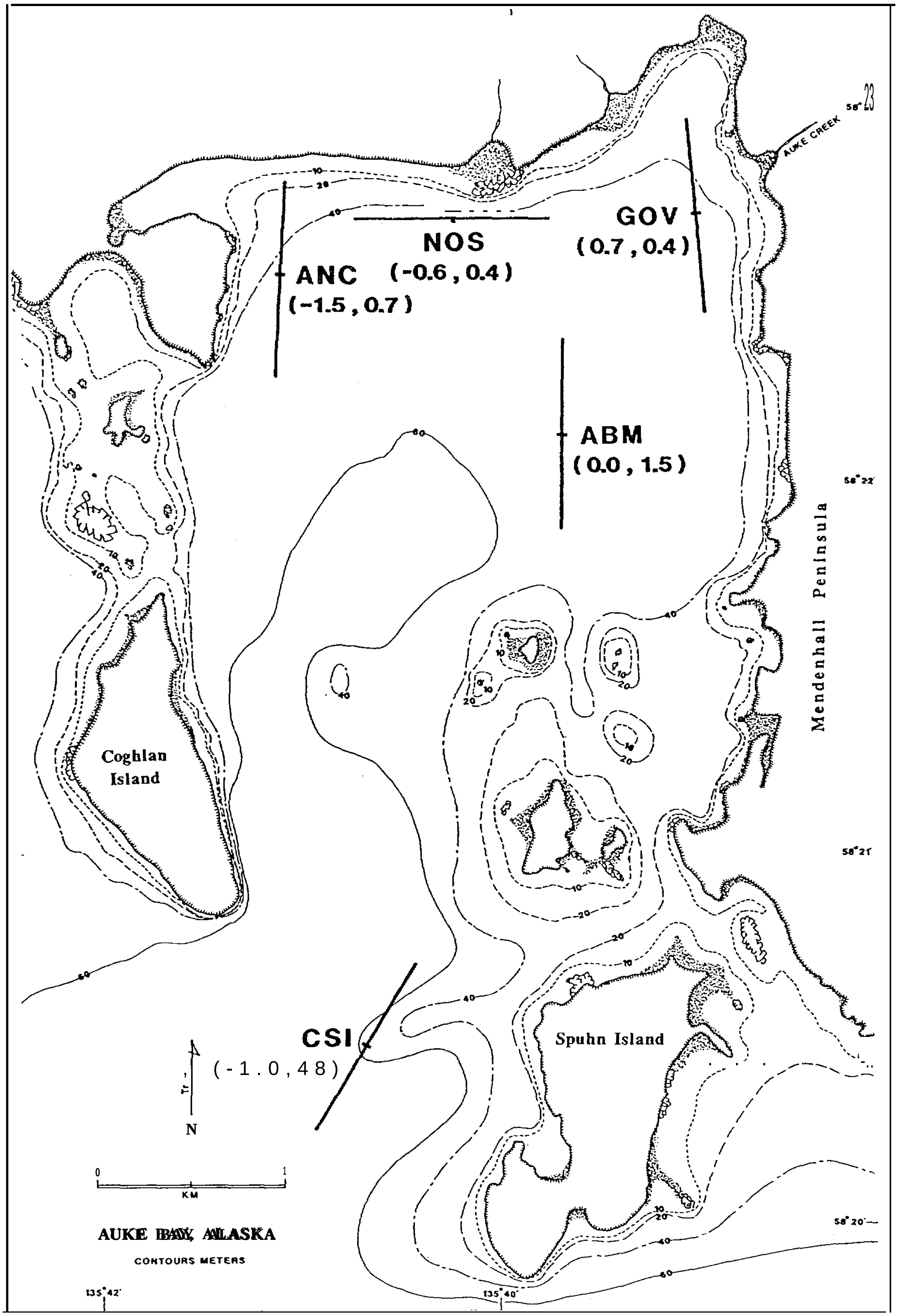

Figure 3. I —Map of Auke Bay showing the five plankton sampling stations,

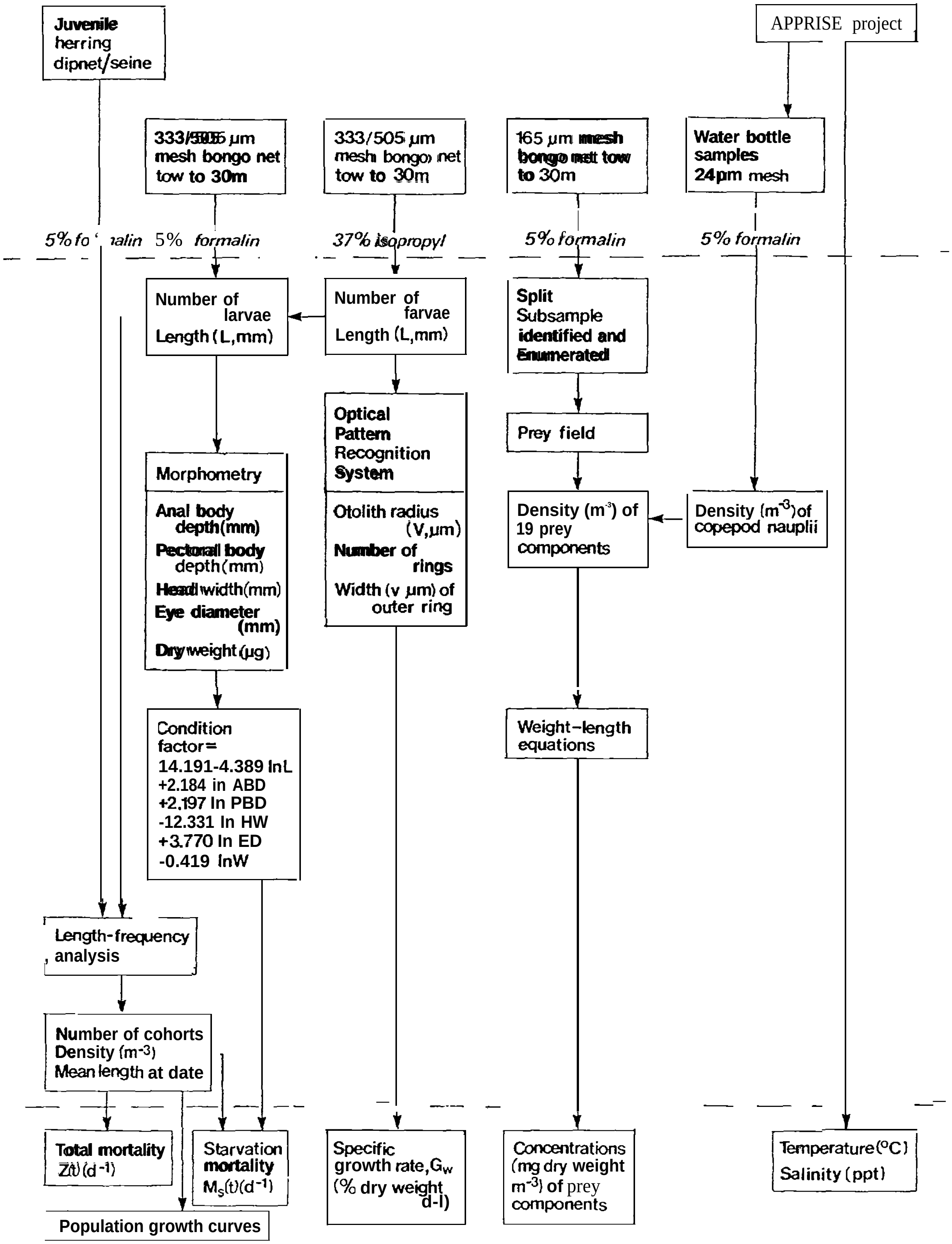

Figure 3.2—Flow chart of procedures for sampling herring larvae, prey, and predators in Auke Bay and for analysis of data.

Each sample of zooplankton was preserved in 5 % seawater formalin, then split several times into subsamples, one of which was completely identified and enumerated. A prey field of 19 components, consisting of copepod nauplii, copepodites and adults, cladocerans, mollusc veligers, polychaete trochophores, and small fish eggs, was identified from the zooplankton samples. Identification of the prey species was based on studies of the diet of herring larvae in southern British Columbia waters and on relationships between prey width and herring length reported by Checkley (1982) for Atlantic herring larvae, *Clupea harengus harengus*. A separate prey field was assigned to each length class of herring larvae (divided by 3-mm increments) to account for changes in diet with size and age. Densities (number/m^3) of each component of the prey field were converted to prey concentration (mg dry weight/m^3) using weight-length equations taken from the literature.

Densities of copepod nauplii, which were not accurately measured by the 165-pm-mesh samples, were estimated from 30-liter water bottle samples passed through 24-μm-mesh bag nets. These bottle samples were collected weekly at 5-m depth intervals from O to 30 m at three stations in Auke Bay by personnel from the APPRISE (Association of Primary Production and Recruitment in a Subarctic Ecosystem) project. Temperature and salinity data were taken from measurements made at ABM station by APPRISE personnel.

Three classes of predators were identified from the macrozooplankton samples: gelatinous predators, including 10 species of jellyfish; semigelatinous predators, including the chaetognath *Sagitta elegans*; and crustacean predators, including hyperiid amphipods of the genus *Parathemisto*. Densities of these three classes were converted to concentrations using weight-length equations taken from the literature.

Growth curves were extended to the early juvenile period by measuring lengths of juvenile herring captured with dipnets off the docks at the head of Auke Bay in late August.

3.4 RESULTS

Five cohorts of herring larvae were identified from modes in the length-frequencies of the formalin and alcohol samples. They hatched in or near Auke Bay at an average interval of one every 18 days from 18 April to 30 June. Five cohorts per season are not uncommon in Atlantic herring, and a spacing of 18 days falls within the range of 17-19 days reported for Atlantic and Pacific herring.

Growth curves constructed from length-frequency analysis showed that the first four cohorts grew at an average rate of 0.31 mm/d from hatch to the early juvenile stage (Fig. 3.3).

Regressions of the number of rings in the sagittal otoliths against date of capture showed that rings were not deposited at daily rates, but at average rates of 0.91, 0.75, and 0.84/d for cohorts 1, 2, and 3, respectively (Fig. 3.4). Only the rate for cohort 2 was significantly ($p < 0.05$) lower than l/d. Therefore, otolith age was calculated as the mean number of rings divided by the cohort-specific slope of the regression of ring number on date. Average rates of growth of otolith-aged larvae were 0.37,0.33, 0.34, and 0.50 mm/d for cohorts 1, 2, 3, and 4, respectively (Fig. 3.5), None of the rates within the two sets of population growth rates are significantly different from each other, and all fall within the range reported for other natural populations of Pacific and Atlantic herring larvae.

Specific growth rates (G_w, % dry weight/d) of individual herring larvae were calculated from the width of the outermost ring of the sagittal otoliths using a fish length–otolith radius regression and a weight–length regression (Fig. 3.6). The G_w ranged from 2.8 to 22.5 % per day and was correlated only with length of the larvae: it was low at hatch, peaked at a length of 20.1 mm (or an age of 38 days, assuming that length at hatch is 8.8 mm and growth is 0.3 mm/d), and declined in larger larvae (Fig. 3.7). A similar result was reported by Oiestad (1983, cited by Kiorboe and Munk 1986) for Atlantic herring larvae reared in large enclosures and fed on natural zooplankton.

The absence of measurable relationships between G_w and prey concentration, and between G_w and temperature, was due to a lack of contrast in the environmental data. Average temperatures of the upper 20 m of the water column fell within a narrow range of 7.2–8.2°C. Mean prey concentrations ranged from 20.1 to 171 mg dry weight/m^3, but Kiorboe and Munk's (1986) feeding experiments with Atlantic herring larvae reared in laboratory aquaria on copepod nauplii indicate that this is the prey range over which G_w begins to slowly approach an asymptote (Fig. 3.8).

In order to compare the G_w of Auke Bay herring with the predictions of the regression model reported

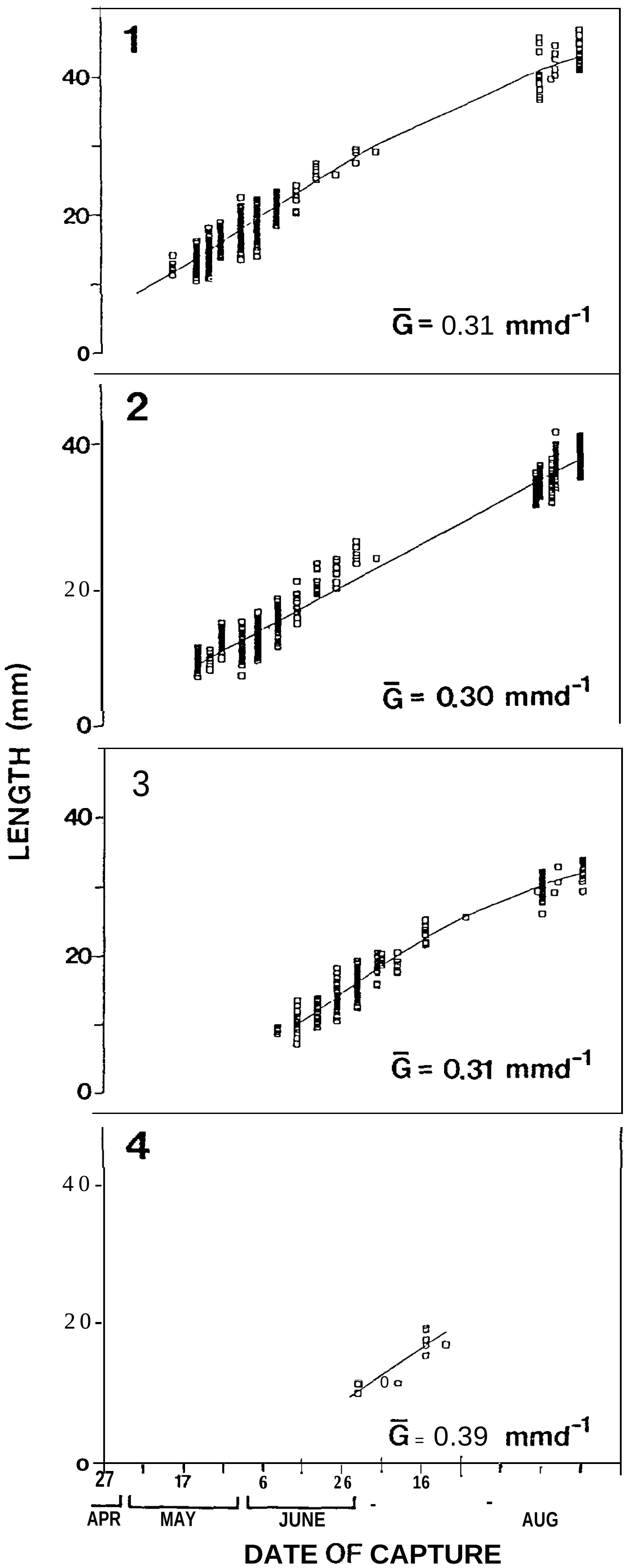

Figure 3.3—Growth in length of cohorts 1 to 4 based on analysis of length frequencies at date of capture of larvae and juveniles. Average growth rates, G, are shown. Curves are linear or Gomperz growth models:

Cohort 1: L =
8.8exp ((0,0344/0.0191) (1 – exp (- 0.0191t))).

Cohort 2: L =
8.8 + 0.2985.

Cohort 3: L =
8.8exp ((0.0430/0.0295) (1 – exp (-0.0295 t))).

Cohort 4: L =
8.8 + 0.3861.

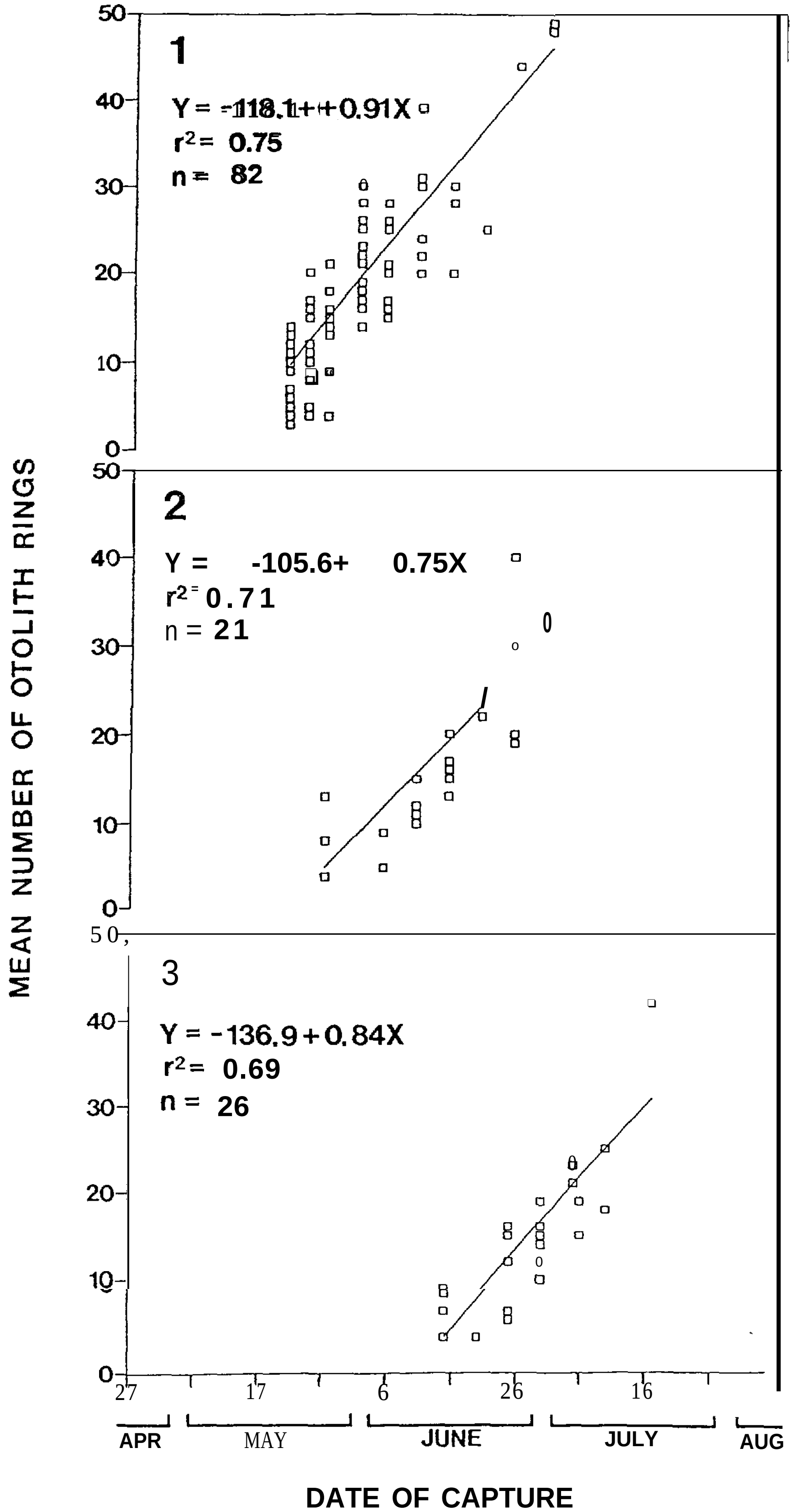

Figure 3 .4 —Mean number of rings in the two sagittal otoliths of herring larvae of cohorts 1, 2, and 3 as a function of their date of capture. Lines are linear predictive regressions of ring number on date.

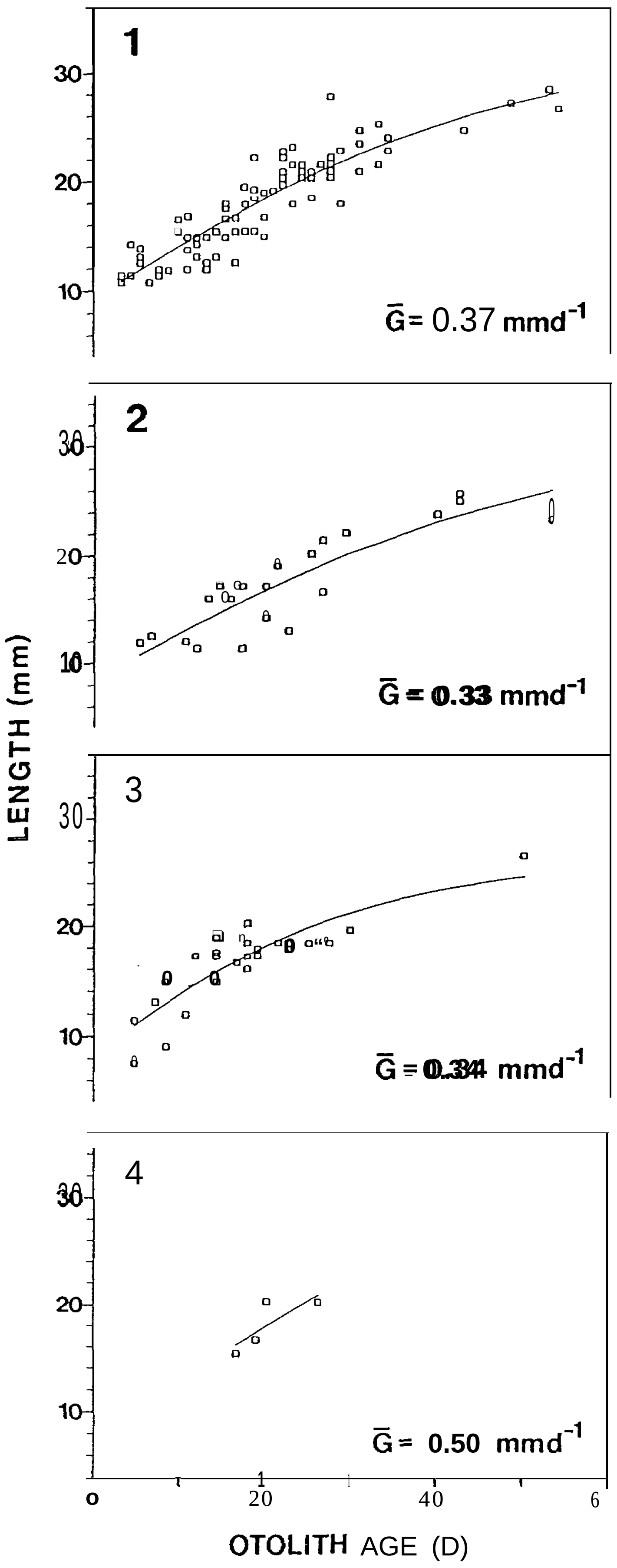

Figure 3.5—Growth in length of cohorts 1 to 4 based on the mean number of rings in the sagittal otoliths, where age (t, d) = number of rings/average number of rings deposited in 1 day. Average growth rates, G, are shown. Curves are linear or Gompertz growth models:

Cohort 1: $L = 9.3\exp((0.049/0.039)(1-\exp(-0.039t)))$.

Cohort 2: $L = 8.6\exp((0.048/0.037)(1-\exp(-0.037t)))$.

Cohort 3: $L = 8.4\exp((0.064/0.056)(1-\exp(-0.056t)))$.

Cohort 4: $L = 7.9 + 0.50t$.

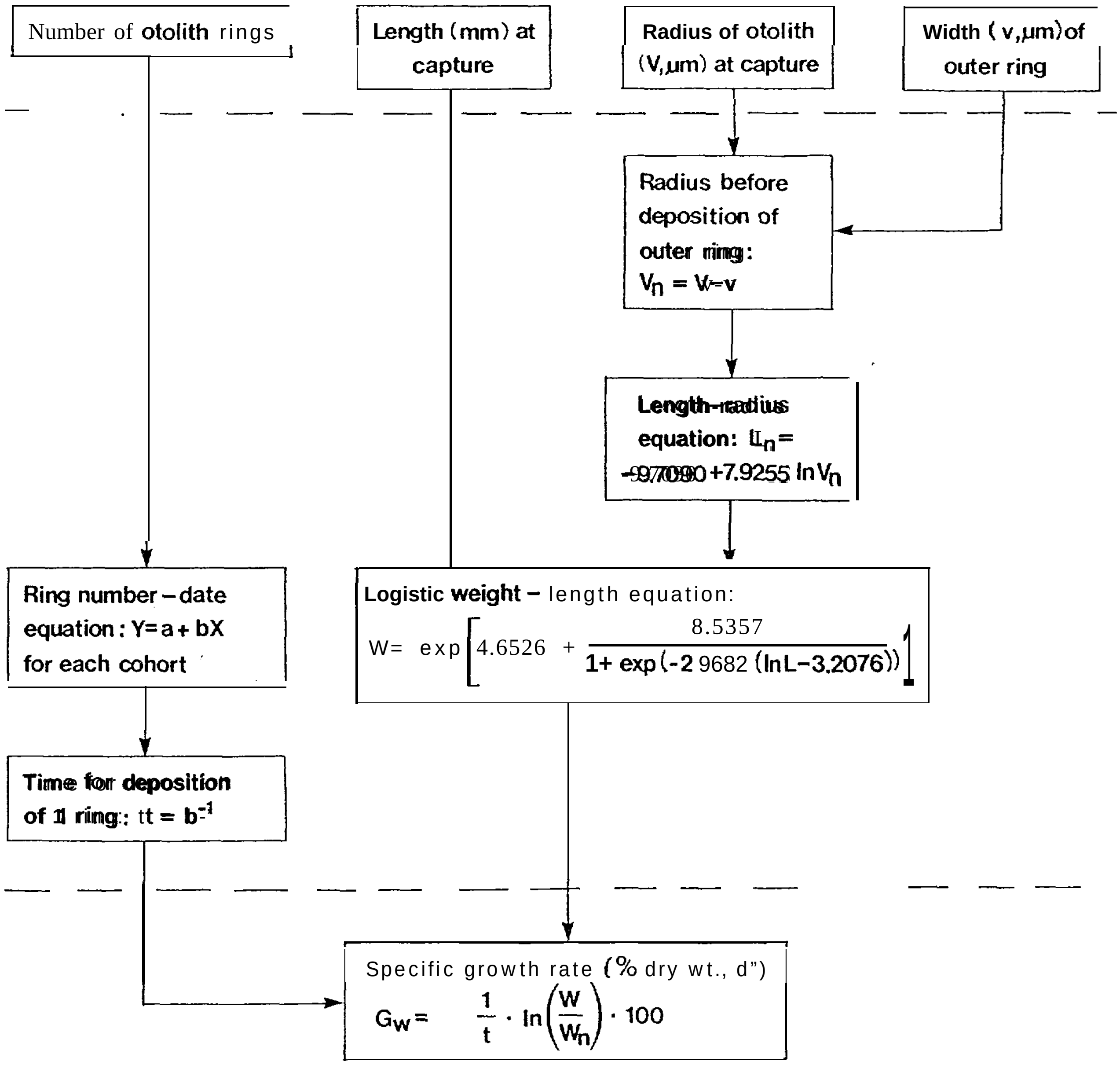

Figure 3.6—Flow chart of procedures for calculation of specific growth rate from information on length of herring larvae at capture, otolith radius at capture, width of outermost ring of otolith, and the average number of days required for the deposition of one ring.

by Kiorboe and Munk (1986), G_w was adjusted to that of a 13-mm-long larva (their model was developed from 1- to 3-week-old herring larvae with an average length of about 13 mm). Auke Bay herring larvae had an average G_w that was 2 %/d higher than the average G_w predicted by the model, which suggests that Auke Bay herring larvae were feeding on patches of prey of higher concentration than was measured by towed plankton nets. This observation does not invalidate Kiorboe and Munk's (1986) model. Rather, this study supports the application of their model to natural environments. Scaling the intercept of their equation by the regression of G_w on length measured for Auke Bay herring larvae leads to an equation for critical prey concentration—i. e., concentration at which G_w <0 mg/m^3 (Fig. 3.9). This equation predicts a C_{crit} of 18.3 mg/m^3 for newly hatched herring larvae 9 mm long, which is

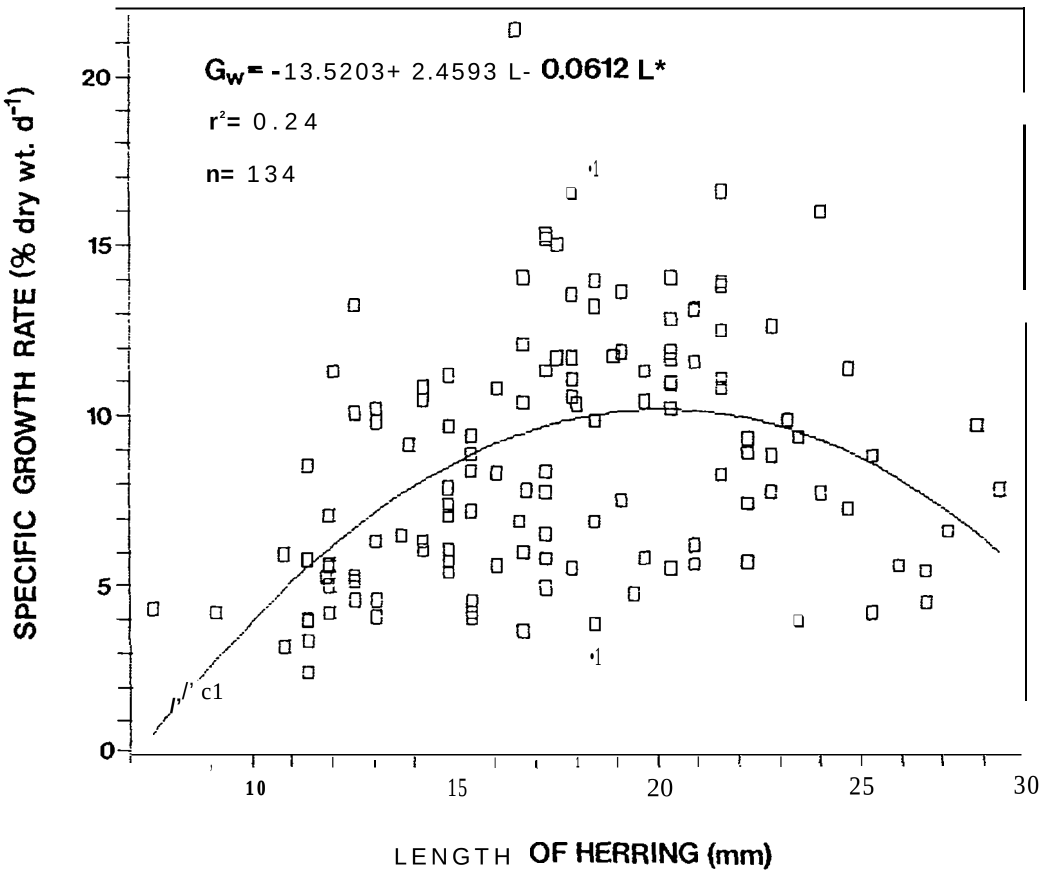

Figure 3.7—Specific growth rate (G_w,% dry weight/d) of herring larvae as a function of length (L, mm).

lower than 96 % of the mean prey concentrations measured in Auke Bay.

The fitness of herring larvae, as defined by a morphometric condition factor, CF, increased with increasing mean prey concentration, C (mg dry weight/m^3), according to the regression equation: CF = 2.269 - 0.867lnC. This equation predicted that fitness would fall below the level of starvation (CF = O) at a critical mean prey concentration of 13.7 mg/m^3. The relatively close agreement in C_{crit} between two different methods strongly supports the conclusion that prey concentrations, growth rates, and fitness of herring in Auke Bay were high in the spring and summer of 1988.

All estimates of mortality of herring larvae presented here are based on the assumption that Auke Bay is a retention area for herring larvae that hatch into it, and that losses due to advection and diffusion are negligible. This assumption was based on a graphical examination of the movements of the centroids of the cohorts between sampling dates, and on regression analysis of the change in spatial variance of larval density with time. Both methods indicated that there was no significant advection or diffusion of herring larvae out of or into Auke Bay. This argument is supported by the fact that the rates of advection (0.2 km/d) and diffusion (0.1-0,2 km^2/d) expected under the assumption of retention are similar to the rates of advection (0.15 km/d) and diffusion (0.08 and 0.48 km^2/d) measured for Pacific herring in the sheltered waters of Bamfield Inlet, British Columbia, by McGurk (1989). The mechanism of retention may be the counter-clockwise gyre of surface currents that forms after stratification of the water column.

Pareto-type population models: $N(t) = N_0(t/t_0)^{-b}$, where N(t) = density/m^3 of larvae at age t (d), N_0 = density at age t_0, and b = coefficient of mortality, provided better fits to the density data of cohorts 1 and 2 than did linear models (Fig. 3.10).

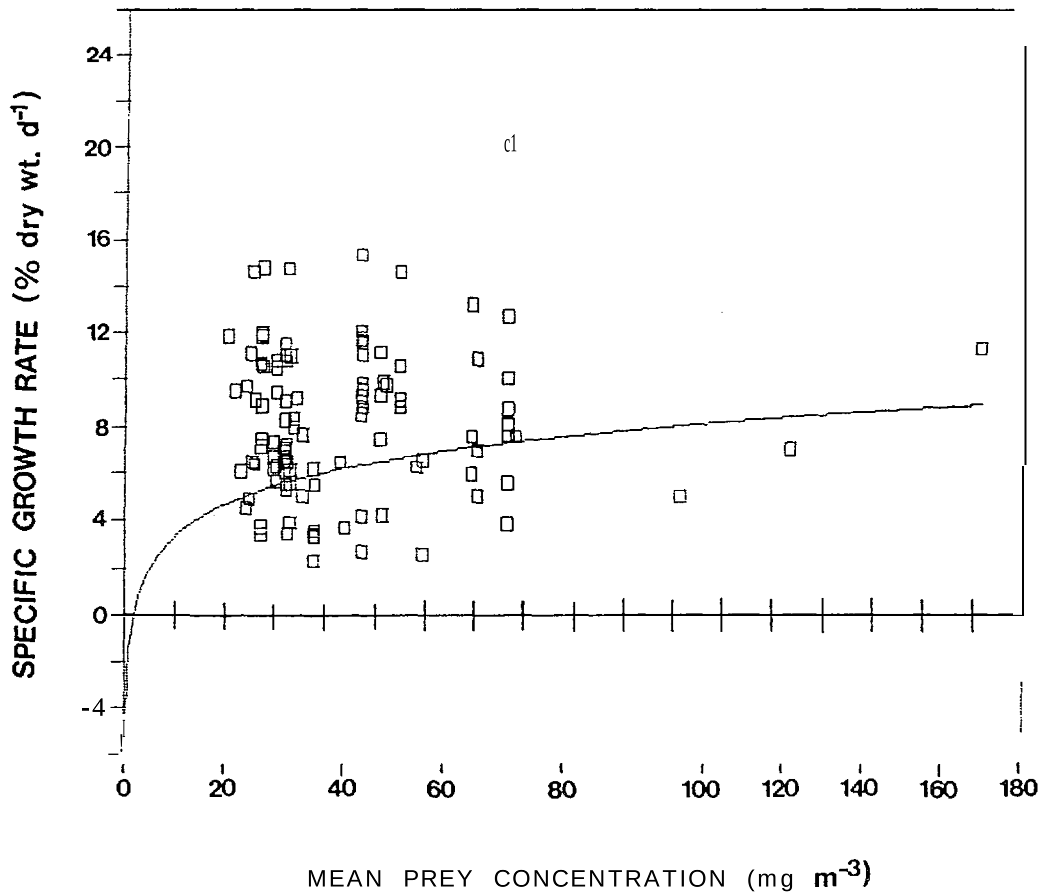

Figure 3.8—Specific growth rate (G_w, % dry weight/d) as a function of mean prey concentration (C, mgdryweight/m^3). G_w was standardized toaherring length of 13 mm. The curve is a regression model reported by Kiorboe and Munk (1986): $G_w = -1.36 + 2.00 \ln C$, that was developed from the growth of 1- to 3-week-old Atlantic herring larvae reared in laboratory aquaria on a diet of copepod nauplii.

Estimates of mortality could not be calculated for cohorts 3, 4, and 5. Total mortality (Z(t) = b/t per day) of both cohorts was highest during the yolk sac and first-feeding stage and fell rapidly with age (Fig. 3.11). Z(t) was higher in cohort 1 than in cohort 2, but the average rate of mortality due to irreversible starvation (M_s (t) per day) was lower in cohort 1 than in cohort 2. Predation is presumably the cause of all mortality not caused by starvation, and since jellyfish made up more than9596 of the concentration of invertebrate predators in Auke Bay in 1988, jellyfish are presumed to be the dominant invertebrate predators.

The magnitude of mortality due to jellyfish predation was assessed using the results of enclosure experiments of jellyfish predation on yolk-sac capelin larvae, *Mallotus villosus,* that were recently reported by de Lafontaine and Leggett (1988). This study is the only one to date that has used enclosure volumes large enough to avoid a container effect on the predation mortality rates. The authors found that the mortality, Z (per day), of capelin larvae increased directly with the density, P (number/m^3), of the jellyfish *Aurelia aurita,* according to the regression equation: Z = 0.0014 + 0.1266P, and that this relationship was independent of the initial density of capelin larvae and of the presence of alternative prey. This equation was adjusted to take into account the decreasing vulnerability of fish larvae to jellyfish predation as the larvae grow in size, by using the results of Bailey's (1984) study of the effects of size of fish larvae on vulnerability. He

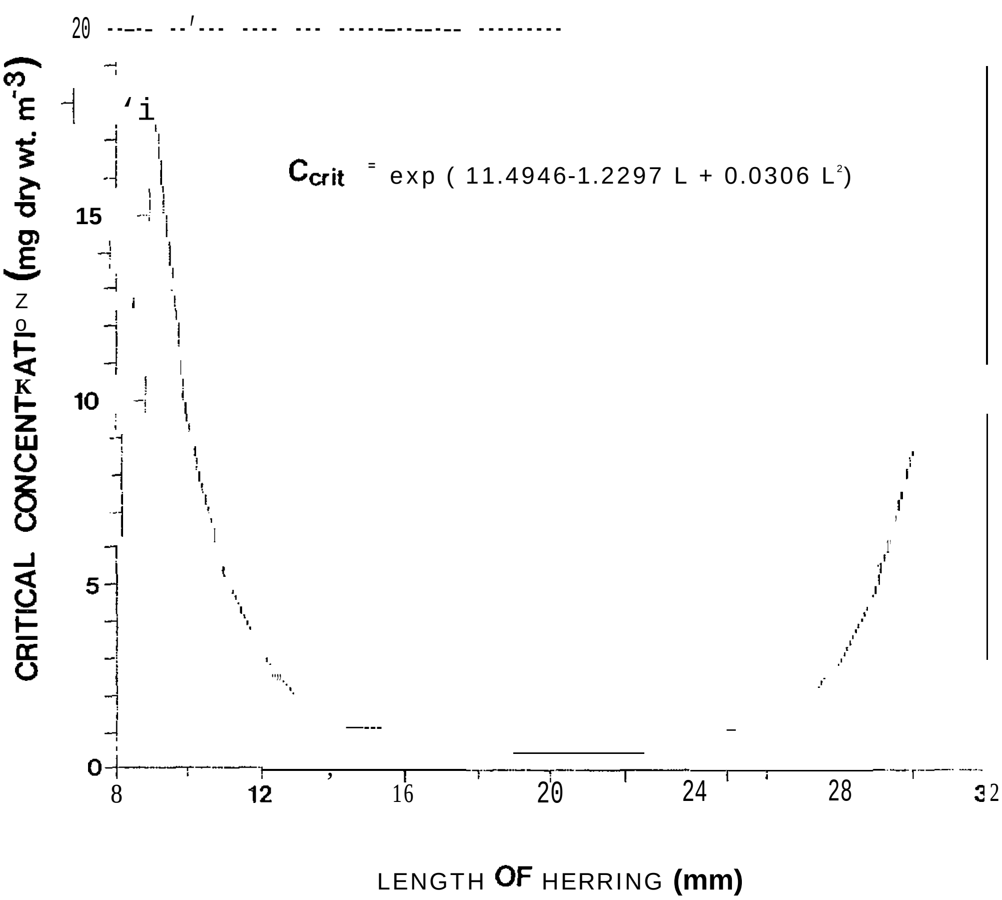

Figure 3.9—Critical prey concentrations (mg dry weight/m³) at which G_w = O as a function of length of herring larvae.

reported that predation rate, Y (number of larvae eaten per cross-sectional area of a medusa/h), decreased with length, L (mm), of fish larvae according to the regression equation: $Y = 0.2397 \exp(-0.1721L)$. Thus, Z was multiplied by the ratio of the Y at length L to Y at the average length of capelin larvae used in de Lafontaine and Leggett's (1988) experiments (L = 5.5 mm). The predation mortalities predicted by this equation from the concentrations of jellyfish in Auke Bay (assuming 1 "*Aurelia*" = 0.384 g dry weight) and the mean lengths at date of capture of herring larvae in cohorts 1 and 2 exhibit trajectories that are similar in shape to those of the total mortalities measured from the population models, Predation mortalities are also generally larger than those from starvation. The sum of starvation and predation mortalities at date of capture of cohort 2 is in substantial agreement with the Z measured from the population model, but the sum of starvation and predation mortalities of cohort 1 is lower than the measured Z.

3.5 SUMMARY

1 Growth of herring larvae in Auke Bay in the spring and summer of 1988 was uniformly high because the prey concentrations and average water temperatures were high.

2 Specific growth rates of Auke Bay herring larvae were low for first-feeders, peaked at 11% in larvae 20 mm long. and then declined in larger larvae.

3 Specific growth rates of herring larvae in Auke Bay were 2 %/d higher, on average, than those predicted from Kiorboe and Munk's (1986) equation relating growth and prey concentration, which suggests that herring fed on high-density patches of prey that were not detected by

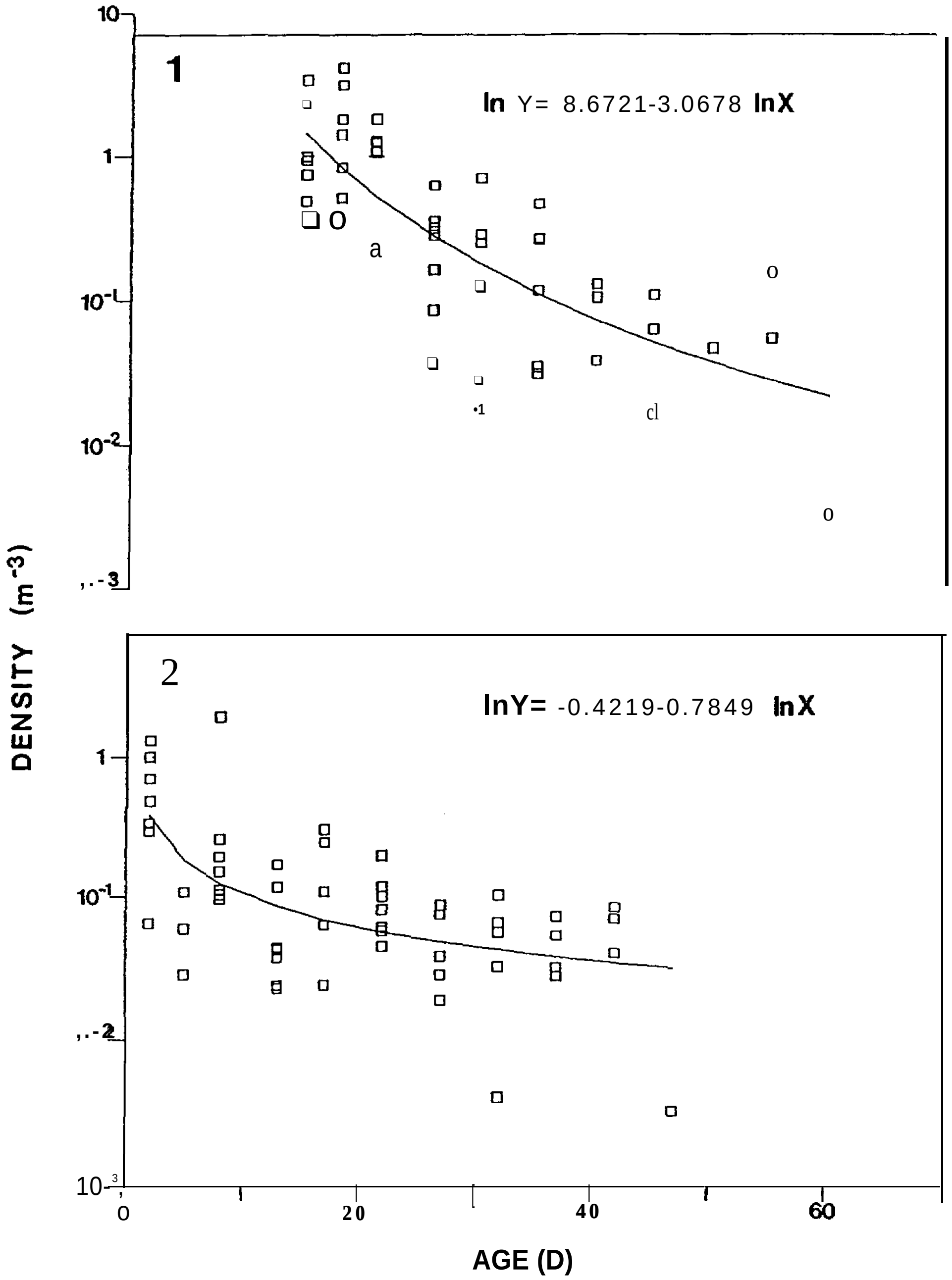

Figure **3.10—Density** of herring larvae (N/m^3) of cohorts 1 and 2 as a function of age (t, d). Curves are Pareto-type population models: N= $N_0(t/t_0)$ ‘b where b= mortality parameter.

plankton net tows that integrated the upper 30 m of the water column.

4. Kiorboe and Munk’s (1986) equation can be successfully applied to. natural environments in order to predict minimum estimates of specific growth rate of herring larvae from prey concentrations.

5. The total mortality of herring larvae in Auke Bay decreased exponentially with age. Although irreversible starvation was measured during the first-feeding period of two cohorts, it was less important than predation in at least one of the two cohorts.

6. These results imply that predation was the primary factor controlling survival of herring larvae in Auke Bay in 1988, and that the concentration of food was a secondary factor. Jellyfish were the most important invertebrate predators.

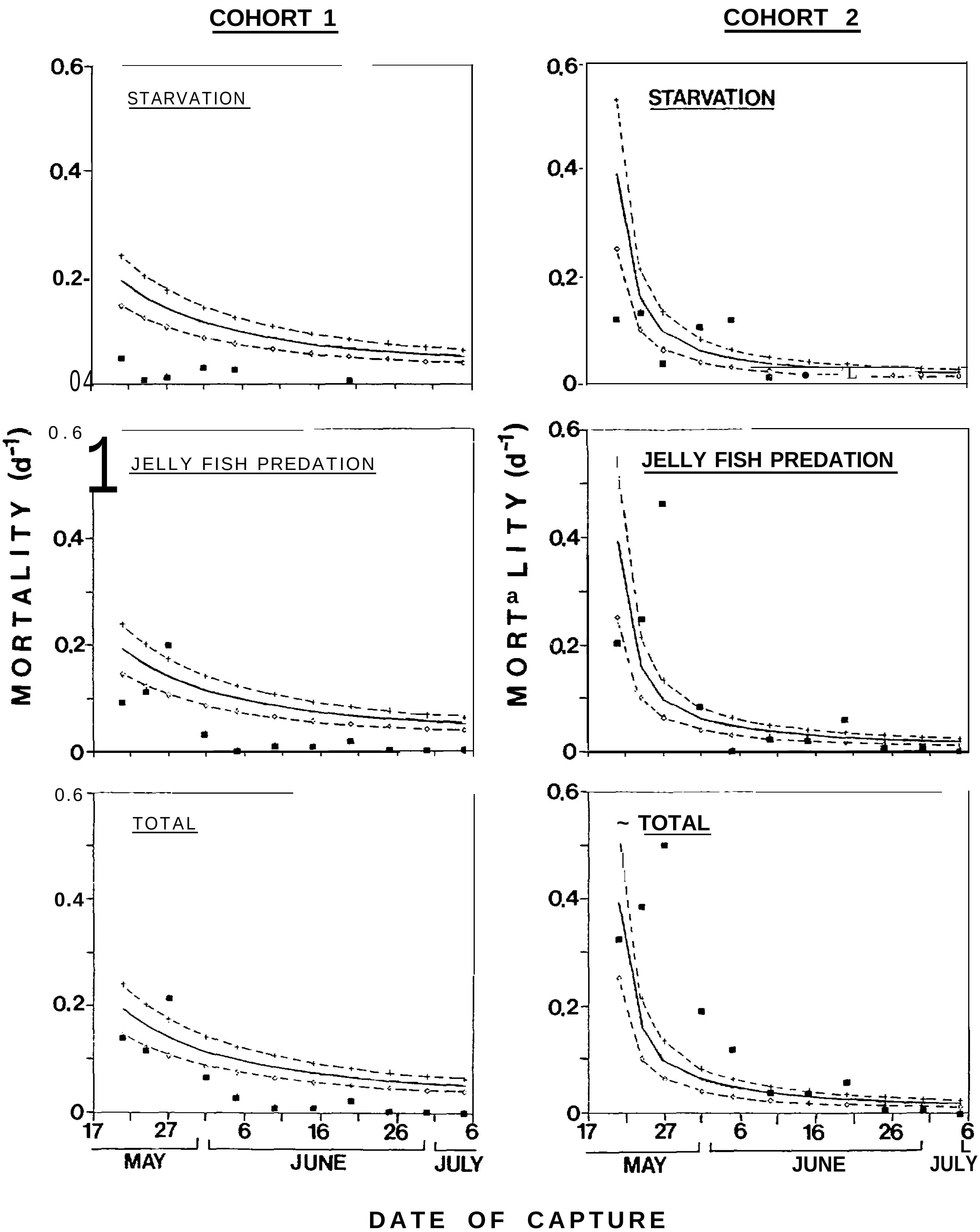

Figure 3.11—Starvation, predation, and total mortality of cohorts 1 and 2 as functions of date. Solid curve is total mortality ($Z(t) = b/t$, per day) measured from population model and broken tunes are 95% confidence limits of Z: closed circles are starvation mortality calculated from morphometric condition factor, and predation mortality calculated from concentrations of jellyfish in Auke Bay.

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Chapter 4

Genetic Stock Identification of Sockeye and Chum Salmon from Bristol Bay, Alaska

RICHARD L. WILMOT, REBECCA EVERETT, AND WILLIAM A. GELLMAN
Alaska *Fish and Wildlife Center and Fisheries Management Service,*
U. S. Fish and Wildlife Service, 1011 East Tudor Road, Anchorage, Alaska 99503

4.1 INTRODUCTION

A study was initiated in 1987 to determine the amount and distribution of genetic variation in populations of Pacific salmon of Bristol Bay, Alaska, and to evaluate the use of this variation as a tool for identifying stocks of salmon in a mixed-stock sample taken offshore. The first year of study focused on chum and sockeye salmon stocks. Chinook and coho salmon stocks were sampled in year two, followed by pink salmon in year three.

4.2 RESULTS

Chum salmon show good genetic separation between the individual stocks sampled in the Bristol Bay region and excellent separation between north Alaska Peninsula stocks and inner Bristol Bay stocks. Simulated mixed populations of peninsula and inner bay stocks were constructed using actual data from the baseline populations. In each simulation, the known percentage of inner bay stocks (and, vice versa, peninsula stocks) ranged from O to 100% at 10% intervals (i.e.. 10:90%, 20:80%). The proportion of fish from each region was then estimated using the genetic stock identification program (GSI). For all simulations. the GSI was accurate within ± 5% (Fig. 4.1).

Only four genetic characters were found to be variable and usable in identifying Bristol Bay sockeye salmon stocks. The amount and distribution of genetic variation was found to be insufficient for accurate estimates either by stock or by region. In a test similar to that used for the chum salmon, the stocks from inner Bristol Bay and the north Alaska Peninsula were pooled in varying ratios. also at 10 % intervals. In this test, however, the proportions estimated from the GSI program were in error by as much as 50% ± 25% (Fig. 4.2).

4.3 CONCLUSIONS

Given its accuracy in the tests. we believe the GSI is sufficient to use immediately for identifying Bristol Bay chum salmon stocks in an offshore mixture. One potential problem is lack of data on other chum salmon stocks that could contribute to an offshore mixture in this region—particularly from the Kuskokwim drainage. To fill this void, we are planning on sampling this drainage in 1989. Yukon River chum salmon stocks could also contribute to the offshore mixture. However, these stocks have been sufficiently sampled as part of the Canada-United States Yukon River Treaty negotiations.

Further work on sockeye salmon will be necessary in order to obtain accurate estimates of stock contributions to an offshore mixture. The first step is to more extensively sample the complex river/lake systems in the Bristol Bay region. Although the breeding structure in many of these systems is likely to be very complex, our initial sampling did not reflect this complexity. Second, we need to finish defining other variable enzyme systems in order to add more characteristics to the analysis, We know of at least one more variable system that we are confident of characterizing. Finally. we are investigating the use of nongenetic characteristics for distinguishing different stocks, such as the degree of parasitic infection. scale patterns, and morphological characters, which can be treated similarly to the genetic characteristics.

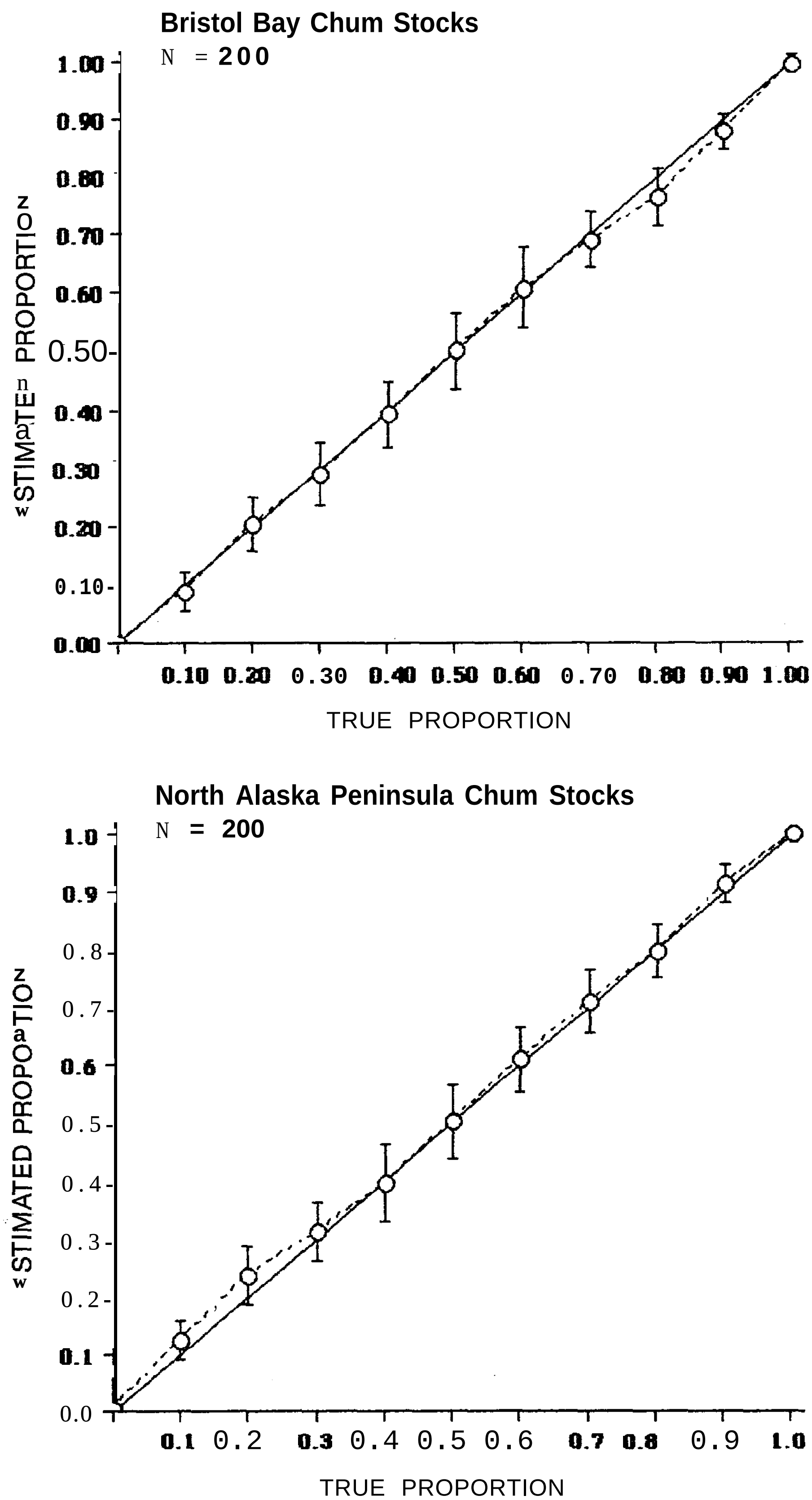

Figure 4.1—True proportions of Bristol Bay chum salmon stocks (inner bay and north Alaska Peninsula) versus the proportions estimated by the GSI program. Error bars are one standard deviation.

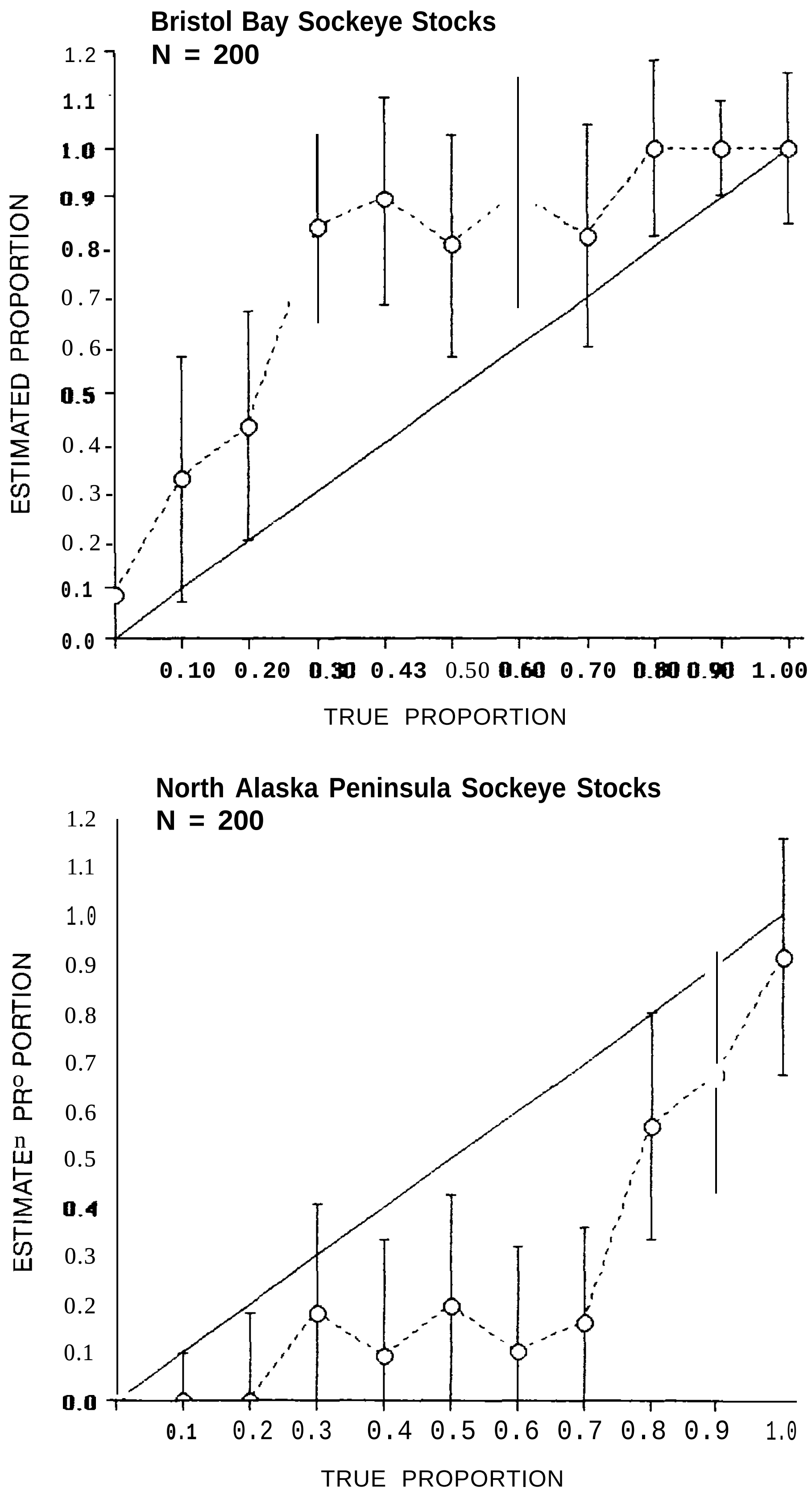

Figure 4.2—True proportions of Bristol Bay sockeye salmon stocks (inner bay and north Alaska Peninsula versus the proportions estimated by the GSI program. Error bars are one standard deviation.

Chapter 5

Effects of Petroleum Contaminated Waterways on Migratory Behavior of Adult Pink Salmon

DOUGLAS J. MARTIN
Pacific Environmental Technologies, inc.,
170 W. Dayton St., Suite 201, Edmonds, Washington 98020

5.1 INTRODUCTION

The purpose of this investigation was to determine if exposure to oil-contaminated waters would disrupt the migration of adult Pacific salmon. Previous research in the laboratory (Pearson et al. 1987) found that adult coho salmon have a detection threshold of 10-7 ppb for the water-soluble fraction (WSF) of crude oil. This research also found that at WSF concentrations of 0.1 to 1.0 ppb the chemosensory response to WSF is degraded, but not irreversibly Based on the findings of Pearson et al. (1987) a field investigation was designed to address the following questions:

1) Will migrating adult salmon avoid oil-contaminated waters at concentrations near or above the chemosensory detection threshold?
2) If adult salmon encounter WSF concentrations above 1.0 ppb, are there any signs of disorientation and do they find their home stream?

5.2 STUDY AREA AND METHODS

The behavior of adult salmon in the presence of oil-contaminated waters was studied by tracking pink salmon movements during periods with and without oil contamination as they migrated through Jakolof Bay, located near Seldovia, Alaska. Ultrasonic transmitters were attached to adult salmon which were captured at the mouth of Jakolof Creek. During an ebb tide, groups of 10-20 tagged salmon were released from a holding pen located 2 km from Jakolof Creek. Their movements were tracked by a freed array of hydrophores as the fish returned to their home stream. Horizontal and vertical movement patterns, swimming speed, and duration of return to the home stream were examined in order to identify behavioral responses to oil exposure.

A solution of aromatic hydrocarbons similar in composition to the WSF of Prudhoe Bay crude oil was injected into the water column from a diffuser located midway between the fish holding pen and the mouth of Jakolof Creek. The diffuser was designed to create a vertically mixed hydrocarbon plume. Salmon were released from the holding pen when the hydrocarbon plume had extended approximately 300 m downstream. This enabled the salmon to have an option of moving either into or around the plume.

Hydrocarbon dispersion rate and concentration within the plume were estimated from a two-dimensional vertically integrated hydrodynamic model in combination with a water quality model. The hydrodynamic model was driven by tides and the water quality model was calibrated by dye dispersion studies. Predicted hydrocarbon concentrations were verified by analysis of water samples. The hydrodynamic model and diffuser design were developed from oceanographic data collected from a reconnaissance survey conducted during April 1988.

The salmon tracking experiments were conducted during late July to correspond with the spawning migration of pink salmon to Jakolof Creek. Tracking experiments conducted without hydrocarbon discharge were designated as controls and experiments with hydrocarbon discharge were designated as treatments. Three control experiments and three treatment experiments were conducted on an alternating schedule during the period from 19 July to 29 July. Experiments were not conducted for a minimum of 2 days following each treatment run, in order to allow time for the hydrocarbon plume to be flushed from the bay.

Total concentrations of hydrocarbons in Jakolof Bay prior to the experiments and during the control experiments ranged from O to 2.2 ppb. Concentrations during the experiments ranged up to 64.9 ppb run, in order to allow time for the hydrocarbon plume to be flushed from the bay.

Total concentrations of hydrocarbons in Jakolof Bay prior to the experiments and during the control experiments ranged from O to 2.2 ppb. Concentrations during the experiments ranged up to 64.9 ppb at 25 m from the diffuser. Hydrocarbon samples indicated the plume was not vertically mixed and was only present in the lower half of the water column. The plume model was adjusted to account for this variation, and the estimated hydrocarbon concentrations were. verified by water samples. Plume shape was generally the same for all treatments but the rate of development was dependent on size of the tide.

5.3 RESULTS

Salmon returning to the home stream through uncontaminated waters exhibited two types of movement behavior. After release from the holding pen salmon showed a searching behavior that was characterized by: variable horizontal movements that were generally directed up bay against the ebb current with short periods of movement either across or with the current, movement up and down in the water column with a higher frequency of large-amplitude compared to small-amplitude vertical movements, and swimming at a slow speed (mean ground speed 0.26 m/s). The duration of the searching behavior was similar within an experiment but varied among experiments. When fish began to move along a straight horizontal course toward the home stream the amplitude of vertical movement decreased and swimming speed increased (mean ground speed 0.46 m/s). The latter behavior was defined as an active migration behavior.

Two of the three treatments (numbers 1 and 2) did not result in a test of exposure to oil because the plume did not intercept the homing fish. This problem resulted from insufficient knowledge of the migration route and migration speed of salmon in Jakolof Bay in relation to the plume location. The location and timing of fish release relative to the location and movement of the hydrocarbon plume were critical for the successful exposure of salmon to oil. Salmon were exposed to oil-contaminated water during treatment number 3 only.

In the presence of oil, pink salmon initially show a searching behavior with the following characteristics: (1) variable horizontal movements into and out of hydrocarbon concentrations ranging from 1.0 to 10.0 ppb, (2) large-amplitude vertical movement patterns, (3) negative rheotaxis, and (4) movement at low speed. This searching behavior resulted in movement down bay and presumably out of the higher hydrocarbon concentrations (i.e., >1,0 ppb). Following this behavior, pink salmon exhibited an active migration behavior and successfully returned to the home stream by migrating through uncontaminated waters outside of the plume.

5.4 DISCUSSION

Differences in movement behavior of salmon during treatment 3 compared to the behavior of salmon during the control experiments indicated that hydrocarbon concentrations ranging from 1.0 to 10.0 ppb caused a temporary disruption of the salmon migration to the home stream. Fish returning to the home stream through uncontaminated waters spent less time searching, showed positive rheotactic movements, and swam at the depth of the interface of the steep salinity gradient. Fish exposed to contaminated waters spent significantly more time searching, showed negative rheotactic movements, and swam at a depth well below the interface of the steep salinity gradient. Following this behavior salmon displayed an active migration behavior (positive rheotaxis) and successfully returned toward the home stream by migrating initially through low hydrocarbon concentrations (i.e., near 1.0 ppb) along the plume edge and finally through uncontaminated waters outside of the plume.

The cause for this change in behavior and the resulting delay of the return migration after oil exposure is not clear. Salmon exposed to hydrocarbon concentrations greater than 1.0 ppb are either avoiding contaminated water by searching for an uncontaminated route or are becoming temporarily disoriented until they eventually swim clear of the plume. Understanding the mechanism for this delay is confounded by the timing when fish were exposed to the plume. Salmon encountered the plume during the searching phase of their return; therefore, the response observed may or may not be entirely due to the effects of oil. Horizontal movement patterns and the duration of the return varied during the control experiments, indicating that factors other than oil contamination affect movement behavior. Variation in movement behavior during the searching phase may be related to differences in current speed and the depth of low-salinit y surface waters, which may affect how quickly salmon can detect the home stream cue. Had salmon encountered the plume during the active migration phase when fish were assumed to be homing, the interpretation of results would likely be more clear.

The distinction between avoidance and disorientation requires an identification of specific behavioral characteristics during migration that are indicative of either an avoidance or a disorientation response. Avoidance in this case is defined as detection of unsuitable conditions coupled with continued orientation (i.e., no loss of home stream cue) and disorientation is defined as inability to detect chemical cues necessary for orientation either by sensory impairment or by masking. Based on these definitions, a salmon avoiding the plume would likely display a searching behavior with the extent of the vertical and horizontal search more or less limited by the boundaries of the home stream cue. Since movement in or adjacent to the home stream cue is required for orientation, salmon could only avoid the contaminant if an uncontaminated route existed within the boundaries of the home stream cue. If the latter condition exists, then searching movements that take the fish out of the plume should be immediately followed by active migration behavior and a return to the home stream. In contrast, a salmon that became disoriented would display a searching behavior (i.e., vertical and horizontal movements) that would not be limited by the boundaries of the home stream cue. Based on homing behavior observed in fresh water (Johnsen 1982), a loss of the home cue (i.e., disorientation) would result in negative rheotactic movements until the fish could reestablish the cue. Homing could only be successful if a portion of the home stream cue were uncontaminated and only for those fish that by chance migrated along the uncontaminated route.

The movement behavior observed during treatment 3 suggests that adult pink salmon may become disoriented in the presence of hydrocarbon concentrations ranging from 1.0 to 10.0 ppb. All fish showed negative rheotactic movements and headed down bay after or during exposure to the hydrocarbon plume. All but one of these fish continued down bay out of tracking range. This behavior would suggest the fish were unable to detect the home stream cue. Fish that conducted horizontal searches both within and outside of the plume (e.g., fish nos. 82 and 83) did not detect the home cue even though the search pattern outside of the plume crossed the eventual return route. If fish were avoiding the contaminated area they should have resumed their homeward movement along the return route outside of the plume. The absence of a positive response suggests that the chemosensory capabilities may have been impaired. Pearson et al. (1987) found that the chemosensory capabilities of coho salmon were temporarily degraded (i.e., for a few minutes) when fish were exposed to hydrocarbon concentrations (composed of 97% monoaromatics) of 0.1 to 1.0 ppb for 30 minutes. Exposures to WSF concentrations above 1.0 ppb and for longer periods have not been evaluated; therefore, the lasting effects of chemosensory impairment are unknown. Fish nos. 82 and 83 were exposed to concentrations >5.0 ppb for 3 to 4 minutes and to concentrations ranging from 1.0 to 5.0 ppb for up to 41 minutes. The eventual return of these fish and the other fish that headed down bay indicates that the cause for the negative rheotaxis was temporary. These fish presumably headed down bay out of the hydrocarbon plume, became oriented in uncontaminated waters, and returned along the home stream cue. The latter assumption is supported by the behavior of fish no. 77, which successfully homed after negative rheotactic movements resulted in movement outside the plume. After a period of 10 to 15 minutes outside the plume fish no. 77 turned and actively migrated toward the home stream. All the fish that headed out of tracking range down bay returned after 12 to 19 minutes, which is similar to the orientation period exhibited by fish no. 77.

Examples of disruptions of salmon migration due to oil or other water pollution are rare. Weber et al. (1981) reported that adult coho salmon returning to two parallel fish ladders avoided using one ladder when it was contaminated with WSF concentrations reaching 3.2 ppm. Pearson et al. (1987), however, speculated that the result of this study was not an example of avoidance, but rather an indication of disorientation and most likely as a result of chemosensory impairment. Pearson et al. (1987) reanalyzed the data from Weber et al. (1981) and found that the WSF released into the test stream was at levels sufficient to cause chemosensory impairment and that fish returns to the stream were correlated with WSF concentration. Pearson et al. (1987) believed that chemosensory impairment inhibited salmon from locating the test stream during the experiments. Saunders and Sprague (1967) reported that Atlantic salmon avoided high levels of zinc and copper pollution in a tributary of the Miramichi River by returning prematurely downstream during their normal spawning migration. Pearson et al. (1987) were also critical of these results because heavy metals were known to reduce olfactory response in salmonids. Therefore, the downstream movement observed by Saunders and Sprague (1967) was more likely due to the loss of ability to detect the home stream odor. Westerberg (1983a,b) observed negative rheotactic movements by Atlantic salmon released in a branch of the Lule estuary that was polluted with effluent from a steelworks and coke plant, whereas salmon released in an unpolluted branch of the same estuary showed a slow but steady migration upstream. The latter may also be an example of disorientation due to chemosensory impairment.

5.5 CONCLUSIONS

These findings suggest that adult pink salmon can become disoriented in the presence of hydrocarbon concentrations ranging from 1.0 to 10.0 ppb. Disorientation is caused when salmon lose the homing cue, either from masking or impairment of chemosensory capabilities. Previous researchers of salmon migration in streams have found that when salmon lose the home cue, they have a negative rheotaxis and swim downstream until they find the home cue. Research conducted in a fjord system has shown that salmon with their olfactory nerves severed make large-amplitude vertical searches, whereas unaltered control fish make small-amplitude vertical searches during migration. In this study, adult pink salmon showed a similar disorientation behavior in the presence of oil-contaminated waters. Additional research is needed to confirm this response and to determine the effects on migration if the home cue is completely contaminated.

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Chapter 6

Fisheries Oceanography Coordinated Investigations (FOCI): Walleye Pollock Recruitment in the Western Gulf of Alaska

JAMES D. SCHUMACHER
NOAA, Environmental Research Laboratories, Pacific Marine Environmental Laboratory, 7600 Sand Point Way, N.E., Seattle, Washington 9811.5
and
ARTHUR W. KENDALL, JR.
NOAA, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way, N.E., Seattle, Washington 98115

6.1 INTRODUCTION

Fisheries Oceanography Coordinated Investigations (FOCI) is a NOAA program of applied research which began in 1985. It is a long-term, cooperative effort primarily between scientists at the Pacific Marine Environmental Laboratory of Ocean and Atmospheric Research, and the Alaska Fisheries Science Center of the National Marine Fisheries Service. Some research is funded by FOCI at other institutions, including satellite oceanography (A. C. Vastano, Texas A&M University) and zooplankton dynamics (L. S. Incze, Bigelow Lab; and P. Ortner, AOML/NOAA). The goal of FOCI is to gain an understanding of the influence of the biotic and abiotic environment on recruitment to various commercially valuable fish and shellfish stocks in Alaskan waters.

Most FOCI research has been conducted on walleye pollock spawning in Shelikof Strait (Fig. 6.1). The Shelikof Strait fishery was chosen for study because: (1) the spawning is of short duration and occurs over a small area when compared to other pollock spawnings; (2) there is a favorable signal-to-noise ratio in the resulting larval patch, which is relatively predictable in its time and place of appearance; (3) the abundance of larvae makes biotic studies (e.g., growth rates, mortality) feasible; (4) the structure and fate of the patch appears to be strongly influenced by upper-ocean dynamics; and (5) general aspects of the physical oceanography of the area are reasonably well known.

Variations in fish stock are thought to be related to events during the first few months of life as planktonic eggs and larvae. Although juvenile fish may not be directly affected by transport variations, the location where they spend their first summer results from their transport as eggs and larvae (Norcross and Shaw 1984). The pollock in Shelikof Strait spawn free-floating planktonic eggs (-1.8 mm diameter) near the bottom during spring in a small, well-defined region off Cape Kekurnoi. Eggs hatch after about 14 days and by early spring a patch of larvae forms, rises into the upper 50 m, and is transported to the southwest by the prevailing currents (Kendall et al. 1987). The larvae are 3-4 mm at hatching and grow to about 15 mm during an 8-week planktonic phase. The planktonic stages rely on physical processes for transport. The FOCI hypothesis is that survival is greatest for larvae and juveniles that remain in coastal waters along the Alaska Peninsula as opposed to those transported off the continental shelf. Survival is also influenced by physical and biological processes within the "larval patch," regardless of where it is transported.

6.2 PROGRAM HIGHLIGHTS

A detailed description of FOCI (Reed et al. 1988) and data reports (Wilson et al. 1986; Incze et al. 1987) are available. In this report, we summarize some past results and describe some recent and ongoing research. The hypothesis was a logical first step; however, there was only anecdotal evidence

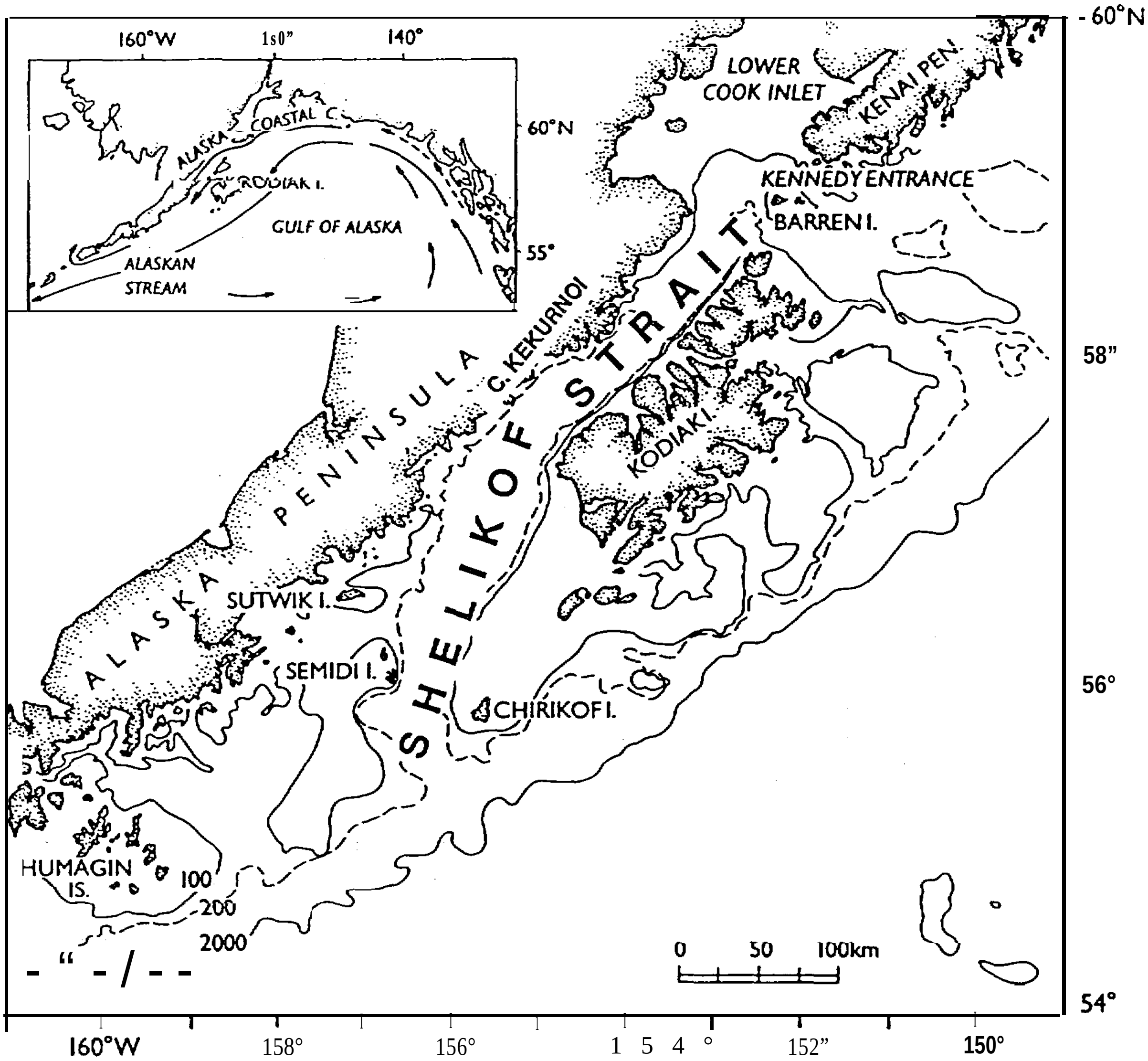

Figure 6. I —Bathymetric setting of the FOCI study area. Most observations were collected between 154° and 157° W, although some sampling has occurred from Kennedy Entrance almost to Unimak Pass. The insert shows the two major circulation features: the oceanic Alaskan Stream and the Alaska Coastal Current.

that the coastal region was a nursery ground for pollock. In addition to the yearly egg and larval surveys, late larvae/early juveniles were first sampled in 1987, and 18 satellite buoys were deployed to mimic larval drift (Hinckley et al. 1989). Late larvae/juvenile fish were found concentrated along the coast and their distribution was centered about 500-600 km southwest of their hatching site (Fig. 6,2). A trawl survey in August and September showed that the distribution had moved and was now centered about 100 to 250 km farther west (between Sanak Island and the Shumagin Islands). Comparing location of eggs to late larvae/juveniles, a drift of about 10 cm/s was inferred. A similar current speed was evident from satellite-tracked buoy trajectories with several buoys grounding in the Shumagin Islands approximately two months after deployment. Using- results from otolith analysis of samples from early and late surveys, estimates of mortality were made (Fig. 6.3). The relatively constant and reasonable estimates suggest the technique was stable and the requisite assumptions met. The marked increase in mortality rate for animals hatched on about 18 May indicates the possible impact of environmental factors.

The relation between estimates of age-3 pollock to the Shelikof Strait fishery and the Northeast Pacific

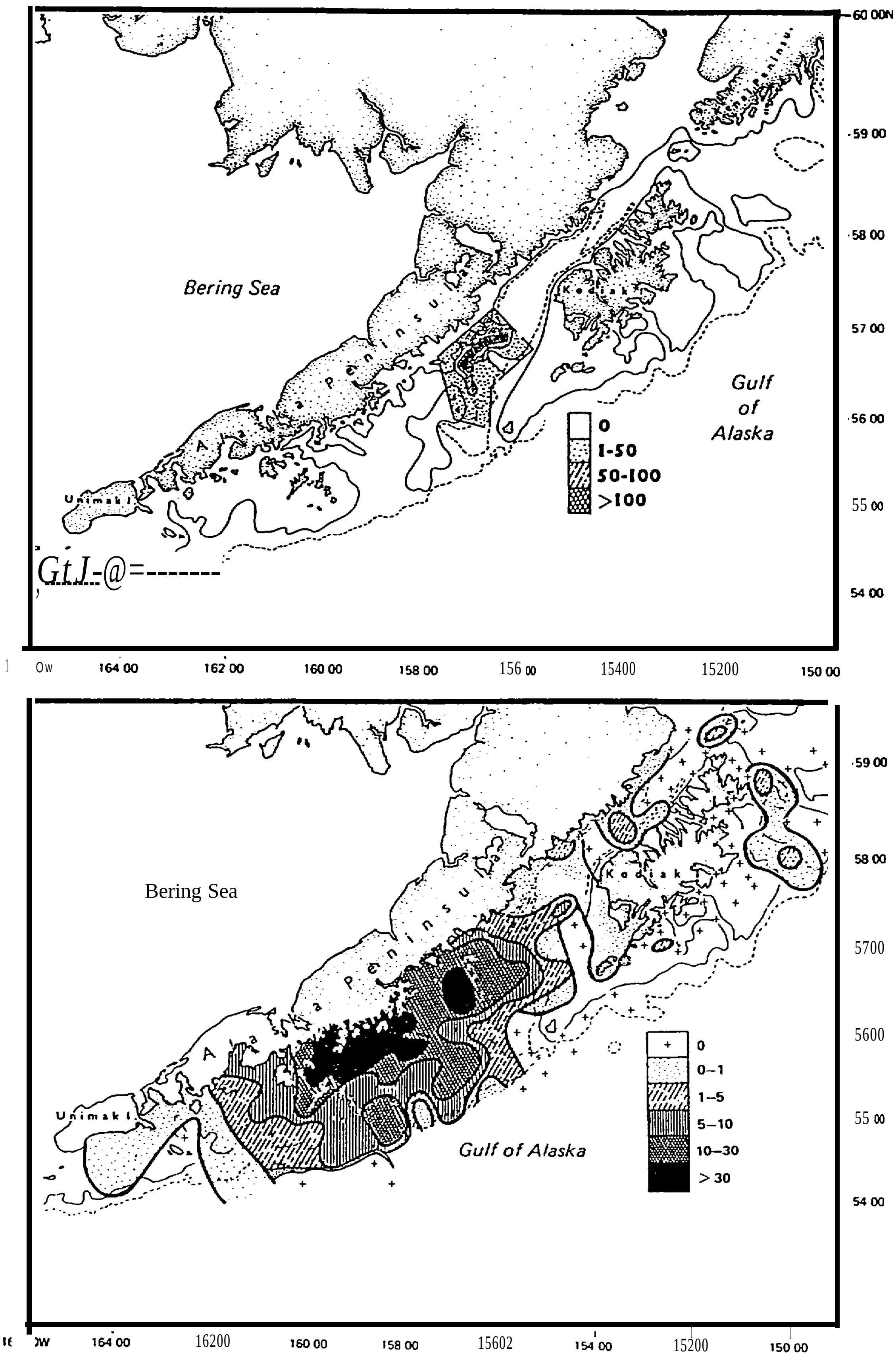

Figure 6.2—Distribution of larvae (per tow) 18–29 May 1987 (upper panel), and distribution of late larvae and juvenile fish (per 10 m^2) 17 June–16 July 1987 (lower panel),

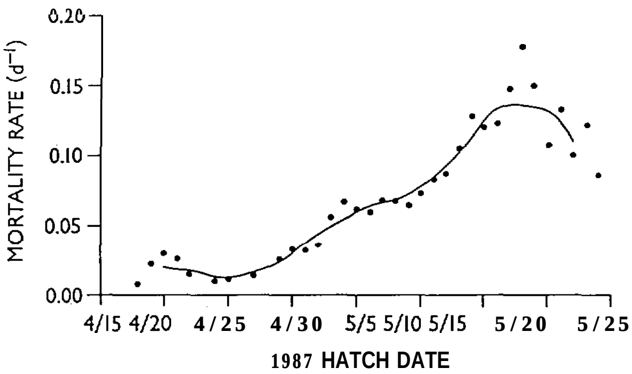

Figure 6.3—Mortality rate of pollock larvae as a function of hatch date for samples collected in May and in June-July of 1987. It is assumed that both surveys included all of the population (K. Bailey and M. Yoklavich, pers. commun.).

Pressure Index (NEPPI) is shown in Figure 6.4. NEPPI measures the strength and position of the Aleutian low-pressure area by comparing the pressure near Dutch Harbor, Alaska, with pressure over the western continental United States (Emery and Hamilton 1985). While there is not enough data on age-3 recruits to provide statistical significance, the relation suggests that as NEPPI increases, the number of age-3 recruits decreases. This implies good recruitment from spawning when the Aleutian low is weak, absent, or displaced.

While our focus is on impact of environmental conditions on recruitment, there are possible density-dependent variations (Megrey 1989). Studies of density-dependence as it affects egg quality have concentrated on egg size and reproductive output. Egg size was found to decrease from Shelikof Strait westward and to decrease over the time period of spawning within Shelikof Strait. Laboratory studies show that egg size is not strictly related to the size of the female and that egg size decreases by 11-13910 over the spawning period of an individual female. Comparing different years shows the largest eggs in 1981, smallest in 1982, and intermediate in 1984, 1985, and 1986. These interannual differences in egg size do not correspond with differences in stock biomass.

Three factors are thought to act singly or in some non-linear combination to affect survival of fish larvae: drift, predation, and food. Circulation in the upper 150 m is dominated by the Alaska Coastal Current (ACC), which meanders southwestward through Shelikof Strait and appears to bifurcate near the Semidi Islands (Schumacher and Reed 1986). Recent estimates quantify the partition: approximately 25'70 of the ACC continues along the peninsula, with the remainder flowing seaward (Schumacher et al. 1989); however, 67% of the seaward flow turns west south of the Semidi Islands. Larvae in this branch are not likely to be transported into oceanic waters. Buoys which were transported off the shelf have later entered the Bering Sea.

While transport of eggs is not presently considered a critical factor in survival, its possible affect is being considered. The buoyancy of pollock eggs at various stages was examined (Kendall and Kim 1989): eggs are relatively light just after spawning, become heavier and reside deeper in the water in middle stages, and become lighter and rise just before hatching. Due to the estuarine-like circulation (Reed et al. 1987), position in the strait will affect transport, with those hatching into larvae in the strong Alaska Coastal Current experiencing different dispersion than those that hatch into the weak flow shoreward of the ACC.

Between 1981 and 1985, spawner biomass and mean egg concentration in the region declined concordantly (Incze et al. 1989). Concentrations of larvae shortly after hatching, however, differed widely. There was no indication that the distribution or abundance of predators or prey were different in the two years. These observations suggest that physical processes were responsible for the lack of an identifiable "larval patch" of pollock in late May 1985. Apparently most of the emerging 1985 larval year-class was incorporated into the ACC and transported away from the coast (or at least outside the survey area). Analysis of long-term current records shows that each year the ACC attains mean speeds in winter/spring of 20 to 40 cm/s. Even at the lower limit, planktonic material would be transported offshore prior to development. Changes in the spatial behavior of the AC C are likely a more important factor in recruitment than are overall interannual differences in current speed.

Physical observations show two modes of larval transport in the region: the rapidly moving Alaska Coastal Current, and the weak mean flow toward the southwest shoreward of the ACC (Kim and Kendall 1989). Larvae shoreward of the core of the ACC will remain on the shelf through development. Satellite infrared (AVHRR) images from several

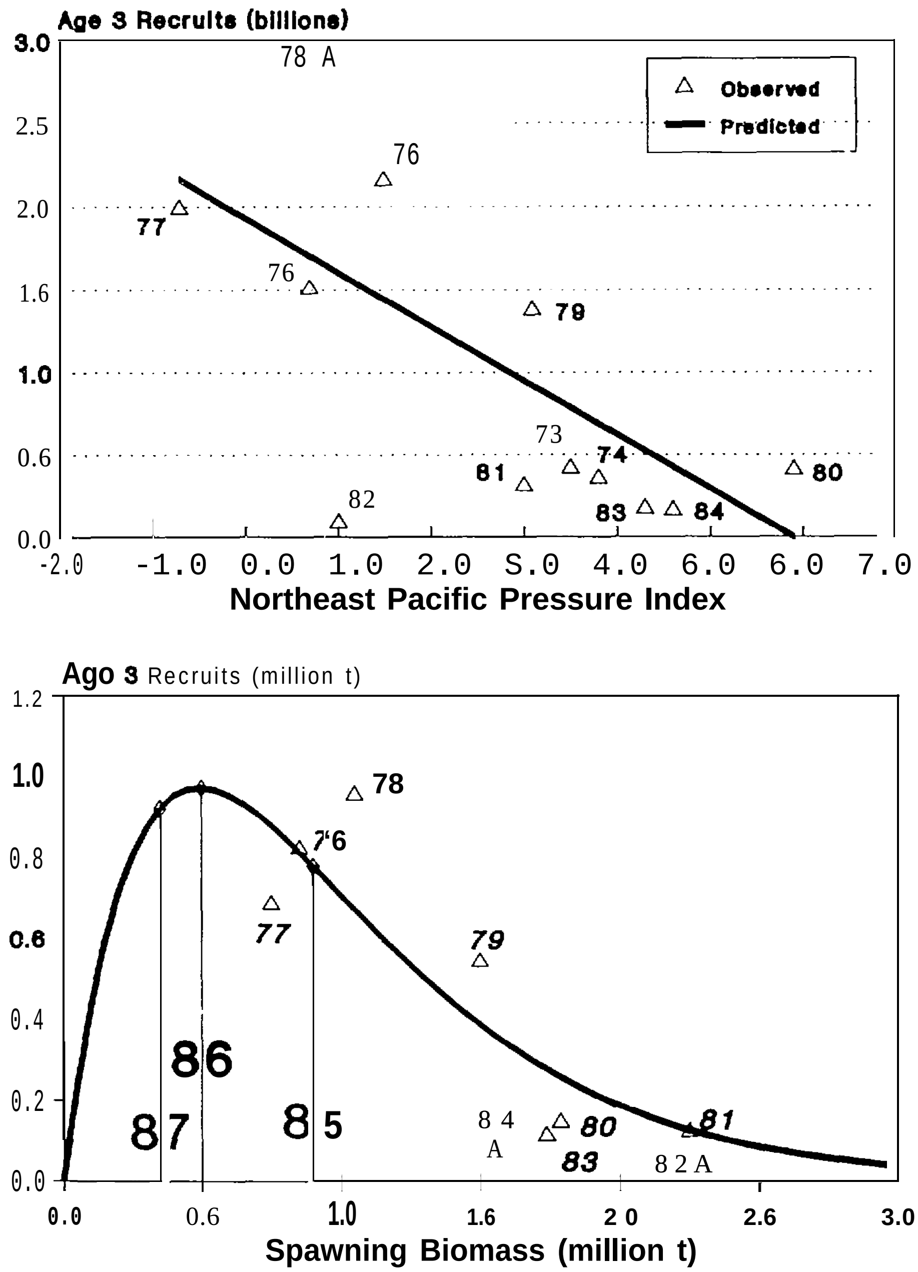

Figure 6,4—Relationship between age-3 recruits and NEPPI (upper panel) and between age-3 recruits and spawning biomass (lower panel), For 1985 to 1987, estimates of age-3 recruits are not yet available.

years indicate that eddies are present. Eddies provide a mechanism to both aggregate larvae anrl to retain them on the shelf.

These features are likely related to the baroclinic instability (Mysak et al. 1981) and may be enhanced by the complex winds (Fig. 6.5). Such winds also cause pulses in volume transport (Schumacher et al. 1989) which, in turn, may induce spatially complex features in the velocity field. Using data from 20 occupations of a CTD transect across lower Shelikof Strait since 1985. and carefully selecting a level of no motion, the mean volume transport was estimated to be 0.58 x 10^6 m^3/s. Based on data since 1976, bottom water properties varied considerably; in particular, relatively cold, fresh water was present during much of 1986 (Fig. 6.6). Abnormally cold conditions may affect egg development and adult pollock growth and maturation.

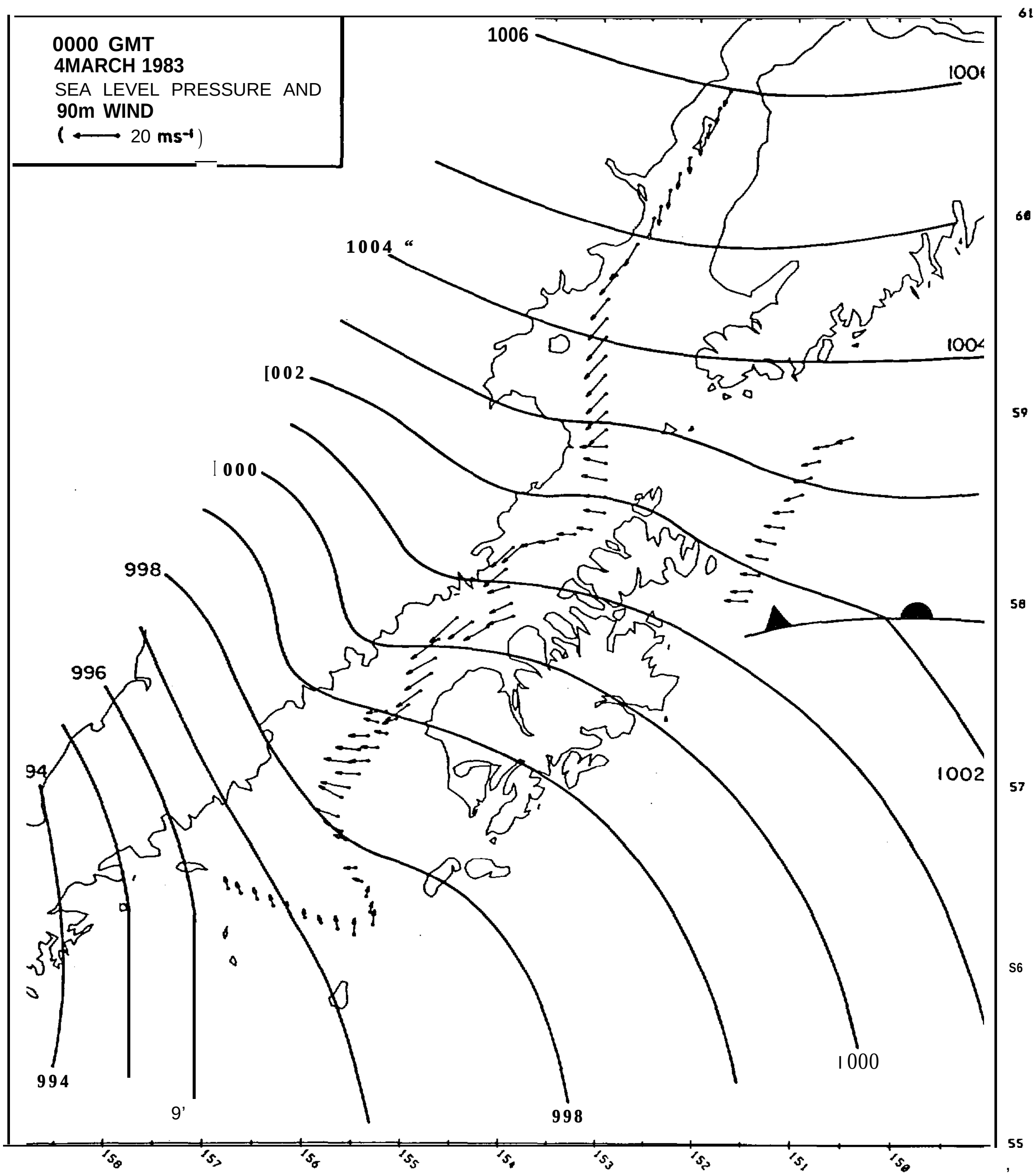

Figure 6.5—Winds measured from a NOAA aircraft, Note how the wind direction changes from nearly along the isobars to across isobars between the Alaska Peninsula and Kodiak Island.

Observation of predation on larval fish is an extremely difficult problem (Hunter 1981). Biochemical techniques assist in recognition of specific fish proteins in the stomachs of field-caught invertebrate predators (Theilacker et al. 1986). An antibody probe for egg yolk proteins in predator guts was developed in 1987 and tested in the field in 1988. We determine the distribution and abundance of these predators from plankton samples. This should enable us to determine the predatory impact on pollock larvae and, through an understanding of the biology of the predators, ultimately address the question of interannual variation in predation on larval stages.

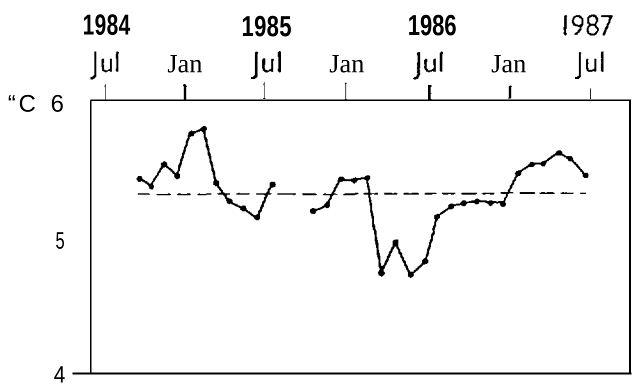

Figure 6.6—Time series plot of monthly mean temperature measured within 15 m of the bottom of the sea valley between the Semidi Islands and Chirikof Island, Instruments were either current meters or water level recorders (Reed and Schumacher 1989).

Nutrition of larval fish has been the most extensively investigated part of their biology (Hunter 1981; Cushing 1983; Paul 1983). Although an inadequate food supply may lead directly to starvation. it may also slow growth rate and thus increase vulnerability to predation. Several approaches within FOCI investigate nutrition of larvae, how to measure it and reasons for its variations. Criteria were developed in 1988 for determining larval condition using histology, morphology, and RNA/DNA. The RNA/DNA analyses of 1987 and 1988 have been completed, Age and growth rate, as measured by daily increments on larval otoliths, is another technique that will be applied to estimate nutrition of larvae and provide evidence of other aspects of their history (Brothers and McFarland 1981; Walline 1985). These analyses have been completed for the years 1983, 1985. 1986. and 1987.

The kinds of food (generally copepod nauplii for small larvae and small copepods for large larvae) available and eaten by larval pollock continue to be investigated by examining stomach contents of larvae and field collections of zooplankton and microzooplankton. The distribution and production of food organisms are related to oceanographic conditions and the distribution. growth, and apparent nutritional health of larvae. Experimental laboratory studies of energetic and electron transport system activity were conducted in 1988. Laboratory work on feeding mechanisms and other aspects of larval behavior is currently under way.

An ongoing effort exists to ensure collection of quality data. Making accurate measurements of currents in the FOCI study area is confounded by surface-wave activity and biological fouling. Current data from three different instruments (Aanderaa RCM-4 with Savonius/paddle wheel rotors and Neil Brown ACM) moored at shelf and slope locations were compared (Stabeno and Spillane 1989). For depths less than about 100 m, it appears that the paddle-wheel has a much better response (compared to the ACM) than the Savonius rotor (Fig. 6.7). Experiments to determine how to best catch late larvae and early juveniles showed the Methot net was the most effective device. A considerable effort is devoted to statistical interpretation of field samples of eggs and larvae as they are used to estimate distribution and abundance.

6.3 FUTURE PLANS

Efforts to gain better understanding of pollock spawning and egg and larval development will continue through field and laboratory studies. Particular emphasis will be on nutrition of larvae. Although relatively large-scale forcing appears to be important, we now recognize that smaller features may also have major impacts. Particular emphasis will be placed on matching mesoscale space and time scales of circulation with biological processes. Attempts to derive detailed data on horizontal divergence of velocity are also planned. Quantitative satellite analyses will use a sea surface temperature imagery to provide estimates of fronts and eddy features and sea surface flow distributions.

During 1989, field operations included (1) continuation of the time series of egg and larval distribution, water properties, currents and meteorological data: (2) experiments to examine physical property and biological (including secondary production rates) differences between Alaska Coastal Current and coast waters; and (3) deployment of an array of 10 moorings (including a surface meteorological buoy and two Doppler acoustic current profilers) off Wide Bay to examine lateral larval dynamics. Conceptual integrated models of biological and physical processes are being developed and will be followed by more sophisticated, numerical efforts, Finally the understanding gained will be provided to those responsible for managing the pollock fishery in the Gulf of Alaska.

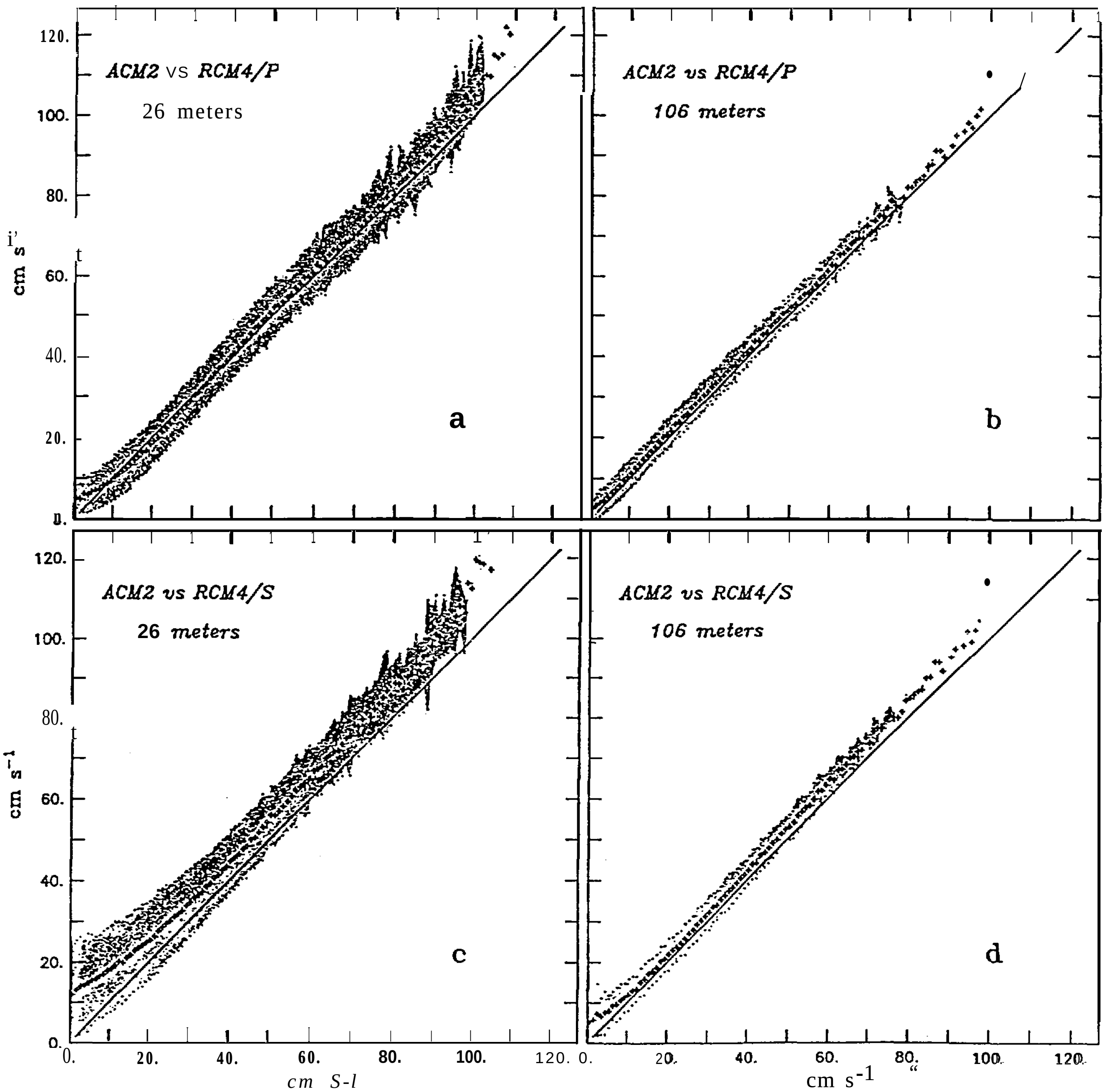

Figure 6.7—Mean speeds of Aanderaa current meters equipped with standard Savonius rotor (RCM4/S) and with a new paddle rotor (RCM4/P) as a function of an acoustic current meter (ACM). Number of points in each subset: (a) 20,125, (b) 13,972, (c) 27,580, and (d) 6,860. The shaded area contains more than 90 % of the data (Stabeno and Spillane 1989).

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Chapter 7

Effects of Habitat and Environmental Variables on Red King Crabs, and Settling of *Glaucothoe*

STANLEY D. RICE and MALIN M. BABCOCK
NOAA, National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory, P. O. Box 210155, Auke Bay, Alaska 99821

7.1 INTRODUCTION

Bering Sea red king crab (*Paralithodes camtschatica*) populations crashed in the early 1980s. There is considerable speculation on the causes of the population decline. Understanding of the population dynamics of king crabs is limited by the lack of biological knowledge, particularly for the larval and juvenile life stages. The impacts of environmental and habitat variables on the early life stages remain largely unknown.

The objectives of this research were to determine the role of environmental and habitat variables on red king crab eggs, larvae, and juveniles. Many of these variables influence year-class strength. Adults were not the focus of the study, except for ovigerous females that were incubating eggs. Both laboratory and field studies were conducted at Auke Bay. southeast Alaska.

A comprehensive report detailing the results of our research on red king crabs is scheduled to be finished in spring 1990.

7.2 EFFECTS OF ENVIRONMENTAL VARIABLES

7,2.1 Egg-Adult Studies

Two studies focused on the environment of eggs: the long-term incubation of eggs at different temperatures, and the seasonal migration of ovigerous female king crabs in Auke Bay.

Incubation and temperature.—In this study, our objectives were to determine the hatching time of eggs and viability of larvae after long-term incubation of ovigerous crabs at various constant temperatures.

Ovigerous crabs were held at constant temperatures (0, 3, 6, 9, and 12°C) for up to 1.5 years in the laboratory Eggs were sampled and staged every 2 weeks, and hatching times and larval viability were monitored.

Development of the egg stages was linear and proportional to temperature, but hatch date was not. Eggs of crabs held at 12° C developed at the highest rate. but hatching was delayed and viability at hatch was poor. Development at 3, 6, and 9°C was normal. The difference in hatch times between eggs held at 3 and 6°C was 10%, while hatch times of eggs at 9°C were 25 % different from those held at 6°C. The eggs held at O°C began to hatch at 1.5 years; however, several of the adult females molted before egg hatch, and their clutches remained with the old exoskeleton and died.

Small differences in environmental temperatures outside of 3–6° C may cause significant differences in hatch time. The environmental temperatures for ovigerous king crabs are being monitored in the tracking study and will be compared to the laboratory test.

Migration of ovigerous **crabs.**—Female red king crabs are reported to attain sexual maturity at an age of 5.5 years and a carapace length of about 95 mm, although the age and size at sexual maturity may be a function of latitude. These primiparous spawners generally produce fewer larvae than multiparous females, which have been sexually mature for more than 1 year. Laboratory studies have shown a significant relationship between size of females and time of larval release. A similar relationship exists for body size and time of molting, with the smaller primiparous females molting and mating earlier than larger females. These data agree with field observations of primiparous females being courted in shallow water a month before multiparous females. Although female red king crabs display strongly synchronized seasonal reproduction. the relationships just described suggest that the timing of reproductive events in the two groups of females is not identical, and that the patterns of migratory behavior may also differ.

A l-year study was initiated in May 1988 to describe the seasonal migration of female red king crabs. The primary objectives of this study were (1) to determine the patterns of migration of female red king crabs, (2) to compare the migratory patterns of primiparous and multiparous females, and (3) to identify the main environmental correlates of crab movements.

The physical and environmental parameters of Auke Bay are similar to those of several areas of historical red king crab abundance and commercial importance and may therefore serve as an appropriate model for the study of red king crab migration.

Ultrasonic tags with a 2-year life expectancy were attached to the carapace of 10 primiparous females (carapace length = <108 mm) and 10 multiparous females (CL = >124 mm). The two groups have been tracked weekly using an ultrasonic receiver and directional hydrophore since their release in late May and early June 1988, respectively. The relative position and depth of the crabs are recorded, and bottom water samples are collected near individual crabs or groups of crabs to determine water temperature and salinity. The following results are from the first 6 months of this l-year study.

Preliminary results indicate a difference in migratory behavior between primiparous and multiparous females. Primiparous crabs, which were released at a site toward the entrance to the bay, split into two main groups by midsummer. One group migrated about 5 km from the bay to an area of Stephens Passage where depths exceeded 100 m. They remained in this area of deeper water throughout the summer and early fall. In October they began to move into shallow water areas in the direction of their initial release. The second group of primiparous crabs migrated into Auke Bay and has occupied areas overlapping or adj scent to the areas occupied by multiparous crabs.

The multiparous crabs were released at the head of the bay and have remained within 3 km of their initial release. They formed a large aggregation in the deeper water of the bay and remained there throughout the summer and early fall. In October the multiparous crabs began to move into the shallow areas of the small islands and reefs within the bay.

Both groups of primiparous crabs occupied depths that on average were greater than those occupied by multiparous crabs throughout the 6-month tracking period. The timing of the movement of all three groups of crabs into shallow water appears to have been highly synchronized in late October.

Water temperature, which is a function of depth, shows a similar relationship among the three groups of crabs. Both groups of primiparous crabs occupied colder water than the multiparous crabs throughout the 6-month period. The multiparous crabs occupied areas with a mean water temperature during this time of 6.5 ‘C, while the two primiparous groups occupied areas with mean water temperatures of 6.3 and 6.1°C. The movement of all crabs to shallower water appears to occur during the period when thermohaline mixing or vertical mixing of the entire water column, a phenomenon typical of higher latitudes, occurs.

Data from the first 6 months of tracking indicate that (1) female red king crabs form aggregations and that they migrate in groups, and (2) red king crabs seem to have a preference for certain locations within an area.

7.2.2 Larvae Studies

A series of larvae studies investigating behavioral movement capacities, physiological tolerances, and diel movement patterns was conducted by Thomas C. Shirley and Susan M. Shirley, University of Alaska Southeast. These studies linked laboratory and field data.

Temperature and **salinity.—**A series of tolerance and preference tests were conducted for stage I and II zoeae exposed to a matrix of temperatures and salinities. Each test utilized over 3,000 larvae.

Larvae showed thermal tolerance for water temperatures up to 15 ‘C, and reduced survival in salinities below 25 ppt. There were no horizontal or vertical temperature preferences. Larvae responded to dilute seawater, sinking through dilutions less than 27.5 ppt.

Phototaxis, **geotaxis, rheotaxis.—Larvae** were positively phototactic, down to low light levels. Phototaxis was dominant over geotactic and rheotactic responses. Swimming speeds measured in the laboratory were about 4 times the rate needed to explain diel movements in the field.

Vertical **movements.-Two** replicate tows at each of six depths (open/close nets) were conducted in Auke Bay at 4-hour intervals for 24 hours. These tows were repeated weekly during the summer. Crab larvae were identified and enumerated by species, stage, depth, and hour. King crab larvae had a definite diel pattern: they rose in the water column during the day (positive phototaxis), and sank during the dark periods. Larvae were not found in the surface waters, which were typically below 25 ppt salinity. Concentrations of larvae declined at depths of 20 and 30 m.

7.3 HABITAT, COHORT DENSITY, AND DIET

7.3.1 Habitat and Cohort Density

Young-of-the-year (YOY) red king crabs are naturally well spaced in intertidal areas or in habitat that provides cover, while 2-year-old and older crabs often congregate in large pods. When being held in the laboratory, YOY crabs often cannibalize molting individuals. Cannibalism occurs less often among older individuals. We undertook experiments to determine habitat preference and effects of habitat and cohort density on growth and survival. Both tests were conducted on two ages of juvenile king crabs.

Habitat **preference.—**Young-of-the-year (carapace length = 6-13 mm) habitat preference tests were conducted in five fiberglass tanks with translucent fiberglass covers. Each tank was divided by screens into three sections. Each of these 15 sections provided crabs a choice of four out of five habitat types closely resembling habitat encountered by juvenile crabs in their natural environment: (1) sand, 3 cm deep; (2) shell hash covering 100% of the sand base; (3) shale fragments covering 100 % of the sand base; (4) cobble covering up to 50'% of the sand base; and (5) bryozoan and hydroid assemblages (*Dendrobeania murravana, Microporina articulate, Sertularella* sp., *Sertularia* sp.). Crabs were introduced into the center of the tank sections, ensuring uniform access to the four habitats.

The tests with 2- to 3-year-old crabs (initial carapace length = 23–38 mm) were similar, except that 122-cm-diameter fiberglass tanks were used. Twelve 24-hour trials were conducted. Crabs were not fed during the tests, but some naturally occurring food may have been available in the bryozoan–hydroid habitat.

We also tested the effects of starvation on habitat preference. During each run the location of each crab and its degree of cover were recorded every 3 hours after a l-hour adjustment period.

Both ages of crabs preferred the bryozoan assemblages over the other habitat substrates, and sand was the least preferred. For YOY crabs tested individually, 53 % (± 4.39ZO) chose bryozoans overall, while crabs tested at a cohort density of four chose bryozoans 437. (± 2.3%) of the time. Sand was chosen 1.5% (±1.2%) and 5% (±1.2%) of the time, respectively. YOY crabs were more exposed at night compared with daytime observations (74.8 % vs. 38.4 %). Activity (as measured by whether an individual had changed position from the previous observation) was significantly higher at night than in daylight: 83% (~ 6.6%) were active at night, and 73 % (~ 7.2 %) during the day. Starved YOY crabs showed preference patterns similar to the control crabs; however, they were more often exposed during daytime observations (51% [± 6%] versus 447o [± 770] for controls). The 2- to 3-year-old crabs clearly preferred the bryozoan assemblages or cobble, regardless of cohort density. At the lesser density of four cohorts, bryozoans were the unequivocal favorite (47 % ± 4%), while in a more crowded situation (density = 12), crabs selected bryozoans and cobbles equally (32% and 31%). Even the starved 2- to 3-year-old crabs (density = 12) preferred the bryozoan assemblages.

Clearly, habitat with some amount of cover, providing protection from predation, is important to both ages of crabs tested. During periods of darkness, crabs are somewhat more dispersed over available habitat, more likely to be exposed (and vulnerable to predation), and more active than in daylight hours. Hungry crabs also tend to be more dispersed, exposed, and active. Habitat where these crabs, as glaucothoe, settle out of the water column is extremely important to survival, and alteration or loss of suitable habitat providing protection (and food) for very young juvenile red king crabs can only have a negative effect on the population.

Habitat and cohort **density.—**We maintained groups of 3, 7, or 11 crabs on sand, cobble, or plastic “plants,” testing YOY and pod-crabs, to monitor molting success, growth, and cannibalism. Crabs were fed a rotating diet suggested by the diet study results (see below). They exhibited less cannibalism than expected, and habitat cover or cohort density had little effect on their survival and growth. When crabs were not fed shrimp, however, cannibalism of molting individuals increased, particularly in the 2- to 3-year-old crabs. Therefore, diet may play a more important role than habitat and cohort density in promoting survival and reducing the incidence of cannibalism.

7.3.2 Diet

Effects on growth.—Juvenile king crabs are opportunistic omnivores: reported stomach contents include almost everything that lives in the same areas as the crabs and that would leave recognizable stomach contents. The objective of this study was to determine effects that limitations on variety of prey could have on king crab growth. Groups of 20 crabs were maintained on one of eight diets for two full intermolt periods and growth rates were then compared. Diets were: (1) shrimp, (2) herring, (3) clam, (4) squid, (5) all of the preceding, (6) all of the preceding plus kelp, (7) commercial shrimp-food pellets, and (8) starvation.

Significant differences in growth followed this order: shrimp = mixed = mixed plus kelp = herring > squid = clams > food pellets > starvation.

Crabs that showed greater growth and number of molts also had shorter intermolt times. Starved crabs did not molt, but did not die either (all eight survived for 3 months; six survived 4 months). Herring was associated with higher mortalities despite being a good growth diet. The more association crabs had with herring, either as all or part of their own diet or as all or part of the diet of other crabs in the same tray, the greater their risk of death. This increased mortality probably results from fish oil clogging the gills or acting as a substrate for bacteria.

Diet greatly affects growth rates in juvenile king crabs. For all laboratory studies, shrimp should be included in the diet but herring should be avoided. Researchers should be cautious about between-test comparisons of growth because diet is an easily overlooked variable. In the real environment, these results imply that there could be serious negative effects on juvenile king crab growth (and therefore recruitment) if the variety of foods is restricted.

Effects on cannibalism.—From the results of the habitat/density tests and the diet test discussed above, we attempted to determine if diet really does mediate cannibalism. We reared six groups of 10 YOY crabs on each of two diets: (1) shrimp (a "good" growth diet), and (2) mussels (a "poor" growth diet; see clams, above). Crabs were then monitored for incidence of cannibalism and rate of growth. We also maintained 16 isolated crabs on each diet to see if inability to augment the provided diet by cannibalism affected growth. Diets were switched after 112 days to see if effects were reversible. Two- to three-year-old crabs were tested in three groups of eight crabs per diet.

Surprisingly, mussels proved to be a better diet than shrimp: significantly more cannibalism was observed in crabs maintained on shrimp than on mussels. Reversing the diets at 112 days reversed the incidence of cannibalism. Results for 2- and 3-year-old crabs were less clearly defined, but similar. Growth was significantly reduced and intermolt time was significantly longer for isolated shrimp-eating crabs (absence of crab meat in diet) than for isolated mussel-eating crabs or the grouped crabs on either diet. A "poor-growth" diet leads to cannibalism in juvenile king crabs. Augmenting "poor-growth" diets with cannibalism increases growth of the survivors.

7.4 SETTLING OF GLAUCOTHOE

In assessing our research program to understand more about critical environmental and habitat requirements in red king crab larvae and early juvenile stages, it became apparent that a missing piece in the puzzle is the transition from stage 4 zoea (pelagic) to glaucothoe to first instar (benthic). As a first step in studying this process, we designed a small project to determine the most effective substrate collectors for capturing the settling glaucothoe stage.

Collectors were deployed at the northeast and northwest corners of Auke Bay, Alaska, These sites were chosen primarily because numerous juvenile king crabs from the previous year's settlement were observed there during January–April 1988, and we surmised that early instars of king crabs do not migrate far from the initial point of settlement. In addition, the benthic substrate at both sites afforded abundant cover for newly settled crabs. Scuba divers deployed collectors at 8.3 m and 2.3 m below mean lower low water (MLLW) at site A; collectors at site B were deployed a 3.8 m below MLLW.

Five collectors of each design (see below) were deployed at each depth. They were attached to concrete block anchors with 5-mm polypropylene cord fitted with brass snap links. The collectors were buoyed 0.8 m above the bottom of the bay by plastic floats attached to polypropylene cord fitted with snap links.

The box-type collectors were constructed of 6-mm-mesh galvanized hardware cloth and were filled with (1) ''Tuffie''* pot scouring pads, (2) Penn Plax ' 'Aqua Plant" plastic aquarium plants, or (3) American Air Filter ' 'Amer-glas'' furnace filters. Plate-type collectors were constructed of 6-mm-thick PVC sheeting covered with either indoor-outdoor carpet or fine mesh plastic screening. Screened-plate collectors (4) had Penn Plax ''Baby Hide Out" plastic aquarium plants fastened to them; carpeted-plate collectors (5) had Fritz ' 'Breeding Grass" fastened to them.

Scuba divers deployed collectors in mid-May 1988. Collectors were monitored approximately once a week, and samples collected were examined in the laboratory.

A total of 34 glaucothoe and instars (plus one glaucothoe molt) were collected. Artificial plants and Baby Grass were most successful, with 10 individuals found on each type (59% of total). Another seven individuals were found on Tuffies substrate (21 % of total); the remaining seven individuals were found on Astroturf with tufts and the furnace filter collectors.

The first glaucothoe was collected on 27 May 1989. Twenty-two were found on the collectors 9-30 June, representing 65% of the total collected during the experiment. The last were collected 8 August. Of the 34 specimens collected, 18 (53%) were glaucothoe, 13 (38%) were first (Cl) instars, and three individuals (9%) were second (C2) instars.

During the spring and summer of 1989, we plan to expand this study using the successful collectors to focus on the timing of settlement, location, and habitat in the vicinity of the occurrence of settling.

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* Use of brand names does not imply endorsement by the National Marine Fisheries Service.

Chapter 8

Dietary Composition and Daily Ration of juvenile King Crab in the Southeastern Bering Sea

W. H. Pearson, D. L. Woodruff

Battelle Pacific Northwest Laboratories, Marine Sciences Laboratory, Sequim, Washington 98382

and

Bruce J. Higgins

Marine Concepts, Inc., Seattle, Washington

8.1 INTRODUCTION

This project was initiated to determine how petroleum contaminants could impact the commercially valuable crab resources of the southeastern Bering Sea. The main objectives were (1) to determine the food requirements of juvenile red king crab, *Paralithodes camtschatica,* and Tanner crab, *Chionoecetes bairdi,* in the waters north of the Alaska Peninsula; and (2) to assess potential impacts from Outer Continental Shelf (OCS) development (Pearson et al. 1984).

The project entailed several tasks: the location and collection of crabs, shipboard experiments on stomach clearance rates, 24-hour trawling to determine a diel feeding chronology and daily ration, determination of the carapace size-stomach volume relationships, visual examination of stomach contents, calculations of dietary composition, and construction of a caloric intake schedule.

Because crabs grind food with their gastric mill, difficulties in identifying prey have confounded other food habit studies of king and Tanner crabs (Tarverdieva 1976, 1978). In this study, however, prey types not detectable by traditional stomach analysis were identified by an immunoassay of stomach contents. This and other techniques were used to assess and correct various biases in conventional food habit studies designed to study the composition of crustacean diets.

8.2 LOCATION OF JUVENILE CRABS

For the project, three cruises north of the Alaska Peninsula were conducted by NOAA vessels in June, August, and October 1982 (Fig. 8.1). Juvenile red king crab (carapace length [CL] >40 mm) were concentrated off Port Moller, whereas juvenile Tanner crab (C. *bairdi*, carapace width [CW] <20 mm) were concentrated in the Amak Island-Black Hill region. Juvenile tanner crab, C. *opilio,* were not found in the study area.

Juvenile Tanner crab, C. *bairdi,* were most abundant near Amak Island at depths of 55-65 m in June, 65-75 m in August, and over 80 m in October. Essentially all (98%) of the tanner crab collected were less than 20 mm CW.

Juvenile king crab (50-80 mm CL) were concentrated off Port Moller and Cape Seniavin. In June, August, and October, only adult king crab occurred west of Nelson Lagoon. Off Port Moller, juvenile king crab were deeper in August (65-75 m) than in June (55-65 m). In contrast to the hundreds of juvenile king crab taken off Port Moller in June and August, only one was taken in October. Daylight television camera tows off Cape Seniavin and Port Moller revealed that juvenile king crab occurred on sandy bottoms where large numbers of ascidians and sponges were growing on the large tubes of polychaete worms. The crabs were solitary, not aggregated or podded.

Although most of the juvenile king crab collected ranged in size between 50 and 80 mm CL, a small number measuring less than 20 mm CL were collected by divers or trawls in rocky areas off Nelson Lagoon and near Amak Island. Other OCSEAP-sponsored studies found higher abundances of the smallest juvenile king crab (CL <30 mm) in the inner parts of Bristol Bay in shallow nearshore areas

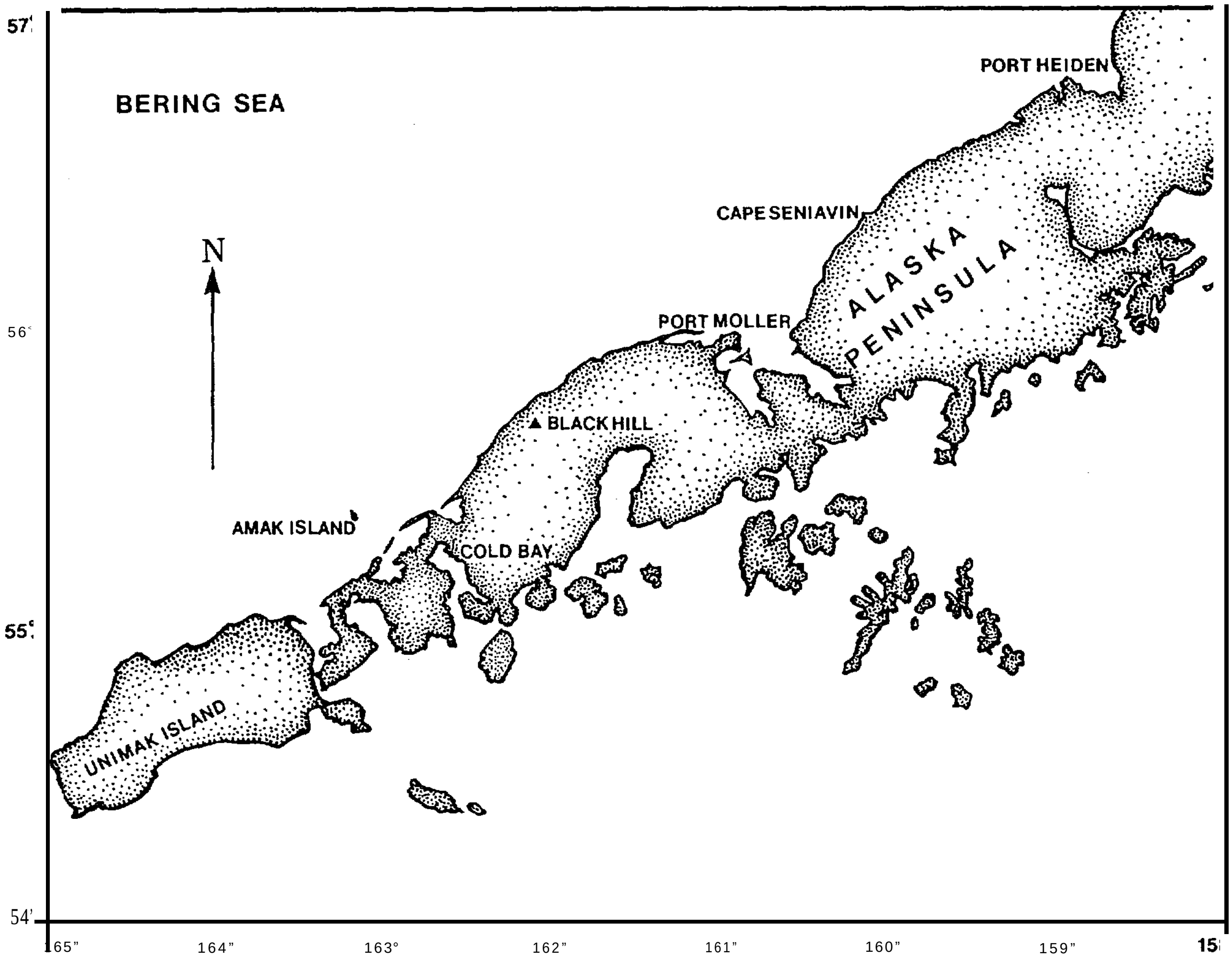

Figure 8. I —The study area in the southeastern Bering Sea.

amongst cobble and rock with abundant epifauna (McMurray et al. 1984).

8.3 FOOD REQUIREMENTS

8.3. I Shipboard Experiments

Shipboard experiments showed that multi-compartmental exponential decay models described the evacuation of stomach contents in juvenile king crab. Figure 8.2 is a plot of the decay in dry weight of the naturally occurring stomach contents as a function of time. Stomach residence times calculated from these models vaned with prey type from hours to days (Table 8.1). Soft-bodied prey items (clam meat and polychaete worms) were reduced to 10 % of their original dry weight in less than 11 hours, whereas prey items with hard body parts (shrimp, barnacles, and fish) were reduced to 10% of their original dry weight only after 1 to 2 days.

Power laws described the relationships between carapace size and maximum stomach volume in both king and Tanner crabs. For the king crab, the power function relating maximum stomach volume (V in ml) to carapace length (L in mm) was:

$$V = 2.22 \times 10^{-5} L^{2.87}$$

For the Tanner crab, the power function relating maximum stomach volume (V in ml) to carapace width (W in mm) was:

$$V = 2.68 \times 10^{-5} W^{2.69}$$

These equations differ substantially in mathematical form from that given by Cunningham (1969) and cited and used by Jewett and Feder (1982) for adult king crab. They used quadratic best fits derived from a more restricted range of data. Our power functions are consistent with the general finding that

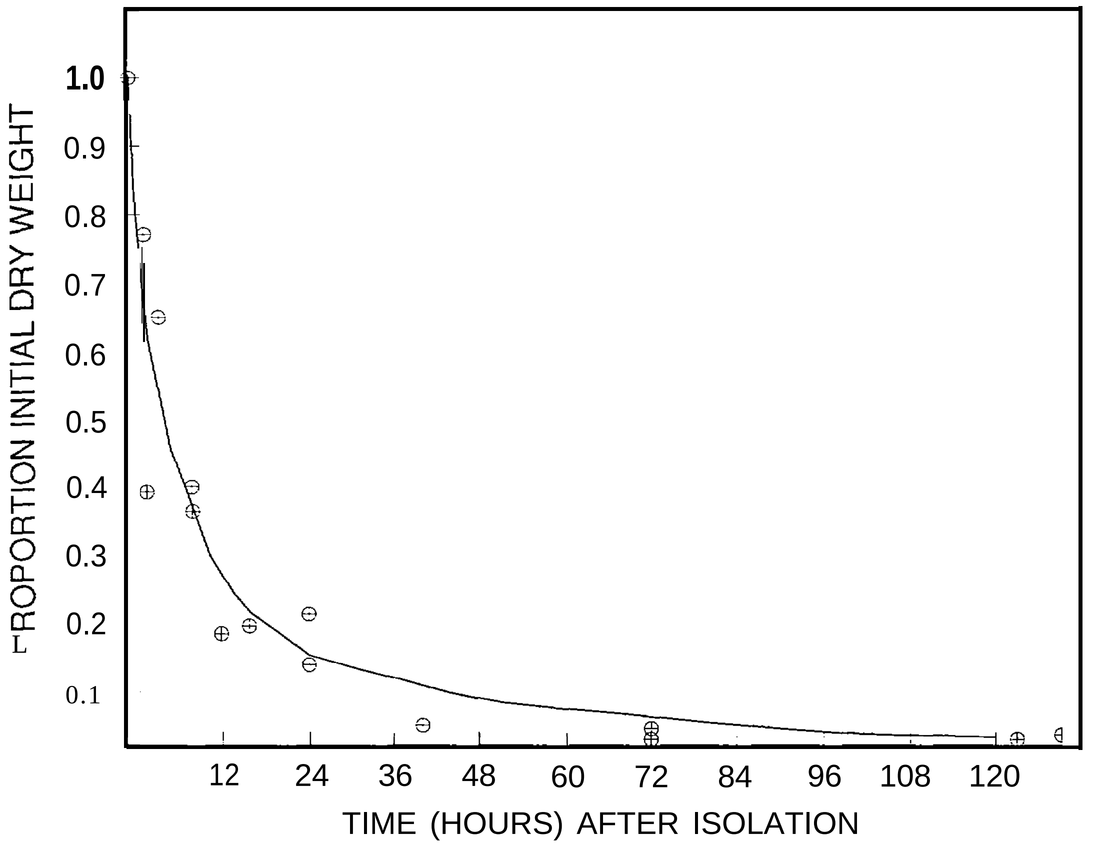

Figure 8.2—Decay curve for the clearance of all items naturally present in the stomachs of juvenile king crab. The proportion of the initial value for dry weight of stomach contents (g dry weight/g crab wet weight) is plotted against time (hours after isolation).

Table 8. I —Stomach clearance rates for specific prey items fed to juvenile king crab. Mean life is the reciprocal of the decay constant.

Prey	Compart-ment mean life (h)	Time (h) to 107C of initial dry weight	Time (h) to 5% of initial dry weight
Diced clam	2.0 4.5 x 10^5	6.1	asymptotic to 5% at 11 h
Shrimp	3.7 44.5	37.5	68.5
Barnacle	4.4 7.8 3.0 x 10^4	asymptotic to 20% at 48 h	
Juvenile fish	0.7 8.2 172.0	26.5	129.5
Tube worm	4.9	10,8	14.2

power functions describe allometric relationships in crustaceans.

8.3.2 Diet Feeding Chronologies and Daily Ration

In the diel feeding chronologies for juvenile king crab (53–80 mm CL) in June and August, peaks in dry weight of stomach contents indicated two feeding periods, midnight to 0800 hours and 1300 to 1800 hours (Fig. 8.3). Although the diel feeding chronologies were similar in June and August, the average amount of food in the stomach was higher in August.

Using the diel feeding chronologies and a multi-compartmental exponential model for stomach evacuation, the daily rations of juvenile king crab were calculated to be 6.30 and 11.92 mg dry weight per gram of crab wet weight per day in June and August, respectively. The daily ration determined by Tarverdieva (1978) for adult king crab was 3.1 mg/g crab wet weight, about one-quarter to one-half

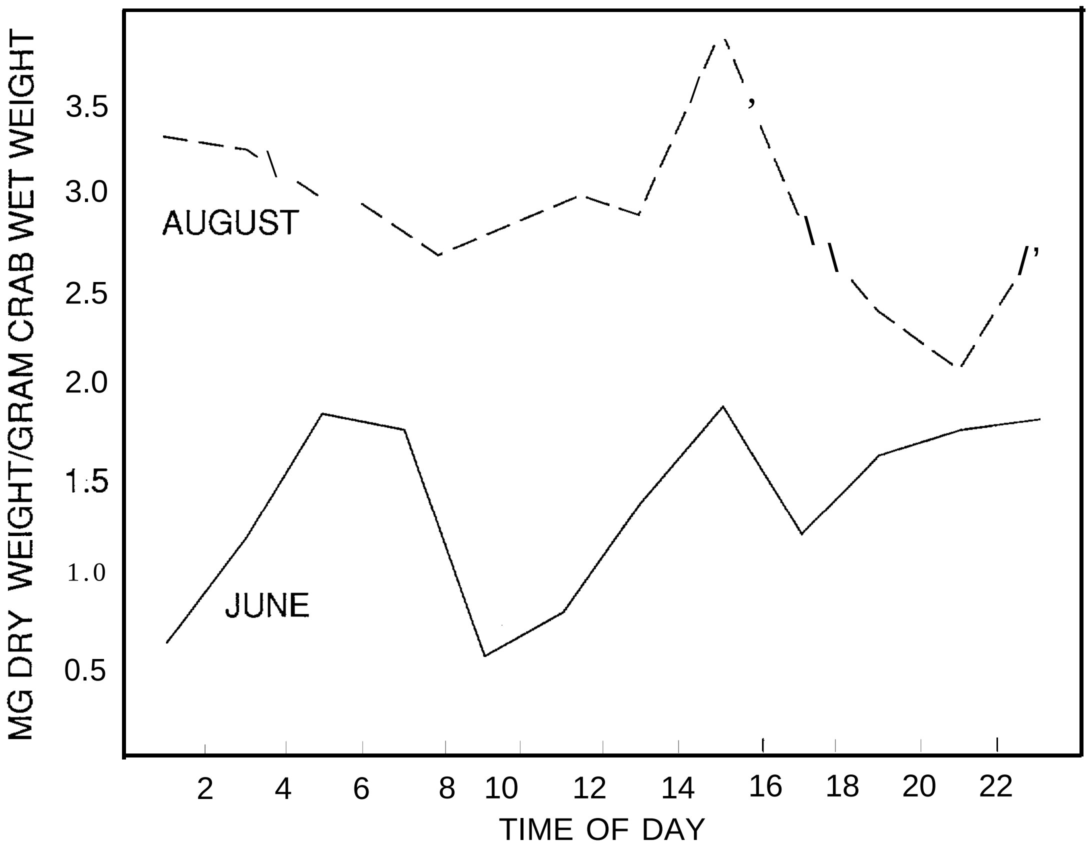

Figure 8.3—Standardized dry weight of stomach contents (mg dry weight/g crab wet weight) versus time of day for juvenile king crab.

of our daily rations. The difference between our rations and Tarverdieva's could be a reflection of seasonal differences, but is more likely the result of the correction for clearance rate in our calculations.

8.3.3 Dietary Composition

Visual examination of stomach contents was used to determine dietary composition, with each prey item ranked by frequency of occurrence (Table 8.2). Because such examinations are biased in favor of prey items with long stomach residence times, this examination alone did not indicate relative importance in the diet. After correction for stomach residence times, molluscs and echinoderms, whose hard parts dominate stomach contents, became of lesser importance, whereas soft-bodied polychaete worms became the first-ranking dietary item (Tables 8.2 and 8.3). Measuring dry weights of the hard parts of prey items and estimating soft tissue intake with appropriate ratios gave a measure of dietary composition by bulk. This, in turn, was converted into calories. Four taxa (two polychaete worms, a sand dollar, and a clam) accounted for 92 % of the soft tissue dry weight in the overall diet.

8.3.4 Caloric Intake

The caloric intakes of juvenile king crab (53-80 mm CL) in June and August were 17.5 and 42.2 calories per gram of crab wet weight per day, respectively. Two polychaetes, *Pectinaria* sp. and a sabellid, constituted over 50 % of the caloric intake in June and August. The sand dollar, *Echinarachnius parma,* constituted 3670 of the caloric intake in June and only 2 % in August. Bivalves constituted 3 % of the caloric intake in June but 25 % in August. The major bivalve in the August diet was a small, thin-shelled clam, *Tellina* sp. Older juvenile king crab appear to be predators of small, poorly motile benthic organisms living at or just beneath the sedimentary surface.

8.3.5 Immunoassay of Stomach Contents

The immunoassay provided evidence that juvenile king crab, especially the smallest juveniles

Table 8. 2—Dietary composition (% frequency of all visually observed occurrences) from visual examination of stomach contents of juvenile king crab corrected for stomach residence times and including floe and sand, June cruise.

Taxa	A Uncorrected dietary composition (%)	B Residence time (h)	C Relative composition (A/B)	D Corrected dietary composition (%)
GASTROPODS				
Neptunea sp.	0.0000	259	0.000000	0.0000
Oenopota sp.	6.3545	259	0.024535	2.1967
Retusa obtusa	1.6722	259	0.006457	0.5781
Naticidae	0.0000	259	0.000000	0.0000
Neverita nana	1.3378	259	0.005165	0.4625
Trochidae	0.0000	259	0.000000	0.0000
Solariella sp.	9.3645	259	0.036157	3.2372
Others	0.6689	259	0.002583	0.2312
PELECYPODS				
Cyclocardia crebricostata	12.3746	259	0.047778	4.2778
Tellina sp.	2.6756	259	0.010330	0.9249
Spisula polynyma	5.3512	259	0.020661	1.8498
Others	0.3344	259	0.001291	0.1156
CRUSTACEANS				
Balanus sp.	0.6689	259	0.002583	0.2312
Paguridae	3.3445	68	0.049184	4.4036
Others	3.6789	68	0.054102	4.8439
POLYCHAETES				
Pectinaria sp.	2.3411	14	0.167224	14.9722
Sabellidae	1.6722	14	0.119446	10.6944
Others	3.0100	14	0.215002	19.2499
ECHINODERMS				
Echinarachnius parma	14.0468	259	0.034235	4.8558
MISCELLANEOUS				
Hydroid	0.3344	11	0.030404	2.7222
Bryozoan	0.3344	11	0.030404	2.7222
Plant matter	0.3344	24	0.013935	1.2477
Fish	0.6689	130	0.005145	0.4607
Floe	14.7157	90	0.163508	14.6394
Sand	14.7157	259	0.056817	5.0871
TOTAL	100.00	—	1.6765	100.00

(CL <30 mm), consume soft-bodied prey types overlooked by conventional analyses of stomach contents. In the smallest juvenile king crab, the immunoassay detected polychaetes, oligochaetes, and nematodes not detected visually and not seen visually or immunologically in the stomachs of the larger juvenile crabs (CL >30 mm). The immunoassay confirmed that the smallest juvenile king crab were preying on different prey items than the larger juveniles; however, the immunoassay required more refinement than expected to apply it to the analysis of crab stomachs.

8.4 POTENTIAL IMPACTS OF OIL AND GAS DEVELOPMENT

Potential impacts from oil and gas development could derive from habitat disturbance, exposure to contaminants from platform discharges, and oil spills. Oil spills, rather than habitat disturbance and platform discharges, would be more likely to have harmful impacts on the smallest juveniles because of their shallow nearshore distribution. Conversely, habitat disturbance and platform discharges, rather than oil spills, would be more likely to affect larger juveniles, because of their concentration off Port Moller in depths of 40-70 m.

Table 8.3—Dietary composition ('% frequency of all visually observed occurrences) from visual examination of stomach contents of juvenile king crab corrected for stomach residence times and including floe and sand.

Prey item	June	August	Overall
GASTROPOD			
Neptunea sp.	0	0.13	0.06
Oenopota sp.	2.20	1.14	1.70
Retusa obtusa	0.57	0.13	0.36
Naticidae	0	0.64	0.30
Neverita nana	0.46	0.51	0.48
Trochidae	0	0.13	0.06
Solariella sp.	3.23	2.16	2.73
Others	0.23	0.76	0.48
PELECYPODS			
Cyclocardia crebricostata	4.28	0.38	2.42
Tellina sp.	0.92	3.44	1.12
Spisula polynyma	1.85	0.51	1.21
Others	0.12	0	0.06
CRUSTACEANS			
Balanus sp.	0.23	0.51	0.36
Amphipods	0	0.97	0.46
Paguridae	4.40	0	2.31
Others	4.84	4.84	4.84
POLYCHAETES			
Pectinaria sp.	14.97	11.77	13.45
Sabellidae	10.69	11.77	11.11
Others	19.25	0	10.09
ECHINODERMS			
Echinarachnius parma	4.86	1.14	3.09
MISCELLANEOUS			
Hydroid	2.72	20.97	11.41
Bryozoan	2.72	14.98	8.5
Plant matter	1.25	2.75	1.96
Fish	0.46	0.25	0.36
Floe	14.64	13.78	12.38
Sand	5.09	3.43	4.30

Chronic indirect effects could derive from loss or reduction in the food supply of juvenile king crab. An oil spill in the shallow nearshore zone can reasonably be expected to reduce the density of food important to juvenile crabs, but prediction of the extent of such restriction in the crabs' food supply depends upon the characteristics of the spill. From findings with other crustaceans, it is reasonable to expect that a restriction in food supply will retard growth in juvenile king crab if alternative food is not available.

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Chapter 9

Current Status of King and Tanner Crab Fisheries with Particular Reference to the Eastern Bering Sea

ROBERT S. OTTO
NOAA, National Marine Fisheries Service, Alaska Fisheries Science Center,
Kodiak Laboratory, Resource Assessment and Conservation,
P. O. Box 1638, Kodiak, Alaska 99615

9.1 INTRODUCTION

Alaska crab fisheries have undergone radical changes during the last decade. In 1978, the major species of crabs in U.S. landings were blue crab (*Callinectes sapidus*) from the eastern and gulf states, Tinner (snow) crabs (*Chionoecetes bairdi*, *C. opilio*) and king crabs (*Paralithodes camtschatica*, *P. platypus*, *Lithodes aequispina*). Each made up 29–31% of total U.S. crab landings (Fig. 9.1, Table 9.1). By 1987, Tanner crabs still made of 29 % of the U.S. catch, although C. *opilio* had replaced C. *bairdi* as the dominant species; but king crab had fallen to only 8% (Fig. 9.2). The species composition of the king crab catch also changed dramatically; red king crab (*P. camtschatica*) made up over 95% of landings in 1978 but only about 50 % in 1987. Preliminary 1988 statistics from the Alaska Department of Fish and Game (ADF&G) show the same pattern, with king crab fisheries approximately split between red and golden king crabs, and Tanner crab fisheries now dominated by C. *opilio*. It is worth noting that with the exception of a small fishery in southeast Alaska, fisheries for golden king crab (*L. aequispina*) were virtually nonexistent in 1978. In terms of landed value, king crabs declined from 5970 of the U.S. catch in 1978 to 31% in 1987. The decline in value of king crab has not been as sharp as the decline in landings (Figs. 9.3 and 9.4, Table 9.2). Tanner crab landings have gained in value since 1978. Despite drastic changes in landings and species composition, Alaska landings still dominate U.S. crab fisheries.

9.2 ALASKA AND WORLD KING CRAB LANDINGS

The precipitous decline in world king crab landings that began after 1980 is entirely a reflection of Alaskan fisheries that make up the entire U.S. fishery (Table 9.3, Fig. 9.5). Landings elsewhere in the world (mostly U. S. S. R.) have increased substantially. The Bristol Bay red king crab fishery that dominated world landings during the late 1970s is now a minor component. Landings of blue king crab (*P. platypus*) that makeup almost all of the U.S. landings from the Bering Sea District (eastern Bering Sea exclusive of Bristol Bay) have been more stable but never large, although they reached 40970 of U.S. landings in some years. The entire Gulf of Alaska has been closed to red king crab fishing from 1983 onward. Only minor catches of golden king crab have been made in the Gulf of Alaska, and all Kodiak area landings since 1983 are of this species. Preliminary 1988 statistics show a continuation of these trends except that the Bristol Bay landings declined from 12.4 (1987) to 7.4 million pounds.

Going into the 1988-89 season, the only Bering Sea-Aleutian Island fisheries that remain active are those for red and brown king crabs in the western Aleutians (Adak). Preliminary ADF&G statistics show the following catches (millions of pounds) relative to 1987-88:

Stock	*1987-88*	*1988-89*	*%*
Dutch Harbor brown	1.2	1.5	+ 25
Adak brown	1.2	1.5	—
Adak red	1.2	1.7	+ 42
Pribilof blue	0.6	0.0	-100
St. Matthew blue	1.0	1.3	+ 30
Bristol Bay red	12.3	7.4	- 40
Norton Sound red	0.3	0.2	-33

The following qualifications should be noted: the above statistics are on a seasonal rather than an annual basis; the Adak brown king crab fishery is in

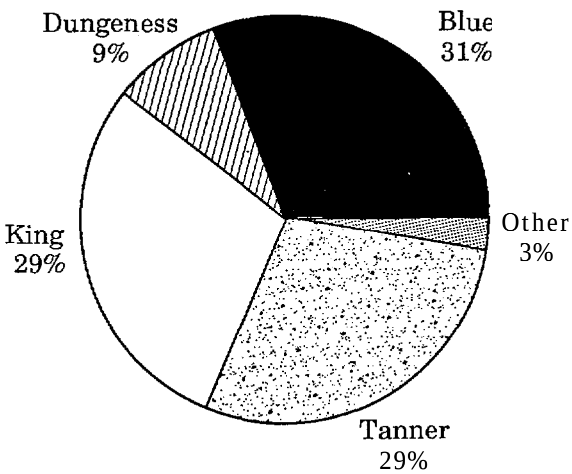

Figure 9.1—Contribution of various species to U.S. crab landings in 1978. Total is 449 million pounds.

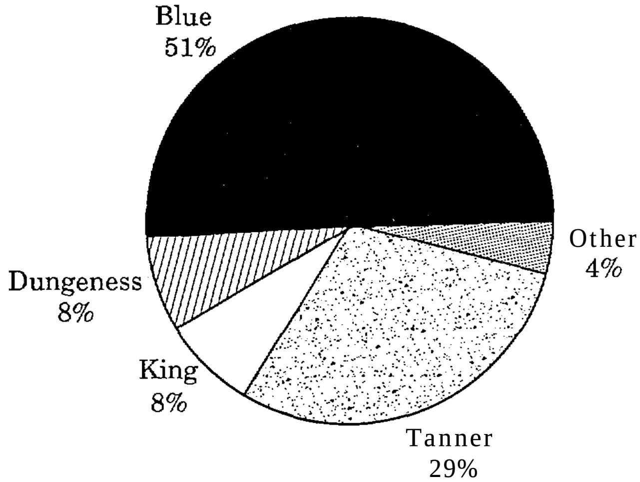

Figure 9.2—Contribution of various species to US. crab landings in 1987. Total is 386 million pounds.

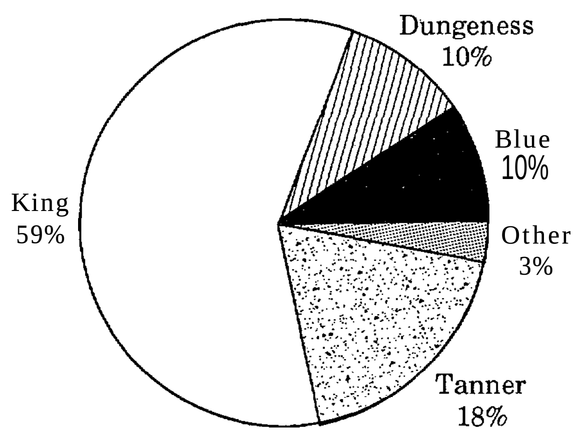

Figure 9.3—Contribution of various species to the total value of U.S. crab landings in 1978. Total value was $285 million.

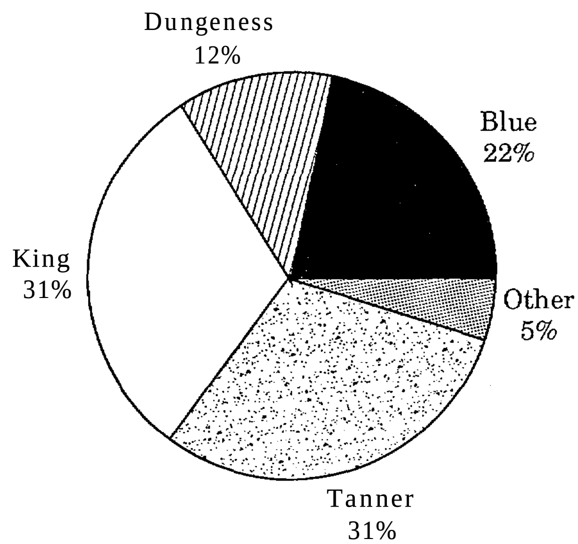

Figure 9.4—Contribution of various species to the total value of U.S. crab landings in 1987. Total value was $322 million.

progress; and the Pribilof blue king crab fishery was closed in 1988 due to low stock abundance. Comparative figures given for Adak red king crab apply to the period ending December 11 in both seasons, while the majority of the brown king crab fishery usually takes place after January 1. Over the past two seasons the Adak brown king crab fishery catch has declined from 12.3 to 7.9 million pounds. It seems unlikely that more than 8.0 million pounds will be landed this season. As a result, total landings of king crabs from the Bering Sea and Aleutians in the 1988-89 season will probably be about 20 million pounds, a decline of 20% relative to 1987-88.

9.3 BRISTOL BAY RED KING CRAB

Declines in landings of Bristol Bay red king crab are mirrored by declines in stock abundance estimates and catch per unit effort over the last several years. Size frequency data show no signs that this stock will recover in the immediate future (Figs. 9.6 and 9.7, from Stevens et al. 1988). The abundance of crab that would be expected to recruit over

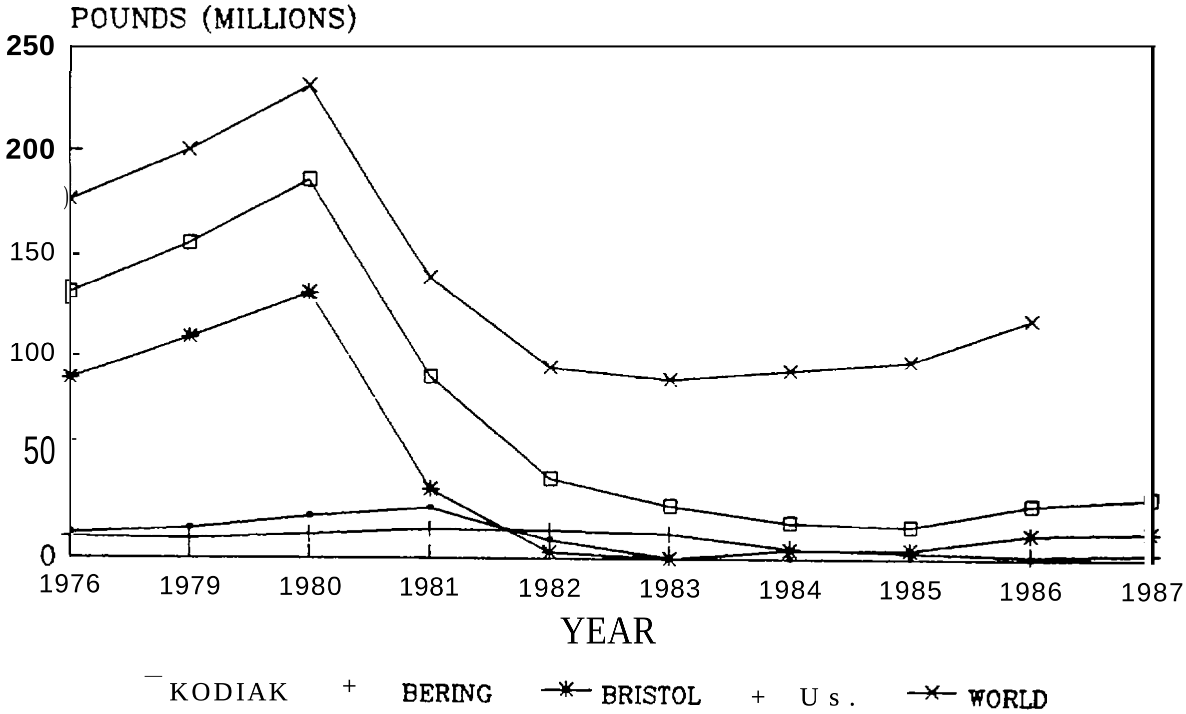

Figure 9.5—Contribution of major U.S. king crab fisheries to world landings.

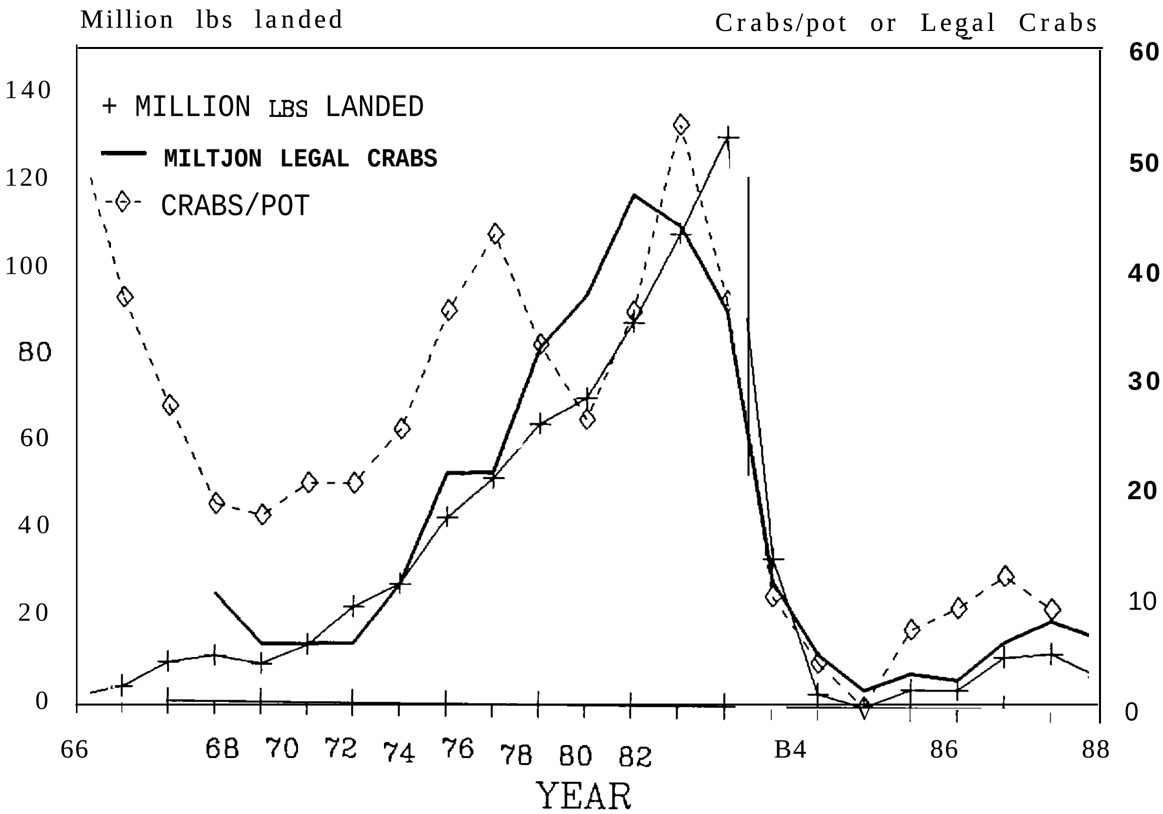

Figure 9.6 —U.S. landings in millions of pounds, catch per unit of effort as crabs per pot, and the abundance of legal red king crabs (*P. camtschatica*) in millions in Bristol Bay, estimated from the NMFS trawl surveys.

the next two years is at an all-time low. While no agreement has been reached as to the cause of the drastic decline in red king crab abundance (see Otto 1986), the Bristol Bay stock of red king crab is clearly approaching an all-time low and should be managed very carefully.

9.4 ALASKA AND WORLD TANNER CRAB LANDINGS

In 1978, C. *bairdi* was the dominant species in U.S. Tanner crab catches, and major production centers existed in Kodiak and the eastern Bering Sea

Table 9. I —U.S. crab catch in millions of pounds.

Year	Blue	Dungeness	King	Tanner	Other	Total
1978	138.2	39.2	130.2	129.5	11.9	449.2
1979	152.8	38.7	154.6	131.4	11.7	489.2
1980	163.2	38.3	185.6	121,7	14.3	523.1
1981	195.1	35.6	88.1	107.5	19.8	446.0
1982	195.5	32.9	38.5	68.8	14.0	349.6
1983	191.7	28.8	25.6	61.1	9.8	317.0
1984	201.6	25.0	17.2	48,8	20.5	313.0
1985	190.5	28.3	15.4	85.8	17.7	337.6
1986	184.5	22.4'	25.9	110.0	12.9	355.7
1987	197.8	29.5	29.1	113.8	16.2	386.4
Total	1,810.9	318.7	710.9	978.4	148.8	3,966.8
%	45.7	8.0	17.9	24.7	3.8	100,0
Average	181.1	31.9	71.0	97.8	14.9	396.7

SOURCE: Fisheries of the United States (NOAA/NMFS, Current Fisheries Statistics, various years).

Table 9.2 —U.S. crab catch in millions of dollars.

Year	Blue	Dungeness	King	Tanner	Other	Total
1978	28.1	28.4	168.1	52.6	7.8	285.0
1979	31.4	31.1	148,6	64.8	8.4	284.2
1980	35.2	21.6	168.7	55.2	10.7	291.4
1981	46.4	29.1	157.7	47,3	16.0	296.6
1982	49.4	31.0	114.6	72.7	14.6	282.2
1983	55.1	36.6	67.8	53.9	9.9	223.4
1984	56.0	37.4	40.2	34.6	18.4	186.6
1985	53.6	39.3	40.3	51.5	18.4	203.0
1986	58.0	29.1	87.7	83.4	12.0	270.1
1987	70.8	38.5	98.8	98.7	15.0	321.9
Total	484.0	322.1	1,092.5	614.7	131.2	2,644.4
%	18.3	12.2	41.3	23.2	5.0	100.0
Average	48.4	32.2	109.3	61.5	13.1	264.4

SOURCE: Fisheries of the United States (Per Table 9. 1).

(Fig. 9,8, Table 9.4). Currently C. *opilio* provides almost all of the world catch. Almost all of the U.S. catch of C. *opilio* comes from the Bering Sea. By contrast, the decline of *C. bairdi* in the eastern Bering Sea led to a closure of that fishery in 1986 and 1987 (Fig. 9.9). Although not as precipitous, the decline of C. *bairdi* in the eastern Bering Sea was almost as severe as that of red king crab. Fisheries for C. *bairdi* in the Gulf of Alaska have also declined, but not as precipitously. Alaska provided about 5870 of the world Tanner crab catch in 1978 but only 4770 in 1986 (data from UN/FAO).

Table 9.3—World king crab catch in millions of pounds.

Year	Kodiak	Bering Sea	Bristol Bay	Us.	Other	Total
1978	12.0	10.3	87.6	130.2	45.9	176.1
1979	14.6	9.2	107.8	154.6	45.6	200.2
1980	20.4	11.5	129.9	185.6	45.0	230.6
1981	24.2	13.8	33.6	88.1	49.0	137.1
1982	8.7	13.4	3.0	38.5	54.1	92.6
1983	0.1	11.7	0.0	25.6	61.3	86.9
1984	0.0	4.7	4.1	17.2	73.8	91.0
1985	0.1	3.0	4.2	15.4	80.1	95.5
1986	0.1	1.3	11.4	25.9	90.1	116.0
1987	0.1	2.2	12.3	29.1	n.d.	n.d.
Total	68.3	70.8	306.3	580.0	544.9	1,049.8
Average	6.8	7.1	30.6	58.0	60.5	116.6

SOURCES: UN/FAO, Fisheries Statistics of the United States; Alaska Department of Fish and Game.

Table 9.4—World Tanner crab catch in millions of dollars.

Year	Kodiak	Eastern Bering Sea		Other Alaska	Us.	Other	Total
		C. *opilio*	C. *bairdi*				
1978	33.3	1.7	66.6	27.9	129.5	92.7	222.2
1979	29.2	31.1	42.5	28.6	131.4	90.8	222.2
1980	18.6	39.3	36.6	27.2	121.7	129.4	251.1
1981	11.7	50.5	29.7	15.6	107.5	123.8	231.3
1982	13.8	29.4	11.0	14.6	68.8	128.1	196.9
1983	18.9	26.1	5.3	10.8	61.1	110.0	171.1
1984	14.8	26.8	1.2	6.0	48.8	109.3	158.1
1985	12.0	66.0	3.1	4.7	85.8	117.7	203.5
1986	9.0	97.0	0.0	4.0	110.0	123.7	233.7
1987	4.8	101.9	0.0	7.1	113.8	n.d.	n.d.
Total	166.1	469.8	196.0	146.5	978.4	1,025.4	1,890.0
Average	16.6	47.0	19.6	14.6	97.8	113.9	210.0

SOURCE: Alaska Department of Fish and Game.

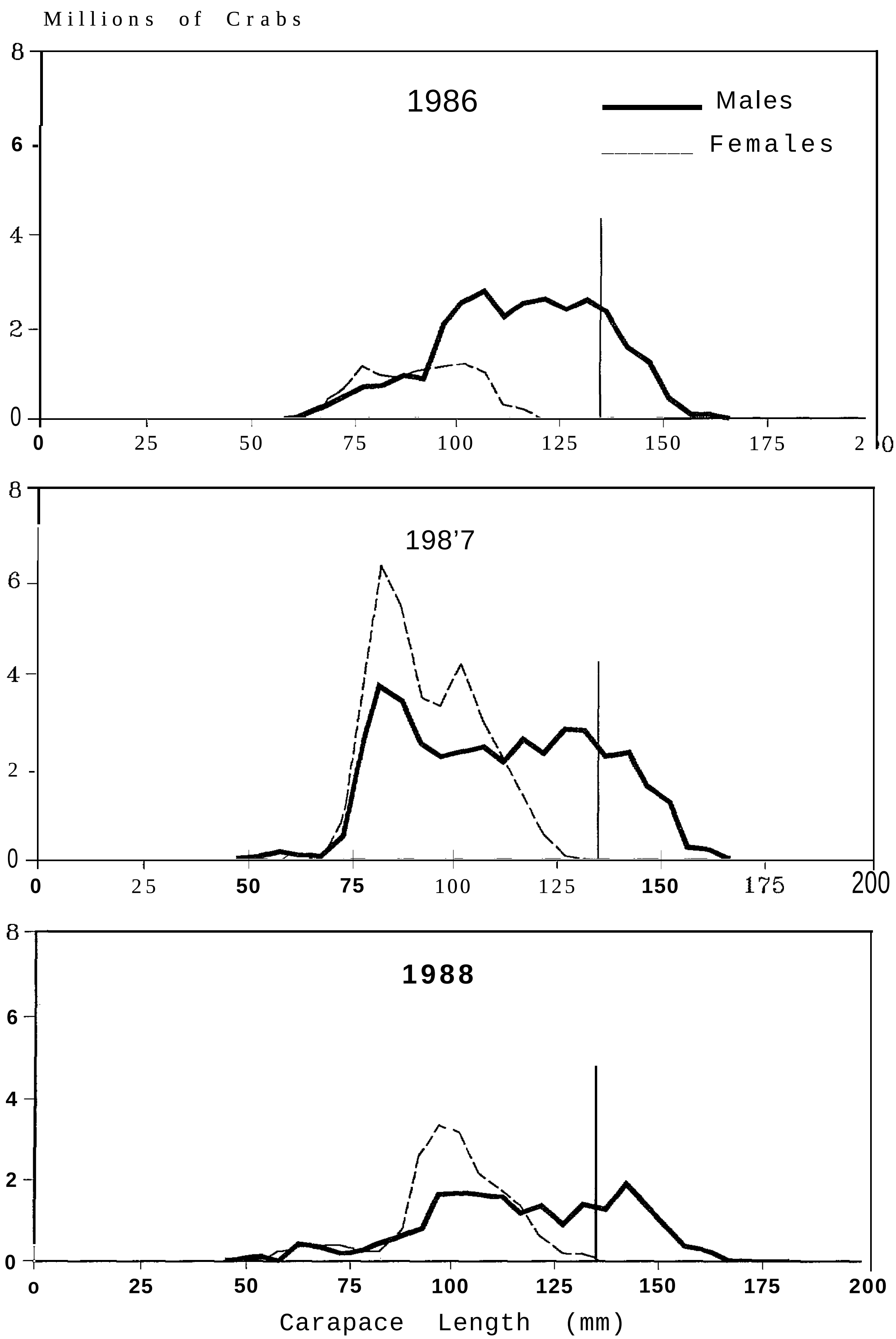

Figure 9.7—Estimates of abundance for red king crab (F'. *camtschatica*) by 5-mm length classes, 1986-88. Vertical line indicates lower limit of legal size.

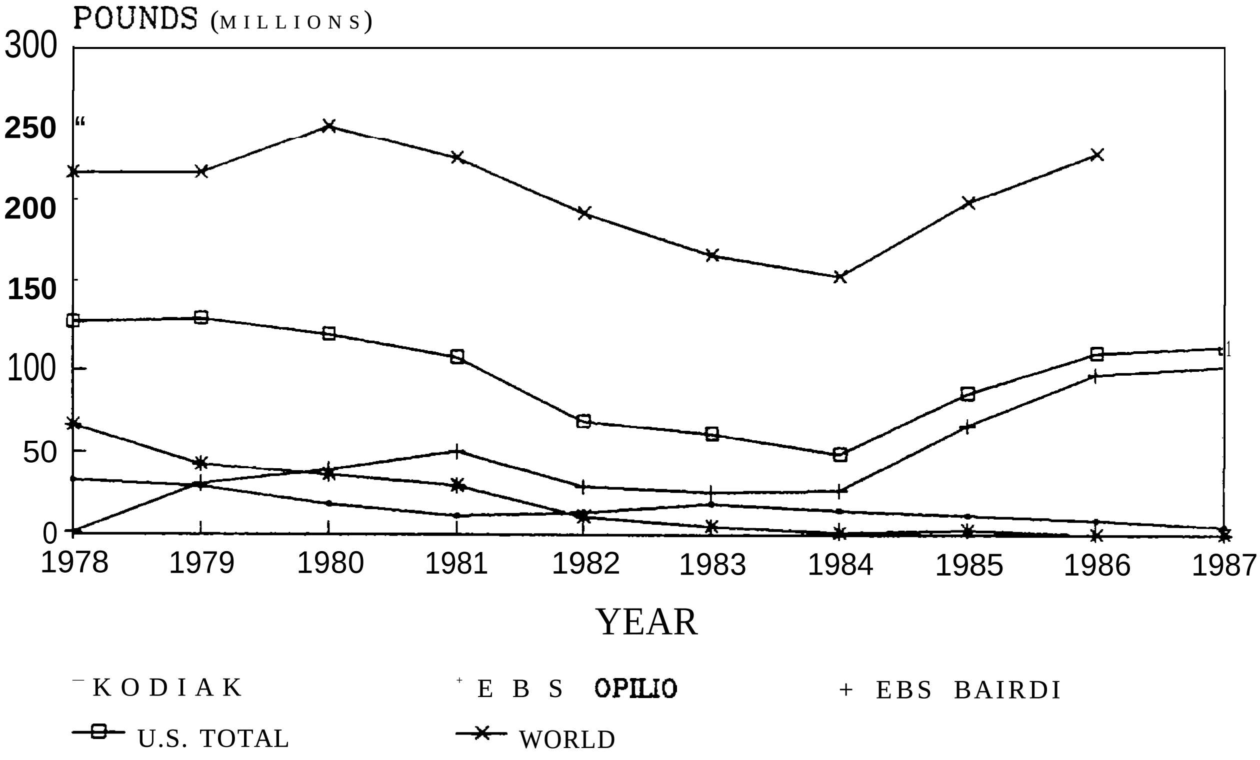

Figure 9.8—Contribution of U.S. Tanner crab fisheries to world landings.

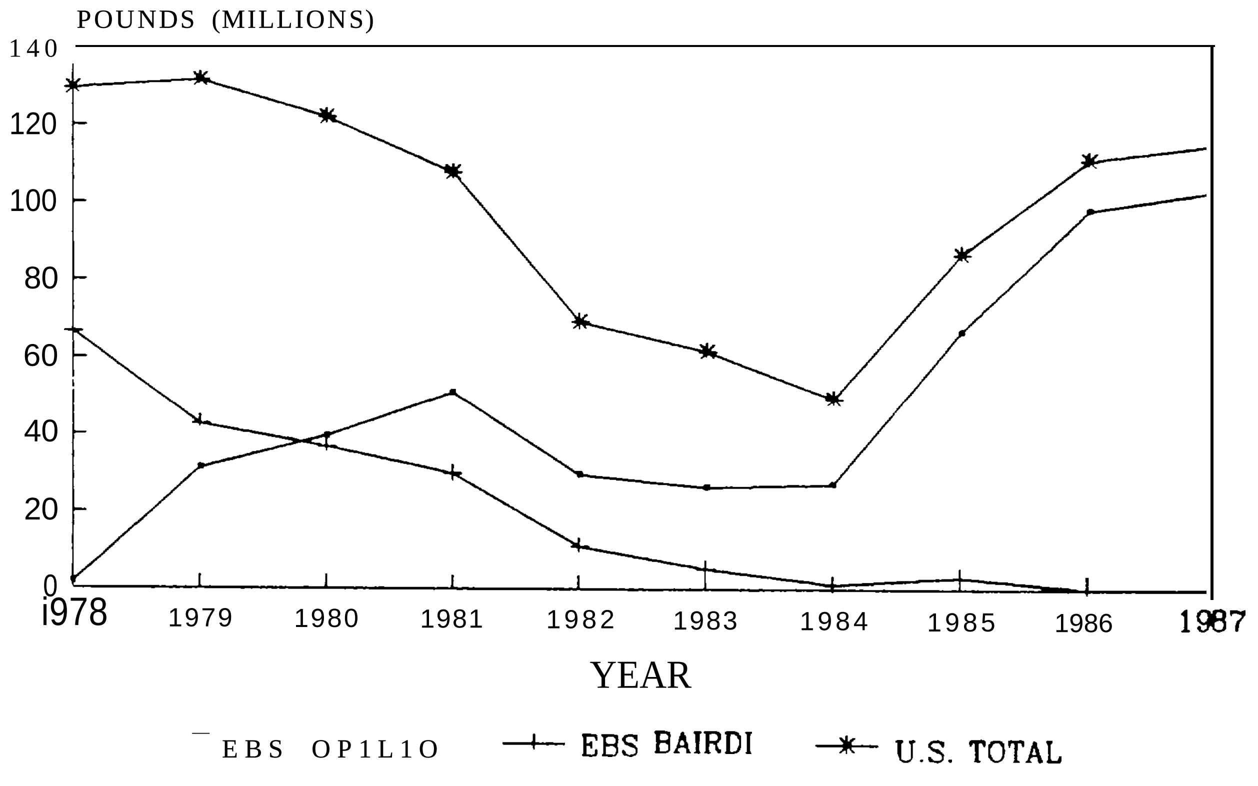

Figure 9.9—Contribution of the eastern Bering Sea to U.S. landings of Tanner crabs.

9.5 BERING SEA TANNER CRABS

The Tanner crab fishery opened on January 15. Guideline harvest levels (GHL) for the eastern Bering Sea based on the 1988 trawl survey are as follows:

	1989 *GHL*	1988 *Catch*
C. opilio, east of 173° W	**95.6**	**75.7**
C. *opilio,* west of **173°** W	**36.4**	**59.7**
C. *bairdi,* E. Bering Sea	13.5	2.2

There is considerable uncertainty relative to the overall landings expected in the eastern Bering Sea-Aleutian Islands area. The 1988 eastern Bering Sea C. *opilio* fishery produced a record catch of 135.4 million pounds (worth over $100 million) exceeding the guideline of 110.7 million pounds. This discrepancy was largely due to better than expected fishery performance, which allowed ADF&G to adjust catch levels upward during the season. Conversely, the C. *bairdi* fishery produced 2.2 million pounds compared to a guideline of 5.6 million pounds, because of unforeseen ice conditions and an early closing prompted by concern over high incidental catches of molting red king crab. Because no surveys are conducted in the Aleutians, no guidelines exist for these areas. The Aleutian fishery consists of incidental catch in king crab fisheries and produced only 0.4 million pounds in 1988. The Bering Sea-Aleutian Islands area will probably produce considerably more than 2.2 million pounds of C. *bairdi* and about 135 million pounds of C. *opilio* in 1989. Population estimates from the 1988 survey, 17.4 million legal male C. *bairdi* (±70%), were imprecise and ice conditions are worse than normal. The bycatch of molting red king crab in the C. *bairdi* fishery, which led to a closure in 1988, is also a concern in 1989.

The C. *bairdi* fishery was historically concentrated in Bristol Bay and to a lesser extent near the Pribilof Islands, while the C. *opilio* fishery has usually taken place outside Bristol Bay. The status of C. *bairdi* is not entirely clear, but population estimates and catch per pot have generally followed fishery trends, and size frequency data look promising (Figs. 9.10 and 9.11, from Stevens et al. 1988).

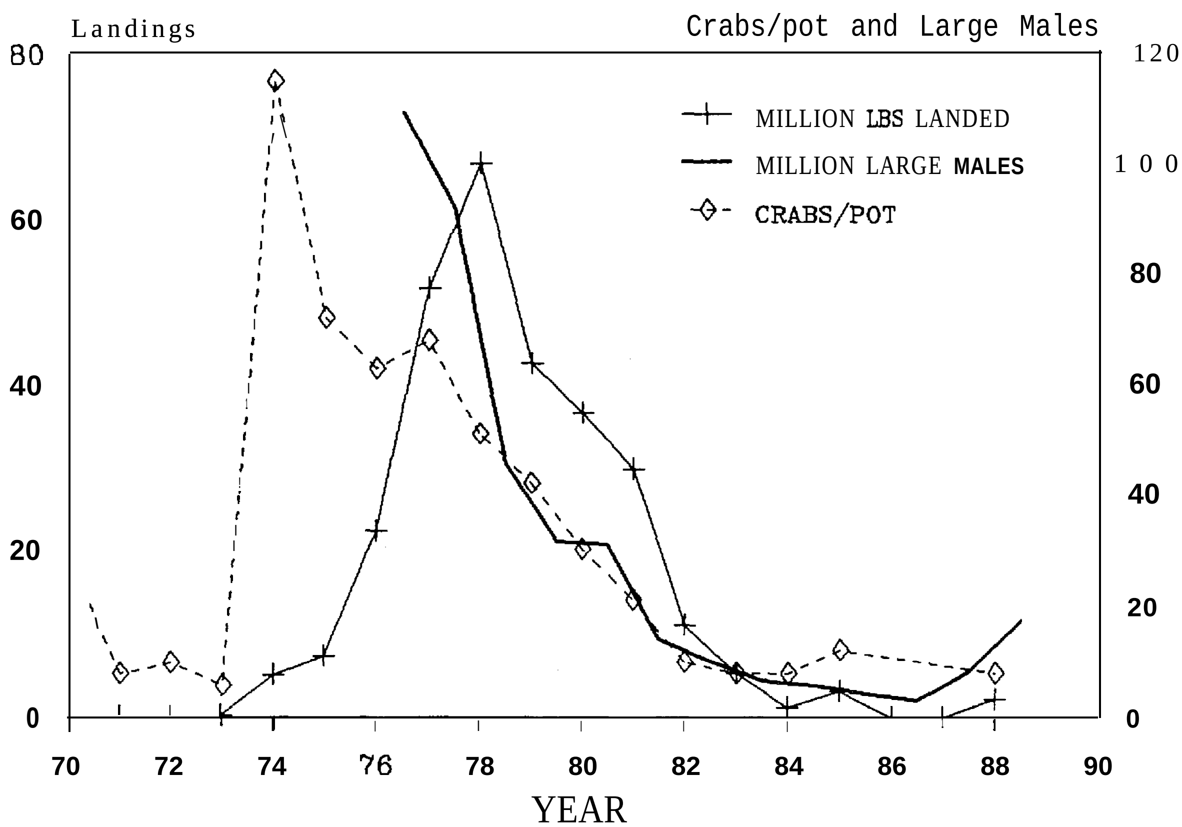

Figure 9. 10 —U.S. landings in millions of pounds, catch per unit of effort as crabs/pot, and the abundance of large C. *bairdi* in Bristol Bay and the Pribilof District in millions, estimated from the NMFS trawl surveys.

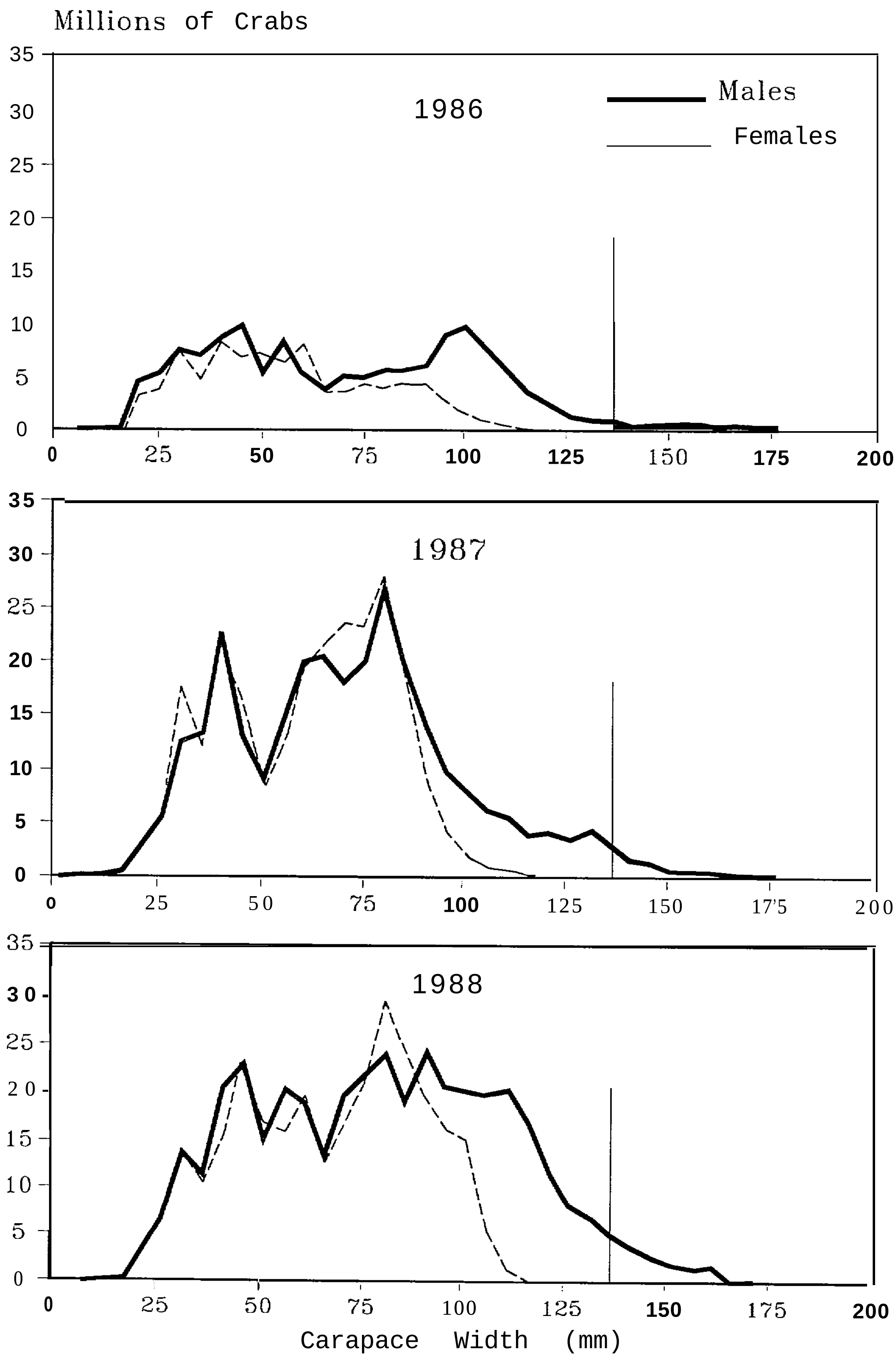

Figure 9. I I —Estimates of abundance for C. *bairdi* in Bristol Bay and the Pribilof District by 5-mm width classes, 1986-88. Vertical line indicates lower limit of legal size.

9.6 REFERENCES CITED

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Chapter 10

An Industry Perspective on Fisheries and OCS Development in the Southeastern Bering Sea and the North Aleutian Basin

ARNI THOMSON

Alaska Crab Coalition, 3901 Larry Way, N. E., Suite 6, Seattle, Washington 98107

10.1 INTRODUCTION

The Alaska Crab Coalition (ACC) was formed in 1985 with organizational goals to protect and rebuild Bering Sea crab resources and fisheries, The founders and leaders of the ACC are essentially the survivors of the collapse of the red king crab (*Paralithodes camtschatica*) fishery in 1981. They are crab fishermen who did not diversify into regional groundfisheries but rather have redirected their effort to the harvest of the *opilio* crabs (*Chionoecetes opilio*). Recent harvests of this species of Tanner crab (100-130 million lb. annually) rival the pre-1981 commercial catches of red king crab. The ACC actively participates in the management process of Alaskan crab fisheries and, as a group, maintains a strong commitment to the conservation of all fishery resources.

Due to time constraints of the Information Update Meeting forum, I would like to identify, but only briefly describe, several serious issues impeding the recovery of Bering Sea crab populations.

10.2 LACK OF CONFIDENCE

Given the notorious record of the Bering Sea crab fleet of the 1970s and the collapse of the resource in 1981, the ACC has experienced considerable difficulty in convincing fisheries managers, within both the Alaska Department of Fish and Game (ADFG) and the North Pacific Fishery Management Council (NPFMC), of its sincerity. This perception remains despite the ACC's recommendations to the NPFMC requesting conservative fishery measures on the crab industry in the form of smaller quotas and additional closures. The lack of confidence by management authorities is viewed as a major hurdle facing the ACC in its attempts to help the "Sick Man of the Bering Sea," the red king crab.

10.3 COOPERATIVE RESEARCH

The ACC recognizes that overfishing and fishing/handling mortalities (in crab and groundfisheries) have, in addition to environmental factors, contributed to the decline of king crab and *bairdi* Tanner crab (C. *bairdi*) populations in the southeastern Bering Sea. Today's Bering Sea crab fleet rivals that of 1980 in terms of fishing power and effort expended in fishing. This is important, considering that in 1980 there was 10 times the volume of king crab resource available to be harvested. ACC fishermen no longer derive their entire livelihoods from king and *bairdi* crab fisheries, but rather are more reliant upon the *opilio* crab.

The .4CC realizes that research dollars within governmental agencies are limited, and that certain information needs pertaining to the management and conservation of stocks might best be addressed through cooperative research. The ACC is presently reviewing options with various state of Alaska and federal agencies to enter and participate in cooperative research involving tagging, handling mortality, habitat and early life history. We have proposed to offer logistics (platform) support as a fishermen's contribution to research. We encourage applied research in vital areas such as juvenile habitat relationships and early life history in the nearshore North Aleutian Basin. Such approaches are viewed by our group as measures necessary to fully understand the effects of fishery and other sources of mortality on crab productivity, as well as to identify critical habitats.

10.4 FISHERIES BYCATCH

Bycatch in trawl fisheries is presently recognized by the NPFMC and the National Marine Fisheries

Service (NMFS) as an ' 'allocation" rather than a ' 'conservation" issue. This is so despite record low harvests of king and *bairdi* crab fisheries. The ACC disagrees with the NPFMC on this issue and maintains that bycatch is a major conservation problem. Bycatch, defined as the incidental catch of prohibited species in fisheries for cod, pollock, and flounders, is discarded by the trawl industry as waste. Bycatch species are thought to sustain high levels of mortality in the process. Prohibited species comprising the bycatch include Pacific halibut, Pacific salmon, Pacific herring, shrimp, scallops, steelhead trout, and other continental shelf resources (e.g., crabs).

The associated research and management emphasis of the NPFMC appears to be focused on the development of groundfish/trawl fisheries in the Bering Sea. As an example of the rapid growth in this industry, Dr. Lee Alverson, a noted fisheries expert, is quoted in the *Seattle Post-Intelligencer* (2 May 1988) as comparing the growth of domestic Bering Sea groundfisheries to "one new Columbia Center [a Seattle skyscraper] every year." The Americanization of ground fisheries in the Bering Sea is expected to impose greater restrictions on the foreign fishing fleet operating within the U.S. Exclusive Economic Zone. Current regulations, requiring trained U.S. observers onboard, prohibit foreign fishing in much of Bristol Bay in the so-called "Pot Sanctuary" (Fig. 10.1), an area that until recently was historically ' 'off limits" to bottomfishing because of its importance to juvenile halibut. Since 1981, however, the shallow waters of the North Aleutian Basin have been the site of a burgeoning fishery for flounders and cod. It is the bycatch and habitat changes associated with the extensive trawling in this area that are of concern to the ACC and other fishermen groups. These waters provide important habitat for crab, herring, halibut, and salmon resources of Bristol Bay. The ACC is concerned that current management decisions do not adequately safeguard these resources from trawl-induced changes in populations and habitats.

In 1981, the coastal waters along the north side of the Alaska Peninsula were opened to a joint venture yellowfin sole fishery. By 1984 it was widely recognized that the high incidental catches of prohibited species, chiefly red king crab, *bairdi* Tinner crab, and juvenile halibut, posed a serious management problem. Marine Resources Company International, the American-Soviet joint venture operating in the area, voluntarily imposed a bycatch reduction on itself in 1985. However, this action resulted in little change in bycatch harvests and in 1986 the NPFMC issued an emergency rule establishing bycatch quotas, or caps, on this industry in several fishery districts in the Bering Sea (Fig. 10.2). A third district (not shown in Fig. 10.2), Zone 3, lies north of the Pribilof Islands. In 1987, the Bering Sea Fishery Management Plan was amended (Amendment #10) to close a portion of Zone 1 to trawl fisheries (Fig. 10.2).

The performance of joint venture processors in Zone 1 for the period 1983-88 is shown in Table 10.1. In 1983 there was a high bycatch of red king and *bairdi* crabs. The greatly reduced bycatches (greater than 50%) of red king and *bairdi* crabs between 1986 and 1988 demonstrate the effectiveness of bycatch quotas and existing time and area closures (during softshell periods of crab reproduction and molting). Gear improvements have also been made within the trawl industry to alleviate the bycatch problem and some of the observed decreases in catch may be attributed to these efforts.

Crab resource assessment surveys of the NMFS in 1987 and 1988 have indicated a general improvement in the status of *bairdi* crabs, but not red king crabs during this period (pers. commun. R. Otto, NMFS, Kodiak, Alaska). In fact, the abundance data suggest a doubling in population size of the *bairdi* crab population each year. This strengthening of *bairdi* numbers is seen by the ACC as evidence that freed bycatch caps and fishery closures provide simple and effective incentives for ' 'clean" fishing. However, the Northwest and Alaska Fisheries Center (NWAFC) has proposed new bycatch allocations for 1989 (Fig. 10.3) that greatly exceed those of previous years. These caps reflect the current philosophy within the NWAFC that a "floating 1% of biomass for bycatch" formula for bycatch is biologically acceptable, The ACC has serious reservations about this strategy and strongly opposes the ' 'liberal" 1989 bycatch levels (Fig. 10.3). A 15 March-15 June closure of fishing in the area south of 58° N and 162°W and 163 'W can be expected to provide some protection to regional crab and halibut populations.

Another concern of our group pertains to enforcement of the established bycatch quotas in domestic fisheries. Without a defined data collection (observer) program in place, this will be difficult. Even though significant reductions have been achieved, the problem of bycatch remains controversial, and will likely worsen with the rapidly developing domestic fishery and liberalized quotas of 1989.

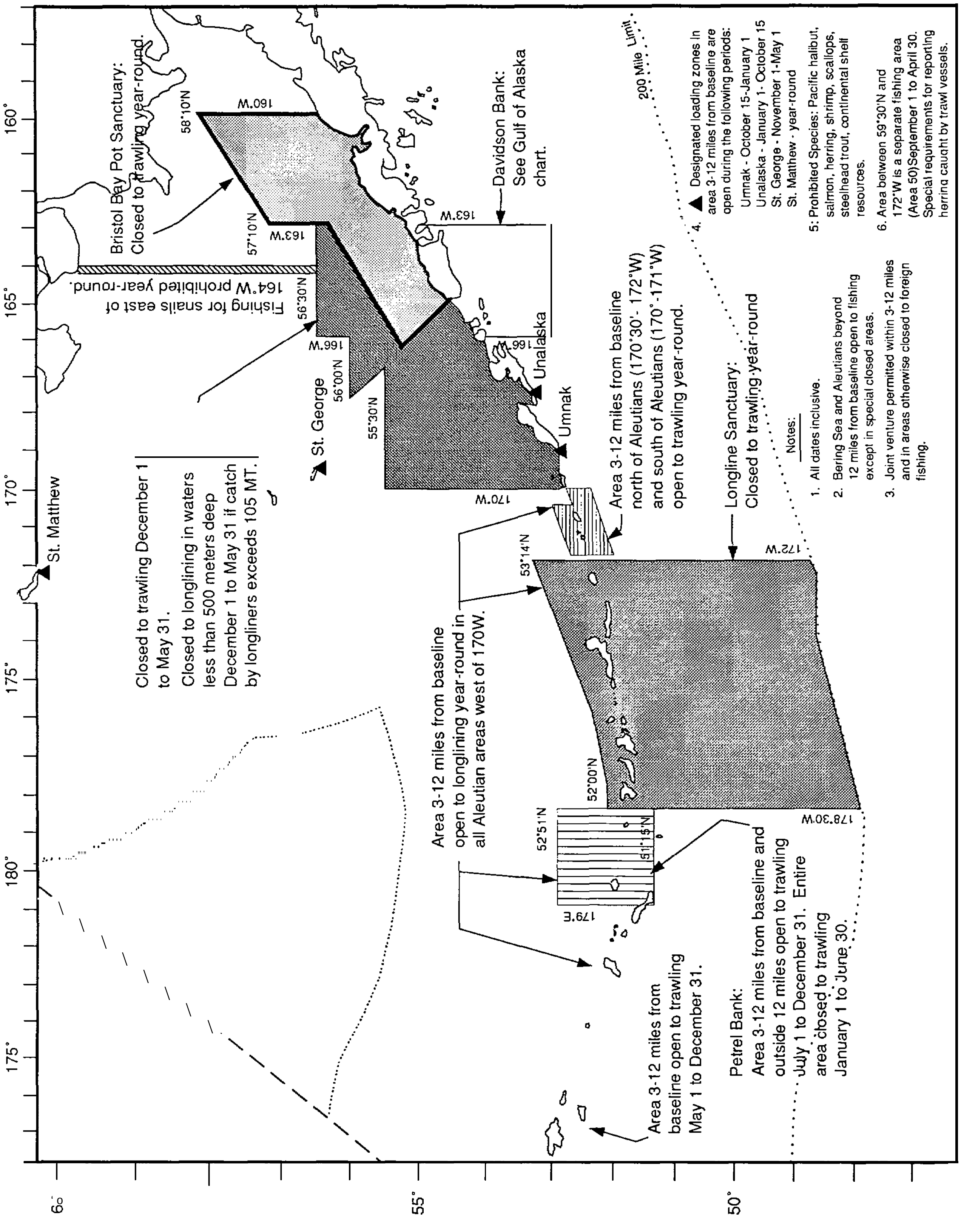

Figure 10.1—Foreign fishing regulations in the Bering Sea–Aleutian Islands Management Area (NMFS, Juneau, Alaska).

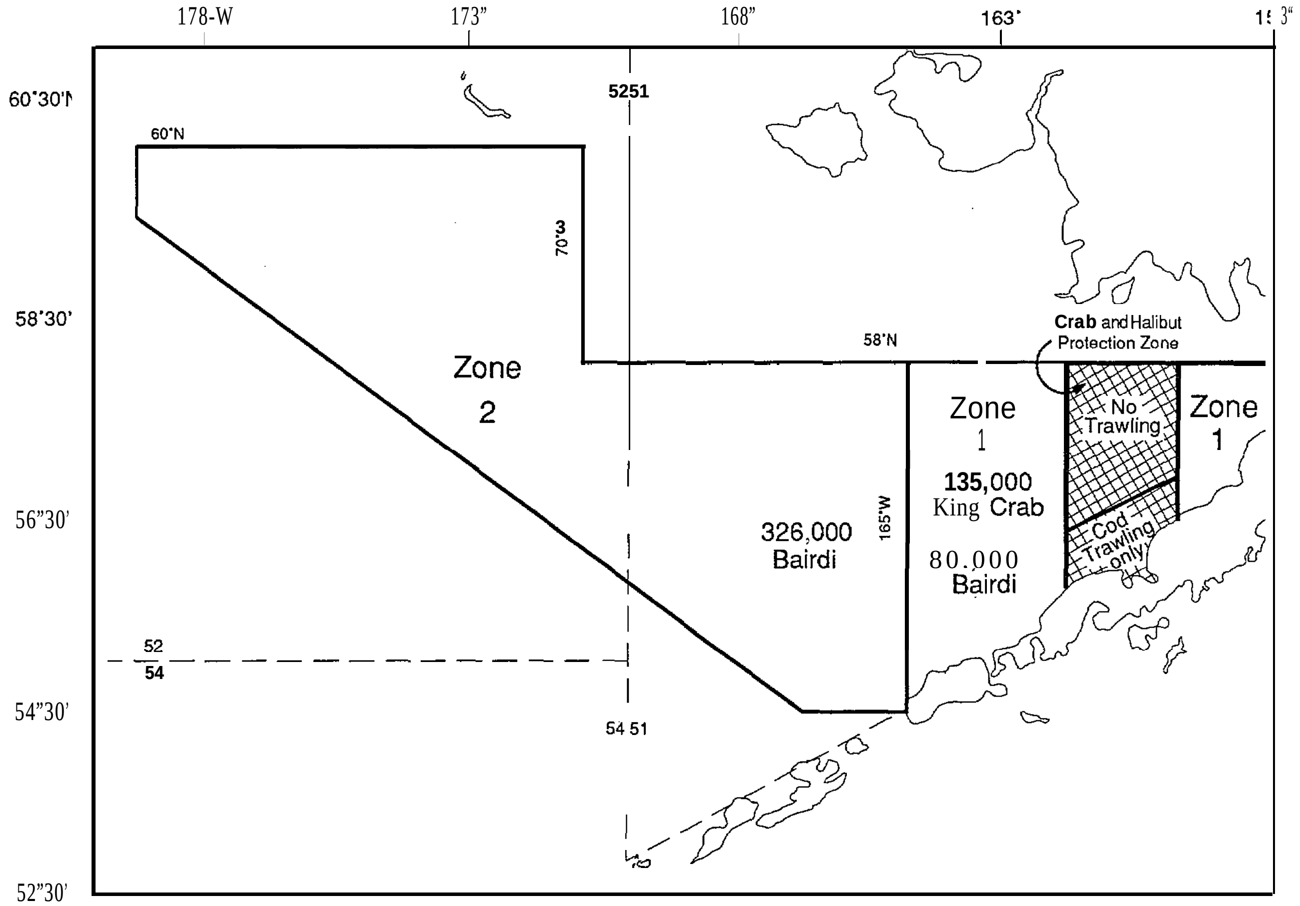

Figure 10.2—Eastern Bering Sea trawl bycatch restrictions on king and Tanner crabs as established by Amendment 10 to the Bering Sea-Aleutian Islands Fishery Management Plan (April 1987).

A closer inspection of catch statistics reported for joint venture fisheries operating in Zones 1-3, during the period 1 January to 6 August 1988, reveals the magnitude of the bycatch problem with respect to halibut and crabs (Table 10.2). Last year during this fishing period, nearly 1.5 million halibut were captured incidentally by joint venture fishermen. Most of these fish were taken in Zone 1 (20%) and Zone 2 (73%) of Bristol Bay. Similarly, almost 600,000 *bairdi* crabs and 73,000 red king crabs were taken (and

Table 10. I —Joint venture processor performance in Zone 1 flounder fisheries prior to and after Amendment 10 to the Bering Sea-Aleutian Islands Fishery Management Plan (1986-88). Statistics from NMFS, NWAFC, Seattle, WA.

		Red king crab		Tanner crab, C. *bairdi*	
Year	Groundfish (ret)	Bycatch (number)	Rate (per ton)	Bycatch (number)	Rate (per ton)
1983	34,233	497,285	14.5	361,152	10.5
1984	45,924	230,050	5.0	149,786	3.2
1985	207,000	813,000	4.0	669,000	3.2
1986	75,942	127,571	1.6	117,000	1.5
1987	74,269	64,398	0.9	98,161	1.3
1988	100,768	.50,722	0.5	92,492	0.9

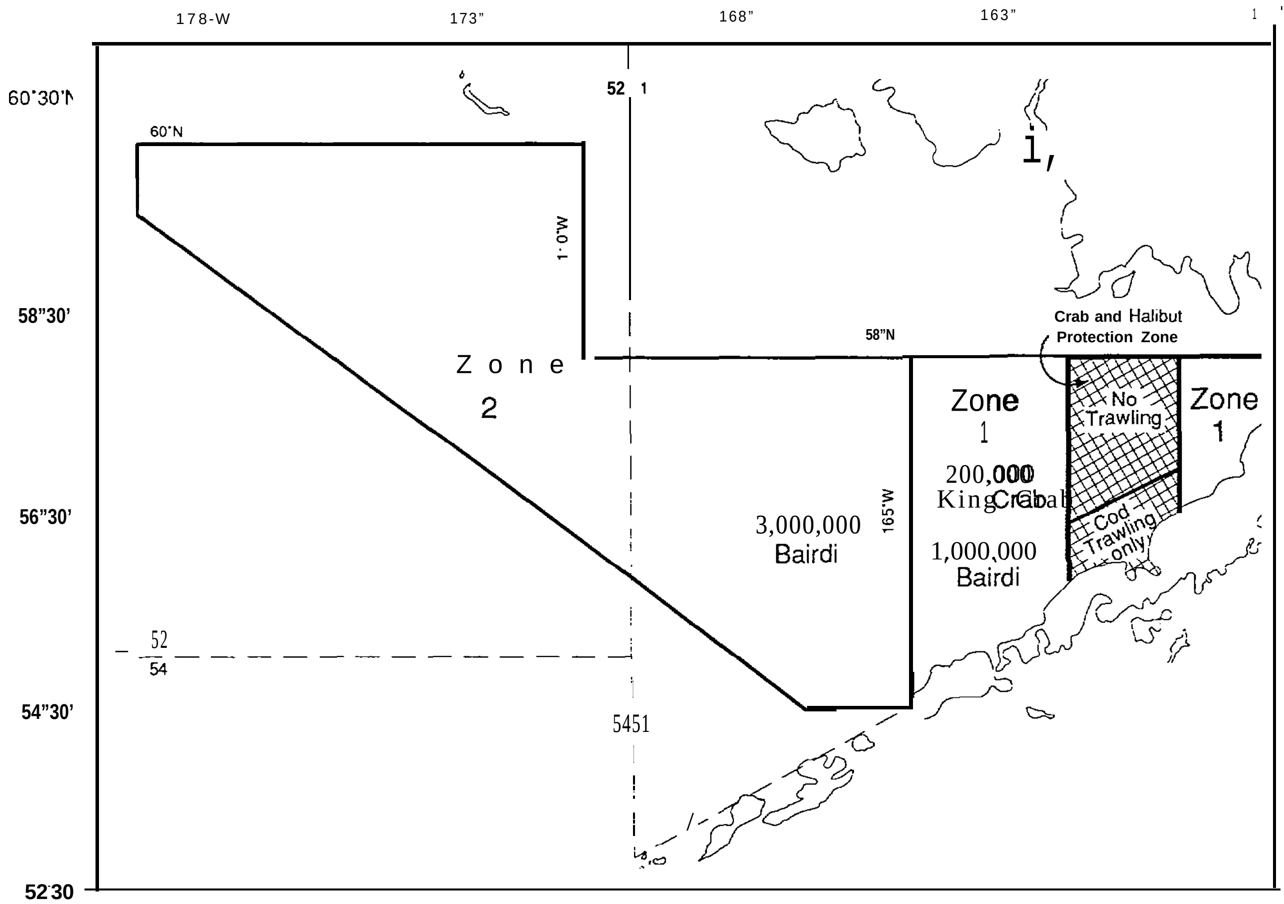

Figure 10.3—Eastern Bering Sea trawl bycatch restrictions on king and Tanner crabs in 1989.

released) by joint venture fishermen. Observed bycatches in Zones 1 and 2 accounted for 95% of the total *bairdi* crab and 87 % of the reported red king crab bycatch. In the case of red king crabs, 82% of the bycatch was reported from Zone 1. Zone 1 was re-opened for yellowfin sole and other flounder fisheries (domestic and joint venture) on 8 December 1988 (Table 10.3). Between 8 and 31 December, 32,752 juvenile halibut (averaging 2.2 lb. per fish), 53,857 *bairdi* crabs, and 2,374 red king crabs were reported as bycatch by trained NMFS observers.

If nothing else, the bycatch statistics indicate the importance of Zones 1 and 2 to juvenile halibut and crab resources of Bristol Bay. OCSEAP and other research in the North Aleutian Basin has indicated that the coastal waters of the lease area (corresponding to Zone 1) are of prime habitat importance to larval and juvenile king crab. McMurray et al. (1984) reported on the distribution and abundance of juveniles near Port Moller and in other parts of Bristol Bay (Figs. 10.4-10.6). The findings and recommendations of these OCSEAP investigators with regard to fishery resources and habitats are summarily ignored by NPFMC and NMFS research leadership in the course of conducting the "business" of fisheries management. Of course, this attitude is not representative of all NPFMC members or NMFS personnel. The ACC believes that this information must be carefully evaluated before fishery boundaries in Zone 1 are expanded by the NPFMC to accommodate further growth in the trawl industry.

"Therapeutic bottom trawling" is almost prescription, in the NPFMC forum, since there is "no conclusive evidence" to prove otherwise. The bottom trawling experiment of 1981 (the opening of the "Pot Sanctuary" to joint venture sole fisheries) has just been liberalized to accommodate the swollen groundfish industry and the concommitent bycatch needs of the 50 factory trawlers who operate routinely without observers. There is great concern among Bering Sea crab fishermen about the effects of bottom trawling on benthic habitats and crab productivity.

Further explanation of the statistical information presented herein is invited and can be addressed to

Table 10.2—Summary of 1988 Bering Sea joint venture prohibited species catches for the period 1 January through 6 August 1988. Statistics from NMFS, NWAFC, Seattle, WA.

Prohibited species	Target fishery	Zone	Groundfish catch (ret)	Prohibited species catch (numbers)	Prohibited species rate (numbers)
Pacific halibut	JV Flounder	1	100,768	147,241	1.46
		2	196,474	371,566	1.89
		3	94,484	49,172	0.52
		1-3	391,726	567,979	1.45
	JV Other	1	158,909	159,638	1.00
		2	421,076	717,869	1.70
		3	170,448	48,336	0.28
		1-3	750,432	925,843	1.23
	Total All JV	1	259,677	306,879	1.18
		2	612,550	1,089,435	1.78
		3	264,931	97,508	0.37
		1-3	1,142,158	1,493,822	1.31
Bairdi Tanner crab	JV Flounder	1	100,768	92,492	0.92
		2	196,474	285,903	1.46
		3	94,484	28,318	0.30
		1-3	391,726	406,713	1.04
	JV Other	1	158,909	90,987	0.57
		2	421,076	97,351	0.23
		3	170,448	1,119	0.01
		1-3	750,432	189,457	0.25
	Total All JV	1	259,677	183,479	0.71
		2	612,550	383,254	0.63
		3	264,931	29,437	0.11
		1-3	1,142,158	596,170	0.52
Red king crab	JV Flounder	1	100,768	50,722	0.50
		2	196,474	2,645	0.01
		3	94,484	9,559	0.10
		1-3	391,726	62,926	0.16
	JV Other	1	158,909	8,924	0.06
		2	421,076	957	0.00
		3	170,448	19	0.00
		1-3	750,432	9,900	0.01
	Total All JV	1	259,677	59,646	0.23
		2	612,550	3,602	0.01
		3	264,931	9,578	0.04
		1-3	1,142,158	72,826	0.06

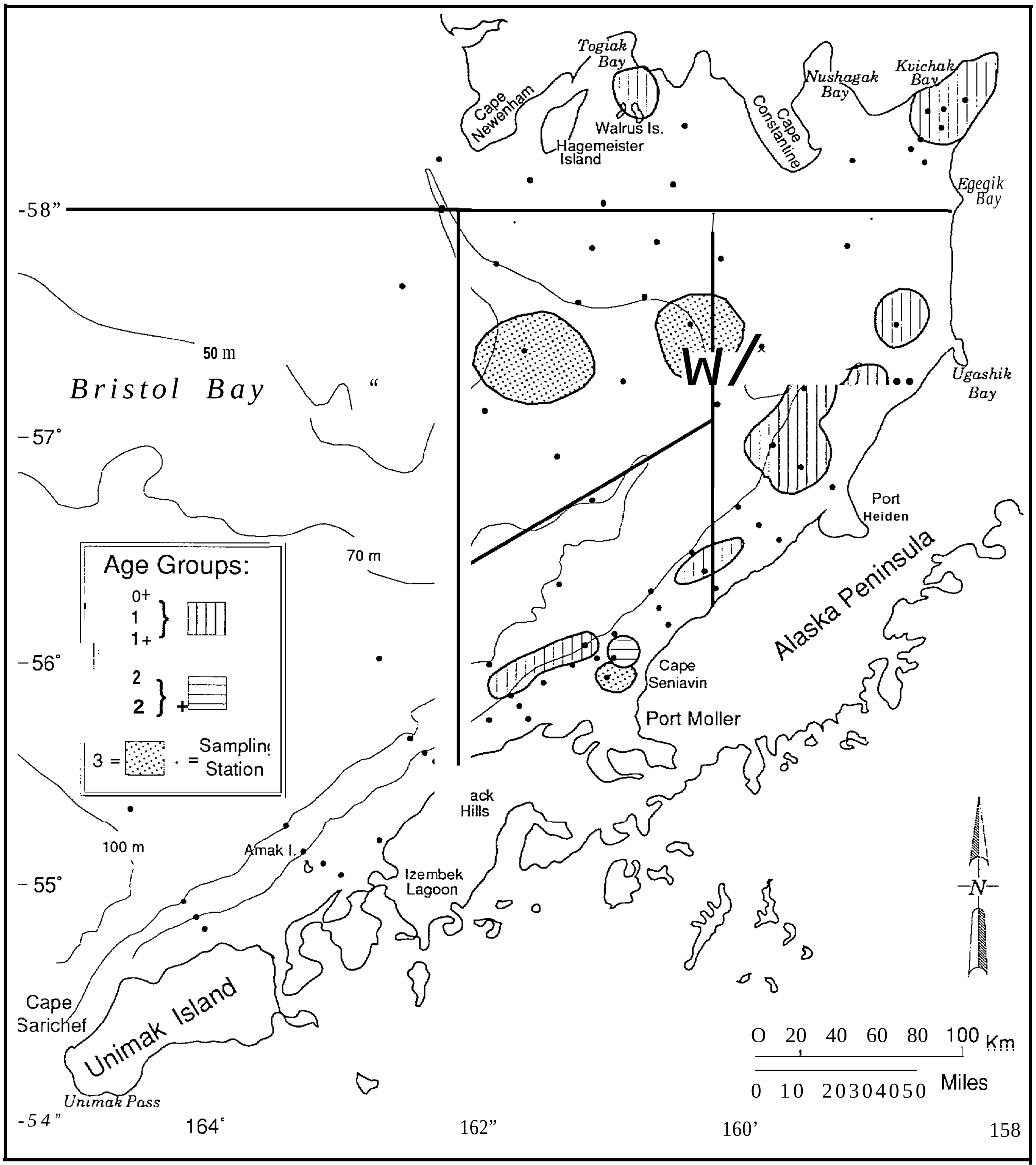

Figure 10.4—Distribution of juvenile red king crabs age 3 and younger in June 1983 (McMurray et al. 1984).

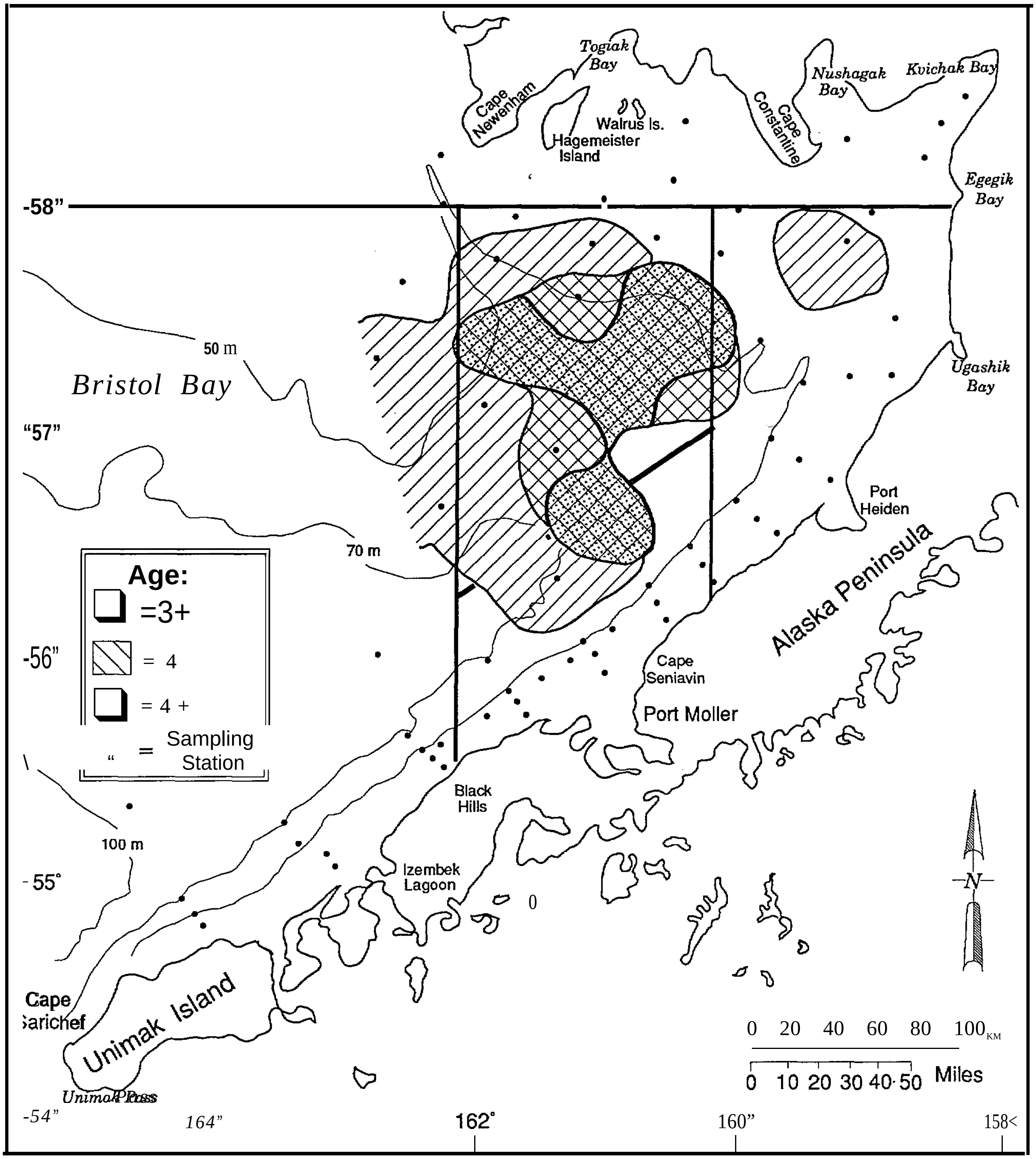

Figure 10.5—Distribution of juvenile red king crabs older than 3 years in June 1983 (McMurray et al. 1984).

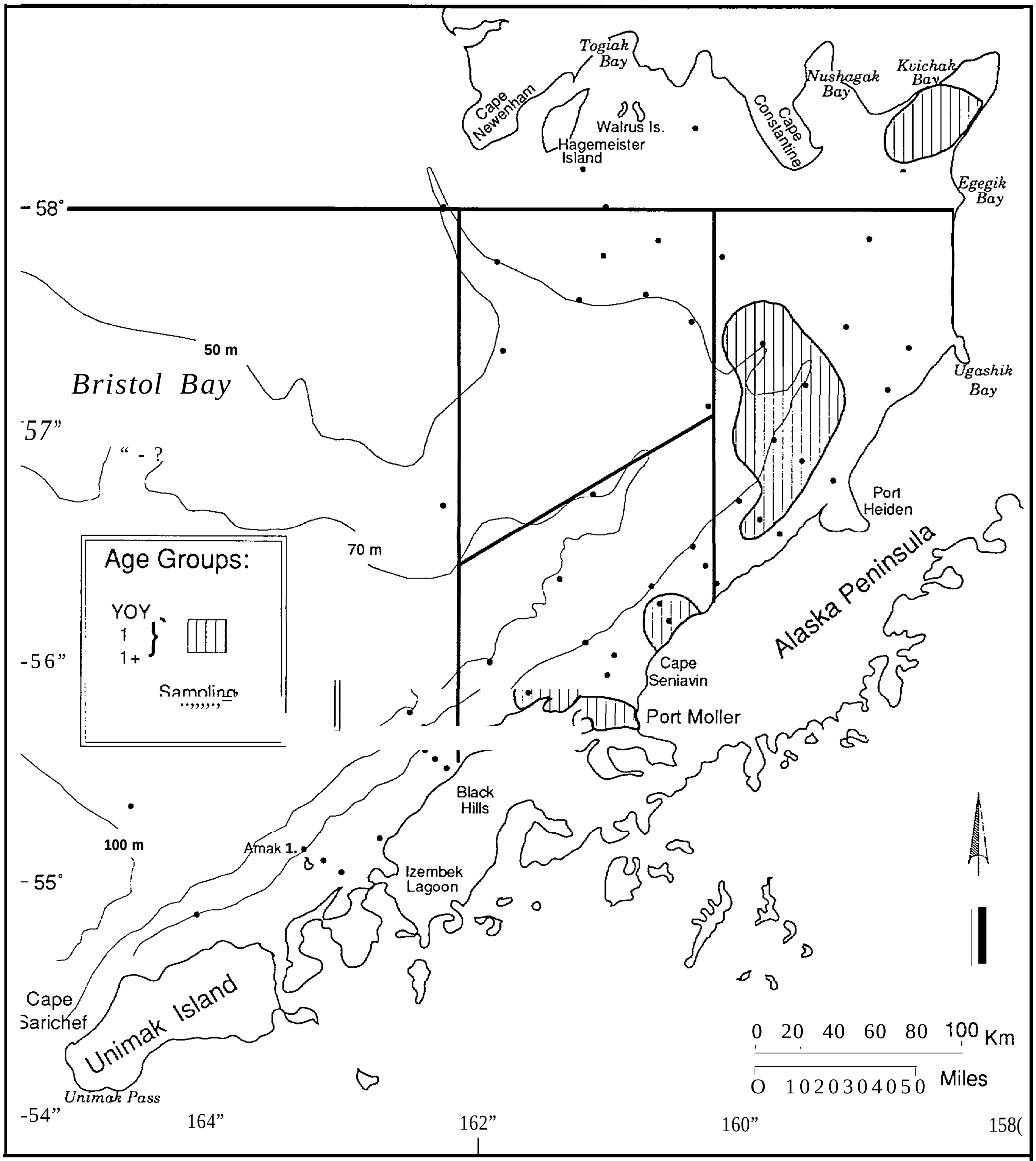

Figure 10.6—Distribution of juvenile red king crabs age 3 and younger in September 1983 (McMurray et al. 1984).

Table 10.3—Reported catches of groundfish and selected prohibited species by domestic and joint venture fishermen operating in Zone 1 of Bristol Bay, 8-31 December 1988. Catch statistics from NMFS, Juneau, AK (12 Jan. 1989).

Species	JVP	DAP	Total
Groundfish (ret)	8,724.3	797.0	9,521.3
Yellowfin sole	3,608.7	74.0	3,682.6
Other flatfish	1,377.2	185.8*	1,563.0
Red king crabs (no.)	2,035.6	339.0	2,374.6
Bairdi Tanner crabs (no.)	45,484.5	8,373.0	53,857.5
Halibut (ret)	19.1	18.3	37.4
Halibut (no.)	15,385.6	17,367.0	32,752.6
		Rate (per mt groundfish)	
King crabs (no./mt)	0.233	0.425	0.249
Bairdi Tanner crabs (no./mt)	5.214	10.506	5.657
Halibut (mt/mt)	0.002	0.023	0.004
Halibut (no./mt)	1.764	21.791	3.440

* Includes 164.02 mt of rock sole.

the Alaska Crab Coalition. Copies of written reports mentioned in this presentation can also be obtained from the ACC office.

It is hoped that particular attention will be paid to the problem of factory bottom trawling for cod in the Port Moller area. This area has been identified in OCSEAP reports as the primary nursery area for juvenile king crabs.

10.5 STATE AND FEDERAL FISHERY JURISDICTION

An ongoing 12-year jurisdictional dispute between state and federal mangement agencies (aided and abetted by resident and nonresident fishery participants) impedes the planning and development of cohesive research programs and establishment of protectionist management policies needed to rebuild crab fisheries. Recently, at the January meeting of the NPFMC, a management plan with federal oversight and state of Alaska management was approved at the regional level. The ACC hopes that this plan will be approved in Washington, D.C., and that it will foster cooperative research and management efforts between industry, scientists, and managers alike. The AC C is actively pursuing cooperation with Soviet and Canadian experts on scientific issues and fishing practices as they may pertain to the Bering Sea.

10.6 OCS OIL AND GAS DEVELOPMENT

The ACC has two major concerns regarding offshore development in the North Aleutian Basin (OCS Sales 92 and 117). A major issue we see relates to the impacts of potential oil spills on Bering Sea crab populations. In the event of OC S development activities, we would recommend the transfer of oil through pipelines overland to tanker loading facilities in the Gulf of Alaska as the environmentally safest method of transport. Increased vessel traffic through Unimak Pass and possible collisions involving tankers could be disastrous.

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Chapter 1 I

Commercial Fishing Harvest and Employment Forecast Methodology

PATRICK L. BURDEN

Northern Economics, P, O. Box 110921, Anchorage, Alaska 99.516

II.I INTRODUCTION

The Bering Sea is a frontier area for Outer Continental Shelf (OCS) petroleum exploration and an area of bountiful fisheries harvests in the North Pacific. The fisheries that occur in the Bering Sea are some of the largest in biomass and value in the world, and the potential for OCS exploration to damage the resource and the communities that depend upon it is recognized by the Minerals Management Service (MMS).

MMS has supported many studies of environmental research and community socioeconomic and sociocultural systems in the Bering Sea region. Besides research on the physical environment, MMS has conducted four studies since 1980 through its Social and Economic Studies Program to predict and analyze potential changes in commercial fishing industries due to OCS oil and gas activities. Because of the secondary source data that were available, these reports were limited to discussion of the contribution of the industry to the economies of local communities.

MMS relies upon the information developed in these fishing industry studies, and the forecasts developed through various models, to develop environmental impact statements. The information available to MMS from these reports and models is critical because expansion of the groundfish industry is the driving force for growth in the region. The rapidly changing conditions in the Bering Sea fishing industry also make it difficult for MMS staff to employ previous reports to estimate future levels of activity.

To obtain more current information on the Bering Sea commercial fishing industry, MMS contracted with Northern Economics to conduct a study of the industry in this area, The purpose of the study is to update the earlier commercial fishing industry studies, with an emphasis on the contribution of the industry to local community economies. In addition, the study will develop harvest and employment forecast models for use by MMS.

This abstract describes the major procedural steps proposed for the Bering Sea Commercial Fishing Harvest and Employment Forecast analysis.

11.2 METHODOLOGY

The objectives of the Commercial Fishing Harvest and Employment Forecast study are (1) to forecast harvest levels by species and fishery for the Bering Sea fishing industry, and (2) to estimate future levels of local fishing-related and processing employment and other changes in the study communities. To meet these objectives, the study uses a microcomputer spreadsheet model. The model employs data from the Northwest and Alaska Fisheries Center (NWAFC), Alaska Department of Fish and Game, Alaska Department of Labor, and other federal and state agencies. The following sections provide information on the major modules that will be developed within this spreadsheet-based program.

I I .2. I Regulatory Process

The study employs a panel to provide expert opinion on components of the general forecasting process that require judgement or prediction of future events. Regulatory decisions are often determined by political decisions rather than economic market forces, making them difficult to predict with an economic model. The use of an expert panel to provide some of these critical assumptions has several inherent advantages. First, it is possible to contact many of the people who will influence the decision through their participation in the fishery or management of the fishery. Given their role in determining the eventual outcome, it is likely that the opinions of expert panel members will make it possible to predict a narrow range of future events. Second, MMS can use these same experts to update the critical assumptions used in the model as the industry evolves. This ensures that the model can be used as a planning tool in the future.

II.2.2 Biomass and Harvest Estimates

The biomass and harvest estimates needed for the model will be derived from two basic procedures. For several of the fisheries, we have data on rate parameters (e.g., recruitment) which allow prediction of future harvest levels. For major commercial fishery stocks in the eastern Bering Sea, a spawner-recruit relationship exists for only one species, walleye pollock (NWAFC 1987).

For many of the other species, we do not have the information on the rate parameters necessary to estimate biomass and resulting harvest levels. For example, a clearly defined spawner-recruit relationship is not available for the different salmon species. In these cases, future harvest levels will be estimated using a statistical analysis of past harvest levels.

In developing a forecast method, the study team is searching for the least complex method that will still provide reasonable results. Regression analysis seems suitable in some instances. Figure 11.1 shows the relationship between the actual harvest for king salmon in the Alaska Peninsula and that predicted by an equation for the years 1967 through 1987. This equation incorporates time and implementation of the Magnuson Fisheries Conservation and Management Act of 1976.

II.2.3 Harvest Estimates

Information from the regulatory process and biomass estimates is combined to provide harvest estimates for each species. These estimates provide the volume of harvest by month and location.

II.2.4 Ex-vessel Price Forecasts

Because a major goal of this project is to provide MMS staff with a model that can be readily updated, traditional time series methods are used to forecast ex-vessel prices.

Statewide ex-vessel price estimates using regression analysis are adjusted for each management area to make ex-vessel price forecasts for Bering Sea salmon and halibut. For salmon, statewide ex-vessel prices are used, rather than management area prices, since longer time series are available and this method requires fewer ex-vessel price models. Regression estimates for shellfish and groundfish use Bering Sea data with no adjustments for management area.

Inadequate time series data and structural changes in the groundfish industry and herring fishery preclude the use of regression analysis in determining ex-vessel prices and wholesale prices for factory-trawler products. A group of industry and agency representatives estimates these prices.

Stepwise multiple regression analysis determines the variables used in the forecasting equations, with a goal of using as few variables as possible. For most salmon and shellfish species, the U.S. dollar–Japanese yen exchange rate and the species catch achieve an acceptable R^2. In order to use the equation for forecasting future ex-vessel prices, the relationship between the yen and the dollar must be estimated from other sources. We developed a linear regression equation for the exchange rate using time as the independent variable. This equation has a coefficient of determination of .82.

II.2.5 Industry Allocation

In the analysis, harvests will be allocated among the different participants in the fishery according to type of gear used and type of processing (shore-based or at-sea). As fisheries continue to evolve within the study area, it is likely that allocations will shift somewhat between user groups.

This analysis of trends provides the basis for examining diversification and expansion in the fisheries. One example is the growth of joint-venture fisheries and their recent decline. Information on the current number of catcher-processors and those under construction provides a strong indicator of future allocation proportions between shore-based and at-sea processing. An analysis of present trends and responses by the group of industry and agency representatives drives the allocation decisions in the model.

II.2.6 Fleet Characteristics

All salmon fisheries of Alaska, and most herring fisheries, are under a limited entry program managed by the Alaska Commercial Fisheries Entry Commission which limits the number of people who may fish for salmon, and for all practical purposes,

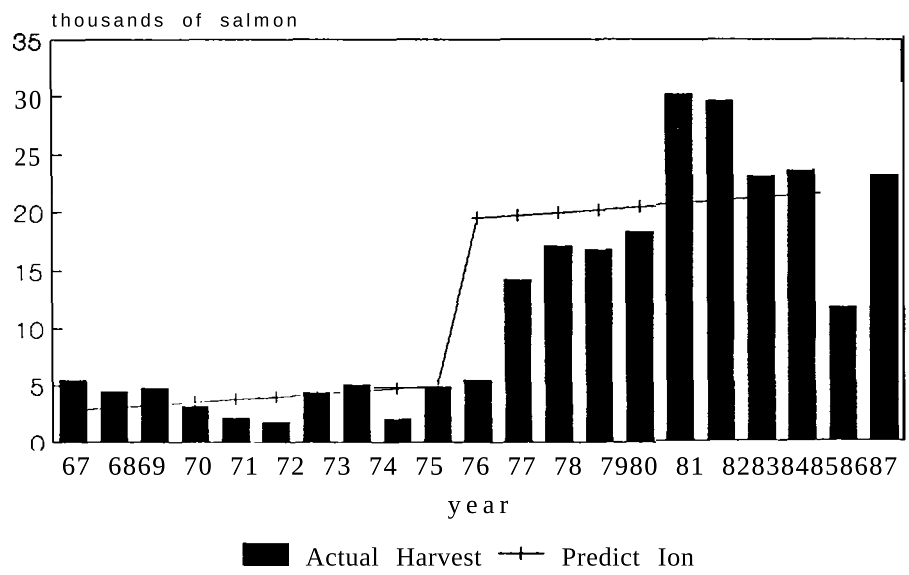

Figure II. I —Actual and predicted harvests of Alaska Peninsula-Aleutian Islands king salmon, 1967-87 (from Alaska Department of Fish and Game catch data).

limits the number of vessels involved in the fishery. The North Pacific Fisheries Management Council is considering limited entry and related programs to control the harvest effort on sablefish and other groundfish species.

Regulations will determine the number of vessels involved in managed fisheries. For fisheries that do not have restrictions on the number of participants or vessels, some technique must be employed to limit numbers forecast by the model; for example, extrapolation of the recent growth trend in numbers of trawlers and factory trawlers operating in the Bering Sea would result in a very large number in 20 years. In this model, break-even analysis is used to forecast future numbers of vessels in unmanaged fisheries. This technique estimates the break-even fleet size for trawlers operating in the Bering Sea and will be adapted to include longliners and other vessels. Operating characteristics of each gear type and the pro forma operating statements are used to estimate the total break-even fleet size for the Bering Sea.

I 1.2.7 Community Economic Zone

Community Economic Zone is a term used to describe a geographic area that acts as a supply region of marine resources for a community. Vessels from the community fish within this area, and processors depend upon the area to supply fish for their operations. One method of determining the importance of various areas in the Bering Sea for each community is to investigate the harvest from each statistical area by vessels from a selected community, and landed in the same community by all vessels. Various agencies collect this information but cannot provide it because of disclosure problems.

To overcome this problem, NWAFC provided a small sample for each gear type that incorporates distance of the statistical area from the port of landing, and the percentage of total harvest for each sampled landing. The data reflect a distance decay factor as suggested by location theory, and simple curve fitting is employed since the data are not sufficient for robust analysis.

I I .2.8 Employment and Income Estimates

Income and employment from fishing industry activities separate into two categories: the fishing sector and the processing sector. Income from processing is easier to determine because state unemployment laws require seafood processing companies to submit records of monthly employment and payroll to the Alaska Department of Labor. Harvesting sector employment and income are much more difficult to estimate. As self-employed workers, fishermen are not required to record employment and income with the state. Thus harvesting sector income and employment must be estimated from other parameters, such as the number of participants in each fishery by specific gear type.

Crew factors developed by the Alaska Department of Labor and the Commercial Fisheries Entry Commission are available for each fishery by gear type. Multiplying the crew factors with the number of vessels participating in each fishery by gear type provides an estimate of harvesting sector employment for each particular gear type. Together, these estimates provide a total estimate of harvesting employment.

Gross vessel income is estimated from the average harvest of each species by vessel type and the forecast prices for each species. Crew shares and owner's income are determined after subtracting operational expenses. All of these items are included in the break-even tables for each vessel type.

Processing sector employment is derived from Alaska Department of Labor data, which provide processing employment by quarter. These data, recent trends in processing technology, and input from our expert group are used to estimate the labor needed to process specific amounts of fish. These "employment factors" are then used to estimate future harvesting employment, based on projected fish harvests.

II.2.9 Community Analysis

The Minerals Management Service intends to use the Rural Alaska Model (RAM), developed under a separate contract, to forecast how commercial fishing activities will affect community population, employment, and income. Fishing activity forecasts will provide information on projected employment and income and allocate it to a port. This information will be used in the RAM model to forecast direct and indirect effects on community population, employment, and income. Fishing activity impacts on population, community economy, infrastructure, and public finance are addressed by this study.

Chapter 12

Social Indicator Systems for Coastal Villages in Alaska

JOSEPH G. JORGENSEN
Human Relations Area Files, Inc., an agency of Yale University,
1517 Highland Drive, Newport Beach, California 92660

12.1 INTRODUCTION

In late 1986 the Social Indicators research team embarked on a longitudinal analysis of a questionnaire administered to about 820 respondents located among 31 villages, principally coastal, from Kodiak in the south to Nuiqsut in the north. The research design, commonly called the Solomon Four Group, allows us to exercise controls for internal and external threats to validity by using multimethods, multidata sets, and random sampling without replacement, Several panels[1] are nested within a separate sample pretest–posttest[2] design which allow-s us to gain statistical power while controlling for threats to validity. Upon completion of the research following the 1990 field session, we will have administered 560 reinterviews of the questionnaire, at two points in time, to panels drawn at random from the original samples. We will also have administered 340 protocol interviews (170 initial and 170 reinterviews) to two panels drawn at random from the initial questionnaire samples. In all, we will have administered 1,720 interviews using two instruments (questionnaire and protocol) among the 820 respondents.

The goal of the research is to develop two valid systems of social indicators, one based on a key informant protocol and the other based on a questionnaire. We are seeking indicators that are few in number and sensitive to changes in social and economic conditions. The research is driven by theoretical questions that seek to provide answers to questions posed by the Minerals Management Service (MMS). In its Social Indicators request for proposals, MMS specifically sought to ascertain the effects of administrative, service, and economic issues on village life. These issues are examined with a large series of variables by contrasting the responses from persons residing in "Hubs" with those of persons residing in ''Villages'' (small, less differentiated, less serviced communities).[3] The MMS also wanted to discriminate among threats from OCS activities. Because all villages do not experience the same threats from OCS activities, we address this issue by contrasting persons who reside in ' 'Test" villages with those who reside in ' 'Control" villages, ! We exercise other controls by contrasting respondents living in villages organized in "Boroughs" with respondents who do not live in villages organized in boroughs, hence ' 'Not Borough,' '[5] and contrast persons residing in predominantly "Native" villages with those residing in

[1] The panels. nested in both the questionnaire and the protocol designs. control for the ' 'ecological fallacy."' a specification error in which results from group 1 are attributed to group 2 if groups 1 and 2 are separate or commingled (sampling with replacement) target populations

[2] Separate questionnaire samples drawn without replacement in 1989 (Schedule A) and 1990 [Schedule B) control for "'testing effect"': chat is. the threat of reactivity when a person's response to a question is conditioned by an earlier response to the same question. Thus. if a reinterview- response is influenced by the response to the initial interview. the influence is called ''testing effect."

[3] Hubs rarely are overwhelmingly Native. and small village Villages (the double ' 'village'' is not a mistake. it is the distinction between periphery and center) are rarely Mixed. Exceptions occur in both classifications, although the classifications change over time as well. For examples, Unalakleet. a secondary Hub, lost that status when regularly scheduled jet service to the village ceased. Wainwright, a Village. experiences an influx of non-Natives whenever large amounts of CIP funds are available.

[4] Although Hub villages have experienced the bulk of the direct and indirect consequences from OCS activities, Test villages are often closer to lease sale areas, potential reserves. and transportation lanes than all other villages. Those that are not so situated. such as Aniak and Anaktuvuk. are Control villages.

[5] In the Borough/Not Borough theoretical contrast. differences in access to state government and the services it provides and in access to public sources of income through bonding authority are obvious and important differences that are correlated *with* household income. household size. public infrastructure. and public superstructure,

villages of' 'Mixed" racial and ethnic heritage.[6] We have also introduced strata to control for the effects of history on the persistence of cultural traits (Central Pacific Yupik vs. Siberian Yupik vs. Aleut vs. Inupiaq).[7]

We have completed the second year of field research and entered the third. The nature of the research design is such that threats to validity are not fully checked until the fourth year, so the results reported at this point are concluding hypotheses based on a careful assessment of the problems we have encountered and on methods we have employed to construct validity, statistical testing validity, reliability, sensitivity, and sampling efficacy.

12.2 RESULTS

12.2.1 Questionnaire Results

Among the hundreds of statistical operations that have been performed on these data is a large number of tests of significance of differences of the questionnaire variables by the theoretical contrasts in the study design. The contrasts yield differences which we anticipated on the basis of whether respondents lived in (1) communities that were composed mostly of Natives or that were ethnically Mixed (>2570 non-Native); (2) communities that were Hubs for services, transportation, and businesses or that were Villages on the peripheries of the hubs; (3) communities that had a high likelihood (Test) or a low likelihood (Control) of being affected by OCS activities; and (4) communities that benefit from Borough organization or that do not (Not Borough).

At- the conclusion of the second field research year, 34 of 55 theoretical contrasts (N = 548) are significant at $p \leq .04$ (t-test for the significance of difference between means). We will discuss the results from only one of those contrasts, that between Mixed and Native communities.

The Mixed/Native contrasts detect significant differences in 8 of 11 measures. Respondents in Mixed villages reside in smaller households (HHsize), have smaller proportions of naturally occurring meat and fish in their annual diets (A33), have more education (Cl), pay more for utilities and housing (D1C, DIE), have higher incomes (D2), invest more in commercial fishing or other businesses (D3A), and reside in larger homes than do respondents in Native villages. Differences are not significant in the number of meals eaten with relatives outside the household in the past week (A32), the number of days that friends were visited during the past week (D13), or the number of public meetings attended during the past month (D16). The differences and similarities take on greater meaning only when analyzed in a multivariate model, of course, but the differences are nonetheless important when compared with the other theoretical contrasts. An important point is that "traditional activities" (visiting and eating meals with friends and relatives) are similar in Mixed and Native villages. Employment, income, and perhaps education, appear to influence the differences between the types of communities.

We will be able to use the questionnaire data to determine changes in multivariate relations following the third field year. Here we will turn to the KI protocol data to provide some multivariate understanding of the Mixed/Native contrast.

12.2.2 Protocol Results

I have selected only one theoretical contrast to demonstrate the relations among the KI variables when controls are exercised. The Mixed (ethnic) / Native contrast is as powerful for KI data as for QI data. In the QI contrasts it is clear that Mixed household incomes are significantly higher than Native household incomes, on average. However, Multidimensional Scale Analysis of 48 protocol variables among the Mixed subsample and the Native subsample demonstrates that high income is not an exclusive feature of Mixed villages, and that within Mixed villages, high incomes are not restricted to nontraditional, non-Native households.

Nevertheless, in the Mixed villages in particular there is a marked bifurcation between a constellation of variables that distinguish high income, nontraditional households with accompanying ethics, from a constellation of variables that distinguish traditional households with accompanying ethics. Yet the traditional variables subdivide into two distinct areas, one of high income and one of low. The variables that are central to the entire traditional region measure traditional subsistence and sharing activities.

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[6] Ethnicity is important because Native and non-Native residents differ in their educational and occupational backgrounds in general, They also differ in their cultural backgrounds as well as their relations to the state and federal governments.

[7] Language similarity is the best known indicator of historical (and continuing) relations among people. If speaking the same language correlates with sharing similar customs and beliefs, whether those beliefs were inherited, borrowed, or both, history will be reflected by significant differences among language strata.

The differences between the traditional and non-traditional multivariate relations are sufficiently marked to label one "Western" and the other "Traditional." The positively and highly correlated Western variables include small households; stable marriages (no divorce); stable household composition over several years: clear expectations for the observation of household rules by old and new members alike; the use of informal solutions and, if deemed necessary, formal external agents to resolve conflicts within the household; personal ethics that promote competition; enculturation practices that are directive (stipulations attached to requests, formal demands, encouragement for success, manipulation); marked differences in the treatment of sexes; the belief that formal schooling is strongly associated with financial success; and couples in which the informant, the spouse, or both are migrants to the village.

Participation in several church-related activities on a regular basis correlates highly with these variables, as does active participation in religion. But these traits have been ubiquitous features of traditional Eskimo and Aleut society for a century as well.

The traditional cluster is organized around the opposites of those variables we have identified as Western, so I will highlight only the most important differences. The central features of the Traditional region that tie low incomes and high incomes together are the high variety of naturally occurring resources that are harvested, the high amount of protein from naturally occurring resources in the diet, the large proportion of income that is invested in subsistence extraction, and the giving and receiving of resources, labor. and cash through sharing.

The major differences between high earner households and low earner households in the Traditional region are that high earners are bigger givers than receivers. and invest less of their total income in subsistence harvests—principally because they have larger incomes so a smaller proportion accomplishes more in funding their extraction expenses. In contrast to the Western set, the Traditional region includes the ethical belief that a person should work to develop skills so as to assist one's family and wider network of kinspersons; the belief that the environment is endowed with spirits and that Natives have special relations to their environment; and the belief that a person is ethically obliged to cooperate with others, especially in sharing in a communitarian fashion.

A complex division occurs in the Traditional region between persons who are actively engaged in modalities and politics and who are "big givers," and those who are not so active in politics and are "big receivers." This is not to suggest that some people only receive and others only give. Higher incomes correlate with more giving of cash and labor and receiving of goods and labor. Lower incomes receive cash, labor, and resources and give resources and labor. The poorest, the elderly, and the infirm are primarily receivers, mostly of cash, but also of some labor (easier to comprehend by scanning the matrix or a three-dimensional solution).

The Western/Traditional household and ethics distinctions that obtain in the Mixed subsample are not so obvious in any other contrast, almost surely because no other contrast requires that the informants be sampled from villages that are composed of 25% or more non-Natives. One question that stimulated the development of our theoretical contrasts was whether Native household organization, ethics, enculturation practices, and opinions about the value of schooling would change toward those generally measured among non-Natives. From these synchronic data it is not evident that they have changed because of employment or income; however. temporal measures in which we can measure the stability of correlations and clusters of correlations upon reinterviewing two or more times will be required before this question can be answered.

Multivariate relations in the Native subsample are very different from those in the Mixed subsample. The Native subsample does not bristle with high PRE coefficients and variation is considerable, a product of the wide range of variation among 23 villages representing five different languages and several dialects from Kaktovik in the high Arctic to Old Harbor in the subarctic. Nevertheless, the data for Native villages, in general, lend empirical warrant to our expectations for family household structures, ethical codes, and subsistence practices that are much different from non-Natives and even different from some of the practices of Natives that occur in the Mixed villages.

Three strong regions emerge in the Native solution, all of them reflecting traditional culture. .4 fourth, comprising high, stable earned income from private sources, is unrelated to the traditional regions, again showing that persons with high incomes in the Native villages represent a sufficiently wide range of behaviors, sentiments. and household organizations to be set apart from any of the variables that measure traditional culture.

The largest traditional region has as its core the subsistence extraction variables, large households, and the giving and receiving of labor and resources locally. A second, related cluster draws together variables measuring political activity. As we learned in so many of the contrasts between large villages with well-developed infrastructures and superstructures (Hubs/Mixed/Test) with the small villages (Native/Control/Village), in the small and less developed villages the variables that measure giving cash locally and beyond the village and the receipt of cash are located close to the variables that measure need and impoverishment.

Of equal importance are the variables with which the giving of cash are fitted into a cluster. They correlate with the ethic of personal responsibility for attainment so as to assist others, a belief that the environment is endowed with spirits, the espousal of a communitarian ethic, and the practice of traditional enculturation and maintenance of traditional gender distinctions. Native ethics, sentiments, and beliefs fit Native practices in this contrast.

In the Native villages a distinctive set of variables within the Traditional region is composed of older household heads dependent on stable unearned income, cash assistance, and social services. There is correct perception of the goals and locus of control of social service agencies.

12.2.3 Cognitive Attitudes About Natural Resources and Management

We sought cognitive attitudes about natural resources, their availability, management and use. The KI sample from which these data are drawn is small (N = 58) and is not representative of the target universe of this study. It is heavily influenced by the large Mixed villages of Kodiak, Dillingham, and Nome, and by the heavy emphasis on the private sector fishing industries of Kodiak Island and Bristol Bay.

We will restrict ourselves to a brief assessment of a few sea mammal and fish species to demonstrate the importance of the distinctions between species that are viewed as commodities and those that are not. The commercial marine invertebrates, fish, and roe-on-kelp are cognized very differently from almost all land mammals, sea mammals, birds, and plants. Ambivalence is expressed about two species, walrus and herring. Our discussion of a few will be representative.

Among sea mammals, for example, attitudes about the availability of walrus, belukhas, and bearded seals correlate very highly and positively with the attitudes that they can be managed and that Natives or Native institutions, perhaps with some assistance, should manage them; Natives have better understanding of ice, wind, and water than do federal or state agencies, or oil company scientists; oil developments are deleterious or will make the situation no more worse than it is at present; significant symbols are attached to environments over a long period of time; and informants think that 10 years ago there was more sharing than goes on at present. It is interesting, though, that persons for whom walrus are not available or who do not have access to them, the attitude is that the federal government, not Natives, should manage the species. Even half of the Natives who have access to walrus agree that the federal government should manage the walrus population. We will return to a discussion of this attitude after we discuss bowheads.

Bowheads are especially important because of their symbolic significance to Eskimo culture. They are available to only 8 informants in our Schedule B KI sample, yet the 38 for whom they are not available hold interesting attitudes about whether, who, and how bowheads should be managed. Among those who had access, by a ratio of 2:1 informants thought that the amount was insufficient. By a ratio of 4:3 informants thought that bowheads could be managed (1 :1 if not available; 1.75:1 if available), and by a ratio of 4:1 informants thought that local Natives or Native organizations should manage them (7: 1 if not available; 2.5:1 if available), As for understanding of sea mammals, Natives or Natives and some institutions or commissions were thought to know more than any state agency, federal agency, or oil company scientists by a ratio of 1.5:1 (1.3: 1 if not available; 7:1 if available).

The most revealing crosstabulation is the cognitive attitude of availability of bowheads with the opinion about who would manage them better. By a ratio of 2:1 the International Whaling Commission (IWC) and the federal government were considered to do a poorer job than Natives would do, and by 13:1 Natives were considered to be able to do either as good or better a job in managing bowheads than the federal government, following I WC-determined quotas, are doing (6: O if bowheads are not available).

These results are different from those for walrus, in which the split was about 1 : 1 as to who would better manage the species, Natives or the Federal

Government. This may well imply that bowheads have greater symbolic significance for more village residents than do walruses and, of course, greater sympathy for bowhead hunters than for walrus hunters. Walrus hunters pursue ivory—a commodity—and that may bother some informants not so engaged, while causing some of those that are engaged in the activity to prefer third party regulation.

Only 4 persons out of 55, including those with access and those without access to bowheads, think that oil-related developments will be beneficial, and 20 think they will be deleterious. It is as strong a negative relation as is the comparable gamma for walrus and oil-related developments.

Attitudes about fish are very different from those expressed about sea mammals as to who informants think should manage resources, who manages them best, who best understands fish, and the consequences of oil developments. The availability of fish correlates positively with the thought that salmon (and herring) can be managed; should be managed by the Alaska Department of Fish and Game (ADFG); that ADFG does a better or at least an equivalent job to that which could be done by Natives in managing salmon (and herring and bottom fish); that the informants or persons in the local community seldom influence decisions made by ADFG about managing fish; that state and federal officials or oil company scientists best understand water; that the time required to gain know-ledge about the environment is relatively brief (1-5 years); and that the consequences of oil development will be either beneficial or mixed with more benefits than disbenefits.

This set suggests the attitudes of Western entrepreneurs and businessmen who have learned to operate within a system controlled by government regulators and appreciate the status quo, even if they harbor resentments and express criticisms of the regulations and the regulators. Any fears expressed about oil developments are more than outweighed by prospects of benefits-presumably sales and employment—from oil developments. Optimistic responses may represent persons engaged in or in some way interdependent with the fishing industry.

For herring, on the other hand, attitudes are much more similar to those that are expressed about bowheads. There is a definite ' 'traditional," at least Native, cast to the relations among availability of herring (F) and attitudes that they can be managed; should be managed by Natives or Natives and/or Native organizations; would best be managed by Natives or Natives and some agencies; seldom influence regulators; Natives best understand water, ice, and fish; it takes many years, perhaps a lifetime, to gain knowledge about an environment; and the consequences of oil developments will be deleterious.

Inasmuch as Natives gained access to the herring fishery without need of an entry permit, especially in the Bering Strait region but not restricted to that region, the differences in attitudinal responses about salmon, their management and knowledge about them, and the attitudes on the same topics for herring appear to reflect differences between Natives and non-Natives and/or persons who reside in villages heavily engaged in commercial fishing and persons residing in villages more peripherally engaged in commercial fishing. A larger sample that will allow us to make theoretical contrasts will be required so that we cannot only contrast Mixed and Native subsamples, but also exercise controls for sex, age, and ethnicity (race). Significant symbols attached to the environment are few. This is a hallmark, it appears, of the commodity orientation to the environment.

Chapter 13

Overview of Subsistence Research in the Bristol Bay Region, Southwest Alaska

JAMES A. FALL
Alaska Department of Fish and Game, Division of Subsistence,
33.3 Raspberry Road, Anchorage, Alaska 99.518-1599

13.1 INTRODUCTION

The purpose of this report is to provide a brief overview of the current status of research by the Alaska Department of Fish and Game. Division of Subsistence, in the Bristol Bay region. After providing some background on the region and the Division of Subsistence, the paper examines the following: (1) definition of subsistence research, (2) division research in the Bristol Bay region, (3) major findings, (4) significant subsistence issues facing the region, and (5) future plans for the division's research program,

13.2 BACKGROUND

In 1985. the population of the Bristol Bay region (Fig, 13.1) was 6,514. About 68% of the population was Alaska Native in 1980. There are about 25 communities in the region (Table 13.1). Two regional centers (Dillingham and the Bristol Bay Borough) contained 46.5% of the total population and 76.8% of the non-Native population in 1980. Besides the two regional centers. most communities are small, predominant]>- Alaska Native villages. ranging in population size from 10 (Ugashik) to 556 (Togiak), either Dens'ina Athabaskan or Yup'ik Eskimo, There are, however, a few predominantly non-Native settlements (Iliamna, Port Alsworth) and a small, dispersed non-Native population. especially around Lake Clark.

Commercial salmon fishing is the dominant industrv: commercial fish processing is also important, but most of these jobs go to nonlocal residents. Services, government, and retail trade are important in regional centers. Some jobs also occur in big game and sportfishing guiding, and transportation. Trapping is an important source of winter income in many villages (e. g., New Stuyahok, Nondalton, Pilot Point). Much of the cash-producing work is seasonal, Subsistence hunting and fishing are major parts of the economies of all communities in the region (Wright et al. 1985).

Therefore, although a number of unifying themes tie the region together, it is not ' "homogeneous."' There is a mix of ethnic groups, community types, and economic interests.

The Division of Subsistence has had an active research program in the Bristol Bay region since 1980. We have had up to five permanent employees in two area offices, Dillingham and King Salmon. Presently, we have three permanent staff in the Dillingham office, supervised from Anchorage. The King Salmon office closed in August 1987.

13.3 DEFINITION OF SUBSISTENCE RESEARCH

The nature of subsistence research in Alaska is shaped by the requirements and implementation of state and federal laws. Alaska's subsistence statute (1978, amended 1986) and the Alaska National Interest Lands Conservation Act (ANILCA) (1980) require that regulatory and land management agencies identify subsistence uses of fish and wildlife resources, adopt regulations providing an opportunity for people to participate in these uses, and, in times of resource shortage, provide a preference to subsistence uses over other uses (such as commercial and recreational), Federal law (ANILCA Sec. 810) also requires that agencies assess possible restrictions on subsistence uses that may be caused by any land use action which thev allow.

The Division of Subsistence was created by the state to take the lead in collecting, organizing, and disseminating information about subsistence uses.

The division's charge in the Alaska Statutes (AS 16.05.094) is:

> To compile existing data and conduct studies to gather information, including data from subsistence users, on all aspects of the role of subsistence hunting and fishing in the lives of the residents of the state, to make this information available to the public, governmental agencies, and other organizations, and to apply this information during participation in the state and federal resource management systems.

Accordingly, our research goals are tied directly to the data needs of resource and land managers, regulatory boards, and user groups. This information includes ' 'baseline" data on harvest levels, levels of participation, methods and means, seasons, and locations of harvest. Also collected are other data which assist the regulatory boards in applying their policy on subsistence uses ("the eight criteria" [5 AAC 99.010]), and which identify customary and traditional uses, such as history of use and distribution and exchange patterns. We also compile data,

Table 13. I —Communities of the Bristol Bay region, southwest Alaska, and associated Division of Subsistence technical papers.

Subregion and community	1985 Population	% Alaska Native, 1980	Associated technical paper[1]
Togiak			
Togiak	556	94.3	Wolfe et al. 1984
Twin Hills	44	95.7	
Nushagak River			
Aleknagik	180	89.6	
Clarks Point	79	88.6	
Dillingham	2,141	57.0	Fall et al. 1986
Ekwok	107	92.2	(Project under way, 1/89)
Koliganek	161	95.7	(Project under way, 1/89)
Manokotak	309	92.9	Schichnes and Chythlook 1988
New Stuyahok	339	94.0	(Project under way, 1/89)
Portage Creek	35	91.7	(Project under way, 1/89)
Iliamna Lake			
Igiugig	38	75.8	Morris 1986
Iliamna	126	40.4	Morris 1986
Kokhanok	68	96.4	Morris 1986
Levelock	109	87.3	(Project under way, 1/89)
Newhalen	165	94.3	Morris 1986
Nondalton	234	93.1	Behnke 1982, Morris 1986
Pedro Bay	70	93.9	Morris 1986
Port Alsworth	67	NA	Morris 1986
Naknek River			
King Salmon	648	NA	Morris 1985
Naknek	382	50.6	Morris 1985
South Naknek	195	85.5	Morris 1985
Remainder, Bristol Bay Borough	101	11.9[2]	Morris 1985
Upper Alaska Peninsula			
Egegik	112	76.0	Morris 1987
Pilot Point	79	86.4	Fall and Morris 1987
Port Heiden	108	64.1	Fall and Morris 1987
Ugashik	10	80.0	Fall and Morris 1987

[1] In addition, Wright et al. (1985) contains overviews of each subregion.

[2] Includes King Salmon.

SOURCES: Alaska Department of Labor (1987), United States Bureau of the Census (1984).

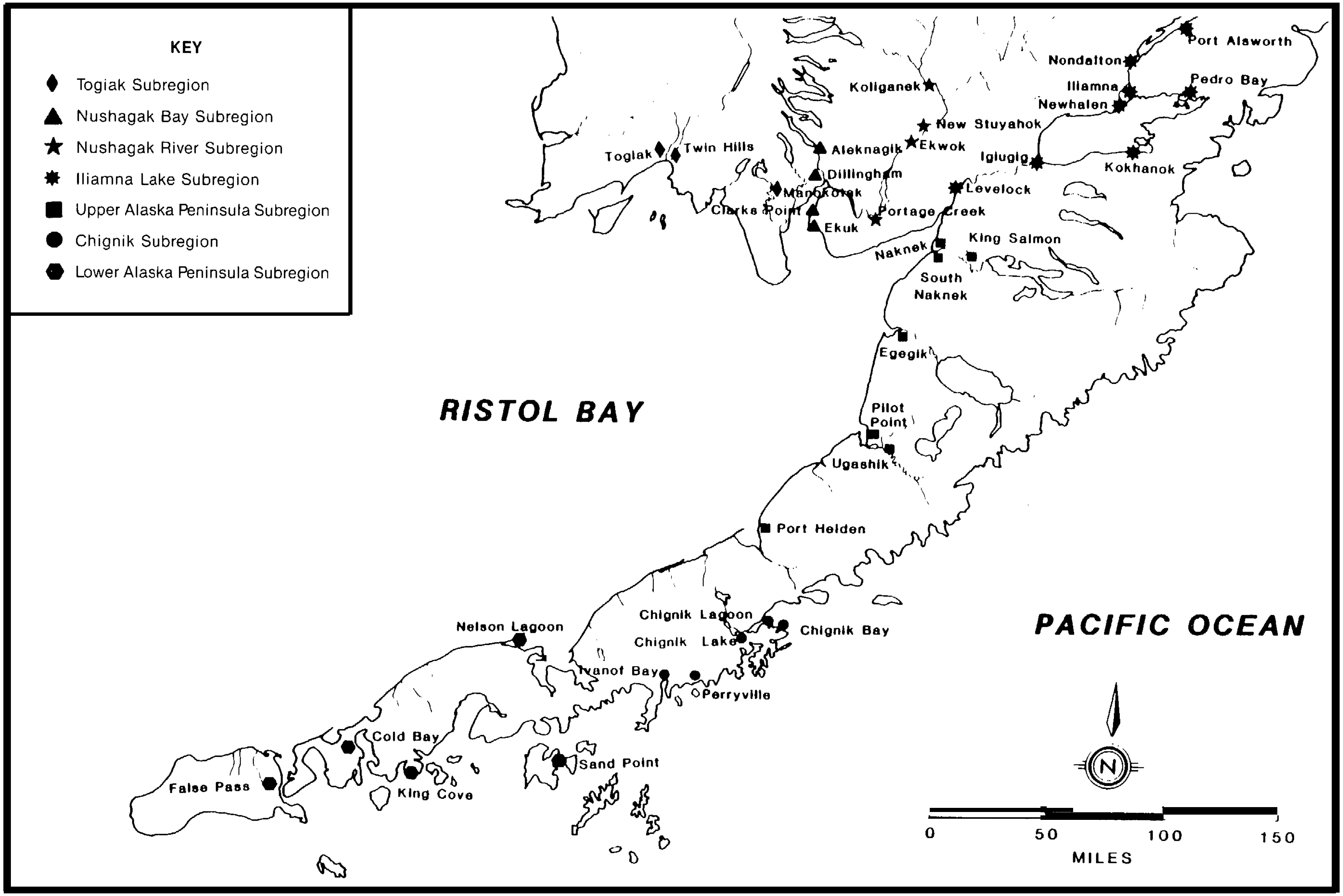

Figure 13.1—The Bristol Bay region. (The Chignik and Lower Alaska Peninsula subregions are not discussed in the report.)

such as socioeconomic and demographic information, which help identify rural areas (5 AAC 99.012).

The cornerstone of our program is community-focused research which follows an anthropological–ethnographic methodology. Projects are developed in consultation with communities, which review the designs as well as draft reports. Respondent confidentiality is assured. Data collection methods which have been used in the Bristol Bay Region include household interviews using standardized questionnaires, key respondent interviews, participant observation, resource use area mapping, catch calendars, and consultation of other primary and secondary source materials.

Advantages to this community-focused approach include reliable data, staff familiarity with communities and people, local people's familiarity with our program, and community involvement in the resource management system, a system which communities can use to achieve regulatory reform and protect subsistence opportunities.

What the division does not do should also be acknowledged. First, the research is not focused exclusively on Alaska Natives. Second, we are not involved in the enforcement of regulations, nor do we make regulatory or land management decisions. Finally, we are not ' 'advocates" for any groups. That is, our role is not to build ' 'cases" for particular groups or communities on a particular issue. Given the statutory requirement that subsistence uses be provided for, our role is to provide high quality documentation on all aspects of subsistence uses and rural Alaska ways of life.

13.4 SUBSISTENCE RESEARCH IN THE BRISTOL BAY REGION

In the effort to establish basic documentation of subsistence patterns, the division has conducted research at some level in every Bristol Bay community. We have completed (or are about to complete) baseline community studies in all but 4 of the 25 communities. We have published and distributed 18 technical papers based upon this field research.

The division has developed a computerized Community Profile Data Base, and communities of the Bristol Bay region are very well represented in the data base (perhaps better than any other region except southcentral) (Walker et al. 1988).

Extensive subsistence use area maps are now available for every Bristol Bay community. Every community in the region has a set of these maps, and they are part of the department's Regional Habitat Guide Reference Map Series (Alaska Dep. Fish and Game 1985). The division is also developing a computerized catalog of its map products (Walker et al. 1987).

The division is responsible for issuing subsistence salmon permits in the Bristol Bay Management Area and compiling harvest data based on these permit returns. We have trained local residents to issue permits, and explained to the communities why the department needs the harvest data, We have also begun developing computerized historical data bases of subsistence harvests, initially with an emphasis on salmon.

Some recent and current projects include:

1. A baseline study of Manokotak, which is undergoing final editing and will be published shortly (Schichnes and Chythlook 1988).
2. Fieldwork in four Nushagak River communities in the spring of 1988 by J. Schichnes and M. Chythlook. Data analysis is under way and a technical paper will be completed in 1990,
3. Fieldwork in Togiak on subsistence and sport fisheries interactions in 1987. The final report is expected in the next few months (Gross 1987).
4. A compilation of available information on traditional uses of nonsalmon freshwater fish in the region. A draft technical paper will soon be ready for review.

13.5 MAJOR FINDINGS

Subsistence harvests in the Bristol Bay region are among the highest in the state, ranging from 200-250 pounds per person in the regional centers to 600–800 pounds or more per person in some Nushagak River and Iliamna Lake villages. To put these harvests in perspective, consider that the average household in the western United States purchased about 222 pounds per person of meat, fish, and poultry in 1978 (U.S. Dep. Agriculture 1983). Subsistence production in almost every Bristol Bay community exceeds this level of use. Per capita harvests appear to have been stable since the early 1970s. Subsistence salmon harvests have increased in some districts.

We have found that a seasonal cycle of subsistence and commercial salmon fishing, big game hunting (moose, caribou), nonsalmon fishing, and trapping continues to form the basis of the economic life of Bristol Bay communities. We have also documented the existence of complex regional exchange patterns involving resources such as marine mammal products, herring, game, whitefish, and salmon. Clearly, subsistence use of fish and game continues to play a central economic and sociocultural role in every community of the Bristol Bay region.

Subregional patterns exist, as defined by species mix and relative harvest quantities. For example. salmon dominates, with caribou and moose second. in the Nushagak and Iliamna areas. On the Alaska Peninsula, caribou is dominant, with salmon second. Per capita harvests in villages range from about 400 to 800 pounds; harvests are lower in regional centers (200-250 pounds), but still substantial. We have documented the occurrence in regional centers of subpopulations that harvest at even higher rates. Dillingham has been a model of a ' 'regional center" for regulatory board discussions of rural-nonrural classification. This has been a particularly notable applied aspect of our Bristol Bay work.

The research has provided some insights on social organization in the region. For example, the organization of subsistence production continues to follow the domestic mode (e. g., New Stuyahok). Matri-centered subsistence fishing groups evidently exist in some communities (e. g., Manokotak). The ' 'super-household" concept (Wolfe 1987) was developed to a large degree with data from Bristol Bay (Manokotak, Nondalton, Port Heiden).

Concerning patterns of land use, extensive areas have been documented for moose and caribou hunting. There is some evidence of territoriality regarding salmon fishing areas and. to a lesser extent, hunting areas. These data have been used in the state's Bristol Bay Area Plan, and continue to be used in coastal management determinations.

13.6 CURRENT SUBSISTENCE ISSUES

Currently the major subsistence issues in the Bristol Bay region are the following:

1. Growth of recreational uses of game and especially fish. Sportfishing effort and harvest have increased markedly over the last 10 years, in part because of the growth of the sportfish guiding industry (often based at local lodges). The issue involves crowding or appropriation of traditional subsistence fishing sites, resource allocation, seasons, and allegations of waste (sometimes linked to cultural objections to ' 'catch and release" fishing in some villages). As a consequence, the state has two planning efforts under way, one in the Nushagak–Mulchatna drainage, and the other for state lands within the Togiak Refuge.
2. Harvest monitoring. A good program is in place for monitoring salmon. but better data are needed on caribou and moose harvests. A need also exists to develop culturally sensitive means of tracking harvest trends, so that baseline data for regulatory board allocation decisions will be available if restrictions become necessary.
3. Conservation System Unit planning. This issue is, in part, tied in with growth of recreation uses, especially in the Togiak Refuge. Another issue is eligibility to hunt for subsistence in national parks (Lake Clark, Aniakchak).
4. Oil and gas development, including OCS development. Regional concerns include effects on fish and wildlife populations used for subsistence and the increased competition for wildlife resources that results from regional population growth caused by such development.
5. Several specific resource issues currently exist, including winter moose hunts, cow moose hunts, caribou bag limits, Dolly Varden management concerns for the Togiak River, and nonsalmon freshwater fish in general (e.g., lack of harvest data, increasing sport demand).

13.7 FUTURE RESEARCH

The following are the major goals of the Division of Subsistence's program in the Bristol Bay region over the next several years:

1. We will complete remaining community baseline studies. including Nushagak River (mid 1990); Le\-clock (late 1989); and Aleknagik and Clarks Point (a fiscal year 1990 project). Pending community approval. a project in Togiak and Twin Hills could occur in FY 1990 or 1991.
2. Under a contract with the MMS, we are standardizing the organization of our Bristol Bay community survey data and tying these data to other household and community level information, such as subsistence salmon harvests and commercial fisheries participation and earnings. This project will be completed by October 1989.
3. The division will continue to operate the Bristol Bay subsistence salmon permit system in order to address the concerns of managers and local users. maintain contacts with communities. monitor the major subsistence resource. and maintain the historical data bases for monitoring trends in salmon use.

4. We will continue to maintain first-hand contacts with communities through participation in advisory committees, regional councils, and planning groups, as well as through more informal channels.
5. We may try to broaden our involvement in monitoring the harvest of key species, such as caribou and moose, in coordination with the Division of Wildlife Conservation.
6. We will design other issue-oriented research projects, such as those focusing on the Togiak River issues or nonsalmon freshwater fish.
7. We will continue to update our comprehensive community research. No update projects are planned at present, but these have been done in other regions several years after major regulatory changes. Such projects might be appropriate for Dillingham and the Bristol Bay Borough in the future.
8. Division personnel will use the results of their projects to write papers for professional journals and popular articles.

In summary, the division's future Bristol Bay research program will focus less on baseline community studies (although we will do updates) and more on issue-oriented research and harvest monitoring geared toward the development of historical data bases. Another emphasis will be on improving the communication of our research results to people and groups beyond the "regulatory loop." This effort will include the preparation of papers for professional peer review and publication.

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Chapter 14

Marine Mammal Habitat Use in the North Aleutian Basin, St. George Basin, and Gulf of Alaska

JOHN J. BRUEGGEMAN, GREGORY A. GREEN, RICHARD A. GROTEFENDT, RONALD W. TRESSLER
*Envirosphere Company, Plaza Center Building,
10900 N.E. 8th Street, Bellevue, Washington 98004*
and
DOUGLAS G. CHAPMAN
*University of Washington, Center for Quantitative Science,
3787 15th Avenue, N. E., Seattle, Washington 98115*

14.1 INTRODUCTION

Surveys were conducted in 1985, 1986, and 1987 north and south of the Alaska Peninsula and eastern Aleutian Islands to determine the abundance. distribution, and habitat use patterns of endangered whales and other marine mammals (Fig.14.1). In 1985. aerial surveys representing almost 40,000' nmi of effort were conducted during seven periods between April and December (Fig. 14.2). Surveys were conducted along north–south transect lines systematically distributed over the shelf, slope, and rise of the continental margin. Effort was greatest on the shelf, where marine mammal diversity and abundance were expected to be highest. In 1986. aerial surveys representing almost 18,000 nmi were conducted during four periods between March and October to determine sea otter use of the study area and to test the hypothesis that sea otters occurring north and south of the Alaska Peninsula seasonally migrate through False Pass (Fig. 14.3). The surveys were conducted along north–south transect lines systematically distributed in open water areas less than 38 fathoms deep and also along the coast and around all islands. Lastly, in 1987, a vessel survey representing over 2.000 nmi of effort was conducted south of the Alaska Peninsula during June–July to examine the annual use patterns of endangered whales observed during the 1985 survey (Fig. 14.4). Surveys were conducted along north-south transect lines located on the shelf. Detailed descriptions of the procedures and results of the three surveys are documented in three final reports (Brueggeman et al. 1987, 1988a, b).

14.2 CETACEAN SURVEY RESULTS

The 1985 and 1987 surveys showed that a variety of endangered and nonendangered cetaceans use the study area annually. Eleven species of cetaceans were observed in over 2,000 sightings in the study area during those surveys (Table 14.1). The sightings included four species of endangered whales: gray, humpback, finback, and sperm. Gray whales were most abundant, followed by approximately equal numbers of humpback and finback whales, and considerably fewer sperm whales. Humpbacks and finbacks were observed in both 1985 and 1987, whereas the other two species were not observed in 1987 due to the time and location of the survey. The most frequently sighted cetaceans not listed as endangered were the Dan porpoise and killer whale, which were observed during both surveys, Other cetaceans included Cuvier's beaked whale, Baird's beaked whale, minke whale, belukha w-hale, and harbor porpoise.

Species diversity was greater in the lease planning areas south of the Alaska Peninsula than it was in those to the north. Except for gray whales, which were regularly observed on both the north and south sides, endangered species were only observed south of the peninsula. Conversely, Dan porpoises and killer whales were encountered in every planning area. These results show that, except for gray whales,

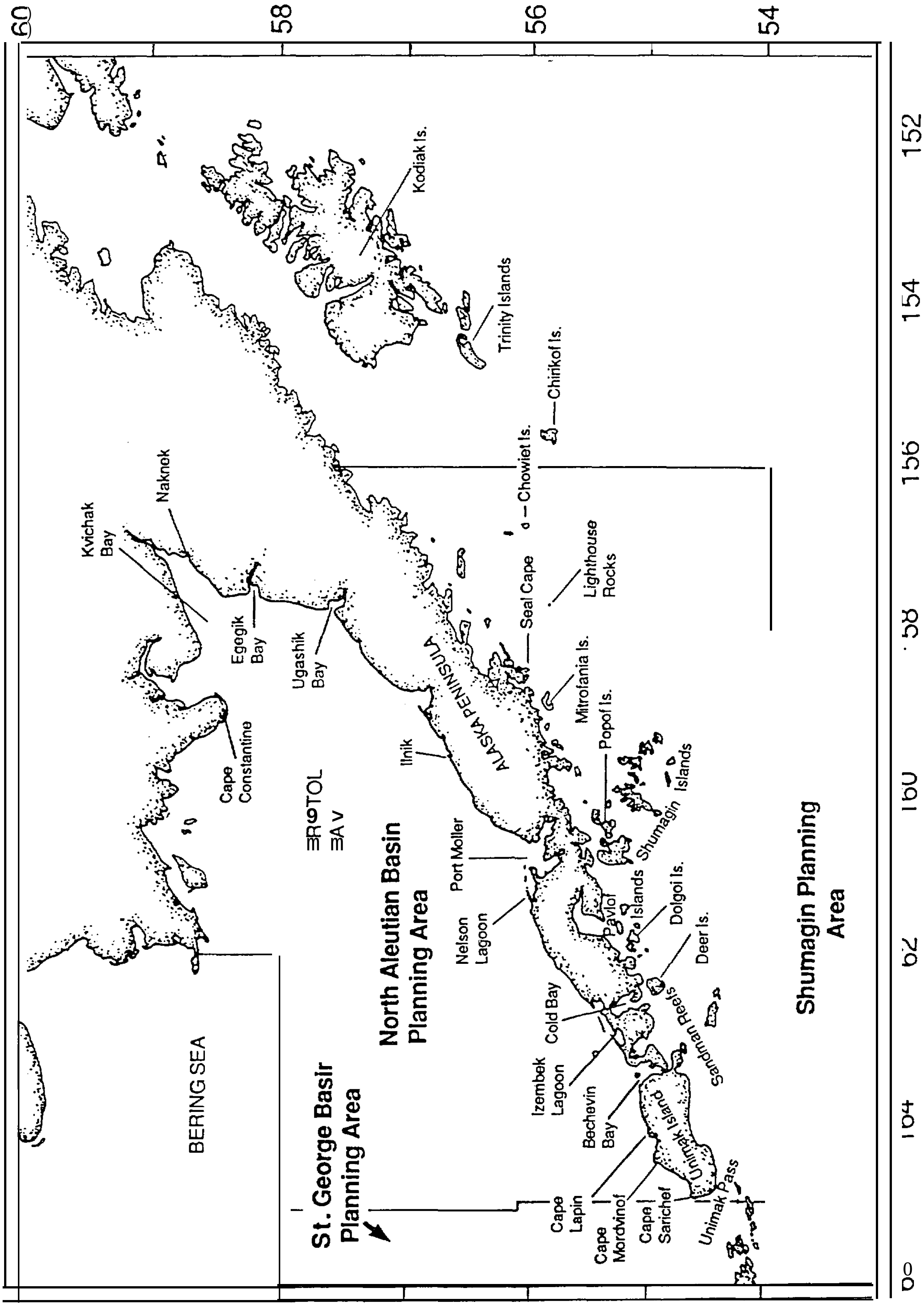

Figure 14.1—Study area for cetacean and sea otter surveys, 1985–87.

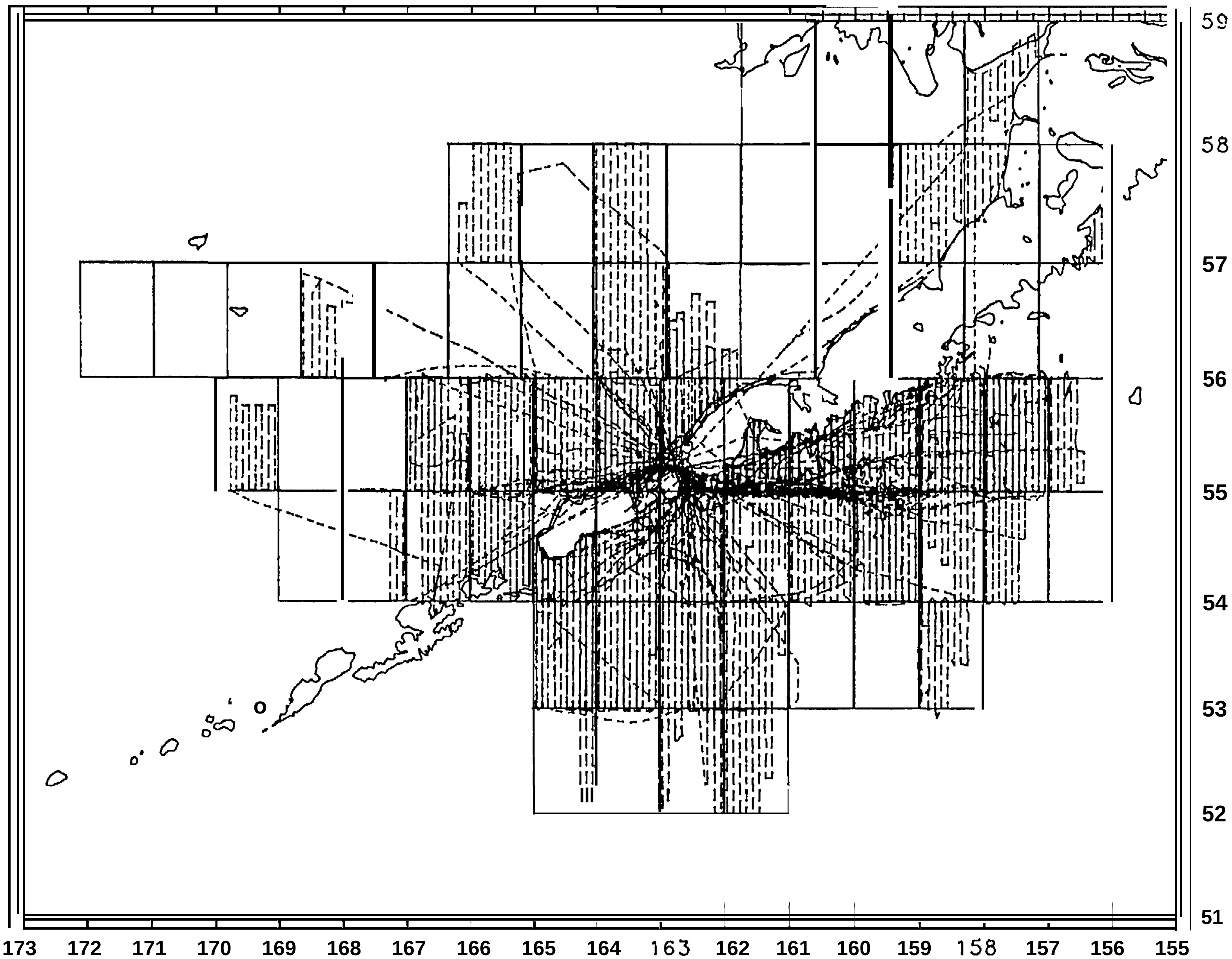

Figure 14.2—Location of transect lines surveyed for cetaceans from airplane, April–December 1985.

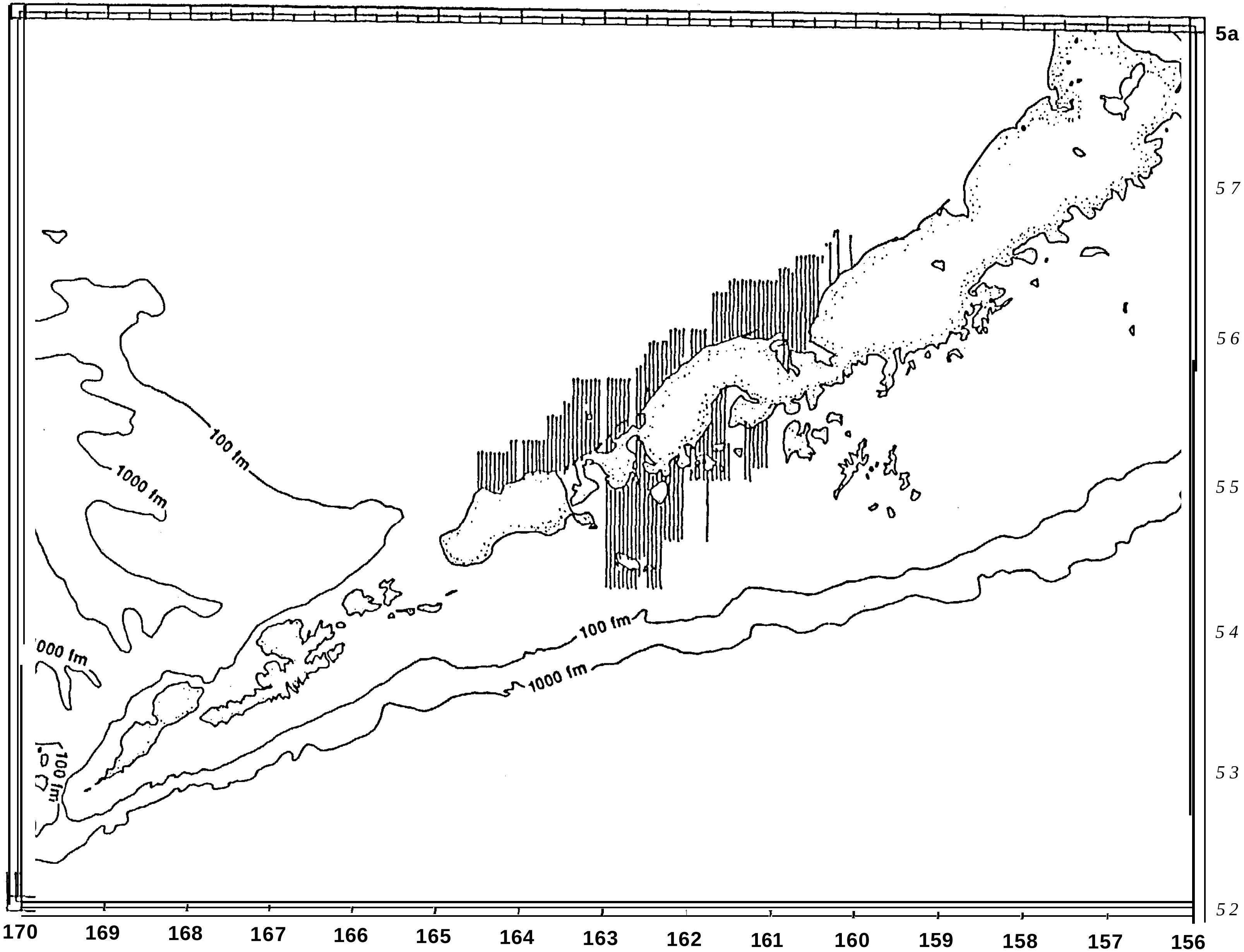

Figure 14. 3—Location of transect lines surveyed for sea otters from airplane, March-October 1986 (coastal and island surveys are not shown).

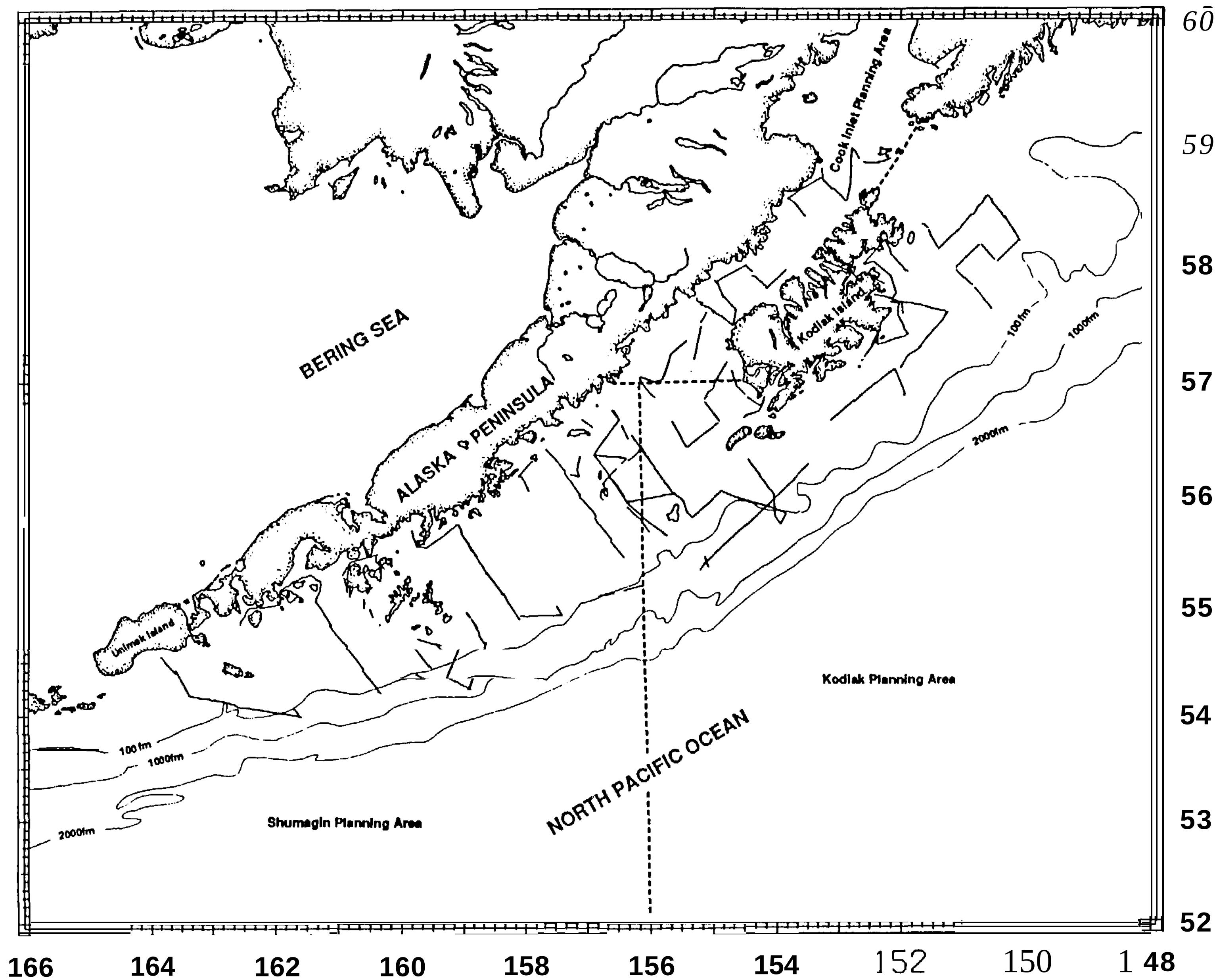

Figure 14.4—Location of transect lines surveyed for cetaceans from vessel, June-July 1987.

Table 14.1—Cetaceans observed in the study area, April-December 1985 and June-July 1987.

Species	1985 (38,050 nmi)	1987 (2,034 nmi)
Endangered		
Gray whale	589	**0**
Humpback whale	185	150
Finback whale	149	122
Sperm whale	23	0
Nonendangered		
Dan porpoise	**157**	**351**
Killer whale	**67**	**101**
Unidentified and other species*	**104**	36
Total	**1,274**	*760*

* Cuvier's and Baird's beaked whales (1 5), minke whale (20), belukha whale (8), harbor porpoise (4), and unidentified species (93).

endangered species of whales primarily occur south of the Alaska Peninsula. Cetacean use was lowest in the St. George Basin, west of the Alaska Peninsula.

Temporal use of the study area varied among the most abundant cetaceans. Gray whales migrated through the study area in the spring (April-May) and in the fall to early winter (November-December). Some animals also summered along the peninsula. Finbacks and sperm whales occurred in the study area throughout the summer, whereas humpbacks were present during both summer and fall. Dan porpoises and killer whales were encountered throughout the April-to-December survey periods. These findings indicate that the study area is an important link for gray whales migrating to their seasonal ranges, a summering area for all four endangered species of whales, and probably part of the range of Dan porpoises, killer whales, and other cetaceans throughout the year.

These cetaceans were primarily distributed over the shelf of the continental margin. All endangered whale species were observed on the shelf except for the sperm whale, which occurred in the deeper waters over the slope and rise. Killer whales also occurred primarily over the shelf, whereas Dan porpoises were ubiquitous. These results show that cetaceans are widely distributed over the continental margin, but that species diversity is highest on the shelf.

Observations of gray, humpback, and finback whales were numerous enough to allow close examination of their spatial distributions. Thirty-nine groups of 121 gray whales were observed south of the Alaska Peninsula between Seal Cape and Unimak Pass during the spring migration (Fig. 14.5). All but two groups were sighted within 4 nmi of the mainland or islands; the remaining two groups were approximately 110 nmi from shore. Surveys were not conducted on the north side during the spring. During the fall migration, 296 groups of 466 gray whales were observed on both sides of the peninsula (Fig. 14.5). Approximately 95% of the whales north of the peninsula were within 5 nmi of shore; the distribution was closer to shore as the animals approached Unimak Pass from Ugashik Bay. The distribution south of the peninsula was also coastal (<12 nmi from shore) from Unimak Pass to Seal Cape, but became more pelagic as the animals moved from Seal Cape toward Kodiak Island. A small contingent of animals also followed the outer continental shelf edge off the Shumagin Island complex. In between the two seasonal migration periods, small numbers of gray whales summered primarily near the bays and lagoons north of the peninsula, which feature sandy substrates in contrast to the rocky substrates characteristic south of the peninsula. These results show that gray whales use the nearshore habitats of the Alaska Peninsula during the spring and fall migration periods and are closely associated with the bays and lagoons, primarily north of the peninsula, during the summer. We could not confirm an offshore fall movement corridor from the Pribilof Islands to Unimak Pass as discussed by Braham (1984), although we completed almost 2,500 nmi of survey effort in the suspected area.

A total of 167 groups of 335 humpback whales were observed south of the peninsula during the summer and fall. The whales were widespread from Sanak Island to waters just east of Kodiak Island (Fig. 14.6). All of them were observed on the shelf, except for two groups sighted in deep water during the late summer and fall (traveling in the direction of their wintering areas). The humpbacks on the shelf were primarily associated with the 50-fathom isobath, particularly near banks. They were found at Sanak, Shumagin, Albatross, and Portlock banks, as well as on an unnamed bank west of the Semidi Islands. Whales were observed at Sanak, Shumagin, and the unnamed bank in both 1985 and 1987, suggesting that humpback feeding herds exhibit

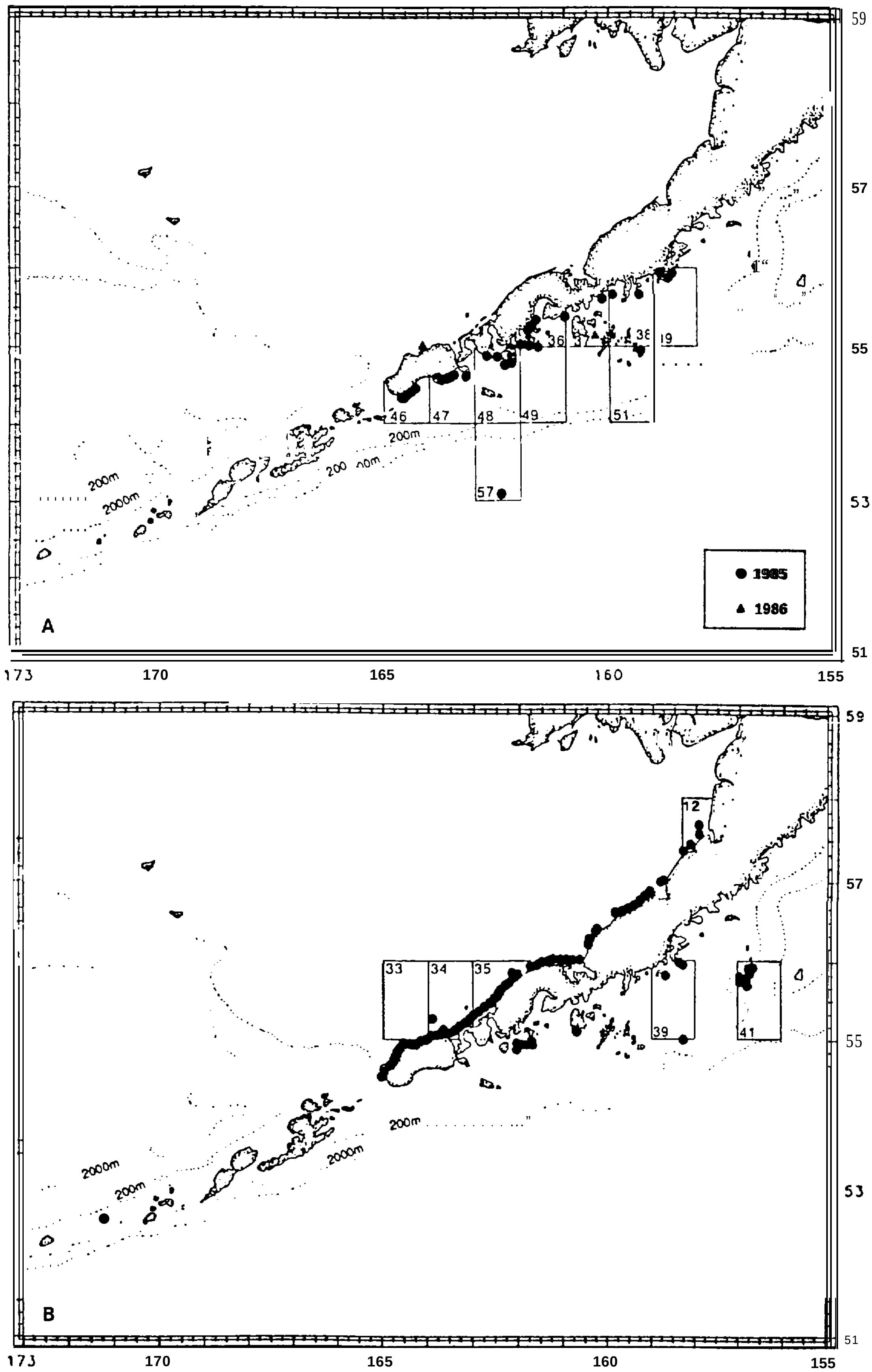

Figure 14.5—Location of gray whales observed in the study area: A, spring; B, fall.

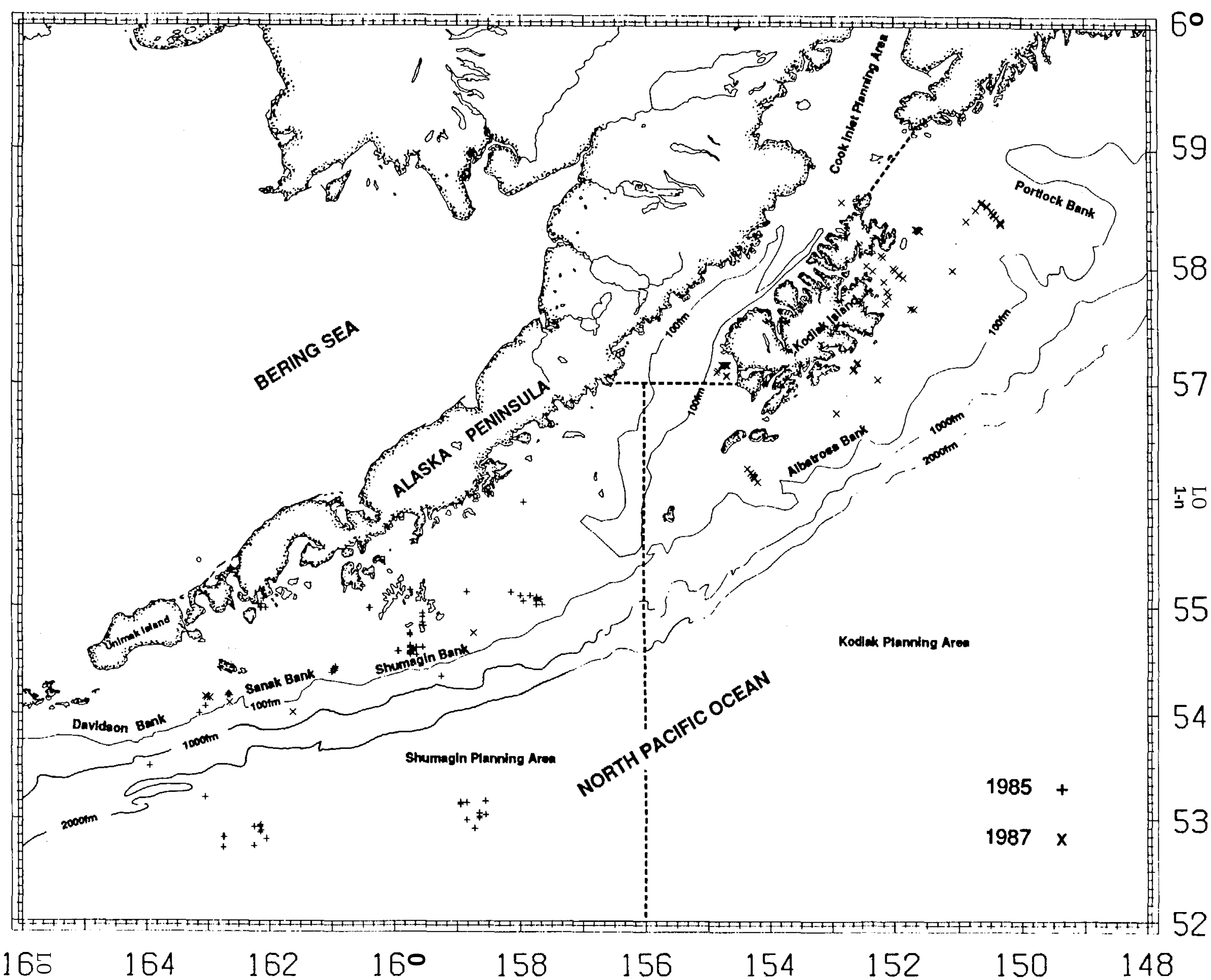

Figure 14.6—Humpback whale locations recorded during the 1985 aerial surveys and 1987 shipboard surveys.

fidelity to these areas. These findings indicate that humpback whales are widely distributed in the study area and are closely associated with oceanic banks, where prey productivity may be high.

A total of 132 groups of271 finback whales were observed south of the Alaska Peninsula during the summer. The whales were widespread on the shelf from Sanak Island to east of Kodiak Island (Fig. 14. 7). Most whales were associated with the 50- and 100-fathom isobaths, particularly near the Shelikof Strait Canyon, Shumagin Bank, and the unnamed bank west of the Semidi Islands. Whales were repeatedly observed in these areas between survey periods and survey years, suggesting fidelity to these sites. Although finback whale distribution overlapped with humpback distribution, the two species typically concentrated in separate areas. The results show the importance of banks and canyons to finback and humpback whales during the summer feeding period. No finback or humpback whale calves were observed during 1985 or 1987.

Humpback and finback whale abundances in the study area during 1985 and 1987 were estimated using the line transect procedure. The number of humpback whales was estimated at 333 ± 108 (SE) animals in the Shumagin Planning Area in 1985 and 1,247 ± 392 in the Shumagin and Kodiak areas in 1987. Finback whale abundance was estimated at 184 ± 45 animals in the Shumagin Planning Area in 1985 and 1,257 ± 563 animals in the Shumagin and Kodiak areas in 1987. These estimates do not include missed animals or animals below the surface during the surveys. They suggest that over 50% of the 2,100 humpbacks and approximately 10% of the 17,000 finbacks estimated in the North Pacific Ocean summer south of the Alaska Peninsula.

14.3 SEA OTTER SURVEY RESULTS

A total of 7,580 groups of 22,791 sea otters were observed in the study area between March and October 1986 (Table 14.2). Otters were more common north and south of the Alaska Peninsula than in the Fox Islands, where shallow water habitat was more limited in area. Animals occurred north of the peninsula from Unimak Pass to Cape Seniavin (Fig. 14.8). Densities were higher between Unimak Pass and Cape Lieskof than from Cape Lieskof to Cape Seniavin, where shorefast ice seasonally affects the suitability of the habitat. Otters were particularly concentrated in the vicinity of Izembek and Moffet lagoons and Amak Island. Otters observed south of the peninsula occurred throughout the nearshore areas and island complexes, including the Sanak–Caton, Pavlof, and Shumagin islands. All of the islands comprising the Fox Island complex were inhabited by otters.

We estimated that the study area supports approximately 30,000 sea otters (Table 14.3). Total counts were used to derive island estimates, and strip transect procedures were used to derive open water estimates. Estimates of total abundance in the study area were similar in different seasons. Distribution varied among the planning areas: abundance was highest in the Shumagin Basin, somewhat lower in the North Aleutian Basin, and lowest in the St. George Basin. Our estimates, while conservative (because they do not account for missed animals), suggest that the population has declined since estimates were made in the 1960s and 1970s. Moreover, shifts in abundance we observed at the major island complexes suggest the population has not reached equilibrium. The consistency of the

Table 14.2—Survey effort and number of sea otters observed in the study area, March-October 1986.

Planning area	Effort (nmi)	Number of otters	Number of groups
North Aleutian Basin	9,020	12,536	3,821
Shumagin	8,099	9,396	3,469
St. George Basin	704	859	290
Total	17,823	22,791	7,580

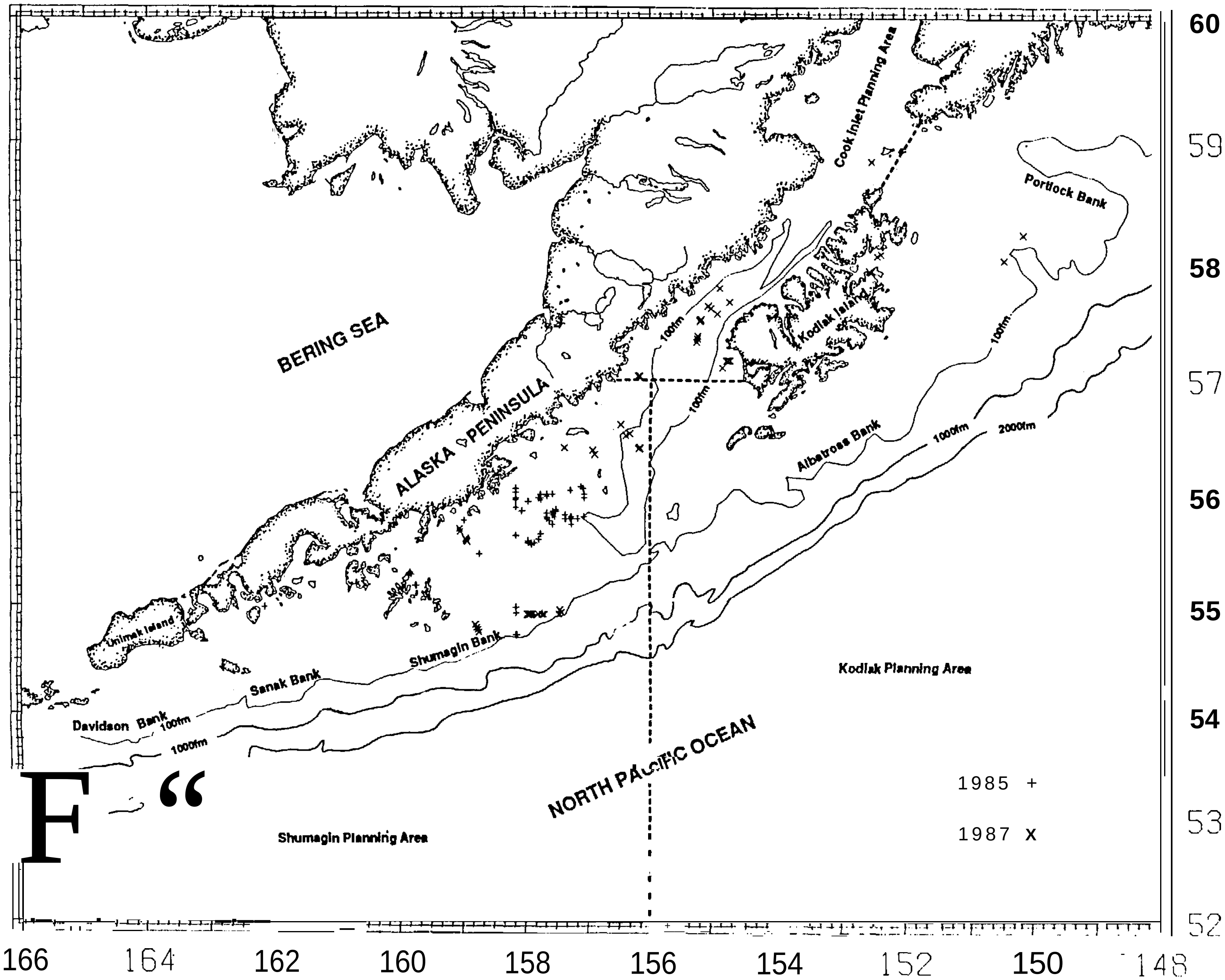

Figure 14,7 —Finback whale locations recorded during the 1985 aerial surveys and 1987 shipboard surveys.

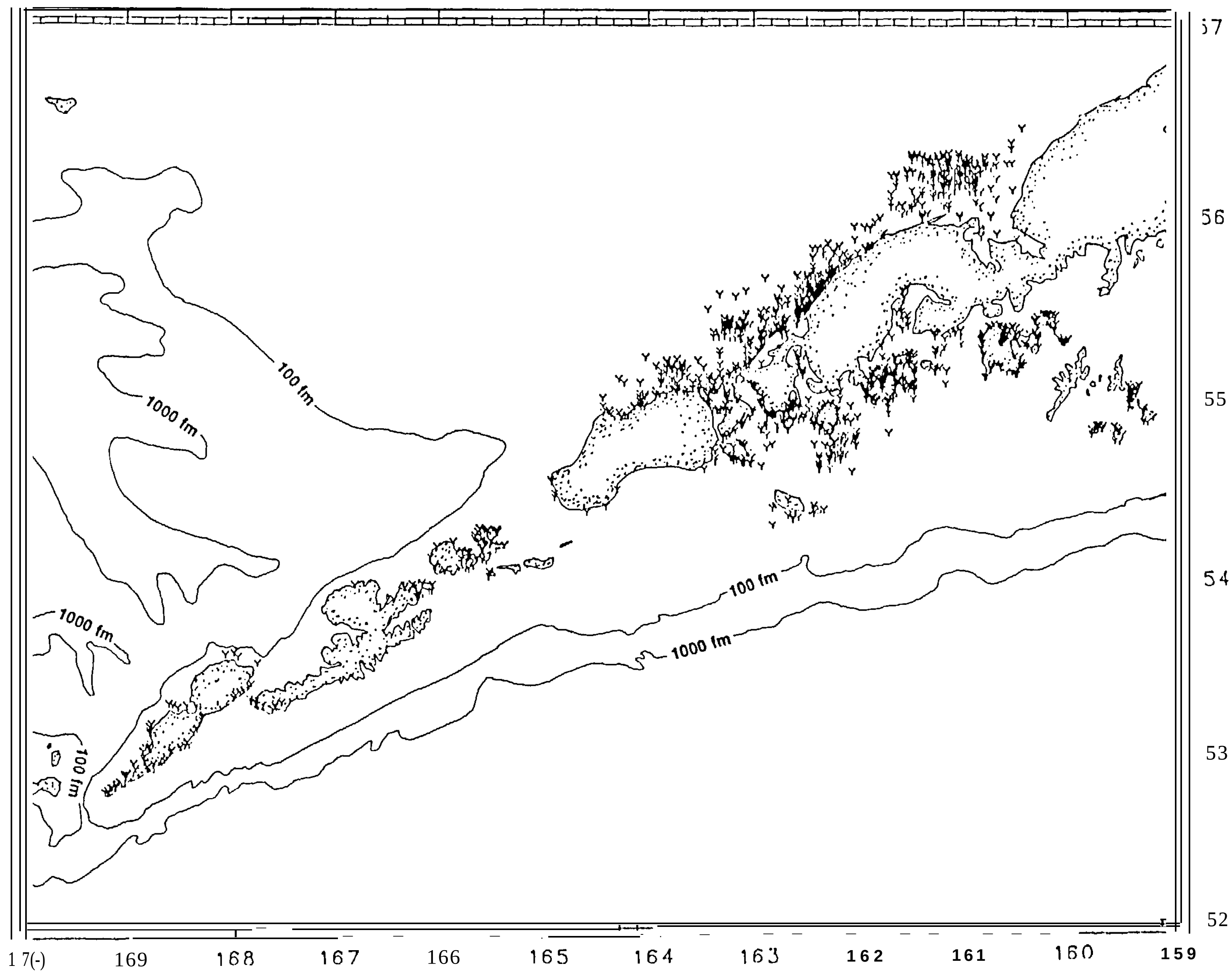

Figure 14.8—SCM otter distribution in the study area, 1986.

Table 14. 3—Estimated abundance (+95 % CI) of sea otters in the study area.

Season	North Aleutian Basin (All areas)	Shumagin		St. George Basin (Islands)[2]	Total
		Open water	Islands[1]		
Spring	9,207 ± 5,109	15,958 ± 9,771	1,877	858	27,900
Summer	13,091 ± 5,408	13,469 ± 8,956	1,877	858	29,295
Fall	9,061 ± 3,044	14,979 ± 11,856	1,877	858	26,775

[1] Highest seasonal count for each island was summed to obtain total abundance.
[2] Islands were surveyed once in the summer season.

seasonal estimates north and south of the peninsula indicates that otters do not seasonally migrate through False Pass, at least during the time period and under the environmental conditions associated with our study.

14.4 ACKNOWLEDGMENTS

We thank the survey team of A. W. Erickson, M. Herder, S. Small, S. Landino, B. Hanson, and E. Bowlby. Field support was provided by the crew of the NOAA ship *Miller Freeman* and the NOAA aircraft pilots, who significantly contributed to the enjoyment, success, and safety of the project. We are especially grateful for the support provided by L. Jarvela and other NOAA and MMS staff. The project was sponsored by the MMS, Department of the Interior, through an interagency agreement with NOAA, Department of Commerce, as part of the Outer Continental Shelf Environmental Assessment Program.

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Chapter 15

Status of Belukha Whales in Cook Inlet

DONALD G. CALKINS

Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska 99502

15.1 INTRODUCTION

Belukhas are medium-sized whales which lack a dorsal fin, although a ridge is often present near the middle of the back. Birth pigmentation ranges from blue-gray to dark brown and gradually changes to light gray as whales become juveniles. Males become white at approximately 9 years, while females become white as early as 6 years of age but may retain some gray coloration for as long as 21 years. The belukha's complex acoustic behavior, thought to be the finest resolution biosonar yet discovered, is an adaptation which makes the belukha particularly well suited for survival in the turbid waters of Cook Inlet.

15.2 DISTRIBUTION

Belukhas have a circumpolar distribution in seasonally ice-covered arctic and subarctic waters. Several geographically separated stocks are recognized. In Alaska two stocks are recognized: the western arctic stock consists of belukhas that seasonally occupy waters of Bristol Bay and the Bering, Chukchi, Beau fort, and East Siberian seas; and the Cook Inlet stock, centered in Cook Inlet, occupies the northern Gulf of Alaska from as far west as Kodiak to Yakutat Bay (Fig. 15.1).

Cook Inlet is used throughout the year by belukhas. Seasonal concentrations and habitat partitioning occur. In general. concentrations occur in the upper inlet in the spring and early summer (.April–June). Sightings of belukhas are common throughout the inlet in midsummer and through autumn (July–November). Belukhas apparently use the lower inlet more heavily in winter. Only one documented sighting of belukhas in the upper inlet has been made in the period from December through March.

Belukhas concentrate in northwestern Cook Inlet in the spring. Although the reasons for this behavior are not entirely understood, several possible explanations become apparent when this stock is compared with belukha stocks from other areas. Belukha stocks commonly concentrate near river mouths in spring. Possibly, they gather at river mouths at this time to calve and breed. It has also been surmised that the warmer water temperatures found in estuarine areas in the spring are important to all segments of the belukha population, not just the reproductive age classes or neonates. Secondarily, the concentration areas may afford some shelter from storms. Availability of an important food source may also be a cause of river mouth concentrations. This was not considered a major factor for belukhas concentrating in the MacKenzie estuary, because most of the whales harvested by Natives had empty stomachs. This is an important difference from the Bristol Bay stock and also, possibly, from the Cook Inlet stock. In Bristol Bay, belukhas do feed in estuaries in the spring and may be primarily drawn to the area by both downstream migrating salmon (*Oncorhynchus* spp.) smelts and returning adults and an early run of smelt (*Osmerus dentax*).

No definitive link has been shown between belukhas concentrating at the mouth of the Susitna River and an important food source. However, the arrival of several species of anadromous fish (similar to those found in Bristol Bay) concurrent with the build-up of belukhas in northwestern Cook Inlet is strong circumstantial evidence of such a relationship. One of the most important of these anadromous fish species (in terms of biomass) is the eulachon or hooligan (*Thaleichthys pacificus*) which arrives in the Susitna estuary in May and June and enters the river for spawning in two major migrations. Escapement in these two migrations has been estimated to be several hundred thousand fish in May and several million fish in June, It seems likely that eulachon in Cook Inlet could be analogous to smelt in Bristol Bay, which are considered to be important in the diet of belukhas in early spring. This suggests that the belukha concentration in upper Cook Inlet in May and June occurs, at least in part, in response to the arrival of an important food source.

The question of whether the Cook Inlet belukha stock is isolated from the nearest stock, in Bristol Bay, has not been fully answered. Some evidence suggests that this stock is both geographically isolated and genetically different from other stocks. Fay (Univ. Alaska, Fairbanks, pers. commun.) analyzed available material and suggested the possibility of a differentiation in cranial morphology, However, the sample size of Cook Inlet belukha skulls was too small for a conclusive study when analyzed in 1978 and remains so today.

The lack of sightings of belukhas along the south side of the Alaska Peninsula south of Kodiak Island suggests that movements between the Cook Inlet belukha stock and the Bristol Bay stock are rare if they occur at all. However, belukhas are obviously capable of such movements. If belukhas move between Cook Inlet and Yakutat Bay, it certainly seems possible for them to move between Cook Inlet and the Bering Sea. Such movements would probably occur in winter, when observation is unlikely.

Belukhas are also found outside Cook Inlet, although not on a predictable basis. Sightings of belukhas have been made near Kodiak island in March and July and near the entrance to Prince William Sound in March. There have also been reports of sightings of belukhas at the Barren Islands, Marmot Bay on the northwest side of the Kodiak Archipelago, in Shelikof Strait, and off Montague Island. Approximately 200 belukhas were sighted in Prince William Sound in July 1983. Belukhas were first reported in Yakutat Bay in 1976.

Subsequent sightings have been made in Yakutat Bay, including a report by a local fisherman that they are sighted annually. Those reports appear speculative, and could not be substantiated in discussions with other residents of the area. The relatively small number of animals sighted at any one time, always less than 30, suggests a group of visitors rather than a self-sustaining population. Most likely, the belukhas seen in Yakutat Bay are occasional visitors from the Cook Inlet stock.

15.3 POPULATION SIZE

The Cook Inlet stock was first surveyed by the Alaska Department of Fish and Game in 1964-65 and estimated at a minimum of 300 to 400 whales. In subsequent aerial survey/sighting combinations, the highest minimum direct count I have obtained for a single day was 479 animals on 21 August 1979. Some investigators have speculated that three times as many whales are present as are counted in this type of survey. Using a correction factor of 2.7 to account for submerged whales (which was developed for estimating belukha whales in similar conditions in Bristol Bay) yields a minimum estimate of 1,293 whales in Cook Inlet in August 1979.

15.4 FOOD HABITS

All five species of North American Pacific salmon return to Cook Inlet to spawn. Outmigrating salmon smelt are found in many river systems in Cook Inlet in the spring. As in Bristol Bay, belukhas most likely eat outmigrating smelts and adult salmon in Cook Inlet. The only information currently available on food habits of belukhas in Cook Inlet concerns the consumption of salmon.

In January 1986, 12 Floy spaghetti tags and one Floy anchor tag were taken from the stomach of an adult, male belukha found dead on the beach near Windy Point in Turnagain Arm of upper Cook Inlet. All of the recovered spaghetti tags that were identifiable had been placed on adult salmon migrating up the Susitna River at river miles 20, 22, and 80, in conjunction with the Susitna River hydroelectric studies (Mike Thompson, Alaska Department of Fish and Game, pers. commun.). The Floy anchor tag had been applied to an adult sockeye salmon (*Oncorhynchus nerka*) by the Cook Inlet Aquiculture Association.

The species composition of the 13 adult salmon and the locations where the salmon were taken by the belukha are unknown. Belukhas readily ascend rivers, occasionally traveling several hundred kilometers. However, sightings of belukhas in the Susitna River are uncommon. Tagging crews stationed on the Susitna River during 1983 through 1985 reported no sightings of belukhas above river mile 3. It is possible that the fish could have moved downstream, below river mile 3, although salmon would be unlikely to return nearly 80 miles downstream after tagging. The belukha could have consumed dead or dying salmon which had spawned and subsequently were flushed downstream, but belukhas have not been known to scavenge on dead or dying fish.

The whale was nearly 4.5 m long and appeared to be old, judging from its size and the wear on its teeth. This could mean that it was in poor physical

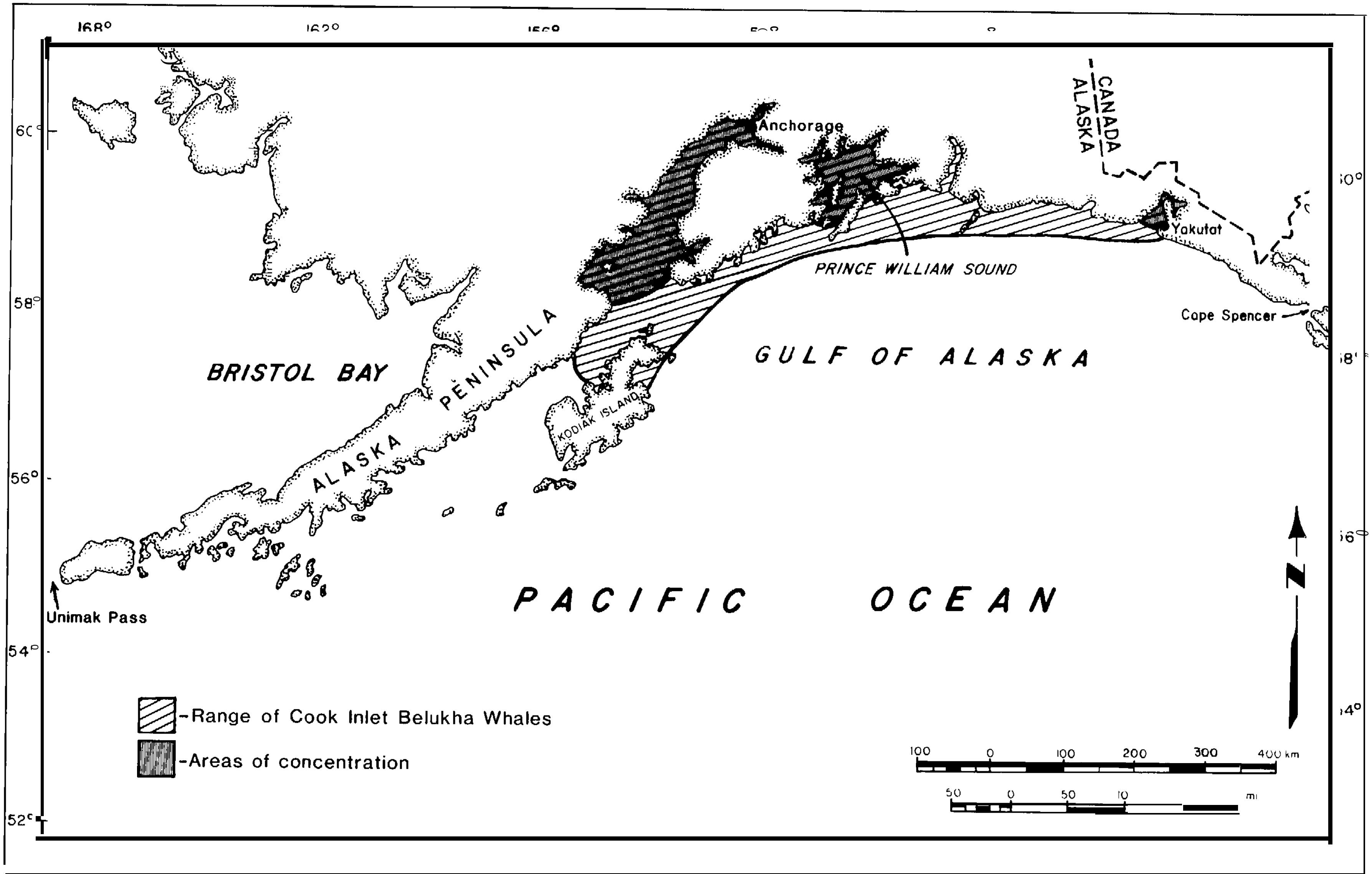

Figure 15. —Range of belukha whales in the Gul. of Alaska.

condition prior to its death and was attempting to utilize more easily available food sources.

Belukhas feed in the upper 10 m of the water and are known to consume at least 100 different species of fish and invertebrates in other parts of their range. Common in the diet are smelt, capelin (*Mallotus villosus*), eulachon, herring- (*Clupea harengus*), and saffron cod (*Eleginus gracilis*). Many of these species are found in Cook Inlet and maybe important in the diet of belukhas. Pacific tomcod (*Microgadus proximus*) may take the place of saffron cod in Cook Inlet. It is possible that belukhas may feed on tomcod in Cook Inlet in autumn and winter, when salmon and eulachon are not available.

Pollock (*Theragra chalcogramma*), shrimp, octopus, and sculpins are important in offshore areas in other parts of the belukha's range. These food sources are all found in areas adjacent to Cook Inlet, particularly the Kodiak area, Prince William Sound, and the Yakutat area. These species are likely to be important to belukhas when they are outside of Cook Inlet.

15.5 REPRODUCTION

Because almost no information on breeding and reproduction is available specifically for Cook Inlet belukhas, it must be inferred from studies in other parts of the range. Normally, a triennial reproductive cycle appears to be common. Females generally first breed in the spring just prior to their fourth or fifth birthday, whereas males initially breed at 8 years of age. Gestation is estimated to last 14-15 months and births occur in June or July. Lactation may last for up to 2 years, although the duration of dependant nursing may be considerably shorter. Breeding can take place while the female is still lactating.

Calving in Cook Inlet probably takes place while the belukhas are concentrated at the mouths of rivers in the upper inlet (from the Susitna River to the Belukha River) during May and June. It appears common for belukhas to take advantage of warmer water temperatures in many estuarine areas during this period. Thermal advantage would be particularly important to neonates during the first few days of life because of their relatively small surface to volume ratio and limited fat deposits.

15.6 RECOMMENDATIONS

If we are to truly understand the status of belukha whales in Cook Inlet, several important studies should be undertaken. The following recommendations are in order of priority: develop a realistic, statistically sound estimate of the total Cook Inlet belukha stock; develop a method for monitoring trends in abundance; determine the taxonomic status of this stock; determine seasonal movements, distribution, and habitat use patterns; identify the use and importance of food species; define the sex and age composition of the herd; and monitor subsistence harvests.

Chapter 16

Status of Northern Fur Seals

THOMAS R. LOUGHLIN
NOAA, National Marine Fisheries Service, National Marine Mammal Laboratory, 7600 Sand Point Way, N. E., Seattle, Washington 98113-0070

16.1 INTRODUCTION

About 72% of the current estimated population of northern fur seals (*Callorhinus ursinus*) are found on St. Paul and St. George islands, Pribilof Islands, Alaska. where they breed and pup during summer (Fig. 16.1). A small portion occurs on San Miguel Island. California, and Bogoslof Island, eastern Bering Sea. Alaska. The remainder of the population occurs in the U.S.S.R. on the Commander Islands (17 %), Robben Island (6%), and a small proportion on the Kurile Islands.

Typically. fur seals of all ages and both sexes leave the Pribilof Islands in October or November and then return to the rookeries in June or July for breeding, Females and some young males migrate as far south as California and are found along the continental shelf; they remain pelagic until their return to the Pribilof Islands in June. Parturition occurs soon after arrival at the rookeries. Adult males probably remain in the Gulf of Alaska, along the Aleutian Islands, and parts of the Bering Sea after the breeding season.

16.2 CURRENT STATUS

The Pribilof Island fur seal stock numbers about 800,000 and is probably stable following a sharp decline during 1976-81. The most useful index of population size is the number of pups born (Fig, 16.2). Estimates of pup production are obtained using a shearing sampling (mark-recapture) method and counts of dead pups (York 1987). The number of adult females is estimated by dividing the number of pups born by the weighted, average pregnancy rate of adult females (about 68%). These estimates are then added to counts of adult males to obtain an estimate of the entire breeding population on the Pribilof Islands.

Pups comprise about 20-30% of the total population. At St. Paul Island during the period 1912-24, pup production increased from about 67,000 to 162,000 and then to over 460,000 in 1940. The level remained high until the mid-1950s. then declined to about 170,000 by 1981. Between 1975 and 1981 the pup population decreased at about 7.5% per year. Since then pup production has leveled off and begun to increase. In 1988, the estimated number of pups born was 202,000, 18% higher than the 171,000 born in 1987. However, on St. George Island more pups were born in 1987 (28,000) than in 1988 (25,000). The count of adult males on both islands has declined during the period starting in the 1970s.

Causes of the 1975-81 fur seal pup decline have not been specifically identified, but may include the combined effects of a female harvest during 1956-68, entanglement in debris, weather, resource availability, and disease. Because of the decline in pup production during 1975-81, and for other reasons, the population was designated as ' 'depleted"' on 18 May 1988, pursuant to the Marine Mammal Protection Act.

Fur seals were hanested for their fur on the Pribilof Islands from 1786 to 1984 (Fig. 16.3). From 1940 to the late 1950s, about 50.000 subadult males were harvested per year, dropping to about 25,000 per year during the last few years of the harvest,

\\'bile in the Bering Sea during the breeding season, female fur seals feed primarily on walleye pollock, Atka mackerel, capelin, herring, and squid. Adult territorial males usually remain on the rookeries during the breeding season and do not feed. Subadult males eat prey similar to that consumed by females. but also feed on nearshore prey such as

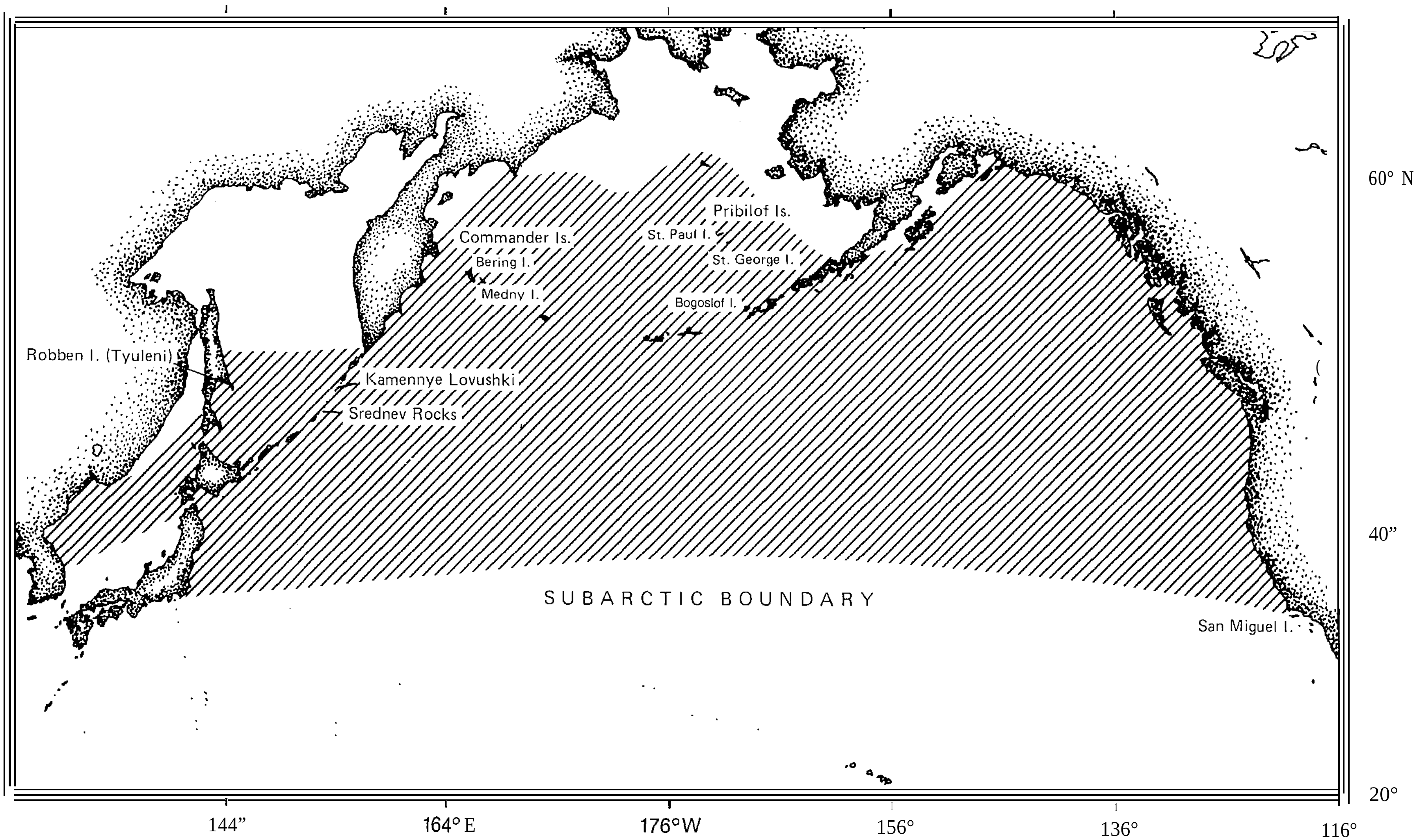

Figure 16. I —General oceanic distribution and breeding islands of the northern fur seal. (Adapted from Lander and Kajimura 1982.)

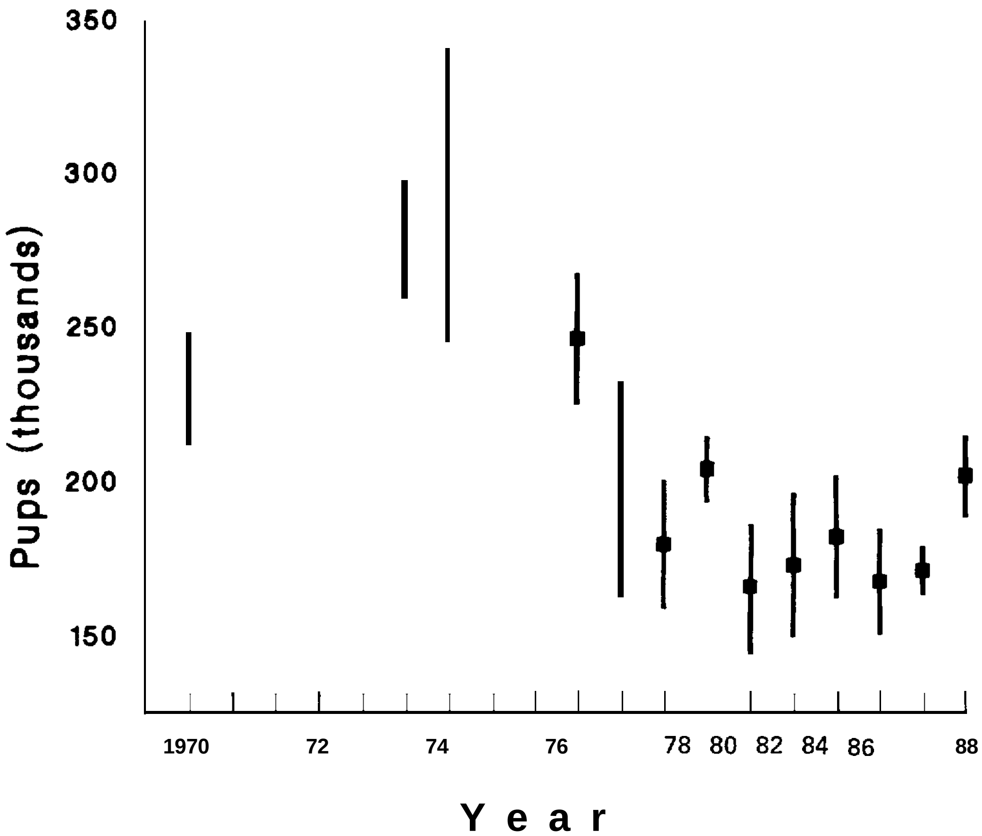

Figure 16.2—Number (in thousands, with approximate 95% confidence intervals) of northern fur seal pups born at St. Paul Island, Alaska, 1970–88.

sand lance. Female feeding trips average 5.9 days and may result in round-trip distances of more than 400 km. Fur seals occur in the Gulf of Alaska and Aleutian Islands area during north- and southbound migrations. While there, they eat sand lance, herring, capelin, pollock, squid, and an assortment of other prey.

16.3 ONGOING RESEARCH

Current research on northern fur seals at the National Marine Mammal Laboratory includes assessing incidental catch in pelagic gill net fisheries, monitoring population trends, describing feeding locations and feeding behavior, and other projects designed to investigate the interaction of fur seals in the marine ecosystem.

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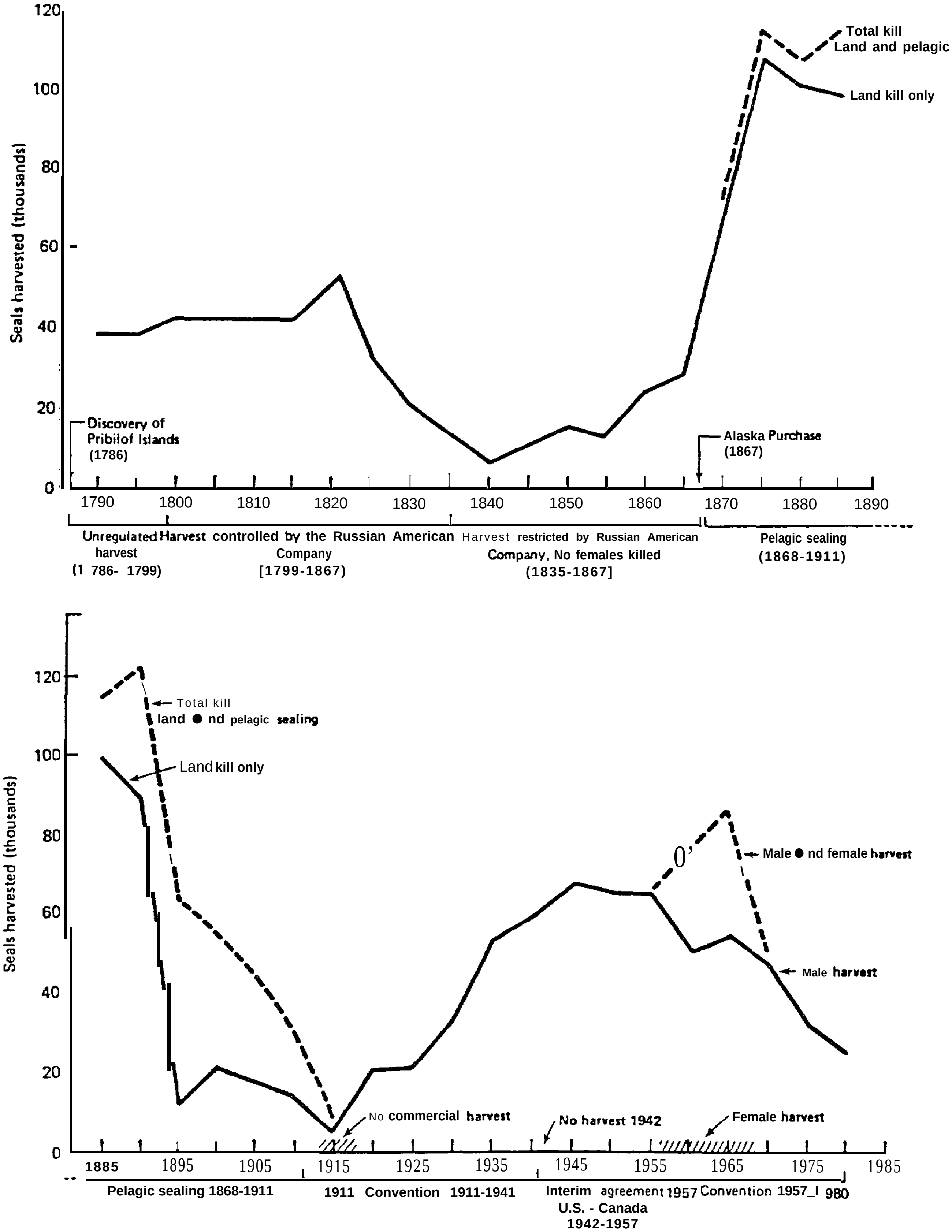

Figure 16.3—History of northern fur seal exploitation, 1786-1979, Pribilof Islands, Alaska. Data are 5-year averages (York 1987).

Chapter 17

Status of Northern Sea Lions

THOMAS R. LOUGHLIN
NOAA, National Marine Fisheries Service, National Marine Mammal Laboratory, 7600 Sand Point Way, N. E., Seattle, Washington 98115-0070

17.1 INTRODUCTION

The breeding range of northern (Steller) sea lions (*Eumetopias jubatus*) extends around the North Pacific Ocean rim from the Kurile Islands and Okhotsk Sea, through the Aleutian Islands and southern Bering Sea, along Alaska's southern coast, and south to California (Fig. 17.1). The centers of abundance and distribution are the Gulf of Alaska and Aleutian Islands, respectively. Northern sea lions do not migrate, but disperse widely after breeding and may occur near ice or on northern islands in the Bering Sea during fall and winter. Adult breeding animals and some subadults occupy rookeries during the breeding season, which extends from late May to early July; nonbreeding animals use haulout sites during the same period.

17.2 CURRENT STATUS

Aerial-photographic, ship, and land surveys were conducted in 1984–88 to assess the abundance of northern sea lions from the central Aleutian Islands through the Gulf of Alaska. The number of sea lions found at all surveys sites totaled about 68,000 in 1985, a decline of 52 % in 27 years from approximately 140,000 in 1958 (Fig. 17.2). Numbers have declined throughout most of Alaska, with the greatest declines in the eastern Aleutian Islands (797G) and western Gulf of Alaska (73 %); the population in southeast Alaska appears to be stable. Significant declines have also occurred in the western Aleutian Islands and Kurile Islands. Pup production at most rookeries has also declined. For example, at Walrus Island, Pribilof Islands, Alaska, the number of pups declined fron 2,866 in 1960 to less than 200 in 1987. At Marmot Island in the Kodiak Island area, pup numbers declined from 6,741 in 1979 to only 3,136 in 1988.

The observed declines probably occurred in two phases. The first began in the early 1970s and was confined to the eastern Aleutian Islands and western Gulf of Alaska. The second phase began in the late 1970s with most areas of Alaska (except southeast Alaska and Prince William Sound) being affected. The northern sea lion is being considered for designation as "depleted" under the Marine Mammal Protection Act.

Causes for the decline have not been specifically identified, but probably include the synergistic effects of commercial fisheries, disease, and environmental perturbations that affect resource availability. Emigration, toxic pollutants, and entanglement are not considered major causes of observed declines.

The most extensive studies of northern sea lion food habits, reproductive rates, movements, and growth were conducted in the Gulf of Alaska, principally near Kodiak Island, during 1975–78 and 1985-86. Walleye pollock were the principal prey during both study periods, but the pollock consumed in the later study were smaller than in the 1970s. Other important prey were octopus, flatfish, and sand lance. Reproductive rates had not changed significantly between the two study periods (near-term pregnancy rate of about 607C). Interestingly, standard length, girth, and weight of females were smaller in the 1980s than in the 1970s, suggesting a reduced state of overall physical fitness, perhaps due to lowered nutritional levels (Fig. 17.3).

17.3 ONGOING RESEARCH

Current research on northern sea lions in Alaska is conducted only by the National Marine Mammal Laboratory. Previously, the Alaska Department of Fish and Game had an extensive research program on sea lions in the Gulf of Alaska, but they have terminated those studies due to budget constraints.

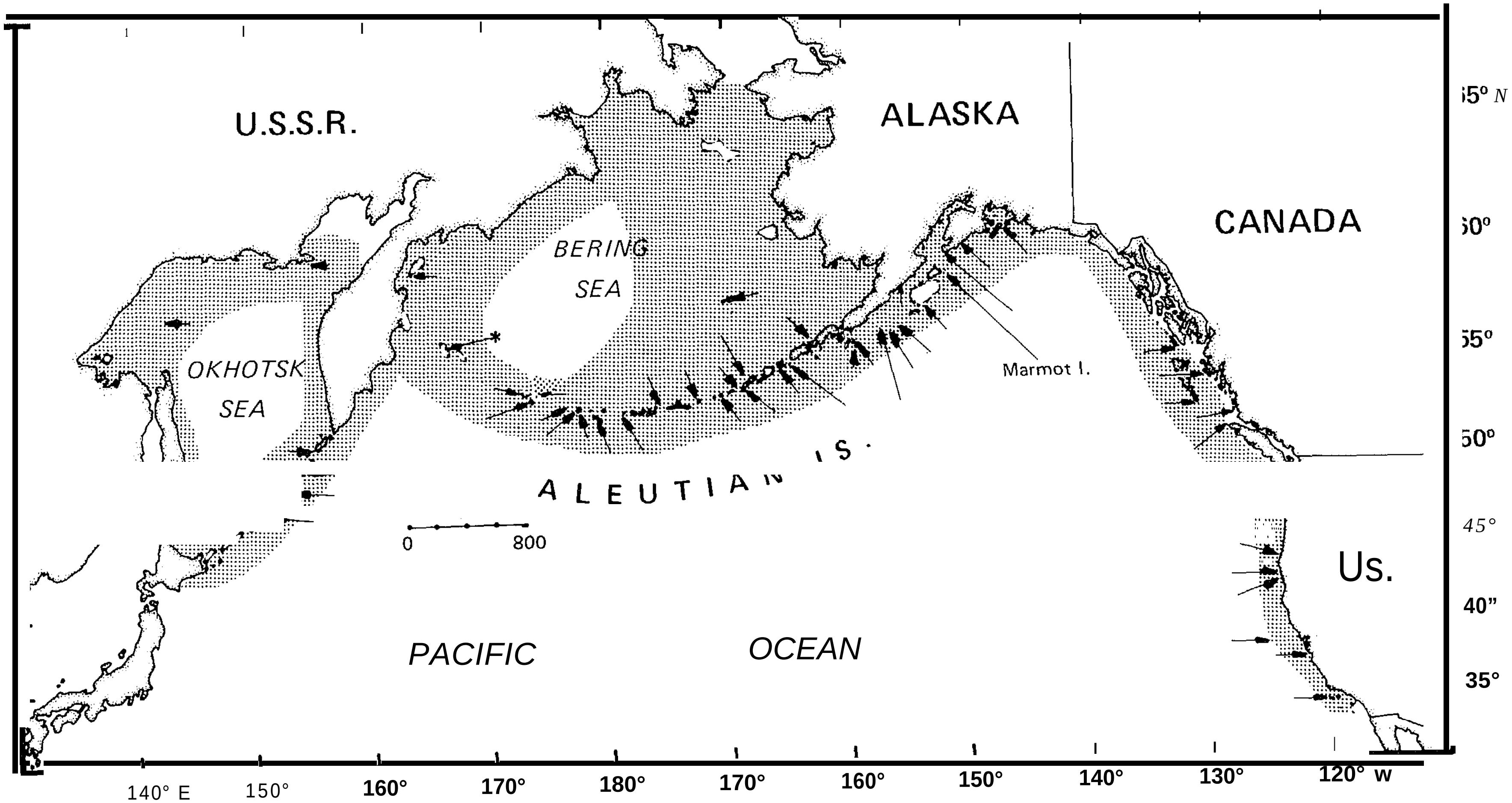

Figure 17. I —Map depicting suggested world distribution (shaded areas) and rookeries (arrows) of northern sea lions. Marmot Island, the largest sea lion rookery, is also shown, (Adapted from Loughlin et al. 1982.)

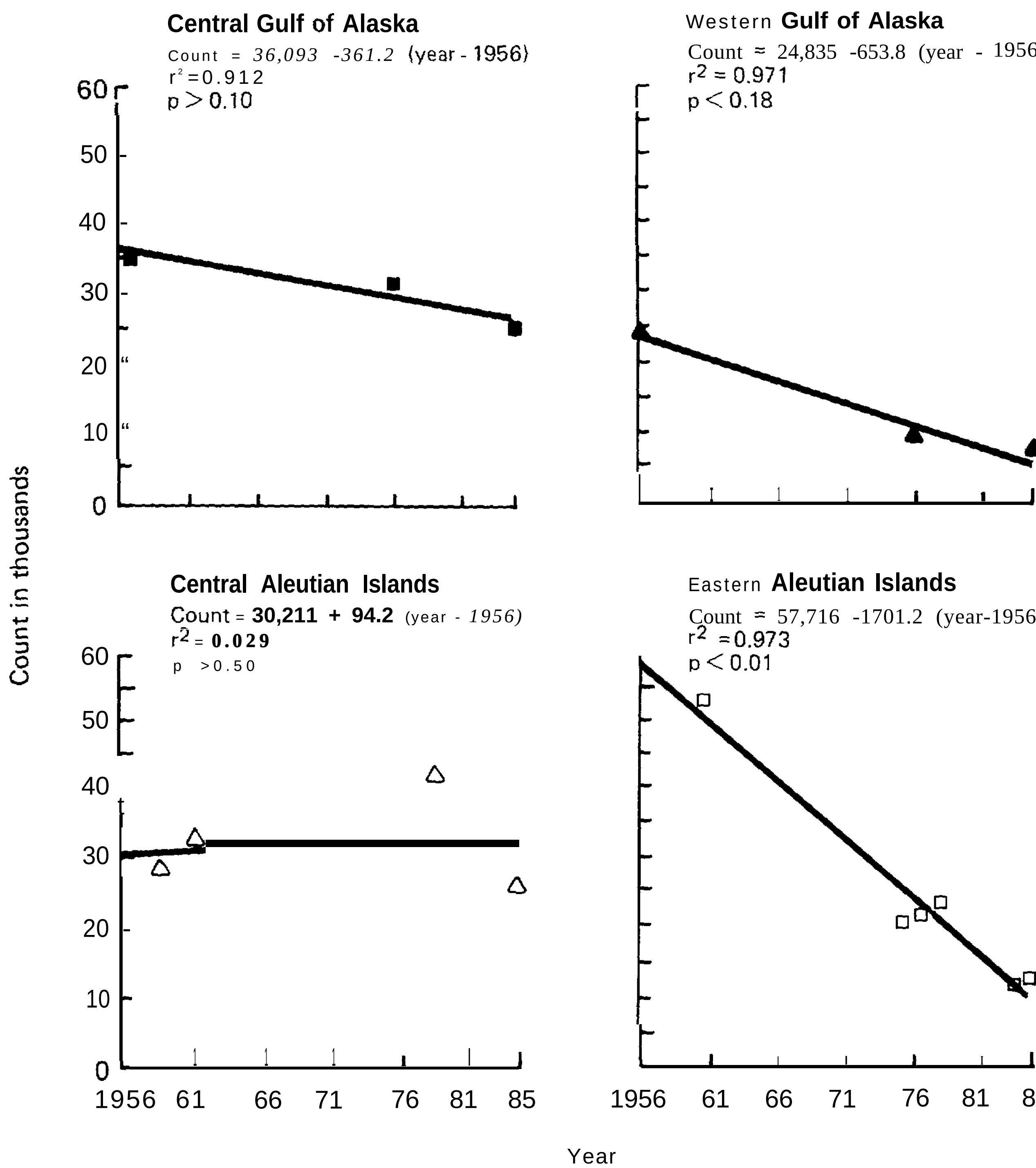

Figure 17.2—Trends in total adult and juvenile northern sea lion abundance by area in Alaska, for spring and summer surveys conducted in 1956-85. (Adapted from Merrick et al. 1987.)

Planned research by the National Marine Mammal Laboratory includes a survey throughout the northern sea lion range during 1989 which will involve Soviet, United States, and Canadian participation. Other planned studies include monitoring the status and behavior of key sea lion populations on Marmot Island and elsewhere, testing the use of satellite tags to define foraging locations and movement, examining stock differentiation through morphometrics and chemical analysis, and related studies.

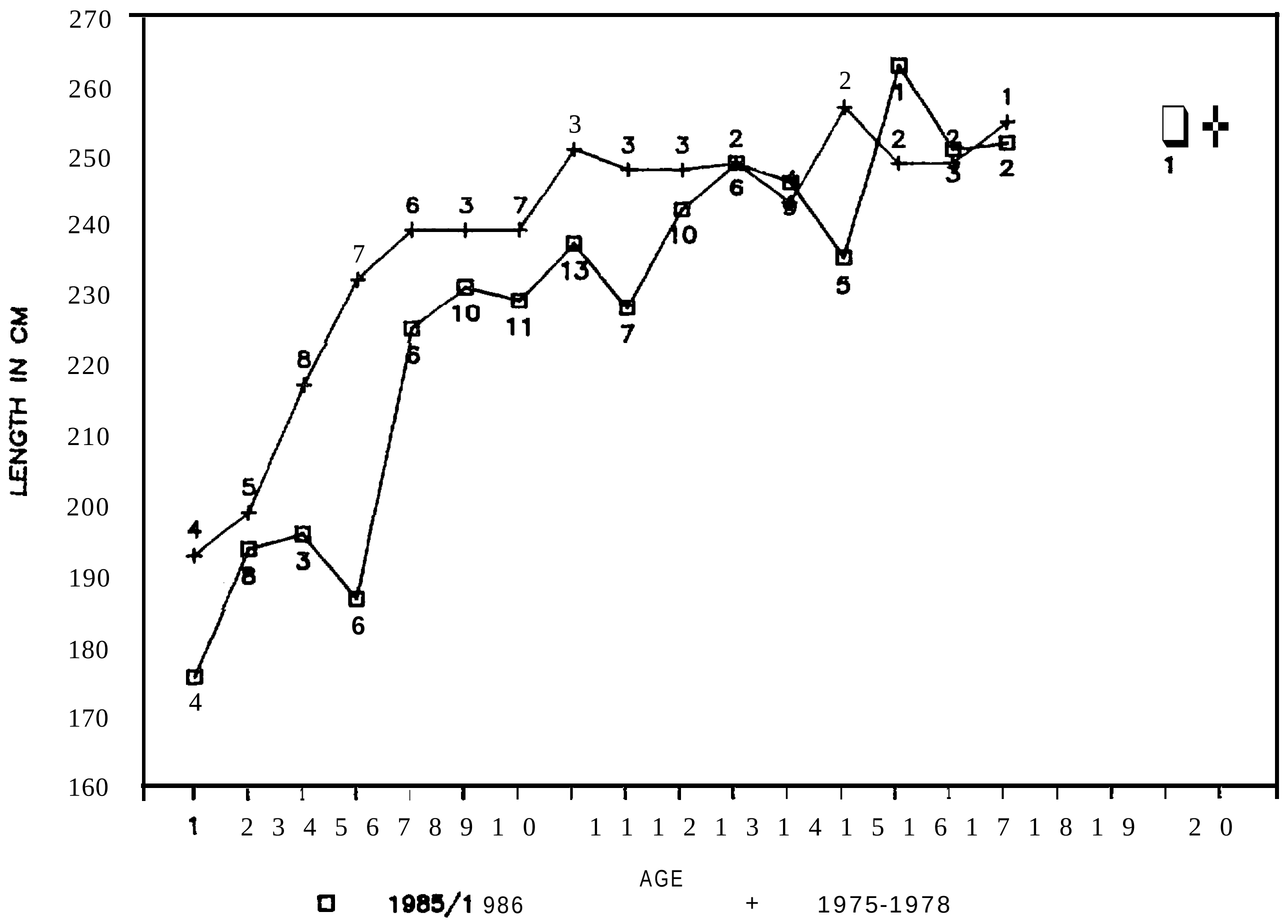

Figure 17.3—Comparison of mean standard lengths of female northern sea lions collected near Kodiak Island, Alaska, 1975-78 and 1985-86. Number at each data point is sample size for that age class. (Adapted from Calkins and Goodwin 1988.)

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Chapter 18

Movement Patterns of Western Alaska Peninsula Sea Otters

CHARLES MONNETT and LISA MIGNON ROTTERMAN
Department of Ecology and Behavioral Biology, University of Minnesota, Minneapolis, Minnesota 55455

18.1 INTRODUCTION

A substantial population of sea otters (*Enhydra lutris*) is known to reside in waters along the northern shores of the Alaska Peninsula and Unimak Island (Lensink 1960, 1962; Kenyon 1969; Schneider 1976; Cimberg et al. 1984). Data from censuses and surveys (Lensink 1962; Cimberg et al. 1984) suggest that some individuals in this population may make unusual seasonal movements. Although sea otters are usually considered to be non-migratory (e.g., Kenyon 1969), it has been suggested that many of the individuals that reside in the unprotected waters of the Bering Sea make a seasonal migration. This migration may be between the nearshore and more distant areas offshore (Lensink 1962), or between the Bering Sea and the Pacific Ocean through Bechevin Bay and Isanotski Strait (Cimberg et al. 1984).

In order to evaluate whether these movement patterns represent a seasonal migration, individual sea otters were monitored by radio-telemetry and the results were compared with data from other populations.

18.2 STUDY AREA AND METHODS

18.2.1 Dates and Location

This study was conducted in waters adjacent to the Alaska Peninsula in the vicinity of False Pass, Alaska (Fig. 18.1). Sea otters were caught and implanted with radio-transmitters during August 1986, in Bechevin Bay and on the southeast side of Amak Island in the Bering Sea. Dependent pups were caught in Bechevin Bay during July and August, 1986. Instrumented otters were monitored every 2 to 3 months between August 1986 and March 1988 in order to detect major movements about the Alaska Peninsula and Unimak Island. Areas that were routinely searched included the waters between Cold Bay and southwestern Unimak Island in the Pacific Ocean and between Port Moller and Cape Sarichef in the Bering Sea.

18.2.2 Methods

Adults were captured with modified, floating gill nets (e.g., Odemar and Wilson 1969; Garshelis et al. 1984). Dependent pups were caught with a dip net from the bow of a 21-foot Boston Whaler. Upon capture, otters were weighed and each was marked with a red, numbered, plastic ‘ ‘temple” tag (Temple Tag Company, Temple, TX) through the interdigital webbing of its hind flipper (e.g., Ames et al. 1983). Individuals to be implanted with radio-transmitters were immobilized with a combination of fentanyl (0.05 mg/kg) and azaperone (0.20 mg/kg) (Williams et al. 1981). A 164-MHz radio-transmitter was surgically implanted in the peritoneal cavity by a licensed veterinarian using a procedure similar to that described by Garshelis and Siniff (1983). Radio-transmitters measured 85 mm x 5 mm x 25 mm and weighed 150 g (Cedar Creek Bioelectronics Lab, Bethel, MN 55005). Transmitters had an expected life of about 18 months and transmitted at unique frequencies. After completion of the approximately 20-minute surgery, the individuals were injected with naloxone (0.01 mg/kg), an antagonist to fentanyl. They were released when they had fully recovered from the anesthetic.

Instrumented otters were monitored from various aircraft (Piper Supercub and Piper Arctic Tern, 50 hours; Piper Navajo, 25 hours; and DeHavilland Twin Otter, 20-30 hours) that were equipped with four-element Yagi antennas mounted on wing struts on each side (Gilmer et al. 1981). Radio-transmitter frequencies were monitored with 2,000-channel,

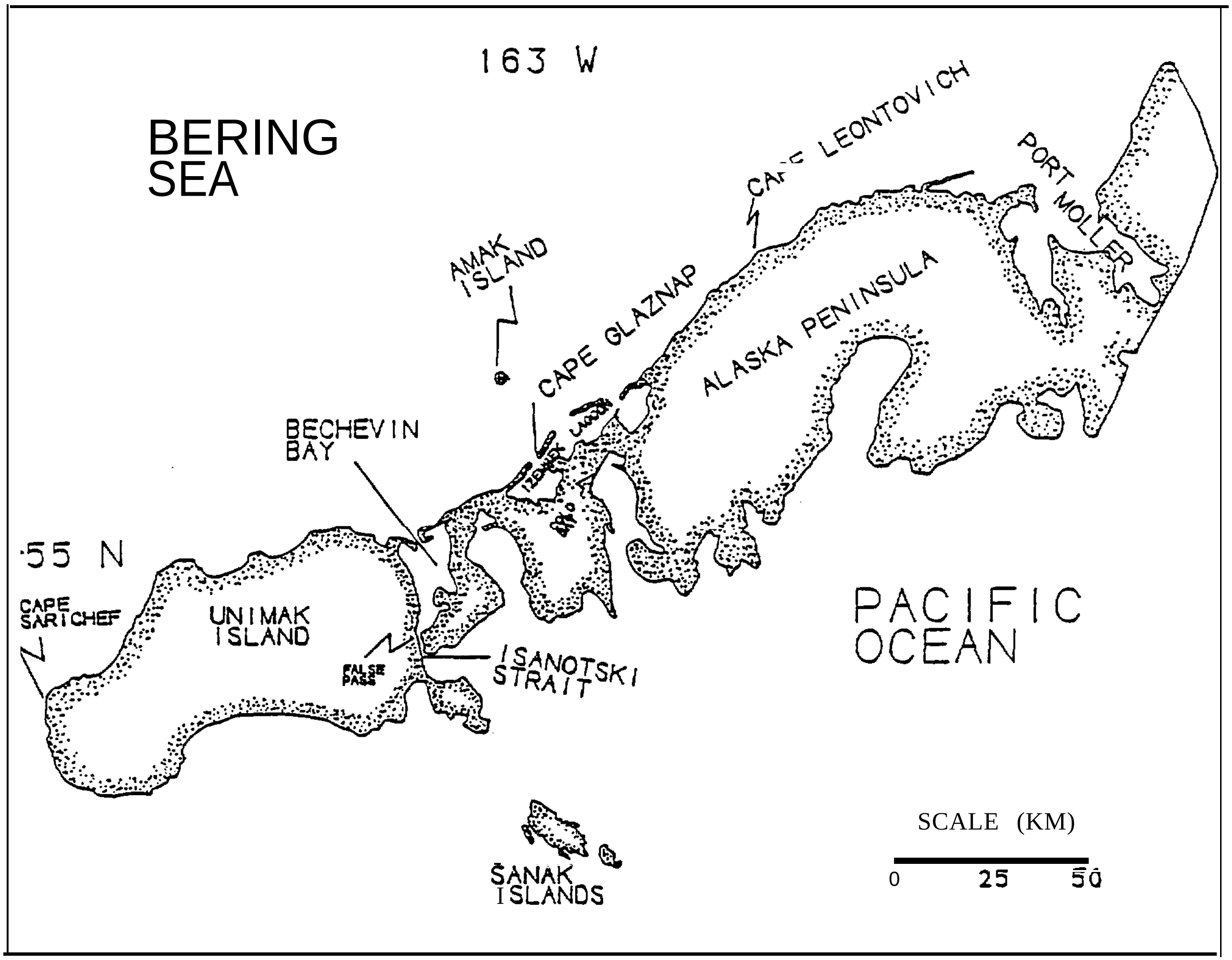

Figure 18. I —Map of study area with locations mentioned in the text.

programmable, scanning receivers (Cedar Creek Bioelectronics Lab). Aircraft were flown at 80-150 knots at altitudes varying from 80 to 2,000 m, depending upon aircraft type, weather conditions, and research protocols. When searching from single-engine aircraft, flight paths were parallel to the coastline and separated by about 2 km. Altitude was increased as distance from shore was increased so that aircraft remained within gliding distance of land at all times (i.e., approximately 1 unit of altitude for every 5 units of distance from shore). Searches from dual-engine aircraft were sometimes flown as described above but more frequently followed along north-south transects separated by about 2 km. Relatively offshore portions of the Bering Sea and waters north of the Sanak Islands were searched in this pattern.

Annual survival rate estimates, based on telemetry data, were calculated using the method developed by Trent and Rongstad (1974). An index of home range dimensions, "distance between extreme locations" (DBEL), was employed, as suggested by Garshelis and Garshelis (1984). The DBEL is the minimum distance an otter would have to swim to travel between its two most widely spaced fixes during some time interval. It is approximately equal to the maximum dimension of the home range during that time interval.

18.3 RESULTS AND DISCUSSION

18.3.1 Capture, Tagging, and Instrumentation

Sixteen adult sea otters, 12 females and 4 males, were caught and instrumented. Twenty-two dependent pups were dip-netted and marked in the vicinity of Bechevin Bay.

Four individuals (two female-pup pairs) died while entangled in nets during capture activities at Amak Island. All four animals were apparently killed during fighting between the adult females and a single large male that was entangled in the same section of net. Because of stipulations in the permit under which the Fish and Wildlife Permit Office had authorized these activities, this event, which occurred during the second day of activities at Amak Island, forced cessation of all capture efforts. Further information on this incident can be found in Monnett and Siniff (1987).

18.3.2 Monitoring

Attempts were made to locate instrumented sea otters from aircraft on 22 days and 181 fixes were obtained. All individuals except one male, number 86114, were relocated after instrumentation. The long-term status of number 86114 is not known, but he behaved normally when released following surgery.

18.3.3 Survival

Ten of the twelve females were monitored for periods ranging from 539 to 580 days. Two of the ten individuals were not located during the March 1988 survey. However, since these intervals correspond to the expected life of the transmitters, approximately 550 days, it seems more likely that the transmitters expired than that the individual females died. With respect to the other two females, contact was lost with one of these females, 86108, after 208 days. The twelfth female, 86113, was resighted only one time, 59 days following instrumentation. At that time, she was located at the far eastern edge of the study area. The lack of further sightings may indicate that she traveled beyond the bounds of the area surveyed, The estimated annual rate of survival for the females is either 0.89, 0.94, or 1.0 depending upon whether both, one, or neither 86108 and 86113 are assumed to have died. These values are similar to the range of values reported for similar telemetry studies of sea otters in Alaska and California. Siniff and Rails (1988) measured an annual adult female survival rate of 0.91 in California. Monnett et al. (1988, unpubl. data) observed a survival probability of 1.0 (20,718 otter days) for adult females in Prince William Sound, Alaska.

Excluding the male that was not resighted following surgery, the remaining three males were monitored for periods ranging from 206 to 572 days. If male 86101 (monitored 206 days) is assumed to have died, male survival is calculated as $p = 0.76$. We regard three males to be an insufficient sample to permit any conclusions. Adult male survival in California was observed to be 0.67-0.71, depending upon assumptions made about missing individuals (Siniff and Rails 1988). Adult males in Prince William Sound exhibited an annual probability of survival of 0.95 (6,725 otter days) (Monnett et al. 1988, unpubl. data).

18.3.4 Movement Patterns and Distribution

On the basis of six radio-locations, two female sea otters were observed to move into waters south of False Pass. .411 movements south of False Pass occurred between 1 October and 31 March (Fig. 18.2).

Males.—The instrumented males occupied home ranges near where they were originally captured. None exhibited a tendency to make a seasonal migration between the Bering Sea and Pacific Ocean. Movements of two representative males are summarized in Figure 18.3. During the period of the study, the respective distances between extreme locations (DBEL) of the males were 10.5, 20.0, and 23.5 km. The telemetry data suggested that, for a

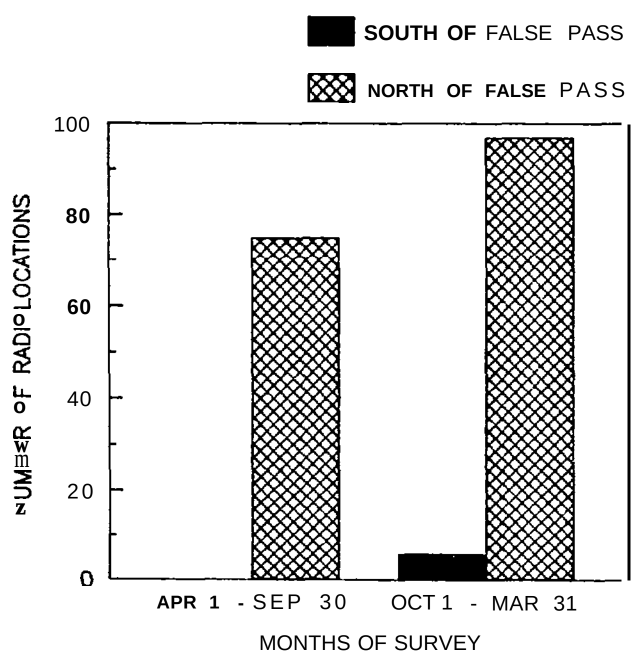

Figure 18.2—Radio-locations of sea otters in western Alaska Peninsula study by time of year.

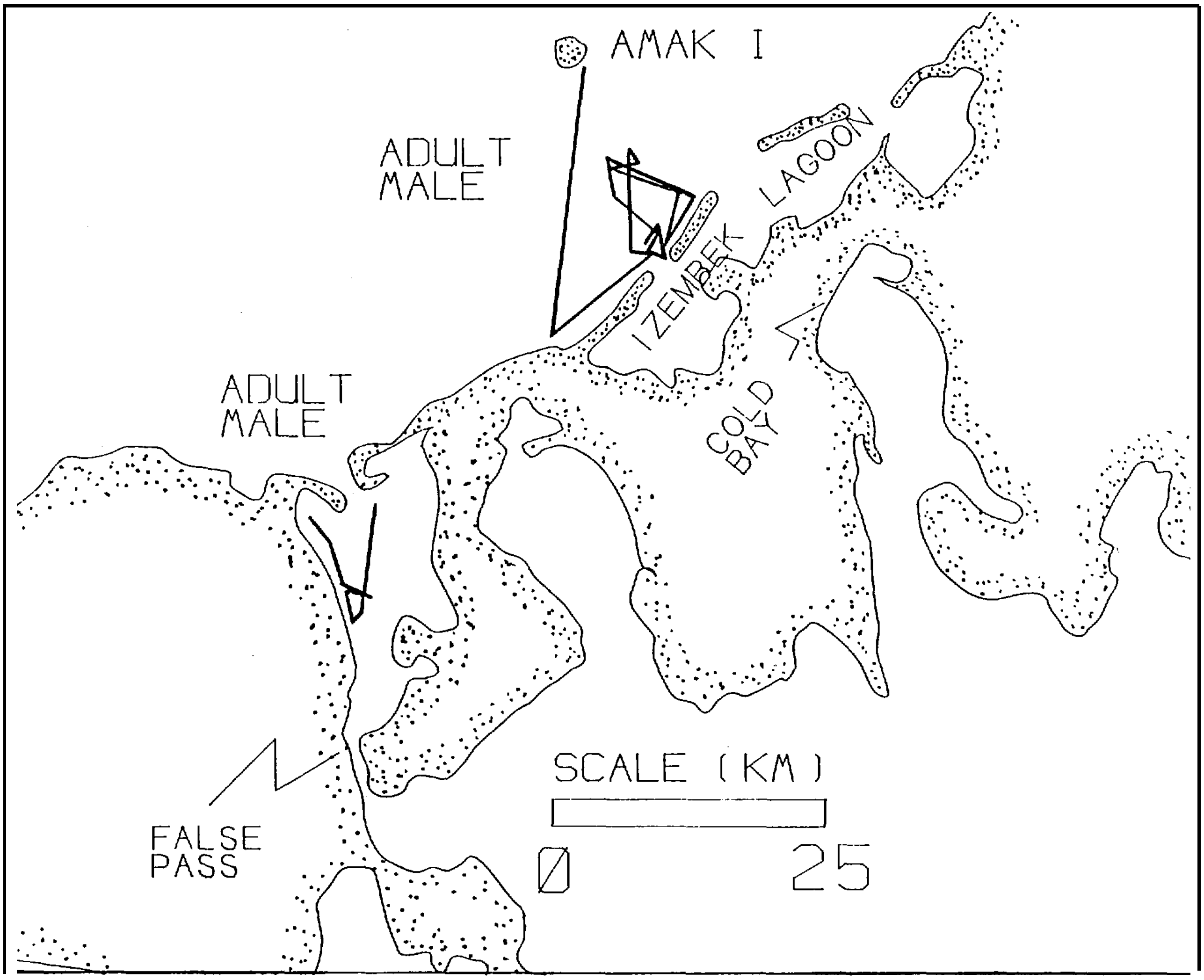

Figure 18. 3—Summary of the movements of two radio-instrumented male sea otters

prolonged period, the movements of male 86101 were restricted to the relatively protected waters within Bechevin Bay and adjacent Catherine Cove. Given the predominance of females in that general area, his movements suggest that he occupied a breeding territory along the western border of Catherine Cove. The other two instrumented males (86115 and 86116) traveled routinely about the less protected waters north of Izembek Lagoon, between Amak Island and a sandbar at Cape Glazenap.

The distances of the movements observed for the three males fall within the range of magnitudes of movement observed during telemetry studies in Prince William Sound. However, they are somewhat more restricted than the movements of males in California (Fig. 18.4). The distribution of the DBEL of males in Prince William Sound is clearly bimodal. This bimodality reflects differences between males that remain on breeding territories throughout the year versus those that travel between breeding areas in eastern Prince William Sound and wintering aggregations in Orca Inlet. Males in the Prince William Sound study occupied breeding territories that were located about 30-40 km from haulouts in the non-breeding area. Thus, males that overwintered in such aggregations needed to travel about 40 km to reach them. In an earlier study in eastern Prince William Sound, Garshelis and Garshelis (1984) found that four territorial males moved about 100 km between breeding areas at Green Island in central Prince William Sound and the non-breeding area in Orca Inlet.

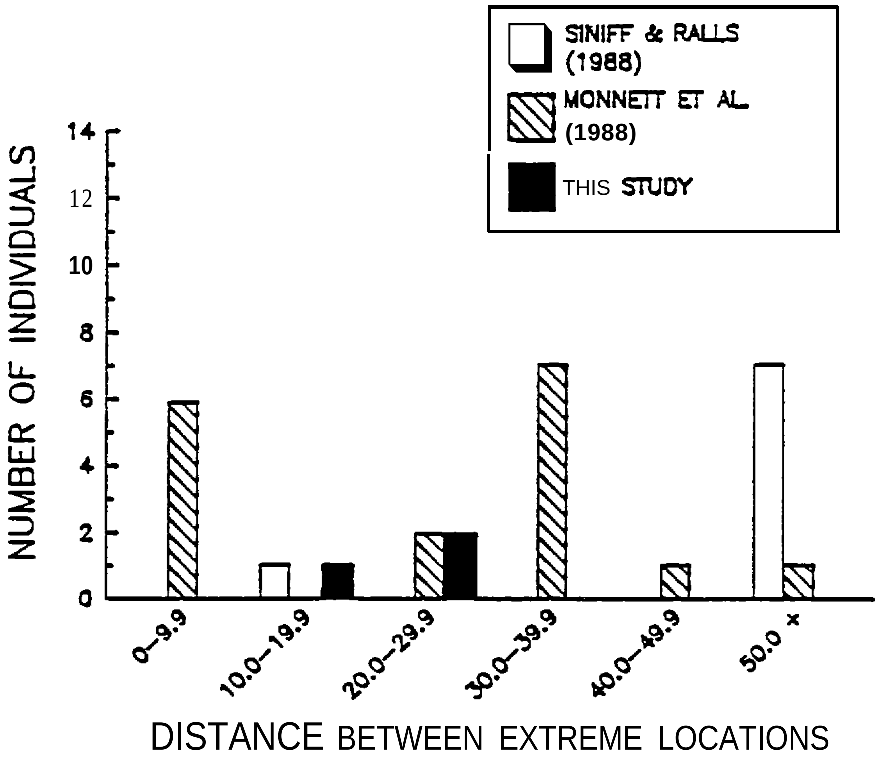

Figure 18.4—Distances between extreme locations (kilometers) of radio-instrumented male sea otters in Alaska Peninsula study. Data from three males are plotted with data from those in other studies for comparison.

Females.—During the period of monitoring, some females showed a tendency to move between Bechevin Bay and the Bering Sea and between Bechevin Bay and the Pacific Ocean. Movements to the Bering Sea occurred during the summer, whereas movements to Isanotski Strait and Ikatan Bay occurred during the fall and winter. Such movements suggest that some seasonal differences may exist in the distribution of females. However, females did not appear to make a mass seasonal migration during either the winter of 1986–87 or 1987–88. Periodic short-duration movements into the Bering Sea and Pacific Ocean by a few females suggested that female home ranges could be large and that such movements may be routine (e. g., Fig. 18.5). The home ranges of all 11 females captured in Bechevin Bay in August appeared to include at least a portion of Bechevin Bay during late summer, fall, and winter. Several case histories are significant, and are presented below.

Two females traveled at least as far south as Isanotski Strait. Female 86104 moved through Isanotski Strait into the Pacific Ocean between 25 August and 9 October 1986 (Fig. 18.5). When observed on 9 October 1986, she was in a resting group of over 100 females, some of which were accompanied by small pups. She had returned to Bechevin Bay when monitored on 16 December and was in Isanotski Strait near False Pass on 25 February 1987, and again during January and March of 1988. Female 86112 was observed in Isanotski Strait on 16 December 1986. However, she apparently did not spend the bulk of the winter outside Bechevin Bay, as she was located near the Isanotski Islands, in Bechevin Bay, during both October and February.

Two females moved from Bechevin Bay to the Bering Sea. One of these females was radio-tagged (Female 86112), and was one of the females observed in Isanotski Strait. This female apparently made a brief trip to nearshore areas of the Bering Sea in October 1986, but was observed back in Bechevin Bay shortly thereafter. The non-instrumented female traveled from Bechevin Bay to Amak Island

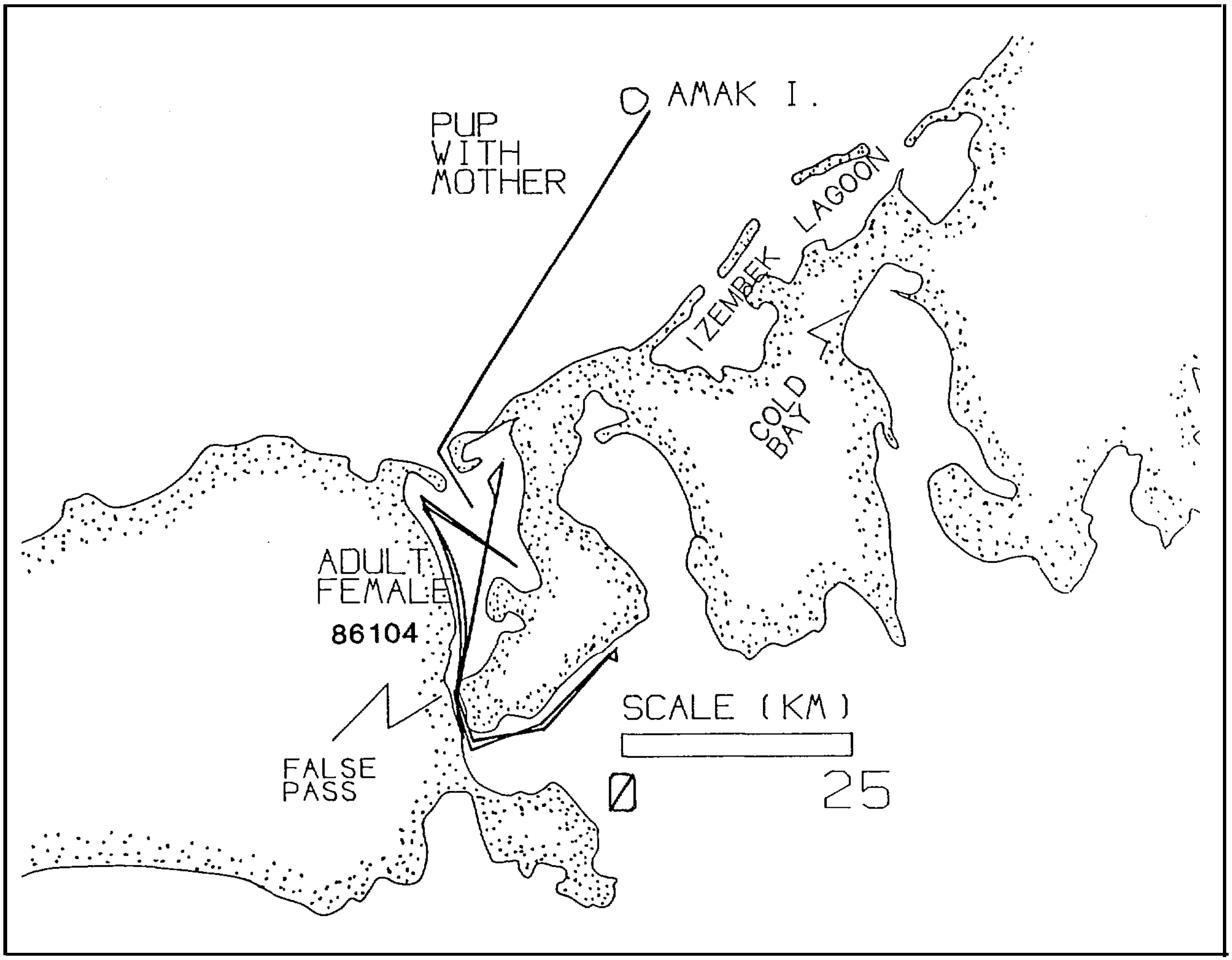

Figure 18.5—Summary of movements of two Alaska Peninsula sea otter study females. The upper set of vectors represent the movements of a pup that was tagged with a flipper tag in Bechevin Bay as it was carried about by its mother. The lower set of vectors summarizes the movements of a radio-instrumented female.

(50 km) during early August 1986 (Fig. 18.5). She was observed at Amak Island with a pup that had been marked with a red flipper tag in Bechevin Bay.

Female 86113, a very large adult, moved 48 km across the Bering Sea between Amak Island and Cape Leontovich, which lies northeast of Izembek Lagoon. When observed, she was in one of several moderate-sized groups that were situated about 7 km offshore.

The results discussed above do not suggest that a seasonal migration between the Bering Sea and Pacific Ocean is a common or required feature of the movement patterns of female sea otters. However, they do indicate that the home ranges of some females may include portions on both sides of the Alaska Peninsula.

Female sea otters in this study appeared to be more sedentary than females in Prince William Sound. The median DBEL of the Alaska Peninsula females was 15.5 km, with a range of 7-48 km, whereas the median DBEL of Prince William Sound females was 25 km. However, the distribution of DBEL for Alaska Peninsula females is not appreciably different from the total distribution of DBEL reported in telemetry studies in Alaska and in California (Fig. 18.6).

18.4 GENERAL COMMENTS

These data do not support the hypothesis that male or female sea otters normally make seasonal migrations between the Bering Sea and the Pacific

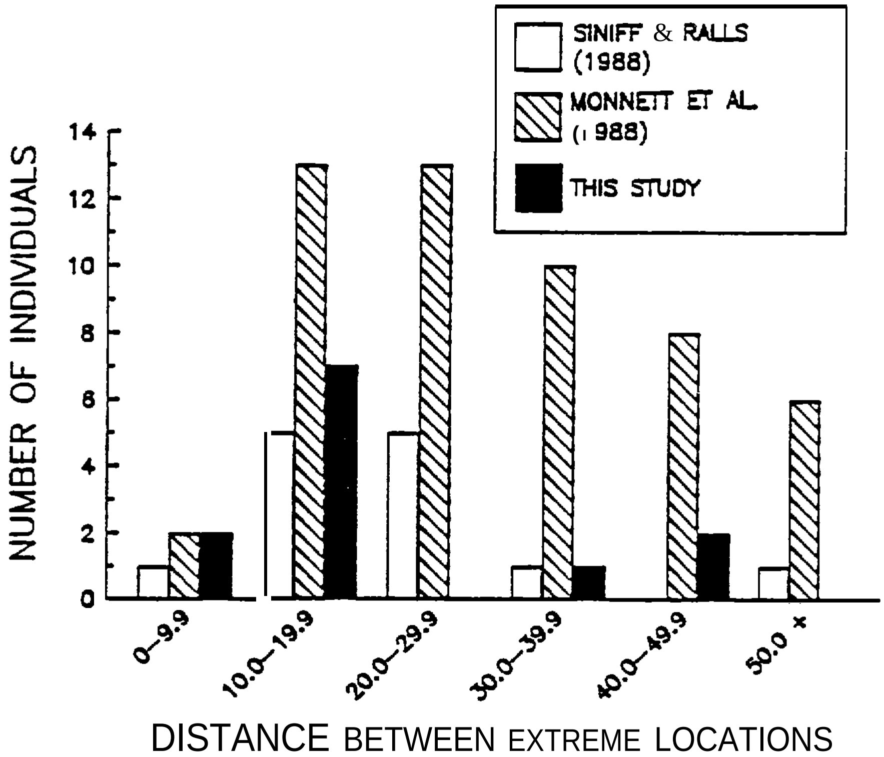

Figure 18.6—Distances between extreme locations (kilometers) of radio-instrumented female sea otters. Data on females in the Alaska Peninsula study are plotted with data from other studies in Alaska and California for comparison.

Ocean, either through Isanotski Strait or around the western end of Unimak Island. However, weather conditions in the study area, and in all of southern Alaska, were unusually mild during the winters of 1986-87 and 1987-88. Lakes in the vicinity of Cold Bay-, on the Alaska Peninsula, remained unfrozen for most of both winters during this study. Sea ice did not form in the study area at times of the year when it would normally have been present.

The western Alaska Peninsula sea otter population is unusual in that its northward expansion has apparently been limited by the occasional formation of sea ice (Kenyon 1969: Schneider and Faro 1975), The lack. therefore, of such severe conditions during the monitoring period may be important in interpreting movements observed during the study. A significant number of sea otters are known to have died during a period of record-breaking cold in the early 1970s. Individuals died of malnutrition and related stresses when they w-ere excluded from feeding areas by the formation of continuous shorefast ice and by the encroachment of sea ice (Schneider and Faro 1975). A similar situation apparently has been known to develop in the Kurile Islands and along the southeast Kamchatka coast (Nikolaev 1941). There, it was found that when winter drift ice blocked all open water, sea otters starved unless they were able to move to ice-free areas. Thus it is possible that sea otters would make migrations (such as those hypothesized by earlier authors) when subjected to the more severe winters common in this area.

18.5 ACKNOWLEDGMENTS

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Chapter 19

Black Brant Aircraft Disturbance Studies

DAVID WARD
*U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center,
1011 East Tudor Road, Anchorage, Alaska 99503*

19.1 INTRODUCTION

Each spring and fall, nearly the entire population of Pacific black brant (*Branta bernicla nigricans*) stages at Izembek Lagoon near the western end of the Alaska Peninsula. During these staging periods, brant feed on extensive beds of eelgrass (*Zostera* marina), accumulating fat reserves necessary for egg production and incubation in spring and for migration in fall to wintering areas as distant as Mexico. Izembek Lagoon contains one of the largest beds (17,868 ha) of eelgrass in the world. Its importance to brant and other avian populations has led to its designation as a wetland of international importance under the RAMSAR (International Union for the Conservation of Wetland Habitats) convention.

In fall of 1984, staff of Izembek National Wildlife Refuge observed increased disturbance (flight) of black brant, Canada geese (*Branta canadensis*), and emperor geese (*Chen canagica*) from helicopter overflights associated with Outer Continental Shelf petroleum exploration. Petroleum exploration is expected to occur along the North Aleutian Shelf and St. George and Navarin basins, and the existing 10,000-ft. runway at Cold Bay may be used for industry support facilities. Additional aircraft traffic is expected from a U.S. Coast Guard (USCG) search and rescue facility also proposed for Cold Bay.

Increased aircraft traffic over the lagoon may be detrimental to the ability of brant to store sufficient reserves for reproduction and migration. Increased human disturbance may displace geese from preferred foraging habitats, reduce food intake, and alter the amount of pre-migratory fat accumulation, The establishment of petroleum industry and USCG support facilities at Cold Bay would also increase the local human population and associated recreational activities, such as hunting. boating, and aviation, on or near the lagoon. These activities may result in additional stress for staging geese. The biological implications of stress due to increased levels of human disturbance, particularly aircraft, are unknown. Management strategies to minimize detrimental effects on geese using this critical staging area may be necessary.

Since 1985 the Alaska Fish and Wildlife Research Center has been carrying out research to assess the impacts of increased human disturbance on fall staging geese at Izembek Lagoon. The objectives of the research have been to: (1) determine the effects of aircraft overflights and other human activities on the behavior, distribution, and habitat use of brant and other geese; (2) record noise levels associated with aircraft overflights and examine whether noise is related to the response of geese; and (3) evaluate the potential impact of disturbance on the energetic of migration of geese. Preliminary results of these studies are discussed below.

19.2 PRELIMINARY RESULTS

Numerous aerial and ground counts at Izembek Lagoon have described brant use of the lagoon and surrounding estuaries during spring, fall, and winter. Peak numbers occurred in fall, when it is believed that the entire Pacific flyway population (150,000 in 1988) congregated in late September. Spring use occurred between April and May, with peak numbers averaging <50,000 birds. Winter populations of brant have historically been low (< 100) but since 1980 numbers have increased to an average of 3,800 brant. Izembek is also important to Canada geese in fall and to emperor geese in spring, winter, and fall. The Canada goose population, averaging between 45,000 and 55,000 birds, is composed almost entirely of *Branta canadensis taverneri*. The Izembek complex may well be the most important fall staging area in Alaska for this medium-size

Canada goose. Greatest numbers of emperor geese (5,000-10,000) occurred during fall and spring, and fewer than 2,000 birds during winter.

The distribution of geese in fall varied both spatially and temporally, within and between species. Brant used the entire lagoon but were most heavily concentrated in the western portion. Canada geese were less widely dispersed and preferred areas near their feeding and roosting sites on tundra. The distribution of emperor geese, even more confined, was limited to selected foraging areas and roost sites on barrier islands. Tide level and date had the greatest influences on the distribution of geese.

In 1987, 33 backpack radio transmitters were placed on brant at widely separated breeding areas in the western Canadian Arctic and at one area in western Alaska to better understand the timing, duration, and habitat use of brant at Izembek. Radio-tagged brant arrived at Izembek on dates which reflected the distances traveled from breeding areas. The duration of stay, averaging 49 days, was not significantly different between brant from different breeding areas. Although radio-tagged brant used the entire lagoon, there was considerable segregation between high Arctic Canadian brant and low Arctic Canadian and Alaskan breeders.

The amounts of time that brant spent in different daylight activities were measured in order to quantify the energy costs associated with both disturbed (increased alert, maintenance, massing, flight) and undisturbed (decreased resting, feeding) behaviors. Observations of flocks of geese were recorded from several elevated sites along the shoreline of Izembek Lagoon. Instantaneous scans of individuals within flocks (N = 985) provided a basis for estimating major behaviors (feeding, resting, maintenance). Continuous observations of randomly selected individuals for 1 minute (N = 2,500) provided a method for assessing the influences of age and also a means for quantifying less common behaviors (aggression, alert). Feeding was found to be the most important behavior for brant during low tide, accounting for about 60– 70 % of their daylight time. Other behaviors were swimming (19 %), resting (2 %), maintenance (10%), alert (1.7%), and aggression (0.3%). The frequency and duration of flight by brant were examined by two other methods to better understand time invested in this energetically costly behavior. Estimates ranged from 1 to 4% of their total time. All behaviors were highly influenced by tide.

During fall of 1985-87, all potential (incidental) disturbances were recorded to provide baseline data of disturbance levels prior to expected changes in levels of human disturbance at Izembek Lagoon. A total of 2,038 disturbance events were recorded in 1,912 hours of observation. The mean number of potential disturbances did not differ between years, averaging 1.1 disturbances per hour. Aircraft (53 %) and hunters (670) were the most frequent human-related cause of disturbances, and bald eagles (*Haliaeetus leucocephalus*) (23 %) were the most important natural disturbance. Commercial aircraft accounted for approximately 4070 of all aircraft, while helicopters accounted for less than 1$70.

Experimental overflights, where altitude and lateral distance of the aircraft to geese were known, provided a method to control for variables that may affect the responses of a flock. The responses of over 1,600 flocks of brant were estimated from overflights by nine types of fixed-wing and four types of rotary-wing aircraft. Brant were far more sensitive to aircraft than Canada or emperor geese. In general, helicopters caused a longer behavioral response, at greater distances, than fixed-wing aircraft. Preliminary data analysis was initiated on six types of aircraft to define the zone of influence for each stimulus as defined by altitude and lateral distance to the flock, and to determine the relative importance of other factors influencing the disturbance response. Response of brant to single-engine and multi-engine airplanes decreased with greater airplane altitude and lateral distance. Response to helicopters decreased with greater lateral distance, but was not reduced by increasing altitude.

In 1987 we initiated additional research to measure aircraft noise and provide a more complete understanding of the responses of brant and other geese to aircraft overflights. Forty-two noise recordings were made of five types of aircraft: three types of fixed-wing aircraft (Piper 150, Cessna 180 and 206) and two types of rotary-wing (Bell 206-B and 205). The Bell 205 helicopter was considerably louder than any other aircraft, producing 4 times as much noise as the Piper 150. The two helicopters produced distinctly different noise spectra than fixed-wing aircraft. Noise of aircraft generally attenuated with increased altitude and lateral distance to the microphone. However, the amount of noise in some cases increased at combinations of increased altitude and greater lateral distance. This phenomenon was present for all aircraft, but was most apparent with the Bell 205 helicopter.

Behavioral response of brant at various combinations of aircraft type, lateral distance, and altitude was highly correlated (R = 0.80) with noise level. Distance of initiation of response was farther and magnitude of response was greater for the Bell 205 helicopter than for any other aircraft. The estimated threshold at which brant respond to aircraft noise appears to occur at or above a sound exposure level of 65 dB in A-weighted scale (dBA) or a maximum instantaneous noise of 60 dBA. These levels are considerably lower than those reported in the literature for other birds.

Research in 1988 continued to assess and quantify the behavioral response of geese to measurements of aircraft noise, but emphasis was placed on determining levels of acoustical noise that cause geese to respond. Preliminary analyses of over 60 overflights indicated that threshold levels of brant response (alert or flight behavior) to noise maybe lower than levels estimated in 1987. Although our data indicate that brant response is correlated with an auditory stimulus, it is not clear whether the stimulus is solely auditory or a combination of auditory and visual.

19.3 FUTURE RESEARCH

Research to evaluate the expected impact of disturbance on the energetic of migration and reproduction in brant is planned. A predictive model will be developed to manipulate and test patterns of disturbance. Ultimately, the model will help provide guidelines for management strategies to minimize increased human disturbance at Izembek Lagoon.

Chapter 20

North Aleutian Shelf Coastal Ecosystem

JOSEPH C. TRUETT
LGL Alaska Research Associates, Inc., 505 West Northern Lights Blvd., Anchorage, Alaska 99503

The North Aleutian Shelf (NAS) ecosystem, here defined to extend from Unimak Pass to near Port Heiden and seaward to the 50-m depth contour (Fig. 20.1), is part of the highly productive Bering Sea. Important populations of vertebrates (mammals, birds, and fish) use the area, and there is concern that oil and gas leasing could affect them. The following summary describes these populations and the physiochemical and biological features of the ecosystem on which they depend. The ultimate purpose is to help managers make more accurate predictions of impacts of oil and gas exploration and development on the populations of major interest.

The summary is organized as follows. First, distributions and abundances of the most important vertebrates are described. Then we discuss the food-chain components and physical factors that influence these distributions and abundances. Important exchanges of food-web materials between the NAS ecosystem and adjacent areas are identified. A list of additional information that needs to be collected to better predict impacts of petroleum-related activities on important ecosystem components is presented.

Most of the information presented is from the recent NOAA-sponsored NAS environmental characterization study (Truett 1987); investigators in this study collected biological and physiochemical data at sampling stations distributed throughout the NAS from depths of 3 m to greater than 50 m (Fig. 20.2). Additional recent information sources include Troy et al. (1988) and Isakson et al. (1986).

20.1 VERTEBRATE DISTRIBUTION AND ABUNDANCE

Very few of the vertebrates in the North Aleutian Shelf are distributed uniformly from the coast seaward to the deepest areas. Fish show depth preferences as follows: (1) sand lance, rainbow smelt, and yellowfin sole are most abundant at 20-m depths and shallower; (2) pollock, salmon, and rock sole are most abundant near the 50-m depth zone and beyond; and (3) herring and capelin are typically more abundant in the deeper waters except very briefly in late spring or summer when they come near shore to spawn (Craig 1987). Among the birds, shearwaters, murres, auklets, and phalaropes generally concentrate in waters more than 30 m deep; cormorants, gulls, and sea ducks show preferences for waters shallower than 30 m. Within these broad limits, some birds (shearwaters, murres) show seasonal or annual differences in their depth zones of concentration (Troy and Johnson 1987a). Among mammals, gray whales, Steller sea lions, walruses, and harbor seals are usually restricted to shallow depths (<20 m) very near shore; northern fur seals are generally most common farthest from shore. Sea otters, generally most common near shore, become more common in winter in deeper water out to 50 m (Troy and Johnson 1987b).

Distributional abundances of some animals vary with east-west (coastwise) location in the NAS. No clear pattern of coastwise abundances of fish emerged from Craig's (1987) data, but it is known that some fish are more abundant at the eastern end of the NAS toward inner Bristol Bay (e. g., salmon, capelin) or near embayments such as Port Moller where spawning is concentrated (Isakson et al. 1986; Craig 1987). Among birds, crested auklets (in winter) and shearwaters (in fall) usually concentrate at the western end of the study area near Unimak Pass, and some others (e.g., red-faced cormorants, glaucous-winged gulls) concentrate in summer near known nesting colonies (Troy and Johnson 1987a). Mammals showing marked coastwise concentrations include Steller sea lions and harbor seals, which are more abundant near haulout areas, and sea otters and fur seals, which are more abundant near the western end (Troy and Johnson 1987 b).

Fish are generally much more abundant in late spring and summer than during other seasons

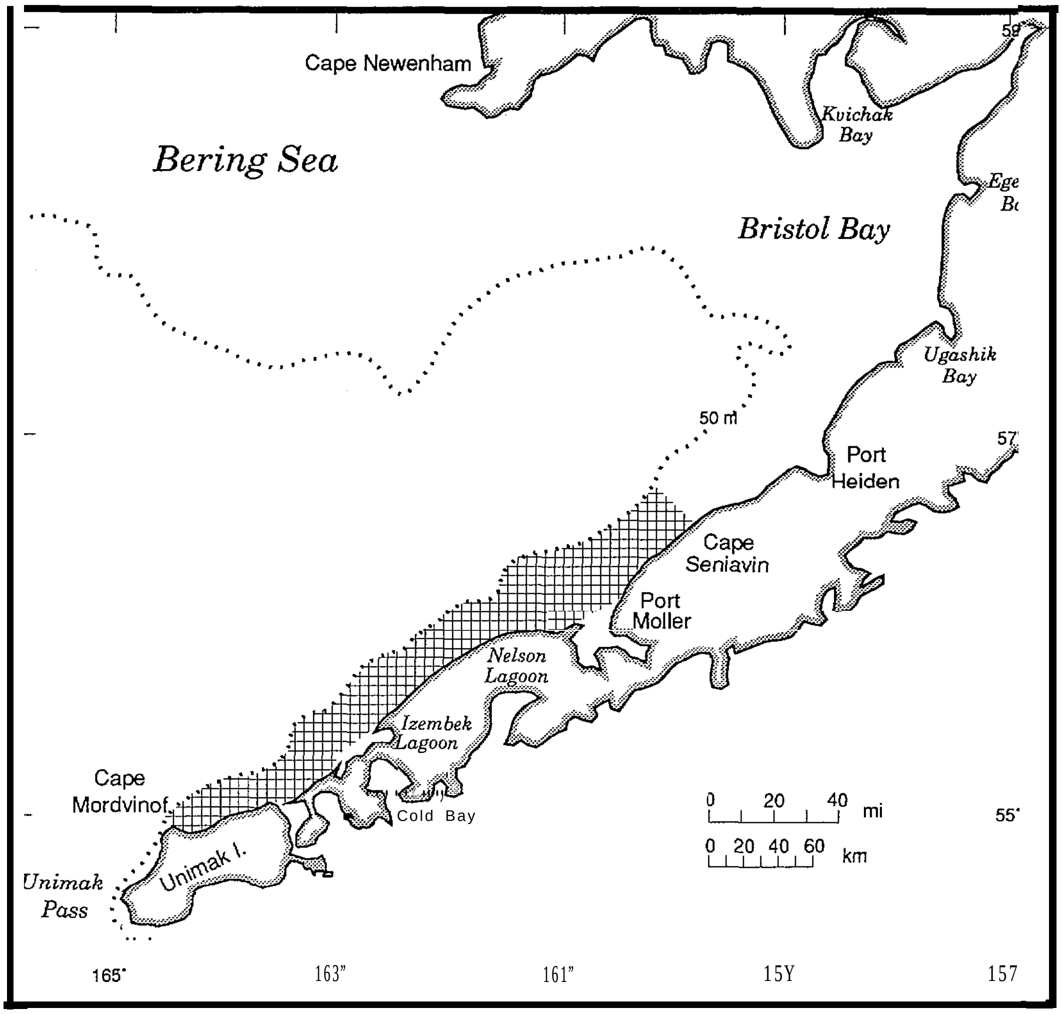

Figure 20. I —Area of research for the North Aleutian Shelf coastal ecosystem study, eastern Bering Sea, Alaska.

(Craig 1987). Forage fish (herring, capelin, sand lance) begin moving into the area in large numbers in late spring to spawn and/or feed; most are gone by late summer. Most salmon (juvenile and adult) movements through the NAS take place in late spring and early summer, and most are concentrated mainly in deeper waters. Demersal fish are most abundant in the area in summer; most (particularly large individuals) vacate the area in winter, though juvenile yellowfin and rock sole winter there.

Bird abundance, like that of fish, is greatest in the NAS in summer (Troy and Johnson 1987a). The main reason for the overwhelming summer abundance is the presence of several million short-tailed shearwaters, which nest in the southern hemisphere and spend their non-breeding period in the Bering Sea. Other species more abundant in summer than in winter are the black-legged kittiwake and the glaucous-winged gull; both species nest on nearby coasts. Birds more abundant in winter than in summer are crested auklets, scoters, eiders, murres, and cormorants. If shearwaters were excluded, total winter bird densities in the NAS would be higher than summer densities.

Mammals vary among species in their seasonal abundance and local distribution (Troy and Johnson 1987 b). Sea otters, the most numerous mammals in the area, apparently shift their distribution to deeper waters in winter but may show no marked seasonal difference in overall abundance. Steller sea lions and harbor and Dan porpoises show no marked seasonal differences in abundance or in distribution. Harbor seals are most abundant in the NAS in summer, and gray whales during spring and fall migrations. Most other mammals are expected to be most common there in summer.

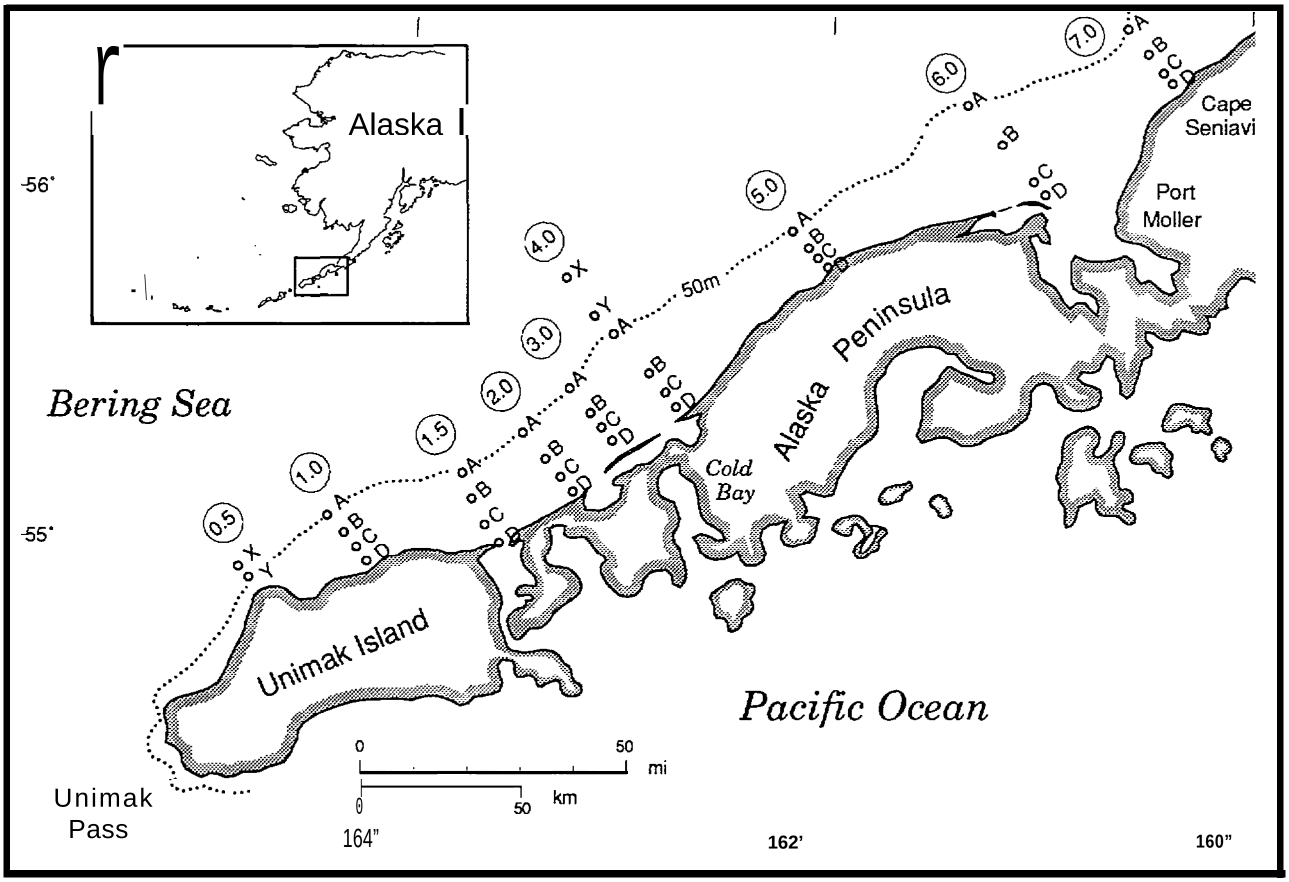

Figure 20.2—North Aleutian Shelf study area showing locations of transects and sampling stations (redrawn from Truett 1987). Sampling station depths: X, 100 m; Y, 75 m; A, 50 m; B, 35 m; C, 20 m; D, 33-10 m.

Abundances of many vertebrates are known to vary among years in the southeastern Bering Sea (Wooster 1983). This has been observed on the NAS for the abundant fish species (Isakson et al. 1986; Craig 1987), bird species (Troy and Johnson 1987a), and some mammals (Troy and Johnson 1987 b).

20.2 INFLUENCES OF PREY DISTRIBUTION AND PHYSICAL FACTORS

Several food-web factors influence the distributions and abundances of fish, birds, and mammals on the North Aleutian Shelf. Major points follow.

(1) Many of the vertebrates are more abundant in the NAS in late spring and early summer than they are in late summer, fall, or winter. The major groups in this category are birds (murres, shearwaters, kittiwakes, gulls) and fish (salmon, herring, capelin); these groups feed extensively on water-column invertebrates and pelagic fish (Troy and Johnson 1987a; Craig 1987). Nearly all these species feed heavily on euphausiids, or on fish such as sand lance that eat euphausiids (Thomson 1987b) (e.g., see Figs. 20.3-20.5). Most species that are equally or more abundant in late summer, fall, or winter, are either year-round residents (harbor seals, cormorants), benthic feeders (sea otter, ducks, yellowfin and rock sole) (Fig. 20.6), or both (Craig 1987; Thomson 1987a, b; Troy and Johnson 1987 b).

(2) Populations of most of the vertebrate species that are seasonally abundant on the NAS in spring and early summer require large energy supplies preparatory to or during breeding, or for their young, at this time of year. This need means that each individual must acquire more food per day than at other times of the year, suggesting that prey abundance might strongly influence the distribution of vertebrate fauna.

(3) The biomass of water-column prey of vertebrates is much greater in late spring and early summer than it is in other seasons. These seasonal differences may strongly influence the seasonal abundances of the vertebrate predators in particular,

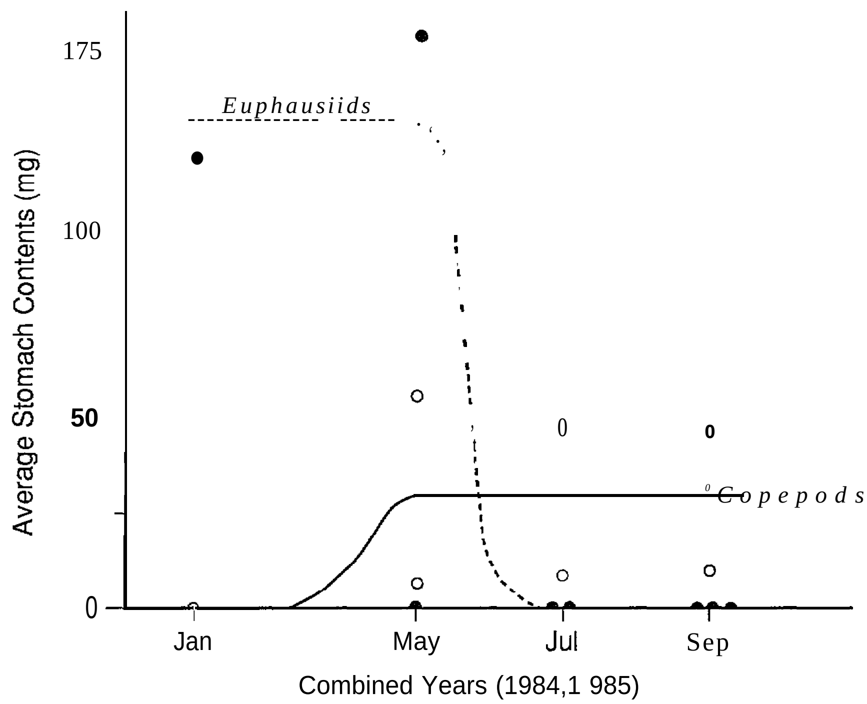

Figure 20.3—Seasonal importance of euphausiids and copepods in the diets of sand lance on the North Aleutian Shelf. Each data point represents one size or site-specific group of fish (redrawn from Craig 1987).

leading to the relative abundance of water-column feeders in spring and summer.

(4) The timing of the phytoplankton bloom has strong implications for seasonal zooplankton abundance. Relatively large numbers of euphausiids may have overwintered on the shelf; they become the dominant water-column zooplankton in early spring (Thomson 1987a). At this time, particularly in eastern parts of the NAS that are removed from the shelf edge, only small numbers of copepods are available from overwintered populations to take advantage of the phytoplankton bloom, and not until midsummer do they reach near maximum numbers and dominate the zooplankton community. As a consequence of copepod scarcity in spring, phytoplankton production is very inefficiently grazed by the zooplankton community and most probably is exported or sinks, to be consumed by the benthos (Thomson 1987b).

(5) The biomass of benthic-feeding vertebrates is seasonally more stable than that of pelagic species, probably reflecting the seasonal stability of the benthic prey base. Benthic-feeding vertebrates and their benthic prey are abundant in both summer and winter.

(6) The water-column prey (zooplankton) biomass per unit area on the North Aleutian Shelf appears to be substantially lower than that reported to occur in the middle and outer Bering shelf domains. The relatively high consumption of zooplankton by vertebrate (fish, bird) and invertebrate (jellyfish) consumers could contribute to the low biomass (Thomson 1987b).

Three physical factors—topography of shoreline habitats, presence of sea ice in winter, and water temperature in summer—strongly influence the distribution and abundance of many vertebrates. With respect to topography, some vertebrates concentrate at oceanside cliffs, some concentrate on islands, and some are associated with bay and lagoon systems; few concentrations occur along relatively featureless coasts. Winter ice invasion, the extent of which varies among years, has positive effects on some species (e. g., walrus) but negative effects on others (e.g., sea otters, harbor seals, waterfowl, and seabirds) (Troy and Johnson 1987a, b). Water temperature, also variable among years, appears to have important effects on the summer distribution of North Aleutian Shelf fish (Craig 1987); salmon juveniles, sand lance, capelin, herring, and some

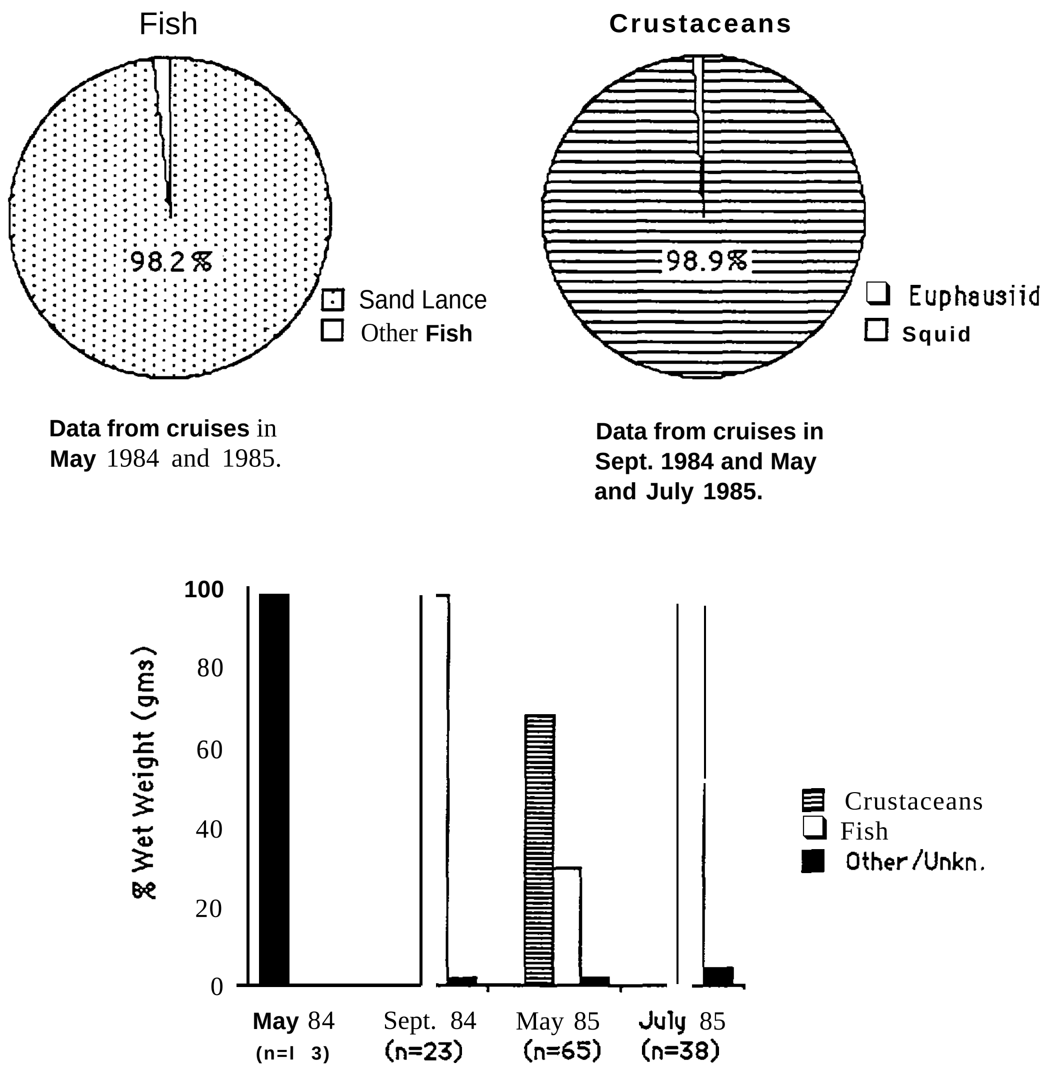

Figure 20.4—Stomach contents of surface-feeding birds (139 individuals of four species) collected during four cruises over the North Aleutian Shelf, May 1984 to July 1985 (Troy and Johnson 1987a). (Sample sizes: 85 black-legged kittiwakes, 36 short-tailed shearwaters, 17 Aleutian terns, and 1 Arctic tern.)

demersal fish distribute themselves according to water temperature regimes. The attractiveness of the coastal zone to fish in summer and the survival of fish larvae may hinge on the temperature patterns of nearshore areas relative to those of adjacent areas.

20.3 PRIMARY PRODUCTION, NUTRIENTS, AND TRANSPORT

Two sources of carbon—eelgrass transported from coastal lagoons (mainly Izembek lagoon) and *in situ* phytoplankton production—are available as a food chain base for the euphausiids, copepods, and benthos on which the vertebrates depend. Eelgrass production contributes a very small part of the total; its greatest contribution is to the local benthic food web. Phytoplankton production is the major carbon source; it is apparently supported largely by deep-ocean nutrients and approximates or exceeds (on a per unit area basis) annual carbon fixation levels elsewhere on the shelf (Schell and Saupe 1987).

The general circulation and water exchange patterns that prevail in the southeastern Bering Sea and on the North Aleutian Shelf (Kinder and Schumacher 1981; Schumacher and Moen 1983) suggest transport into the NAS from the west (by

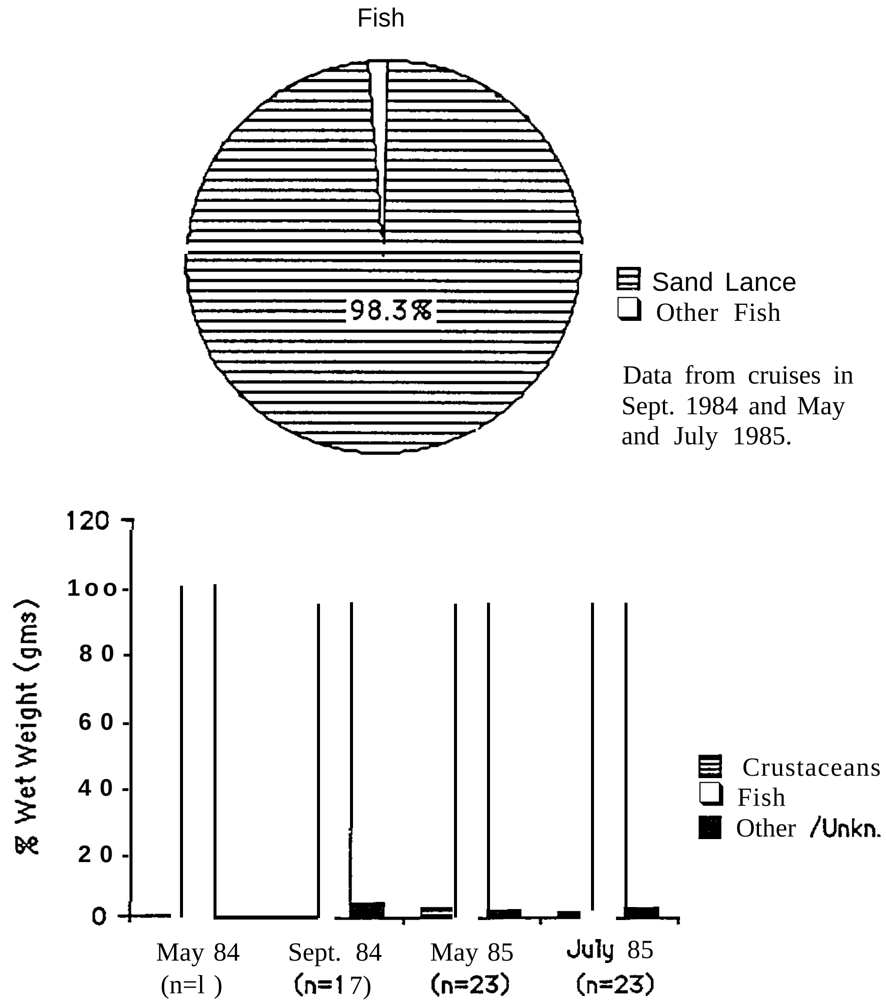

Figure 20.5—Stomach contents of water-column-feeding birds (64 individuals of three species) collected during four cruises over the North Aleutian Shelf, May 1984 to July 1985 (Troy and Johnson 1987a). (Sample sizes: 19 common murres, 12 thick-billed murres, and 33 red-faced cormorants.)

advection) and from the north (by dispersive exchange) (ESE 1987) (Fig. 20.7). Portions of the water and transported material that come from the west appear to be derived from the Alaska Coastal Current that moves into the area from the shelf south of the Alaska Peninsula (Schumacher and Moen 1983), but larger portions are derived from deep Bering and/or Pacific water that enters to the north of Unimak Island (see Hood 1986, Troy et al. 1988). Water that enters the NAS from the north (i.e., from the middle domain) also originates in the deeper Bering Sea, as discussed by Whitledge et al. (1986). Radiocarbon signatures of organisms collected from the NAS reflect a deep-ocean carbon source (Schell and Saupe 1987).

20.4 COMPARISON WITH ADJACENT AREAS

It was initially hypothesized that the structure and function of the coastal domain ecosystem were different from those of the central and outer shelf domains beyond 50-m depths. Though the vertebrate communities and their food webs do show strong differences between shallow and deep shelf areas, in most cases the greatest changes seem to occur nearer the 20-m depth contour than the 50-m contour. Many of these differences occur because waters shallower than 20 m have different (warmer) temperatures in summer, different benthic communities, and easier access by birds and mammals

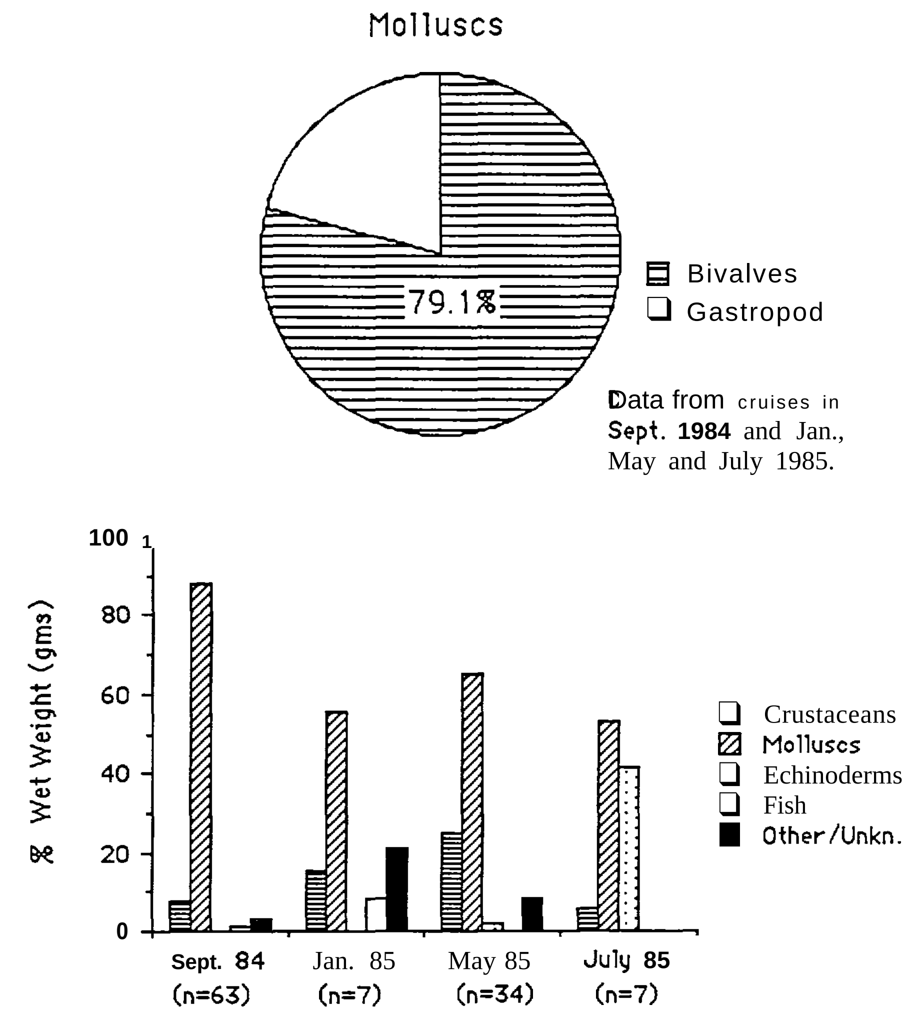

Figure 20.6—Composition of stomach contents of benthic feeding birds (111 individuals of six species) collected during four cruises over the North Aleutian Shelf, September 1984 to July 1985 (Troy and Johnson 1987a). (Sample size: 12 oldsquaws, 10 harlequin ducks, 22 Steller's eiders. 31 king eiders, 23 white-winged scoters, and 13 black scoters.)

to benthic foods and important shoreline habitats than do waters deeper than 20 m. In many respects, the NAS zone beyond 20 m of depth is ecologically more similar to the adjacent middle shelf domain (depths >50 m) than to the coastal waters (<20 m).

20.5 FURTHER INFORMATION NEEDS

The major information needs with respect to the functioning of the North Aleutian Shelf coastal ecosystem and its vulnerability to oil and gas activities appear to be as follows:

1. Further replication of survey efforts of birds and mammals to assess yearly and seasonal variability in their distribution and abundance.
2. Further information about the relationships between bird and mammal distributions and the distribution of their principal prey species.
3. Better documentation of the summertime distribution of larval and juvenile forage fish (sand lance, herring, capelin) and the migration pathways of spawning adults.
4. More information about the relationships between the abundant and highly predatory jellyfish that invade the NAS in fall. and larvae and juveniles of forage fish and other species (e. g., pollock) that may be eaten by (or commensals of) jellyfish.
5. Further evidence of the source of the euphausiid food-base of birds and forage fish; i.e., does most

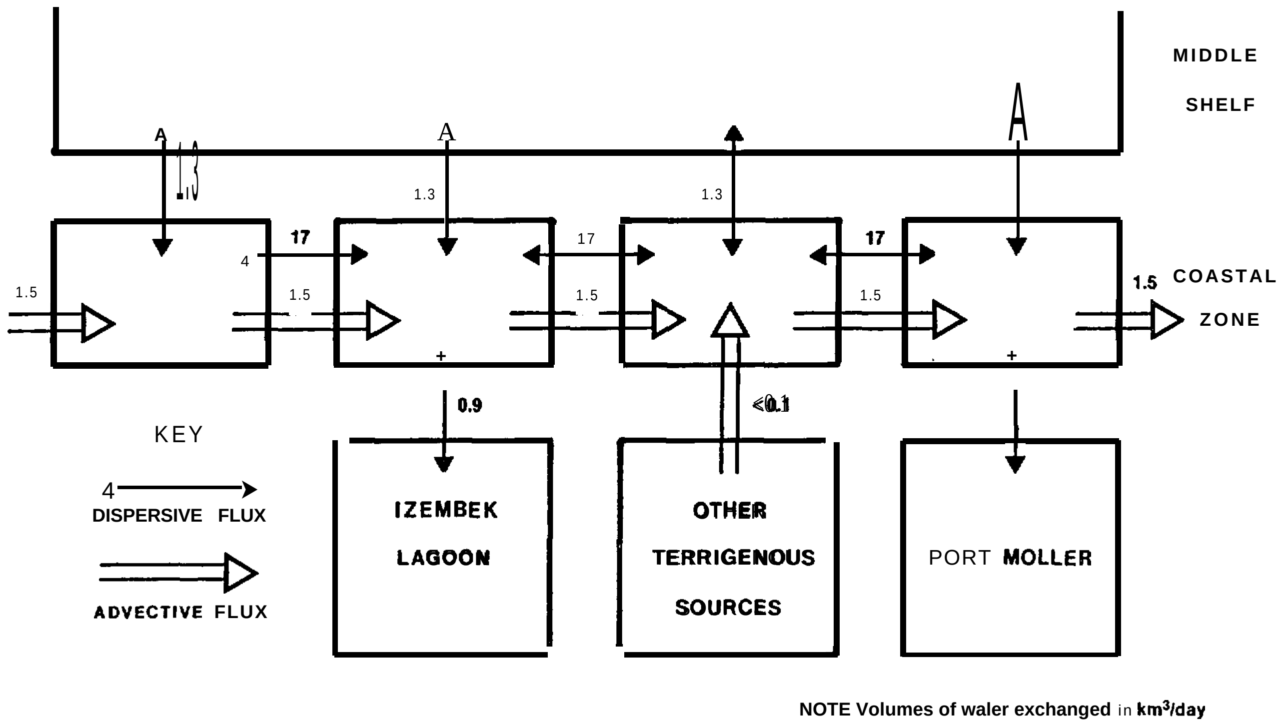

Figure 20.7–Approximate quantification of conceptual model of North Aleutian Shelf coastal zone (ESE 1987).

of the euphausiid prey come from the Bering Sea basin to the west or from the middle shelf domain to the north?

6. Additional documentation that the major sources of nutrients for food webs of the NAS are the deep-ocean basins to the south and west (Pacific Ocean and Bering Sea basins).

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Chapter 21

Marine Birds and Mammals of Unimak Pass

DECLAN M. TROY

LGL Alaska Research Associates, Inc., 505 West Northern Lights Blvd., Anchorage, Alaska 99.503

21.1 INTRODUCTION

Unimak Pass is the major passage linking the northeastern Pacific Ocean to the eastern Bering Sea. Commercial cargo vessels, fishing boats, and oil industry vessels supporting activities in western and northern Alaska transit the pass. The Unimak Pass area receives intensive use by seabirds and marine mammals. In summer, well over one million seabirds nest on islands in the area. During spring and fall, millions of birds and thousands of marine mammals migrate through the pass. Large numbers of these apex predators feed in the area throughout the year, suggesting that the region is capable of high and sustained biological productivity.

Portions of the Bering Sea—St. George Basin, North Aleutian Shelf, Navarin Basin. and Norton Sound—have been or are being considered for leasing for petroleum exploration. In the event of a major oil discovery off western Alaska. tanker and support vessel use of the passage is expected to intensify, increasing the probability of accidents which could result in oil spills and damage to regional biota. The Unimak Pass area is thus somewhat unique in that, with its considerable biological importance. it is considered to be at risk from OCS activities yet is spatially removed from the actual lease areas,

A lack of quantitative information on the nature and extent of use of the Unimak Pass area by marine birds and mammals prompted NOAA and MMS to obtain additional data. This report describes some of the results of efforts to fill the information gaps,

21.1.1 Study Area

The study area encompassed Unimak Pass and adjacent waters within a distance of approximately 50 km, including the Krenitzin Islands. The area of interest was bounded by latitudes 53°30'N and 55°00'N and longitudes 164°00'W and 166°30'W (Fig. 21.1).

21.1.2 Resources of Concern

The species of interest fall into three groups: species that are numerous in the area, species that are very rare, and species of uncertain status.

The abundant species in the region include short-tailed shearwater, tufted puffin, and crested auklet, which are all known to occur in large numbers within the boundaries of our study area.

Several endangered species are known to occur (or formerly did) in the Unimak Pass area. These include right, gray, blue, humpback, and finback whales, and the short-tailed albatross.

Species of uncertain status—those believed to occur in some abundance but whose distribution and actual use of the pass area needed additional quantification-include the northern fur seal, whiskered auklet. and sea ducks,

21.2 METHODS

Three cruises. all using the NOAA ship R/V *Miller Freeman*, were taken for this study:

Fall	18 Sept. -7 Oct. 1986	AIF-86-1O
Winter	14 Feb. -9 Mar. 1987	MF-87-02
Spring	21 Apr. -14 May 1987	MF-87-05

Surveys were made from the flying bridge while the ship was at full steam. Many survey lines were repeated each survey to ensure sampling of all major depth classes and (expected) oceanographic domains (e.g., Gulf of Alaska and Bering Sea sides of the Aleutian Islands. and all passes and straits within the Krenitzin Islands). Transects were 300 m wide and of 10-minute duration; customary procedure for conducting marine bird surveys in Alaska.

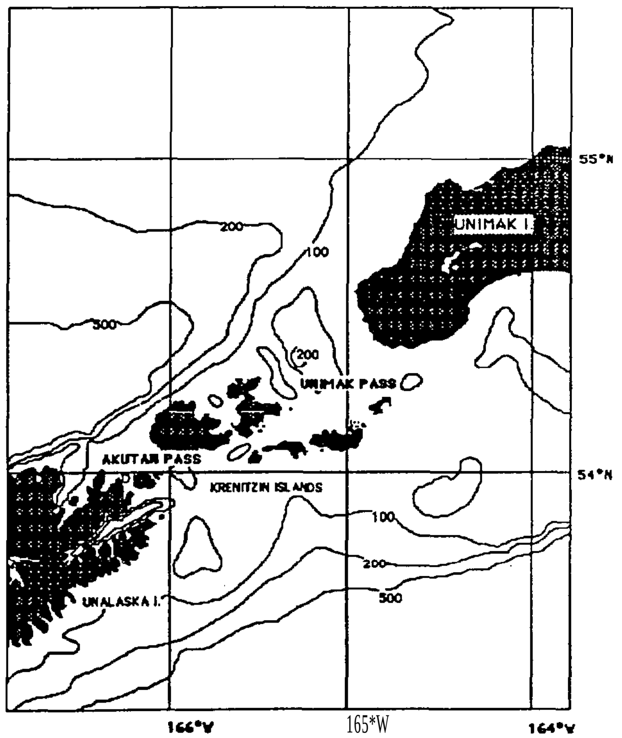

Figure 21. I —The Unimak Pass study area.

Sampling to characterize oceanographic conditions and prey availability was undertaken, usually at night, along transects just censused. This sampling included bongo net samples (zooplankton), CTD casts, and Marinovich midwater trawls (forage fish). Most sample stations were resampled during each cruise.

21.3 RESULTS

21.3. I Distribution of Birds and Mammals

Fall. —Abundances for most species peaked during the fall cruise (Table 21.1). This was particularly true of procellariids, larids, and puffins. Although many species were relatively common during this season, the total density of marine birds was not as high in fall as during the winter, but was considerably higher than during the spring cruise.

Short-tailed shearwaters were overwhelmingly the most numerous species, accounting for almost two-thirds of all birds seen. Next in abundance were black-legged kittiwakes, which accounted for 15 % of all sightings. Three additional species were common (densities ≥10 birds/km^2): whiskered auklet, northern fulmar, and tufted puffin. In all, these five species accounted for 9470 of the birds seen.

Table 21. I —Densities (number/km^2) of marine birds by cruise.

Species	Fall	Winter	Spring
Northern fulmar	9.9	5.3	5.1
Short-tailed shearwater	186.3	0.0	39.1
Black-legged kittiwake	42,1	2.4	1.7
Murre	0.1	14.2	4.7
Whiskered auklet	16.3	11.0	15.3
Crested auklet	0.1	317.8	4.8
Auklet	3.9	58.5	0.3
Tufted puffin	9.9	0.1	0.5
Total	281.0	424.6	79.8
Area sampled (km^2)	748.8	594.0	670.5

Several species, including most of the common ones—northern fulmar, short-tailed shearwater, phalaropes, black-legged kittiwake, and tufted puffin-had an area of localized abundance in the northwest portion of Unimak Pass, off of Akun Island (Fig. 21.2).

As expected, many whiskered auklets were encountered within the passes and straits of the Krenitzin Islands, especially Akutan Pass. However, this species was also numerous in the Gulf of Alaska

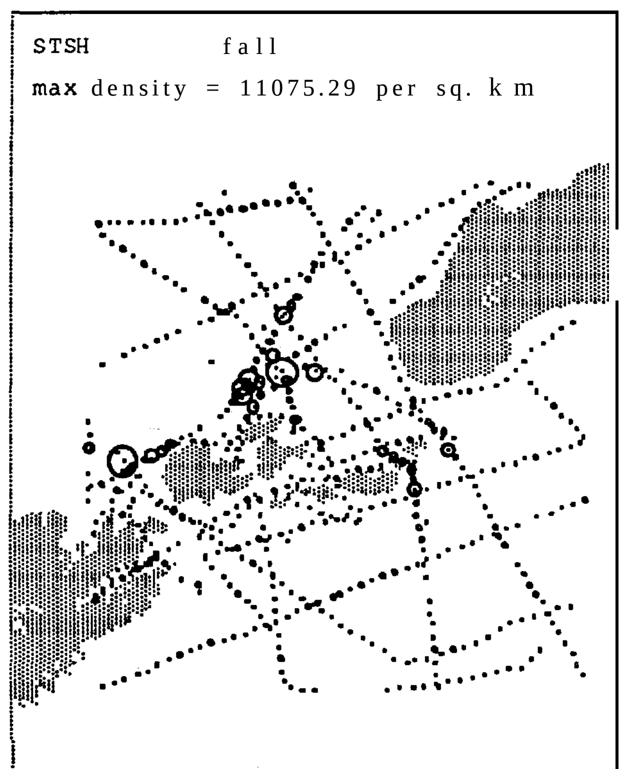

Figure 21 .2 —Distribution of short-tailed shearwaters during the fall 1986 cruise.

south of the islands, with peak numbers occurring off of passes (Fig. 21.3).

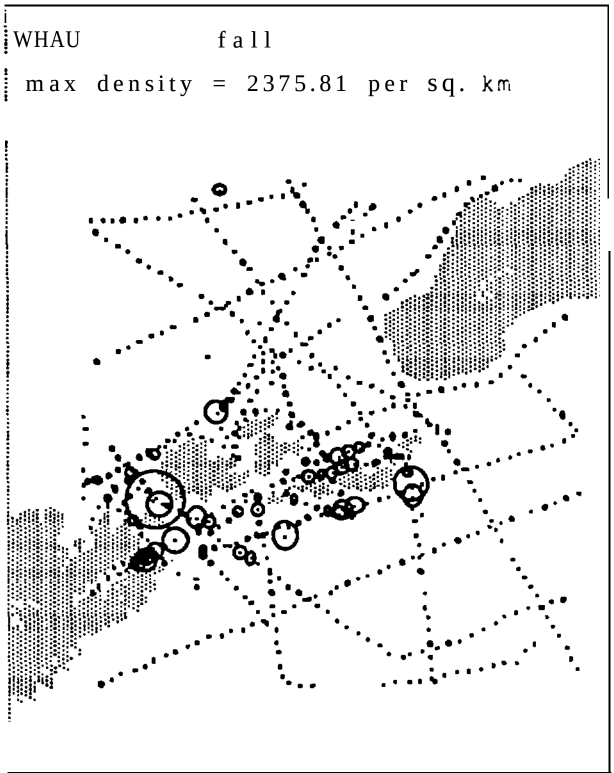

Figure 21.3 —Distribution of whiskered auklets during the fall 1986 cruise.

Most marine mammals also were found at their peak abundances during fall (Table 21.2). Dan porpoises, sea otters, and northern fur seals were most striking in this regard.

Observations of marine mammals were too few to allow broad generalizations regarding distribution.

Table 2 1.2—Densities (number/km²) of marine mammals bv cruise.

Species	Fall	Winter	Spring
Sea otter	0.029	0.007	0.009
Steller sea lion	0.003	0.002	0.000
Northern fur seal	0.039	0.000	0.000
Harbor seal	0.004	0,000	0.000
Killer whale	0.005	0.000	0.009
Dal] porpoise	0,139	0.074	0.051
Gray whale	0.000	0.000	0.003
Minke whale	0.004	0.003	0.001
Fin whale	0.000	0.000	0.003
Total	0.223	0.104	0.076

Northern fur seals were not as common as expected and were confined primarily to the Bering Sea west of Unimak Pass. Most Dan porpoises were observed in the Bering Sea, with peak abundances north of Unimak pass, though they also occurred in the deeper waters of the Gulf of Alaska. Humpback whales were observed in the area of seabird concentration north of Akun Island.

Winter.—The highest overall density of marine birds was recorded on the winter cruise. Sightings were, however, restricted to a small set of species. At least three-quarters of all birds were crested auklets. Murres, predominantly common murres, were the second most abundant group, but they were an order of magnitude less numerous than the auklets. The only other common species w-as the whiskered auklet. These three species accounted for approximately 97% of all marine birds present during the winter cruise,

The centers of abundance of birds occurred in two areas: north of Unimak Island and in the passes and straits of the Krenitzin Islands. Murres were numerous in both of these areas. They were most common in western Unimak Pass, Avatanak Strait, and off of Cape Sarichef (Fig. 21.4). Crested auklets

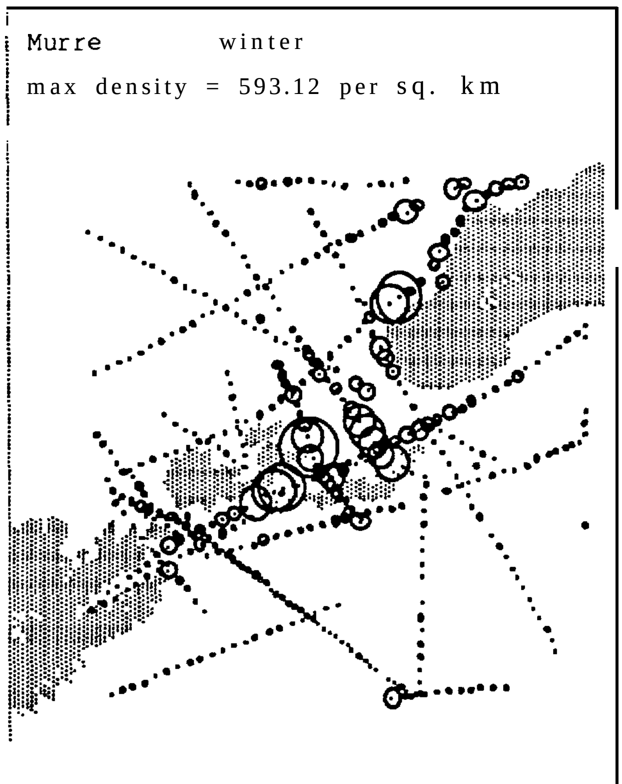

Figure 21.4—Distribution of murres during the winter 1987 cruise.

were concentrated north of Unimak Island (between Cape Sarichef and Cape Mordvinof) and within Akutan Pass (including Baby Pass) (Fig. 21.5). Whiskered auklets were restricted to the Krenitzin Islands, where they were concentrated in the Akutan Pass area and in Derbin Strait (Fig. 21.6).

Marine mammals were rarely observed during the winter cruise. The most numerous species recorded at sea were Dali porpoises, which were largely restricted to the deepest portions of the study area in the North Pacific. The only species of baleen whale recorded during winter was the minke whale, observed in the passes and straits of the Krenitzins.

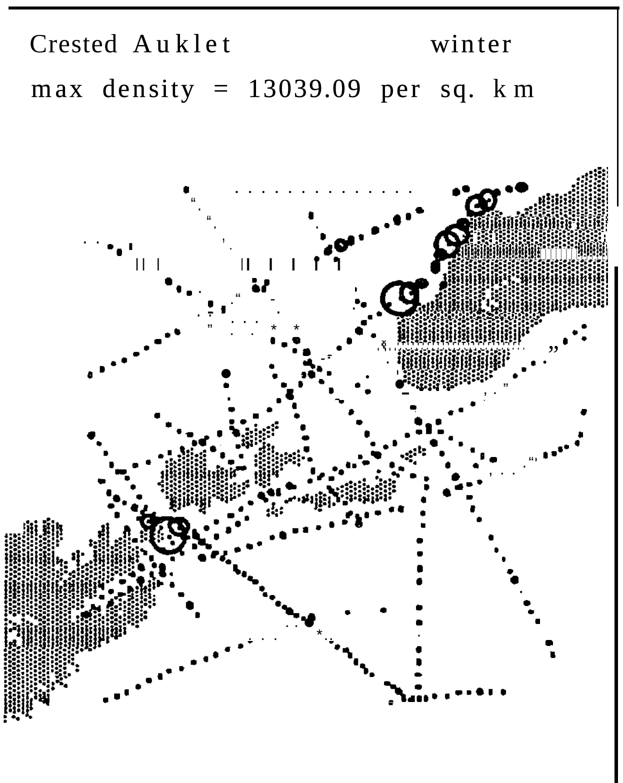

Figure 21.5 —Distribution of crested auklets during the winter 1987 cruise.

Spring.—The fewest marine birds of all of our cruises were observed during the spring cruise. Overall densities were only one-fifth of those recorded during the winter cruise, which ended not much more than a month prior to the start of the spring cruise. This reduction illustrates the dynamic nature of bird populations during times of migration. It was obvious that most winter birds had left for breeding areas and that few of the summer birds had arrived. Indeed, the most numerous species during the spring

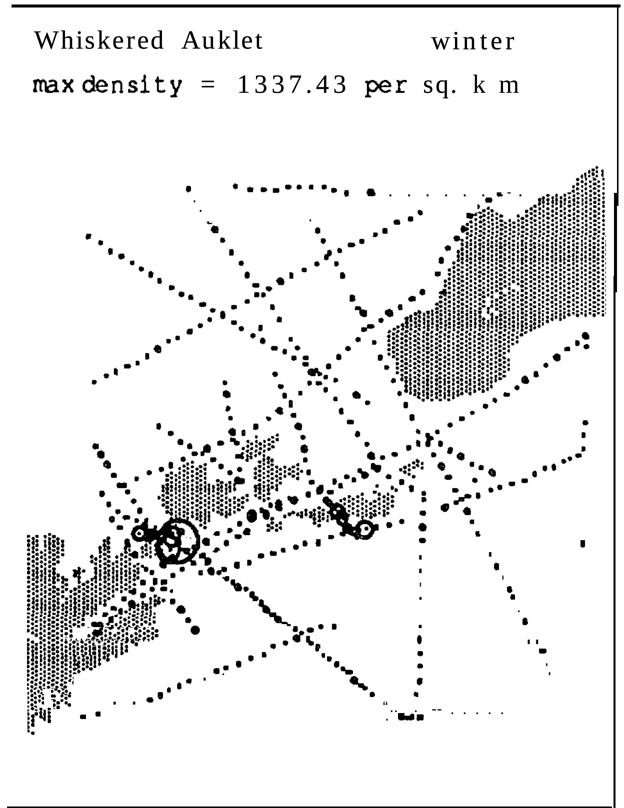

Figure 21.6 —Distribution of whiskered auklets during the winter 1987 cruise.

cruise, the short-tailed shearwater, was only recorded in appreciable numbers towards the end of the cruise.

In contrast to fall, during the spring shearwaters were most numerous in the eastern part of Unimak Pass, near Unimak Island (Fig. 21.7). The only other species commonly observed during this cruise was the whiskered auklet. These two species composed 68% of all the sightings. The whiskered auklet was the only species that was considered common during all cruises. During spring this species was more frequent north of the Krenitzin Islands (still opposite passes) than during the other cruises (Fig. 21.8).

Marine mammals were at their lowest abundance during this cruise, though several sightings were made. Gray whales were recorded, as expected, close to Unimak Island. Finback whales were observed on transects within Unimak Pass. Although not observed during a census, a group of Baird's beaked whales was seen repeatedly in the deep water of the Bering Sea north of Dutch Harbor.

21.3.2 Oceanographic Features

Distributional analyses of water quality variables were based on shipboard CTD casts and nitrate/

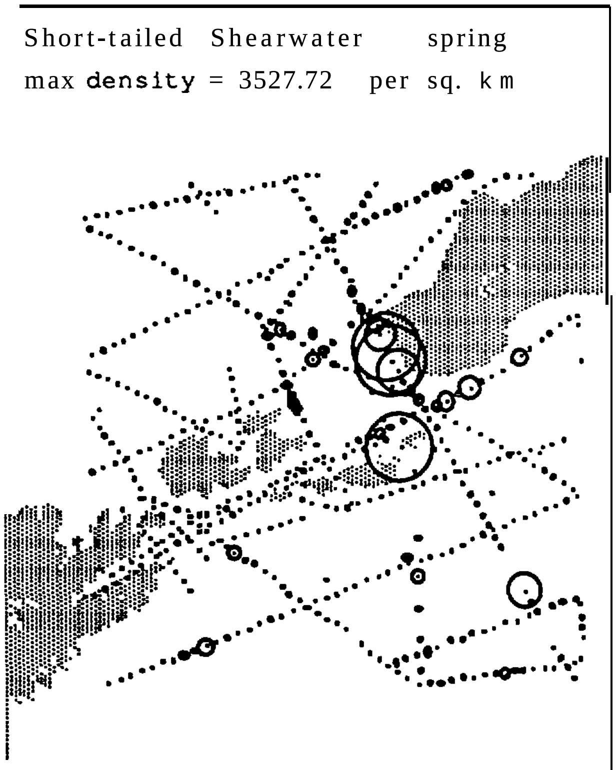

Figure 21.7 —Distribution of short-tailed shearwaters during the spring 1987 cruise.

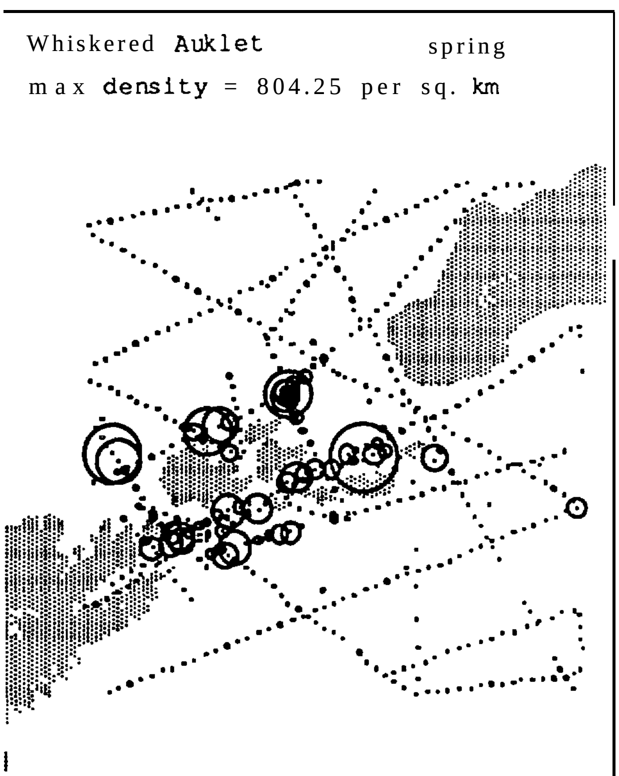

Figure 21.8—Distribution of whiskered auklets during the spring 1987 cruise.

nitrite samples taken on transects throughout the area, and on remote-sensing analyses of sea surface temperatures. Findings having important implications for the vertebrate food webs in the area include:

1. Low-salinity Alaska Coastal Current water was confined in all seasons to the eastern parts of Unimak Pass. Its farthest westward extension occurred in spring.
2. Water quality distributional characteristics indicated that upwelling of deep Gulf of Alaska water south of Unimak Pass and its subsequent transport through the pass was probably an uncommon occurrence. Rather, it seemed that upwelling occurred a few to several hundred kilometers farther west in the Aleutian chain, and that the upwelled water moved eastward along the north side of the chain, eventually reaching the Unimak pass area. This is consistent with recent theory by other researchers.
3. Four different water masses appeared to occur in the study area as a whole, based on surface salinities and mixing regimes. These were Alaska Coastal Current Water (ACW), Shelf Break Water (SBW) (north and west of the pass), Tidally Mixed Water (TMW) (in shallow areas), and what we called Gulf of Alaska Water (GAW) (widely distributed in deeper, western parts of the study area).

Two of the water masses, the Gulf of Alaska Water and the Alaska Coastal Water, were subdivided into northern and southern (Bering and Pacific) masses. In the case of the Gulf of Alaska Water, the Bering and Pacific masses were frequently discontinuous and hence logically analyzed separately The Alaska Coastal Water retained its integrity as it passed through Unimak Pass; however, based on prior studies and the nitrate data, we anticipated that effects of upwelling would be manifested on the Bering Sea component of this water mass but not on the Pacific side. Since the exact point of division cannot be determined, we used Seal Cape. at the narrowest portion of the pass, as the dividing point. Thus, most of Unimak Pass itself is in the northern portion of the Alaska Coastal Water mass.

21.3.3 Prey Resources

Fish. —During the fall cruise very large numbers of small pollock were captured within the Krenitzin Islands. At all times of the year, myctophids were present in the very deep portions of the North Pacific and Bering Sea. Otherwise forage fish were quite rare.

Invertebrates.—Euphausiids and copepods, the zooplankton groups expected to dominate pelagic environments and vertebrate diets, were sampled in the water column and at the surface by nets deployed from aboard the R/V *Miller* Freeman. Estimates of invertebrate wet-weight biomass and composition by major taxa (e.g., copepods, euphausiids) were made. Major findings and their implications include the following:

1. Proportions of the total biomass made up of major zooplankton groups varied seasonally. Gelatinous zooplankton (jellyfish) dominated spring catches northeast of Unimak Pass in the vicinity of the well-known “slime bank” on the North Aleutian Shelf, but was inconsequential in other seasons and places. Euphausiids formed the overwhelming majority of non-gelatinous zooplankton biomass in fall and winter, and a slight majority in spring, Copepods were scarce in fall and winter but nearly equaled the abundance of euphausiids in spring.
2. During fall, euphausiids were virtually absent from the ACW but were present in all other water types. They peaked in abundance in the Bering Sea, particularly in the SBW. During winter, euphausiid distribution changed markedly, with large concentrations in the northern portion of the ACW. By spring, abundance had dropped in most areas and the highest densities were found in the ACW and TMW.
3. Studies of marine bird food habits indicated that euphausiids in bird stomachs from the study area were largely oceanic species; shelf species were uncommon. This finding supports other evidence that water from off the shelf dominates the Unimak Pass area.

21.4 DISCUSSION

21.4.1 Fall Cruise

Marked differences in abundances of marine birds were evident among the water masses. The highest densities occurred in the Shelf Break Water. Short-tailed shearwaters (Fig. 21.9) and black-legged kittiwakes were extremely abundant in waters of this type. During the fall cruise, the spatial extent of this

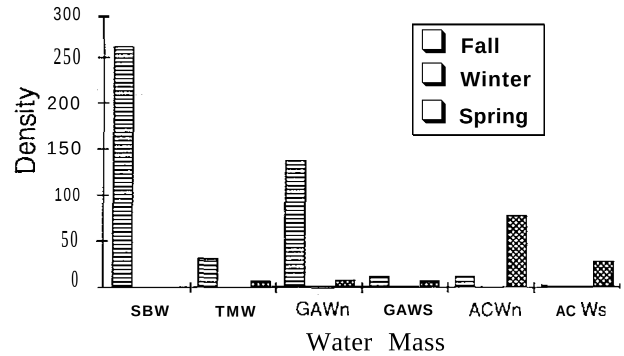

Figure 21,9—Abundance of short-tailed shearwaters by water mass and cruise.

water mass was greater than during other cruises, occupying much of the northwest corner of the study area. Shearwaters were also abundant in the adjacent northern portion of the Gulf of Alaska Water; however, black-legged kittiwakes were abundant only in the SBW. The abundance of birds in the SBW and northern GAW was paralleled by the densities of euphausiids, their principal prey, which were highest in these areas.

The Alaska Coastal Water had few birds in both the northern (ACWn) and southern (ACWs) regions. Horned puffins reached their peak abundance in the south portion of this water mass; however, even here they were quite rare, These areas were also lacking in potential prey for seabirds.

Oceanic areas in the Gulf of Alaska had very low densities of prey species. One species, the black-footed albatross, was found only in this area.

Although absolute densities in the Tidally Mixed Water (TMW) were substantially lower than in the more structured water masses to the north, several species were largely restricted to this water mass. The most notable examples were whiskered auklet (Fig. 21.10) and tufted puffin. Cormorants, murrelets, and common murres were also most frequent in the Tidally Mixed Water. The occurrence of many of these birds in the TMW is probably due to the proximity of the water mass to breeding areas, as many of them nest in colonies in the Krenitzin Islands. Some species, especially tufted puffins, preyed predominantly on the large numbers of young pollock in this area.

In general, the Alaska Coastal Water was little used by birds. Outside of this water mass, bird use on the Bering Sea side of the Aleutian chain was high relative to the Gulf of Alaska side. Intermediate densities occurred in the Tidally Mixed Water.

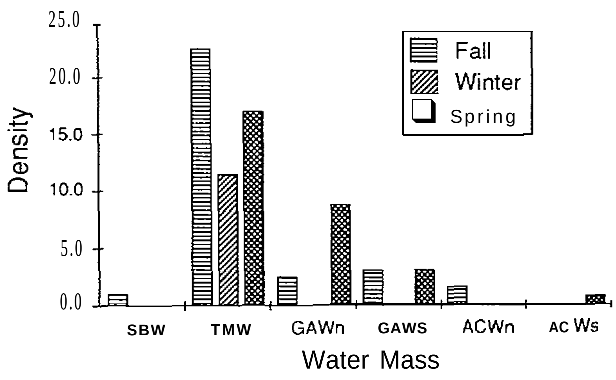

Figure 21. 10–Abundance of whiskered auklets by water mass and cruise.

21.4.2 Winter Cruise

Bird use of the various water masses during winter differed markedly from the use observed during the fall. By a large margin, the highest densities occurred in the Alaska Coastal Water. The contrast between the south and north components of this water mass w-as striking, as almost all birds were in the northern portion. Crested auklets were the most abundant species in this water mass (Fig. 21.11); however, many species' peak abundance was recorded. Other species common in the Alaska Coastal Water (north) were the northern fulmar and common murre. Several species of sea ducks (Fig. 21.12) and gulls also reached peak abundance in this area. A corresponding shift in distribution of prey items was recorded during the winter, as euphausiids became markedly more abundant in the ACWn than elsewhere.

The Tidally Mixed Water apparently increased in importance to birds in winter. Whiskered auklets were still largely confined to this water mass, and even higher densities of crested auklets were seen

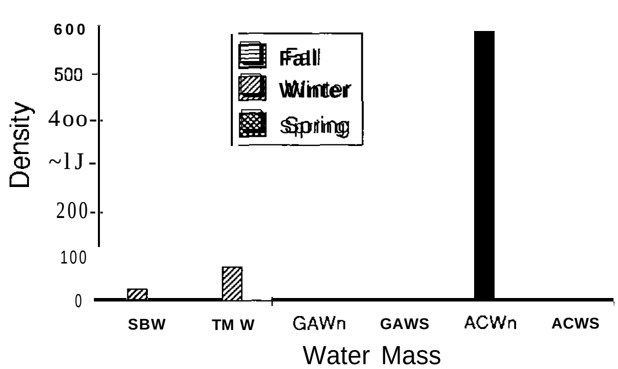

Figure 21. I I —Abundance of crested auklets by water mass and cruise.

using this water. Common murres were also numerous in this water mass although densities were not as high as in the Alaska Coastal Water. Although not common in the areas surveyed by the ship, most sightings of emperor geese and cormorants were in Tidally Mixed Water.

Few birds were observed in Gulf of Alaska Water. The northern portion had more than the southern; however, neither area had many birds. Both tufted and horned puffins peaked in abundance in the north segment of Gulf of Alaska Water but puffins were still rare everywhere during the winter.

The Shelf Break Water mass was much smaller in the winter than in the fall. SBW was identified in two areas, one north of Unalaska Island, the other at the northern edge of the study area. The two areas may have connected to the west of our study area. Moderate densities of birds, many of them auklets (presumably mostly crested auklets), were found in this water mass.

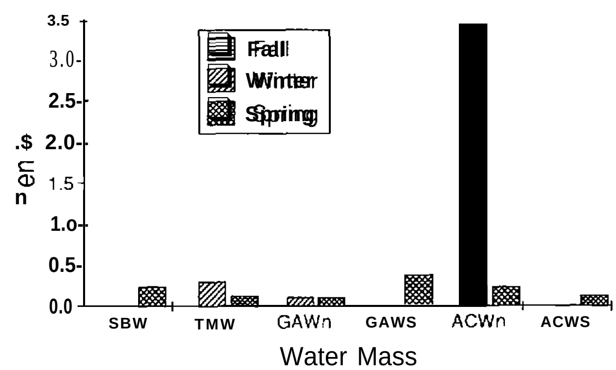

Figure 21. 12—Abundance of oldsquaws by water mass and cruise.

Overall, in winter only a few birds occupied the Gulf of Alaska. Bird use of the western segment of the Bering Sea was greatly reduced, whereas marine birds heavily used habitats in the eastern portion (under the influence of the Alaska Coastal Water). Tidally Mixed Waters were used more heavily in the winter than in the fall.

21.4.3 Spring Cruise

Bird use of the various water masses was much more equitable during the spring cruise than at other times of the year, although overall densities were relatively low. The highest densities of marine birds occurred in the Alaska Coastal Water. This region continued to have the highest abundance of euphausiids, although not as high as during the winter. Although the northern portion was again the most important, the portion south of Unimak Island had more birds in the spring than were observed during any other cruise. In both areas, short-tailed shearwaters predominated.

Gulf of Alaska Water had similar overall densities in both the northern and the southern sectors, but the species composition was rather different. In the south, where densities were highest of all cruises, common murres were the most frequent species. In the north, whiskered auklets predominated, although this species was more numerous in the Tidally Mixed Water.

As mentioned above, the Tidally Mixed Water continued to be the major habitat for whiskered auklets. Although several species peaked in abundance here—murrelets, pigeon guillemots, cormorants—only whiskered auklets occurred in appreciable abundance.

In marked contrast to the results of the fall cruise, the Shelf Break Water was the least used of any of the study area's habitats during the spring cruise. No species, including the less frequently encountered species, peaked in abundance in this habitat.

21.5 CONCLUSIONS

The Unimak Pass area was found to support spectacular concentrations of marine birds and lesser numbers of marine mammals. Marked differences in distribution 'were found both temporally and spatially. Prey availability appeared to play a major role in determining bird distribution.

Virtually all of the key species—shearwaters, auklets, and murres—were found to be preying predominantly on euphausiids. Some of these species frequently feed on fish in many other areas,

In the fall both birds and their prey were most common north of the Krenitzin Islands in SBW and GAWn. Spectacular concentrations occurred in the northwest corner of Unimak Pass (off Akun Island). This location corresponds to an area of reduced salinity, appearing as an island of SBW in the GAWn, and may represent an area of local upwelling.

During winter the euphausiid concentrations were farther east, to the north of Unimak Island within the ACWn. The major bird concentrations, mostly crested auklets and common murres, were also present in this area. The spring cruise found no major concentrations, although the ACW supported the highest densities of birds and prey.

Some species, including the whiskered auklet, did not follow the prey concentrations seasonally. This species was always associated with the Krenitzin Islands and the TMW. Euphausiids were always present in this area, although they did not reach the high densities of some other areas. It may be that zooplankton availability increased during periods of high tidal flux when the birds appeared to be most active in the passes, but sampling was impossible. Birds collected in the passes were found to have been successful in procuring euphausiids.

We did find that whiskered auklets venture much farther from the passes than previously believed. Relatively large numbers were found at sea (5-10 nmi) both north and south of the islands. Abundance in these areas appeared to vary seasonally (birds were concentrated closest to land during winter), and at sea they appeared to be concentrated opposite passes.

Our results tend to support the hypothesis that very little upwelling or influx of nutrients or prey occurs due to movement through Unimak Pass or the other passes we sampled. Instead, upwelling appears to occur in the Bering Sea to the west of our study area. Nutrients (or subsequent trophic products) are then transported east along the north side of the eastern Aleutians and into the North Aleutian Shelf area. However, some evidence of local upwelling north of Akun Island was found during the fall.

Chapter 22

Coastal Zone Oil Spill Model: Performance Test of Wave Propagation Components

MARK REED

Applied Science Associates, Inc., 70 Dean Knauss Drive, Narragansett, Rhode Island 02882-1143

22.1 INTRODUCTION

The coastal zone oil spill model (COZOIL) is a numerical model that simulates the dynamic transport and fate of spilled oil in the coastal marine environment (Reed et al. 1988, 1989; Reed and Gundlach 1989). The model includes explicit representation of all major processes known to affect the behavior of oil offshore, in the surf zone, and within coastal sediments (Fig. 22.1). Processes and fates simulated include:

Processes

- Winds—deterministic or stochastic
- Waves-refraction, diffraction, breaking
- Wave runup and setup
- Currents—tidal, wind-driven, and wave-induced

Oil *Fate— Offshore*

- Spreading
- Evaporation
- Entrainment and dissolution
- Emulsification
- Advection (currents)

Oil Fate—SurfZone

- Spreading—onshore and offshore balanced by wind stress; alongshore by usual processes
- Entrainment
- Radiation stress
- Advection (currents and longshore wave transport)

Oil Fate—Onshore

- Foreshore surface—function of shoreline type, foreshore slope, backshore width
- Sediment and groundwater system—standard fluid and sediment algorithms
- Removal from surface by wave overwash
- Erosion and accretion
- Evaporation
- Reflotation
- Dewatering

22.2 METHODS

The model outputs include boiling-point cut information, overall mass balance, and line plots showing the location of surface and alongshore oil distribution. Other physical parameters such as the depth and shoreline grids and wave and current fields can be displayed. COZOIL is inherently deterministic with respect to results from any single simulation. Stochastic oil-distribution estimates are produced by combining the results of multiple simulations using a statistical analysis processor at the end ofa test.

The wave-refraction, shoaling, and breaking components of COZOIL were evaluated by comparison with field observations taken along the southern shore of Bristol Bay during August and September 1986. The original version of this section of the code has also been tested by the originators (Ebersole et al. 1986). In this project, three sets of field data were selected for test purposes: 12-20 August (case III), 22-29 August (case II), and 6-10 September (case I). Due to the loss of the wave gauge during the field study, the study team was forced to hindcast the offshore waves necessary as input to COZOIL. Although observational data are available for periods other than those listed above, they occur during transient weather events that introduced additional uncertainties into the wave hindcast results. Therefore, the time periods selected represent the most reliable data for model testing.

22.3 STUDY AREA

Figure 22.2 shows the study area, with the coastline divided into “reaches” for model input. .411 reaches are sand, with an evenly sloping bottom and a depth of 6 m below mean low water (MLW) at

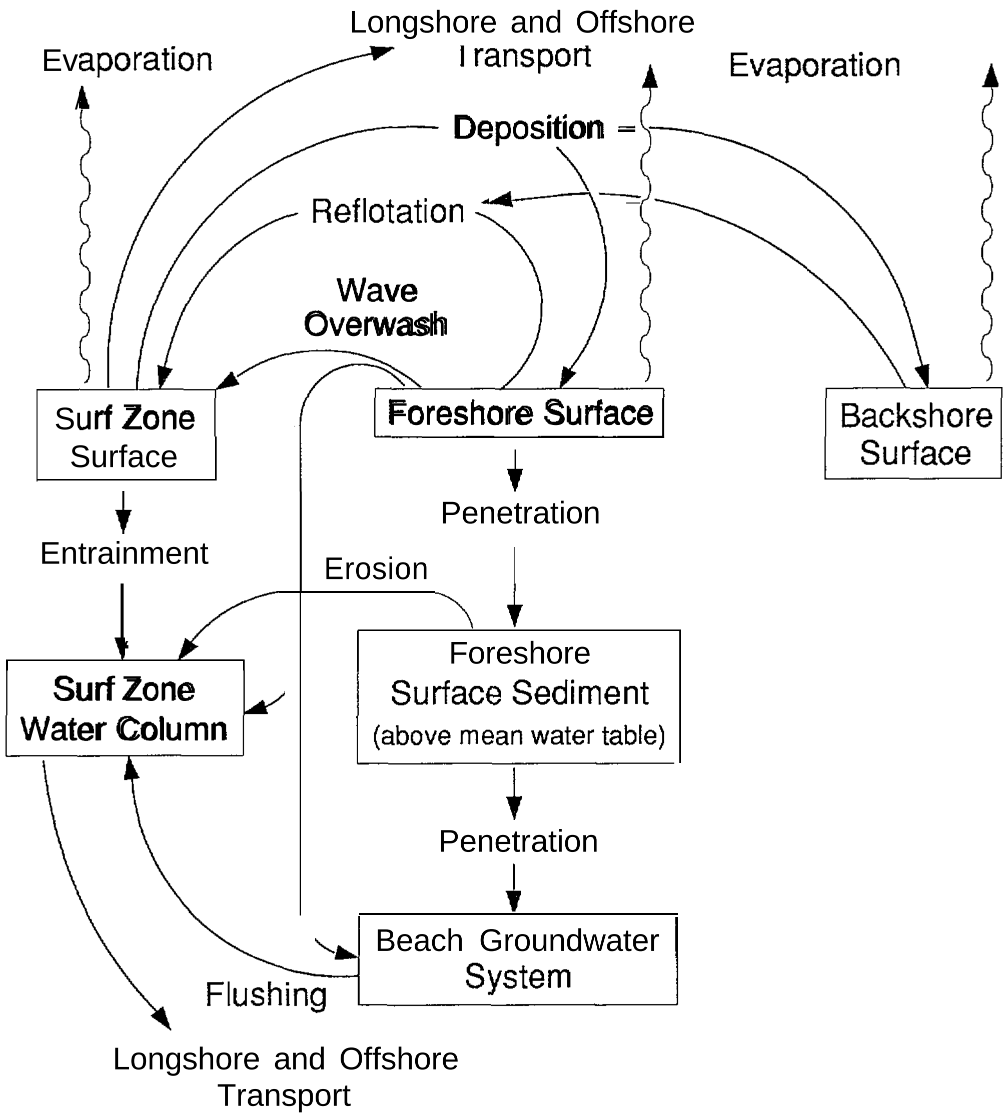

Figure 22. I —COZOIL mass transfer pathways in the coastal zone.

a distance of 2 km offshore. The test cases were run on a **40 x 40** grid system, giving a grid size of 260 m east-west (approximately onshore - offshore) and 460 m north-south (alongshore). The digital depth grid is shown in Figure 22.3.

22.4 RESULTS

Results of model tests are shown in Tables 22.1, 22.2, and 22.3 for test cases I, II, and III, respectively. In several situations, specifically at low tidal levels with relatively large (>1 m) waves at the offshore boundary, waves begin to break several grid cells offshore in the model. A wave which experiences successive breaking as it approaches shore goes through a series of transformations, from higher to lower heights. As depicted in Tables 22.1-22.3, wave heights in these cases are one grid cell (260 m) offshore, because reported heights reflect observations with wave staffs out in the surf zone, rather than wave heights at the beach face. These latter heights would in general be smaller.

Tables 22.4 and 22.5 give statistical summaries of the comparisons between observed breaker heights and angles and those computed by the model. Case I shows a consistent bias between the observed and modeled wave angles, with the modeled angles being an average of 6° more southerly than those observed. Since no such systematic errors occur in the other two cases, we infer that the problem is

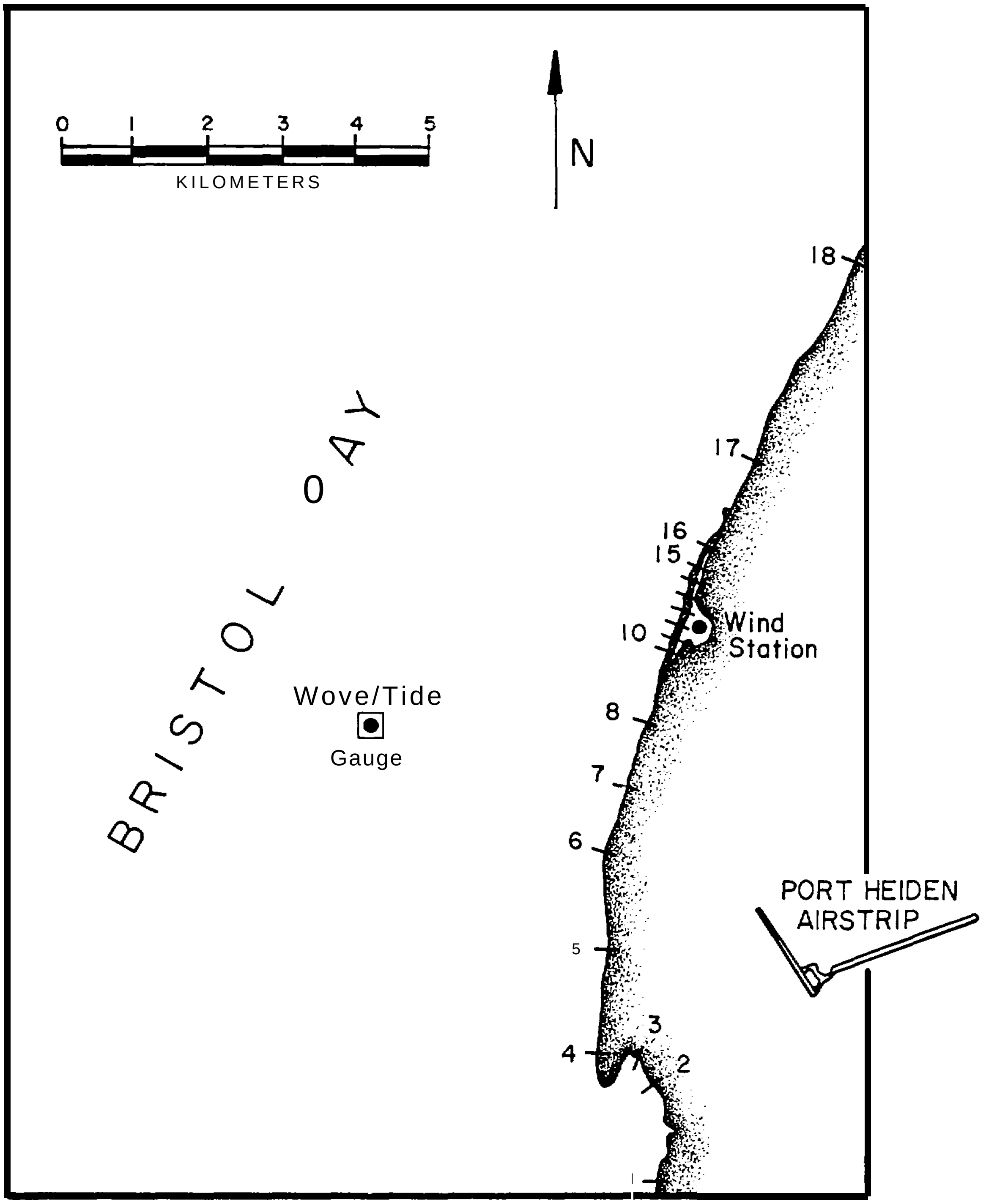

Figure 22.2—Model application domain.

associated with the hindcast methodology. The average error over all three cases is about 1° to the south. The standard deviation around the mean is 6.60. To the extent that we can rely on the hindcast waves as inputs, we can expect the model to be within 6.6° of the observations 68% of the time.

Summary statistical comparisons of wave height are shown in Table 22.5. The overall mean error is 10 cm. Although these data appear to suggest that the model exaggerates wave heights, 10 cm is probably well within the uncertainty limits of the wave hindcast results and the observational accuracy

Uncertainty also exists as to where in the model grid one should compare model output with the

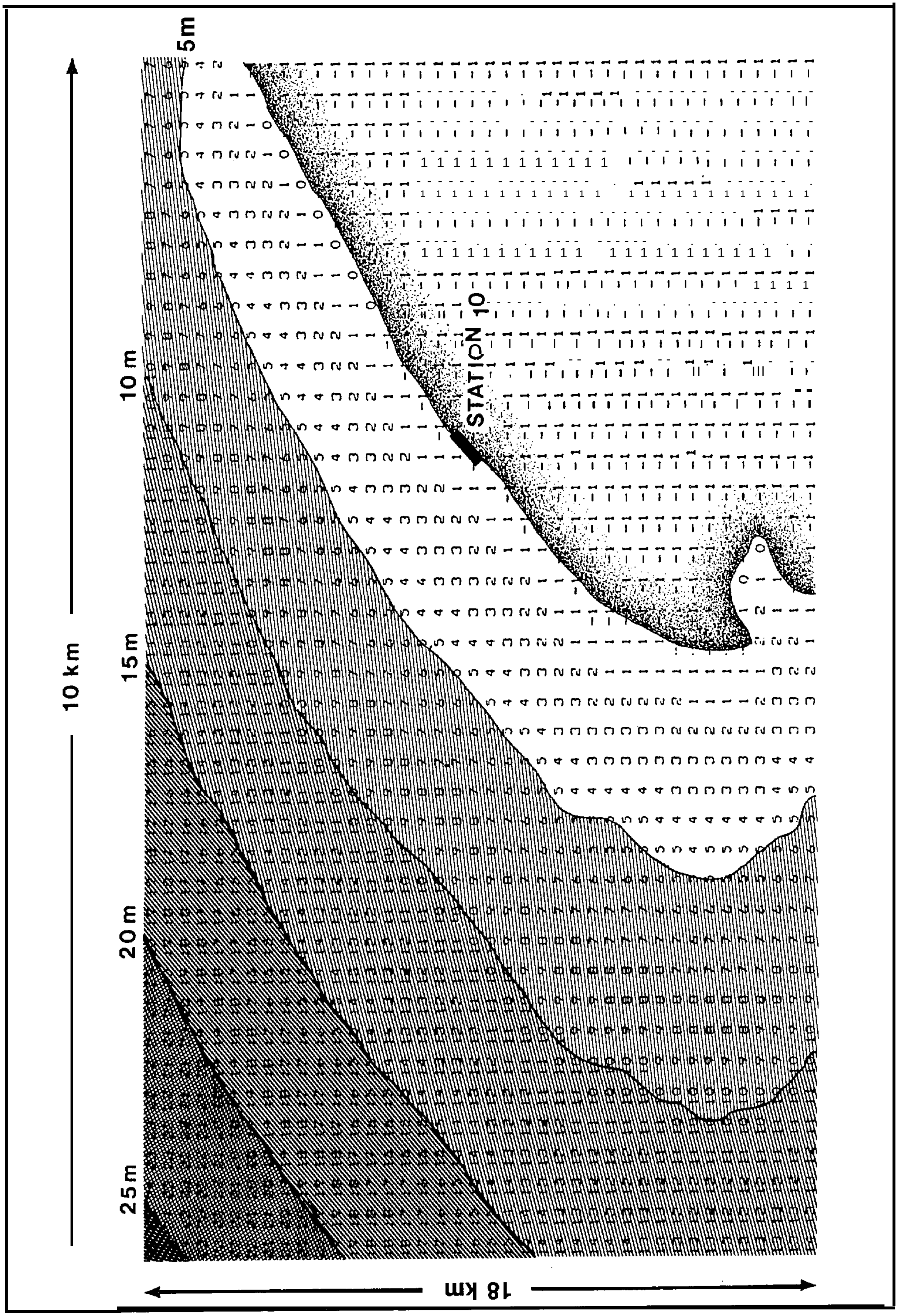

Figure 22.3—Digital depth grid. Depths shown are rounded to meters below MLW; −1 indicates land cells.

Table 22.1—Comparison of modeled and observed breaking-wave heights and angles for test case 1 (6-10 September 1986). (Model output from reach 10.)

		Model Input				Model Output		Observations	
Date	Time	H_s (m)	T_s (s)	β ("T)	Tidal height (m)	H_b (m)	α_b (°)	H_b (m)	α_b (°)
6 Sept.	1500	0.82	8.0	80	2.2	0.9	10	0.6	18
	2100	0.85	8.0"	110	1.2	1.1	- 3	0.7	14
7 Sept.	0300	0.82	7.2	140	1.2	1.1	- 6	1.3	0
	0900	1.01	6.8	120	1.2	0.9	0	1.8	0
8 Sept.	0900	2.19	6.0	120	0.3	0.8**	–8	1.2	0
9 Sept.	0900	1.28	6.0	110	0.0	0.8**	–3	1.1	0
10 Sept.	0900	1.55	6.9	100	-0.3	0.8**	o	1.0	0

* Estimated value.
** Waves breaking more than one grid cell (260 m) offshore. Onshore wave heights are 0.2-0.4 m.

Table 22.2—Comparison of modeled and observed breaking-wave heights and angles for test case 2 (22-29 August 1986).

		Model Input				Model Output		Observations	
Date	Time	H_s (m)	T_s (s)	β (°T)	Tidal height (m)	H_b (ml)	α_b (°)	H_b (m)	α_b (°)
22 Aug.	1600	5.6	11.0*	90	0.6	1.1**	8	1.0	10
23 Aug.	1210	5.0*	11.0	90	1.2	1.3**	10	1.5	15
24 Aug.	1400	1.8	7.0	70	1.8	1.8	13	1.3	15*
25 Aug.	1400	1,8	8.0	70	0.6	0.6	5	0.5	o
26 Aug.	1445	1.0	9.0	70	0.6	1.1**	5	0.9	3
	1915	1.0	7.0	90	2.8	1.0	10	0.5	8
27 Aug.	1530	2.1	6.0	90	0.3	1.0**	3	0.75	3
28 Aug.	1930	1.6	6.5	80	2.3	1.6	13	1.0	5
29 Aug.	1330	1.1	5.0	70	0,3	0.4	10	0.2	3

* Estimated value.
** Waves breaking more than one grid cell (260 m) offshore, Onshore wave heights are 0,2-0.4 m.

Table 22. 3—Comparison of modeled and observed breaking-wave heights and angles for test case 3 (12-20 August 1986).

		Model Input				Model Output		Observations	
Date	Time	H_s (m)	T_s (s)	β ("T)	Tidal height (m)	H_b (m)	α_b (°)	H_b (m)	α_b (°)
12 Aug.	1500	1.4	5.3	70	0.8	1.3**	10	1.4	25
13 Aug.	1400	1.6	5.5	80	0.0	1.5	6	0.8	10
14 Aug.	1300	1.9	7.0	80	-0.8	1.4**	9	1.2	10
	2100	2.2	7.5	80	3.8	2.1	16	2.3	15
15 Aug.	1430	0.9	8.0	125	-0.9	1.1**	1	1.1	o*
16 Aug.	2100	1.7	8.0	85	2.5	1.8	10	1.0	- 5
17 Aug.	1600	1.3	5.8	110	-1.2	0.6**	2	0.5	0
18 Aug.	1750	0.8	5.0	110	-0.6	0.7**	1	0.4	0
19 Aug.	2000	0.9	7.0	115	-0.8	1.1**	2	1.2	0
20 Aug.	2030	1.1	5.5	120	0.0	1.2**	- 6	1.3	- 5

* Estimated value.
** Waves breaking more than one grid cell (260 m) offshore. Onshore wave heights are 0.1-0.9 m.

observations when wave breaking occurs in several offshore grid cells. For example, Figure 22.4 shows the model wave-breaking matrix of the input conditions of 8 September at 0900 hours (case I, Table 22.1). Wave breaking is initiated in four grid cells, or over a kilometer offshore. Figure 22.5, which gives wave height as a function of grid cell, shows waves shoaling up to 2.3-2.4 m before breaking for the first time at a depth of about 3 m. Subsequent breaking reduces wave heights at the beach to about 0.5 m. Observations were made about 100 m into the surf zone, but very local topographic variabilities (e. g., presence of an offshore bar) were not reflected in the model; bathymetry can also affect the results.

The mean wave height for the three cases is about 1 m. The overall standard deviation of 0.3 m can be interpreted to mean that 68 % of the time-modeled wave heights will fall within 3070 of actual values.

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Table 22.4—Statistical summary of model test results for wave angle.

Case	Number of comparisons	Mean absolute error (°)	Mean error (°)	a n−1
1	7	6.0	-6.0	5.9
2	9	3.7	1.7	4.4
3	10	4.3	-0.01	7.3
Overall	26	4.6	− 1.0	6.6

$$\text{Absolute sum of errors} = \sum_{i=1}^{n} |x_{i,mod} - x_{i,obs}|$$

$$\text{Mean absolute error} = 1/n \sum_{i=1}^{n} |x_{i,mod} - x_{i,obs}|$$

$$\text{Mean error} = I/n \sum_{i=1}^{n} (x_{i,mod} - x_{i,obs})$$

Table 22.5—Statistical summary of model test results for wave height.

Case	Number of comparisons	Mean absolute error (o)	Mean error (°)	$\sigma n-1$
1	7	0.2	-0.2	0.4
2	9	0.3	0.3	0.3
3	10	0.3	0.2	0.3
Overall	26	0.3	0.1	0.3

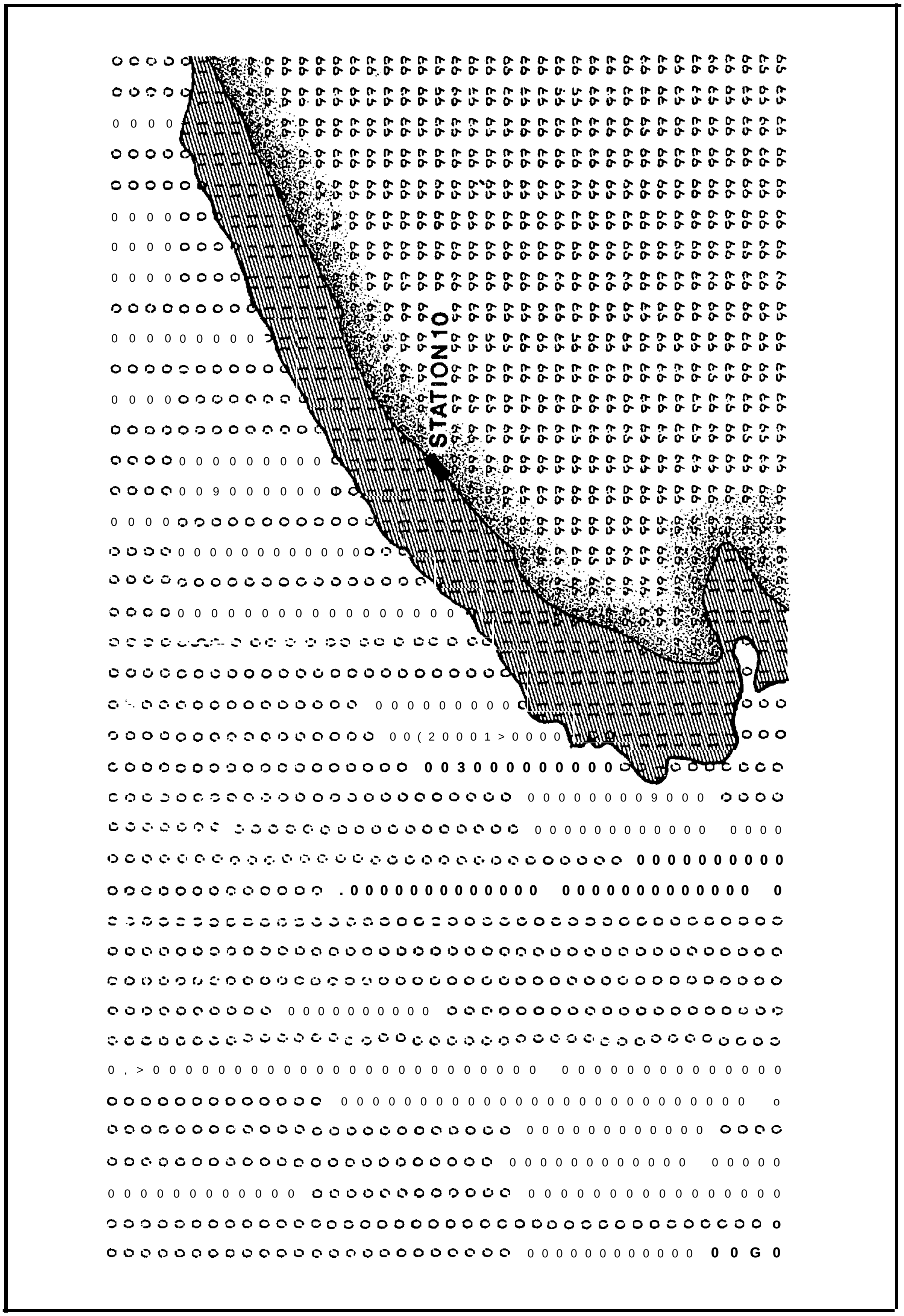

Figure 22.4—Case I (8 September, 0900 hours): modeled wave-breaking matrix; 0 indicates no breaking, 11 indicates breaking, and 99 is a land cell. Heavy line indicates MLW along coastal reach 10, where the observations were recorded.

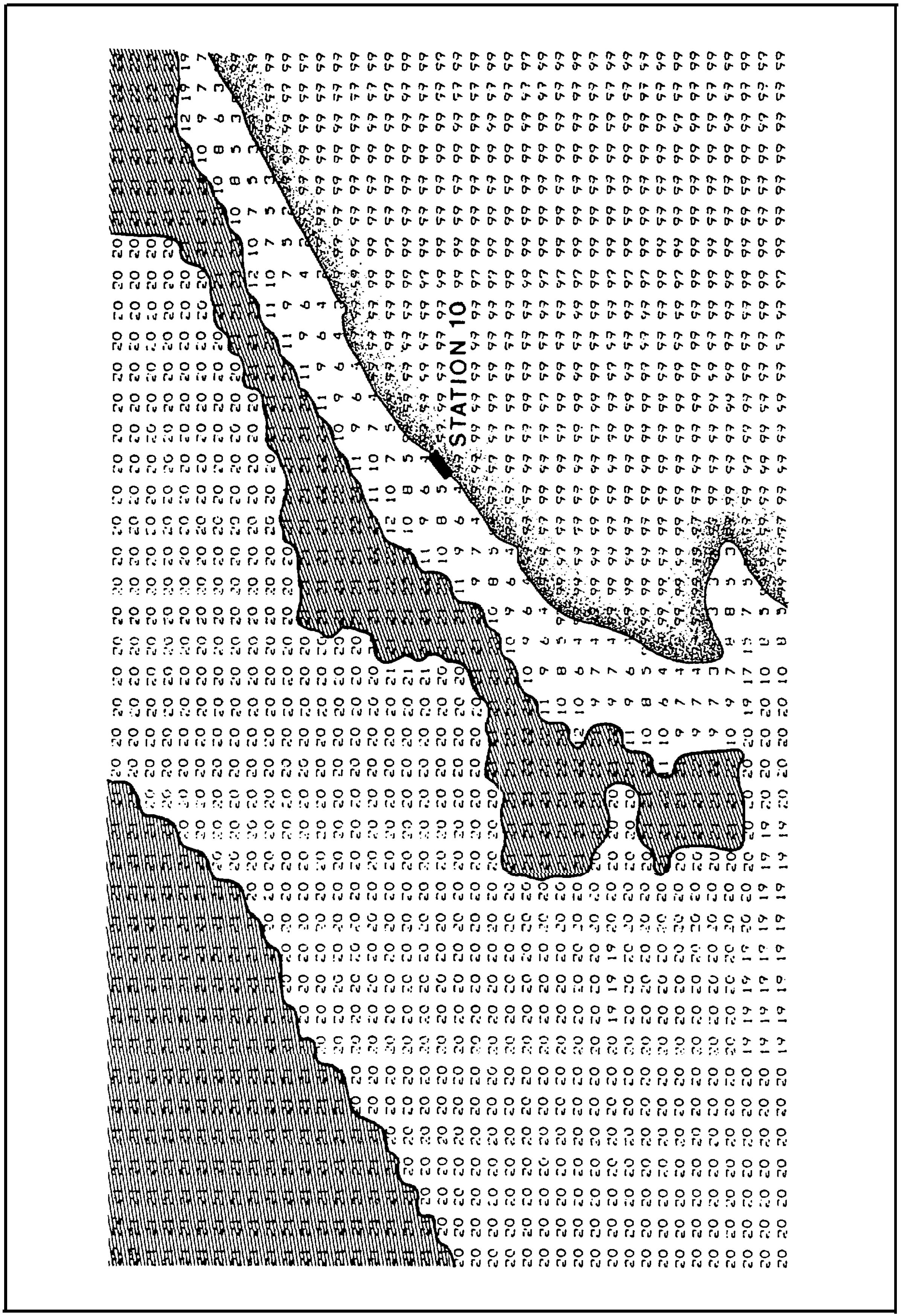

Figure 22.5—Case 1 (8 September, 0900 hours): modeled wave-height matrix (meters, multiplied by 10). Heavy line indicates MLW along coastal reach 10, where the observations were recorded.

Chapter 23

Alaska Oil Dispersant-Use Guidelines

J. W. WHITNEY, C. .4. MANEN, P. O' BRIEN, C. LAUTENBERGER,
C. SLATER, H. METSKER, E. ROBERTSON-WILSON, D. D. ROME, and P. BERGMANN

NOAA, National Ocean Service, Ocean Assessments Division,
2.22 W. Eighth Avenue, #56, Anchorage, Alaska 99513-7543

23.1 INTRODUCTION

The coastal resources of Alaska are unparalleled in the rest of the nation. Alaska's tidal shoreline is 47,300 miles long, 53 % of the total shoreline of the entire United States (Fig. 23.1: McRoy and Goering 1974). This area encompasses vast, productive ecosystems and is a generous source of renewable and nonrenewable resources. It is difficult to respond to spills in remote. isolated, sparsely populated areas (difficulties which are often compounded by darkness and severe weather conditions) in a state as immense as Alaska. To solve these problems, a Regional Response Team (RRT) Working Group, formed in 1983, has been exploring the possibility of using dispersants in response to oil spills in Alaska marine waters. This group consists of representatives of the U.S. Environmental Protection Agency (EPA), State of Alaska, National Oceanic and Atmospheric Administration (NOAA), U.S. Fish and Wildlife Service, the U.S. Coast Guard, and ad hoc representatives from local fishermen. Native, and industry groups.

Decisions concerning dispersant use must be based on an evaluation of the different potential impacts from dispersed oil (oil in the water column) versus undispersed oil (oil on the water surface). If dispersants are used. effects on organisms or systems utilizing the water surface can be decreased or eliminated, but effects on water column organisms will be increased. For example, untreated oil may threaten highly aggregated populations of organisms (migrating or staging populations of seabirds. and breeding sites of birds or mammals) on the surface and dispersed oil may threaten aggregated populations of water column organisms (migrating salmon, and fish or crab egg-s or larvae).

The Alaska General Dispersant L-se Criteria states that in all cases where a response action is deemed necessary, the mechanical removal of oil from the water surface is the preferred method of control. Use of dispersants or other chemicals should be considered only in those instances where the feasibility of physical containment and collection of the oil is limited. and is has been determined that the impact of dispersants and dispersed oil will be less harmful than that of non-dispersed oil. This is clearly reflected in the dispersant use decision matrix (Figure 23.2) which is incorporated into the Alaska Guidelines. In addition, any dispersants being considered for use must be on the current EPA list of accepted dispersants.

The final step of this decision matrix, assessing the environmental impacts associated with and without chemical dispersion, can often be time consuming. and time is at a premium when dispersants might be used. Dispersants work best if applied within the first twelve hours, In order to expedite this assessment and decision. the RRT Working Group established dispersant-use zones that can be applied to specific areas.

23.2 DISPERSANT USE ZONES

Three dispersant use zones were developed. They are defined by (1) physical parameters, including bathymetry and currents; (2) biological parameters. such as sensitive habitats or fish and wildlife concentration areas; (3) nearshore human use activities: and (4) time required to respond to a spill,

23.2.1 Zone I

The use of dispersants in Zone 1 is acceptable and. after consideration of mechanical means, should be

Figure 23. I —Alaska's shoreline compared with that of the continental United States.

evaluated as a response tool to mitigate oil spill impacts. The Federal On-Scene Coordinator (OSC) is not required to obtain approval from EPA or the State of Alaska prior to the use of dispersants in this zone. However, the OSC will notify EPA and the State of the decision as soon as practicable.

Zone 1 is defined as an area in which dispersant use should be considered as a means to prevent or reduce the amount of oil reaching the shoreline or other sensitive resources, including:

a) endangered or threatened species protected by Federal and State governments;

b) nesting, spawning, breeding, and nursery areas for mammals, birds, fish, and shellfish;

c) fish and wildlife concentration areas where these animals feed, rest, or migrate;

d) sensitive marine habitats, including:

1. seagrass beds
2. kelp beds
3. shellfish beds
4. tidal flats
5. marshes
6. shallow subtidal areas
7. low energy bays and harbors
8. rocky intertidal areas;

e) aquiculture and commercial areas which are shallow enough to allow impacts from oil spills; and

f) recreational and industrial areas.

Zone 1 areas are characterized by water conditions (depth, distance, and currents) that will allow dispersed oil to be rapidly diluted to low concentrations. These areas are far enough away from sensitive resources that dispersant operations would not cause disturbances. Because it is likely that spilled oil will impact sensitive resources in this zone, an immediate response is required to mitigate environmental consequences.

23.2.2 Zone 2

The use of dispersants is condition in Zone 2 in order to protect sensitive wildlife and other resources. The OSC is required to consult with the RRT and obtain the approval of EPA and the State of Alaska prior to the use of dispersants in Zone 2. A spill in Zone 2 must be continuously monitored and the need for dispersant response actions reappraised accordingly.

Zone 2 areas are characterized by water conditions (depth, distance, and currents) that will allow rapid dilution of dispersed oil to low concentrations.

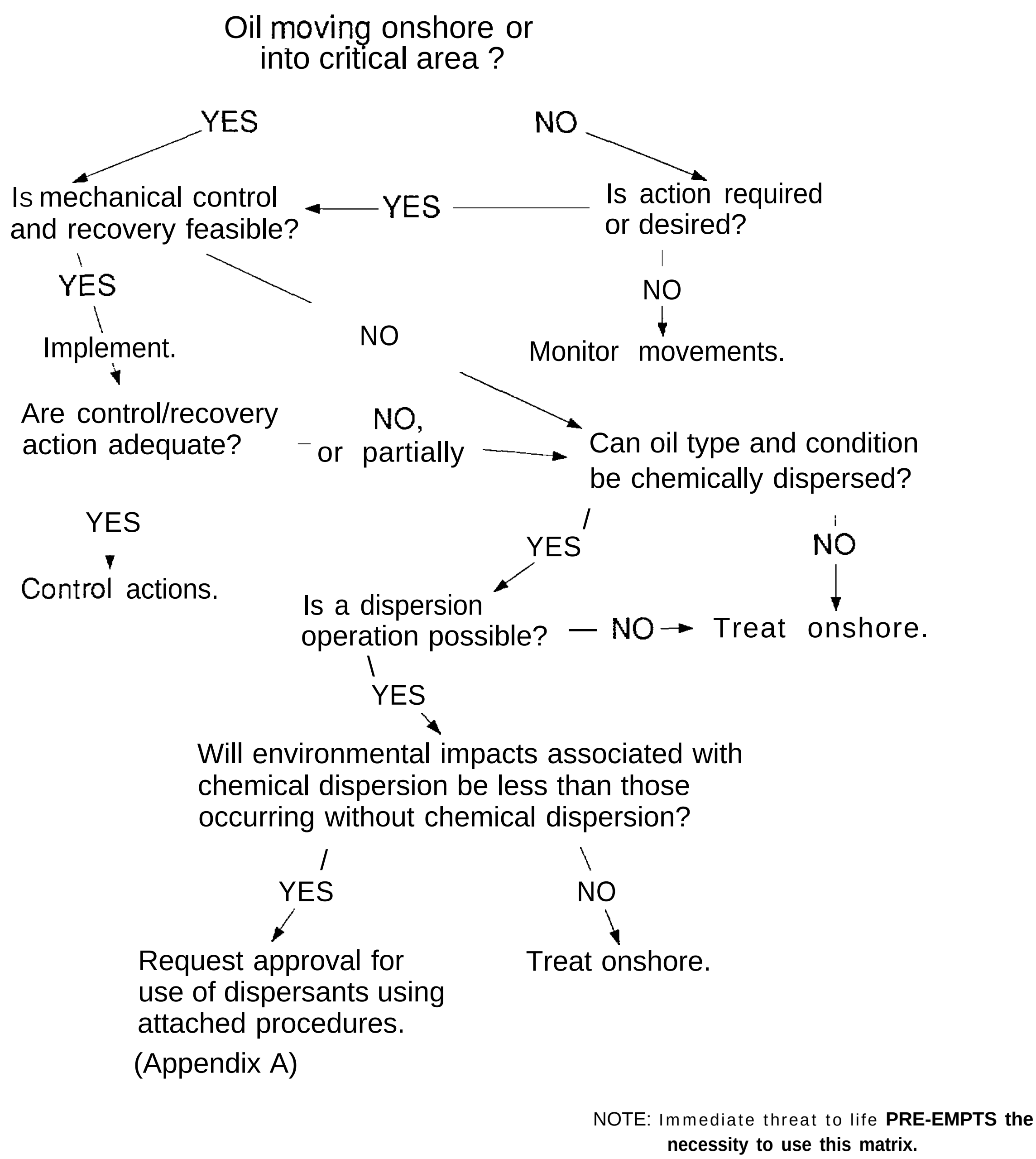

Figure 23. 2—Alaska Dispersant-Use Decision Matrix.

These areas are far enough away from sensitive resources that dispersant operations would not cause disturbances, so an immediate response is not necessary.

23.2.3 Zone 3

The use of dispersants is not recommended in Zone 3. Dispersants maybe used in Zone 3 if, on a case-by-case basis, it is determined that the disturbance of the organisms and/or direct exposure to dispersants or dispersed oil would be less deleterious than the impact of spilled oil. As in Zone 2, the OSC is required to consult with the RRT and obtain the approval of EPA and the State of Alaska prior to the use ofdispersants in Zone 3.

Zone 3 is defined as the area immediately in or around the resources requiring protection, including the resources themselves. Dispersant use in this area may disturb resources, may not have adequate time for effectiveness, may directly expose the resources to dispersants, or may expose other resources to unacceptably high levels of dispersed oil. See the above definition of Zone 1 for examples of these resources.

This classification system is conservative, especially in light of recent data on the effects of dispersants and dispersed oil in shallow water (Gilfillan et al. 1986). Nevertheless, because of the variety of marine and coastal habitats in the Alaskan arctic and subarctic coastal regimes (estuaries, barrier islands and lagoons, exposed high-energy coasts, rocky islands and sea cliffs, wetlands and tideflats), and the permutations possible within these categories, the system is being applied in a site- and resource-specific manner. This allows for the tailoring of the dispersant use zones to specific physical settings and biological resources. The areas to which this classification system is applicable have been ranked in order of probability of an accidental release of oil and include Cook Inlet, Prince William Sound (considered with the Copper River Delta), and Prudhoe Bay (considered with the Sagavanirktok River Delta).

23.3 SPECIFIC GUIDELINES: COOK INLET

The dispersant use classification system was first applied to Cook Inlet, a large tidal estuary in southcentral Alaska (Figs. 23.3 and 23.4). More than half of the population of Alaska is concentrated around Cook Inlet. The major port for the City of Anchorage and southcentral Alaska is located at the head of the inlet. The inlet supports commercial fisheries for all five species of salmon, king, Tanner, and Dungeness crabs, halibut, and shrimp; and is the most popular and accessible sportfishing area in Alaska. Currently, 15 offshore oil and gas production platforms are located in Cook Inlet. The volume of petroleum products shipped through Cook Inlet has reached as much as 8 x 10^7 barrels

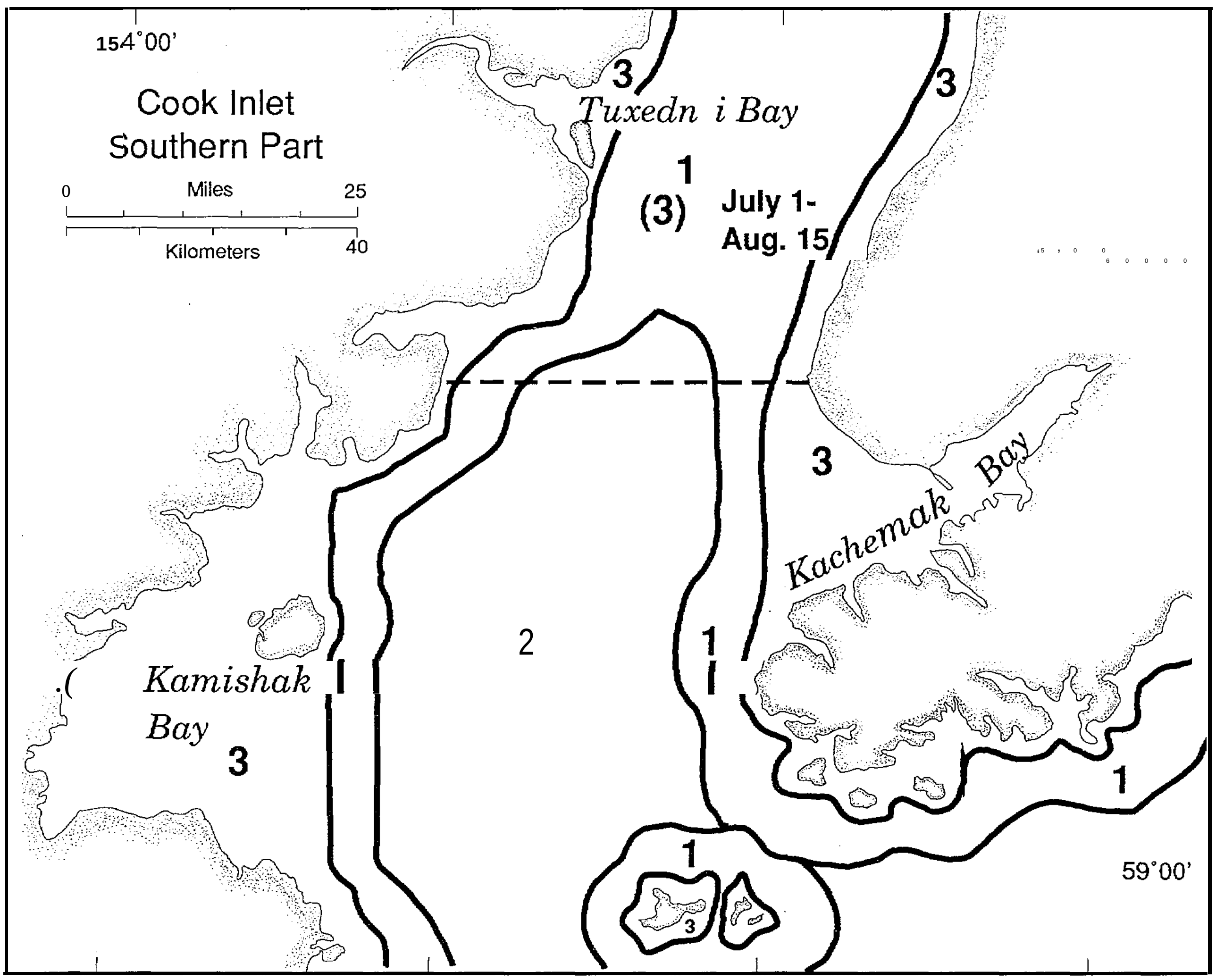

Figure 23. 3—Southern Cook Inlet dispersant use zones.

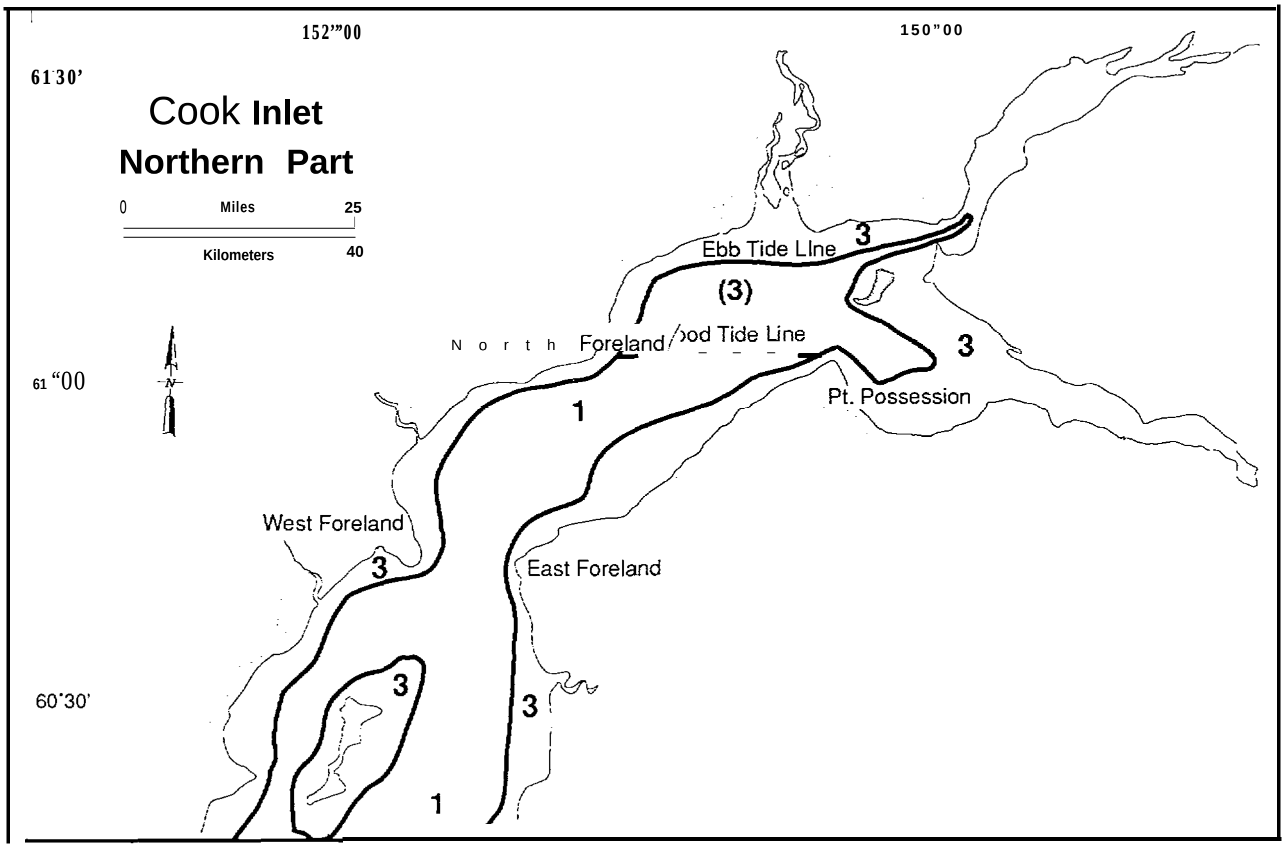

Figure 23.4—Northern Cook Inlet dispersant use zones.

of oil and over 2 x 10^{11} ft^3 of liquid natural gas annually (Davis 1984).

Tides in Cook Inlet are among the highest in the world and currents are very swift; circulation is primarily tidally driven. The physiography of the inlet amplifies tidal flow, with the result that its physical behavior is more like that of a large embayment, though it is an estuary by strict definition (Muench et al. 1978).

The mountain ranges surrounding Cook Inlet contain glaciers which are the sources for most of the stream systems discharging into the inlet. The glacial flour transported by these streams is the source of the large suspended sediment load occurring in the inlet. In the upper inlet, dynamic, very finc, highly fluid bed loads associated with this glacial flour cause low standing crops of benthic invertebrates. There are extensive intertidal mudflats at the mouths of the major glacially fed rivers. Ice, up to four feet thick and a quarter-mile in diameter, forms in the upper inlet in the winter and is transported throughout the upper and middle inlet by tides and currents.

Most of the southwestern shoreline of the inlet is rocky and highly indented, while the northwestern shoreline contains extensive mudflats and coastal wetlands. The eastern shoreline is characterized by raised plateau-like topography—high cliffs footed by sand/gravel beaches and mudflats—with little indentation.

The application of the dispersant use criteria to this area was made easier by the large amount of environmental information collected during the last two decades to plan for and assess the effects of the rapid industrial and population growth in Anchorage. In general, parts of the inlet inshore of the 10-fathom isobath were designated Zone 3. However, where the shoreline consists of rocky headlands and the nearshore depth increases rapidly, this designation was applied to “an area extending one mile out from the shoreline.” This distance allows for ample dilution of dispersed oil prior to its impacting the shoreline or shallow water area.

In lower Cook Inlet, an approximately 5-mile-wide buffer area outside Zone 3 was designated as Zone 1; this would provide adequate time to apply a dispersant prior to oil entering the sensitive Zone 3 area. In middle and upper Cook Inlet, all waters outside of Zone 3 were designated Zone 1 due to the inlet's reduced width in this area. The remaining waters in the lower inlet were designated as Zone 2. Exceptions to these general guidelines are:

1) The area north of Anchor Point is classified as Zone 3 from 1 July through 15 August due to the large salmon migration during this period.

2) Zone 3 is narrower around the Port of Anchorage, the Nikiski docks, and the Drift River offshore loading facility to make it easier to use dispersants in these areas where mechanical containment is difficult, but a high probability for an oil spill exists.

3) In the most northern portion of the inlet, a dual Zone I/Zone 3 designation was adopted to prevent extreme tidal fluctuations from transporting high concentrations of dispersed oil into mudflats and marshes. Under this dual classification, the area is Zone 1 during the first three hours of an ebb tide, but is Zone 3 during the rest of the tidal cycle. These areas are heavily utilized for nesting and staging by waterfowl.

23.4 SPECIFIC GUIDELINES: PRINCE WILLIAM SOUND

Prince William Sound, a series of bays, inlets, islands, and fj orals, is one of the largest tidal estuarine systems on the North American continent not presently influenced by coastal urbanization. The mainland coast is mountainous and deeply carved by glaciers, many of which, like the Columbia Glacier, are still active. River systems are short, with few branches, reflecting the proximity of the mountain ranges to marine water. Bayhead deposits of mud, sand, and gravel are common, as well as glacial outwash deltas and moraines of sand and gravel. Eelgrass beds are common where streams empty into the sound.

Although all of Prince William Sound can be characterized as estuarine, the conditions from one fjord to the next vary, depending on the amount of freshwater input, degree of seasonal icing, turbidity, and the tidal mixing (or flushing) rate. These factors exert a strong control over the marine flora and fauna on a local scale, as well as Prince William Sound as a whole.

The renewable resources of Prince William Sound include prodigious stocks of king, Tanner, and Dungeness crabs; razor, butter, and littleneck clams; scallops; and commercially important fish such as salmon, halibut, herring, flatfish, ocean perch, cod, and hake. Mammals include seals, sea lions, sea otters, and whales. The local bird population is diverse and abundant. At various times of the year, the area is inhabited by over 130 avian species, of which about 60 species contain tens of thousands of individuals, and another 7 species have numbers in the millions.

Prince William Sound is comparable in size to Puget Sound, Washington; the coastline totals approximately 3,000 miles, yet it is populated by less than 5,000 permanent inhabitants in the remote communities of Valdez, Cordova, and Whittier. Valdez is accessible by road, Whittier by railroad, and Cordova by air. The economy of these communities is based on commercial fishing, tourism, and oil. The terminus of the Trans-Alaska Pipeline is in Port Valdez, a fjord in the northeastern portion of Prince William Sound. Oil received from Prudhoe Bay is stored in tanks at the terminal until it can be loaded aboard tankers for shipment to ports on the U.S. West Coast and elsewhere. At the current throughput rate of 2 million barrels a day, nearly three tankers load oil at Valdez every day.

The dispersant use guidelines for Prince William Sound focus on the tanker traffic lanes and reflect the remoteness and fjord geomorphology of the sound. Designation of the tanker lanes primarily as Zone 1 was deemed desirable due to:

1) the large volume of oil transported through the sound via these lanes;

2) the difficulty in mechanically containing and cleaning up spilled oil; and

3) the likelihood that dispersant use would assist in minimizing the environmental effects of a spill, particularly oil contamination of sensitive coastal resources and habitats.

Most of the area outside of the tanker lanes has been designated Zone 3 as a result of the variety and abundance of biological resources and the complicated shoreline of the sound. These boundaries along with the specific zones in the Port of Valdez, Valdez Arm, Hinchinbrook Entrance, and the areas immediately outside of Prince William Sound from the Copper River Delta to the southeastern tip of the Kenai Peninsula are illustrated in Figures 23.5, 23.6, and 23.7.

At the Port of Valdez and in Valdez Arm, the areas inshore of the 100-fathom isobath (approximately) are designated as Zone 2. The area seaward

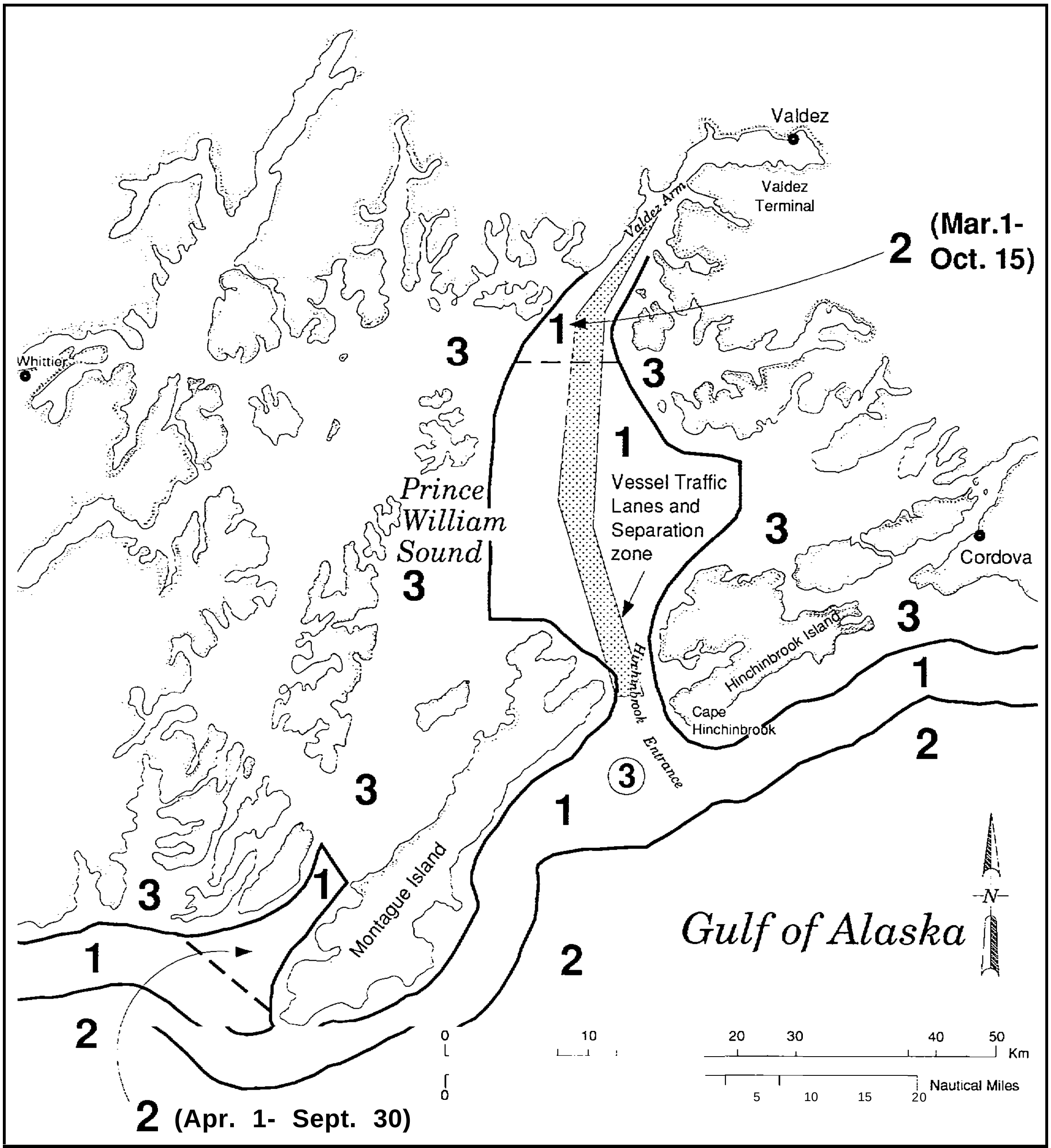

Figure 23.5—Prince William Sound (main body) dispersant use zones with vessel traffic lanes delineated,

of this isobath has been given a seasonal designation. This small portion of Prince William Sound consists almost entirely of tanker traffic lanes and includes the tanker loading berths at the terminus of the Trans-Alaska Pipeline. The Port of Valdez and Valdez Arm also support sensitive fisheries resources, such as outmigrating juvenile salmon, herring spawning and rearing areas, immigrating adult salmon; and commercial fishing activities. Consequently, this portion of the sound has been designated Zone 1 from 16 October to 28 February, when fisheries resources are least abundant; and Zone 2 from 1 March to 15 October, when harvest activities are at a peak (Fig. 23.6). The Zone 2

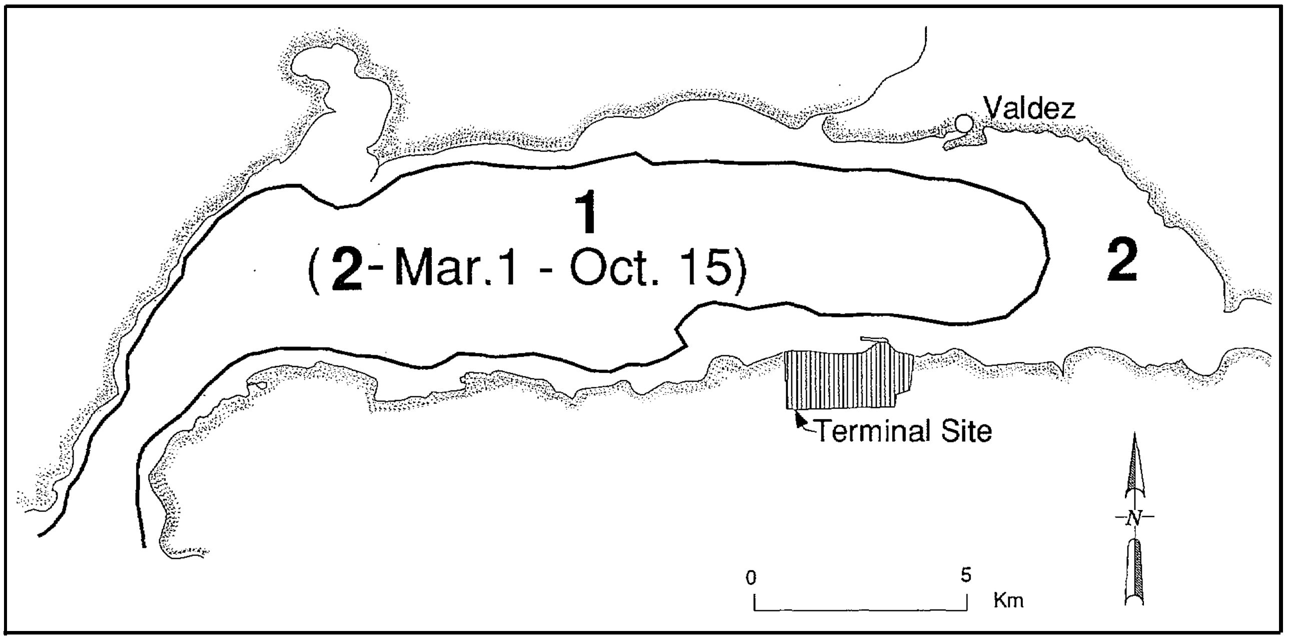

Figure 23.6 —Port of Valdez and Valdez Arm dispersant use zones.

designation will allow a case-by-case decision on dispersant use, based upon the potential for environmental effects.

Hinchinbrook Entrance, which is included in the tanker traffic lanes, is designated Zone 1, with the exception of an area of 1 nmi radius around Seal Rocks. The area around Seal Rocks is designated as Zone 3 because of the importance of this area to marine mammals and seabirds (Fig. 23.5).

To the east, the area inshore of the 3-mile territorial limit along the coast from Cape Hinchinbrook to Kayak Island is designated as Zone 3. This wide Zone 3 designation provides some protection for the coastal resources and the sensitive marsh and tidal flat habitats of the Copper River Delta area (Fig. 23.7). An approximately 5-nmi-wide buffer area extending seaward of this Zone 3 is designated Zone 1. This width should provide adequate time to apply a dispersant before oil enters the sensitive Zone 3 area. The waters seaward of Zone 1 are designated as Zone 2.

To the west of Hinchinbrook Entrance, the waters out to approximately 1 nmi off the outside coasts of Montague and Elrington islands and extending to Cape Junken are designated Zone 3. In this area, water depth increases rapidly with distance offshore, and a distance of 1 nmi should provide enough depth for adequate mixing and dilution of dispersed oil. Again, an approximately 5-nmi-wide buffer area extends seaward of Zone 3, and the waters seaward of Zone 1 are designated as Zone 2.

The southern end of Montague Strait is given a seasonal designation: it is Zone 1 from 1 October to 31 March and Zone 2 from 1 April to 30 September. This dual designation is due to the presence of fishery resources and commercial harvest activity as well as the potential use of the area by oil tankers.

23.5 DISPERSANT-USE CHECKLIST

In addition to following the above guidelines for Cook Inlet and Prince William Sound, the RRT Working Group developed a checklist of items that must be considered regarding the application of dispersants to an oil spill. This checklist consists of such information as basic spill data (including time, location, volume, and product release), spilled oil characteristics, weather and wind conditions at the time of the spill and forecast, predicted oil behavior, proposed dispersant-use plan, and resources at risk. If dispersants are used, the On-Scene Coordinator will send this completed checklist to the RRT chairman and the EPA and state representatives. The checklist has been put into a computer format that allows it to be transferred electronically among government agencies, resource agencies, and industry groups.

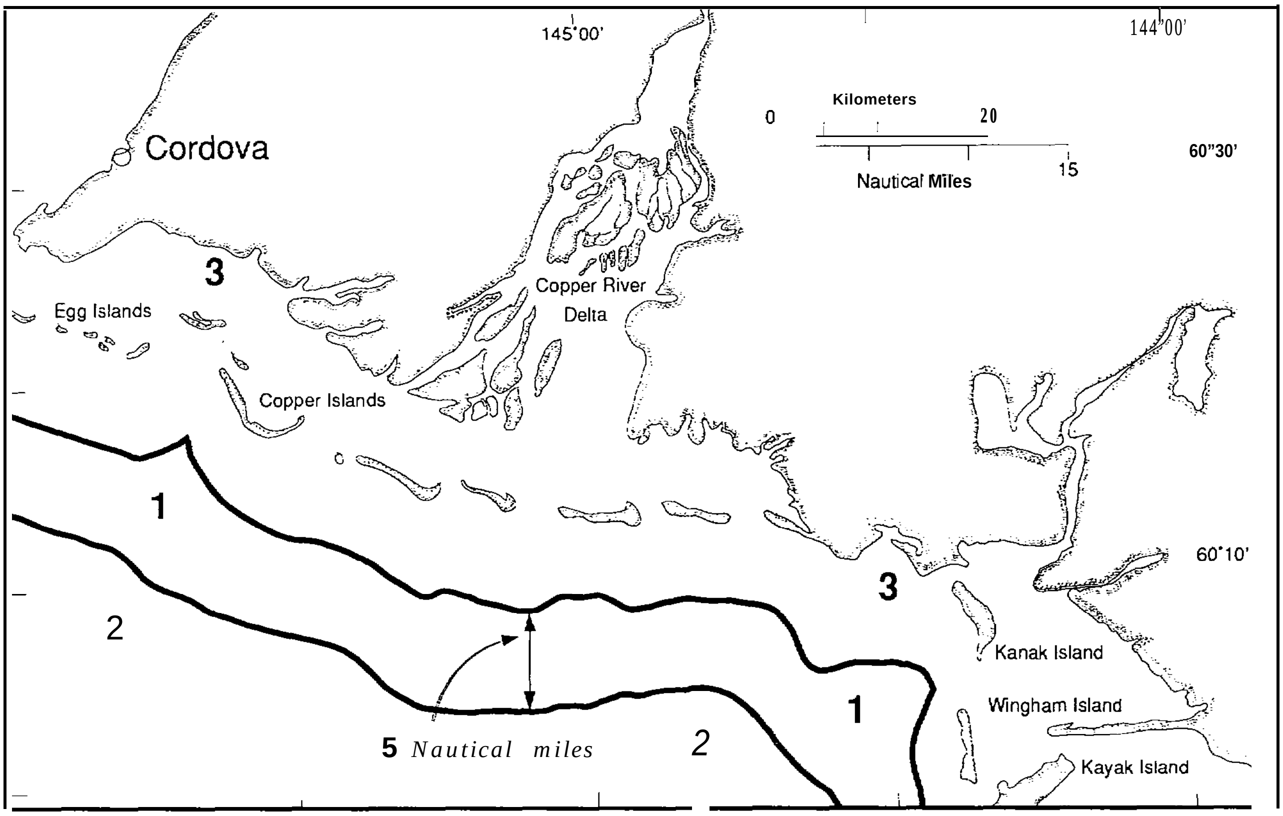

Figure 23.7—Copper River Delta dispersant use zones.

23.6 TIMELINESS OF DISPERSANT-USE DECISION

Development of dispersant guidelines and specific zonations for Cook Inlet and Prince William Sound has increased the speed that a dispersant-use request can be evaluated by the government regulatory agencies. As mentioned earlier, for dispersants to be most effective they must be applied within 12 hours of the oil spill. Due to the familiarity of the RRT Working Group with Cook Inlet and Prince William Sound, it is felt that a dispersant-use decision can be reached within one to two hours for these areas. In other locations in Alaska, which are de facto Zone 2 areas, a dispersant-use decision could take considerably longer.

23.7 ACKNOWLEDGMENTS

Others who have helped bring the Alaska Dispersant-Use Guidelines to where they are today include B. Hahn, L. Fox, Jr., D. Kennedy, C. Getter, L. Tomich, M. Conway, and L. Harris.

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Appendix I

Background Information

Although this information was not presented at the Gulf of Alaska/Cook Inlet/North Aleutian Basin Information Update Meeting, it is included here for those readers who are unfamiliar with the Alaskan OCS leasing program. Herein we attempt to lend some perspective to the meeting within the broader context of the leasing program in the three planning areas considered at the meeting. We also indicate means to access the rather voluminous information base on oil and gas-related issues, and the natural and human environments of the areas.

The Area of Interest

The combined geographic area of the studies discussed at the Information Update Meeting is enormous (see Fig. 1.1). It encompasses five MMS planning areas: the North Aleutian Basin on the Bering Sea side of the Alaska Peninsula, and four contiguous planning areas in the Gulf of Alaska proper—Shumagin, Kodiak, Cook Inlet, and Gulf of Alaska. The southeastmost portion of the region abuts the Canadian border at Dixon Entrance. The federally owned seabed considered for leasing begins three nautical miles offshore, while the more inshore seabed is under jurisdiction of the state of Alaska. The North Aleutian Basin and Cook Inlet areas overlie the continental shelf. In contrast. the remaining planning areas have relatively small proportions of continental shelf and consist largely of oceanic slope, basin, and trough provinces with water depths exceeding 2,000 meters. Oil and gas leasing and exploration activity in the region has thus far been confined to the continental shelf.

Petroleum Leasing and Development Activity

Oil exploration and production in Alaska began onshore around 1900 near Katalla, about 100 km east of Cordova and near the Gulf of Alaska coast. 'l'his small field produced for about 30 years. Exploration elsewhere was unsuccessful until the upper Cook Inlet fields were discovered in the 1950s. Several oil and gas fields have been developed there, including some in the state-owned waters of the inlet proper. About one billion barrels of petroleum have been extracted from the fields, as well as large quantities of natural gas.

The petroleum discoveries in the Cook Inlet area raised considerable industry interest in the adjacent continental shelf, which overlies the Gulf of Alaska Tertiary Province. This area was offered in the first Alaskan OCS oil and gas lease sale on 13 April 1976. Table 1.1 lists sales to date in the Gulf of Alaska and North Aleutian Basin—seven in all. A total of 212 blocks have been leased and 25 exploratory wells drilled. (In addition, nine continental offshore stratigraphic test wells have been drilled.) Thus far, commercial quantities of petroleum have not been found. Note that no exploratory drilling has occurred in the North Aleutian Basin. Due to protracted litigation over Sale 92, the bids received were only allowed to be opened on 11 October 1988. Successful bidders are now preparing drilling plans. More detailed summaries of oil and gas-related activities in the region are presented in Slitor and Wiese (1987) and U.S. Department of the Interior (1988).

The April 1988 Department of Interior 5-Year OCS Oil and Gas Leasing Program schedule lists three forthcoming lease sales in the GOA/NAB region: Sale 114 (Gulf of Alaska/Cook Inlet) in September 1990; Sale 117 (North Aleutian Basin) in October 1990; and Sale 129 (Shumagin) in January 1992. The draft environmental impact statements (DEISs) for each of these sales are scheduled for release in September and October 1989 and January 1991, respectively. The GOA/CI/NAB Information Update Meeting was scheduled to be timely with respect to provision of recent study results useful for preparation of the former two DEISs.

Environmental impact statements (EISs) are prepared in accordance with the National Environmental Policy Act of 1969 (NEPA), which requires that assessments of the environmental consequences of major federal actions affecting the environment be evaluated prior to undertaking such an action, including consideration of mitigating measures, alternatives to the action, irreversible and irretrievable

Table 1.1—Past leasing activit y in the region.

Planning area	Sale No.	DEIS date	Sale date	Blocks leased	Exploration wells
Gulf of Alaska	39	26 Jun 75	13 Apr 76	76	11
	55	31 Aug 79	21 Ott 80	35	1
	RS-1	—	30 Jun 81	1	0
Cook Inlet	CI	13 Jul 76	27 Ott 77	87	10
	60	20 Aug 80	29 Sep 81	13	3
	RS-2	—	5 Aug 82	0	0
Kodiak	46	12 Apr 77	Cancelled	—	—
North Aleutian Shelf	92	17 Jan 85	13 Jan 86*	23	—
Shumagin	—	—	—	—	—

* Sale enjoined. Bids opened on 11 October 1988

commitment of resources, and relationships between short-term uses and long-term productivity of the environment. A variety of other legal mandates and federal regulatory responsibilities for OCS oil and gas leasing also apply, e.g., the Endangered Species Act; see Rathbun (1986) for details.

EISS contain projections of development activities in lease areas that are based upon assumptions about available petroleum resources and technology. These form the basis for assessments of the potential consequences of such development. The assessments focus on pertinent environmental and socioeconomic issues identified and evaluated through a variety of mechanisms, including ' 'scoping" meetings; requests for resource reports and comments from the public, state and federal agencies and other organizations; directed environmental and socioeconomic studies; and meetings such as the recent one.

Relevant Information Sources

EISS are compendia of information pertinent to the proposed actions, including information about estimated petroleum resources and geology, extractive and transportation technology, regional socioeconomic and environmental issues, and the assessments of potential effects of development activities on the human and natural environment. Six EISS have been prepared for past scheduled sales in the GOA/CI/NAB area (BLM 1975, 1976, 1977, 1980, 1981; MMS 1985a). As noted above, three new EISS are scheduled for release during the next two years.

In addition to the EISs, MMS and NOAA/OCSEAP prepare a variety of supporting program documentation and archive and publish investigators' reports.

Six synthesis reports were prepared prior to ' 'frontier" area lease sales in the Northeast Gulf of Alaska, Kodiak, North Aleutian Shelf, and Lower Cook Inlet. These documents are based in part on the results of "synthesis" meetings during which workshops to address selected topics were conducted. However, they also contain additional information on the biophysical environment. Relevant documents are Macdonald and Strauch (1979 a, b), Strauch and Peterson (1980a,b), Hameedi (1982), and Thorsteinson (1984). A synthesis document has not been prepared for the Shumagin frontier area sale due to the area's relatively recent inclusion in the leasing schedule and the apparent low industry interest in the area. Similarly, no such document exists for southeast Alaska OCS waters, which are currently included in the Gulf of Alaska planning area. It should be noted that numerous changes in lease and planning area boundaries have occurred during the course of the leasing program.

Several thousand research documents have been produced under sponsorship of the OCS oil and gas program in Alaska. The *OCSEAP Comprehensive Bibliography* (U.S. Dep. Commer. and U.S. Dep. Inter. 1988) contains listings of over 3,400 reports, publications, and other documents produced by program investigators, many of which are relevant to the GOA/NAB region. The bibliographic data are sorted by author(s) and citation number and are cross-indexed by lease areas and disciplines to citation numbers. The bibliography is available from the NOAA/OAD Alaska Office. Individual documents are available from the National Technical Information Service (NTIS) or by request from the NOAA/OAD Alaska Office. A bibliography of

MMS contractor reports is available from the Alaska OC S Region office.

Compilations of individual reports are also available. The *OCSEAP Final Reports* series contains compilations, usually organized by discipline (e. g., physical oceanography, marine mammals), of the final reports of investigators. Sixty-three volumes of final reports have been produced thus far; they are available from the NOAA/OAD Alaska Office and NTIS.

Finally, a variety of special reports are available—workshop proceedings, technical reports, proceedings of information transfer and update meetings, and books. Two of the last-named are noteworthy in terms of their breadth of topical coverage of the areas considered at the recent meeting: a two-volume monograph on the eastern Bering Sea (Hood and Calder 1981) and a volume on the Gulf of Alaska (Hood and Zimmerman 1986) encapsulate many of the research results for those regions. Copies of the former book are available from NTIS. The latter book should be available from the Government Printing Office (hardbound) or NTIS (fiche, paper).

The MMS has prepared a number of technical reports on selected subjects that pertain to the GOA/CI/NAB region. A report on the status of North Aleutian Basin fisheries information (MMS 1985b) is especially informative.

For information on the availability of MMS Alaska Region Environmental and Socioeconomic Studies Program reports and other documents, contact:

Chief, Technical Publications Unit
Office of Offshore Information
and Publications
Minerals Management Service
1951 Kidwell Drive, Ste. 601, MS-642
Vienna, VA 22180
(703) 285-2604

For information on the availability of OCSEAP documents, contact:

NOAA/National Ocean Service
OAD Alaska Office
222 W. 8th Avenue, #56
Anchorage, AK 99513-7543
(206) 271-3033

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Appendix II

Speakers

Malin M. Babcock
NOAA/National Marine Fisheries Service
Auke Bay Laboratory
P.O. Box 210155
Auke Bay, .4K 99821
(907) 789-6018

John J. Brueggeman
Envirosphere Company
Plaza Center Building
10900 N.E. Eighth Street
Bellevue, WA 98004
(206) 451-4625

Patrick L. Burden
Northern Economics
P.O. Box 110921
Anchorage, AK 99516
(907) 345-5600

Donald G. Calkins
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99502
(907) 344-0541

James A. Fall
Alaska Department of Fish and Game
Subsistence Division
333 Raspberry Road
Anchorage. AK 99518-1599
(907) 267-2359

M. Jawed Hameedi
NOAA/OAD Alaska Office
Federal Bldg., U.S. Courthouse. Room A13
222 W. Eighth Avenue, #56
.4nchorage, AK 99513-7543
(907) 271-3033

Jonathan P. Houghton
Pacific Environmental Technologies, Inc.
170 W. Dayton Street, Suite 201
Edmonds, WA 98020
(907) 775-4682

Jerry Imm
Minerals Management Service
Alaska OCS Region
949 E. 36th Avenue
Anchorage. AK 99508-4302
(907) 261-4620

Joseph G. Jorgensen
Human Relations Area Files
1517 Highland Drive
Newport Beach, CA 92660
(714) 856-8089

Fred King
Minerals Management Service
Alaska OCS Region
949 E. 36th Avenue
Anchorage, AK 99508-4202

Thomas R. Loughlin
NOAA/National Marine Fisheries Service
National Marine Mammal Laboratory
7600 Sand Point Way, N.E.
Seattle, WA 98115-0070
(206) 526-4040

Douglas J. Martin
Pacific Environmental Technologies, Inc.
170 W. Dayton Street, Suite 201
Edmonds, WA 98020
(206) 775-4682

Michael D. McGurk
Triton Environmental Consultants Limited
205-2250 Boundary Road
Burnaby, B.C., Canada V5M 3Z3
(604) 291-0292

Charles Monnett
University of Minnesota
c/. Alaska Sea Grant
Marine Advisory Service
P.O. Box 1846
Cordova, AK 99574
(907) 424-3446

Robert S. Otto
NOAA/National Marine Fisheries Service
Kodiak Laboratory
P.O. Box 1638
Kodiak, AK 99615
(907) 487-5807

Walter H. Pearson
Battelle Marine Sciences Laboratory
439 Sequim Bay Road
Sequim, WA 98382
(206) 683-4151

Mark Reed
Applied Science Associates
70 Dean Knauss Drive
Narragansett, RI 02882-1143
(401) 789-6224

Stanley D. Rice
NOAA/National Marine Fisheries Service
Auke Bay Laboratory
P.O. Box 210155
Auke Bay, AK 99821
(907) 789-6020

James D. Schumacher
NOAA/Environmental Research Laboratories
Pacific Marine Environmental Laboratory
7600 Sand Point Way, N.E.
Seattle, WA 98115
(206) 526-6197

Arni Thomson
Alaska Crab Coalition
3901 Larry Way, N. E., Suite 6
Seattle, WA 98107
(206) 547-7560

Declan M. Troy
LGL Alaska Research Associates, Inc.
505 West Northern Lights Blvd.
Anchorage, Alaska 99503
(907) 276-3339

Joe C. Truett
LGL Alaska Research Associates, Inc.
505 West Northern Lights Blvd.
Anchorage, Alaska 99503
(907) 276-3339

David Ward
U.S. Fish and Wildlife Service
1011 East Tudor Road
Anchorage, AK 99503
(907) 786-3525

John W. Whitney
NOAA/OAD Alaska Office
Federal Bldg., U.S. Courthouse, Room A13
222 W. Eighth Avenue, #56
Anchorage, AK 99503-7543
(907) 271-3593

Richard Wilmot
U.S. Fish and Wildlife Service
Division of Fisheries
1011 East Tudor Road
Anchorage, AK 99503
(907) 786-3316

Appendix III

Attendees

Perry Adkinson
Regional Technical Working Group
Box 42
Dillingham, AK 99576
(907) 842-5535

Randy Bailey
U.S. Fish & Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3466

Kevin Banks
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4614

Paul Becker
NOAA/OAD Alaska Office
222 W. Eighth Ave., #56
Anchorage, AK 99513-7543
(907) 271-3032

Dan Benfield
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4672

Bill Benjey
Minerals Management Service
.41aska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4599

Don Callaway
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4615

Thomas Cook
Chevron USA, Inc.
P.O. Box 104839
Anchorage, AK
(907) 563-2561

Cleveland Cowles
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4617

Joanna Endter
Human Relations Area Files
6133 Kensington Dr.
Anchorage, AK 99504
(907) 337-6846

Rebecca Everett
U.S. Fish & Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3318

Dave Friis
NOAA/OAD Alaska Office
222 W. Eighth Ave., #56
Anchorage, .4K 99513-7543
(907) 271-3652

Kathy Frost
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701
(907) 452-1531

Joy Geiselman
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4596

Karen Gibson
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 26i-4613

Paul Gronholdt
Regional Technical Working Group
Box 288
Sand Point, AK
(907) 383-4081

Don Hansen
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4656

Gail Irvine
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4658

Dale Kenney
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4623

Lloyd Lowry
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701
(907) 452-1531

Paul L. Lowry
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4574

Alan Maki
Exxon Company USA
P.O. Box 196601
Anchorage, AK 99519
(907) .564-3783

Vivian Mendenhall
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503
(907) 786-3517

LTCDR Roger Mercer
NOAA Corps
701 C Street, Box 43
Anchorage, AK 99513
(907) 271-5006

Robert Meyer
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4625

Byron Morris
NOAA/National Marine Fisheries Service
222 W. Seventh, Box 43
Anchorage, AK 99513
(907) 271-5006

Ronald Morris
NOAA/National Marine Fisheries Service
222 W. Seventh, Box 43
Anchorage, AK 99513
(907) 271-5006

Jon Nauman
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4181

Tom Newbury
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 264-4604

Mike Philo
North Slope Borough
Department of Wildlife Management
P.O. Box 69
Barrow, AK 99723
(907) 852-2611

Ann L. Rothe
National Wildlife Federation
750 W. Second Ave., #200
Anchorage, AK 99501
(907) 258-4800

Katherine Rowell
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99513
(907) 267-2377

Nancy Swanton
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4432

Jack Thoeni
Chevron USA, Inc.
P.O. Box 107839
Anchorage, AK 99510
(907) 563-2560

Evert Tornfelt
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 265-4683

Stephen D. Treaty
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4603

Bill Van Dyke
Alaska Department of Natural Resources
P.O. Box 7034
Anchorage, AK 99510
(907) 762-2550

Bob Weinhold
Minerals Managrnent Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4665

Gary Wheeler
Minerals Management Service
Alaska OCS Region
949 E. 36th St.
Anchorage, AK 99508
(907) 261-4684

Michael Wiedmer
Alaska Department of Fish and Game
333 Raspberry Road
Anchorage, AK 99517
(907) 267-2337

Leila Wise
Alaska Department of Natural Resources
Division of Oil and Gas
P.O. Box 107034
Anchorage, AK 99510
(907) 762-2595

John C. Zuck
Bering Sea Fisherman Association
725 Christensen Drive
Anchorage, AK 99501
(907) 279-6519

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

Alaska Office
Federal Bldg., U.S. Courthouse, Room A13
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