Environmental Assessment of the Alaskan Continental Shelf

Interim Lower Cook Inlet Synthesis Report

December 1977

Prepared under contract by: Science Applications, Inc.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

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ACKNOWLEDGMENTS

The completion of this report principally reflects the enthusiasm, constructive criticism and continuing support received from all those who attended the Lower Cook Synthesis Meeting in Anchorage, November 16-18, 1976. Financial support for both the Synthesis Meeting and report preparation was provided by the Bureau of Land Management and administered through NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP).

Preliminary and final versions of the report were prepared by the following staff of Science Applications, Inc. (SAI) under contract to NOAA/OCSEAP: Keith B. Macdonald, Ph.D. (editor, geology and benthic communities); M. Jawed Hameedi, Ph.D. (physical oceanography and plankton); Richard R. Tenaza, Ph.D. (birds and mammals); Edward G. Wolf, M.S. (fish, biological effects studies and contaminant baselines); Kathy K. Petersen and Susan A. Miller (Synthesis Meeting logistics and editorial, typing and graphics assistance for the preliminary manuscript); Debra L. Geolfos (typing of the final report); David G. Crouch (assistance in planning the summary graphics); and Connie M. O'Brien (drafts of final figures).

SAI particularly wishes to acknowledge the continuing support and encouragement received from Herb Bruce and Bob Meyer of the Juneau OCSEAP Project Office and Rudolf Engelmann, Carol Hemington, Marian Cord, and Dave Friis of the OCSEAP Program Office, Boulder, Colorado.

Chapter I

INTRODUCTION

OBJECTIVES AND HISTORY OF THE SYNTHESIS REPORT

Objectives of this report are: (1) to provide regional environmental information in a form useful to BLM and others in decision-making processes related to OCS oil and gas development in the Lower Cook Inlet lease area; (2) to increase and update scientific interdisciplinary understanding of the Lower Cook Inlet region; and (3) to identify important gaps in knowledge of the Lower Cook Inlet marine environment that are relevant to OCS development. Data presented herein were compiled mainly by investigators working under contract to the BLM-funded, NOAA Outer Continental Shelf Environmental Assessment Program (OCSEAP). Some of these investigators participated in a three-day workshop held in Anchorage, Alaska, November 16-18, 1977, for the express purpose of presenting and synthesizing Lower Cook Inlet environmental information.

In addition to investigators, workshop participants (Appendix 1) included OCSEAP personnel, staff members of the BLM office in Anchorage, representatives of the State of Alaska, and personnel from Science Applications, Inc. (SAI). SAI is an OCSEAP contractor whose responsibilities to the program include summarizing, integrating, and synthesizing data generated by OCSEAP investigators into reports such as this one.

Workshop format was designed to foster disciplinary and interdisciplinary team approaches to: (1) identification and mapping of key biotic resources, their habitats and their distributions, including seasonal changes therein; and (2) identification and mapping of physical and biological processes influencing distribution of these key biota and predicting their potential susceptibility to impingement by OCS oil and gas development. Participants were requested beforehand to furnish specifically identified background material providing the most up-to-date information available to facilitate meeting these objectives. This information was utilized throughout the meeting and is incorporated into this document.

The first day of the workshop included presentations on *CIRCULATION AND SEASONALITY* as central themes for environmental research in Cook Inlet and potential oil and gas development activities in the area. A development scenario for the lower Cook Inlet lease area was provided by the Alaska OCS office, Bureau of Land Management (Appendix 2). The remainder of the day was spent in discipline-oriented workshops where data were compared and integrated to provide a complete but simplified summary of the present state of knowledge within each discipline (i.e., physical oceanography, biology, and chemistry-sedimentology). Chairmen of the disciplinary groups summarized their groups' accomplishments during a plenary session on the morning of the second day of the workshop. The afternoon of the second day of the meeting was devoted to interdisciplinary working groups, which identified and discussed environmental interrelationships in Lower Cook Inlet, and attempted to produce maps depicting seasonal correlations between data sets of various disciplines as these might relate to oil and gas development. An attempt was made to identify possible "critical areas," and data gaps were listed. The last day of the workshop included summary presentations and group discussions of the results of the interdisciplinary working groups.

SAI staff took detailed notes of the proceedings and compiled all data products generated. These materials were used to prepare a 354 page preliminary summary (January, 1977) of current knowledge concerning Cook Inlet. NOAA/OCSEAP staff edited and shortened SAI's preliminary summary document to produce a *DRAFT SYNTHESIS REPORT* (March, 1977). This, in turn, was reviewed by all those who attended the November Anchorage meetings, as well as by several knowledgeable government agency representatives. NOAA/OCSEAP and SAI staff jointly reviewed all comments pertaining to the Draft Synthesis. Substantial rewriting and preparation of new graphics by SAI staff, together with a final review by Marian Cord, technical editor for NOAA/OCSEAP, produced the present report.

CONTENTS OF THE REPORT

Proceedings of the meeting, material provided by participants, and recommendations for specific research needs are organized in various chapters. Chapters II (Natural Regions of Lower Cook Inlet), III (State of Knowledge), and IV (Research Needs), contain the bulk of information resulting from the meeting. Chapter II provides subregional descriptions of Cook Inlet; its text is intended for administrative and scientific government personnel, a broad spectrum of the scientific community, and the interested public. The statements are technically correct, but do not include detailed and elaborate scientific knowledge of the identified areas. The contents also reflect the rather limited available scientific data specific to these areas. For more detailed accounts, various sections of Chapter III are referenced. The main body of scientific knowledge is summarized in Chapter III, and emphasis has been placed on summarizing new data presented and pertinent discussions held during the synthesis meeting.

Some material from earlier publications and other reports, such as OCSEAP Principal Investigators' Quarterly and Annual Reports, has been used in abridged and summarized form where required for continuity and thoroughness. Chapter IV identifies gaps in knowledge and provides a summary of research needs which can be used as input for program direction and emphasis for future research.

GRAPHICS

The initial report contained 157 graphics summarizing distributional data generated during the preliminary synthesis! Many of these had already been published elsewhere, while others have since appeared in NOAA/OCSEAP Research Unit (RU) Quarterly and Annual Reports.

Graphics remain important in this volume also, however, their numbers have been greatly reduced to minimize duplication and those that synthesize diverse data sets predominate. As far as possible, uniform formats emphasizing the location of proposed lease blocks have been used. Maps and gazetteers that include most of the place names referred to as localities in the report are included at the end of this Introduction.

LIMITATIONS

This report is essentially a progress report -- an integrated compendium of products resulting from the synthesis workshop. Future meetings are planned to review research programs, to fill data gaps and update this report, and to bring us nearer to a true synthesis of environmental knowledge. Limitations of the data in this report should be apparent from the description of its origin given above. It is not intended to provide a complete review of relevant literature. *IT REPRESENTS AN INTERIM SUMMARY*

OF KNOWLEDGE AND MUST NOT BE VIEWED AS THE DEFINITIVE WORK ON THE LOWER COOK INLET AREA. Not all disciplines were represented among the meeting participants. In particular -- sea ice, geologic hazards, microbiology, and biological effects studies were not covered.

PREVIOUS PUBLICATIONS

Background information on several aspects of Cook Inlet and environs is available in the publications listed below. No attempt has been made to abstract or summarize these data in the present report.

The Cook Inlet Environment, A Background Study of Available Knowledge. C.D. Evans *et al.*, U.S. Army Corps of Engineers, Alaska District, Anchorage, Contract No. DACW85-72-C-0052 (August 1972).

Alaska Regional Profiles: South Central Region. L.L. Selkregg, Arctic Environmental Information and Data Center, University of Alaska, Anchorage, 255 pp. (July 1974).

Lower Cook Inlet, Final Environmental Impact Statement Proposed 1976 OCS Oil and Gas Lease Sale No. CI. U.S. Department of Interior, Bureau of Land Management. 3 Volumes (November 1976).

Additional, more specialized data, are included in the following reports:

Environmental Standards for Northern Regions, A Symposium. University of Alaska (June 13-14, 1974), Anchorage, Alaska. D.W. Smith and T. Tilsworth (eds.), Institute of Water Resources, No. 62, 389 pp. (March 1975).

Baseline Data on the Oceanography of Cook Inlet, Alaska. L.W. Gatto, Cold Regions Research and Engineering Laboratory, Report 76-25, 84 pp. (July 1976).

Circulation Studies in Kachemak Bay and Lower Cook Inlet. D.C. Burbank, Alaska Department of Fish & Game, Marine/Coastal Habitat Management, Anchorage, 207 pp. (March 1977).

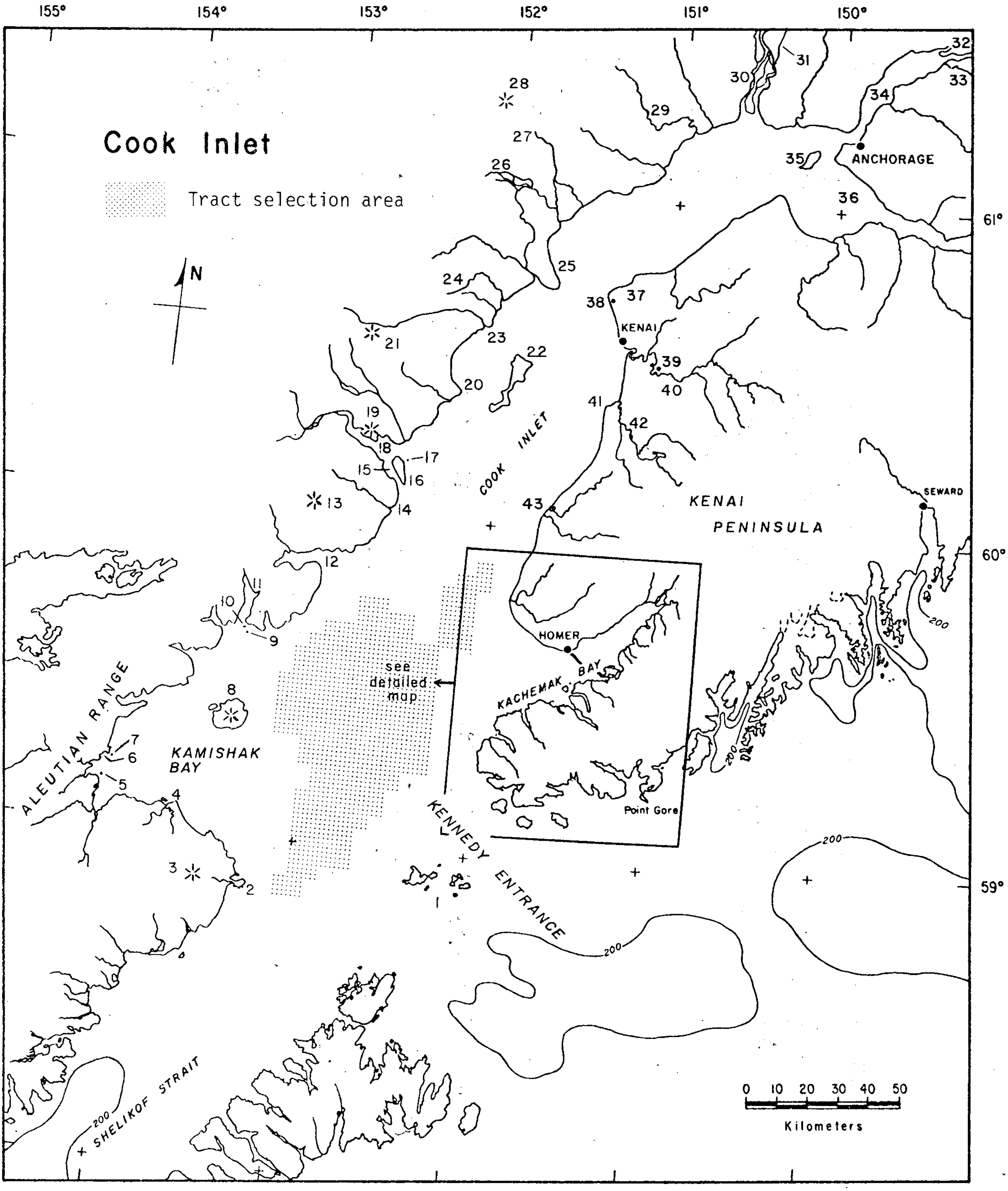
Suspended Sediment Transport and Deposition in Alaskan Coastal Waters. D.C. Burbank, MS Thesis, University of Alaska, Fairbanks, 222 pp. (December 1974).

Marine Plant Community Studies, Kachemak Bay, Alaska. Dames & Moore, Final Report Job No. 6791-003-20. For Alaska Department of Fish & Game, Anchorage, 288 pp. (November 1976).

A Fish and Wildlife Resource Inventory of the Cook Inlet-Kodiak Areas. Alaska Department of Fish & Game, under contract to Alaska Coastal Management Program, Division of Policy Development and Planning. 2 Volumes (1976).

Figure 1-1 Cook Inlet locality map and gazetteer. Alphabetical place name listing in lefthand column, listed by number in righthand column. See Figure 1-2 for Kachemak Bay place names (44 through 71)

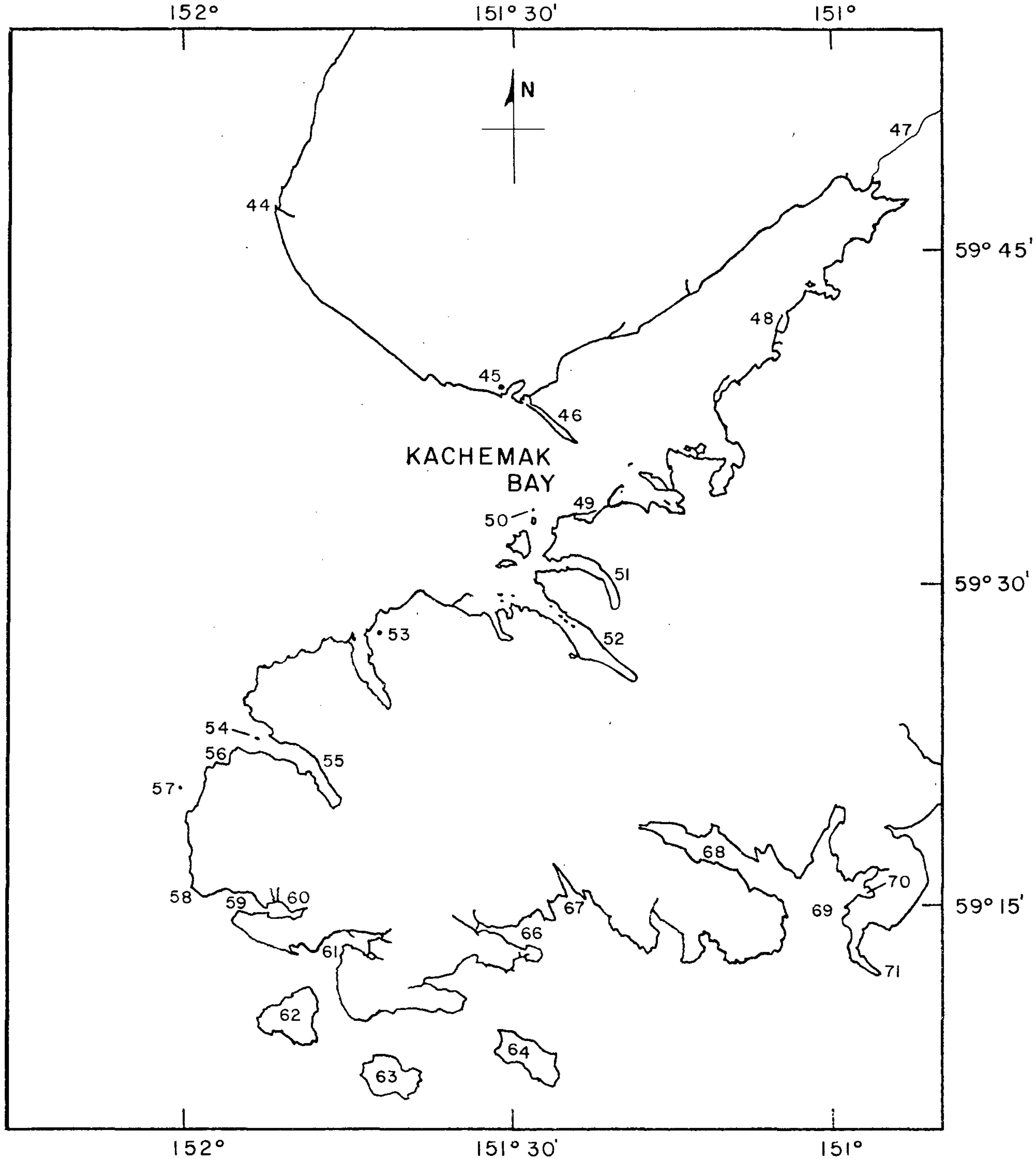
6.	Amakdedulia Cove	1.	Barren Islands
8.	Augustine Island	2.	Cape Douglas
1.	Barren Islands	3.	Mt. Douglas
29.	Beluga River	4.	Douglas River Flats
24.	Big River	5.	McNeil Islet
2.	Cape Douglas	6.	Amakdedulia Cove
41.	Cape Kasilof	7.	Nordyke Island
27.	Chakachatna River	8.	Augustine Island
12.	Chinitna Bay	9.	Pomeroy Island
16.	Chisik Island	10.	Iniskin Island
4.	Douglas River Flats	11.	Iniskin Bay
17.	Duck Island	12.	Chinitna Bay
37.	East Forelands	13.	Iliamna Volcano
35.	Fire Island	14.	Iliamna Point
31.	Fish Creek	15.	Tuxedni Channel
20.	Harriet Point	16.	Chisik Island
11.	Iniskin Bay	17.	Duck Island
10.	Iniskin Island	18.	Tuxedni Bay
14.	Iliamna Point	19.	Rusty Mt.
13.	Iliamna Volcano	20.	Harriet Point
22.	Kalgin Island	21.	Redoubt Volcano
42.	Kasilof River	22.	Kalgin Island
40.	Kenai River	23.	Redoubt Bay
34.	Knik Arm	24.	Big River
33.	Knik River	25.	West Forelands
32.	Matanuska River	26.	McArthur River
26.	McArthur River	27.	Chakachatna River
5.	McNeil Islet	28.	Mt. Spurr
3.	Mt. Douglas	29.	Beluga River
28.	Mt. Spurr	30.	Susitna River
38.	Nikishka	31.	Fish Creek
43.	Ninilchik	32.	Matanuska River
7.	Nordyke Island	33.	Knik River
9.	Pomeroy Island	34.	Knik Arm
23.	Redoubt Bay	35.	Fire Island
21.	Redoubt Volcano	36.	Turnagain Arm
19.	Rusty Mt.	37.	East Forelands
39.	Soldotna	38.	Nikishka
30.	Susitna River	39.	Soldotna
36.	Turnagain Arm	40.	Kenai River
18.	Tuxedni Bay	41.	Cape Kasilof
15.	Tuxedni Channel	42.	Kasilof River
25.	West Forelands	43.	Ninilchik



Cook Inlet
Tract selection area
N
see detailed map
COOK INLET
KENAI PENINSULA
KENAI
ANCHORAGE
SEWARD
HOMER
KACHEMAK BAY
Point Gore
KAMISHAK BAY
ALEUTIAN RANGE
KENNEDY ENTRANCE
SHELIKOF STRAIT
200
0 10 20 30 40 50
Kilometers
155° 154° 153° 152° 151° 150°
61° 60° 59° 58°
154° 153 152° 151° 150° 149°

Figure 1-2 Kachemak Bay locality map and gazetteer

44. Anchor Point
49. China Poot Bay
65. Chugach Bay
64. East Chugach Island
62. Elizabeth Island
56. English Bay
57. Flat Island
47. Fox River
48. Glacier Spit
45. Homer
46. Homer Spit
59. Koyuktolic Bay
60. Koyuktolic Lagoon
54. Passage Island
63. Perl Island
58. Point Adam
71. Point Gore
61. Port Chatham
69. Port Dick
55. Port Graham
67. Rocky Bay
51. Sadie Cove
53. Seldovia
70. Tacoma Cove
52. Tutka Bay
68. West Arm
66. Windy Bay



Chapter 2

NATURAL REGIONS OF COOK INLET

Cook Inlet, located in south-central Alaska, is a large tidal estuary of the Gulf of Alaska. The Inlet trends northeast-southwest, is approximately 370 km in length and is 139 km wide at the mouth. Knik and Turnagain Arms, northern branches of the Inlet, are 83 and 80 km long, respectively. The Aleutian and Alaska Ranges border Cook Inlet to the northwest, the Talkeetna and Chugach Mountains to the northeast, and the Kenai Mountains to the southeast. Glaciers are common throughout these mountains. The principal rivers (Susitna, Matanuska, and Knik) entering the upper Inlet all carry heavy glacial sediment loads and have formed active deltas. Water depths are relatively shallow (generally < 37 m) in the upper Inlet. South of the Forelands, deeper channels flank both sides of Kalgin Island then merge as the Inlet widens and deepens to the south. Arnold Bouma (USGS, Menlo Park, personal communication)* notes that the bathymetry of the lower Inlet shows a steep ramp running from Kennedy Entrance toward Augustine Island, then bending towards Cape Douglas.

During the course of the Anchorage Synthesis Meeting, it became apparent that much of the data being presented supported a division of Cook Inlet into a number of natural regions. While it was difficult to decide exactly where the boundaries between these regions should be drawn, each appeared to be characterized by rather different physical processes, environmental conditions, biological populations, and fisheries resources. The six natural regions identified are shown in Figure 2-1. In this

*Letter to NOAA/OCSEAP, April 21, 1977.

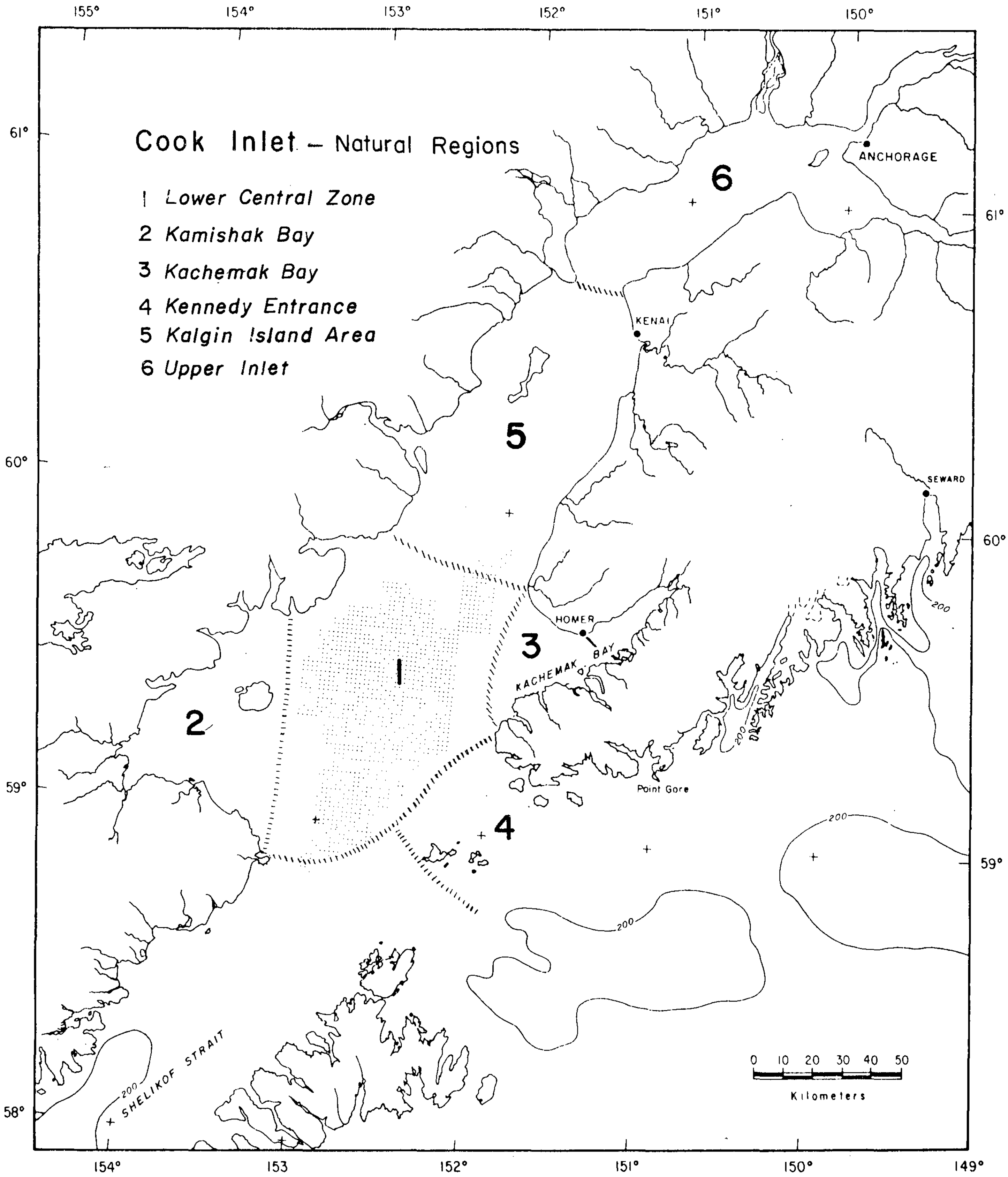


Figure 2-1 Cook Inlet natural regions. See text for additional explanation

chapter the major features of each of the six natural regions are described, and the principal populations likely to be at risk in the event of Lower Cook Inlet petroleum development are identified.

To provide additional perspective for the Synthesis Meeting, BLM-Anchorage provided and discussed a potential lease development scenario for Lower Cook Inlet (Appendix 2). For the reader's convenience a general spatial expression of the *MAXIMUM* development case is reproduced in Figure 2-2. *IT IS IMPORTANT TO STRESS THAT THIS DEVELOPMENT SCENARIO IS NOT A PREDICTION OR FORECAST OF SITE-SPECIFIC IMPACTS. IT IS THE "BEST ESTIMATE" OF HUMAN SPATIAL ACTIVITY THAT WOULD RESULT FROM THE DEFINED MAXIMUM DEVELOPMENT SCENARIO.* For specific detailed information on the scenario, the reader is referred to Appendix 2 and the DEIS and FEIS for the Lower Cook Inlet.

REGION ONE -- LOWER COOK INLET CENTRAL ZONE

This zone is identified as the region lying north of the Barren Islands between Kamishak and Kachemak Bays and south of a line from Anchor Point to Chinitna Bay. Bottom sediments throughout the zone are predominantly poorly sorted sands; shells and shell fragments are common. Bouma *et al.* (1977) have described numerous fields of sand waves, sand ridges and sand ribbons from this region of Cook Inlet; however, at present nothing is known about the possible active migration of these various bedforms.

In general, the central zone is an area of tide-dominated circulation. Regional tidal energy is dissipated by bottom friction; turbulence is considerable and the water column is not highly stratified. Preliminary interpretations of a limited sequence of tidal current measurements, used to

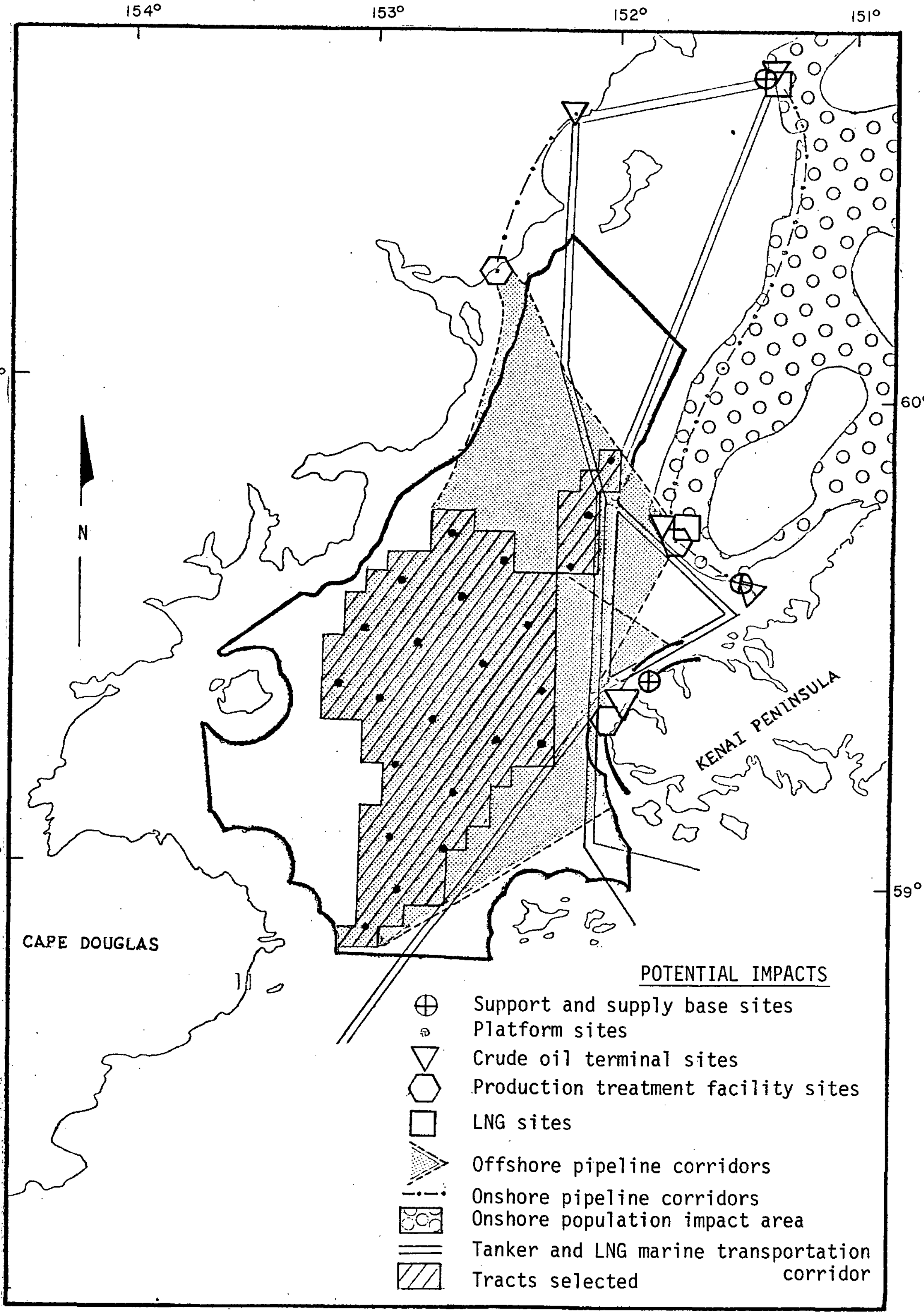


Figure 2-2 Potential locations of impacts resulting from the petroleum development scenario. Figure provided by BLM/Alaska OCS Office, Anchorage; see Appendix 2 for complete explanation

model Inlet circulation, suggest that the middle of Lower Cook Inlet central zone may be an area of sluggish circulation (i.e., Figure 3-5, Station 26).

Water turbidity due to suspended sediment typically increases from < 2 mg/ℓ on the eastern side of the Inlet (reflecting the inflow of clear Gulf of Alaska water) to 10-20 mg/ℓ on the western side. Primary productivity mirrors this pattern; consistently higher values have been obtained in the eastern and central parts of the Inlet than in the western and upper parts. Larrance (1976) found that phytoplankton blooms peak in late May and do not appear to be nitrogen limited. This high primary productivity occurs a few weeks after a productivity peak in Kachemak Bay and coincides with the onset of thermal stratification.

Benthic invertebrates are well represented, mostly by infaunal clams. Prominent non-commercial species include *Glycymeris subobsoleta, Macoma* spp., *Modiolus modiolus, Nuculana fossa, Spisula polynyma,* and *Tellina nuculoides*. Commercial invertebrates are very abundant. In 1974 the Kamishak Fisheries District (which includes much of this zone plus Kamishak Bay) yielded 3.9 million and 2.7 million pounds of tanner* and king crab, respectively -- the maximum catch for any Cook Inlet fisheries district that year. The relatively deep waters of the central zone are an important overwintering area for both tanner and king crab. Preliminary evidence suggests that subpopulations from both Kachemak and Iliamna Bays spend the winter here or migrate through the area to still deeper offshore habitats.

Blackburn (1977), surveying primarily the demersal fish resources of the central Lower Cook Inlet, reported walleye pollock catches of 80 kg/20 min std tow and higher. Pacific cod were also abundant, with trawl catches

*Tanner crab, *Chionoecetes bairdi*, is also widely known as the snow crab.

greater than 20 kg/20 min std tow occurring at several sampling sites. Butter sole were most abundant east of Augustine Island; catches exceeding 20 kg/20 min std tow occurred frequently. It was also reported that Pacific halibut were taken frequently in this area.

Because of its deeper waters, the central zone may be an overwintering area for demersal fish and Pacific herring. This region might also serve as a transition area between Kachemak and Kamishak Bays. Fish populations may move between these Bays through central Lower Cook Inlet for spawning and feeding.

Murres, gulls, shearwaters, fulmars, puffins, and other seabirds occur in this region; as yet no published data are available to indicate their seasonal abundance. It is possible that sea lions and harbor seals might visit this region to feed on the rich bottom fish stocks, but again, no data are available. Dall and harbor porpoises, killer whales, and minke whales occur and perhaps feed here.

As can be seen from Figure 2-2, present BLM plans include central Lower Cook Inlet for potential leasing. Throughout much of the zone, vigorous tidal circulation can be expected to rapidly dilute and flush away possible contaminants. In the mid-region of the Inlet, however, postulated low tidal energy might slow contaminant diffusion and net mean flow may be too small to effectively advect them away from the region. This would increase their potential for entry into local bottom sediments and food chains. In light of the abundant fish and shellfish resources of central Lower Cook Inlet the implications of this situation require careful consideration.

REGION TWO -- KAMISHAK BAY

Kamishak Bay, located on the western side of Cook Inlet, is a relatively shallow, rocky bay opening to the northeast. No data on the bottom sediments of the Bay are presently available.

It is a relatively low energy environment with tides dominating circulation. Measured current velocities are in the order of 20-30 cm/sec (less than 0.5 knot). The southward net transport of water from upper Cook Inlet along the western shore carries heavy loads of suspended matter into Kamishak Bay. During the winter this pattern is accentuated by the local wind regime which also blows down the Inlet from the north/northeast. The southward flow stays primarily east of Augustine Island, bringing suspended matter to the mouth of Kamishak Bay. Other processes -- tidal currents, wind-driven currents, wind acting directly on flotsam, etc. -- carry the material into the Bay proper. In general, temperature-salinity data indicate a weak exchange between Kamishak Bay and the rest of Lower Cook Inlet.

The transport regime is reflected in the movements of drift ice, most of which is formed on tideflats in upper Cook Inlet. Most years, some of this ice drifts down the western side of the Inlet and is carried into Kamishak Bay, where it accumulates (in marked contrast with Kachemak Bay on the eastern side of the Inlet, which is generally relatively ice-free). During cold winters such as in 1976, drifted ice can extend as much as 5 miles offshore and some intertidal flats may be covered with ice until early May (D. Erikson, ADF&G, Anchorage, personal communication). Drift ice usually reaches a maximum in February.

Drifted ice has two important biological consequences in Kamishak Bay. First, extensive ice reduces use of this area by marine birds. For example, preliminary unpublished census data from D. Erikson and P. Arneson (ADF&G, Anchorage) indicate that in the winter of 1975-76 Kachemak Bay contained nearly eight times as many birds (mostly waterfowl) as did Kamishak Bay. Second, the ice thoroughly scours extensive stretches of the intertidal zone. As a result, attached algae and eelgrass are poorly developed and most populations of intertidal benthic invertebrates contain a preponderance of more tolerant animals and juveniles, or very young populations of perennials (D. Lees, Dames and Moore, Anchorage, personal communication).*

Despite increased turbidity as compared with the eastern and central Inlet, primary production in Kamishak Bay remains high. Larrance (RU #425b, 1977) recorded values of 3-4 $gC/m^2/day$ in July 1976. As a consequence of higher turbidity, primary production of both phytoplankton and macrophytes is restricted to a relatively short period: late spring for phytoplankton and only about six months (May-October) for seaweeds (D. Lees, personal communication). Douglas Redburn (ADEC, Juneau, personal communication)** has suggested that phytoplankton productivity may be enhanced by reduced mixing and declining surface salinities in summer, both of which would enhance water column stratification.

The west coast of Cook Inlet supports a less diverse assemblage of subtidal organisms -- both algae and invertebrates -- than does the east coast. Most of the non-commercial benthic invertebrates represented in the central Inlet are present in Kamishak Bay; several species of shrimp

*Letter to NOAA/OCSEAP, May 23, 1977.

**Letter to NOAA/OCSEAP, May 10, 1977.

and hermit crabs are also represented. The largest commercial catches of tanner and king crabs in Cook Inlet are taken from this region; the peak of fishing activity occurs between September and February. The region north of Augustine Island (Iniskin Bay to Chinitna Bay), is a spawning and settling area for both species of crabs in the spring and summer months.

English (RU #424, April 1976) collected ichthyoplankton egg distribution data throughout Cook Inlet during spring and summer 1976 (Fig. 2-3). Fish eggs were abundant in Kamishak Bay samples, particularly in summer. English attributes this to the presence of a discrete spawning center, reflecting local spawning aggregations of fishes and shellfish (i.e., rather than transport and accumulation of fish eggs from other areas).

Stern (1976) estimated that an average of 1.566×10^5 salmon adults, primarily chum and pinks, migrate into Kamishak each summer. Peak populations have been estimated at 4.276×10^5 salmon adults. ADF&G also notes that the Bay is one of the principal intertidal salmon spawning areas in Cook Inlet. Many salmon fry feed in the Bay throughout spring and summer before migrating offshore during the fall. Additional fry pass through the area from the upper Inlet on their seaward migration.

Fisheries research indicates that in September 1976 a major concentration of halibut was present north of Augustine Island (J. Blackburn, RU #512, April 1977).

Herring are also common in Kamishak Bay and spawn in the intertidal zone during summer. Following southeasterly storms, herring spawn can occur as windroves on the Bay beaches. Spawning herring schools are heavily worked by gulls and other birds, and possibly represent an important food source for breeding birds.

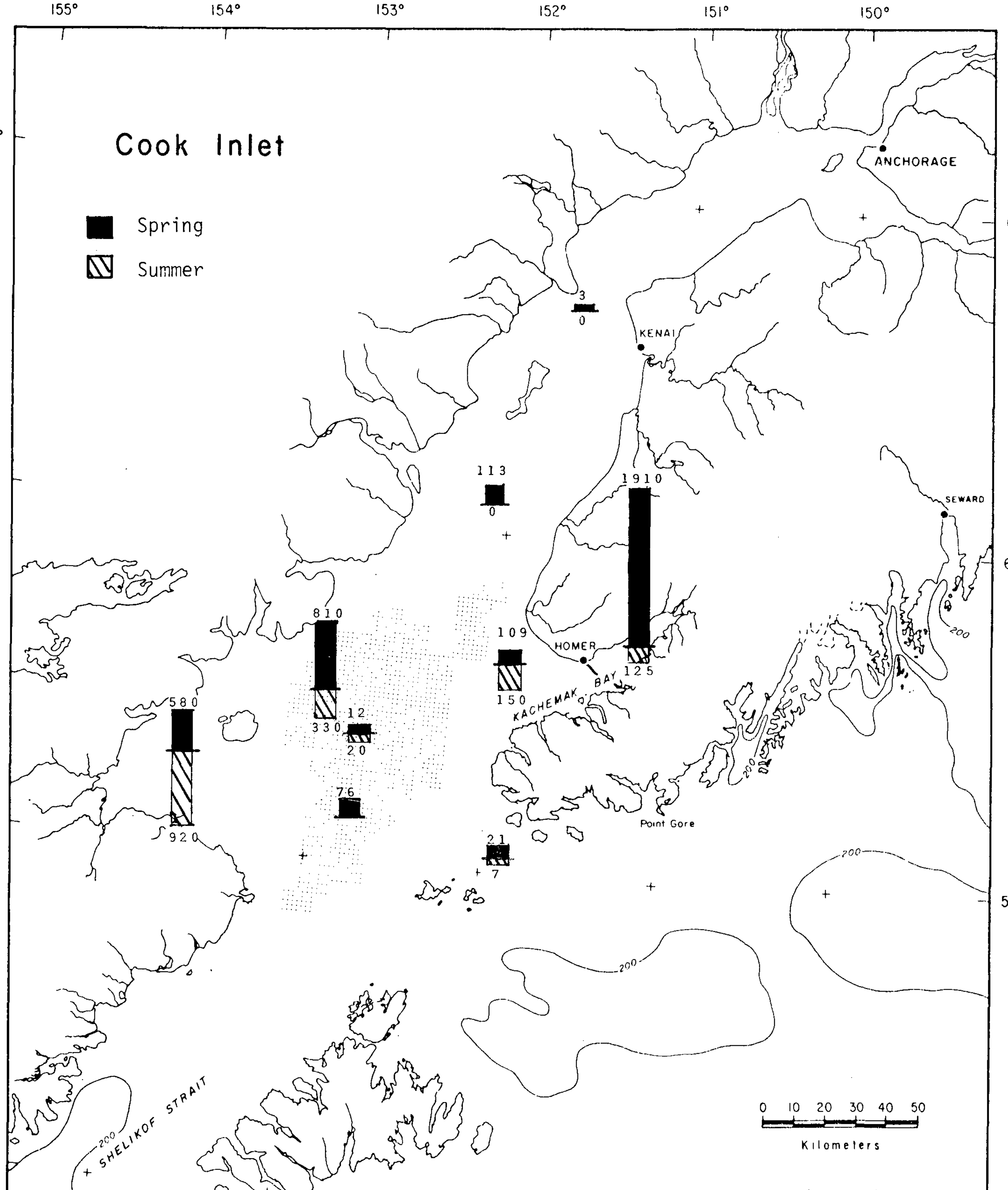


Figure 2-3 Ichthyoplankton distribution in spring (solid) and summer (hachured). Horizontal line indicates sample location; length of bar above/below line proportional to numbers of fish eggs collected per bongo net tow, using standard MARMAP methods. (Adapted from unpublished data provided by T. English, University of Washington, Seattle)

Hatching, out-migration and critical rearing period of fish such as pink salmon, chum salmon, and herring and/or commercially important crustaceans such as tanner and king crabs (all of which are abundant in Kamishak) may be keyed to spring phytoplankton bursts.

Historically, the geographical location and bathymetry of Kamishak Bay have made it less desirable for commercial fishing operations than other areas of Cook Inlet. Price increases for herring roe in Japanese markets and declining catches in Kachemak Bay have recently provided incentive for commercial fisheries to exploit herring in Kamishak Bay (ADF&G, 1976). In 1975, approximately 99% of the total Cook Inlet herring catch came from Kamishak Bay. Some commercial salmon and halibut fishing is also conducted in or near Kamishak.

Preliminary unpublished aerial census data (one survey per season, covering the shoreline and adjacent very nearshore waters) collected by D. Erikson and P. Arneson (ADF&G, Anchorage) during 1976, indicate that in that year, Kamishak Bay hosted significant numbers (> 1200) of waterfowl each season. Oldsquaw accounted for most of the winter census, their largest concentration occurring in Iniskin Bay. Few other birds were present in winter, but gulls, shorebirds and cormorants were all well represented at other seasons. Bird numbers peaked in spring 1976 with the influx of passing migrants (mainly shorebirds) and local breeders. In the summer 1976 census, about 11,000 seabirds were distributed among 34 or more nesting colonies along the coasts of Kamishak Bay. The three most abundant breeding species were glaucous-winged gulls, common murres and tufted puffins. Composition and locations of the five largest nesting colonies in Kamishak Bay are given in Table 2-1.

Table 2-1

The Five Largest Seabird Colonies in Kamishak Bay*

Colony Location	Species	Population Estimates	Colony Totals
Pomeroy Island	Tufted puffin	774	802
	Glaucous-winged gull	18	
	Black oystercatcher	4	
	Pigeon guillemot	6	
Iniskin Island	Tufted puffin	972	3,018
	Horned puffin	6	
	Glaucous-winged gull	1,980	
	Double-crested cormorant	8	
	Pelagic cormorant	52	
Nordyke Islands	Glaucous-winged gull	1,432	1,644
	Tufted puffin	NE	
	Common eider	197	
	Black oystercatcher	7	
	Double-crested cormorant	8	
McNeil Islet	Common murre	2,500	2,500
Amakdedulia Cove	Black-legged kittiwake	750	750

*Based on unpublished preliminary 1976 aerial census data from D. Erikson and P. Arneson, ADF&G, Anchorage

For perspective, outer Kachemak Bay and the Kalgin Island region (including both Chisik and Kalgin Islands) yielded greater numbers of birds than Kamishak Bay, in all four 1976 aerial censuses. While no substantiating data are presently available, it was suggested at the meeting that breeding birds in colonies outside Kamishak might utilize both the spawning adults and juveniles of the Bay's fish and shellfish populations as a food source.

Marine mammals of Kamishak Bay (Fig. 2-4) include resident populations of sea otters and harbor seals. Steller sea lions also occur year-long but in very small numbers; their most important hauling area is Augustine Rocks, which are submerged at high tide. In winter, harbor seals haul out on landfast ice and drift ice, as well as on land at Augustine and other islands as they do the rest of the year. Harbor porpoises are sighted year-round but little else is known of their status. Kamishak Bay appears also to be a very important winter feeding ground for belukha whales (K. Schneider, ADF&G, Anchorage, personal communication, 1976).

REGION THREE -- KACHEMAK BAY

Kachemak Bay is located on the eastern side of Lower Cook Inlet. It is partially divided into inner and outer regions by Homer Spit. The inner Bay is a relatively quiet water environment dominated by fine-grained, organic rich bottom sediments. A broad intertidal mudflat is developed along the north shore of the inner Bay, behind Homer Spit. Sediments in outer Kachemak Bay are more variable. Boulders and cobbles predominate nearshore. A zone of shell debris occurs further out, while the center of the Bay is floored by silts and sands. Grain sizes generally diminish from

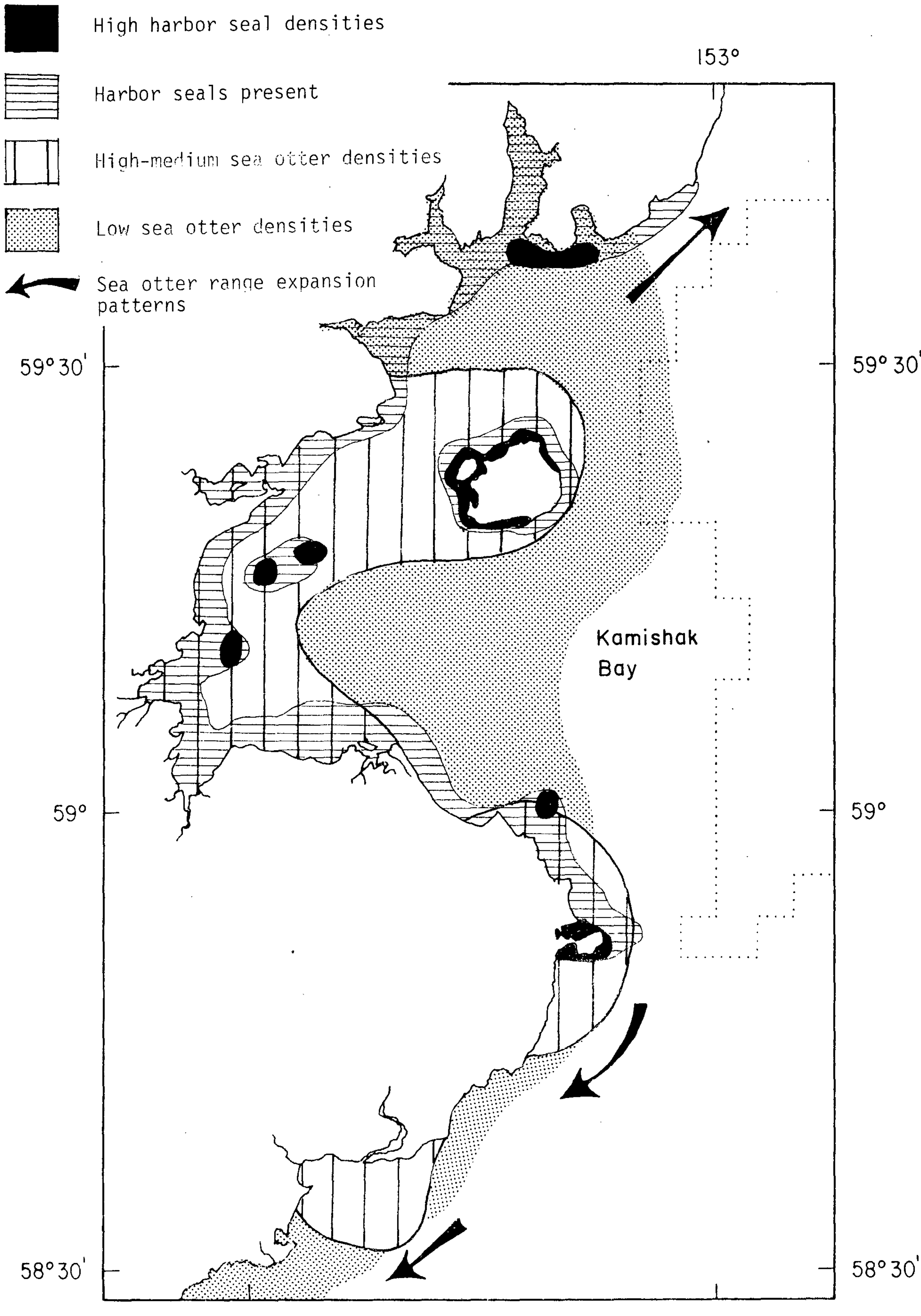


Figure 2-4 Kamishak Bay: graphic summary of selected marine mammal data. (Compiled from data provided by K. Pitcher and K. Schneider, ADF&G, Anchorage.)

central Lower Cook Inlet, eastward into Kachemak Bay (ADF&G, Anchorage, unpublished data).

Kachemak Bay waters show marked seasonal variation in temperature, salinity, and density distribution. In late spring and summer, increased influx of freshwater and warming of surface layers result in the inner part of Kachemak Bay becoming a well-defined, two-layered system. In outer Kachemak Bay, reduced influence of freshwater and large amplitudes of tidal current oscillations result in a more complex two-layered water structure. In fall and winter, when freshwater inflow is very low, surface cooling and winds reduce the stratification. Temperature inversion is known to occur; the slightly less saline upper water becomes colder, the more saline deeper water is warmer. Extensive winter cooling may result in strong convective mixing throughout the water column, especially in the inner Bay.

The velocity field in outer Kachemak Bay, determined by continuous tracking of surface drogues (Wennekens *et al.*, 1975; Burbank, 1977), shows a complex pattern. A clockwise rotating gyre in the outer Bay is considered a consistent feature; a counter-clockwise gyre in the western part is probably transient in nature. There is a distinct possibility that water may recirculate within the western part of Kachemak Bay for a considerable length of time before flowing out.

Drift card release and recovery data (Wennekens *et al.*, 1975; Burbank, 1977) from several points in the Kachemak Bay have shown that some objects adrift in Kachemak Bay drift westward and may end up in parts of Kamishak Bay. A few of the drift cards released from Shell Oil drilling site, in outer Kachemak Bay, were recovered from Augustine Island, Kamishak Bay, and Uganik Island (Shelikof Strait). A few cards released off Cape Kasilof, about 50 miles north of Kachemak Bay, were recovered from Augustine Island, Ursus Cove (Kamishak Bay), and off Uganik Island. Only an occasional card was recovered on the shore northward of release sites in both instances. Even though the trajectories of the drift cards can only be speculated, it is clear that the net surface flow from the eastern part of the Inlet is westward and southwestward. These results can also be interpreted as due to cyclonic circulation in Lower Cook Inlet.

Outer Kachemak Bay is bathed by clear Gulf of Alaska water moving through Kennedy Entrance. This, together with the development of seasonal stratification and influx of runoff from the Fox River wetlands, contributes to an environment that yields extraordinarily high primary productivity values (7.7 $gC/m^2/day$), similar to peak values in the central region of the Inlet. Preliminary data indicate that the burst of high phytoplankton production peaks in May and is relatively short-lived; plankton primary productivity is limited by nitrogen availability in summer. Inner Kachemak Bay is much less influenced by Gulf of Alaska waters than is the outer Bay. A prolonged period of stratification in the inner Bay may explain why combined primary productivity values over the spring and summer are higher here than in outer Kachemak (D. Redburn, ADEC, Juneau, personal communication).

High phytoplankton production is supplemented by the rich macrophyte assemblages and kelp beds that grow along the shores of outer Kachemak Bay and by the productive Fox River wetlands at the head of the inner Bay. The kelp beds and wetlands probably play a very important role in contributing organic detritus to Kachemak Bay food webs. Significant phytoplankton production probably occurs mainly between mid-March and mid-October and is very low during the intervening five "winter" months. Peak macrophyte production occurs during the same late spring to early fall months, but fairly substantial production continues during the winter months. Furthermore, the degradation rate of phytoplankton is probably much faster than in seaweeds, so that the former disappears quickly from the nutrient "bank" soon after phytoplankton production slows down. This leaves macrophytes and terrestrial debris as the major sources of food for many of the animals through the winter, an important period of growth and gonad production for many commercial species (D. Lees, Dames and Moore, Anchorage, personal communication).

Possibly longer residence time of populations due to the gyral circulation, the very high primary production, and a rich source of organic detritus all contribute to an abundant zooplankton community. Meroplankton -- larval states of tanner, king, and dungeness crabs, several species of shrimp (Haynes and Wing, 1977), and ichthyoplankton -- are abundant. Data on planktonic fish eggs (English; RU #424, April 1976) suggest that inner Kachemak Bay is the single most important incubation and spawning area in Cook Inlet during spring. Fewer eggs were collected in plankton tows during the summer (Fig. 2-3). English notes that the abundance of fish eggs in Kachemak probably reflects the presence of local spawning aggregations, and that advection of early life history stages into the area is relatively unimportant.

Intertidal and shallow subtidal benthic invertebrate faunas are now well known through the work of R. Rosenthal and D. Lees (Dames and Moore, Anchorage, 1976). The mudflats that border the northern shore of inner Kachemak support an abundant biota dominated by infaunal polychaetes and clams -- particularly *Macoma* and *Mya*, along with epifaunal mussels (*Mytilus edulis*). These flats are prime feeding grounds for overwintering migrant birds, particularly waterfowl.

The northern shore of the outer Kachemak Bay is a broad rocky shelf covered with cobbles, boulders, and shell debris. The fauna is diverse, dominated by epifaunal suspension feeders. Rosenthal and Lees have prepared species lists and food webs for several shelf locations that provide excellent insights into species interrelationships (e.g., Figure 2-5).

Feder's (RU #281, 1976) offshore benthic samples indicate that hermit crabs and several infaunal clams (*Macoma* spp., *Nuculana* sp., *Spisula polynyma*, and *Tellina* sp.) are well represented. Feder and Lees both stressed the variability of the benthic faunas, which must, at least in part, reflect the diverse sedimentary substrates represented in inner and outer Kachemak Bay.

Kachemak Bay supports the largest population of shrimp in Cook Inlet and is their prime spawning and larval rearing area. A commercial harvest of 4.7 million pounds of shrimp was taken from Kachemak in 1974. King, tanner, and dungeness crabs also spawn and settle in outer Kachemak Bay. Spawning for shrimp and king and tanner crabs peaks in April; for dungeness crab the peak of spawning comes in September (Fig. 2-6). Commercial harvests of king, tanner, and dungeness crabs reached 1.6, 1.1, and 0.7 million pounds, respectively, in 1974. Peak fishing activity lasts through the spring and summer. It is clear that the success and abundance of these commercial invertebrate populations reflects the presence of suitable physical habitat and the high primary production and detritus supplies developed within Kachemak Bay.

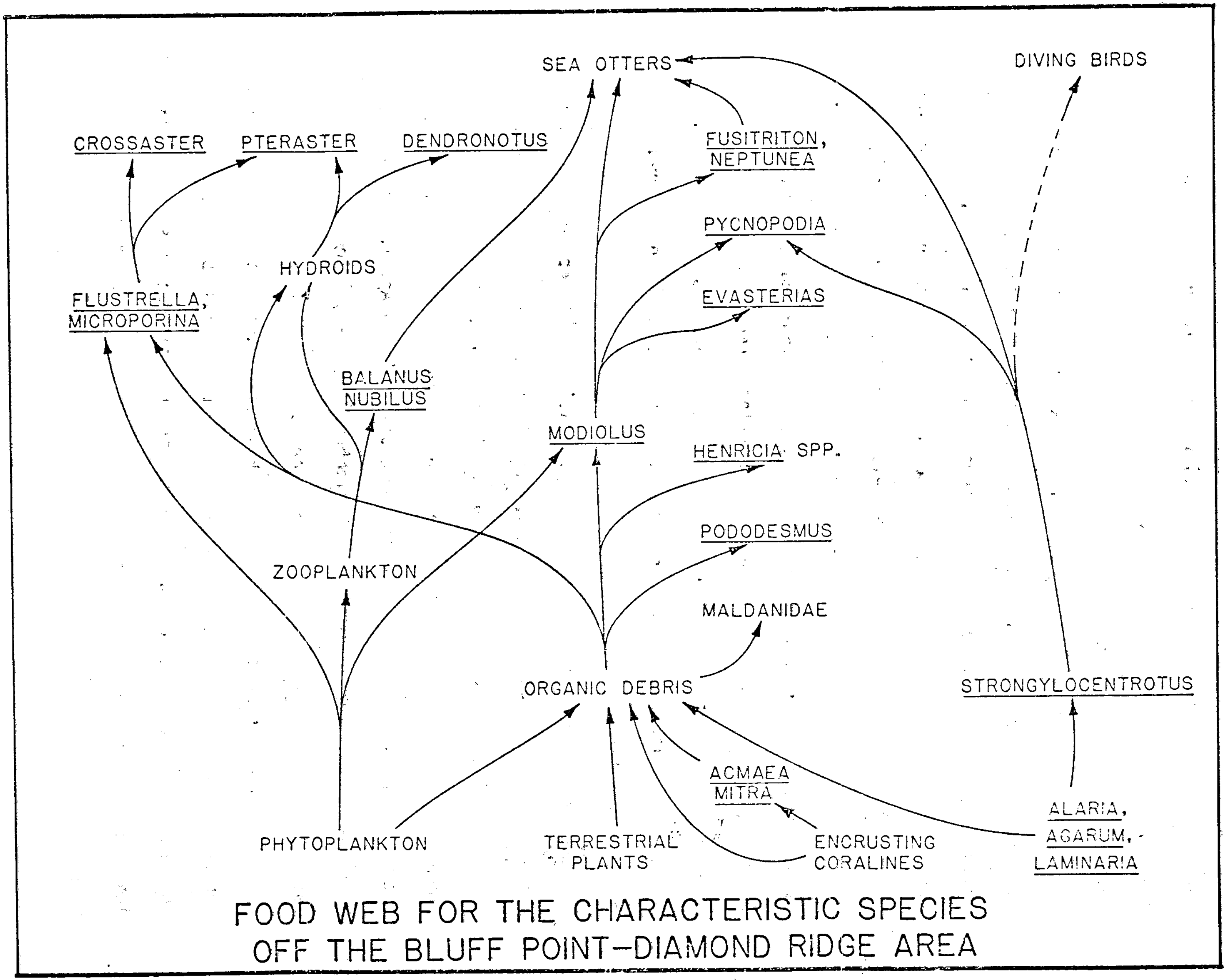


Figure 2-5 Data collected by R. Rosenthal and D. Lees. For additional details see Dames and Moore, ADF&G, Final Report 6791-003-20, November 1976

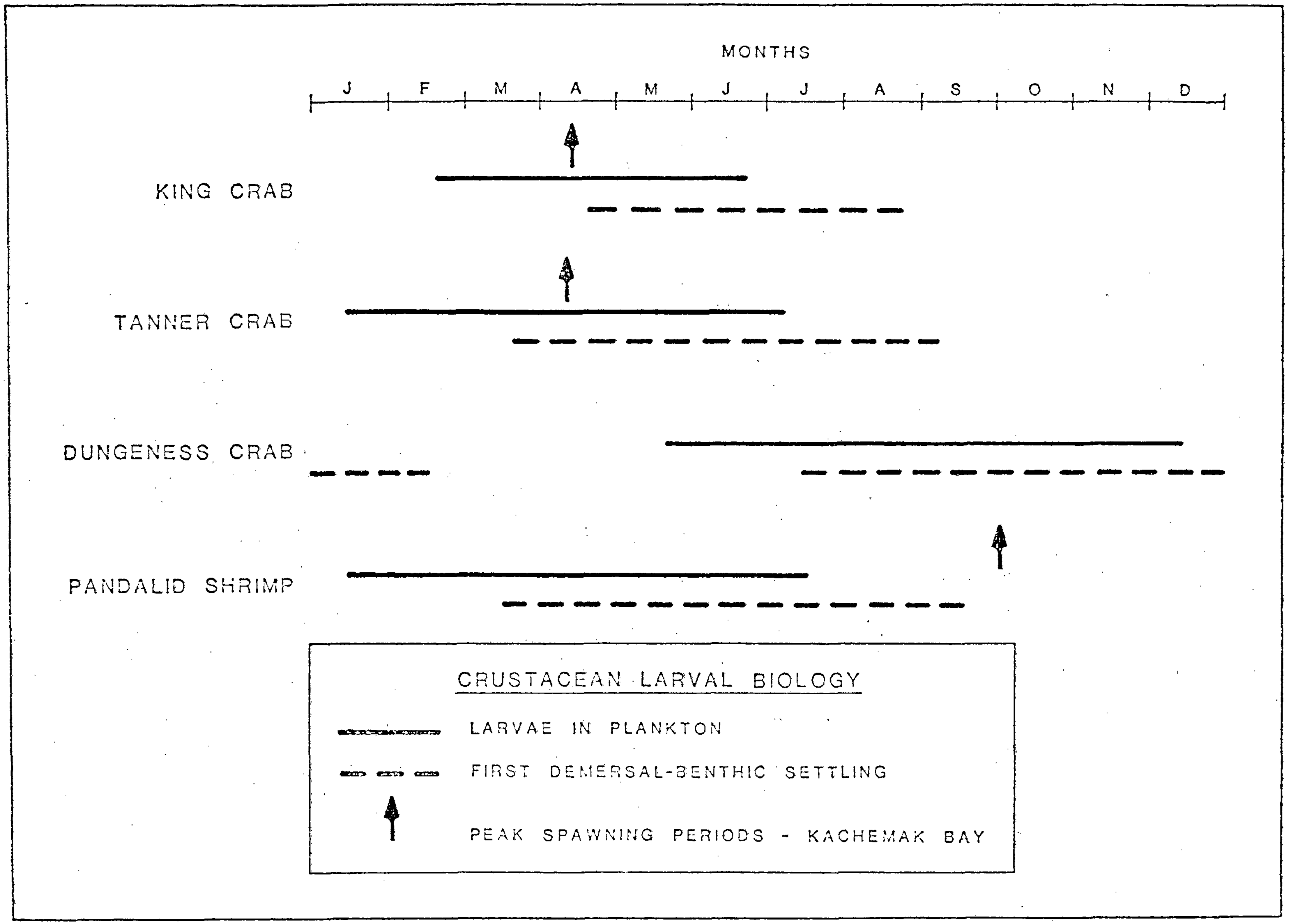


Figure 2-6 Lower Cook Inlet, crustacean larval biology (ADF&G, Vol. 2, 1976)

Knowledge of Kachemak Bay fishery resources is dominated by information collected from commercial fishing. The outer Bay is continuous with the major halibut commercial fishing area on the eastern side of the Lower Cook Inlet. Blackburn (RU #512, April 1977) made catches in excess of 30 halibut/20 min tow in outer Kachemak Bay in early June 1976. This halibut catch rate was only exceeded by values for the Kamishak Bay site, north of Augustine Island, in September 1976.

In 1969 and 1970 the herring catch in Kachemak Bay dominated the Cook Inlet herring fishery. Since then the catch has decreased drastically, reducing the importance of the Bay to the Cook Inlet herring fishery.

Kachemak is also a principal intertidal spawning area for pink and chum salmon. Salmon fry and smolts, hatched within Kachemak Bay and its anadromous streams, feed in the Bay before migrating offshore in the fall. Some commercial salmon catches are made in the Bay. Average annual salmon spawning runs are estimated at 3.147×10^5 adults, the peak spawning population at 8.54×10^5 (Stern, 1976).

Kachemak Bay is the principal salt water sport fishing area in Cook Inlet. Salmon and halibut are the principal target species; flounder, cod, and Dolly Varden are also caught. As the result of increasing restrictions on sport fishing in upper Cook Inlet, increasing human habitation in the upper Inlet, and improved road access to Homer from Anchorage, sport fishing pressure has steadily increased in Kachemak Bay.

Kachemak Bay is inhabited year-round by large numbers of waterfowl and gulls; significant numbers of shorebirds, alcids and cormorants are present seasonally. According to preliminary unpublished nearshore aerial census data for 1976 (D. Erikson and P. Arneson, ADF&G, Anchorage, 1976), nearly 90% of the waterfowl wintering in inshore areas of Kachemak Bay were seaducks (12 species); the remainder were mallards. Surf scoters and goldeneyes were the most abundant species close to shore, while some 10,000 white-winged scoters wintered offshore, in the mouth of Kachemak Bay. Major seaduck habitats in inner Kachemak Bay are shown in Figure 2-7. Ninety percent of the overwintering mallards counted were in China Poot Bay, which also contained significant numbers of seaducks, shorebirds and crows during the 1976 winter census.

During the 1976 aerial censuses, the numbers of birds in Kachemak Bay more than doubled in spring, due mainly to the influx of migrant waterfowl, shorebirds, and gulls. Numbers dropped off by about 30% in summer after the migrants finished passing through. Thirty percent of all birds observed on the Kachemak Bay coast during the 1976 spring survey were in the Fox River Flats wetlands area, including 75% of the shorebirds and all of the geese. In the summer, waterfowl, particularly scoters, dominated the coast. Other species (kittiwakes, gulls, murres, puffins, guillemots, and cormorants) nested in colonies from Point Pogibshi to Gull Island (Table 2-2). Large numbers of marbled and Kittlitz murrelets raft off the southern shore of outer Kachemak Bay in summer, suggesting that they may be breeding in hills nearshore (Fig. 2-7).

In the fall, nearshore regions are dominated by gulls and waterfowl, seaducks and dabbling ducks being the most abundant. Fox River Flats at the head of Kachemak Bay and the shallows that border the northern side of the inner Bay contain extensive ice most winters. The southern side of the inner Bay freezes about once every decade. Since inner Kachemak

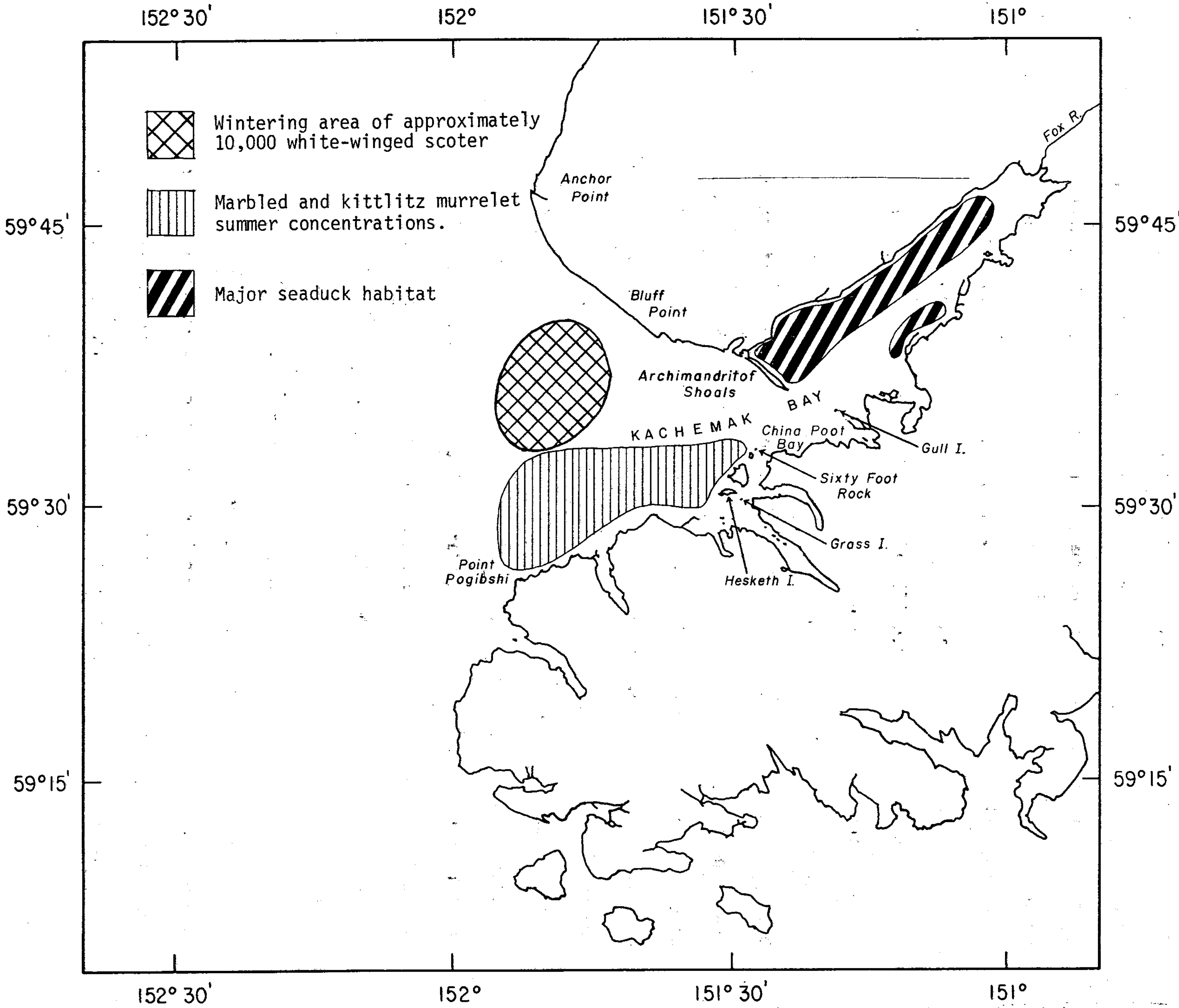


Figure 2-7 Kachemak Bay graphic summary of selected bird use data. (Compiled from unpublished data provided by D. Erikson and P. Arneson, ADF&G, Anchorage)

Table 2-2

Seabird Colonies in Kachemak Bay*

Colony Location	Species	Population Estimates	Colony Totals
Point Pogibshi	Tufted puffin	20	20
Hesketh Island	Horned puffin	4	24
	Pigeon guillemot	20	
Grass Island	Black-legged kittiwake	40	40
Sixty Foot Rock	Tufted puffin	54	554
	Common murre	350	
	Black-legged kittiwake	86	
	Glacous-winged gull	64	
Gull Island	Common eider	2	6,983-8,983
	Glaucous-winged gull	216	
	Common murre	3,000-5,000	
	Red-faced cormorant	62	
	Pelagic cormorant	222	
	Tufted puffin	530	
	Horned puffin	10	
	Pigeon guillemot	12	
	Black-legged kittiwake	3,194	

*Based on preliminary unpublished 1976 aerial census data from D. Erikson and P. Arneson, ADF&G, Anchorage. See map, Figure 2-7.

is a significant wintering ground for waterfowl which feed on the invertebrate faunas of the shallows, the extent and thickness of the ice can significantly influence bird populations.

Mammals present in Kachemak Bay throughout the year include sea otters, Steller sea lions, harbor seals, and harbor porpoises. Dall porpoises and killer whales may also be present. Of these, only the sea otter is known to occur in what are considered to be high densities relative to other areas.

The development scenario outlined in Figure 2-2 and Appendix 2, identifies several potential impacts that could effect Kachemak Bay (support and supply bases, crude oil terminal sites, offshore pipeline and tanker corridors, etc.). Factors such as gyral circulation of waters, which contribute to the Bay's high productivity (Fig. 2-8), could also slow the advection of contaminants away from the area. The importance of Kachemak as a spawning and rearing ground for commercial species of fish and shellfish, dictates that the potential effects of contaminant residence times be thoroughly understood.

REGION FOUR -- KENNEDY ENTRANCE

Located between the Kenai Peninsula and the Barren Islands, Kennedy Entrance carries the main tidal exchange between Cook Inlet and the Gulf of Alaska. The entrance is relatively narrow and deep; the seafloor is marked by a narrow depression, probably scoured out by tidal action. Bottom sediments other than boulders and gravel are scarce and much of the seafloor consists of exposed rocky outcrops.

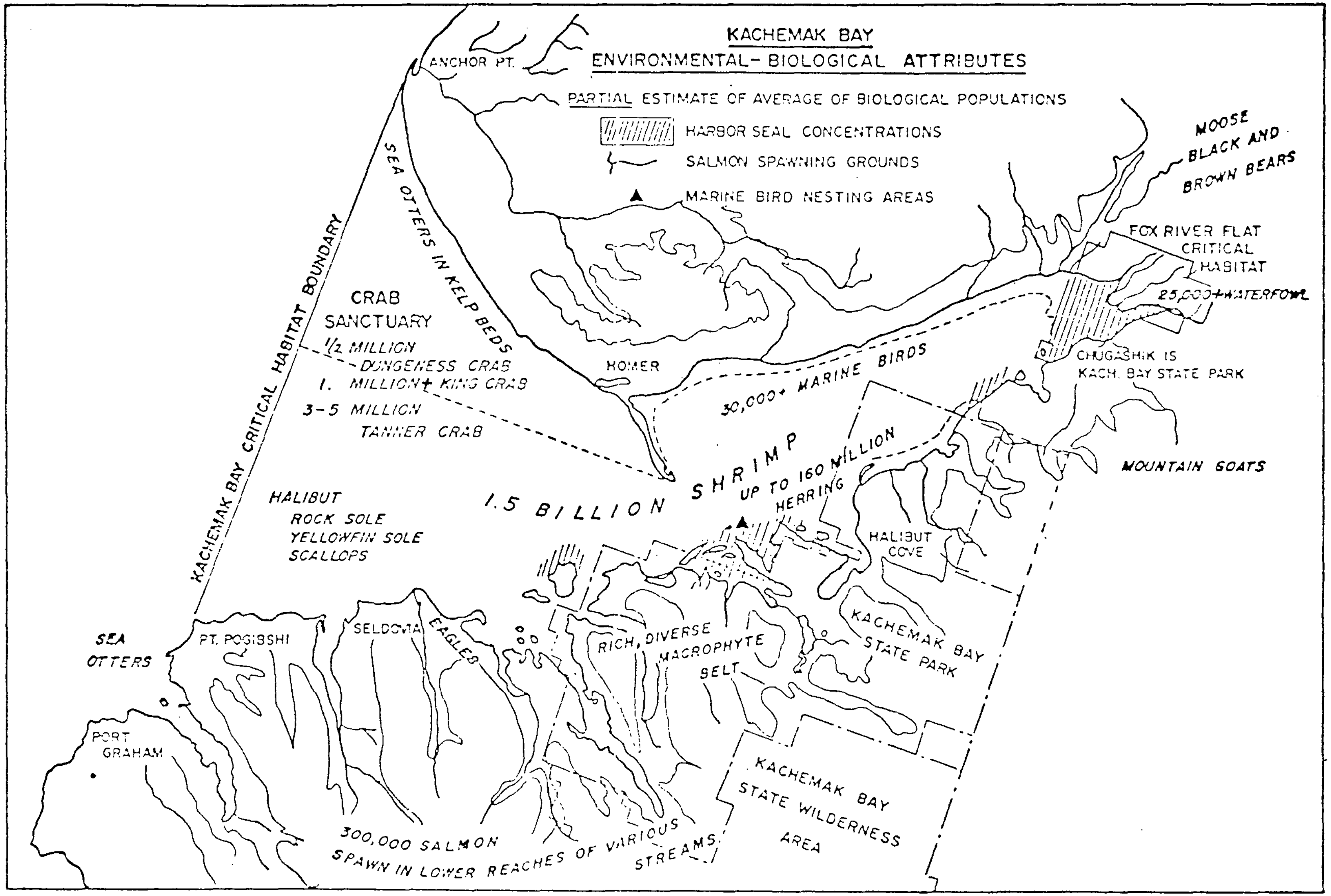


Figure 2-8 Kachemak Bay: graphic summary of environmental/biological attributes (M. Wennekens, AEIDC, Anchorage, personal communication)

Clear Gulf of Alaska waters move through the entrance almost continuously, the swift current regime reversing with each tide. Because of rapid seafloor shallowing, ocean waters moving into the Inlet rise, producing a turbulent regime. Primary productivity may be moderately high (according to chlorophyll concentration) but the only measurement to date was 1 $gC/m^2/day$ in late August (Larrance, RU #156c, 1976).

The shallow sublittoral portions of Kennedy Entrance are partially described in Dames and Moore, 1977. The wave-washed rocky shores of both the Kenai Peninsula and the Barren Islands provide excellent substrates for a diverse and highly productive algal flora. Eelgrass is an important plant in lagoons and protected bays. The biota is rich and the fauna is dominated by suspension feeders. The eelgrass bed in Koyuktolik Bay Lagoon is about the fifth largest in Alaska (this lagoon is also an important salmon rearing area). The benthic fauna developed further offshore is poorly known, but the nature of the seafloor requires that epifaunal suspension feeders (probably both attached and highly mobile forms) predominate.

Significant fisheries for king and tanner crabs exist in the Barren Islands region; 1974 yields were 0.3 and 0.8 million pounds, respectively. Commercial fishing for these crabs extends between September and February. Isolated populations of dungeness crab live in many of the coves and inlets of the Kenai Peninsula and support small local fisheries. Scallops and "hard shelled" clams are present, but quantities are not sufficient to support a commercial harvest.

From the few fisheries resource data available, ADF&G (1976) report some intertidal salmon spawning along the southern coast of the Kenai Peninsula; additional spawning occurs in local anadromous streams.

Blackburn (RU #512, April 1977) made otter trawls in Kennedy Entrance and noted large catches of Irish lords, in excess of 120 kg/20 min tow. Kennedy Entrance is probably the principal migratory pathway by which fish and marine mammals enter Cook Inlet. Because of the extremely high currents, commercial fin fishing is limited in the area. Excluding the Barren Islands crab fishery, most commercial efforts are nearshore along the southern coast of the Kenai Peninsula.

In contrast to other regions of Lower Cook Inlet in 1976, the mainland side of Kennedy Entrance was characterized by relatively low shoreline bird counts and a decrease, rather than an increase, in bird abundance in spring (D. Erikson and P. Arneson, ADF&G, Anchorage, preliminary unpublished aerial census data for 1976). The spring decline was due mainly to a net exodus of seaducks, which made up about 75% of the winter nearshore avifauna. Most of the overwintering nearshore waterfowl were concentrated around the Chugach Islands.

The 1976 summer peak in bird abundance nearshore resulted from an influx of glaucous-winged gulls and black-legged kittiwakes, which contributed 77% to the total nearshore avifauna. Tens of thousands of seabirds breed in colonies from Passage Island to Gore Point; glaucous-winged gulls and black-legged kittiwakes predominate. For nearshore avifauna, fall appears to be a transition period from summer dominance of gulls to winter dominance of seaducks.

Marine mammals (Fig. 2-9) present in significant numbers in winter and the year-round, are sea otters, harbor seals, Steller sea lions, and probably, dall and harbor porpoises. Summer brings an influx of gray whales and sei whales (both endangered species), and minke whales to the vicinity of Kennedy Entrance, but estimates of their local abundance are not available.

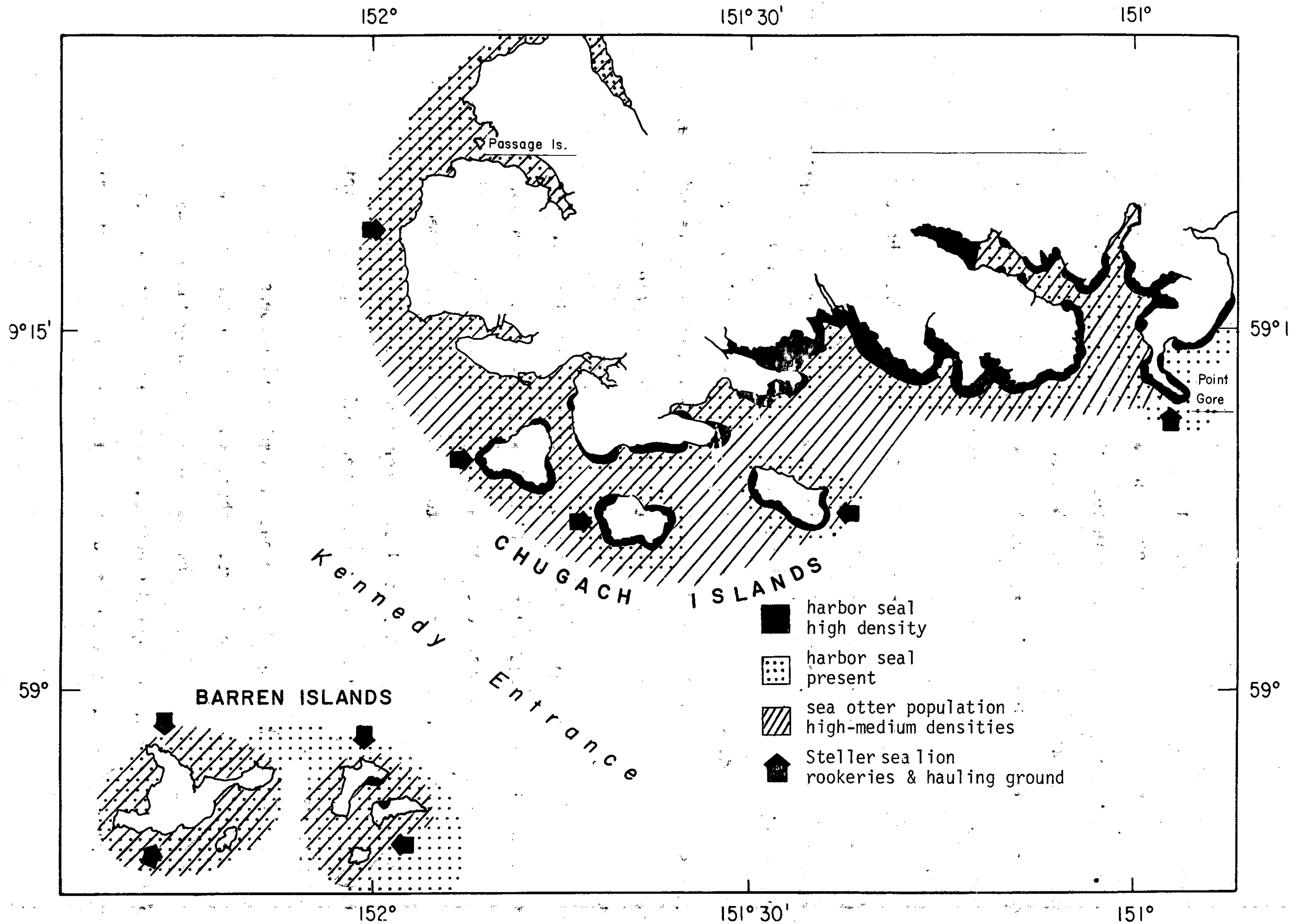


Figure 2-9 Kennedy Entrance: graphic summary of selected marine mammal data. (Compiled from data provided by K. Pitcher and K. Schneider, ADF&G, Anchorage)

REGION FIVE -- KALGIN ISLAND AREA

The Kalgin Island area extends south from the Forelands to the Lower Cook Inlet central zone (Fig. 2-1). It can be characterized as a convergence zone where relatively clear, higher salinity Gulf of Alaska water moving up the eastern side of Cook Inlet meets and mixes with the highly turbid lower salinity water flowing out of the upper Inlet. High frontal activity and downwelling are typical and are usually marked by pronounced trash lines trending northeast-southwest. Maximum freshwater runoff from the upper Inlet occurs in July and at this time the water column may become stratified in the northern portion of the area. In the southern portion of the area the water column remains well-mixed.

Tidal currents reach 150 cm/sec (3 knots) and tidal scouring is reflected in the nature of bottom -- predominantly rock outcrops covered with boulders, gravels, and sands. Water turbidity is high and exhibits pronounced gradients both from east to west and south to north.

Winter ice, mostly formed in the upper Inlet and carried through the Forelands by down-Inlet winds and water transport, becomes increasingly abundant northward of the Kalgin Island area. Considerable ice scouring occurs along the shores of this portion of Cook Inlet.

Primary production throughout this region is greatly reduced because of the turbid water. At the Forelands the photic zone is less than one meter deep. Ice scouring, a lack of suitable habitat, and possibly the highly variable salinity regime, all contribute to a marked decline in the littoral algal flora so well developed in the Kachemak area.

Relatively little is known about the benthic invertebrate faunas; however, both D. Lees and H. Feder are presently working on samples from this portion of the Inlet. Shrimp, crabs, and clams are known to be present offshore and the littoral zone yields both razor and "hard shell" clams. The razor clams are abundant enough to support a small local commercial and a sports fishery. A recent benthic survey by ADF&G (Flagg *et al.*, 1974) also confirmed that the area immediately southwest of Cape Kasilof (water depth of about 10 m) contained significant numbers of juvenile tanner crabs and extremely small razor clams. It may thus be a heretofore unknown settling area for both species.

The Kalgin Island area is possibly the most important commercial fishing region in Cook Inlet. The area is the location of the primary salmon fishery of Cook Inlet, an estimated 3.285×10^5 adult salmon spawners move into the area during spring and summer (Stern, 1976). The peak population of adult salmon has been estimated to be in excess of 7.8 million fish. Commercial catch statistics indicate that over 60% of all salmon caught in Cook Inlet are taken here. Eighty-five percent of the chum harvested in Cook Inlet are caught north of Anchor Point (ADF&G, 1976; Stern, 1976). Although salmon spawn in streams throughout the Kalgin Island area, most of the spawners enter the Kenai and Kasilof Rivers. Several major halibut commercial fishing regions are located in the area and some commercial fishing for herring is done near the east Forelands.

Preliminary unpublished nearshore aerial census data for 1976 (D. Erikson and P. Arneson, ADF&G, Anchorage) provide an overview of bird use in the region. The winter survey detected large numbers of shorebirds and a few seaducks and glaucous-winged gulls, all in Tuxedni Bay. Nearshore bird abundance increased greatly in spring 1976, reflecting an influx of gulls (mostly black-legged kittiwakes) and waterfowl (dabblers, Canada and snow geese, and greater scaup). Most kittiwakes were in Tuxedni Channel near the Chisik Island rookery; a majority of the waterfowl occurred in Redoubt Bay.

Numbers declined again in the summer survey, as the kittiwakes, waterfowl and shorebirds departed; alcids -- mostly murres -- increased in numbers. In summer, approximately 80,000 seabirds, mainly black-legged kittiwakes and common murres, breed in colonies in Tuxedni Bay. Other documented, but relatively small, colonies in the area are at Glacier Spit, Chinitna Bay, and Iliamna Point (Table 2-3).

In fall, migratory waterfowl (mostly dabblers and Canada geese) and shorebirds again move into or through this area, while the exodus of other species causes a net decline in bird abundance. In contrast to spring 1976, when very few waterfowl were observed in Tuxedni Bay, 52% of those tallied in fall 1976 were in Tuxedni Bay.

Although the Kalgin Island region is used extensively by harbor seals and belukha whales in summer, they move southward to Kamishak and Kachemak Bays in winter. Other marine mammals rarely enter the area at any time of the year.

REGION SIX -- UPPER COOK INLET

Cook Inlet north of the Forelands is characterized by extreme tidal range and a well-mixed water column. Freshwater runoff reaches a maximum in late spring and early summer. During this period there is a net movement of freshwater runoff out of upper Cook Inlet of approximately 1.6 km

Table 2-3

Known Seabird Colonies in Northern Upper Cook Inlet

Colony Location	Species	Population Estimates	Total	Ref.
TUXEDNI BAY				
Upper Tuxedni Bay	Black-legged kittiwake	NE	79,000+	1
Duck Island	Black-legged kittiwake	NE		1
	Common murre	NE		
Chisik Island	Black-legged kittiwake	45,000		1
	Glaucous-winged gull	2,000		
	Horned puffin	5,000		
	Tufted puffin	1,000		
	Parakeet auklet	NE		
	Kittlitz murrelet	NE		
	Marbled murrelet	NE		
	Pelagic cormorant	NE		
	Double-crested cormorant	500		
	Common murre	25,000		
Tuxedni Channel	Black-legged kittiwake	NE		1
Rusty Mountain	Glaucous-winged gull	18		2
Tuxedni River	Glaucous-winged gull	39		2
GLACIER SPIT	Cormorants	NE	NE	1
	Glaucous-winged gull	NE		
CHINITNA BAY				
Gull Island	Glaucous-winged gull	305	360	
	Tufted puffin	13		
	Common eider	4		
	Cormorant	38		
ILIAMNA POINT	Glaucous-winged gull	15	15	2

NE = No Estimate.

Refs: (1) U.S.D.I., 1976.

(2) D. Erikson and P. Arneson, ADF&G, Anchorage, preliminary unpublished 1976 aerial census data.

per tide. In winter, because of greatly reduced runoff, the fresh water essentially drifts back and forth with the tides.

Upper Cook is the major source of drift ice for the entire Inlet, most of it forming on the delta flats of major rivers that flow into the Inlet.

Tremendous quantities of glacial sediment (rock flour and gravels) are discharged into the upper Inlet. Suspended sediment concentrations range from 100 to 1,000+ mg/ℓ (Sharma *et al.*, 1974). The water is almost opaque and primary production is probably very low. Extensive wetland areas fringe portions of the upper Inlet and these, along with algal populations that develop on intertidal flats in the summer months, contribute to productivity.

Data on the benthic fauna of this region are scarce; however, Jackson (1970) provides a preliminary listing of intertidal forms. The upper Inlet is second to Kalgin Island in salmon spawner abundance. Population estimates by Stern (1976) put the average at 6.196×10^5 salmon destined for streams in the upper Inlet. The peak population estimate was 1.498×10^6 adult salmon. Some commercial fishing occurs in nearshore areas.

Seabirds are not abundant here but the wetlands which fringe portions of the upper Inlet provide important feeding grounds for migratory waterfowl. Harbor seals and belukha whales move into the area to feed during the summer months but return to Lower Cook Inlet for the winter.

Chapter 3

STATE OF KNOWLEDGE OVERVIEW

Although only the lower central portion of Cook Inlet would be directly involved in the potential OCS lease sale (Fig. 2-1), a full understanding of the possible results of development can only be realized by considering the entire Inlet ecosystem. The purpose of this chapter, therefore, is to summarize the salient features of what is presently known about the physical environment and ecology of Cook Inlet.

Two key elements are immediately apparent. First, Cook Inlet is a very large tidal estuary, famous for its extreme tidal range, as much as 12 m at Anchorage. Tidal currents are swift; they influence bottom topography, control sediment distribution, and help to prevent the Inlet from freezing over in winter. *CLEARLY, A KNOWLEDGE OF CIRCULATION PATTERNS IS FUNDAMENTAL TO UNDERSTANDING COOK INLET DYNAMICS.* Second, Cook Inlet yields major commercial catches of tanner, king, and dungeness crabs as well as shrimp, salmon, herring, and halibut. *WE NEED TO UNDERSTAND WHERE, WHEN, AND WHY THESE SPECIES ARE PRESENT, AND THE DEGREE TO WHICH THEY ARE DEPENDENT UPON, AND CONTRIBUTE TO, OTHER COMPONENTS OF THE COOK INLET ECOSYSTEM.*

This chapter consists of:

- A brief introduction that describes the climate, regional setting and sea ice of Cook Inlet;
- A review of the nature and effects of circulation (including spill trajectory analysis);
- A brief account of ocean chemistry; and,
- An overview of biotic resources within Cook Inlet.

CLIMATE

Regional climate reviews are presented in Evans *et al.* (1972) and Selkregg (1974). OCSEAP-sponsored climatic atlases of the OCS waters and coastal regions of Alaska (including wind and wave data) are in final stages of preparation.

Cook Inlet occupies a transition zone between the Alaskan interior with its cold winters, hot summers, low precipitation, and moderate winds; and the maritime zone with cool summers, mild winters, high precipitation, and frequent storms. January temperatures are generally warmer toward the southern portion of the Inlet, while July temperatures are cooler there (Seldovia averages: January, -4.9°C; July, +13.2°C). In the northern portion of the area the reverse trend exists (Susitna averages: January, -10°C; July, +14.3°C). Annual precipitation tends to increase toward the mouth of the Inlet, with major precipitation occurring in autumn in the upper Inlet. The lower Inlet, with its warmer winter temperatures, receives more winter precipitation in the form of rain than does the upper Inlet. The mean total precipitation over the entire Cook Inlet area is 53 cm per year (Evans *et al.*, 1972). Winter winds are generally from the north/northeast, while during the summer months the prevailing direction is southwest. Mean wind speeds are moderate, with a yearly average of 14 km/h (Swift *et al.*, 1974). Under extreme conditions, winds of 139 to 185 km/h can occur over the open water and storms with 93 to 139 km/h winds are experienced in Cook Inlet every winter (USDI, 1976).

REGIONAL SETTING

Cook Inlet occupies a portion of an elongated structural basin that extends from the tip of the Alaska Peninsula to the Alaska-Yukon border: the Matanuska-Wrangell forearc basin of Berg *et al.* (1972). This fault-bounded structural basin lies at the leading edge of the North American tectonic plate, along the Aleutian Trench. The location of Cook Inlet above a zone of active underthrusting results in significant regional seismic (National Academy of Science, 1972) and volcanic (Wilcox, 1959) hazards. Meyers' (1976) summary of Alaskan earthquake epicenter data, for example, indicates that hundreds of seismic events have been recorded from the Cook Inlet region since 1889, several of which have been marked by earthquakes of magnitude six or greater.

No attempt has been made here to summarize Cook Inlet geologic data, for OCSEAP-sponsored geological studies were not represented at the Synthesis Meeting. Instead, interested readers are referred to the following sources:

- Shallow faulting, bottom instability and movement of sediments in Lower Cook Inlet and Western Gulf of Alaska. Hampton and Bouma, RU #327: Annual and Quarterly Reports (1976-).
- Seismic and volcanic risk studies in the Gulf of Alaska: Cook Inlet-Kodiak-Semidi Island Region. Pulpan and Kienle, RU #251: Annual and Quarterly Reports (1976-).
- Large dunes and other bedforms in Lower Cook Inlet, Alaska. Bouma *et al.* (1977).

Additional background materials are included in NOAA/OCSEAP Annual Technical Summary Reports for 1975-76 and 1976-77 and in Foster and Karlstrom (1967), Evans (1972), Plafker (1972), Selkregg (1974), SAI (1976), and the Cook Inlet Final Environmental Impact Statement, published by BLM (1976). Earlier studies are referenced in: Geologic literature on the Cook Inlet Basin and vicinity, Alaska (Maher and Trollman, 1969).

The Cook Inlet watershed includes an area of some 98,000 km^2 (Fig. 3-1). The Susitna River occupies the largest drainage basin within the watershed, covering an area of some 50,800 km^2. The next largest is that of the Matanuska -- 5,670 km^2, followed by the Knik, Chakachatna, and Kenai each of which drain areas exceeding 2,500 km^2. Together these five rivers provide the major portion of freshwater runoff into Cook Inlet. All of these rivers are fed by glacial meltwaters and exhibit markedly seasonal flow that varies considerably from year to year. Peak discharge from most of these rivers is unimodal; their combined mean discharge varies from a low of about 5,000 m^3/sec in winter to over 90,000 m^3/sec in August (Fig. 3-1).

In a geomorphologically diverse province such as the Cook Inlet watershed, snow accumulation and melt patterns are variable, with snow melting first at lower elevations, and then at higher elevations as the summer proceeds. This process of snow melting, in itself, tends to regulate river flow during the summer. The flow from lakes and glaciers, as well as distribution and timing of general melting, tend to even out the flow curve, minimizing rapid changes in discharge. The threat of glacial lake outbursts is present however, on the Beluga, Big, Chakachatna, Kenai, and McArthur Rivers (Carlson, RU #114, 1976).

Preliminary bathymetry for Cook Inlet is illustrated in Figure 3-2. Kennedy Entrance and the mouth of Shelikof Strait reach depths of over 100 fathoms (180 m) but within the lower Inlet the seafloor rises abruptly to less than 40 fathoms (70 m). Arnold Bouma (USGS, Menlo Park, personal communication)* notes that the steep "ramp" thus formed runs from Kennedy

*Letter to NOAA/OCSEAP, April 21, 1977.

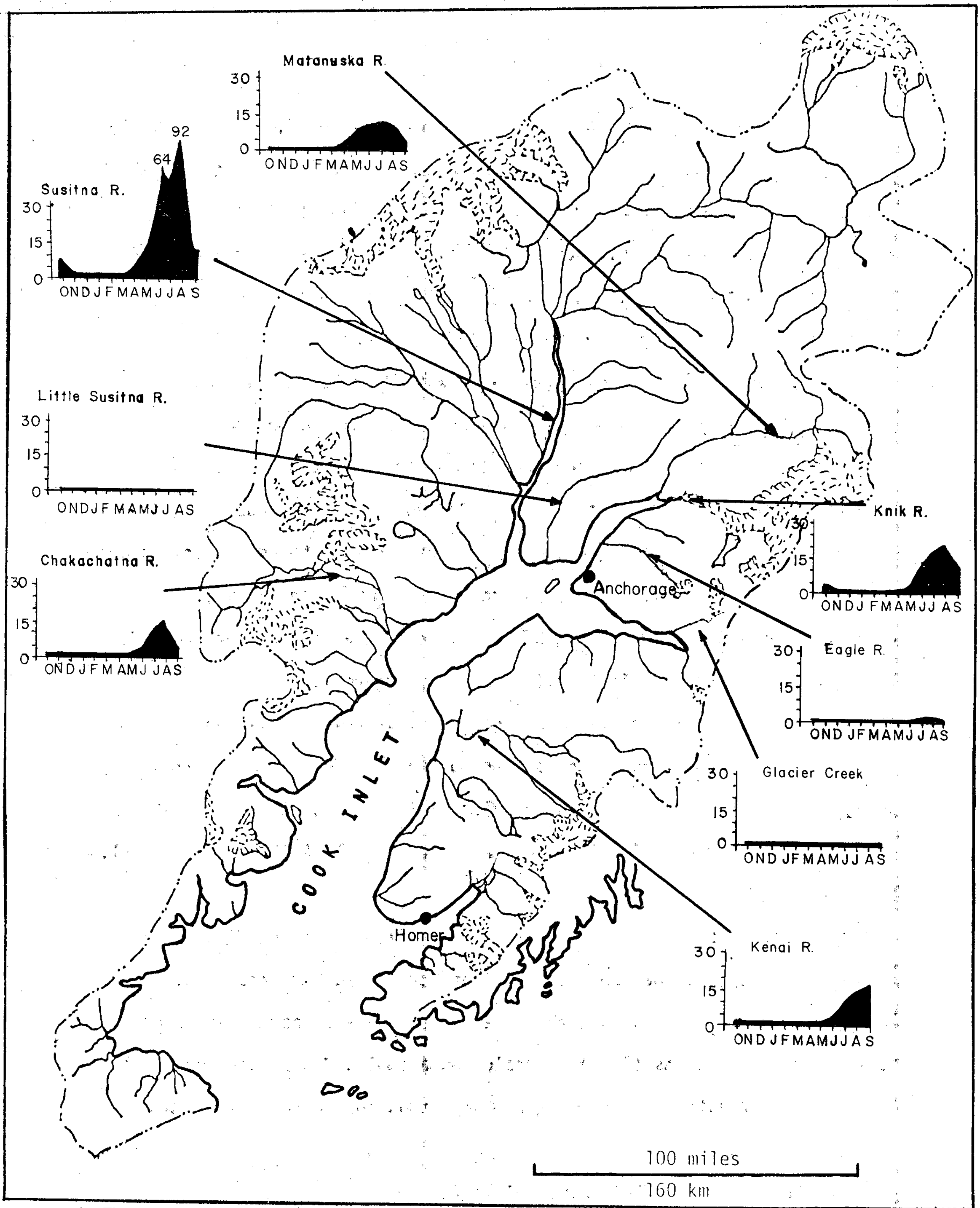


Figure 3-1 Cook Inlet watershed (AEIDC, 1974) and river runoff data (Sharma *et al.*, 1974). Runoff plotted is monthly mean water discharge (1000 m^3/sec) during 1967

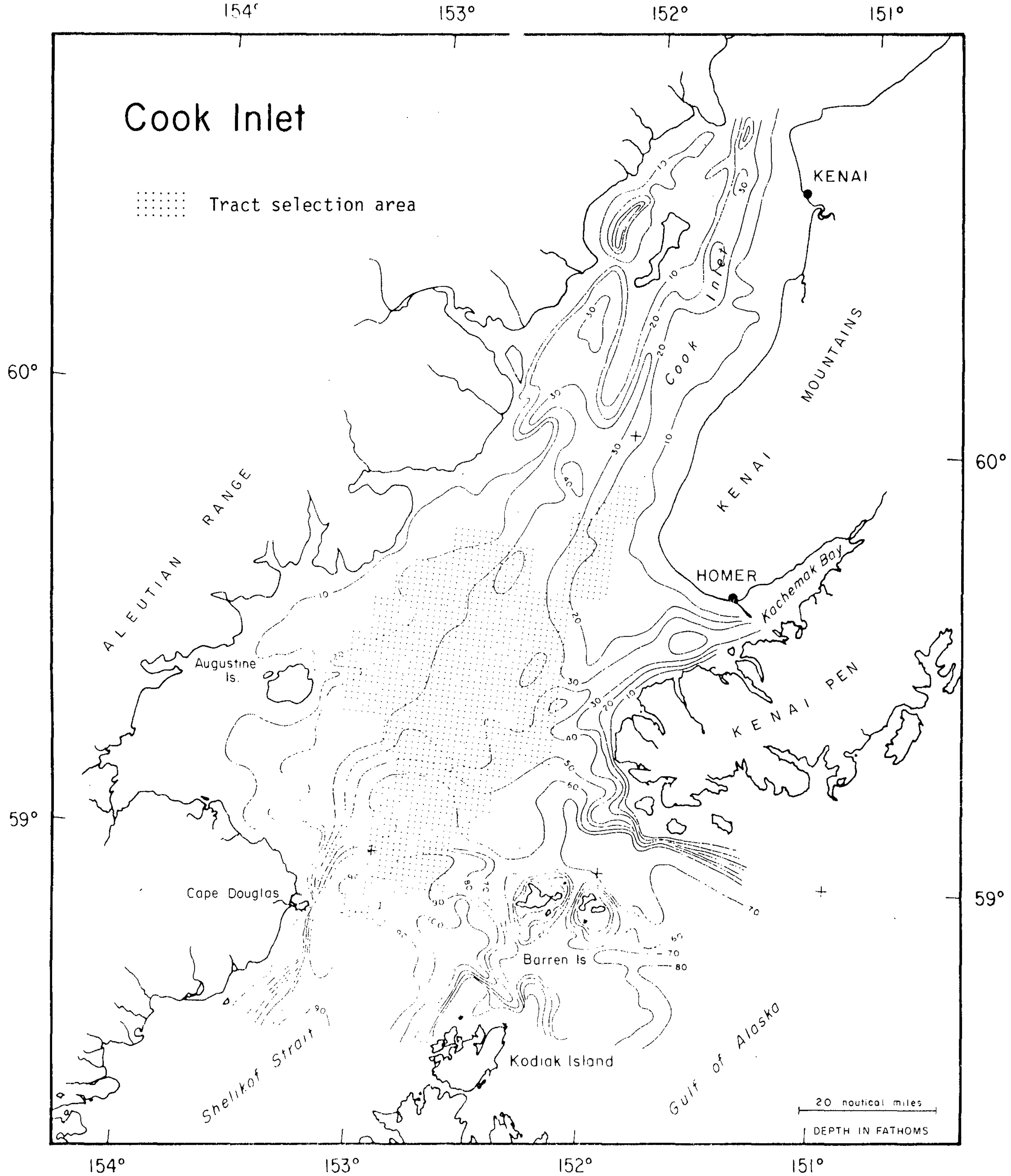


Figure 3-2 Cook Inlet preliminary bathymetry

Entrance towards Augustine Island, then turns south towards Cape Douglas. Tidal flow primarily occurs through Kennedy Entrance; currents are swift and the exposed rock surfaces and coarse seafloor sediments (boulders, sands, and gravel) indicate that bottom scouring is occurring.

SEA ICE

Ice usually forms in upper Cook Inlet early in December with false freeze-ups occurring in late October and November. Breakup is generally complete by late April (Hutcheon, 1972, 1973). Much of the ice forms on the extensive delta tide flats of the upper Inlet. As such, it is "river" ice, considerably harder than typical "sea" ice, and thus potentially more damaging to shipping and structures. Pack ice may extend as far south as Cape Douglas along the western margin of the Inlet and to Anchor Point on the eastern side. Maximum extent is usually attained in the latter half of January. South of the Forelands, ice is generally open pack with small floes (H.R. Peyton, personal communication, 1976).

Some indication of ice condition variability may be estimated by investigating "frost-degree days" (Hutcheon, 1973). Hutcheon's work indicates that the 1971-1972 winter was colder than 90% of the winters since 1928. By inferred direct correlation between "frost degree days" and ice formation rates, the 1971-1972 winter represented one of the more extensive, severe ice seasons in Cook Inlet. During this year, some ships were ice bound in the upper reaches of the Inlet in very close pack ice. Ice conditions in Lower Cook Inlet were not reported by Hutcheon.

Inlet circulation and winter wind regimes both tend to move the ice through the Forelands, past Kalgin Island, and down the west coast of the Inlet. Each winter extensive areas of Kamishak Bay, as far offshore as Augustine Island, are covered with dense pack ice, some of which is formed locally, but most of which drifts down from the upper Inlet and beaches in Kamishak. In contrast, pack ice concentrations in the central and eastern portions of the Inlet are generally low.

Sea ice provides a significant sediment transport mechanism in Cook Inlet, as noted in the following quote from Sharma and Burrell (1970):

> Above the Forelands the Inlet is generally heavily iced from December through April. The saline water remaining on the mud flats during the ebb tide during the winter months yields thin layers of sheet ice which may be disintegrated, transported, and redeposited during subsequent tidal stages. With the continuation of this cyclic phenomenon, alternating layers of ice and sediment may reach a thickness of 5 to 6 m before the floes are transported within the Inlet. Some of the flow ice and contained sediment are carried toward the large sheets. Thus, the winter ice formed in upper Cook Inlet contains significant amounts of both coarse and fine sediment. In has been noted (H.R. Peyton, personal communication, 1968) that surface melting of ice during warming intervals exposes very thin layers (about 0.025 cm) of fine silt.

No data are presently available concerning the possible role of ice in either accelerating or restricting the dispersion of possible oil spills or other pollutants in Cook Inlet.

CIRCULATION

The few sets of data presently available on water temperatures and salinity distributions for Cook Inlet are fragmentary and lack the necessary areal and seasonal coverage to construct a coherent picture of the velocity field and its variations. Present knowledge of the pattern of flow in the

Inlet is inadequate to assess transport characteristics and trajectories of possible contaminants spilled in Lower Cook Inlet. Flow is dominated by tides and generally follows bathymetric contours. There is a seasonal highly variable input of freshwater, but due to high turbulence a typical estuarine two-layered system is not formed except in isolated embayments and coves (e.g., inner Kachemak Bay). The central region of the Inlet appears to be vertically homogeneous; however, on occasions portions of the lower Inlet can be stratified (for example, the region northwest of Kennedy Entrance).

In addition to inferences about Inlet circulation based on temperature and salinity (see CHEMICAL OCEANOGRAPHY, this chapter) measurements, tidal, current meter, and drift card data provide insights into net transport and current patterns.

Cook Inlet tides are of the typical North American west coast type with a marked diurnal inequality superimposed on semidiurnal tides. The observed mean, range, and other parameters for tides at Kenai and Anchorage are given in Table 3-1. Tidal amplitude (0.5 x mean tidal range) approximately doubles from about 1.8 m at the Inlet entrance to 4.7 m at Anchorage. The phase increases from 22° at the entrance to 173° at Anchorage, thus indicating a delay of 5 lunar hours (5 hours and 10 minutes solar) between high water at the entrance and at Anchorage (Mungall, 1973). In general, maximum inflow occurs about 1½ hours before local high water in the upper Inlet; it can be surmised that tides are progressive.

A tidal stream atlas, based on a numerical model describing the amplitude and phase of the M_2 (Principal Lunar) constituent is provided by Mungall (1973). The model did not include either convective acceleration

Table 3-1

Tidal Characteristics at Kenai and Anchorage

(Data are given in meters)

	Kenai	Anchorage
Highest Tide	7.92	10.91
Mean Higher High Water	6.31	9.02
Mean High Water	6.06	8.81
Mean Tide Level	3.37	4.74
Mean Low Water	0.67	0.67
Mean Lower Low Water	0.00	0.00
Lowest Tide	-1.83	-1.49
Mean Range	5.40	8.14
Diurnal Range	6.31	9.02
Extreme Range	9.75	12.40

terms nor flooding boundaries, thus its results should be used with caution. Based on model results, it can be stated that currents at or near high water are fairly strong, and due to the Coriolis effect result in higher tidal amplitude in the eastern part of the Inlet (Fig. 3-3). Amplitude difference across Lower Cook Inlet is about 40 cm; co-amplitude lines tend to subparallel the Inlet axis in the lower part. Two regions of maximum current are between the Forelands (up to 335 cm/sec) and southwest of Fire Island (up to 365 cm/sec).

The central part of Lower Cook Inlet is a region of high tidal energy, especially on the eastern side. The energy involved in tidal excursions is mainly dissipated by working against frictional forces on the bottom, producing a turbulent regime. The water circulation south of Forelands and in the region of Kalgin Island appears to be complex and very dependent on the stage of tide. There appears to be a bifurcation of the relatively clear Gulf of Alaska water south of Kalgin Island as the water apparently follows bottom topography. There are some indications that the inflowing sea water of high salinity and outflowing low salinity water are separated laterally, especially in the vicinity of Kalgin Island. As a result, a shear zone with high frontal activity is formed. This zone, "convergence area" or "trash line" east of Kalgin Island, has been recognized by several investigators; it is considered to be an advective barrier to transport, as drogues are known to have been trapped in the zone for about two months (D. Burbank, ADF&G, Anchorage, personal communication, 1976).

At the latitude of Tuxedni Bay, shoaling of the basin floor forces the deeper oceanic water to the surface during tidal inflow where it mixes with Inlet water. Such topographically induced upwelling would replenish

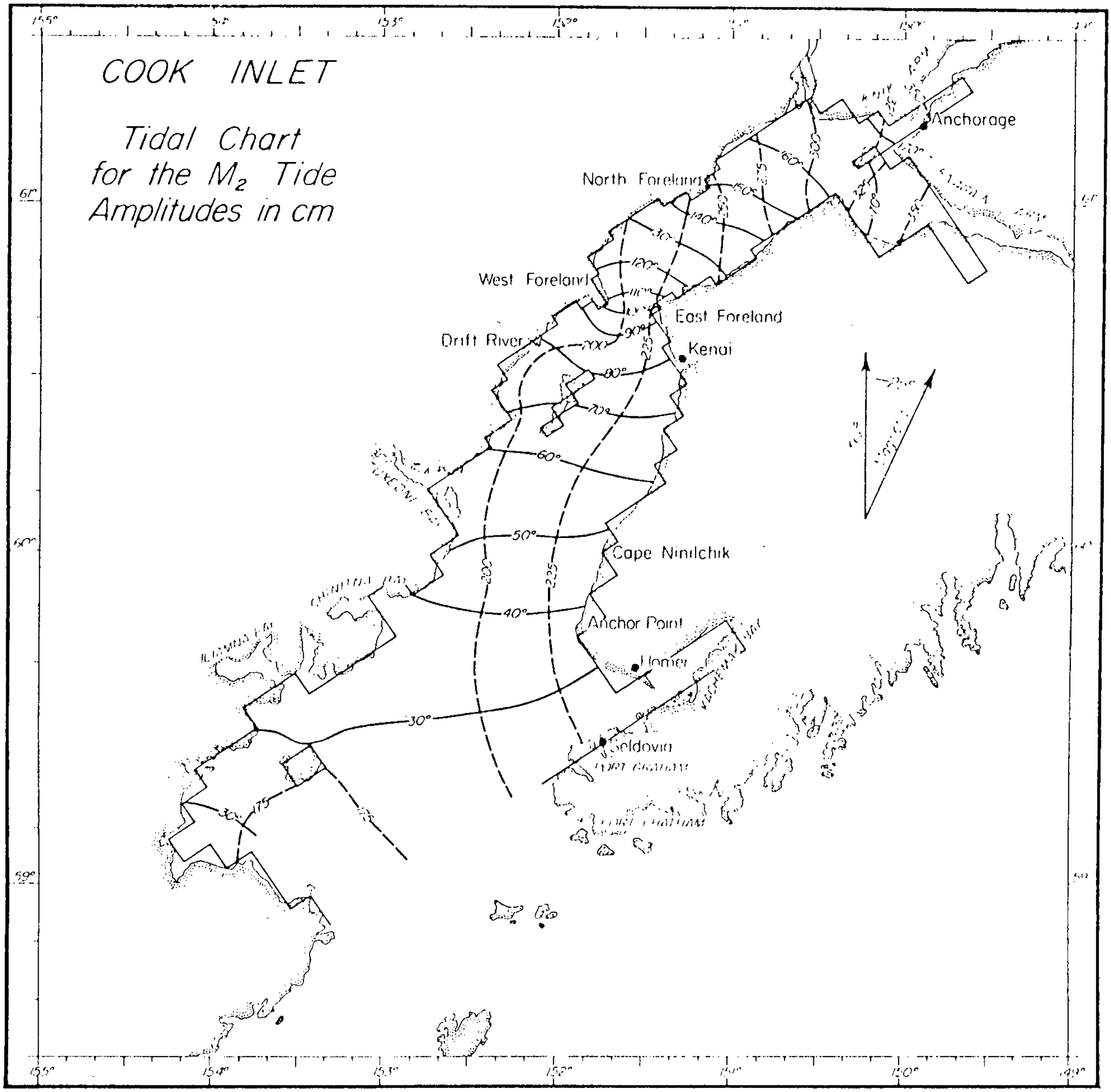


Figure 3-3 Cook Inlet: tidal height (co-amplitude lines, in cm) and tidal phase (co-phase lines, in degrees) contours for the main lunar (M_2) tide (Mungall 1973)

surface layers with inorganic micronutrients, possibly enhancing primary productivity.

Previously obtained current meter data for the Cook Inlet (National Ocean Survey, summer 1973) have been analyzed by NOAA/PMEL. Response analysis, utilizing predictive tidal functions, was used to project current fields on an arbitrarily chosen date, January 1, 1976. As a result, a general "synoptic" picture on a broad spatial scale was produced for the velocity field (Fig. 3-4). The presence of the generally high current velocities was confirmed. Currents with speeds approaching and exceeding 4 knots were predicted during both the flow and ebb periods. The tidal inflow and outflow are both primarily through the Kennedy Entrance. Nearly all (85%) of the variance in current records was attributable to tidal activity. Net inflow was estimated to be of the order of 10 cm/sec. Other salient features of these data included low current vectors in the western part of the Inlet, especially in Kamishak Bay, and the absence of any coherent flow (i.e., a low energy zone) at Station 26.

Although little is known about seasonal hydrographic features and current patterns in Kamishak Bay, as previously stated, it is speculated that it is a low energy area, where surface-borne contaminants may be detained for a longer residence time. Furthermore, wind-induced transport along the western Cook Inlet may also enhance the potential grounding and beaching of contaminants in parts of Kamishak Bay.

After review and subsequent discussions of available evidence regarding Cook Inlet circulation, physical oceanographers attending the Synthesis Meeting generally agreed upon a tentative circulation scheme, presented here in Figure 3-5.

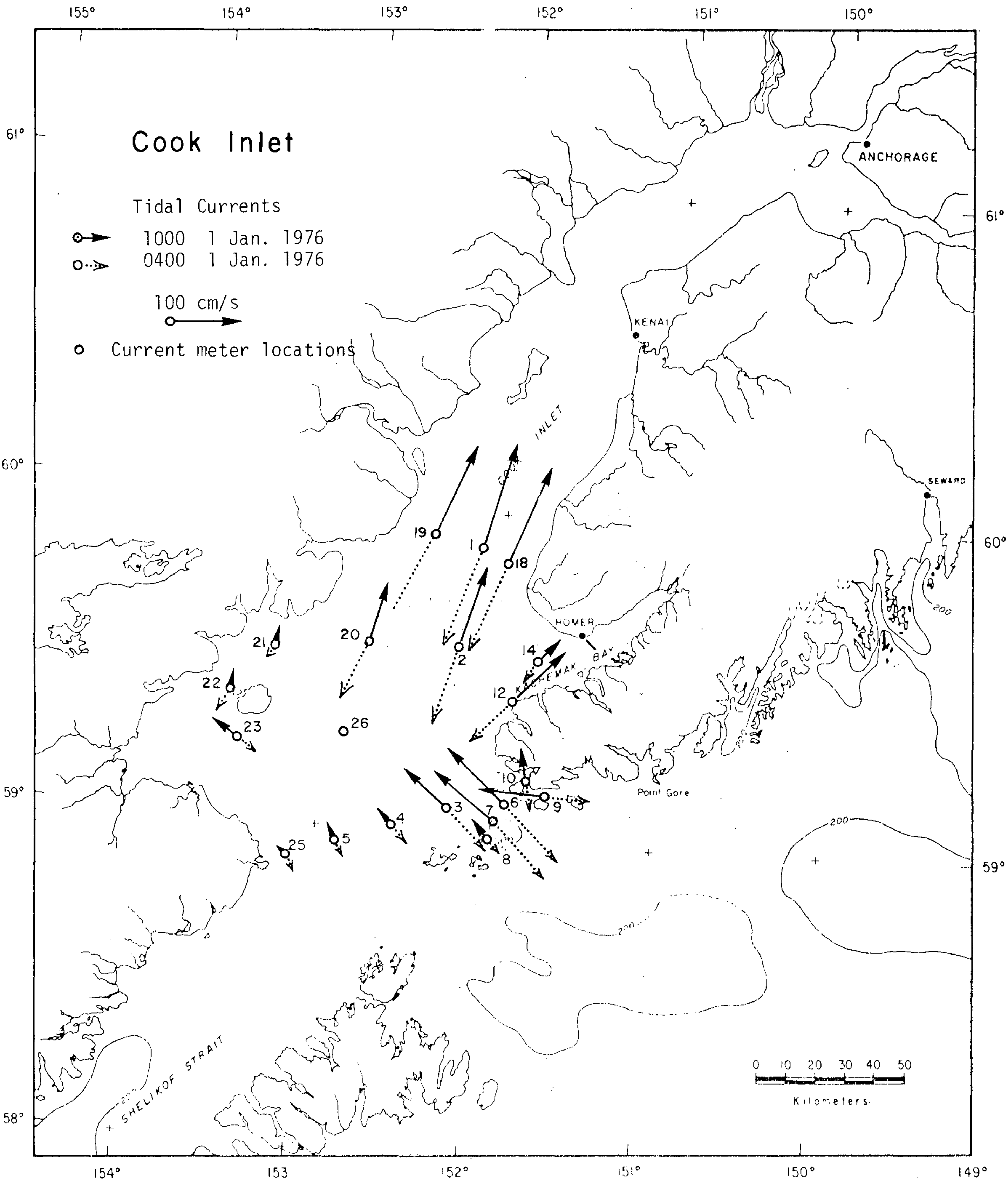


Figure 3-4 Brcad scale "synoptic" picture of predicted tidal currents in Lower Cook Inlet. Response analysis, utilizing predictive tidal functions, was used to project current fields on an arbitrarily chosen date, January 1, 1976 (Redrawn from figures provided by NOAA/PMEL.)

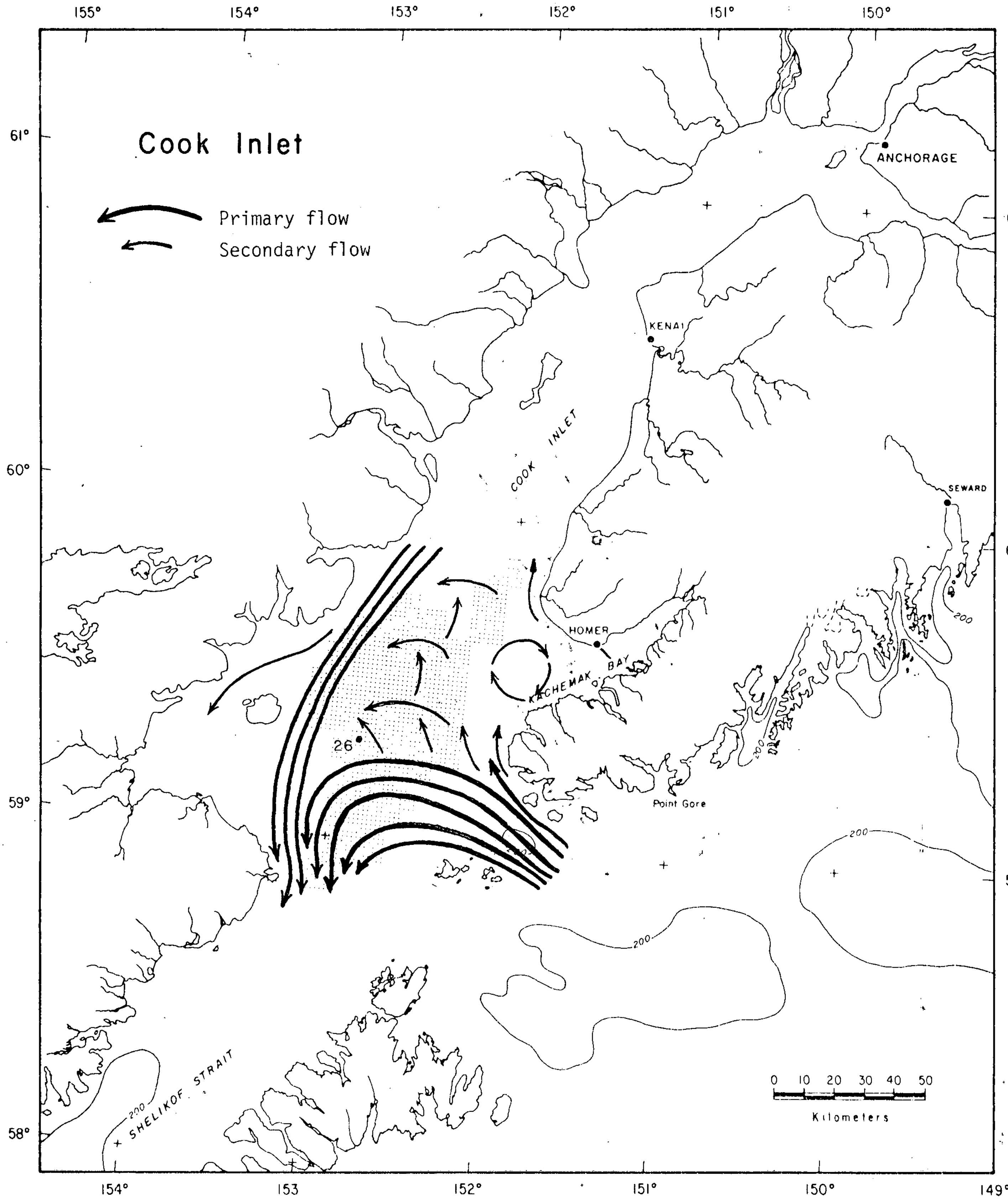


Figure 3-5 Lower Cook Inlet flow regime as derived from hydrographic and current data obtained during summer 1973. Note that the westward primary flow roughly parallels the 100 m depth contour. (Redrawn from an unpublished figure provided by R. Charnell, NOAA/PMEL) See text

Figure 3-5 depicts generalized primary and secondary mean (non-tidal) flow in Lower Cook Inlet, based upon analysis of hydrographic and current data obtained by the National Ocean Survey during summer 1973. The primary flow within the system is probably driven westward through Kennedy Entrance by a surface level difference and is constrained by bottom topography to curve southward, thence out through Shelikof Strait. A second primary flow occurs southward along the western boundary of Lower Cook Inlet and is driven by estuarine flow resulting from freshwater input in upper Cook Inlet. A secondary northward flow into eastern Cook Inlet replaces water entrained laterally into the intense southerly flow on the western side. This southeastern region experiences generally variable flow, including transient eddy-like features. The anticyclonic flow (clockwise) is probably at least quasi-permanent. This circulation scheme (Fig. 3-5) differs somewhat from that presented in the Lower Cook Final Environmental Impact Statement (USDI, 1976; Graphic No. 3) and from that of Dames and Moore's Oil Spill Trajectory Model, described below.

The Dames and Moore Oil Spill Trajectory Model (Miller, 1976) is a simulation model of probable oil trajectories in case of an oil spill from 12 potential sites in Lower Cook Inlet. The model assumes that oil movement can be approximated by the vectorial sum of surface current velocity and approximately 3 percent of local surface wind velocity. Tidal and net drift components are considered. The velocity vector of the centroid of an oil slick was evaluated under varying conditions of wind (speed and direction) and tidal cycles along a grid system, each cell about 4,800 m on a side, for the Inlet.

The circulation scheme developed for the Trajectory Model by Dames and Moore (Fig. 3-6) is based on the same data sets as used for Figure 3-5; however, the two approaches differed in assumptions, data processing and analytical methods. The Dames and Moore scheme is based on mathematical constructs rather than analysis of hydrographic and current data. *AT PRESENT THERE ARE NOT SUFFICIENT DATA AVAILABLE TO RESOLVE DIFFERENCES BETWEEN THE TWO TENTATIVE CIRCULATION SCHEMES* (Figs. 3-5 and 3-6).

A total of 384 trajectories were simulated: 8 wind patterns, 4 tidal phases, and 12 sites. The actual cells contaminated by each trajectory were identified. Cumulative results for coastal impacts of trajectories from all 12 sites are given in Figure 3-7. This figure was constructed by summing the probabilities of each cell for each spill site and dividing by the number of sites. It gives percent probability of exposure at each cell, assuming that a single assumed spill is equally probable from any of the 12 sites. The relative exposure levels along the coastline thus provide an indication, *WITHIN THE LIMITATIONS OF THE MODEL AND THE INPUT DATA*, of those portions of the Inlet which are most likely to be impacted with oil in case of a spill.

The oil spill trajectory analysis is based on several assumptions which may be quite limiting. For example:

- The surface circulation scheme is tentative and lacks winter data. Turbulent eddies are not considered.
- Wind speed data discount possible effects of winter storm winds (50-100 knots).
- The Blokker relationship for oil spill motion has not been verified for high wind and surface current velocities.
- Effects of waves are not considered.

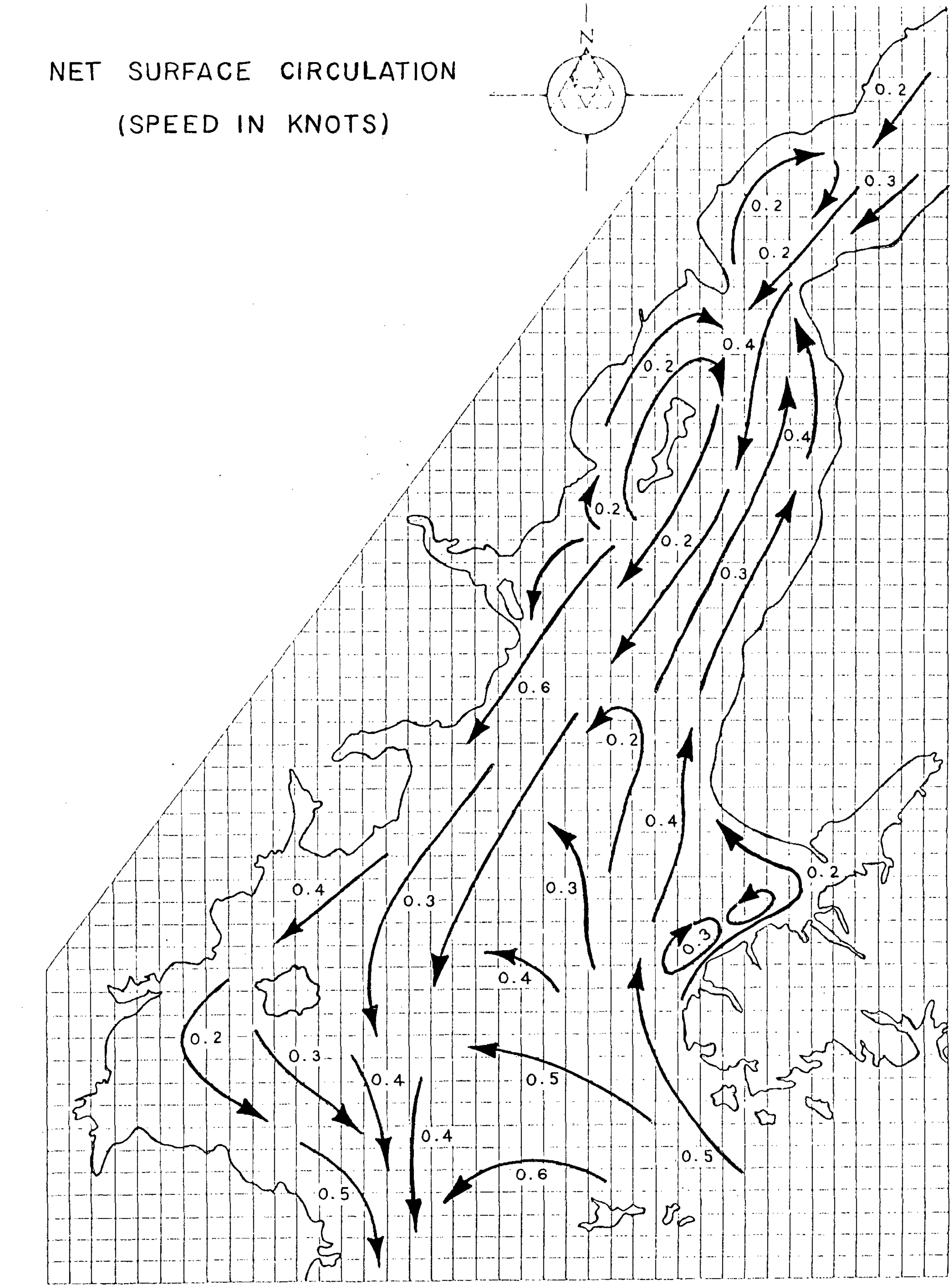


Figure 3-6 Cook Inlet circulation scheme developed for the Dames and Moore oil spill trajectory model (R. Miller, 1976). See text for additional explanation

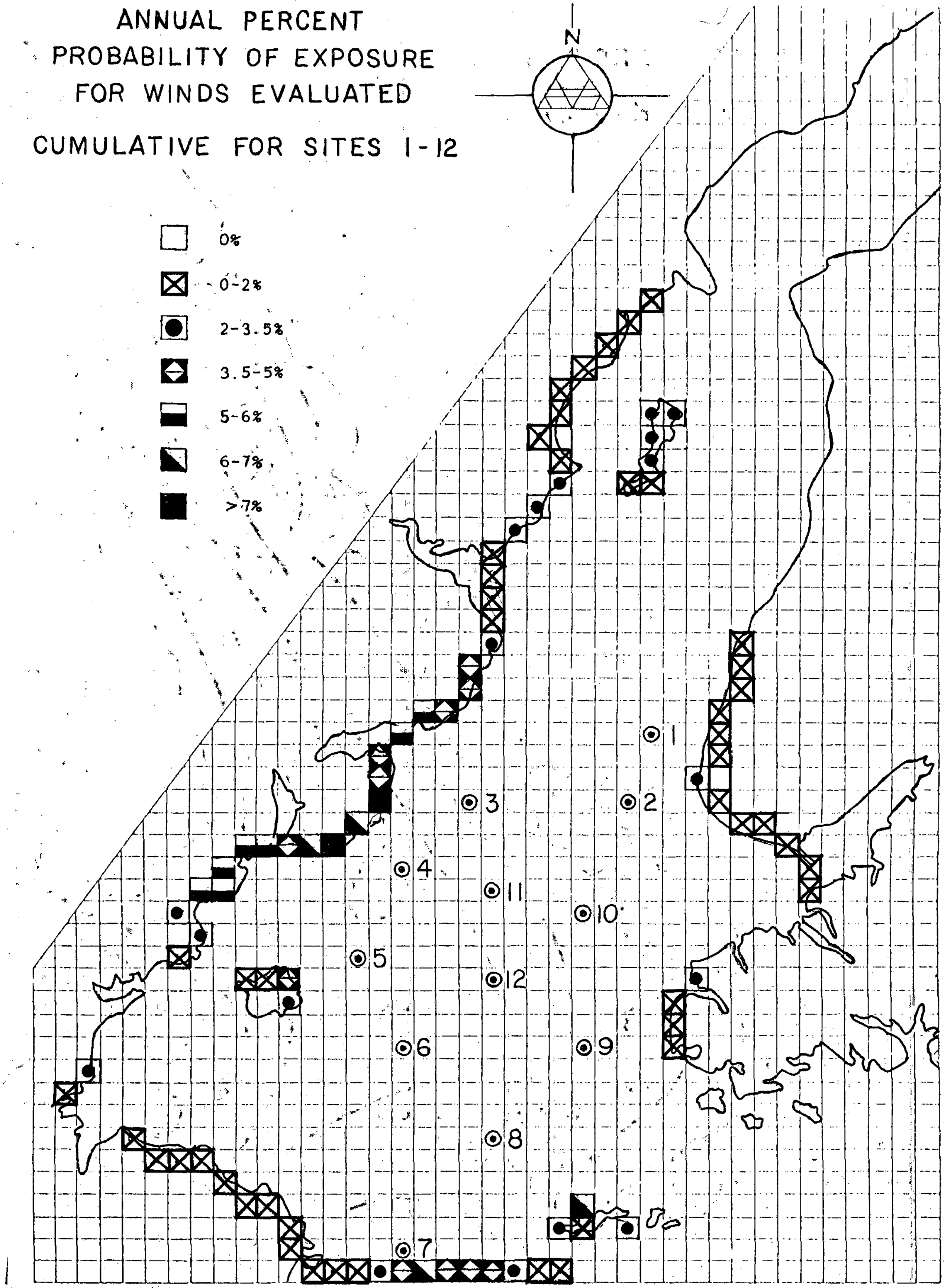


Figure 3-7 Cumulative probabilities of shoreline impacts based on 384 simulated oil spill trajectories using the Dames and Moore model (Miller, 1976). See text for additional explanation

- Spilled oil spreading rates utilized may be too low.
- The model terminates spill trajectories when boundary cells are impacted, which may be unrealistic.

In view of these possible limitations, *RESULTS FROM THE TRAJECTORY ANALYSIS SHOULD BE INTERPRETED WITH CAUTION AND RESTRAINT*. It must be pointed out that the results are not necessarily conservative upper bound estimates of risk. Further work with a broader scope and better data set may very possibly show actual risks to be substantially greater rather than smaller.

Cook Inlet's vigorous circulation directly influences bottom topography (through nondeposition, bottom scouring, migration of sand waves or megaripples), seafloor sediment distributions and suspended sediment transport, the distribution and abundance of dissolved nutrients and, of course, the distributions of larval and adult biological populations.

Cook Inlet bottom sediments consist predominantly of cobbles, pebbles, and sand with minor admixtures of silt- and clay-size material (Fig. 3-8; Sharma and Burrell, 1970; USDI, 1976; Hampton and Bouma, RU #327, 1976). Hampton and Bouma (1976) indicate that, except along coastlines, the coarseness of bottom sediments is directly related to current strength, which in turn is inversely proportional to Inlet width (i.e., narrower inlet → stronger currents → coarser sediments). Bottom conditions are extremely variable with patches of boulders alternating with flat-floored bottom or large underwater sand dunes. Bottom gravels are typically well-rounded, 2-6 cm in diameter. Volcanic ash and shell material are common in the finer-grained sediments.

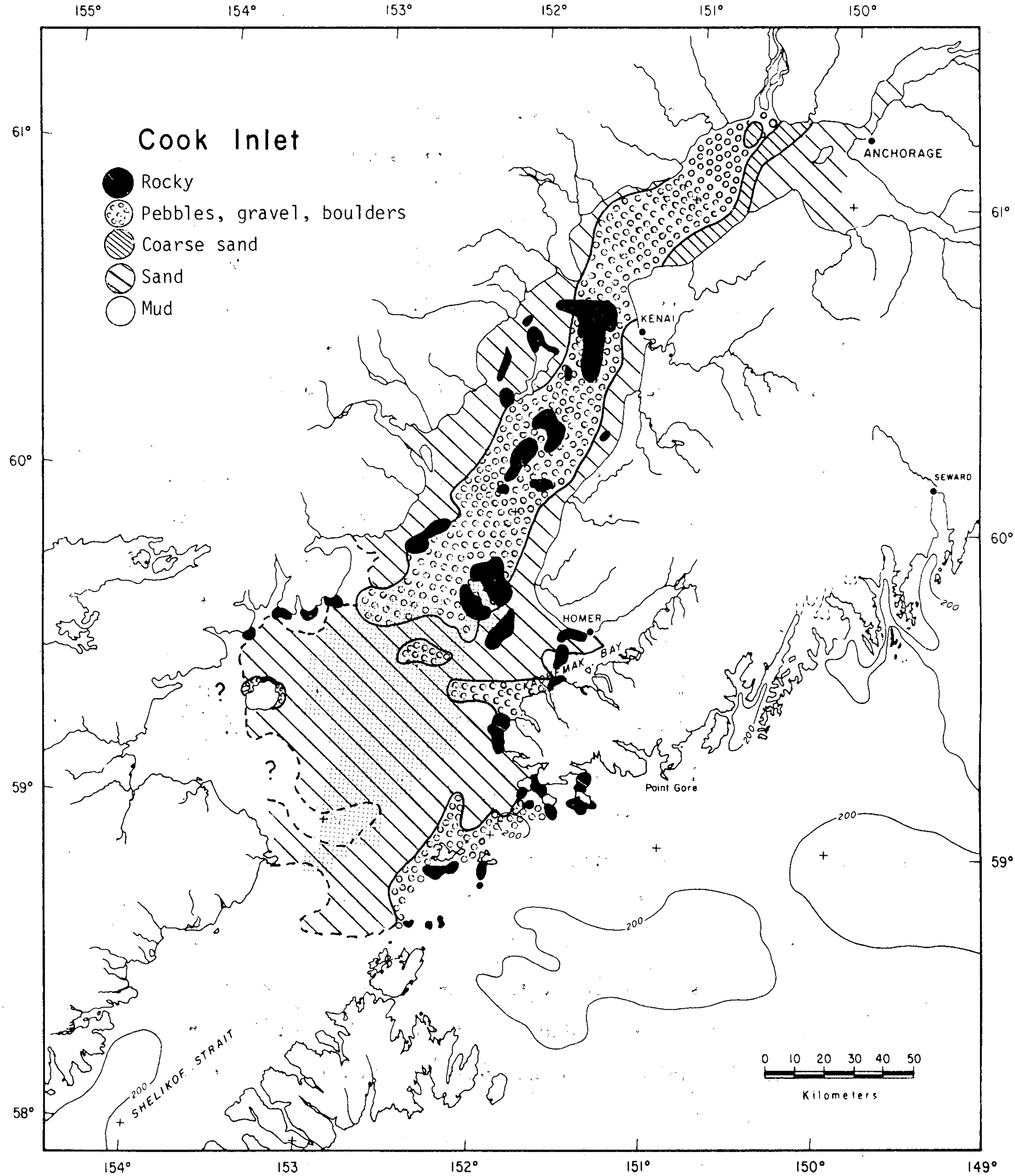


Figure 3-8 Bottom sediment distribution in Cook Inlet. Compiled from preliminary data from Sharma and Burrell (1970), Hampton and Bouma (RU #327, 1976-) and USDI (1976)

Tidal current velocities are sufficient to prevent deposition of muds in the central Cook Inlet Basin. Substantial deposition of fine sediments occurs in Kamishak Bay, although much of the riverborne sediment entering Cook Inlet (largely from the Susitna River and Knik Arm at the head of the Inlet) is carried out into Shelikof Strait (Belon *et al.*, 1975). Other bays also have considerably weaker currents that allow fine-grained sediment to settle there. For example, Tuxedni and Chinitna Bays have exposed mudflats at low tide and a gravity core collected behind Homer Spit in Kachemak Bay consisted of a black muddy sediment with a high organic content (Hampton and Bouma, RU #327, 1976).

The waters of Cook Inlet contain unusually high concentrations of suspended sediment; sediment load in different parts of the Inlet varies enormously (Fig. 3-9; Sharma *et al.*, 1974; Belon *et al.*, 1975). The clear inflowing Gulf of Alaska water, which may extend as far north as Kalgin Island, carries only 1-2 mg/ℓ of suspended sediment. In contrast, near the head of the Inlet, suspended sediment load values may exceed 1,500 mg/ℓ. This material, usually in the silt size range, consists of mechanically abraded debris (rock flour) transported by glacial meltwater streams. This sediment-laden water dominates the surface waters and is easily recognizable in the upper 2/3 of the Inlet and along the western shores of the entire Inlet, associated with outflowing water. The possible role of suspended sediment in removing contaminants from the water column is discussed later in this report.

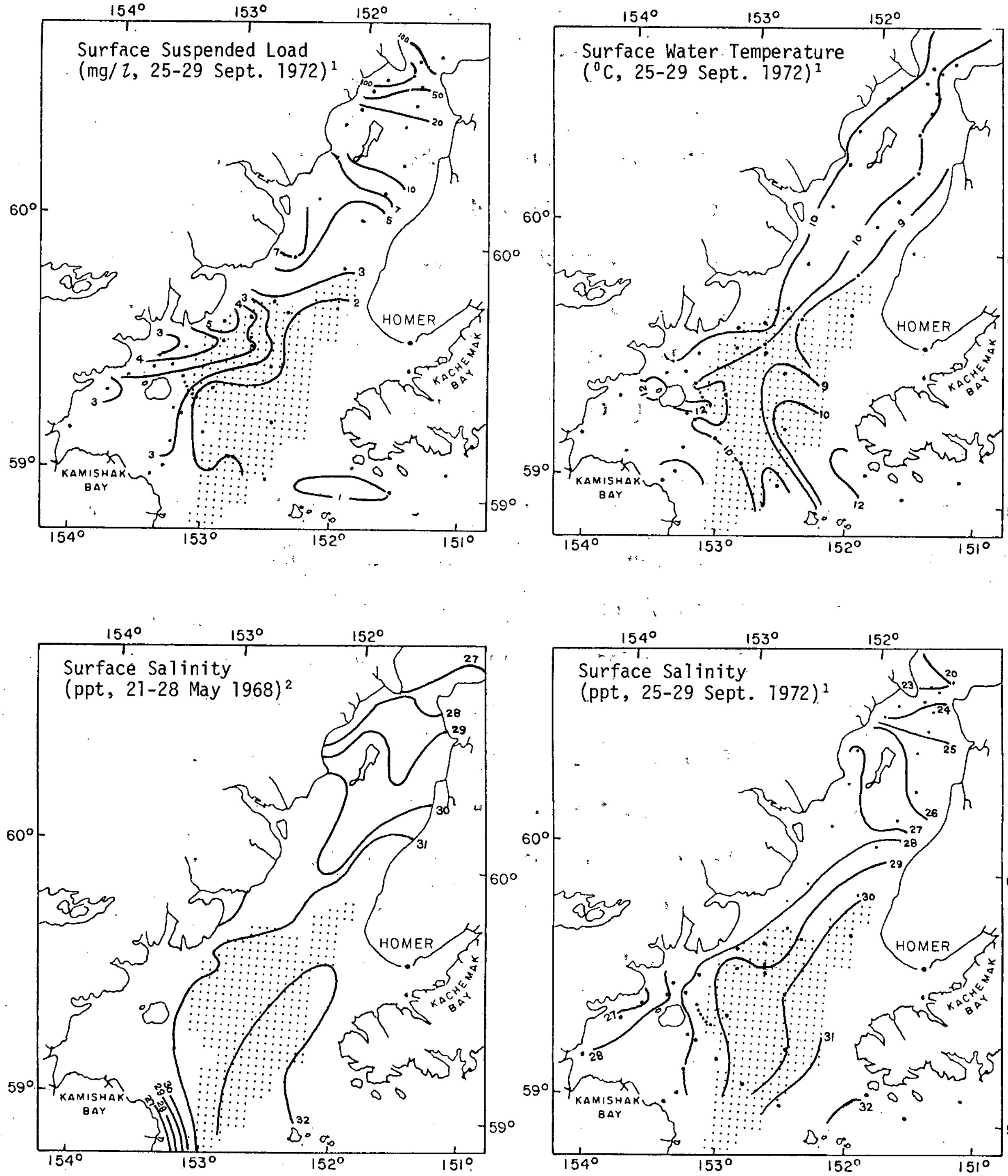


Figure 3-9 Lower Cook Inlet: selected hydrographic data

[1]Redrawn from Sharma *et al.*, 1974.

[2]Redrawn from Smith *et al.*, 1975.

CHEMICAL OCEANOGRAPHY

Typical water temperature and surface salinity values for Cook Inlet are shown in Figure 3-9. In May 1968 data, the influence of inflowing oceanic water can be seen as far north as Kalgin Island on both sides of the Inlet. In September 1972 data, after peak freshwater discharge, a consistent band of less saline water in the western part of the Inlet is easily recognized. In summer, vertical stratification develops in the western sector of the Inlet with colder, saline oceanic water underlying warmer, less saline Inlet water.

In late spring and summer, there is a marked outward movement of the upper Inlet waters in the form of a tongue of less saline water as long as 1.6 km. In winter, when freshwater input is low, there is little freshwater-driven entrainment flow, but flow through the Inlet is probably driven by both wind and sea level differences between Kennedy Entrance and Shelikof Strait. The inflowing colder, more saline water from the Gulf of Alaska provides the major source of inorganic plant nutrients (such as inorganic nitrogen and phosphorus) in the Inlet (cf. Figure 3-10). Freshwater runoff may provide a secondary nutrient source.

Because of high vertical turbulence in Lower Cook Inlet, the average nitrate concentration in the upper 25 m in mid-channel is generally high, between 5 and 18 mg-at N/m^3 (equivalent to 125-450 mg-at N/m^2). In isolated embayments, such as Kachemak Bay, nitrate may be undetectable in the upper 10-15 m in late spring and summer (Fig. 3-11). In these locations primary productivity is limited by nitrogen availability.

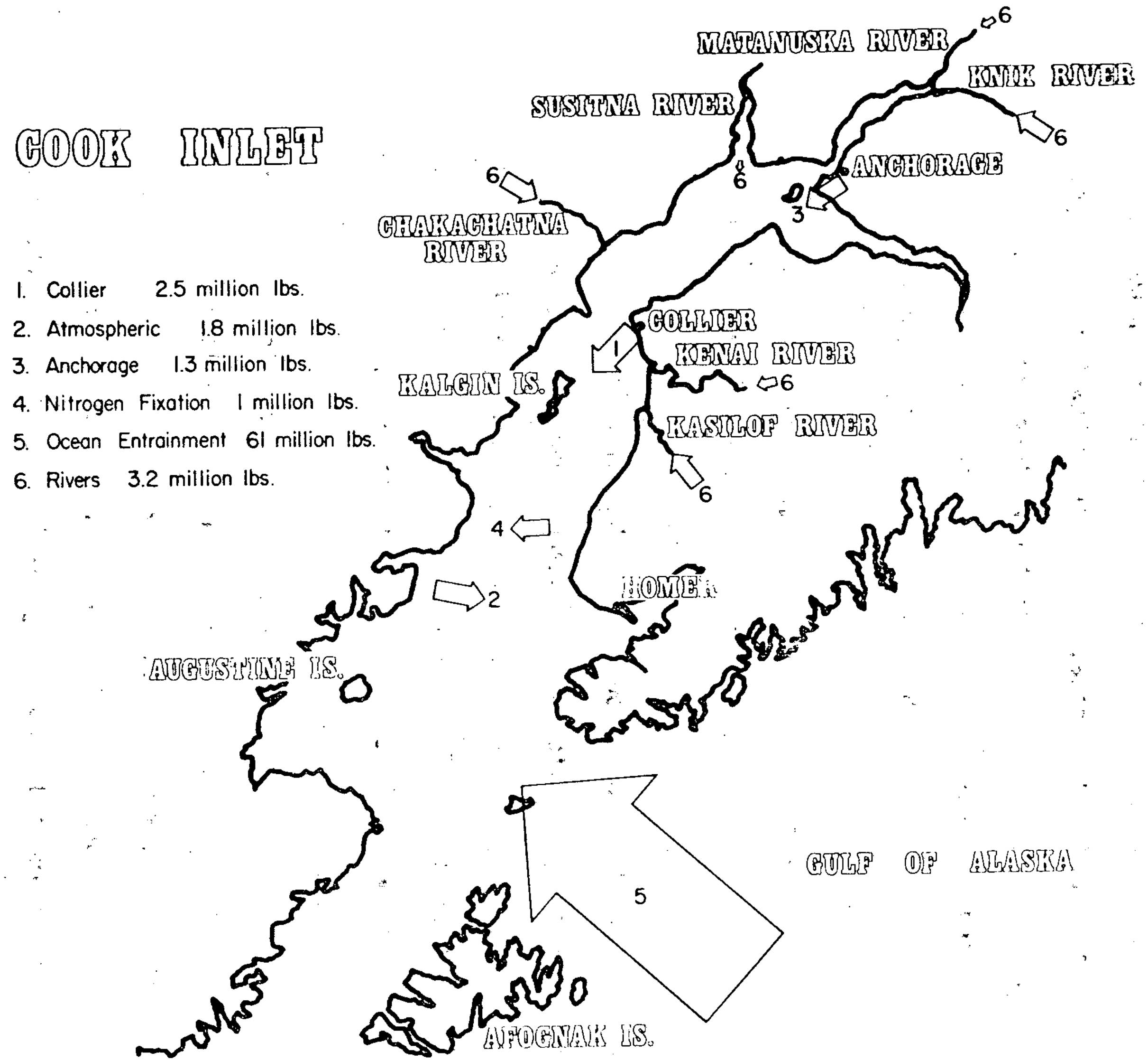


Figure 3-10 Ammonia Inputs to Cook Inlet (Smith *et al.* 1975)

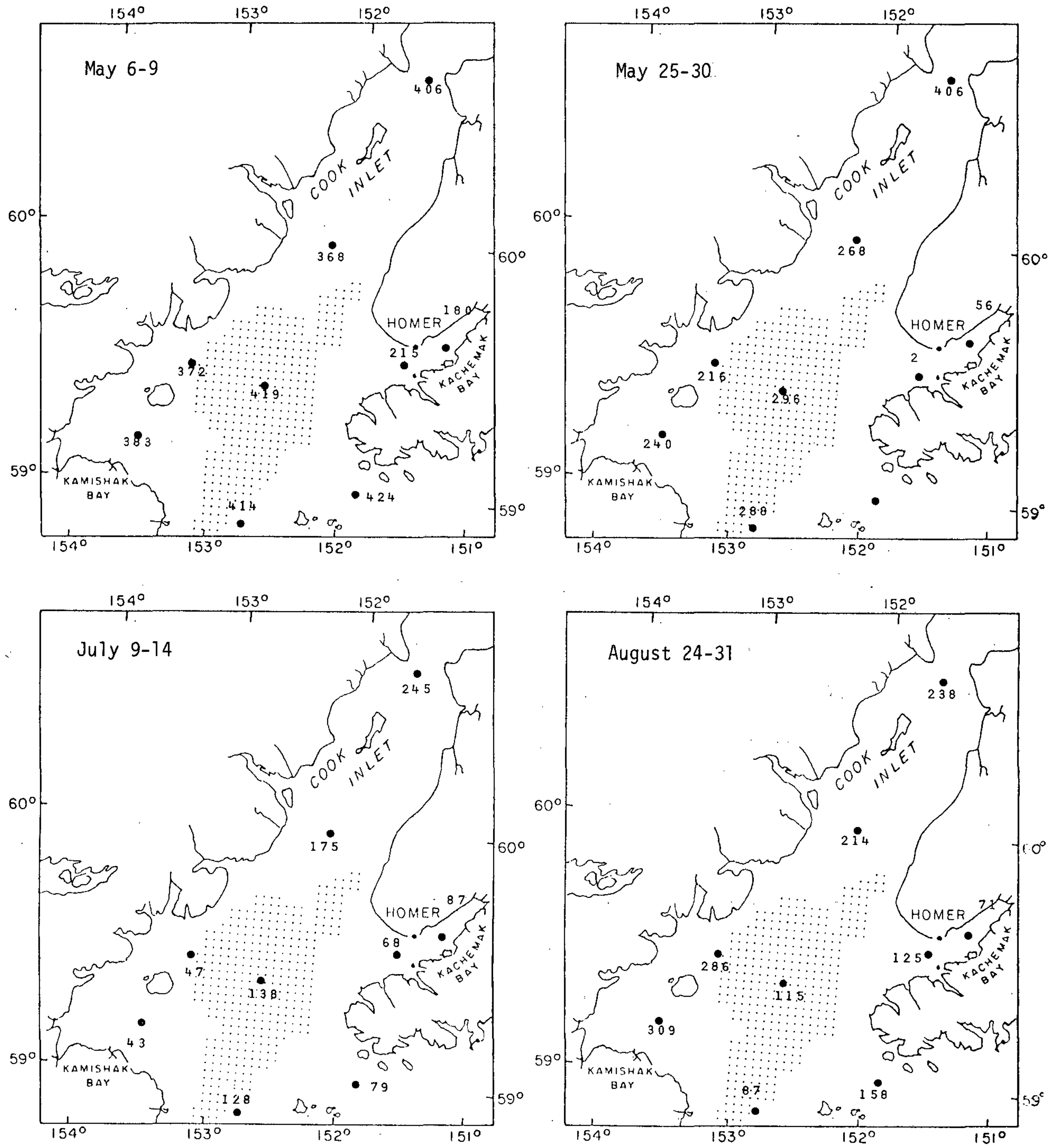
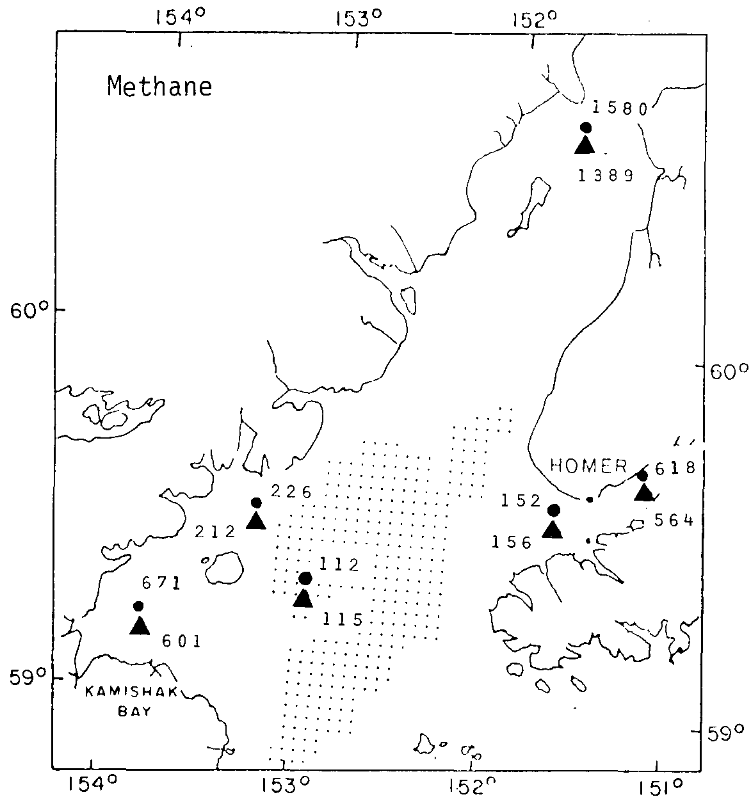


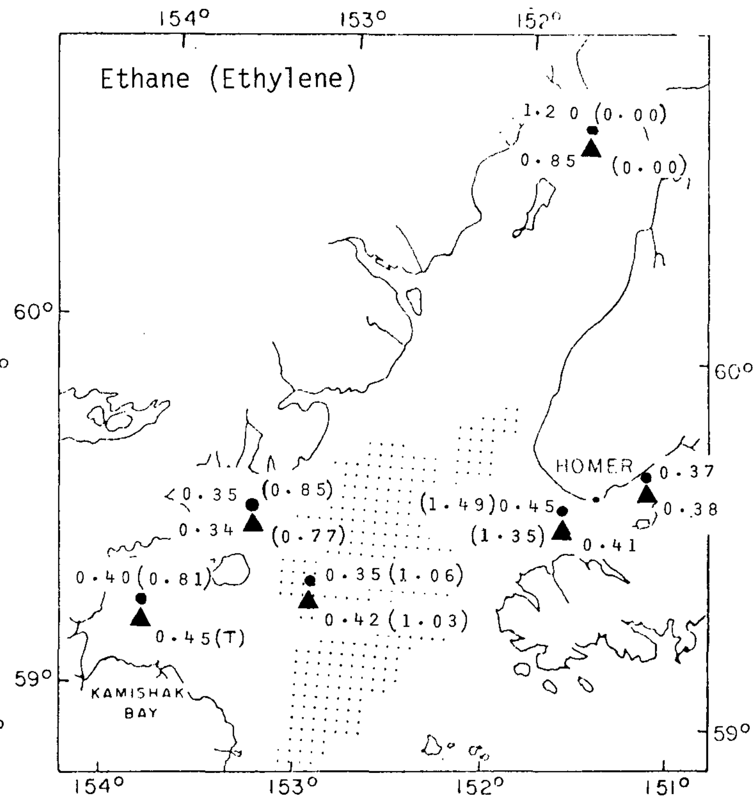
Figure 3-11 Nitrate values in the upper 25 m of the water column. Numbers represent mg at-m^2; divide by 25 for mg at/m^3. (Unpublished data provided by J. Larrance, RU #425b, NOAA/PMEL)

Cline and Feely (RU #152, 1976) proposed that light molecular weight hydrocarbons are useful indicators of petroleum contamination, due to their high solubility and low natural abundance. Preliminary investigations in Cook Inlet south of the Forelands were conducted in April 1976. Methane concentrations (Fig. 3-12) in the near surface and near bottom waters were always above atmospheric saturation (i.e., above 80 to 90 nℓ/ℓ). The highest concentrations, noted near the Forelands, may result from natural petroleum seeps and/or petroleum development and production in the immediate area. Water from Kamishak and Kachemak Bays also contained methane levels markedly higher than atmospheric equilibrium. Data from these Bays suggest that the surface waters may have been a more significant source than the bottom sediments, at the time of observations. More time-dependent data are required to delineate source strengths and duration (J. Cline, NOAA/PMEL, Seattle, personal communication).*

Little spatial variation was noted in ethane concentrations except for those samples collected near the Forelands (Fig. 3-12). Cline and Feely (RU #152, 1976) report that the elevated levels of ethane and methane recorded in the Forelands area possibly originate from petroleum seeps and/or development in the area. Ethylene concentrations, which are of biogenic origin, ranged from 0.00 at the Forelands to 1.49 nℓ/ℓ in Kachemak Bay (Fig. 3-12). The higher concentrations in the lower Inlet are in response to biological activity, and the lack of ethylene in the Forelands suggests that the methane and ethane found there originate from petroleum sources rather than biological sources.

*Letter to NOAA/OCSEAP, May 3, 1977.





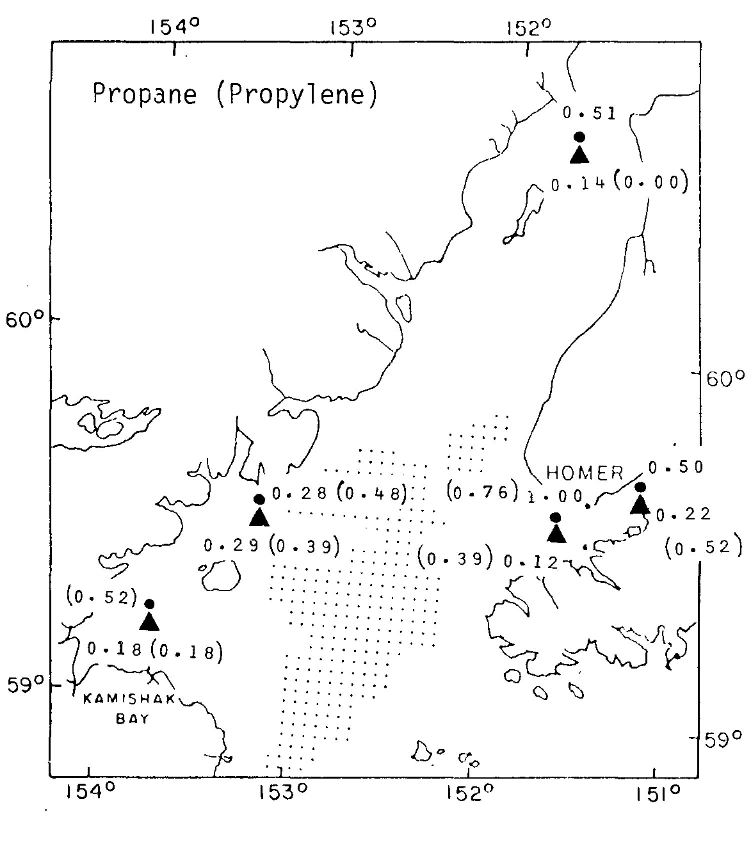


Figure 3-12 Concentrations of selected light molecular weight hydrocarbons (nℓ/ℓ) in surface (●) and near bottom (▲) waters of Lower Cook Inlet during April 1976 (Modified after Cline and Feely, RU #152, 1976)

As with methane and ethane, propane concentrations were high near the Forelands and lower in other areas of the Inlet, except for the Kachemak Bay area (Fig. 3-12). However, the data are too sparse to support any general conclusions at this time (Cline and Feely, RU #152, 1976).

Propylene concentrations were generally higher than the propane levels, indicating biogenic origin (Fig. 3-12). However, the lack of propylene in the Forelands and the lower propylene values in Kachemak point to a petroleum source as the origin of the high propane concentrations in those areas.

Recently acquired LMWH data from Lower Cook Inlet (April 1977) indicate high concentrations of ethane (> 10 $n\ell/\ell$), propane, and butanes north and west of Kalgin Island. The suspected source is north of the Forelands and is probably related to petroleum activities. Intensified studies are underway to identify the source or sources (J. Cline, NOAA/PMEL, Seattle, personal communication).

BIOTIC RESOURCES

Primary Production

Phytoplankton in Cook Inlet is dominated by diatoms, which is expected because the high silicate content of Inlet waters would favor their growth. Silicoflagellates are occasionally also abundant. Previous studies of phytoplankton in the Inlet provide data on the number and variety of species represented (Evans *et al.*, 1972). Fewer species are reported from the upper Inlet than the lower Inlet: in the Knik Arm area, 10-20 taxa of diatoms are recognized, whereas over 30 taxa are known from the lower Inlet.

Widely distributed species of phytoplankton include:

Actinoptychus sp.	*Cyclotella* sp.
Asterionella kariana	*Ditylum brightwelli*
Asterionella sp.	*Fragilaria* sp.
Biddulphia aurita	*Melosira fulcata*
Ceratulina sp.	*Melosira* sp.
Chaetoceros debilis	*Thalassiosira* sp.
Coscinodiscus spp.	

Within Kachemak Bay, *Chaetoceros debilis* is usually the abundant species except in the inner Bay where *Thalassiosira* sp. and *Ceratulina* sp. dominate at different times of the year.

Larrance (RU #425b, April 1977) recently provided data on the seasonal abundance and succession of dominant species of phytoplankton (Fig. 3-13), as well as on primary productivity, nitrate, and chlorophyll *a* concentrations from different locations in Cook Inlet (Fig. 3-14). Samples were collected from April to August 1976; preliminary results are illustrated in Figure 3-14. Mean daily rates of primary productivity, mg carbon assimilated per square meter, from eight stations are also shown in Figure 3-14. High levels of primary productivity were observed during late May; the highest value, 7.7 $gC/m^2/day$, was noted at Station 6 in the inner Kachemak Bay in early May. In Kamishak Bay, the highest value, 3.64 $gC/m^3/day$, was observed in July. Consistently higher values were obtained in the eastern and central parts of Cook Inlet (Fig. 3-14; Stations 1, 2, 5, 6, and 9). The times of initial spring phytoplankton blooms in Kachemak and Kamishak Bays and the central part of the Inlet are different from one another, and appear to be geared to thermal and/or salinity stratification of the water column. Initially (e.g., early April conditions) all waters in the lower Inlet are nutrient rich, but nutrients decrease rapidly with the onset of the bloom. Stations 3 and 4 (Fig. 3-14) were characterized by turbid

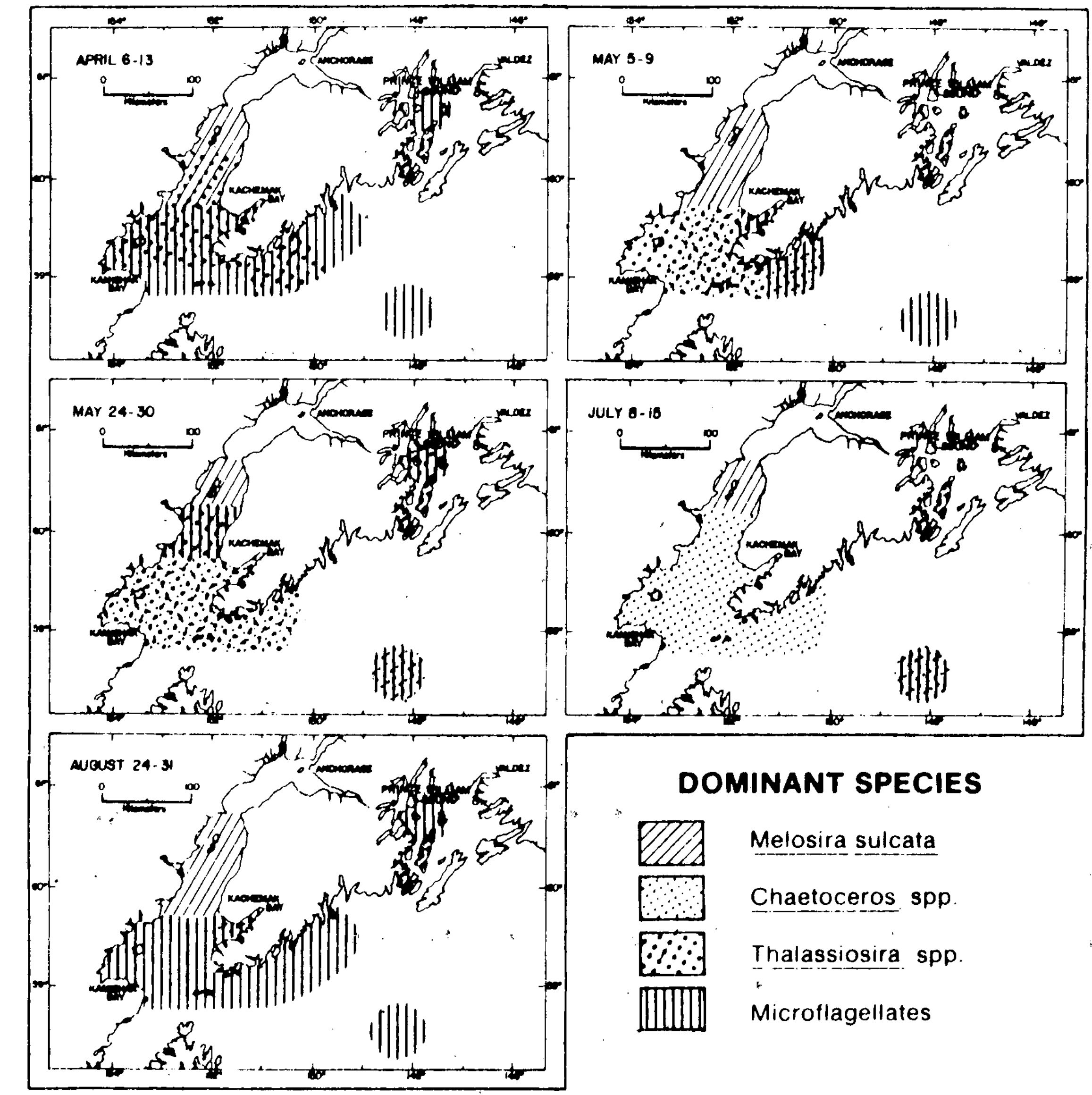
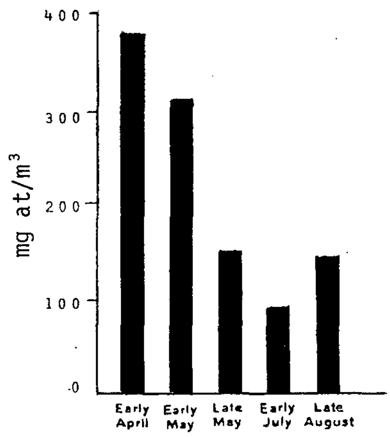
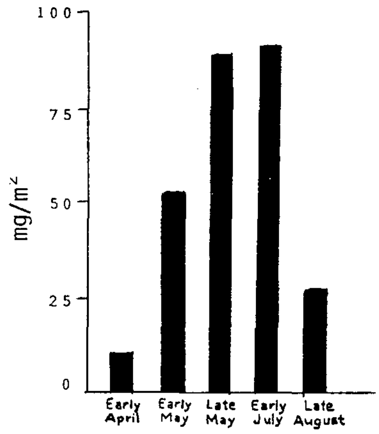


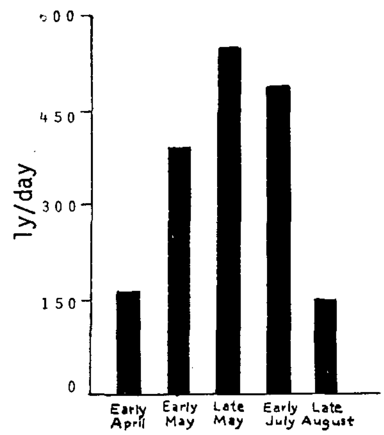
Figure 3-13 Distribution of dominant phytoplankton groups in the Cook Inlet-Price William Sound region, April through August, 1976. (Reproduced from Larrance *et al.* RU #425b, Final Report, April 1977)



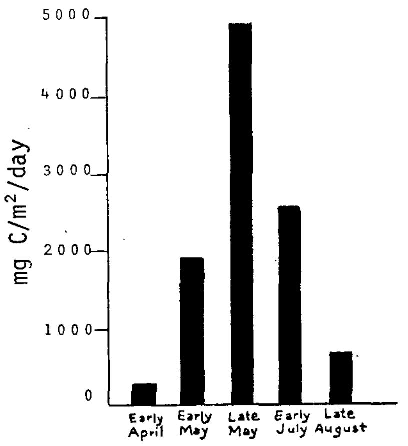
Nitrate concentration



Chlorophyll a concentration



Incident radiation



Mean primary productivity

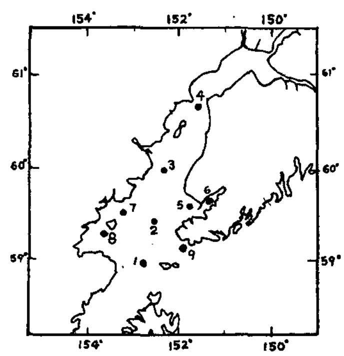
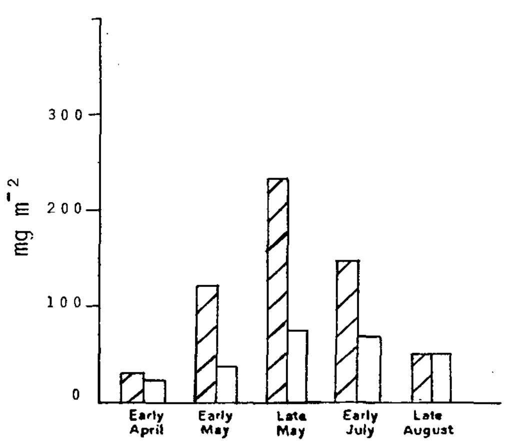
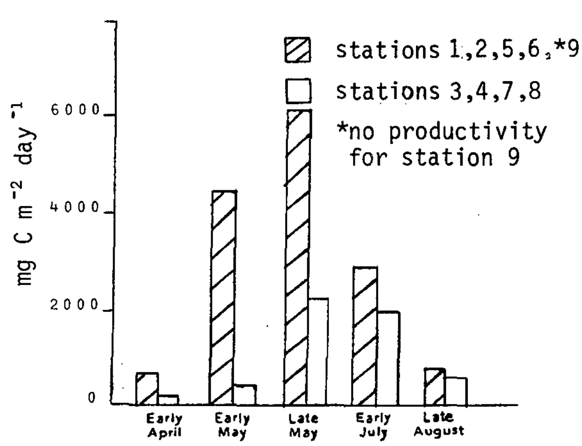


Figure 3-14 Sampling stations and selected data sets from Lower Cook Inlet primary productivity studies (Redrawn from Larrance *et al.*, RU #156c, 1976 and RU #425b, 1977)



Chlorophyll a



Primary productivity

waters and shallow photic zones; at Station 4, the photic zone ranged from 1-3 m. Primary productivity at these stations was about 1/10th of the Kachemak values. Nitrate was uniformly distributed with depth in the upper 50 m at both of these stations and was about 10 mg-at N/m^3.

There was a general correspondence between high concentration of chlorophyll *a* and level of primary productivity. Nitrogen limitation of primary productivity occurs in outer Kachemak Bay waters following the intense bloom in May (cf. Figure 3-11).

In addition to phytoplankton, at least two dozen attached algae and one macrophyte, eelgrass (*Zostera marina*), contribute significantly to primary production in Lower Cook Inlet. The algae occur most abundantly along intertidal and shallow subtidal rocky shores, but their distribution is not uniform around the Inlet (Fig. 3-15). The east coast of Cook Inlet supports a more diverse and more productive algal assemblage than does the west coast; algal production declines sharply along both coasts as one moves north towards the upper Inlet.

It is noteworthy that larger species such as the bull kelp (*Nereocystis luetkeana*) and ribbon kelp (*Alaria fistulosa*) are restricted to the Kennedy Entrance-Kachemak Bay region, while smaller kelps (e.g., *Laminaria, Agarum*) occur on both sides of the Inlet. These distributional variations probably reflect several differences:

- Clear ocean water flows through Kennedy Entrance into the eastern portion of Lower Cook Inlet, while the western side of the Inlet is bathed with lower salinity, more turbid water, moving seaward from the upper Inlet.

- Tidal flushing is much more vigorous in the Kennedy Entrance-Kachemak Bay area than along the coast of Kamishak Bay.

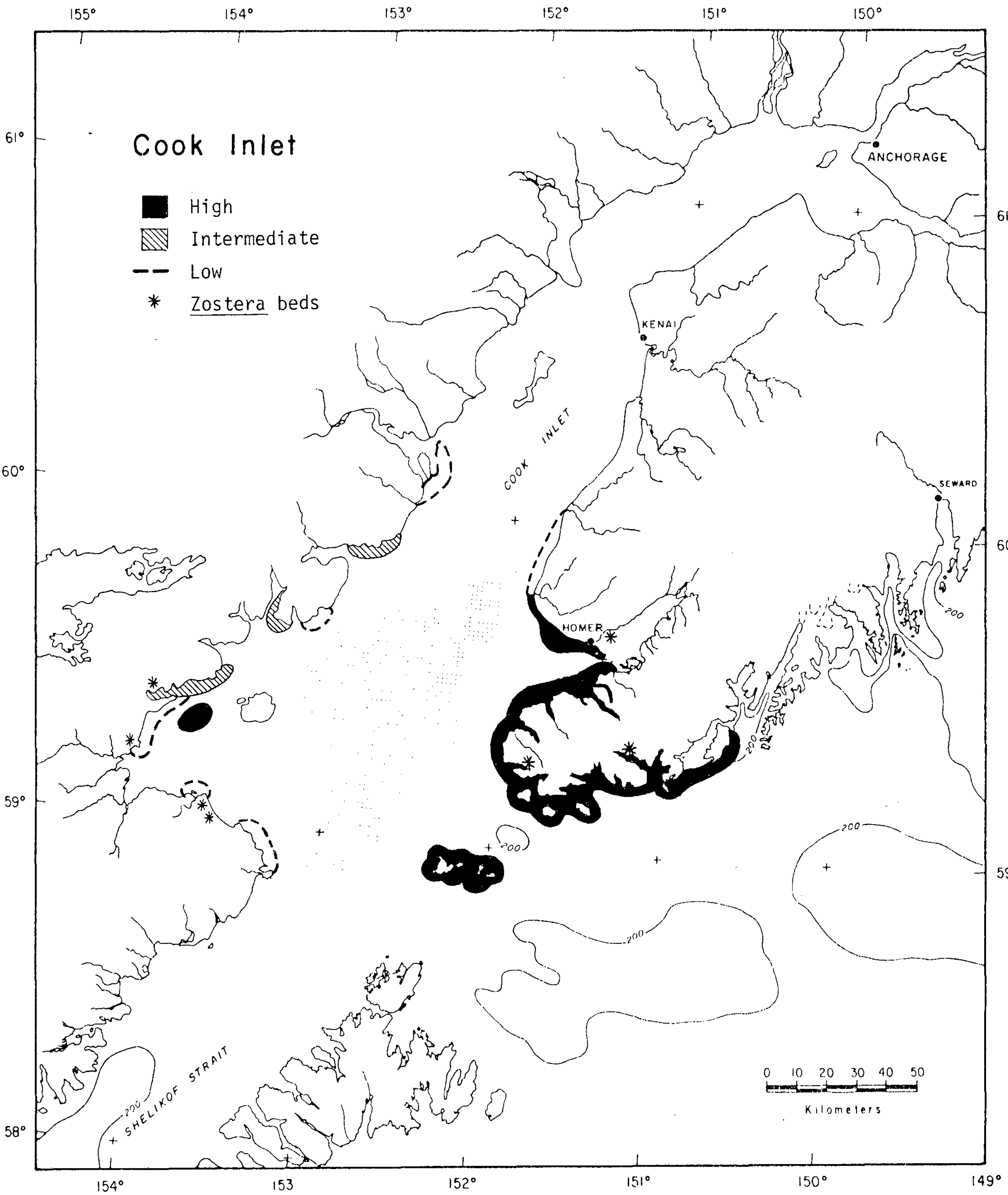


Figure 3-15 Postulated distribution and relative productivity patterns of attached intertidal and subtidal algae in Cook Inlet. (Compiled from unpublished data provided by R. Rosenthal and D. Lees, Dames & Moore, Anchorage)

- Ice scouring of intertidal substrates is an annual phenomenon in Kamishak Bay, but rarely occurs along the coast of outer Kachemak Bay or the Kenai Peninsula.

- Suitable macrophyte substrates (rock outcrops, boulders, cobbles) appear to be more common along the east than the west coast of the Inlet.

R. Wright (Governor's Office, Juneau, personal communication, 1976) notes that algal mats typically develop on intertidal flats in the upper Inlet during the summer months. Jackson (1970) recorded several filamentous green and bluegreen algae (*Cladophora* sp., *Enteromorpha* sp., *Oscillatoria* sp., *Ulothrix* sp., and *Vaucheria* sp.) from these habitats. Diatoms are also often important intertidal plants in mudflats.

Lower Cook's intertidal and subtidal algae exhibit various seasonal patterns of growth and reproduction much like those of land plants. For example, the ribbon and bull kelps (*Alaria* and *Nereocystis*, respectively), are both effectively annual species. In fact, *Alaria* is a perennial genus, but winter conditions remove most of the plants in the beds. The abundance of juvenile plants and plant growth rates both peak in the spring; adult plants are best developed from May through October. *Agarum cribrosum* and *Laminaria* spp., on the other hand, are perennials, present year-round. In these genera growth rates peak in winter.

Intertidal algae and offshore kelp beds provide food for herbivorous macroinvertebrates, particularly the urchin, *Strongylocentrotus* spp. More importantly the larger algae, increasingly abraded and torn adrift by wind, wave, and storm action, also provide organic detritus for suspension and deposit feeding invertebrates. R. Wright (Governor's Office, Juneau, personal communication, 1976) notes that matted clumps of algal debris are sometimes seen in the upper Inlet, having drifted in from the kelp beds to the south. In addition to food and detritus, the macroalgae provide protective cover for benthic invertebrates, attachment sites for eggs and larvae, and habitat for certain nearshore forage fish (cf. Limbaugh, 1955).

The broad-leaved eelgrass, *Zostera marina*, is typical of shallow bays and estuaries but only occurs sparsely in Cook Inlet. In Kamishak Bay *Zostera* regenerates from buried root systems each summer, but the leaves are removed each winter by ice scouring. Eelgrass is present year-round on protected flats behind Homer Spit and in some of the inlets along the Kenai Peninsula (Fig. 3-15). Koyuktolik Bay Lagoon, for example, contains about the fifth largest eelgrass bed in Alaska.

Intertidal salt marshes also contribute to primary production in Cook Inlet. The larger of these wetlands include the Fox River Flats at the head of Kachemak Bay and several areas near Anchorage. In Pacific Coast bays and estuaries *OUTSIDE* Alaska, coastal wetlands (salt marshes, tidal creeks, and tide flats) are known to export nutrients and organic detritus to adjacent marine environments, to provide spawning and nursery areas for certain forage fish, and to provide feeding grounds, flight staging areas and nesting grounds for migratory waterfowl and shorebirds. The relative significance of these possible roles still remains to be determined for Cook Inlet wetlands but their possible biological contributions should not be overlooked. Recent papers by Blumer *et al.* (1972, 1973) and the National Academy of Sciences (1975) indicate that crude oils washed ashore at wetland sites can enter both sediments and food webs, causing adverse effects that may persist for a number of years.

Probably at least as important as coastal wetlands in Lower Cook Inlet, especially on the west side of the Inlet, is the contribution of organic debris of terrestrial origin from the major rivers and numerous other watersheds. The importance of such material has been recognized elsewhere. In British Columbia, for example, Sibert *et al.* (1977) report that fry of chum salmon feed mainly on benthic harpacticoid copepods, rather than on planktonic forms, and are therefore tied in closely at the end of a detritus-based food chain. This is an important finding with considerable relevance to Lower Cook Inlet (D. Lees, Dames and Moore, Anchorage, personal communication).

Zooplankton

Knowledge of zooplankton species (biomass, communities and their ecological significance in Cook Inlet) is limited. A preliminary list of zooplankton species identified from irregularly collected samples (1962-65) from Sadie Cove, Kasitna Bay, Tutka Bay, and Kachemak Bay is provided by Wing and Hoffman (1976). These authors reported that meroplankton species, which spend only a portion of their life cycle in the plankton, were significant components to the zooplankton community; however, holoplankton such as copepods, euphausiids, and chaetognaths were major contributors to biomass. The copepods, *Pseudocalanus minutus* and *Acartia longiremis* were the two most abundant species and were found to be present year-round. In a few samples, *Acartia longiremis* contributed over 60% of total number of zooplankters. Small numbers of *Calanus cristatus* and *Calanus plumchrus*, characteristic species of deeper oceanic waters in the northern Pacific, were also observed. It would appear that these species, along with others, are advected into the Inlet via the Gulf of Alaska waters. Peak seasonal abundance of both the holoplankton and meroplankton was noted from May through July, usually the period of highest phytoplankton primary productivity.

Damkaer (RU #425a, 1976) has provided preliminary results from zooplankton samples collected from April to August 1976. The average settled volumes for the upper 25 m in Kachemak Bay increased from 0.3 $\mu\ell/m^3$ (April 7-8) to 31.0 $\mu\ell/m^3$ (May 7) in about a month and then declined to < 6 $\mu\ell/m^3$, from late May to August. Mid-channel in Lower Cook Inlet, a minimum value of 0.5 $\mu\ell/m^3$, was noted on April 7-8 and a maximum value of 10.4 $\mu\ell/m^3$, on July 11. The variable amount of phytoplankton in net samples from different locations and at different sampling periods did not afford a meaningful comparison of data.

Benthic Invertebrates

Studies by Rosenthal and Lees (RU #417, 1976) are providing the first reasonably complete description of the distribution and species composition of Cook Inlet intertidal and shallow subtidal invertebrate faunas.

The distribution of geological substrate types around the shores of Cook Inlet (Fig. 3-16) is quite variable. Mixtures of cobbles, gravel, and sand predominate; mudflats are rare along the east coast, but occur at the heads of several west coast inlets (e.g., Iliamna, Chinitna, and Tuxedni Bays).

The most abundant intertidal organisms associated with different substrate types are listed in Table 3-2. Epifaunal suspension feeders dominate rock and cobble habitats. Attached forms include sponges, bryozoans, mussels, and barnacles; mobile species include chitons, snails,