Environmental Assessment of the Alaskan Continental Shelf

Interim Lower Cook Inlet Synthesis Report

December 1977

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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).

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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

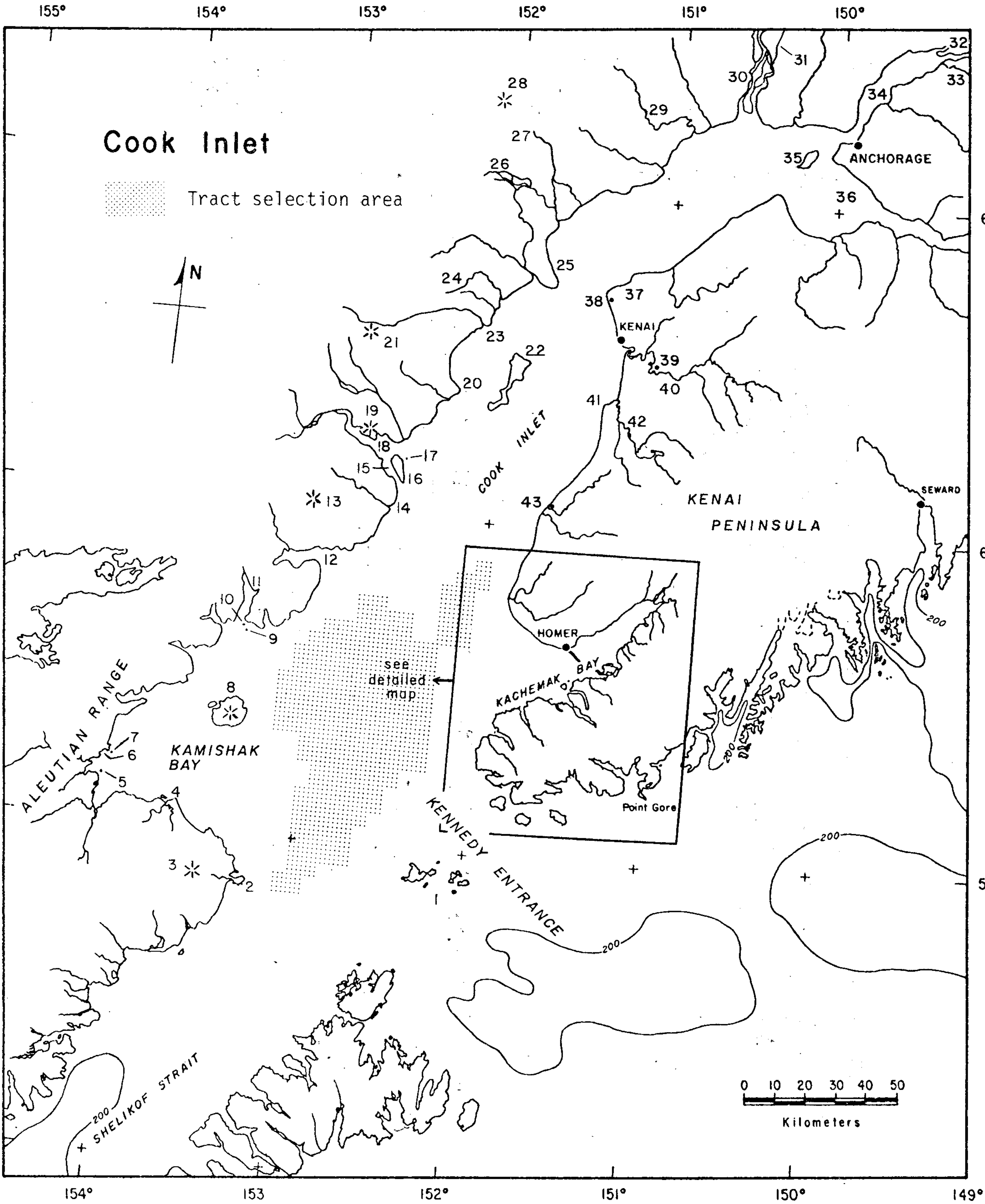
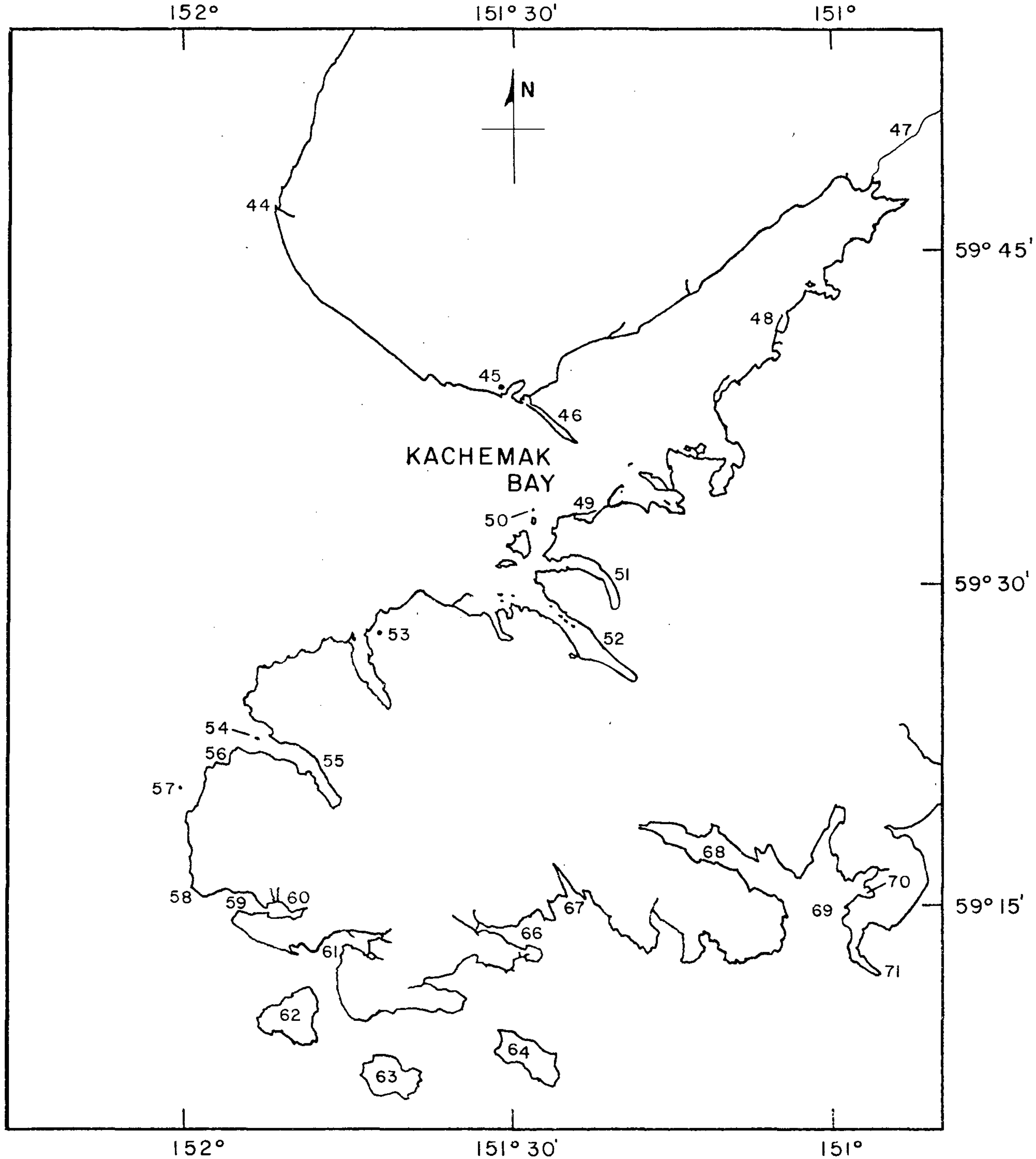

Cook Inlet
Tract selection area
N
ANCHORAGE
KENAI
HOMER
SEWARD
COOK INLET
KENAI PENINSULA
KACHEMAK BAY
Point Gore
see detailed map
KENNEDY ENTRANCE
KAMISHAK BAY
ALEUTIAN RANGE
SHELIKOF STRAIT
200
0 10 20 30 40 50
Kilometers
155° 154° 153° 152° 151° 150°
61° 60° 59° 58°
154° 153 152° 151° 150° 149°

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.

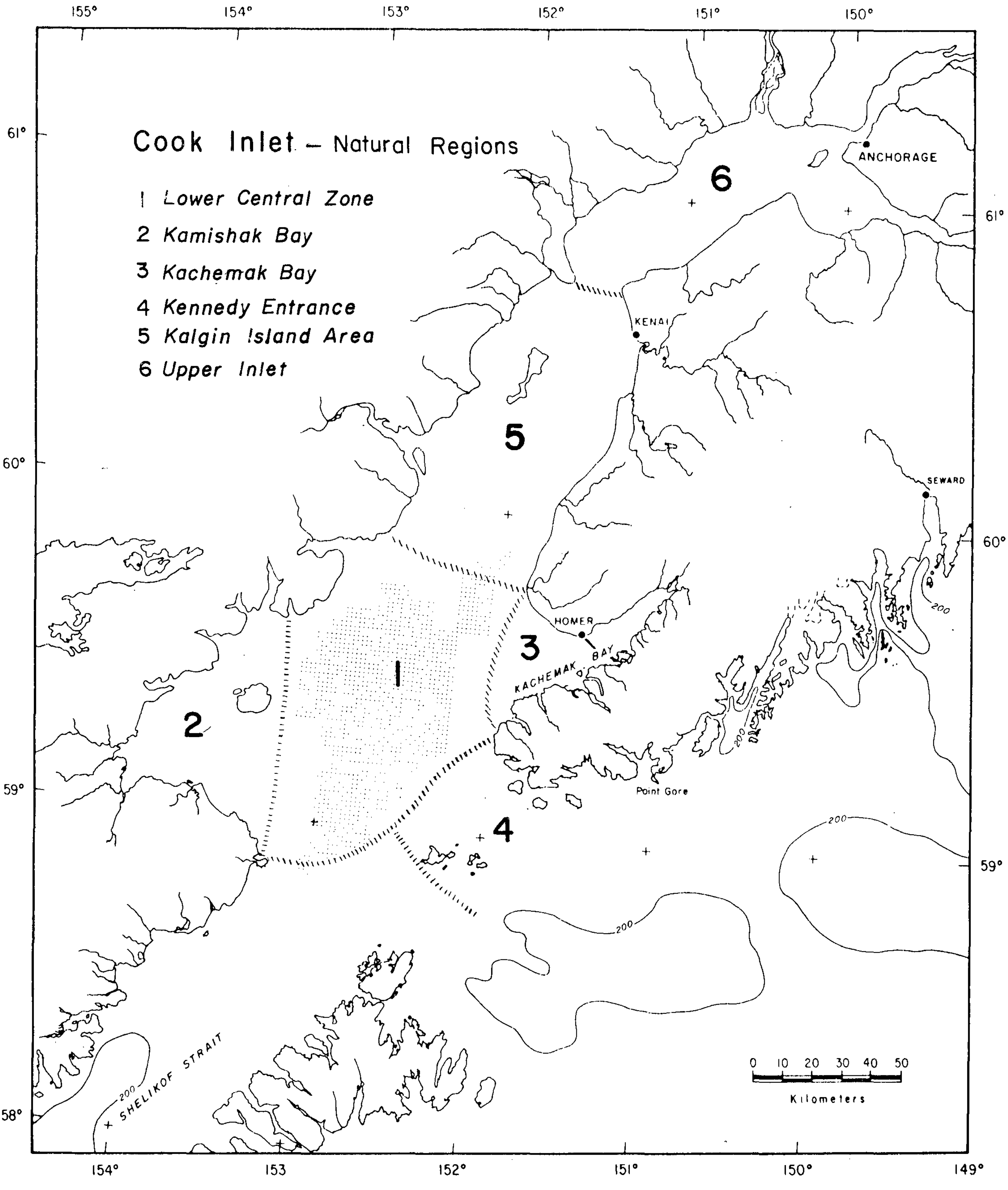


Figure 2-1 Cook Inlet natural regions. See text for additional explanation

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

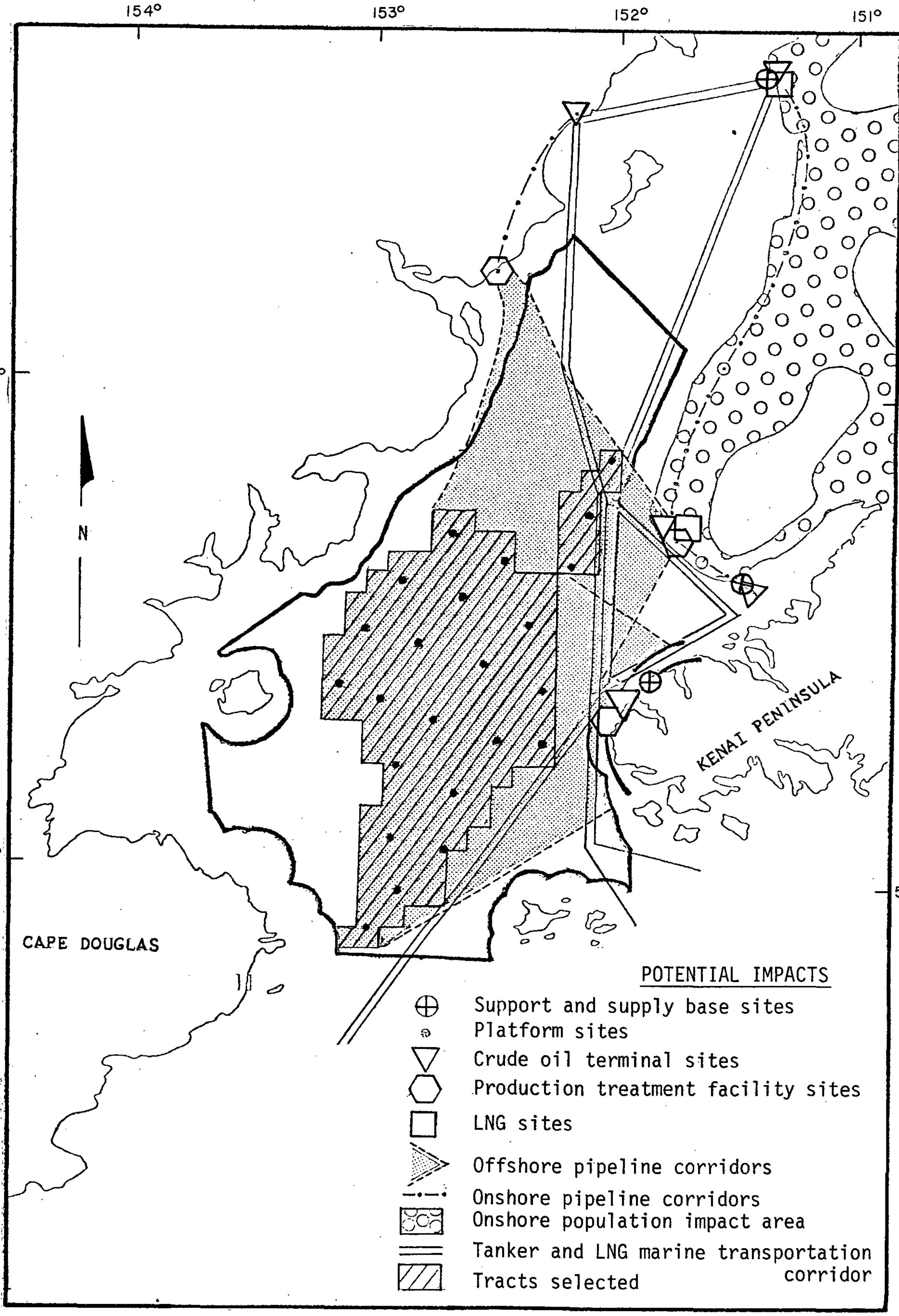


Figure 2-2 Potential locations of impacts resulting from the petroleum development scenario. Figure provided by BLM/Alaska OCS Office, Anchorage; see Appendix 2 for complete explanation

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.

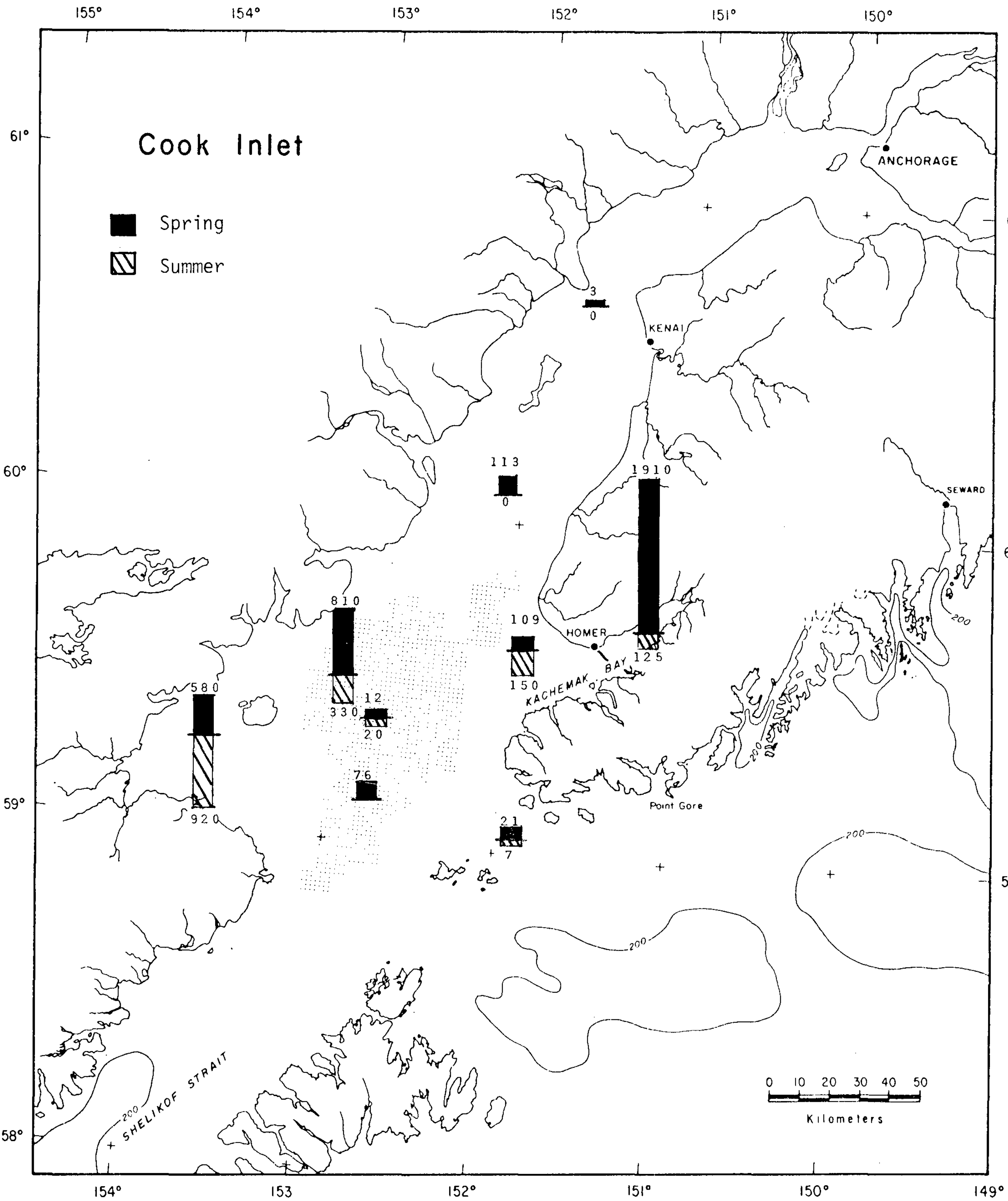


Figure 2-3 Ichthyoplankton distribution in spring (solid) and summer (hachured). Horizontal line indicates sample location; length of bar above/below line proportional to numbers of fish eggs collected per bongo net tow, using standard MARMAP methods. (Adapted from unpublished data provided by T. English, 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

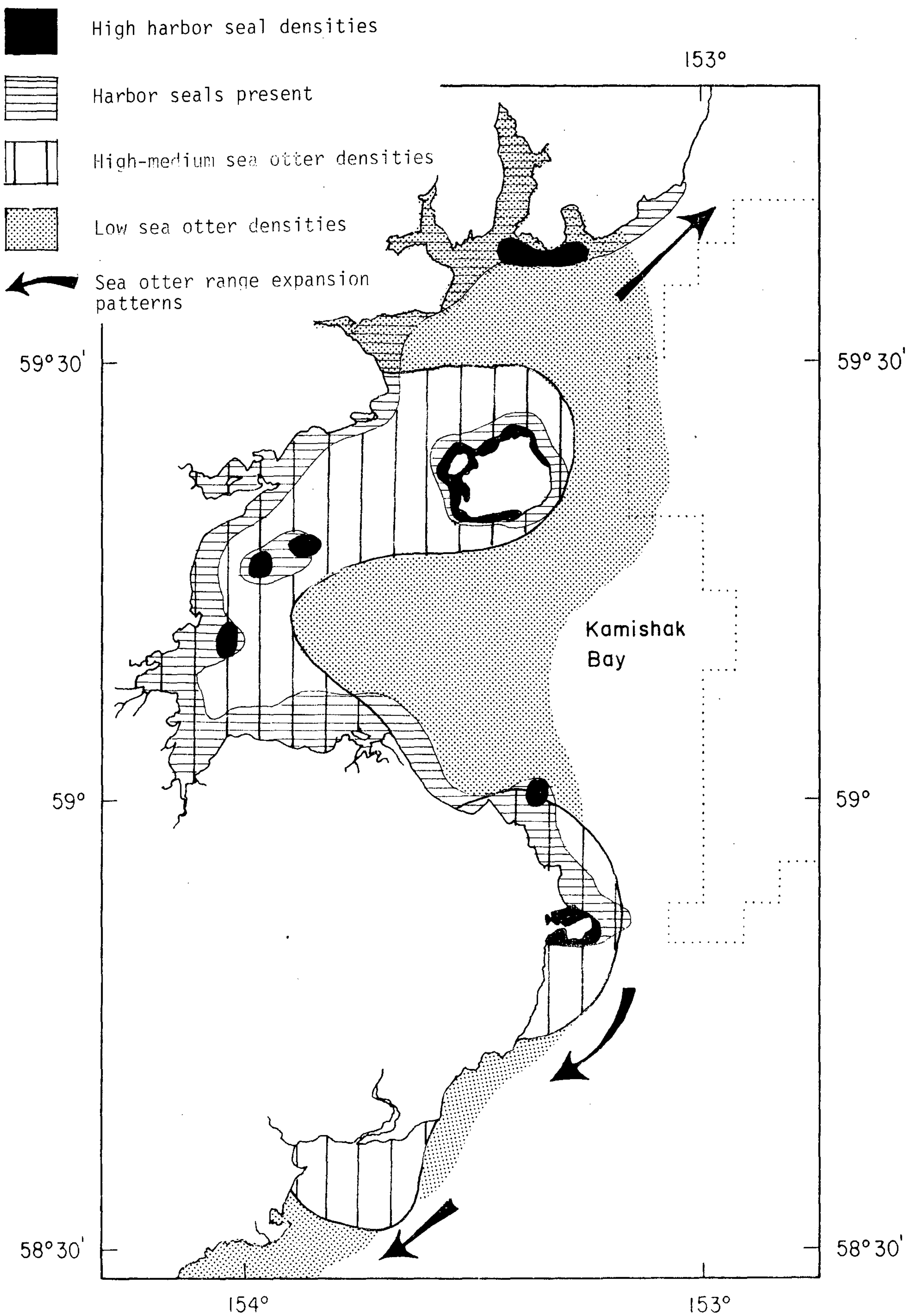


Figure 2-4 Kamishak Bay: graphic summary of selected marine mammal data. (Compiled from data provided by K. Pitcher and K. Schneider, ADF&G, Anchorage.)

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).

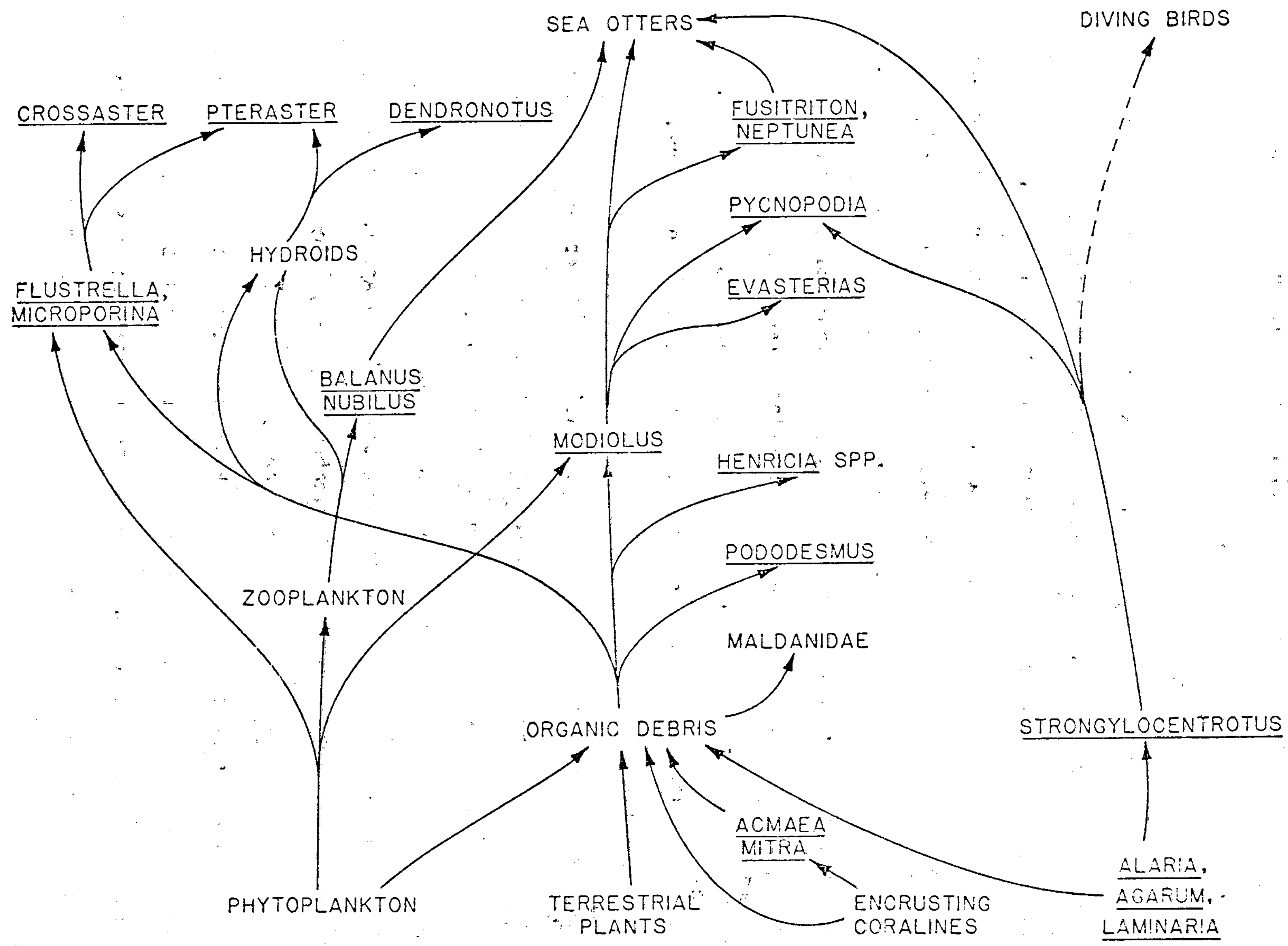
Possibly longer residence time of populations due to the gyral circulation, the very high primary production, and a rich source of organic detritus all contribute to an abundant zooplankton community. Meroplankton -- larval states of tanner, king, and dungeness crabs, several species of shrimp (Haynes 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.



FOOD WEB FOR THE CHARACTERISTIC SPECIES OFF THE BLUFF POINT–DIAMOND RIDGE AREA

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

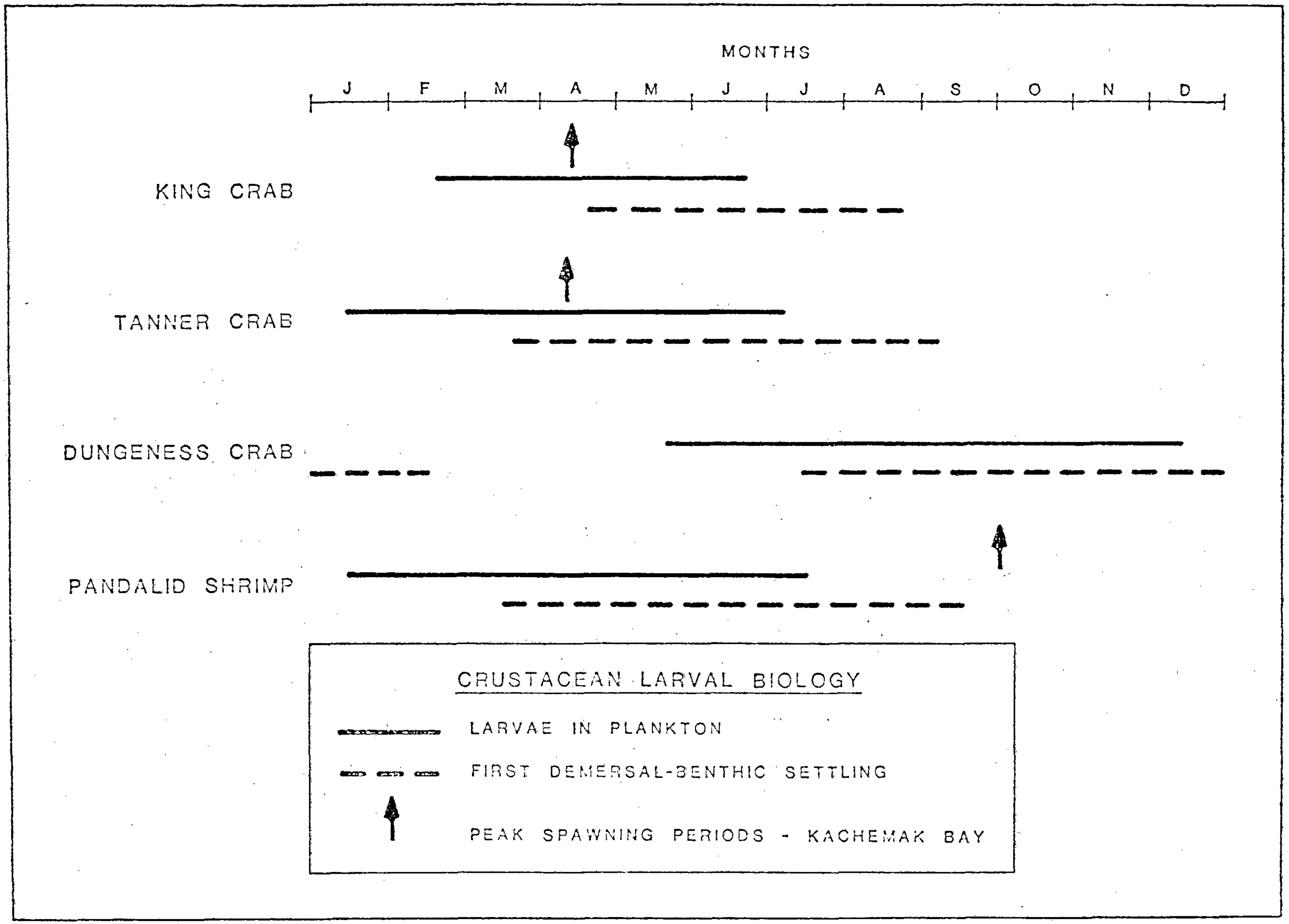


Figure 2-6 Lower Cook Inlet, crustacean larval biology (ADF&G, Vol. 2, 1976)

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

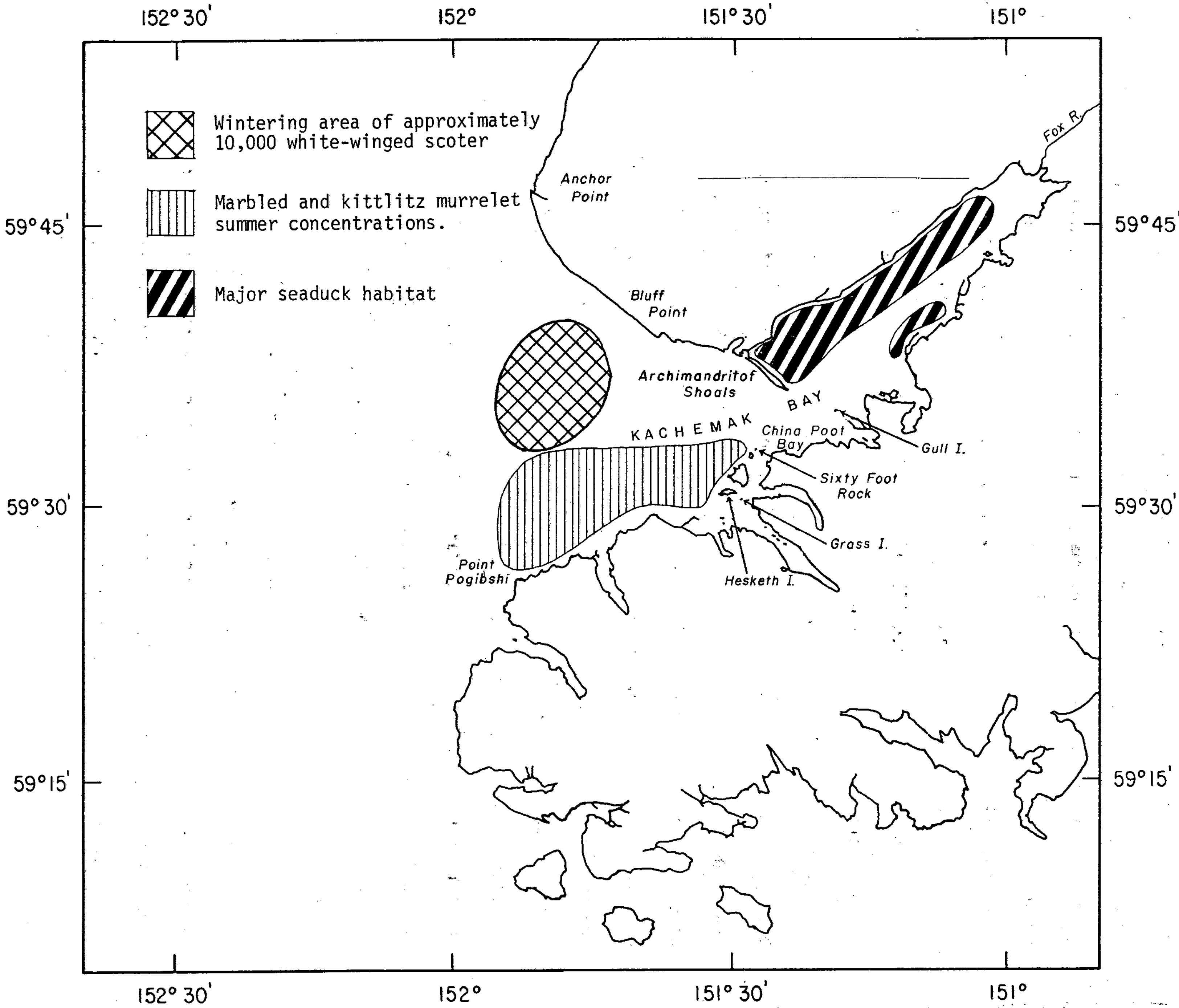


Figure 2-7 Kachemak Bay graphic summary of selected bird use data. (Compiled from unpublished data provided by D. Erikson and P. Arneson, ADF&G, Anchorage)

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.

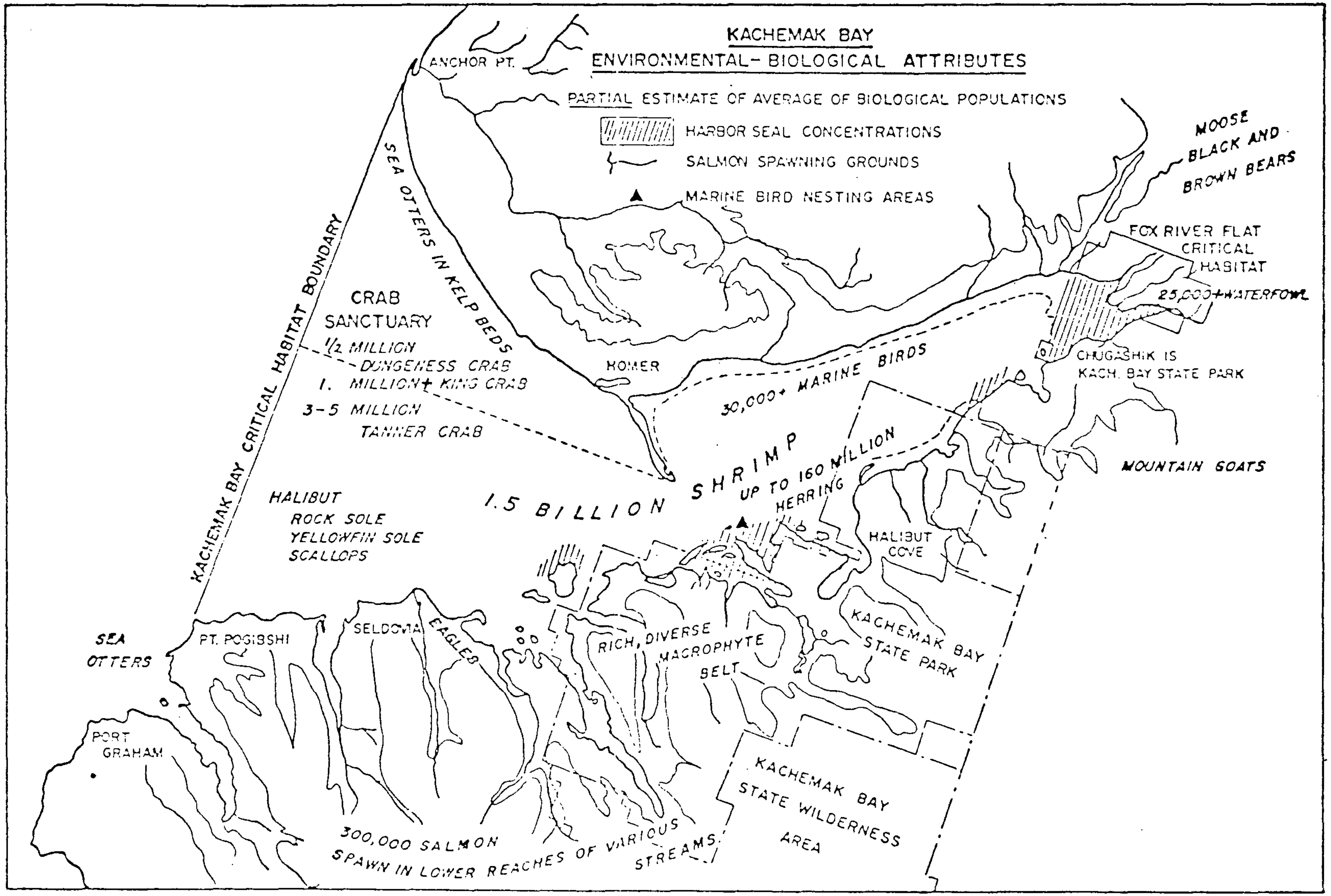


Figure 2-8 Kachemak Bay: graphic summary of environmental/biological attributes (M. Wennekens, AEIDC, Anchorage, personal communication)

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.

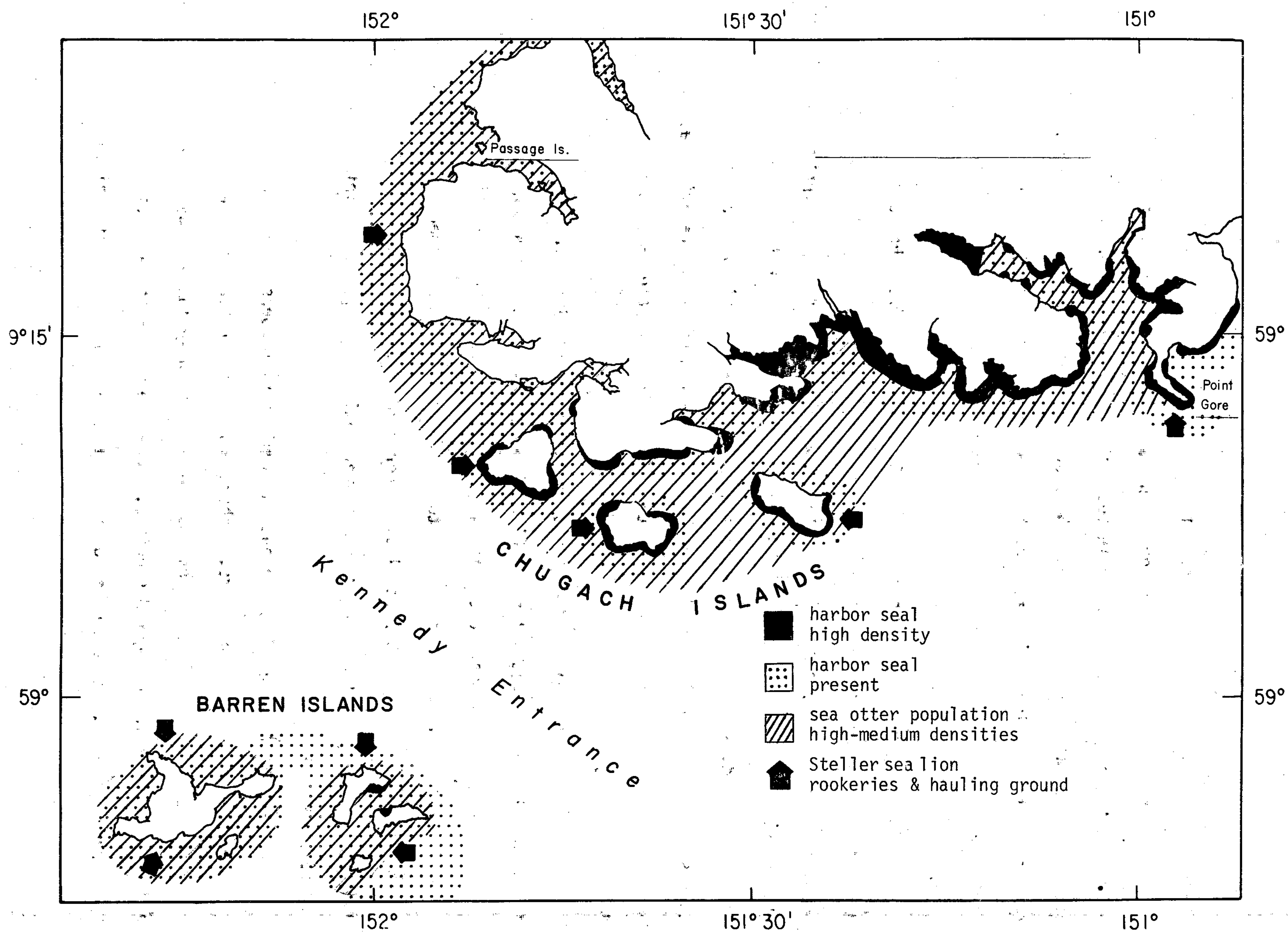


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Figure 2-9 Kennedy Entrance: graphic summary of selected marine mammal data. (Compiled from data provided by K. Pitcher and K. Schneider, ADF&G, Anchorage)

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.

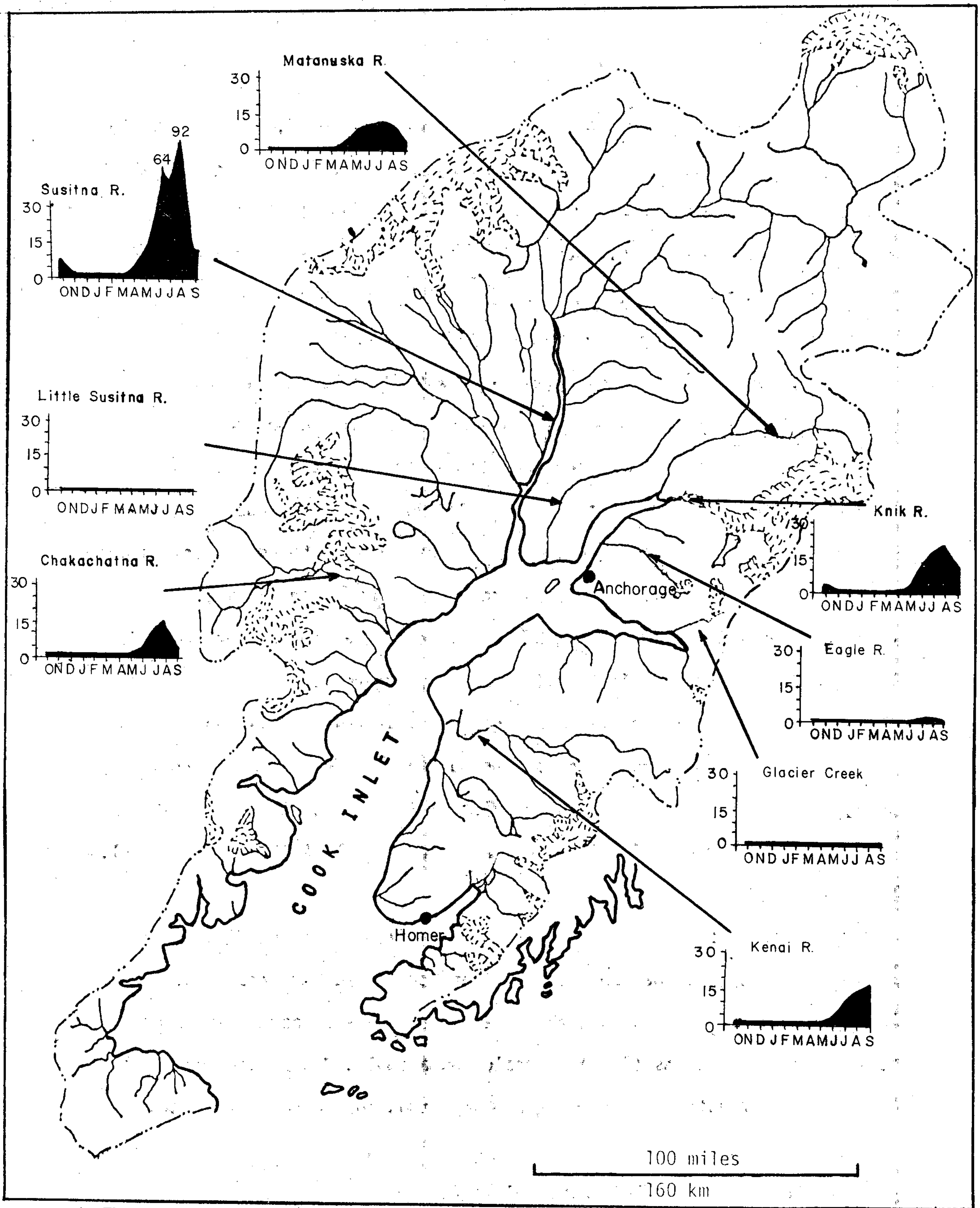


Figure 3-1 Cook Inlet watershed (AEIDC, 1974) and river runoff data (Sharma *et al.*, 1974). Runoff plotted is monthly mean water discharge (1000 m^3/sec) during 1967

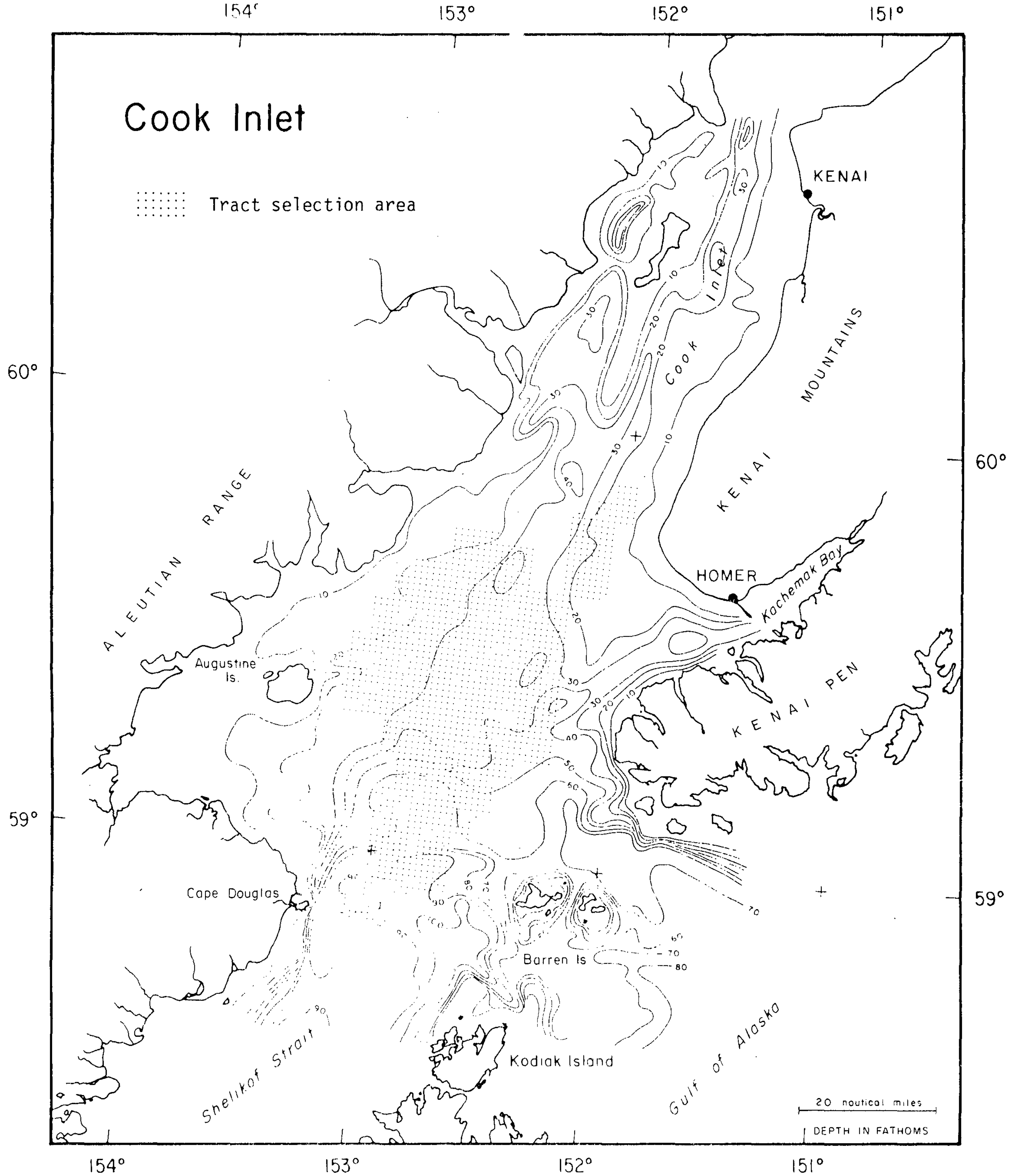


Figure 3-2 Cook Inlet preliminary bathymetry

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

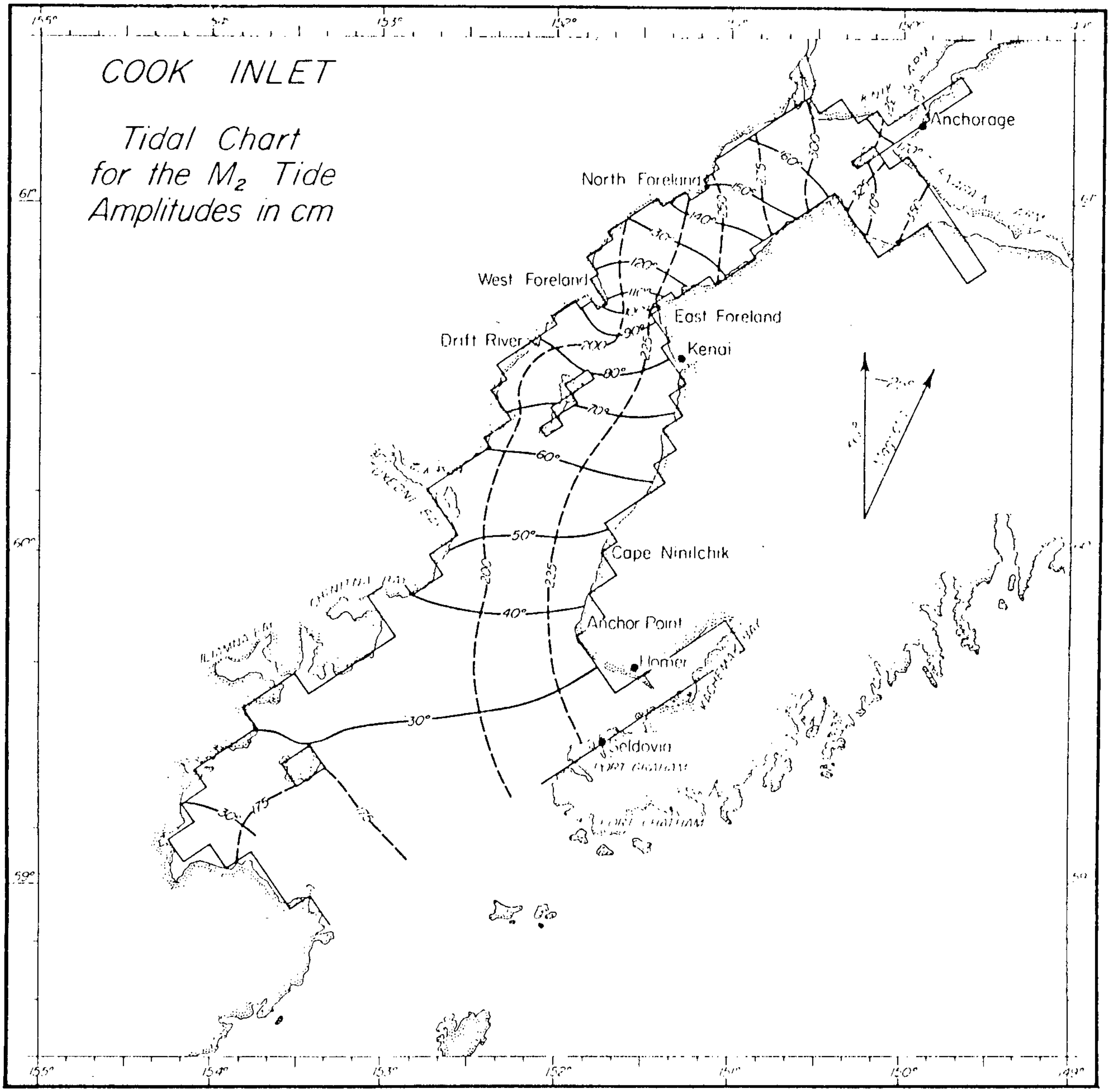


Figure 3-3 Cook Inlet: tidal height (co-amplitude lines, in cm) and tidal phase (co-phase lines, in degrees) contours for the main lunar (M_2) tide (Mungall 1973)

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.

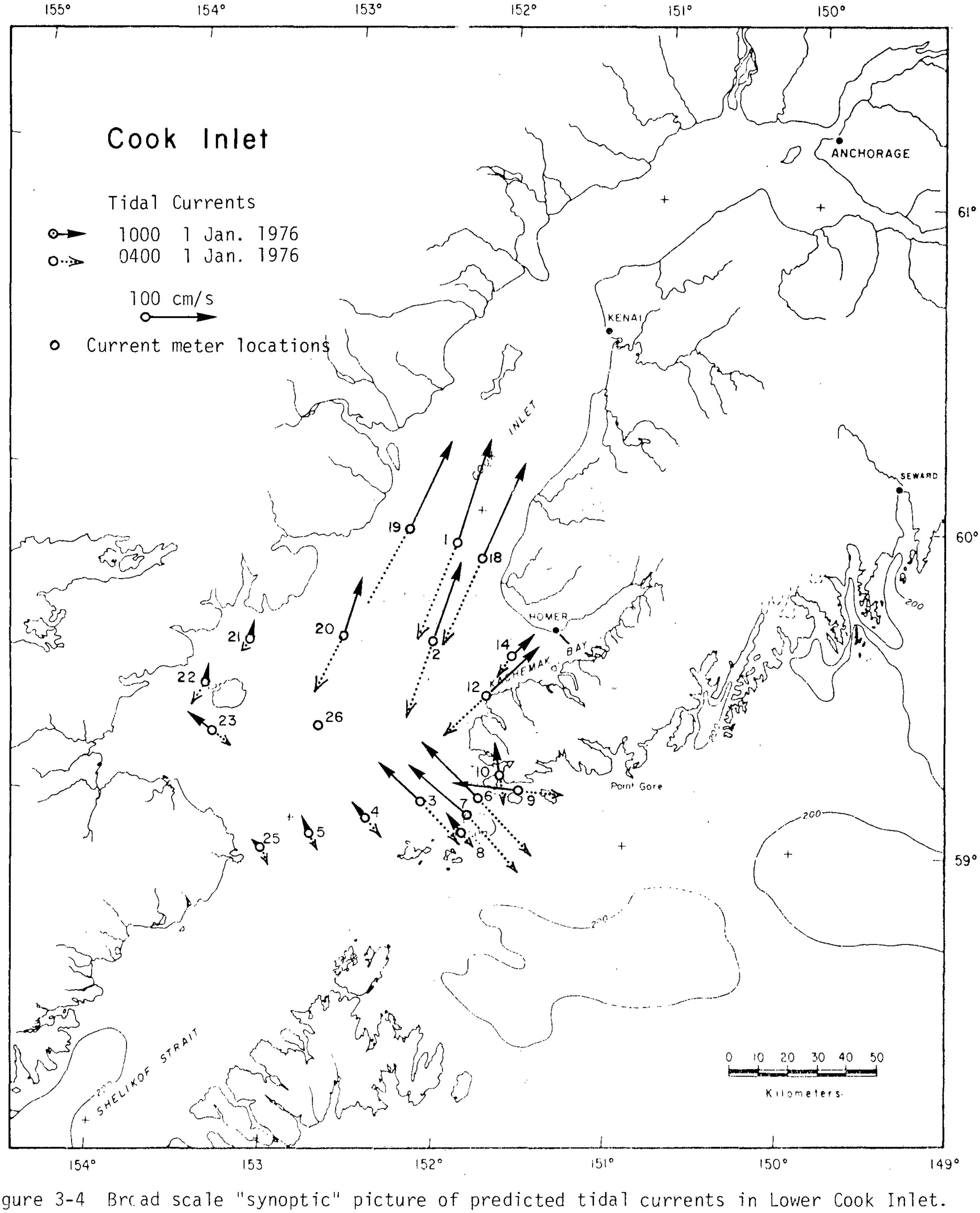


Figure 3-4 Brcad scale "synoptic" picture of predicted tidal currents in Lower Cook Inlet. Response analysis, utilizing predictive tidal functions, was used to project current fields on an arbitrarily chosen date, January 1, 1976 (Redrawn from figures provided by NOAA/PMEL.)

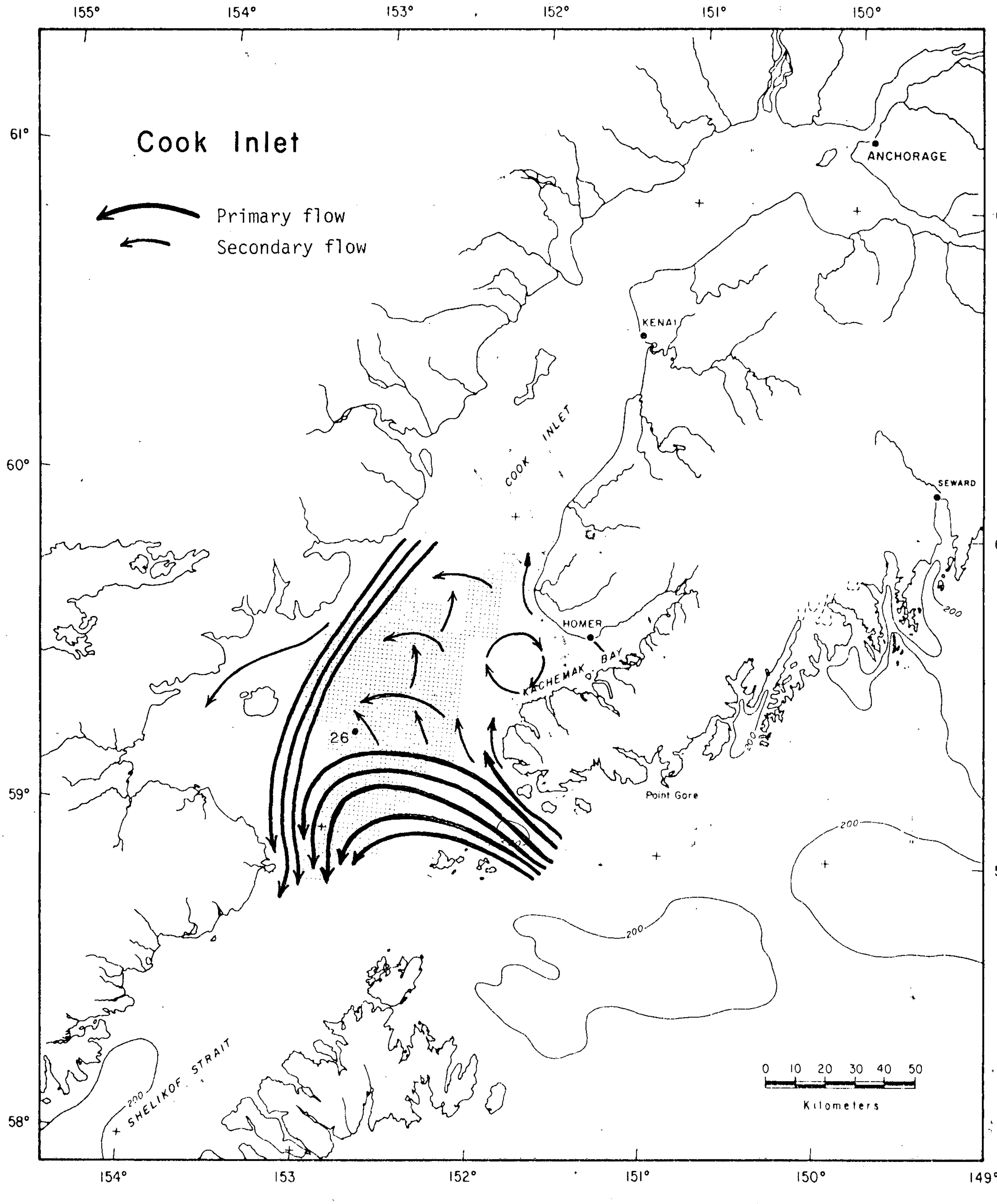


Figure 3-5 Lower Cook Inlet flow regime as derived from hydrographic and current data obtained during summer 1973. Note that the westward primary flow roughly parallels the 100 m depth contour. (Redrawn from an unpublished figure provided by R. Charnell, NOAA/PMEL) See text

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.

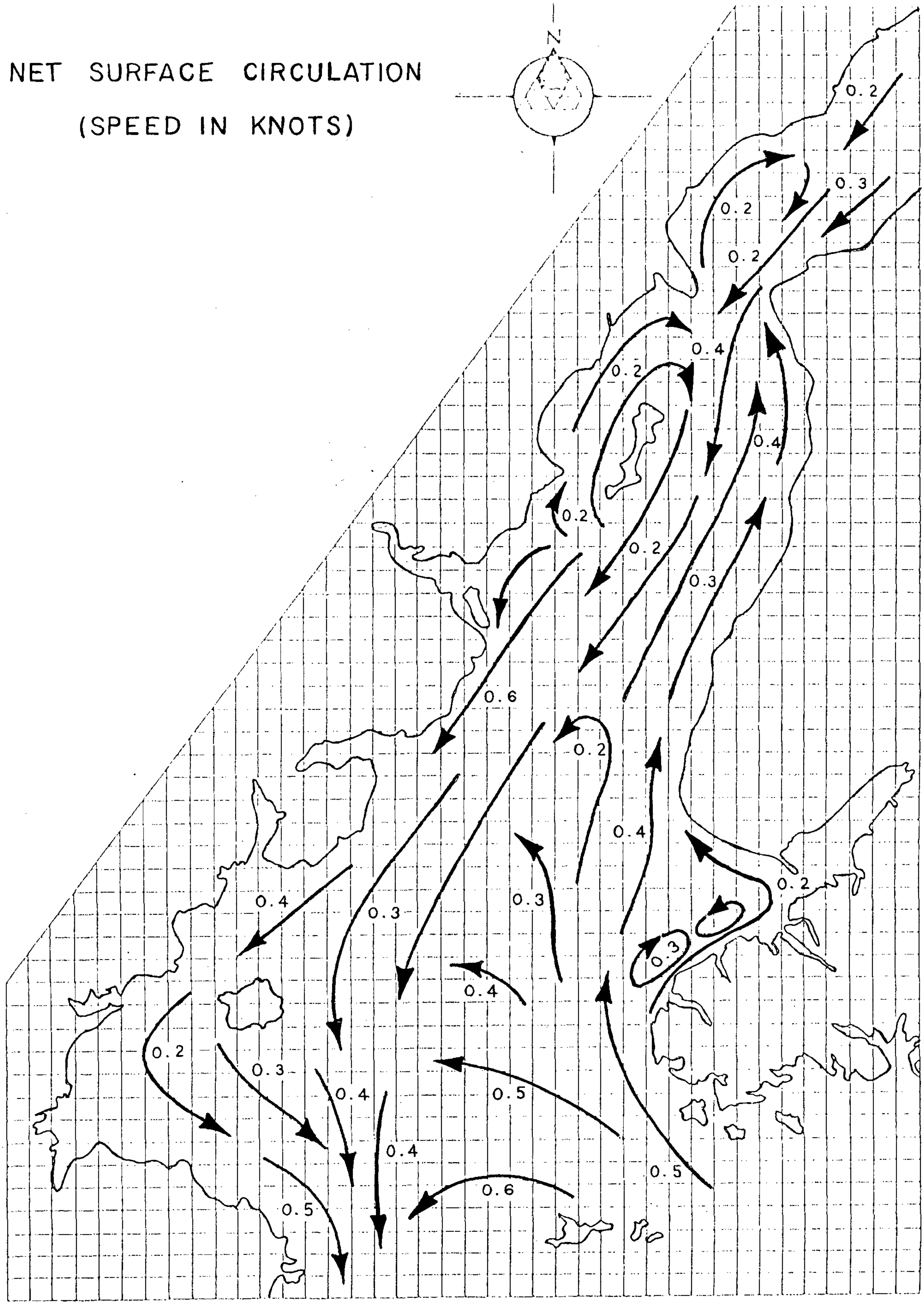


Figure 3-6 Cook Inlet circulation scheme developed for the Dames and Moore oil spill trajectory model (R. Miller, 1976). See text for additional explanation

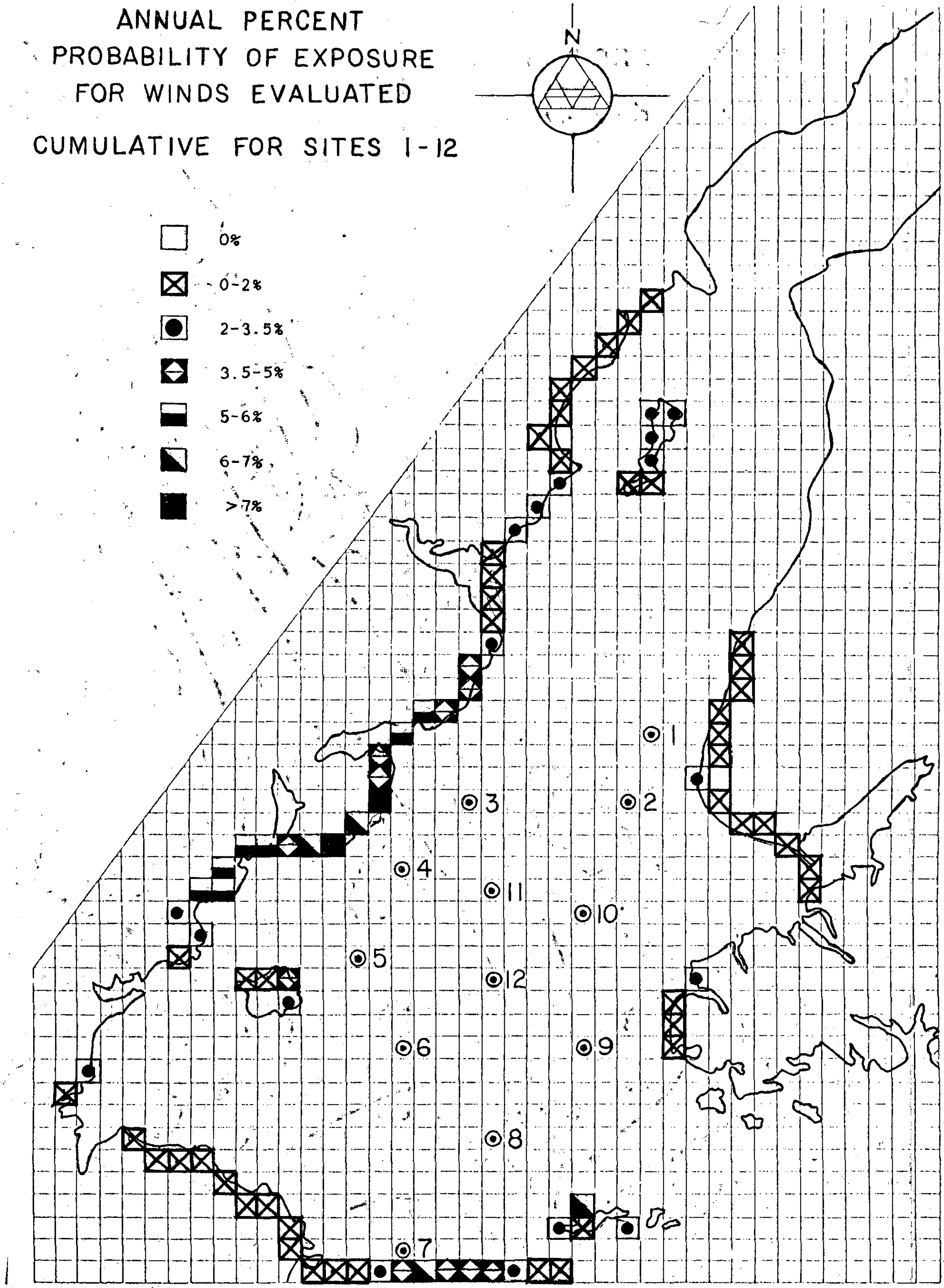


Figure 3-7 Cumulative probabilities of shoreline impacts based on 384 simulated oil spill trajectories using the Dames and Moore model (Miller, 1976). See text for additional explanation

- 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.

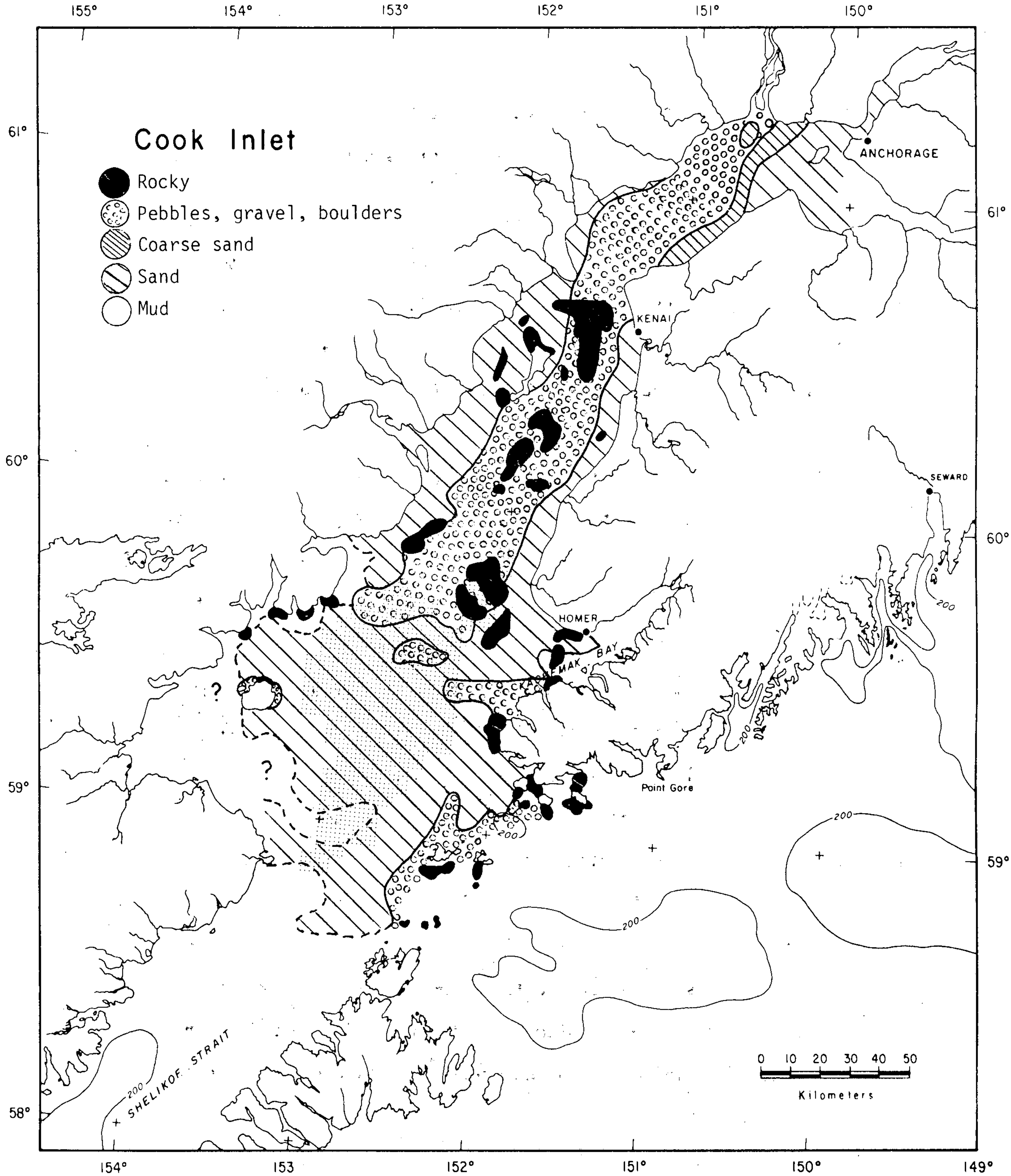


Figure 3-8 Bottom sediment distribution in Cook Inlet. Compiled from preliminary data from Sharma and Burrell (1970), Hampton and Bouma (RU #327, 1976-) and USDI (1976)

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.

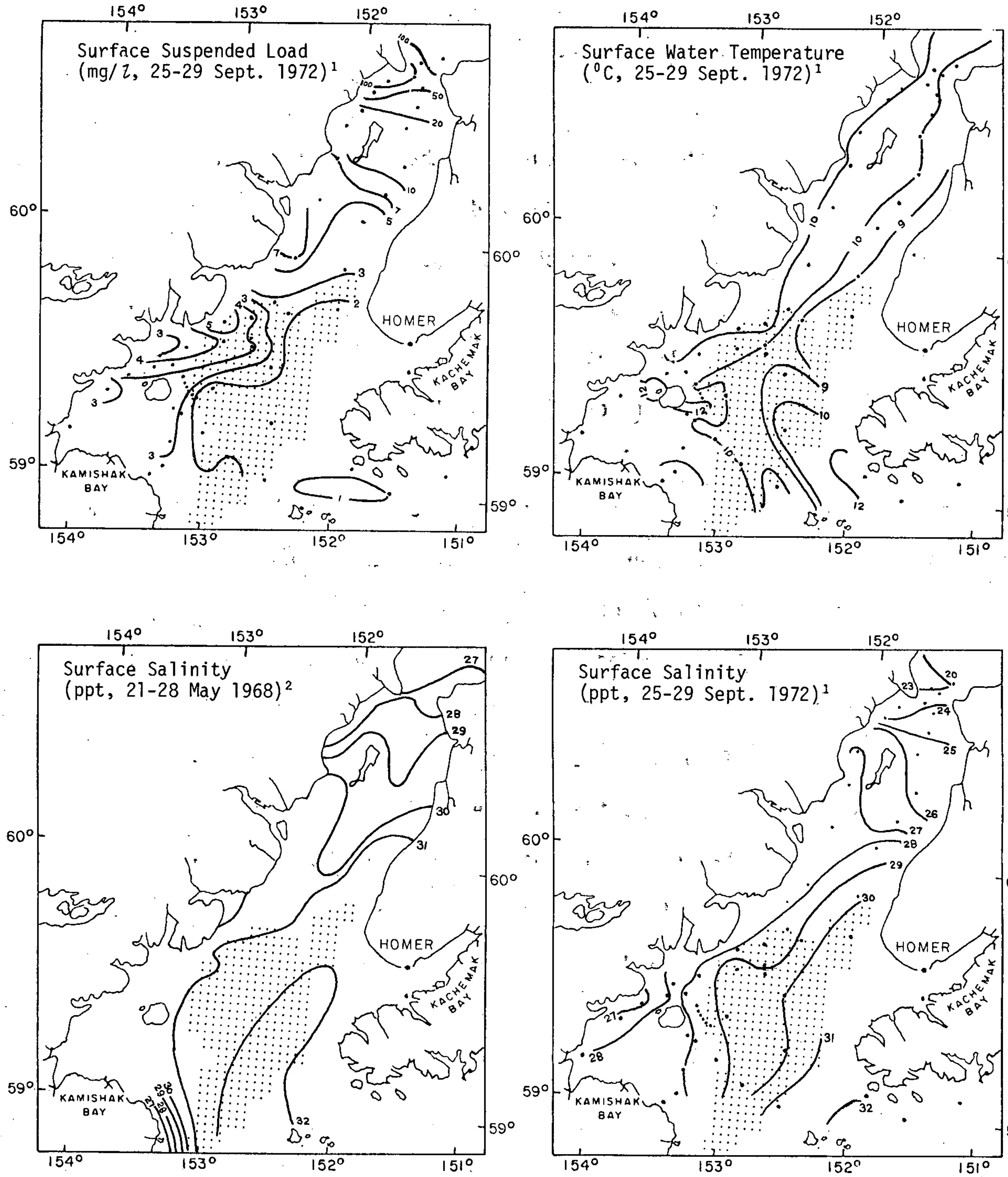


Figure 3-9 Lower Cook Inlet: selected hydrographic data

[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 Ertrance 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.

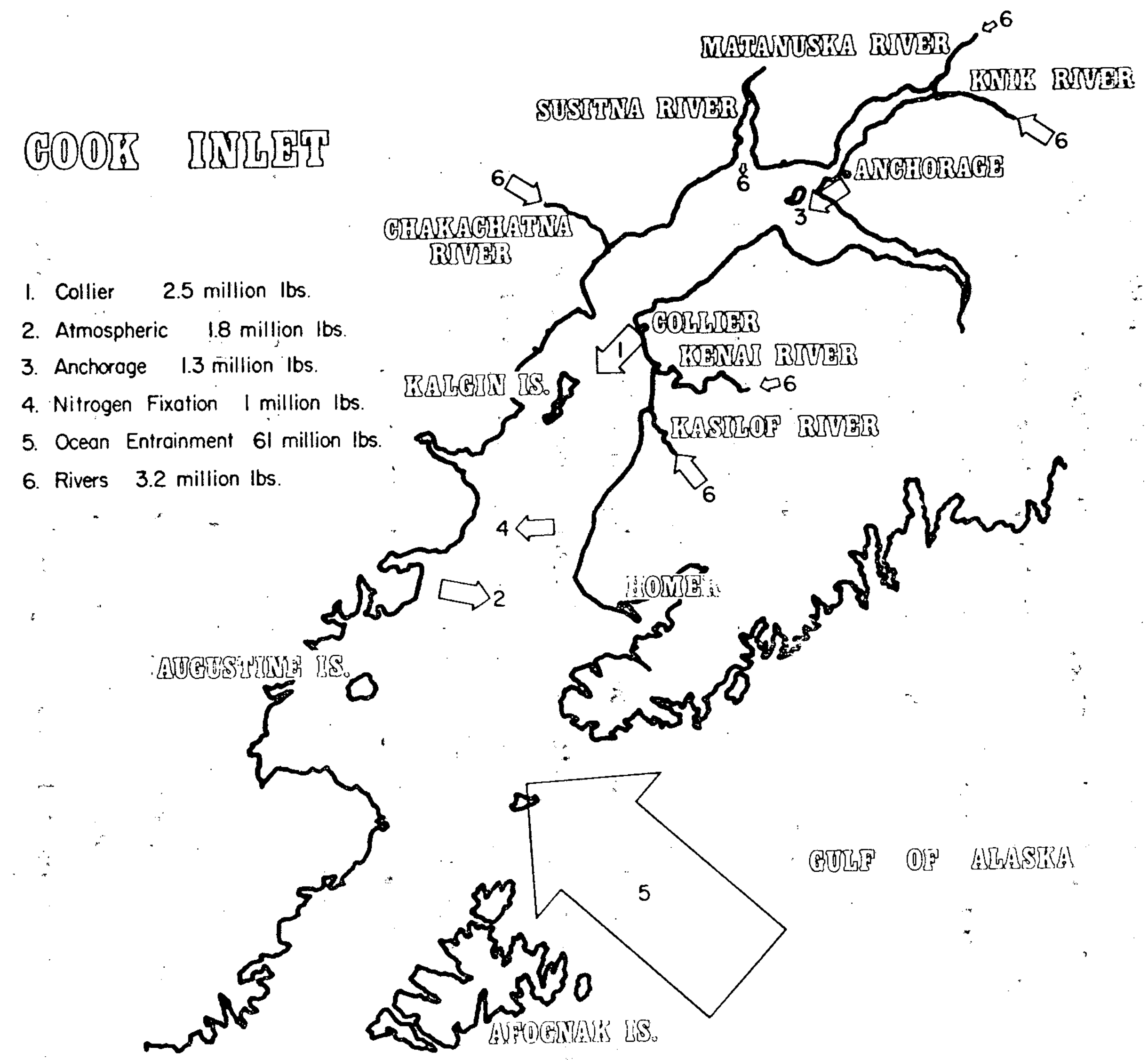


Figure 3-10 Ammonia Inputs to Cook Inlet (Smith *et al.* 1975)

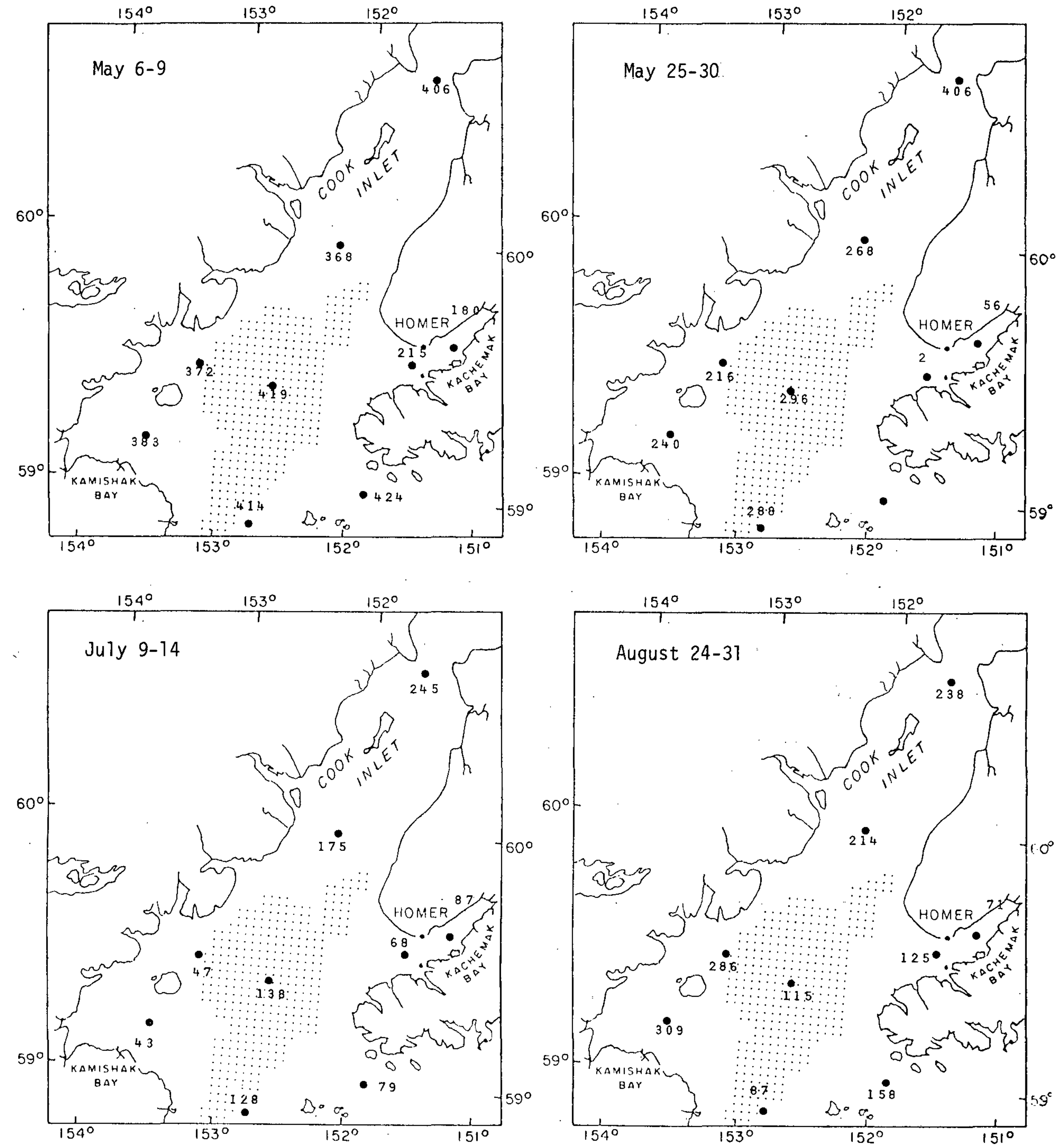
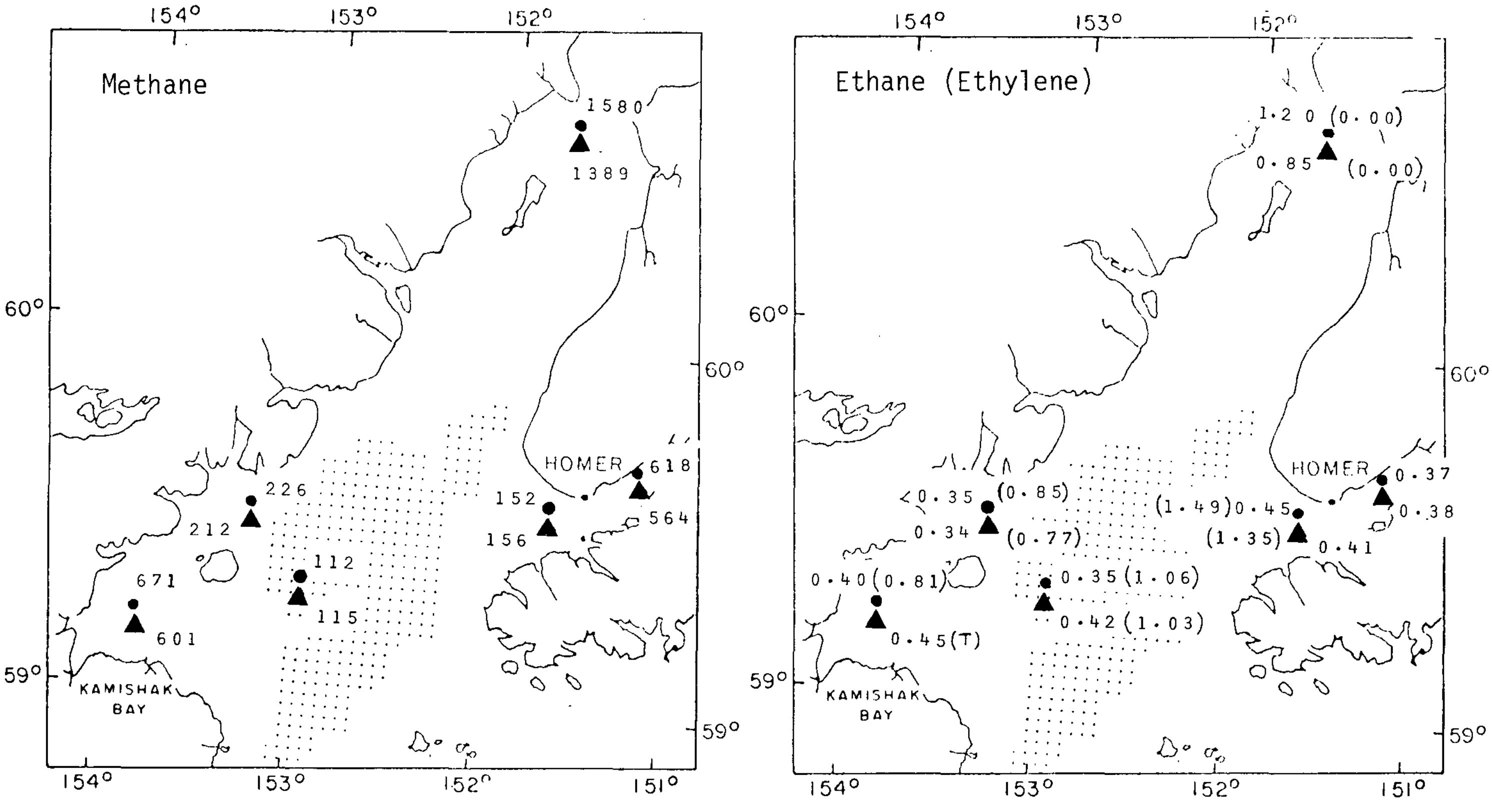


Figure 3-11 Nitrate values in the upper 25 m of the water column. Numbers represent mg at-m^2; divide by 25 for mg at/m^3. (Unpublished data provided by J. Larrance, RU #425b, NOAA/PMEL)

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.



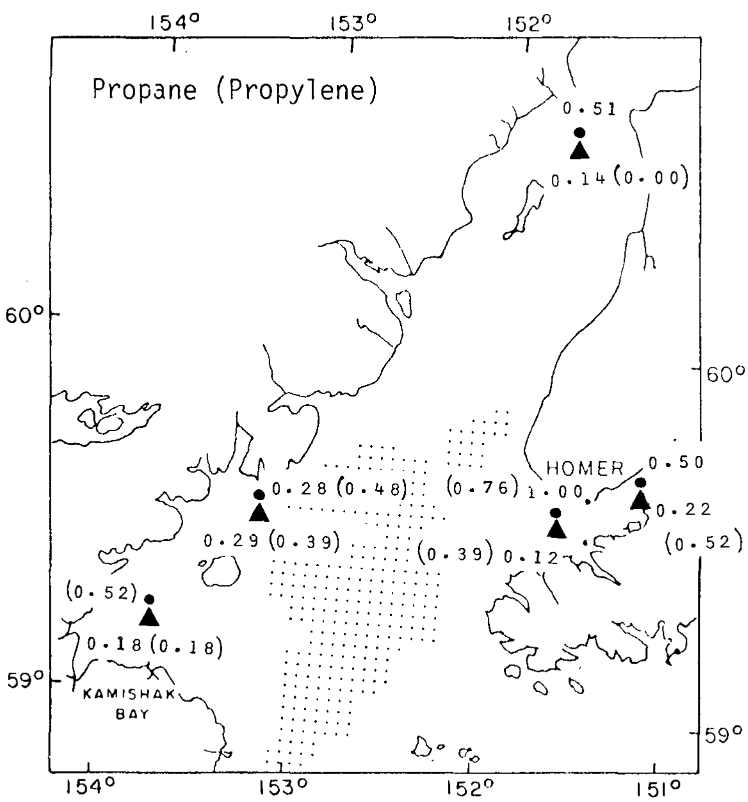


Figure 3-12 Concentrations of selected light molecular weight hydrocarbons (nℓ/ℓ) in surface (●) and near bottom (▲) waters of Lower Cook Inlet during April 1976 (Modified after Cline and Feely, RU #152, 1976)

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 nℓ/ℓ), 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

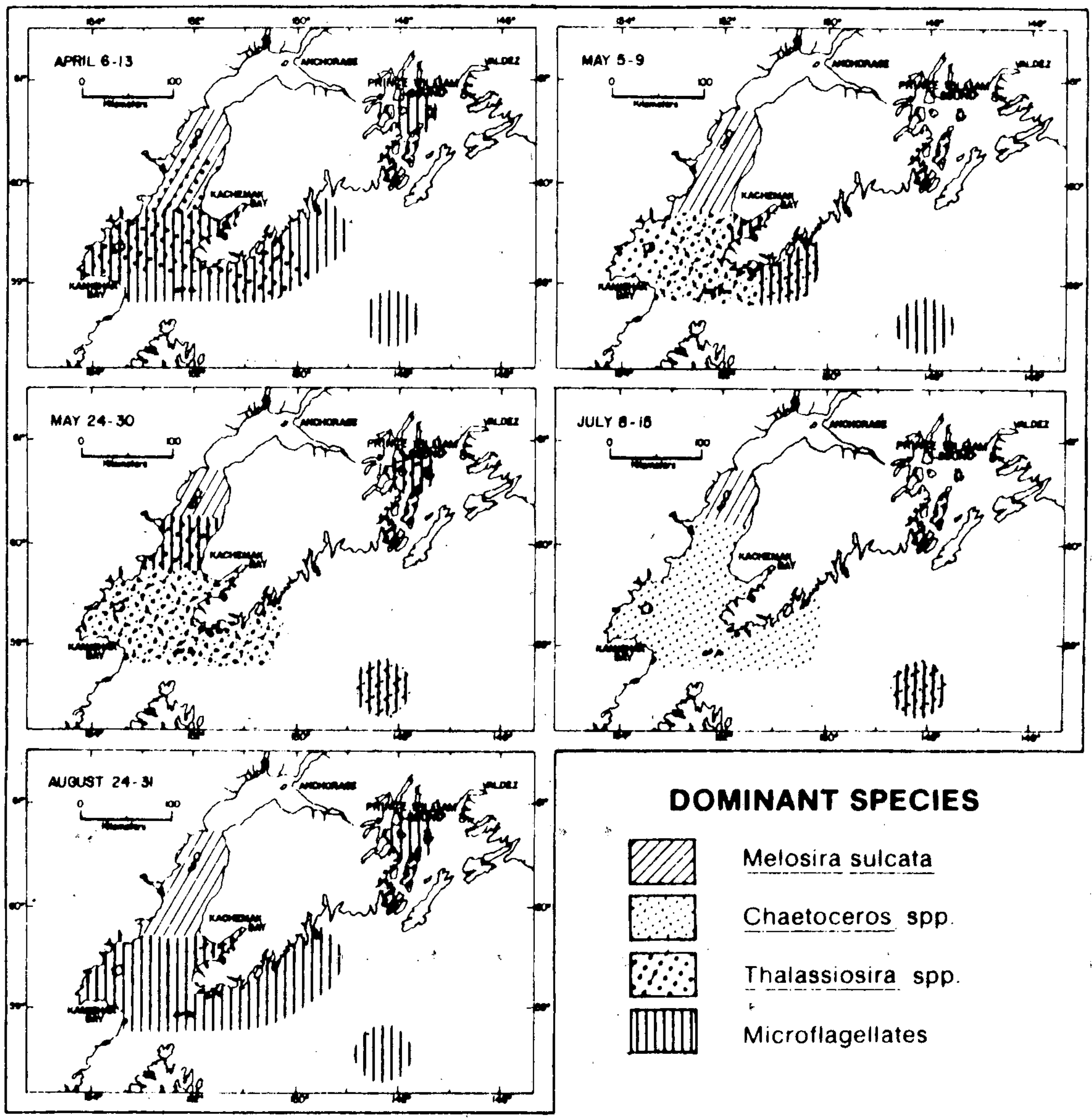
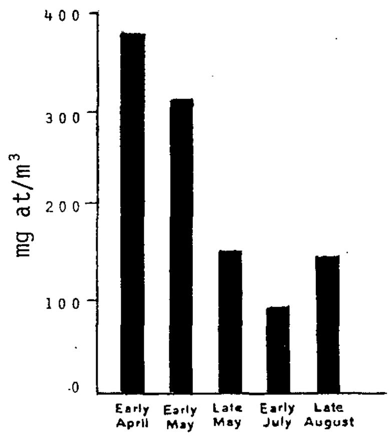
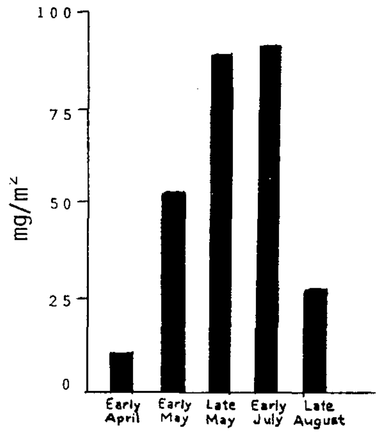


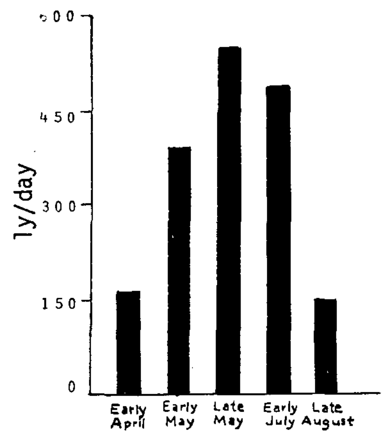
Figure 3-13 Distribution of dominant phytoplankton groups in the Cook Inlet-Price William Sound region, April through August, 1976. (Reproduced from Larrance *et al.* RU #425b, Final Report, April 1977)



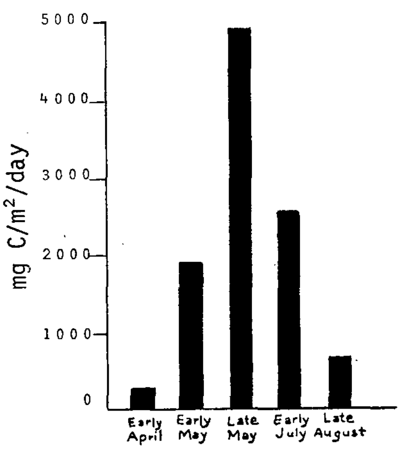
Nitrate concentration



Chlorophyll a concentration



Incident radiation



Mean primary productivity

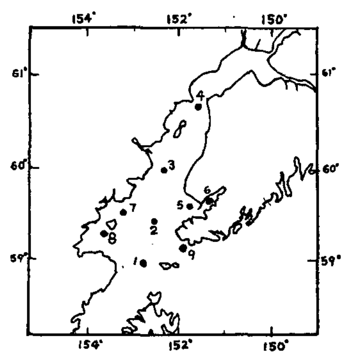
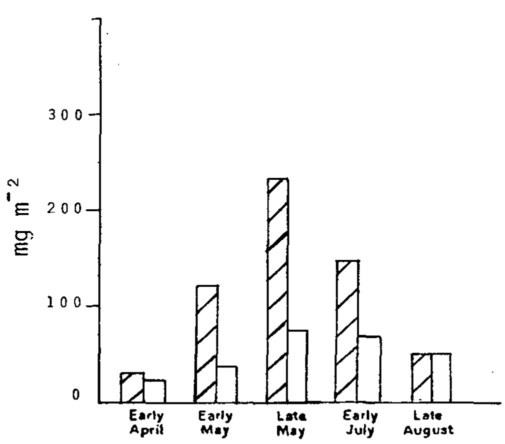
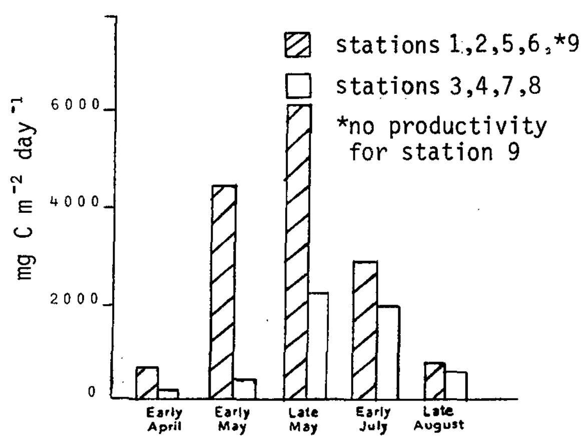


Figure 3-14 Sampling stations and selected data sets from Lower Cook Inlet primary productivity studies (Redrawn from Larrance *et al.*, RU #156c, 1976 and RU #425b, 1977)



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.

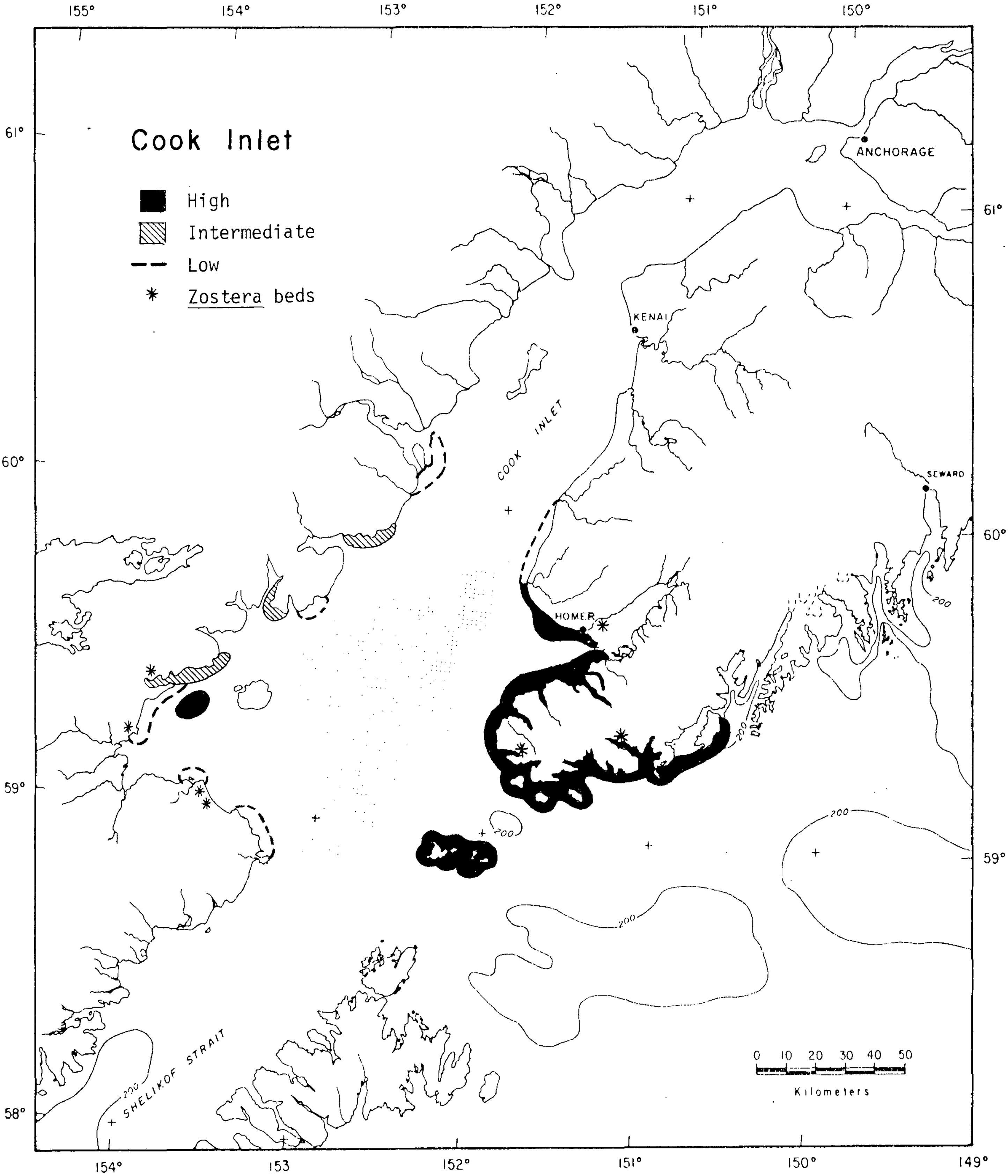


Figure 3-15 Postulated distribution and relative productivity patterns of attached intertidal and subtidal algae in Cook Inlet. (Compiled from unpublished data provided by R. Rosenthal and D. Lees, Dames & Moore, Anchorage)

- 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.

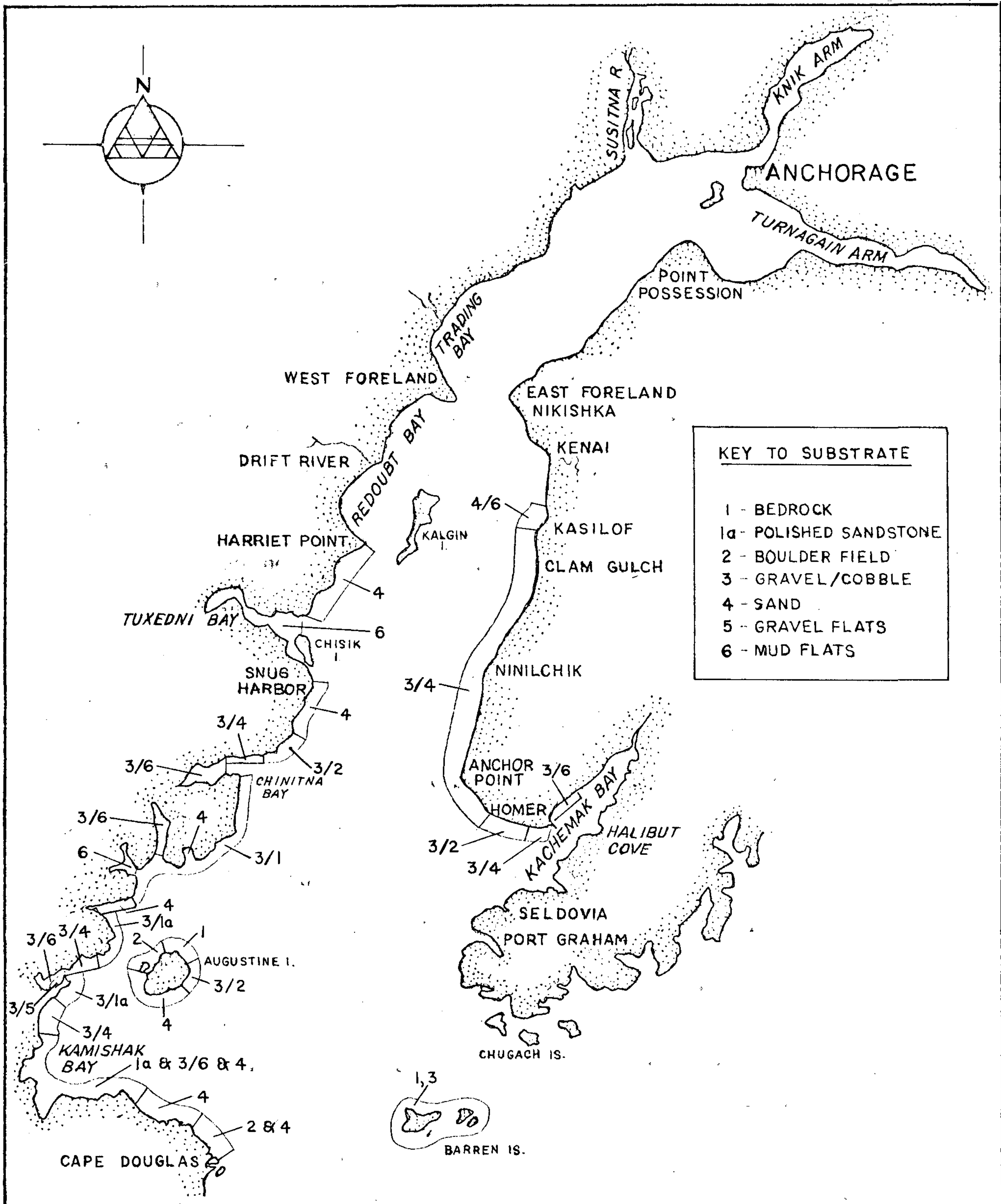
Damkaer (RU #425a, 1976) has provided preliminary results from zooplankton samples collected from April to August 1976. The average settled volumes for the upper 25 m in Kachemak Bay increased from 0.3 $\mu\ell/m^3$ (April 7-8) to 31.0 $\mu\ell/m^3$ (May 7) in about a month and then declined to < 6 $\mu\ell/m^3$, 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,



DISTRIBUTION OF GEOLOGICAL SUBSTRATE TYPES
AS INDICATED BY AERIAL RECONNAISSANCE
IN MAY 1976

Figure 3-16 (Figure provided by D. Lees, Dames and Moore, Anchorage)

Table 3-2

Principal Intertidal Biota: Lower Cook Inlet*

Sand Habitats:	Rock and Cobble Habitats:
Nephtys sp. cf. *caeca*, Polychaete	*Halichondria panicea*, Sponge
Siliqua alta, Clam	*Katharina tunicata*, Chiton
S. patula, Clam	*Acmaea pelta*, Snail
Spisula polynema, Clam	*A. persona*, Snail
Tellina lutea, Clam	*Littorina sitkana*, Snail
	Nucella spp., Snail
Silt and Mud Habitats:	*Mytilus edulis*, Clam
	Balanus cariosus, Barnacle
Laminaria saccharina, Alga	*B. glandula*, Barnacle
Pylaiella littoralis, Alga	*Evasterias troschelii*, Sea Star
Zostera, Eelgrass	*Leptasterias hexactis*, Sea Star
Abarenicola pacifica, Polychaete	*Strongylocentrotus droebachiensis*, Urchin
Echiurus echiurus, Polychaete	
Nephtys sp., Polychaete	
Cliocardium nuttali, Clam	
Macoma balthica, Clam	
Mya arenaria, Clam	
M. priapus, Clam	
M. truncata, Clam	
Protothaca staminea, Clam	
Saxidomus gigantea, Clam	
Spisula polynyma, Clam	

*R. Rosenthal and D. Lees, RU #417, Dames and Moore, Anchorage, unpublished data sea stars, and urchins. A food web for one such community is included in the Kachemak Bay regional summary (Fig. 2-5). Organic detritus provides a major input at the base of the food web; top predators include sea stars, sea otters, and sea birds.

In contrast, intertidal sand, silt, and mud substrates typically yield faunas dominated by infaunal suspension and deposit feeders, particularly polychaete worms and clams. Organic detritus is again important in the food webs. Migratory waterfowl (goldeneye, oldsquaw, scaups, and scoters) and shorebirds (dunlin, western sandpiper) now replace sea stars and sea otters as top predators -- the latter apparently preferring to take epifaunal rather than infaunal prey species (Kenyon, 1975).

The principal invertebrates collected from Cook Inlet shallow subtidal rocky habitats are listed in Table 3-3. The west coast of Cook Inlet apparently supports a less diverse assemblage of subtidal invertebrates than does the east coast -- a trend noted above for the attached algal assemblages. The rocky subtidal communities are dominated by attached algae and epifaunal invertebrates -- sponges, anemones, snails, barnacles, crabs, sea stars, and urchins.

A survey of the benthic invertebrates that occupy offshore habitats in Cook Inlet was recently completed by Feder (RU #281, 1976). Samples were collected throughout the lower Inlet between Kennedy Entrance and Kalgin Island. The principal species collected are listed in Table 3-4; clams, crabs, and shrimp predominate. The patterns of occurrence of some representative species are illustrated in Figure 3-17; all are extremely patchy. While obvious recurrent groups are lacking, it appears that several species -- *Chionoecetes bairdi*, *Crangon* sp., *Macoma* spp., *Nuculana* sp.,

Table 3-3

Shallow Subtidal Biota of Rocky Shores, Lower Cook Inlet*

--West Coast--

Sheltered Habitats

Algae	Invertebrates
Alaria sp.	*Halichondria panicea*, Sponge
Fucus distichus	*Tealia crassicornis*, Sea Anemone
Iridaea lineare	*Nucella emarginata*, Snail
Laminaria saccharina	*Mya truncata*, Clam
L. groenlandica	*Balanus cariosus*, Barnacle
Monostroma sp.	*B. glandula*, Barnacle
Porphyra sp.	*Hapalogaster mertensii*, Crab
Rhodymeria palmata	*Pagurus hirsatiusculus*, Crab
Spongomorpha sp.	*Telmessus cheiragonus*, Crab
Encrusting corallines	*Leptasterias hexactis*, Sea Star
	L. polaris, Sea Star
	Strongylocentrotus drobachiensis, Urchin

Exposed Habitats

Algae	Invertebrates
Ahufeltia plicata	*Halichondria panicea*, Sponge
Cladophora spp.	*Littorina sitkana*, Snail
Halosaccion glandiforme	*Mytilus edulis*, Clam
Porphyra sp.	*Balanus glandula*, Barnacle
Spongomorphia sp.	

Beneath Rocks

Algae	Invertebrates
	Anthopleura sp., Sea Anemone
	Nucella emarginata, Snail
	Photis laeta, Amphipod
	Gnorimosphaeroma oregonensis, Isopod
	Leptasterias hexactis, Sea Star

*R. Rosenthal and D. Lees, RU #417, Dames and Moore, Anchorage, unpublished data.

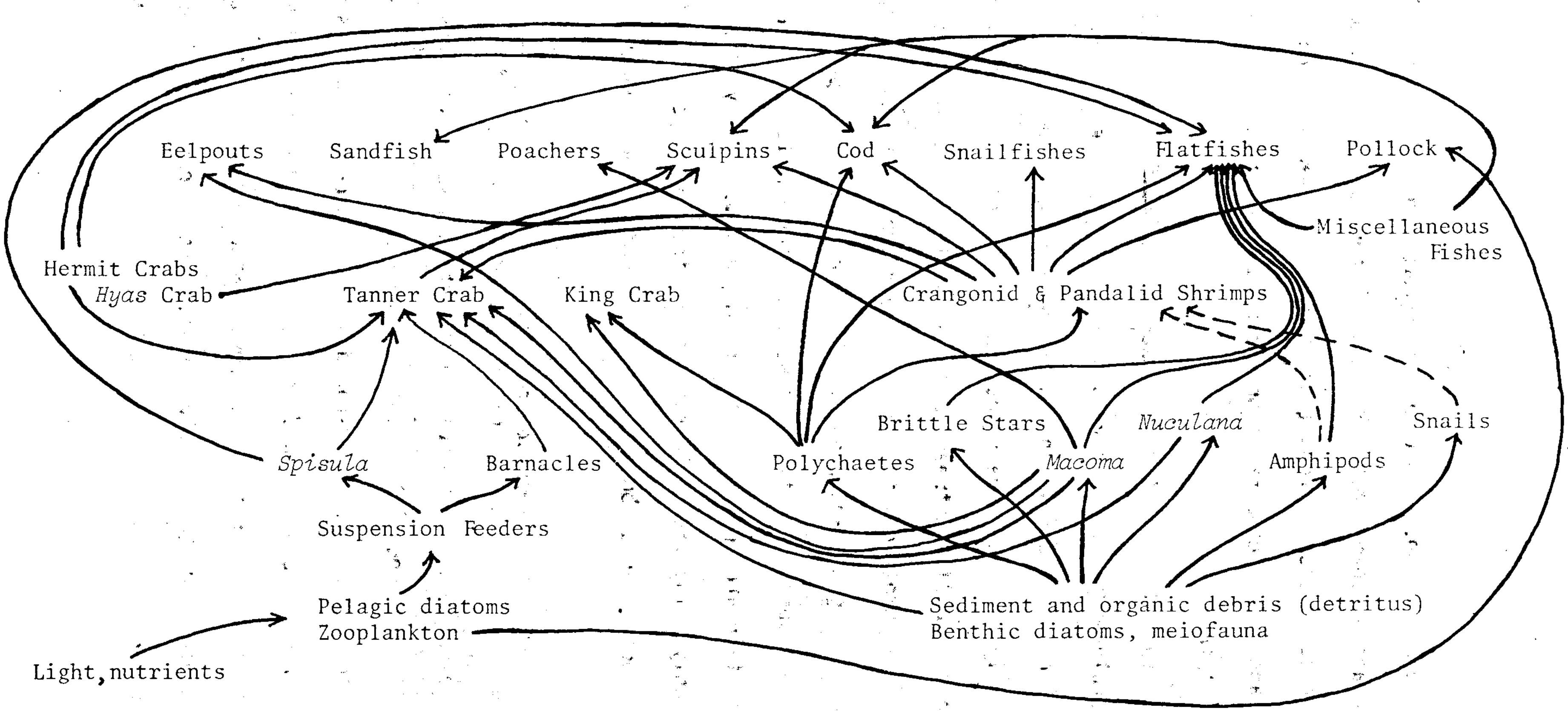


FIG. 3-18 Lower Cook Inlet: Feeding relationships among principal subtidal benthos. (from unpublished data, H. Feder, RU #5/281, University of Alaska, Marine Science Institute)

troschelii, Leptasterias hexactis, Littorina sitkana, Mytilus edulis, Nucella spp.) the release of eggs and planktonic larvae peak during the late spring and summer months.

Cook Inlet supports commercial populations of king (*Paralithodes camtschatica*), tanner (*Chionoecetes bairdi*) and dungeness crab (*Cancer magister*), and pink shrimp (*Pandalus borealis*). Smaller populations of humpy, sidestripe, and coonstripe shrimp (*Pandalus goniurus, Pandalopsis dispar,* and *Pandalus hypsinotus*, respectively) are also present. Razor clams, *Siliqua patula*, are taken in small quantities by both commercial and sports fisherman. Weathervane scallops, *Patinopecten caruinus*, are present, but not in sufficient numbers to support a commercial harvest.

The general life histories of these commercial species are reasonably well known and have been excellently described elsewhere (Buck *et al.*, 1975; ADF&G, 1976). The seasonal distribution of crustacean larvae and settlement in Lower Cook Inlet is summarized in Figure 2-6 (see also Haynes and Wing, 1977).

In Lower Cook Inlet, king and tanner crabs move offshore in the late summer and fall to overwinter in deep water -- midway between Augustine Island and the Barren Islands. In late winter and spring they return to the littoral zone to molt and breed. Females carry fertilized eggs almost a full year before they hatch into planktonic larvae. The larvae settle and take up a benthonic existence after about two months in the plankton. Outer Kachemak Bay (Fig. 3-19) and Iliamna Bay are major spawning and settling areas for both crab species.

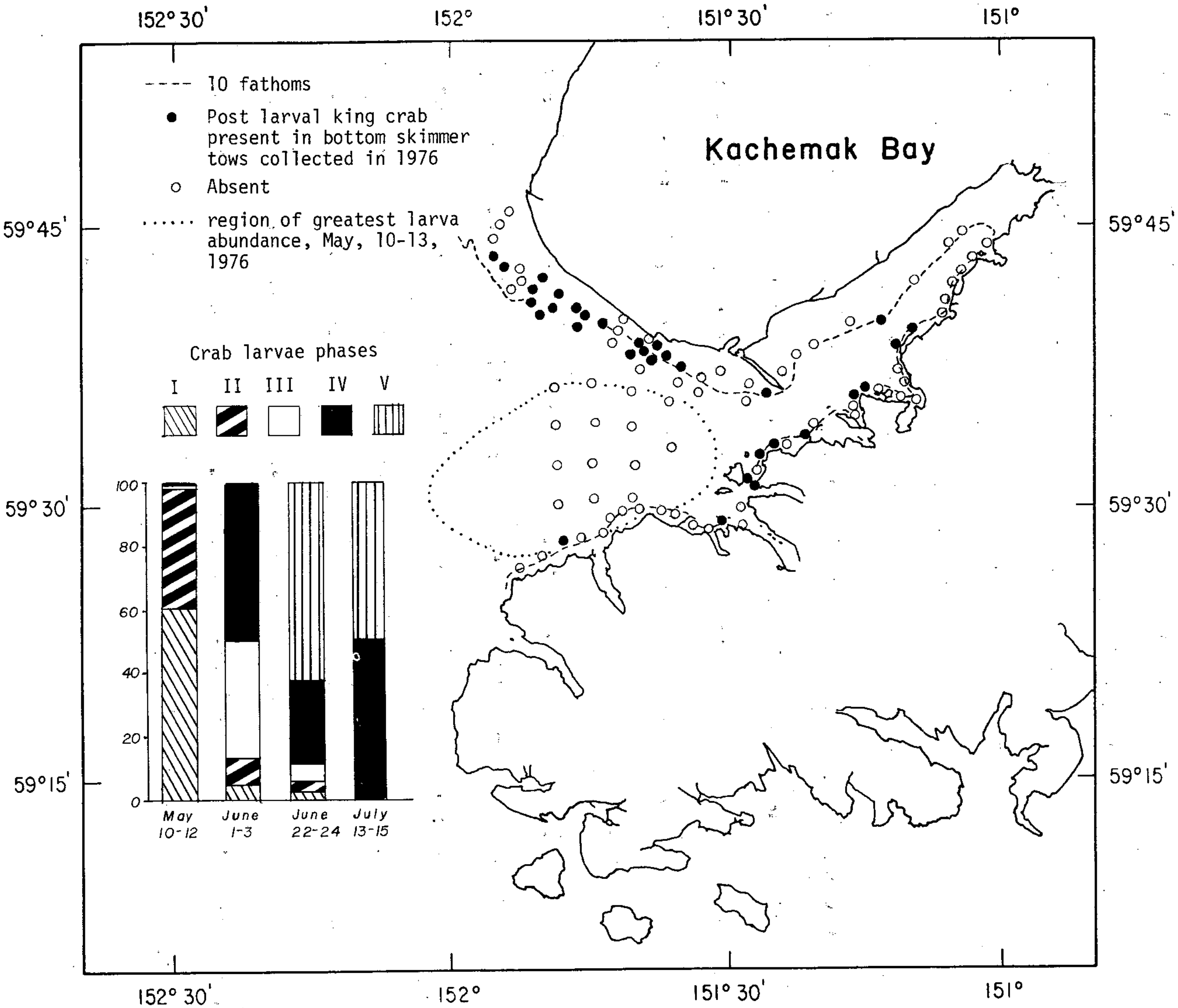


Figure 3-19 Distribution and composition (larval phases I-V) of Kachemak Bay larval and post-larval king crab populations. (Compiled from unpublished data provided by ADF&G, Anchorage)

Significant concentrations of dungeness crabs occur in Kachemak Bay and in coves and inlets around the Kenai Peninsula. Some individual bay stocks remain in shallow water year-round; others migrate offshore in the fall and winter much like king and tanner crabs. Juveniles are associated with eelgrass stands or seafloor accumulations of algal debris.

Shrimp occur throughout most of Lower Cook Inlet with major concentrations in Kachemak Bay and in deep water off Cape Douglas. Adults molt and spawn in shallow water in September; females carry the eggs until they hatch in April and May. Major concentrations of shrimp larvae occur in outer Kachemak Bay from May through at least July (Haynes and Wing, 1977).

Known concentrations of razor clams, "hard shelled" clams (*Saxidomus giganteus, Clinocardium nuttalli*) and weathervane scallops are mapped in Figure 3-20. It is noteworthy that Cook Inlet razor clams exhibit faster growth than other Alaska populations, reaching sexual maturity in three years rather than the five or six years usually required. They also release eggs over a longer period than elsewhere -- mid-July through mid-September, instead of the usual July-August (ADF&G, Vol. 2, 1976).

Cook Inlet is included within the ADF&G Cook Inlet-Resurrection Bay Regulatory District; for management and statistical purposes the Inlet is subdivided into a number of separate fisheries districts (Fig. 3-21). Annual catch statistics for crabs and shrimp taken from Cook Inlet are summarized in Table 3-5.

In 1974, the most recent year for which fisheries statistics are available, tanner crab contributed the greatest proportion of the Regulatory District's total crustacean harvest. Shrimp (predominantly pink shrimp, but also including other species), king crab, and dungeness crab

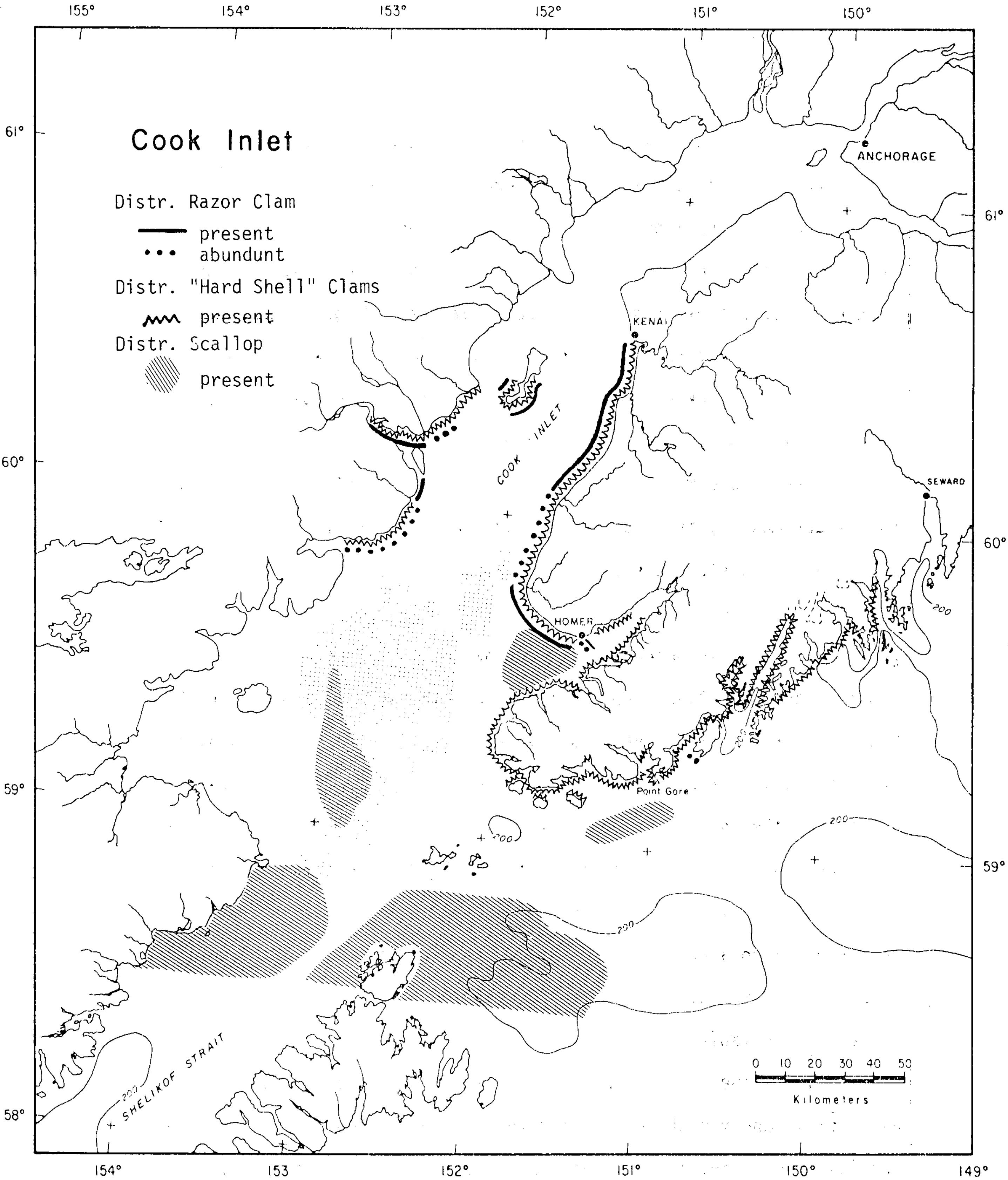


Figure 3-20 Cook Inlet clam populations of possible commercial significance. (Compiled from maps published with ADF&G, 1976)

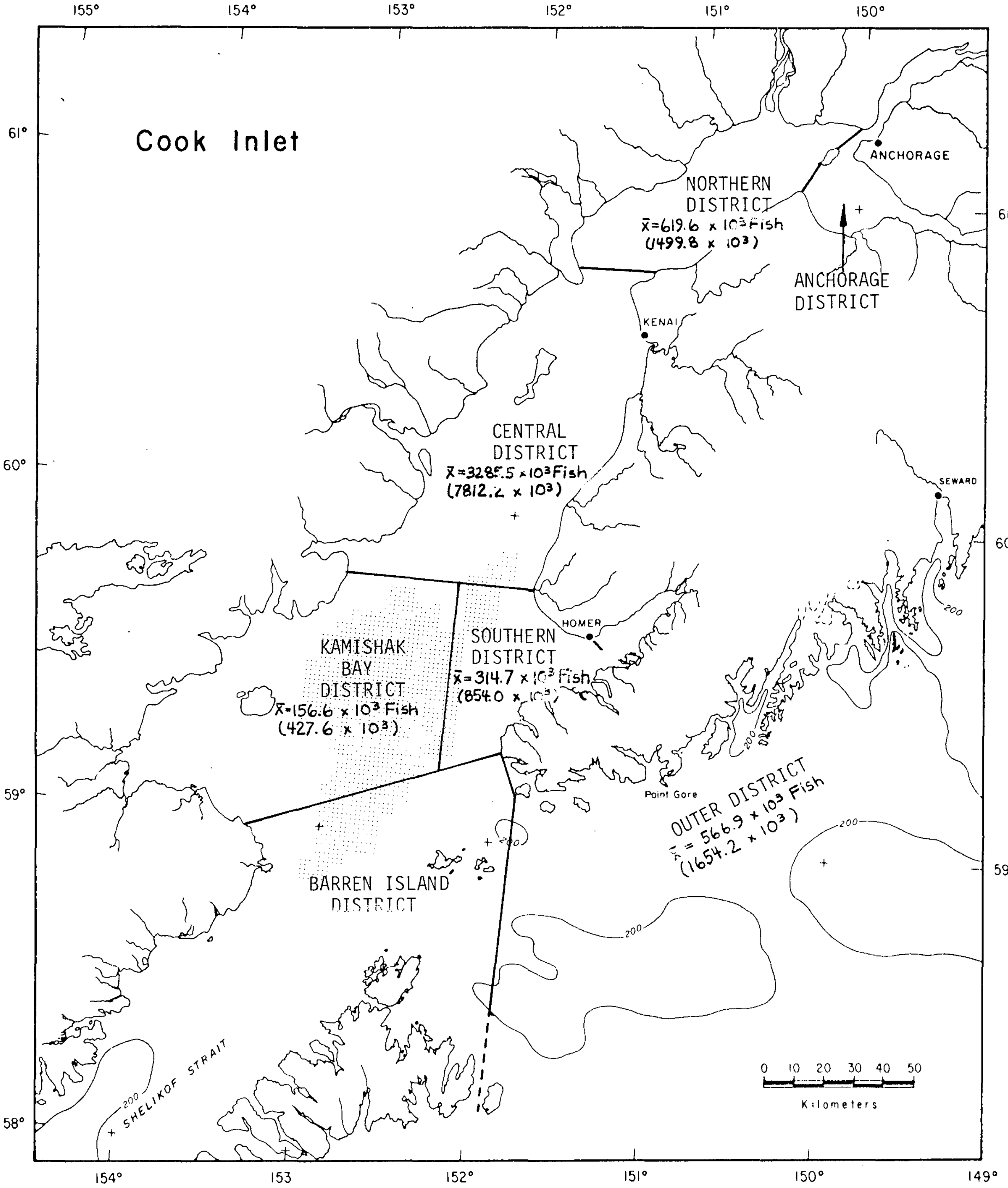


Figure 3-21 Average and (peak) population densities of adult salmon migrating into Cook Inlet by fisheries district. (Adapted from ADF&G, 1976)

TABLE 3-5

Summary of 1960-1974 Cook Inlet Region Catch Statistics for Commercial Invertebrates (in millions of lbs)*

Cook Inlet-Ressurection Bay Regulatory District: Total Catch Statistics through Time (see Figure 3-21)

Species	1974 Catch	Min Catch (Year)	Max Catch (Year)	Three heaviest (1974) monthly catches
King Crab	4.6	2.8 (1965)	8.4 (1963)	Aug., Sept., Feb.
Tanner Crab	7.7	0.003 (1962)	8.5 (1973)	April, May, March
Dungeness Crab	0.7	0.007 (1967)	1.7 (1963)	Aug., Sept., July
"Shrimp"	5.7	0.03 (1968)	5.8 (1970)	Trawl: Jan.,Sept.,July Pot: April,Sept.,July

Cook Inlet Fisheries Districts (Fig. 3-21) 1974 Catch Statistics

Species	Southern District	Kamishak District	Barren Is. District	Outer District
King Crab	1.6	2.7	0.3	0.003
Tanner Crab	1.1	3.9	0.8	1.3
Dungeness Crab	0.7	Trace	0	0.002
"Shrimp"	4.7	0.03	0	0.3

*Compiled from data published in ADF&G, Vol. 2, 1976.

followed in order of declining importance. The Kamishak Bay District (including Kamishak Bay and central Lower Cook Inlet) yielded the greatest quantities of tanner and king crabs, followed by the Southern District (Kachemak Bay). The latter, however, yielded by far the greatest harvests of dungeness crab and shrimp.

Appendix 3 summarizes data describing the distribution, ecology, and potential oil-biota interactions for Cook Inlet's macrophytes and non-commercial and commercial benthic invertebrate faunas.

Fish

Preliminary evidence indicates that species of the families Ammodytidae, Clupeidae, Cottidae, Gadidae, Hexagrammidae, Osmeridae, Pleuronectidae, and Trichodontidae dominate the Lower Cook Inlet fish resource (Blackburn, RU #512, April 1977). Major fluxes in populations occur seasonally and spatially throughout the Inlet (Tables 3-6 and 3-7, and Appendix 3). Of these, the most notable are of those species belonging to the Osmeridae, Salmonidae, and Clupeidae families. During the spring and summer months large numbers of salmon, herring, and smelt move into shallower areas of Cook Inlet from deeper water feeding and overwintering zones and out of the numerous spawning streams. Adult populations move to and congregate in coastal zones at the mouths of "home" streams (salmon, smelt), and along rocky (herring) and sandy (capelin) beaches in anticipation of spawning. Juvenile salmon migrate from spawning streams into estuarine nursery areas; herring and smelt larvae hatch and, likewise, feed in nearshore nurseries.

TABLE 3-6

Tentative Summary of Use of Epipelagic and Littoral Zones by Principal Species of Fish, Lower Cook Inlet*

Species	Season			
	Winter	Spring	Summer	Fall
Pacific herring		A E L	A L J	
Sockeye salmon		A J	A J	
Chum salmon	E L	E L J	A E J	E J
Pink salmon	E L	E L J	A E J	E J
Coho salmon	A	A J	A J	A J
King salmon	A	A J	A J	A
Steelhead trout	A	A J	A J	A
Dolly Varden	A	J	A J	A J
Capelin		A E L	A J	
Longfil smelt		A J	A J	A
Eulachon		A J	A J	A J
Saffron cod		L	A J	A J
Pacific cod	A	A L	A L	
Pacific tomcod		L	J	J
Pacific ocean perch	J	J	J	J
Dusky rockfish	A J	A J	A J	A J
Greenlings	E J	A E L J	A E L J	A E J
Sculpins	A J	A L J	A L J	A J
Poachers		L	L J A	
Sandfish		L	A J	
Prickle backs		A L J	A L J	A J
Pacific sandlance	A J L	A L J	A J	A J
Flathead sole	E	E L	J	
Pacific halibut		A J	A J	
Rock sole		A E L J	L J A	
Yellowfin sole		A J	A E L J	
Starry flounder	E L	E L J	A J	A J
Sticklebacks			A E L J	

A = adults; E = eggs; L = larvae; J = juvenile

◯ = special dependence on littoral zone

*Compiled from numerous sources by J. Blackburn (ADF&G, Kodiak), J. Quast (NMFS, Auke Bay), and E. Wolf (SAI).

TABLE 3-7

Tentative Summary of Use of Benthic Zone by Principal Species of Fish, Lower Cook Inlet*

Species	Season			
	Winter	Spring	Summer	Fall
Pacific herring	A J			A J
Pacific tomcod	A J			
Pacific cod	A J	A E L J	A J	A J
Walleye pollock	J A	A E L J	A J	A J
Poachers[1]	A J	A J	A J	A J
Arrowtooth flounder	A J	A E L J	A J	A J
Pacific halibut	A J	A E L J	A J	A J
Yellowfin sole	A J	A J	A J E L	A J
Alaska plaice	A J	A J	A J	A J
Rex sole	A J	A J	A J	A J
Flathead sole	A J	A J	A J	A J
Butter sole	A J	A J	A J	A J
Rock sole	A J	A J	A J	A J
Dover sole	A J	A J	A J	A J
Starry flounder	A J	A J	A J	A J
Capelin			A	
Eulachon	A		A	
Greenlings	A		A	
Sculpins	A J E L	A J E L	A J	A J
Sandfish	A J	A J	A J	A J
Pricklebacks	A J E	A J L	A J	A J
Pacific sandlance	A J E L	A J L	A J	A J
Rajiidae-skates	A J	A J	A J	A J
Eelpouts[2]	A J	A J	A J	A J
Snailfish	A J	A J	A J	A J

A = adults; E = eggs; L = larvae; J = juvenile

[1]Life history unknown - may take one year for eggs to hatch

[2]Some species lay eggs, some bear live young

*Compiled from numerous sources by J. Blackburn (ADF&G, Kodiak), J. Quast (NMFS, Auke Bay), and E. Wolf (SAI).

All migratory species (salmon) must pass through central Lower Cook Inlet on their way to upper Inlet spawning areas or out to sea as juveniles. Population estimates indicate that in the average year approximately 4 million adult salmon spawners enter Cook Inlet from offshore. Inshore movement peaks during spring through mid-summer. Peak estimates exceed 10 million fish (ADF&G, 1976; Stern, 1976); however, less than a tenth of these utilize spawning habitats in Kamishak and Kachemak Bays (Fig. 3-21). The number of juvenile salmon entering the estuaries of Cook Inlet yearly has been estimated in excess of 100 million fish (Stern, 1976). The number that eventually migrate from Cook Inlet to the North Pacific is not known.

Most anadromous species have left the Inlet by the onset of the winter season. However, some eggs spawned by anadromous species in the intertidal zone remain and some coho and king salmon forage in the Inlet. Most resident species have sought the warmer, deeper, and calmer waters, leaving few fish in the intertidal, shallow subtidal, and surface areas. Saffron cod may be abundant and spawn in shallow water near the Forelands in winter.

Smelt and herring offshore movements are poorly understood, but they may remain in schools seeking deeper water during the winter. Herring may move out of the Inlet to feed and overwinter in the Gulf of Alaska.

Less migratory species, that spend much of their life history within Cook Inlet, typically occupy near-surface or nearshore waters seasonally or during certain phases of their life cycle.

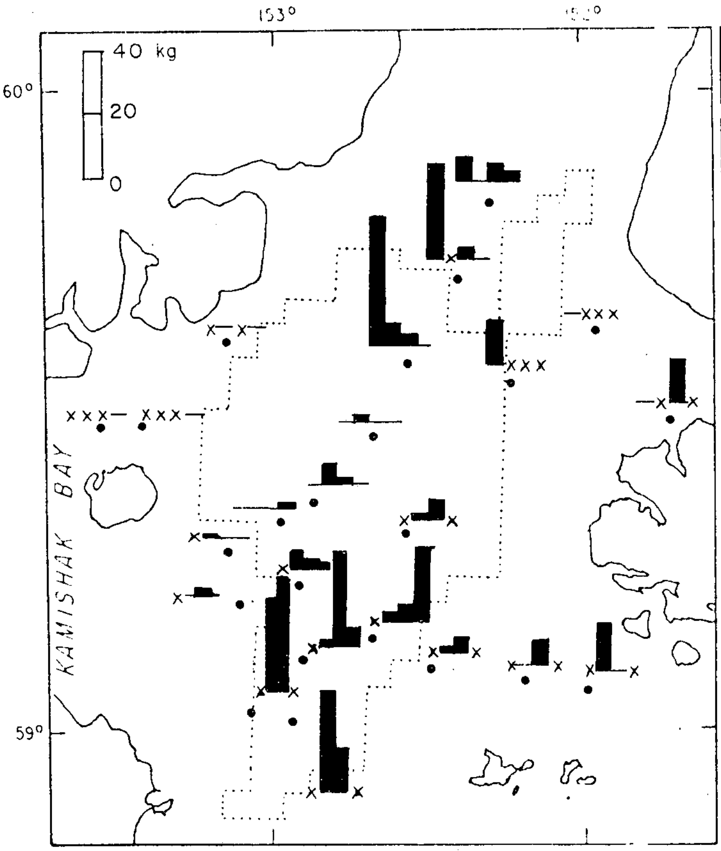
A tentative schedule of fish use of epipelagic and littoral zones is outlined in Table 3-6. Comparable data for benthic zone fish are shown in Table 3-7. The information contained in Tables 3-6 and 3-7, and Appendix 3 illustrates some of the *SEASONAL FEATURES* of fish species inhabiting Cook

Inlet. However, this information is tentative and unevenly documented and should be used with caution. Some preliminary quantitative distributional data are presented in Figure 3-22 (Blackburn, RU #512, April 1977).

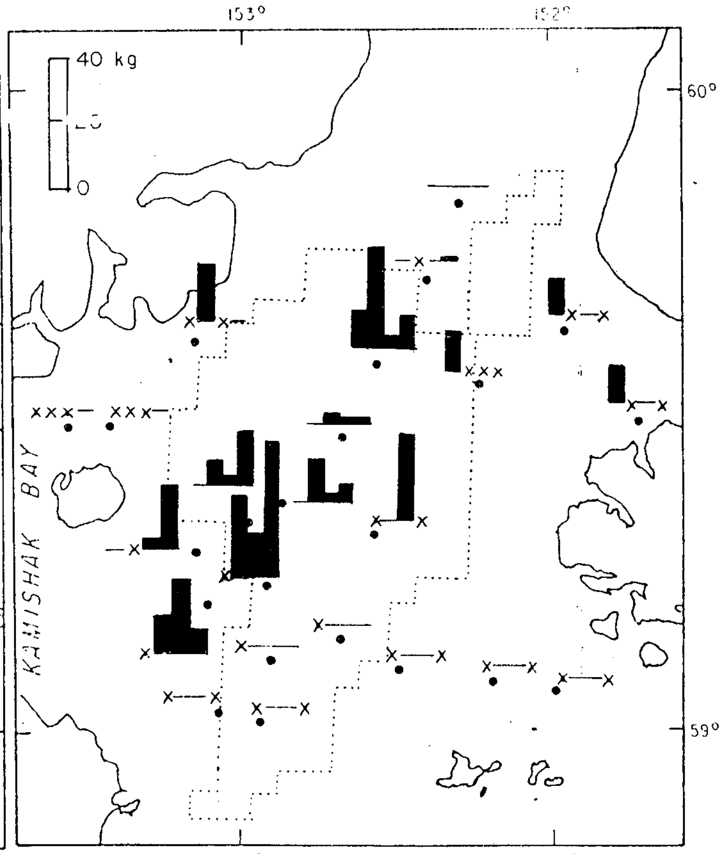
Commercial fisheries are the primary users of the Cook Inlet fish resource (Appendix 3); however, a growing sport fishery also exists. The commercial catch concentrates primarily on salmon, herring, and halibut. Some ground fish such as flounder, rockfish, and sole, are also taken. An estimated average of 4.7 million adult salmon enter Cook Inlet each year. Of these an average of 3.2 million are caught by commercial fishermen. In 1974, the total catch was in excess of 1.6 million fish and valued at $7.1 million.

A new market for herring roe reopened the Cook Inlet herring fishery in 1969. At first, fishing efforts concentrated in Kachemak Bay but declining catches and increasing prices allowed fishermen to seek other areas. In 1975, more than 99% of a total herring catch of 4,149 tons came from Kamishak Bay. In 1974, the last year for which catch and value statistics are available, 2,692 tons of herring were taken, and valued at $484,614 (all commercial catch statistics from ADF&G, 1976 and Stern, 1976).

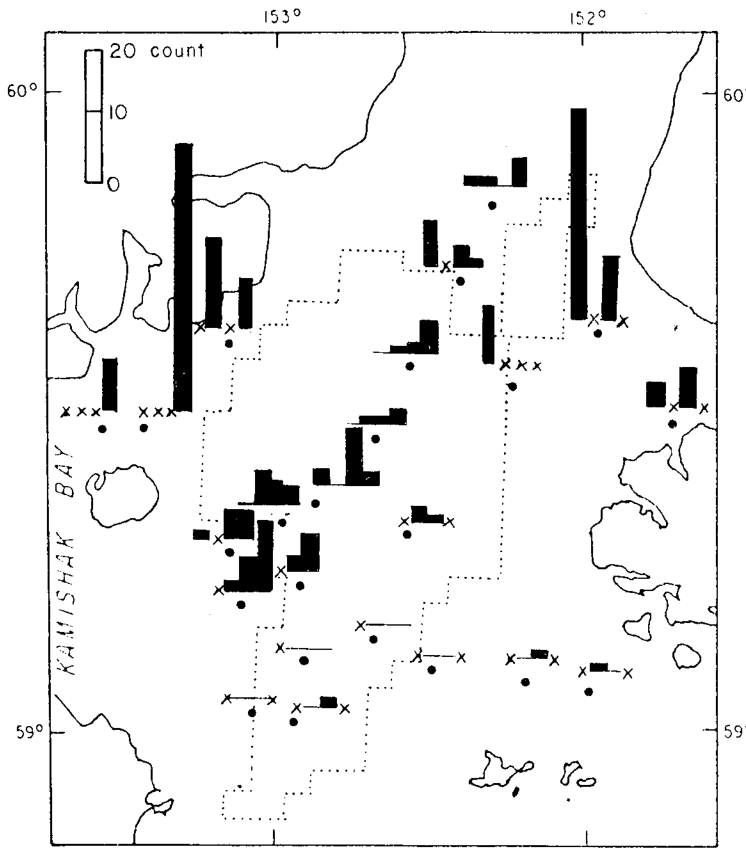
Halibut catch statistics are incorporated within the International Pacific Halibut Commission's statistical area 3A, which includes areas outside of Cook Inlet (ADF&G, 1976). The catch in 1974 was 9.6 million pounds (1976 value, $1.29/lb); it is not known what contribution was made by halibut caught in Cook Inlet.



Pacific cod



Butter sole



Pacific halibut

Figure 3-22 Preliminary presentation of 20 minute otter trawl catches by location and month. Catches in early June, July, August and September are shown left to right respectively for each location. (Redrawn from Blackburn RU #512, April 1977)

• Sample station
× No samples collected

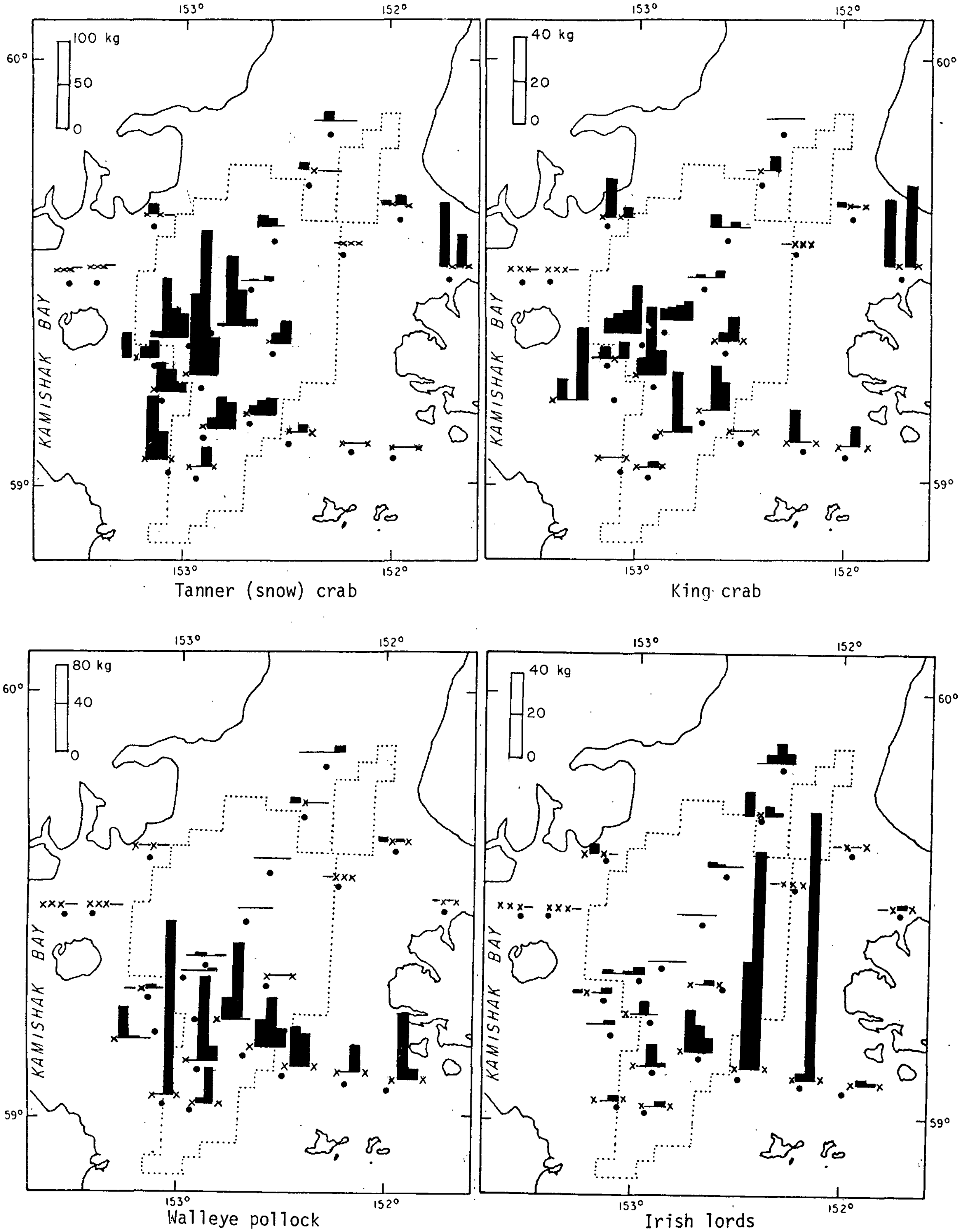


Figure 3-22 (continued)

Birds

Preliminary unpublished 1976 aerial census data (D. Erikson and P. Arneson, ADF&G, Anchorage) indicate that in that year the nearshore and intertidal avifauna of Cook Inlet was dominated in decreasing order of abundance by waterfowl, gulls, shorebirds, alcids, and cormorants. Seasonal and regional variations in relative abundance of each group are listed in Table 3-8. Along the coasts of Kamishak Bay and the outer Kenai Peninsula crows, bald eagles, and loons, though not particularly abundant, were conspicuous elements of the avifauna. A brief characterization of all major bird species in Lower Cook Inlet is given in Appendix 3.

These same preliminary census data illustrate important regional differences in total and seasonal abundance of birds in the Inlet: the most heavily utilized regions on an annual basis are outer Kachemak Bay and the east side of Cook Inlet north of Chinitna Bay, particularly the Redoubt Bay-Kalgin Island and Tuxedni Bay-Chisik Island areas.

All coastal regions of Lower Cook Inlet except the outer Kenai Peninsula undergo a great spring influx of migrants and breeding birds (Fig. 3-23). The main contributors to this spring peak are waterfowl, gulls, shorebirds, and in the Tuxedni Bay area, common murres. In Kachemak Bay, a minor peak also occurs in fall, due mainly to an influx of gulls, and secondarily, waterfowl (Fig. 3-23).

Lensink, Bartonek, and Sanger (RU #337, 1976) have identified 22 species of seabirds and waterfowl utilizing offshore waters of Lower Cook Inlet. Peak numbers of individuals and species are attained in summer. Shearwaters (sooty and short-tailed) are the most abundant birds in offshore waters in summer and have been observed within Cook Inlet at densities as

TABLE 3-8

Relative Seasonal Abundance of the Five Major Bird Groups in Inshore and Intertidal Habitats Compared among Regions of Lower Cook Inlet*

Region	Bird group	Numbers counted during coastal surveys in:			
		Winter	Spring	Summer	Fall
Kennedy Entrance (Region 4)	Waterfowl (all anatids)	3,539	1,218	167	1,258
	Gulls	229	720	4,361	2,031
	Shorebirds	154	135	2	52
	Alcids	19	1	53	14
	Cormorants	241	460	882	974
Kachemak Bay (Region 3)	Waterfowl	8,016	14,104	11,813	9,801
	Gulls	1,185	4,307	4,895	8,237
	Shorebirds	748	5,395	96	48
	Alcids	212	167	54	3
	Cormorants	5	218	14	585
Kalgin Island Area (Region 5)	Waterfowl	144	9,686	4,710	9,061
	Gulls	4	27,843	9,604	5,668
	Shorebirds	3,375	4,304	50	98
	Alcids	0	4	5,626	0
	Cormorants	0	85	138	3
Kamishak Bay (Region 2)	Waterfowl	1,286	7,720	9,883	1,791
	Gulls	0	2,316	1,803	516
	Shorebirds	0	6,111	188	1,223
	Alcids	0	.0	98	1
	Cormorants	7	50	202	120

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

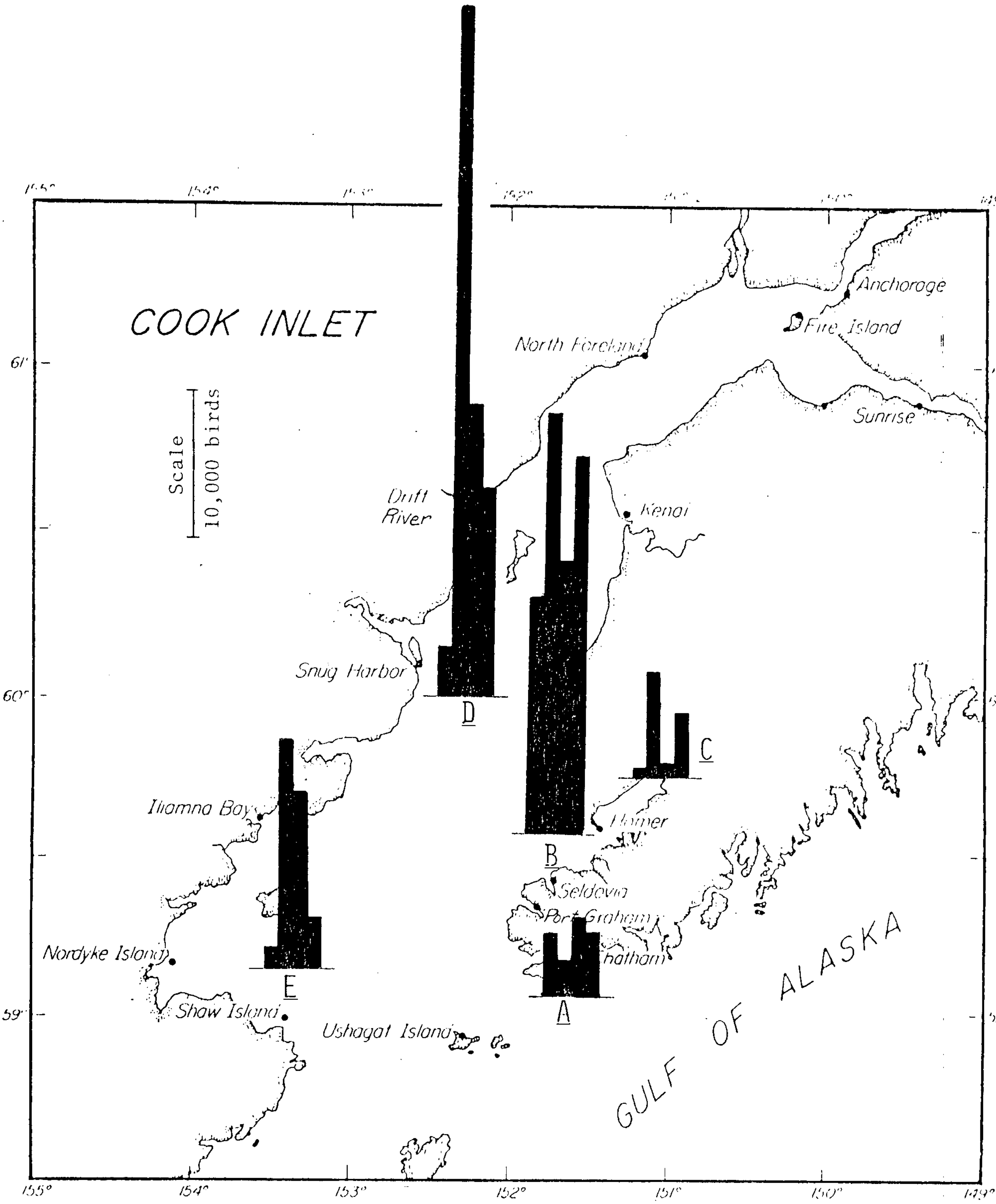


Figure 3-23 Relative seasonal and regional abundance of aquatic and shore birds in Cook Inlet: A. Outer Kenai Peninsula; B. Outer Kachemak Bay; C. Inner Kachemak Bay; D. Northern Lower Cook Inlet; E. Kamishak Bay. Graphs read from left to right: winter, spring, summer, fall. Compiled by SAI staff from preliminary unpublished 1976 aerial census data (one shoreline census per season) provided by D. Erikson and P. Arneson, ADF&G, Anchorage

high as $142/km^2$ along 152°W and $308/km^2$ off of Point Adam (D. Erikson, ADF&G, Anchorage, personal communication, 1976). Even higher densities may be reached around the Barren Islands and Kennedy Entrance. Loons, fulmars, fork-tailed storm petrels, glaucous-winged gulls, blacklegged kittiwakes, and tufted puffins also occur in significant numbers ($1\text{-}5/km^2$) over offshore waters of the Inlet. Highest offshore bird densities in Lower Cook Inlet, as determined by aerial census, occur in the "clean water" region extending from Kennedy Entrance to the mouth of outer Kachemak Bay (D. Erikson and P. Arneson, ADF&G, Anchorage, personal communication, 1976).

The major seabird nesting colonies in the Lower Cook Inlet region are on the Barren Islands (about 500,000 birds of 12 or more species) and on Chisik Island (about 80,000 birds of 10 species). More than 40 smaller colonies are scattered throughout the Inlet in Tuxedni, Chinitna, Kamishak, and Kachemak Bays and Kennedy Entrance. The size and regional significance of the Barren Island colonies must not be underestimated and their ecological role deserves further attention in future synthesis meetings.

A graphic summary of Cook Inlet bird distribution data is presented in Figure 3-24. Tentative summaries of seasonal usage and food habits by principal bird species (Tables 3-9 and 3-10) have been prepared by G. Sanger (U.S. Fish and Wildlife Service, Anchorage) and K. Wohl (BLM, Anchorage). Food habits data for both birds and mammals are also presented graphically in Figure 3-25. Possible hazards to marine birds that might occur during petroleum development in the proposed Lower Cook Inlet lease area are identified in Appendix 3.

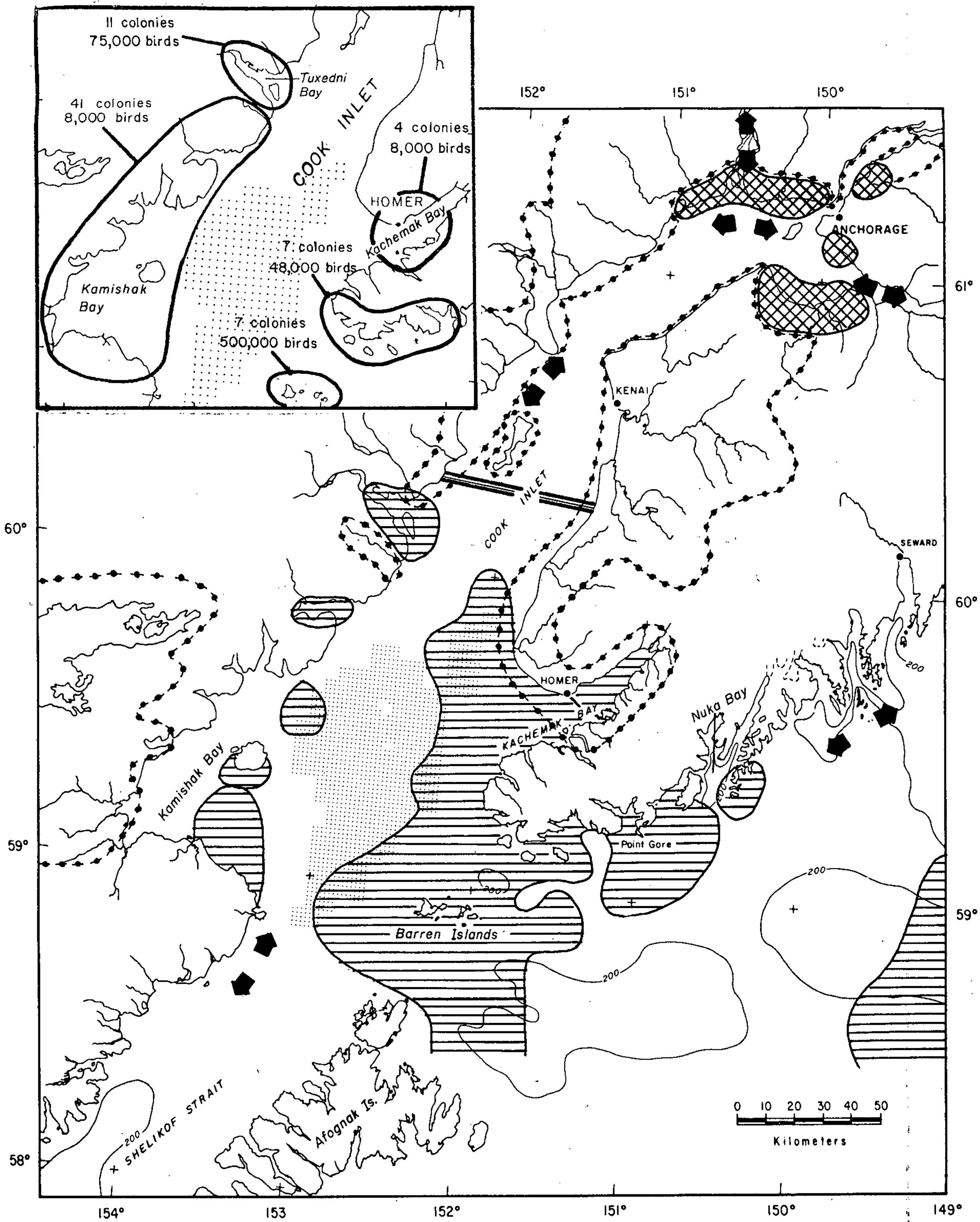


Figure 3-24 Graphic summary of selected marine bird data for the Cook Inlet region. Location of principal breeding colonies shown in upper left inset. Horizontal lines indicate marine bird high density areas -- probably corresponding to foraging areas. The east-west line just south of Kalgin Island separates marine bird medium density areas to the south, from low density areas to the north. Cross-hachured areas near Anchorage represent high density waterfowl habitat; medium and low density waterfowl habitats are enclosed within the dotted lines. Arrows indicate migration routes. (Data compiled by C. O'Brien, SAI Boulder, from numerous sources.)

TABLE 3-9

Tentative Summary of Bird Use by Principal Species, Lower Cook Inlet*

Species	Season				Habitat Use
	Winter	Spring	Summer	Fall	
Sooty shearwater		F,OR,M	F,OR	F,OR	O
Short-tailed shearwater		F,OR,M	F,OR	F,OR	O
Fork-tailed storm petrel	F(?),OR(?)	F,N,OR	F,N,OR	F,OR	I,O
Cormorants	F,OR,OS	F,OR,N	F,OR,N	F,OR,OS	I,O
Geese (Canada & snow)		N,F,OS	N,M,F,OS	F,OS	L,I
Dabbling ducks (pintail and mallard)		N,F,OS	N,M,F,OS	F,OS	L,I
Greater scaup	F,OR	F,OS	F	F,OS,OR	I,L
C. Goldeneye, Oldsquaw, B. Goldeneye, Harlequin	F,OR			F,OR	I,L
Common eider	F,OR,OS	N,OS,F	N,F,M	OS,F	I,L
White-winged scoter	F,OR	F,OS	F	F,OR,OS	I,L,O
Surf scoter	F,OR	F,OS,OR	F	F,OR,OS	I
Black scoter	F,OR	F,OR,OS	F	F,OR,OS	I
Sandhill crane		F,OS		F,OS	L
Bald eagle & Peale's peregrine falcon	F,OS	F,N,OS	F,N,OS	F,OS	I,L
Whimbrel		F,OS			
Rock sandpiper			N(?)	F,OS	L
Least sandpiper		F,OS	N(?)		
Dunlin		F,OS	N(?)	F,OS	L
Western sandpiper		F,OS	N(?)	F,OS	L
Northern Phalarope		F,OS,OR	N(?)	F,OS,OR	I,L
G-W gull	F,OS,OR	F,N,OS,OR	F,N,OS,OR	F,OS,OR	I,O,L
Mew gull	F,OS,OR	F,N,OSOR	F,N,OSOR	F,OSOR	L,I,O†
Black-legged kittiwake	F,OR	F,N,OR	F,N,OR	F,OR	I,O†
Common murre	F,OR	F,N,OR	F,N,OR	F,OR	O,I
Pigeon guillemot	F,OR	F,N,OR	F,N,OR	F,OR	I
Marbled murrelet	F,OR	F,N,OR	F,N,OR	F,OR	I,O†
Kitlitz's murrelet	F,OR	N,F,OR	N,F,OR	F,OR	I,O†
Tufted puffin		N,F,OR	N,F,OR	F,OR	O,I
Horned puffin		N,F,OR	N,F,OR	F,OR	I,O

*Prepared by G. Sanger (USF&WS, Anchorage) and K. Wohl (BLM, Anchorage)

N = Nesting — OS = Onshore resting/staging — †Winter

M = Molting — OR = Onwater rafting

F = Foraging — O = Offshore

L = Intertidal

I = Inshore

TABLE 3-10

Probable Food Habits of Lower Cook Inlet Marine Birds*

Receptor →	Sooty shearwater	Short-tailed shearwater	Cormorant spp.	Oldsquaw	Scoter spp.	Dunlin and western sandpiper	Glaucous-winged gull	Black-legged Kittiwake	Common murre	Pigeon Guillemot	Marbled murrelet	Kittlitz's murrelet	Tufted puffin	Greater scaup	Common goldeneye	Common eider
Capelin (10-14cm)	2								1							
Capelin (6-8cm)		1														
Ammodytes	1		1		1		1	1	1		2					
Rainbow smelt (6-14cm)													1			
Cottids (to 12cm)										1	1					
Blennies										1	1					
Herring roe					1											
Thysanoessa spp (1-3cm)		2									1	1				
Pandalis borealis (7-8cm)			1						1							
Pandolopsis dispar (2cm)									1	1						
Gammarid amphipod						2										
Macoma balthica				1	1	2								3		
Mytilis				3	1	2								3	3	3
Nuculana					1											
Mya				3		2								3		
Polychaeta				3										3		

Data sources: (1) Lower Cook Inlet, (2) Gulf of Alaska, (3) Sweden

*Prepared by A. Sanger (USF&WS, Anchorage) and K. Wohl (BLM, Anchorage), 1976.

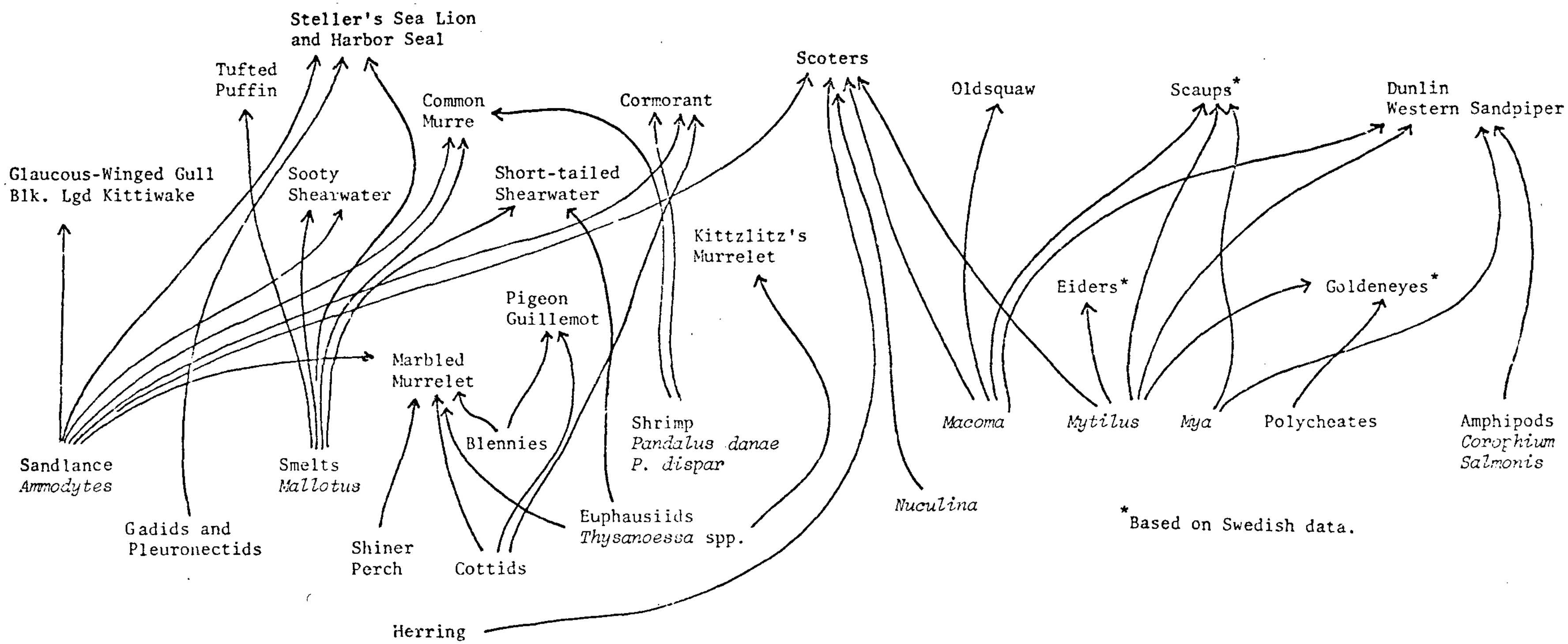


Figure 3-25 Lower Cook Inlet: Invertebrates and fish confirmed as prey species taken by local bird and mammal populations. Compiled by SAI staff from numerous sources including, P. Arneson and D. Erikson (ADF&G); M. Dick and G. Sanger (USF&WS); H. Feder and S. Senner (University of Alaska); D. Lees (Dames & Moore); 1976.

Mammals

Marine mammals known to reside the year-round in Lower Cook Inlet are sea otters, harbor seals, Steller sea lions, and belukha whales (Appendix 3). These species breed within the Inlet proper, or, in the case of Steller sea lion, on the Barren Islands. Harbor and dall porpoises and killer whales also are regularly sighted around the mouth of Cook Inlet and in Kachemak Bay but it is not certain that they represent resident populations. In spring, summer, and fall, minke whales visit the mouth of Cook Inlet and Kachemak Bay and other large, migratory cetaceans and fur seals occur around the Barren Islands. Only the minke whale is of more than minor importance in Lower Cook Inlet proper.

Belukhas and harbor seals undergo a seasonal density redistribution within Cook Inlet, being most abundant in summer north of the Cape Ninilchik-Tuxedni Bay region and most abundant in winter further south (K. Schneider and K. Pitcher, ADF&G, Anchorage, personal communication, 1976).

In addition to the marine mammals described above, black bears and brown (grizzly) bears on the west side of Cook Inlet and river otters, mainly in Kachemak Bay, forage in inshore and intertidal habitats and thus are to some extent dependent upon the health of Cook Inlet's aquatic environment for their livelihoods.

Distribution of principal mammals in Lower Cook Inlet is shown in Figure 3-26. Probable food habits of the four most abundant species are tabulated in Table 3-11.

The sea otter might warrant special attention because its numbers and range in Lower Cook Inlet are expanding. Since it consumes large quantities of shellfish and sea urchins, the sea otter could conceivably

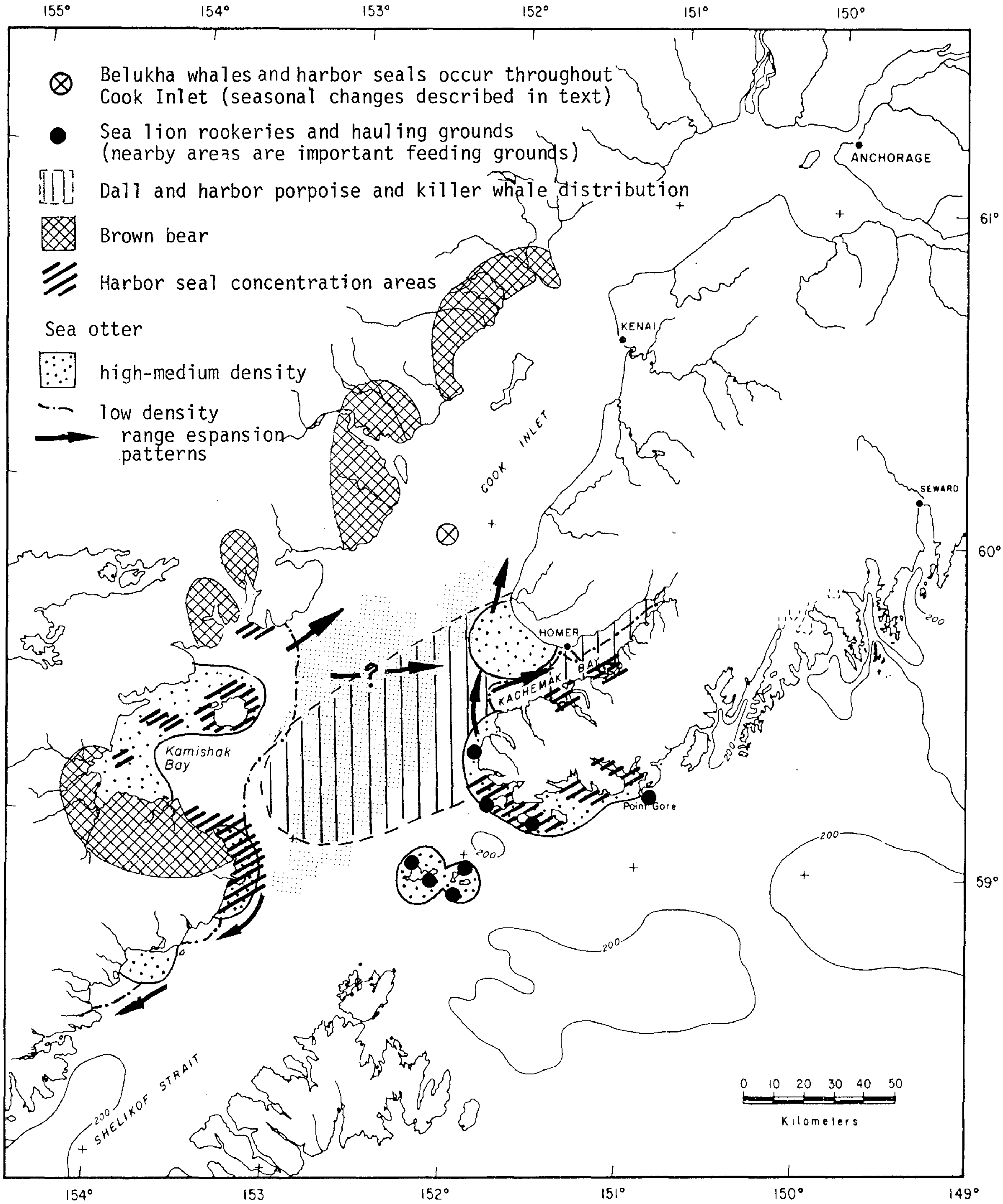


Figure 3-26 Graphic summary of selected marine mammal data from Cook Inlet. (Compiled by C. O'Brien, SAI Boulder, from numerous sources)

TABLE 3-11

Probable Food Habits of Cook Inlet Mammals

Receptors → / Major donors ↓	Sea otter	Steller sea lion	Harbor seal	Belukha
Benthic invertebrates	1			
Gadids		2	2	
Clupeids		2	2	
Osmerids		2	2	2
Cephalopods		2	2	
Pleuronectids		2	2	
Salmonids				2

Remarks:

1. Sea otters modify abundance and age structure of prey populations, which in turn can significantly alter structure of macrophyte community.

2. As yet, no Cook Inlet data on food habits for any marine mammals. These are extrapolations from other areas.

seriously reduce commercial crab stocks and urchin populations. Reduction of urchin populations, which graze on large kelps, would favor expansion of kelp beds. Thus, expansion of the otter population could significantly modify littoral ecology and fisheries resources in Cook Inlet.

Potential hazards to marine mammals that might occur during petroleum development in the proposed Lower Cook Inlet lease area are identified in Appendix 3.

Vulnerability and Food Chain Implications

The vulnerability of biological populations tends to vary throughout the year depending on their ecological life history, distribution, and behavior. For many species two different periods and/or locations of greater than average vulnerability are readily apparent: (1) during periods of population aggregations -- often for reproduction, but also for feeding purposes or during migrations, and (2) during the release of eggs and/or larvae, during larval settlement, or in "nursery grounds" of juvenile forms.

Much of the presently available data on the location and timing of population aggregations and larval development for Cook Inlet species, are included in the following figures, tables and appendix:

Benthic Invertebrates: Figure 2-6; Appendix 3

Fish: Tables 3-6 and 3-7; Appendix 3

Birds: Figure 3-23; Table 3-8; Appendix 3

Mammals: Appendix 3

The interrelationships between predators and prey allow for direct or indirect interchange of impacts resulting from environmental perturbations. These relationships provide the mechanism by which prey species removed through environmental alterations cause an immediate impact on the predator. If the prey species is a primary food source, the predator is immediately reduced through starvation. However, if the predator is an indiscriminate feeder, removal of one or even several prey species may have little effect.

Ed Wolf (SAI) has prepared generalized food webs for families of fish located in Cook Inlet. Much information is lacking for most groups; however, for the Salmonidae and Clupidae (herring) marked contrasts appear (Fig. 3-27). The clupeids are primary forage species and the food web illustrates a predominance of predation on this species. Salmonids, in contrast, are high level carnivores and are shown to feed on many different groups while few organisms prey on them. Clearly the potential exists for widespread ecological impact if forage species, such as herring, are eliminated from the food chain. The effects of removal of one or several salmonid food species, however, remain unclear.

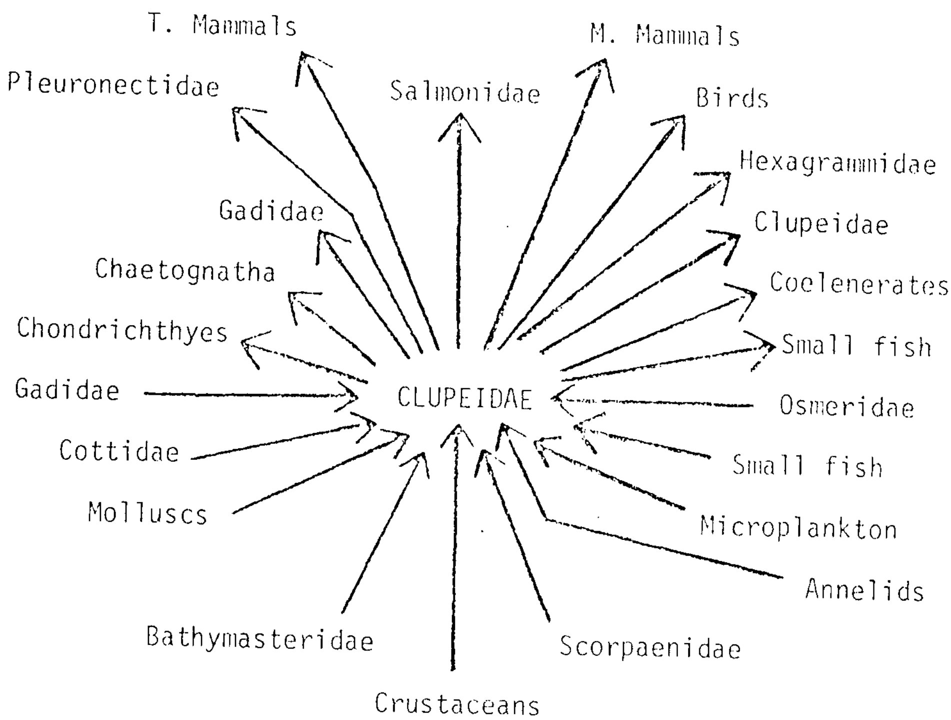
Additional data on feeding relationships among organisms found in Cook Inlet are included as follows:

Offshore Subtidal Benthos: Figure 3-18

Intertidal and Shallow Subtidal Communities: Figure 2-5

Invertebrates, Birds, and Fish: Figure 3-24

Another consideration in predator-prey relationships concerns the possibility of industrial contaminants being passed through the food chain to organisms of subsistence value to man.



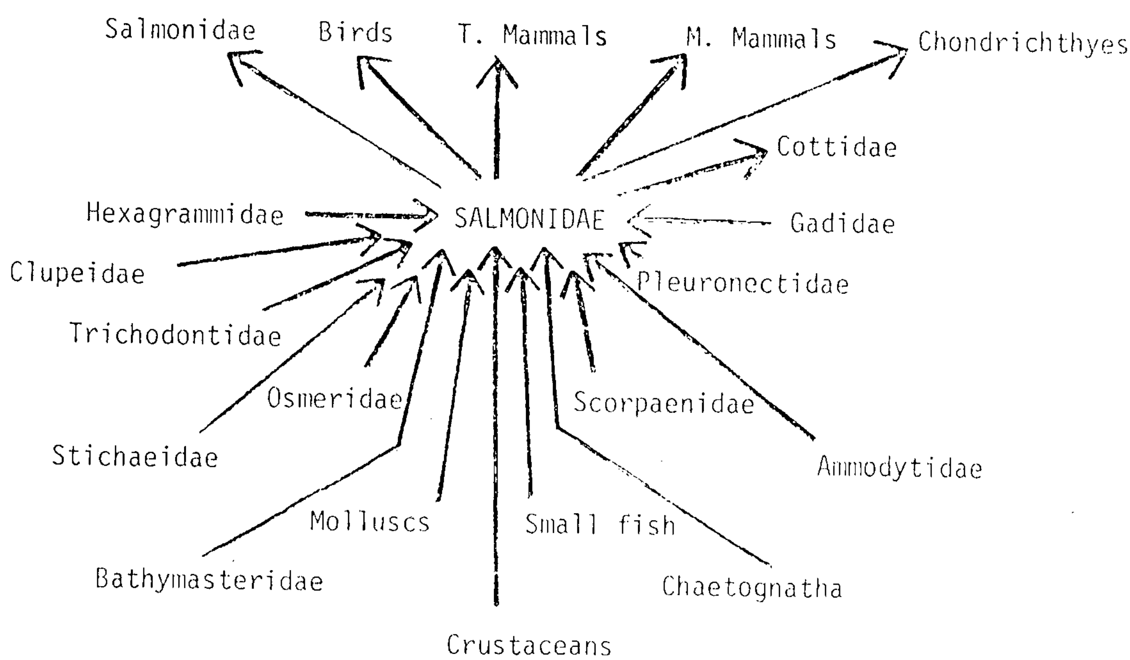


Figure 3-27 Generalized food webs for the fish families Clupeidae and Salmonidae. Data compiled mostly from Hart (1973) and McPhail and Lindsey (1970). Arrows point toward predators.

CONCEPTUAL MODELS: PHYSICO-CHEMICAL BEHAVIOR OF AN OIL SLICK AND THE FATE OF TOXIC TRACE METALS

Figure 3-28 depicts what meeting participants believed to be the major transport mechanisms and processes which will affect a surface oil slick. Each process has been tentatively assigned a relative importance. *ALTHOUGH CIRCULATION IS NOT EXPLICITLY SHOWN, ITS INFLUENCE ON EACH BOX IS OF PARAMOUNT AND OBVIOUS IMPORTANCE.*

The major identifiable processes, other than dispersion, affecting the fate of spilled crude oil or refined products are:

- Evaporation of light fraction
- Emulsification
- Solution
- Absorption to and/or coatings of suspended particles
- Air/sea exchange of hydrocarbons

Direct biological impacts may arise from coating of the organisms, assimilation of emulsified and/or oiled particles, absorption from true solution, and food web transfer mechanisms.

In the treatment of the above major transport mechanisms and processes, the following information is either obtainable for Cook Inlet or may be approximated from appropriate models:

(1) *Evaporation*: Evaporation rates from surface waters of Lower Cook Inlet may be modeled if composition of the crude oil, sea state, wind dynamics, and air and water temperatures are known. Some insight is available from the Kinney *et al.* (1970) report on oil pollution problems in Cook Inlet.

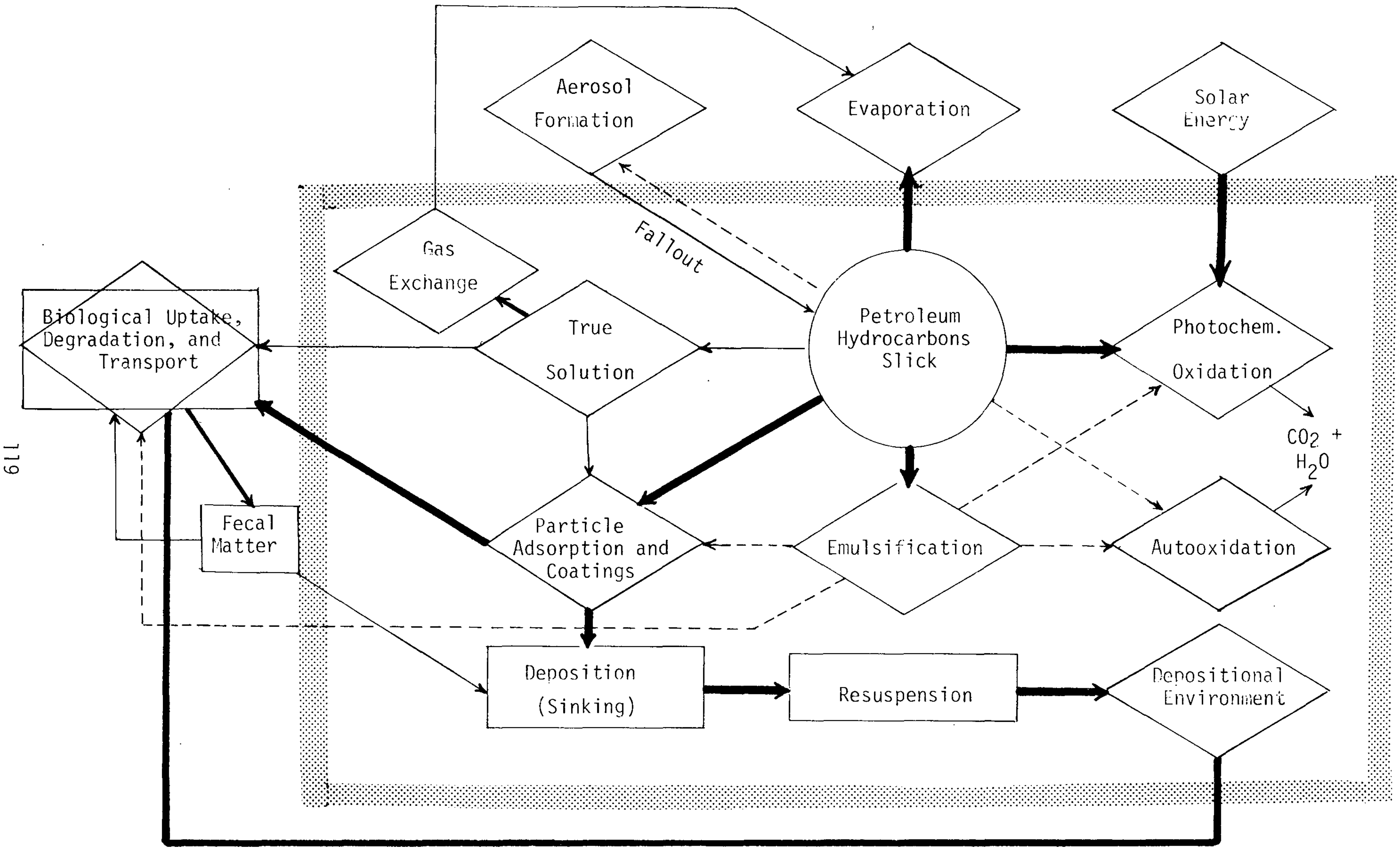


Figure 3-28 Physico-chemical fate of an oil slick. Heavier lines indicate more important pathways, dashed lines indicate least understood (by meeting participants) pathways. Processes within shaded box received most attention from meeting participants

(2) *Emulsification*: This process is little understood but appears to be a major dispersion mechanism. A major data gap exists here.

(3) *Solution*: The principal pathway by which the more toxic low molecular weight fraction enters the water column.

(4) *Adsorption of Oil to Particles*: This process (including oil coatings) provides a direct mechanism by which spilled oil may impact herbivores, first level carnivores, and benthic organisms. Data are not currently available to assess the importance of the process in Lower Cook Inlet. However, studies by the University of Alaska, Institute of Marine Science, Fairbanks, and NOAA/PMEL, Seattle, are currently underway to define the significance of this process.

Adjunct to this problem is the transport capacity of suspended matter and its final depositional site. Significant data gaps exist in the characterization of net depositional environments in Lower Cook Inlet (e.g., Kachemak and Kamishak Bays), and whether these environments might also be critical biological habitats.

(5) *Air-Sea Exchange of Hydrocarbons*: Several studies have indicated that solution effects from a *SURFACE SPILL* are minimal. However, a *SUBSURFACE* discharge that might arise from a pipeline break or well blowout would inject large quantities of relatively soluble hydrocarbons (i.e., aromatic fraction) into the water column. Under these circumstances, circulatory dispersion, biological assimilation and degradation, and air-sea exchange processes become the dominant removal mechanisms.

Figure 3-29 illustrates conceptually the ultimate fate of toxic trace metals (Cd, Co, Cr, Cu, Hg, Ni, Pb, V, Zn, etc.) introduced via brine waters and drilling muds. The major interactions depicted involve the absorption of metals to particles and their subsequent assimilation by organisms.

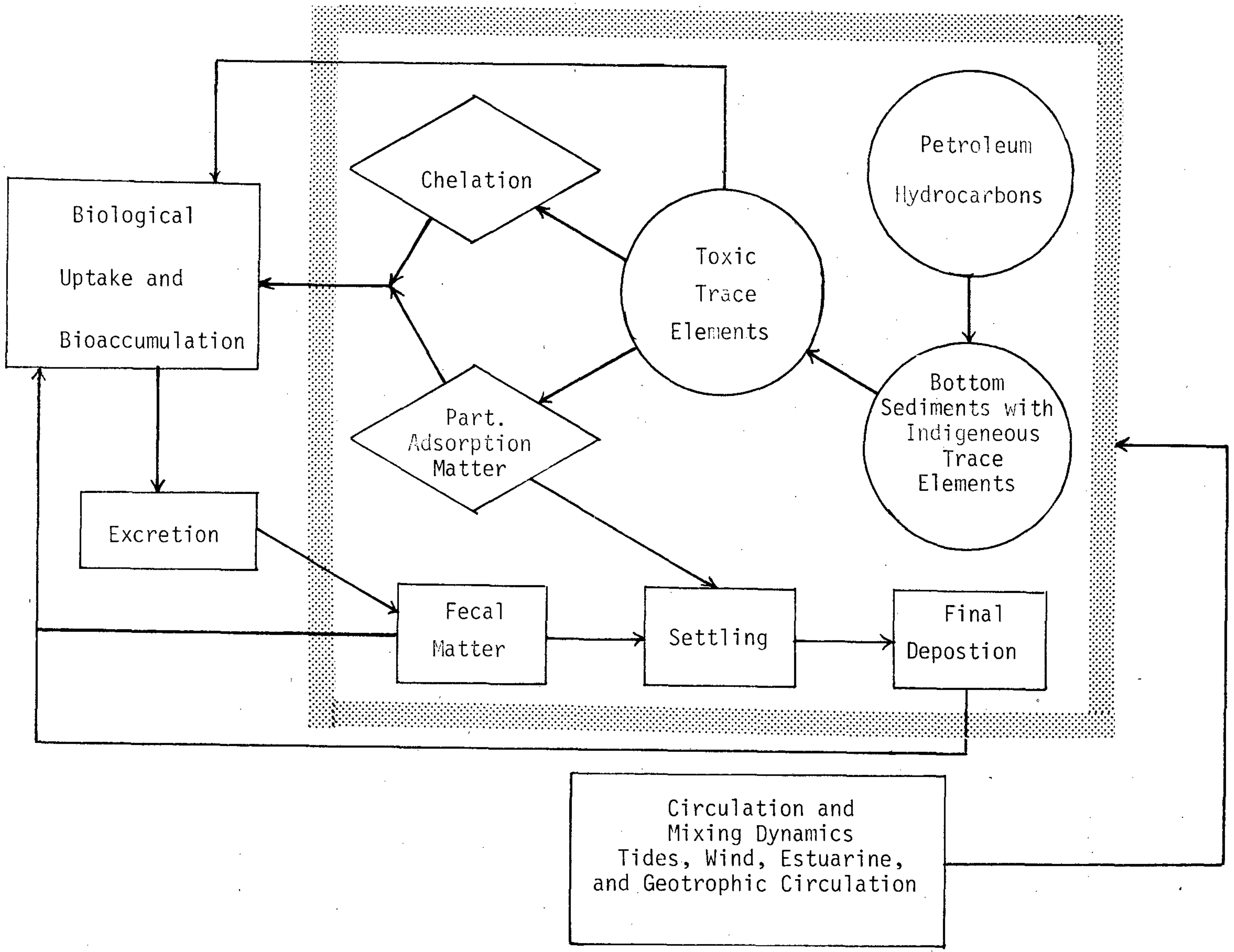


Figure 3-29 Principal elements of the fate of toxic trace metals. (Processes in shaded box received most attention from meeting participants.)

The data base of trace metal abundances and distribution in sediments, water, and biota appears to be lacking, although measurements are being made on bottom sediments (David Burrell, RU #162, University of Alaska, Fairbanks). Six or seven stations were occupied in Lower Cook Inlet for suspended matter (Dick Feely, RU #152, NOAA/PMEL, Seattle) in April 1976.

The major transport and assimilation pathways of toxic trace metals in the marine environment were not well known to meeting participants. Appropriate process studies appear to be lacking at this point, as well as the necessary baseline data that might be used to assess qualitatively the importance of these mechanisms. One potential outcome of petroleum development in Lower Cook Inlet could be the displacement of absorbed trace metals from the surfaces of indigeneous sediments as the result of petroleum hydrocarbon adsorption. The significance of this process needs to be clarified.

The importance of toxic trace metal input to the Lower Cook Inlet ecosystem might be approached through use of a "worst case model." Assume for example, that *ALL* the brine and formation waters from proposed offshore drilling were injected into the waters of Cook Inlet and on the basis of reasonable estimates of water residence times, sediment budget, etc., calculate the accumulation rate of the metals. Necessary research areas are outlined in the following chapter.

Chapter 4

RESEARCH NEEDS AND INFORMATION GAPS

During the Synthesis Meeting numerous data gaps were identified in our present understanding of Cook Inlet as a dynamic, integrated, environmental system. A *COMPLETE* understanding of the system is clearly beyond the scope of both BLM's needs and the present NOAA/OCSEAP studies. A smaller subset of research needs closely identified with offshore hydrocarbon development has therefore been identified and is outlined below.

SEA ICE

- Only minimal data describing sea ice distributions in Cook Inlet are available (Gatto, 1976). In addition to being a navigation hazard, sea ice impacts the intertidal biota and influences winter sea bird distributions within the Inlet.
- 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

- Few sets of data are available on water temperatures and salinity distributions for Cook Inlet; those that do exist are fragmentary and lack the necessary areal and seasonal coverage to construct a coherent picture of the velocity field and its variations.
- Little is known about the seasonal contribution of Gulf of Alaska water to driving Cook Inlet circulation.

- It is extremely important to obtain appropriate data and estimate residence times (exchange rates) of water in the major sections of the Inlet.
- Little is known about seasonal hydrographic features and current patterns in Kamishak Bay.
- Because of the above, there are not sufficient data to clarify ambiguities in our present understanding of Lower Cook Inlet circulation. From this it follows that the transport characteristics and trajectories of possible contaminants spilled in the Inlet cannot yet be adequately assessed.

BOTTOM SEDIMENTS

- At present insufficient data are available describing types of bottom sediments, type of sub-bottom(s), bottom sediment dispersal, erosion and deposition, types and sizes of bedforms and their permanence or immigration. Geotechnical properties of bottom and shallow sub-bottom are lacking. All these are important for platforms, pipelines and anchoring.
- Sediment distribution maps presently provide only partial coverage of the Inlet.

SUSPENDED SEDIMENTS

There are not yet sufficient data to answer the following questions regarding suspended sediments:

- Does suspended material have the capacity to remove contaminants from the water column through which it passes?

- What types of contaminants can be removed, in what quantities and at what rates?
- What is the mechanism of removal?
- If contaminants are removed from the water column by suspended sediment, where does the sediment finally get deposited and what is the fate of the associated contaminants?
- What effects might the accumulation of contaminated sediments have on local *in situ* sediment geochemistry, upon larval settlement, food resources of deposit feeders, and benthic populations in general?
- Might the contaminants be released from the deposited sediments after deposition and if so at what rates?

PRIMARY PRODUCTION

- Little is known about the seasonal contribution of Gulf of Alaska water to the productivity regime either through introduced populations or physico-chemical mechanisms.
- Little information is available addressing the seasonal variation of the phytoplankton community with respect to the nutrient regime, other hydrographic parameters and the zooplankton community *AS THEY EXIST SIMULTANEOUSLY*. A major data gap is concurrent measurement of the above parameters on station.
- Macrophytes are a major food source supporting both commercial and noncommercial resources yet little is known of their biomass or productivity in Lower Cook Inlet.
- The possible role of coastal wetlands in export of nutrients and detritus to adjacent marine environments has not yet been determined.

- Sources of organic matter which drive the benthos and nourish important commercial shellfish and demersal fish need to be identified and quantified.

ZOOPLANKTON/ICHTHYOPLANKTON

- Most zooplankton information presently comes from Kachemak Bay. An expanded treatment (seasonally and spatially) is necessary to document larval drift patterns in the western and central Inlet, and the extent of larval recruitment to Lower Cook Inlet from outside waters. Also, bird-zooplankton-coastal forage fish trophic interactions should be more thoroughly explored.
- The time series sampling has been too fragmentary to capture all life history stages of all important fish and shellfish species. Some ichthyoplankton cannot yet be identified.
- Relationships between the abundance of early life history stages of ichthyoplankton and the sizes of spawning stocks and resulting year class strength has not been established.
- The apparent isolation of ichthyoplankton spawned in Kamishak and Kachemak Bays has not been established.

BENTHIC INVERTEBRATES

- There are not enough data to define recurrent species groups and determine their distributional trends.
- Insufficient data are available for correlating substrate types and the occurrence of certain benthic species -- a valuable predictive tool.

- Very little is known about life histories or seasonal changes among Cook Inlet noncommercially important benthic invertebrate species.
- Benthic fauna in the Kennedy Entrance area is poorly known; data on the benthic fauna of upper Cook Inlet are also very scarce.
- Few data have been accumulated on the effects of crude oil on subarctic invertebrates.

FISH

- Seasonal use and distribution of fish species in Cook Inlet are not well defined; available information is general in nature.
- Much information is lacking about food habits of most species of fish as well as possible changes in feeding habits with different growth stages and seasons.
- Smelt and herring offshore migrations are poorly understood.
- Few data are available on the effects of crude oil on Arctic and subarctic fish species.
- Prey size should be given more emphasis in trophic studies (this applies to fish, bird and mammal studies). For example, ecologically, capelin of 10 cm are different animals than capelin of 20 cm (G. Sanger, USDF&W, Anchorage).

BIRDS

- Reasonably complete census data for Lower Cook Inlet coastal bird populations are only available from four single season aerial censuses completed during 1976 (D. Erikson and P. Arneson, ADF&G, Anchorage). This data base needs to be expanded in order to assess its reliability/variability.
- The location and relative importance of foraging areas utilized by birds from the different regions and breeding colonies of Cook Inlet needs to be established.
- The regional significance of specific breeding colonies, flight staging areas and migration corridors needs to be assessed.
- Approaches to estimating recovery times for bird populations decimated (i.e., 10, 25, 50 percent killed) by natural or man-induced events should be examined.
- Shorebird/waterfowl habitat utilization and ice cover interactions need to be documented.
- The regional significance of the Barren Islands (benthos, birds, and mammals) needs to be more fully explored in future synthesis meetings.

MAMMALS

- Present data describing the species composition, abundance and distribution (both spatially and seasonally) of marine mammals in Lower Cook Inlet are inadequate.

- No locally collected food habits information is available. While data for some species are available from other locations, they could be misleading if applied to Cook Inlet populations.
- It is not known how seal, sea lion, and whale distributions are influenced by changes in distribution of major food species (e.g., pollock, herring).
- Sea otters have drastically altered the structure of marine communities in other areas as they have repopulated former habitat. Sea otter populations are presently expanding into Lower Cook Inlet. Changes that will occur may be difficult to interpret unless studies of benthic invertebrates continue on a long-term basis (i.e., they could perhaps be confused with possible hydrocarbon development effects).
- Marine mammal populations occupy a range larger than Lower Cook Inlet. It is important to recognize potential impacts on their *ENTIRE POPULATIONS* not just those animals occupying Cook Inlet. For example, a reduction in the number of sea lions in the Barren Islands in summer would reduce winter densities throughout the Gulf of Alaska.
- The relative "discreteness" of biological populations (fish, birds, and mammals) utilizing Lower Cook Inlet needs to be explored. If there is a high level of interchange between Cook Inlet and Gulf of Alaska populations then the implications for OCS development impacts might be very different than if the populations are more isolated.

MICROBIOLOGY

- The abundance and distribution of bacteria in Lower Cook Inlet remains poorly known. Data are needed on the abundance of oil-degrading bacteria and rate of petroleum degradation in the Inlet.

DATA RELATED TO OIL SLICK BEHAVIOR

- Emulsification is little understood, but appears to be a major dispersion mechanism.
- Little information is available on the importance of photochemical oxidation in a high latitude environment such as Cook Inlet. Moreover, the products of this oxidation may be more toxic than the original crude oil. Assessment of rates and influence of environmental parameters is needed.
- Data are not currently available to assess the importance in Lower Cook Inlet of the process of adsorption of oil to particles. (Studies by University of Alaska, IMS, and NOAA/PMEL are currently underway to delineate the significance of this process.)
- Related to the above problem is the transport capacity of suspended matter and its final depositional setting. Significant data gaps exist in the characterization of net depositional environments in Lower Cook Inlet (e.g., Kachemak and Kamishak Bays), and in determining if these environments might also be critical biological habitats.

TOXIC TRACE METALS

Trace metals of concern (i.e., Cd, Co, Cr, Cu, Hg, Ni, Pb, V, Zn, etc.) are not readily soluble; therefore, the major transport and assimilation mechanisms are via suspended matter. Critical research areas include:

- Adsorption and chelation kinetics involving suspended matter, particulates, and dissolved organic carbon.
- Transport capacity and trajectories of suspended matter.
- Sediment budget; identification of regions of net sedimentation and depositional rates.
- Bioaccumulation and bioamplification of toxic heavy metals.

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APPENDICES

Appendix 1. List of Participants

Appendix 2. Development Scenario

Appendix 3. Cook Inlet Biota and
Probable Oil Interactions

APPENDIX 1

List of Participants at Lower Cook Synthesis Meeting
November 16-18, 1976
Anchorage, Alaska

James Blackburn
Alaska Department of Fish and Game
Kodiak, Alaska

Herb Bruce
NOAA/OCSEAP
Juneau, Alaska

Garvin Bucaria
Bureau of Land Management
Anchorage, Alaska

David Burbank
Alaska Department of Fish and Game
Anchorage, Alaska

Robert Charnell
NOAA/PMEL
Seattle, Washington

Robert Cooke
Bureau of Land Management
Anchorage, Alaska

Joel Cline
NOAA/PMEL
Seattle, Washington

Herb Curl
NOAA/MESA
Boulder, Colorado

T. Saunders English
University of Washington
Seattle, Washington

Howard Feder
Institute of Marine Science
University of Alaska
Fairbanks, Alaska

Loren Flagg
Alaska Department of Fish and Game
Homer, Alaska

Judy Gottlieb
Bureau of Land Management
Anchorage, Alaska

Jawed Hameedi
Science Applications, Inc.
Boulder, Colorado

Carol Hemington
NOAA/OCSEAP
Boulder, Colorado

Don Henninger
Bureau of Land Management
Anchorage, Alaska

Ed Hoffman
Bureau of Land Management
Anchorage, Alaska

Charles Hoskin
Institute of Marine Science
University of Alaska
Fairbanks, Alaska

Jerry Imm
Bureau of Land Management
Anchorage, Alaska

Jerry Larrance
NOAA/PMEL
Seattle, Washington

Dennis Lees
Dames and Moore
Anchorage, Alaska

Keith Macdonald
Science Applications, Inc.
Boulder, Colorado

Brian Matthews
University of Alaska
Fairbanks, Alaska

Nancy Maynard
Bureau of Land Management
Anchorage, Alaska

Bob Meyer
NOAA/OCSEAP
Juneau, Alaska

Ron Morris
National Marine Fisheries Service
Auke Bay, Alaska

Susan Miller
Science Applications, Inc.
Boulder, Colorado

Kilho Park
NOAA/OCSEAP
Boulder, Colorado

Bob Paulus
Alaska Department of Fish and Game
Anchorage, Alaska

Kathy Petersen
Science Applications, Inc.
Boulder, Colorado

Jay Quast
National Marine Fisheries Service
Auke Bay, Alaska

Douglas Redburn
Alaska Department of Environmental Conservation
Juneau, Alaska

Gerald Sanger
U.S. Fish and Wildlife Service
Anchorage, Alaska

David Shaw
Institute of Marine Science
University of Alaska
Fairbanks, Alaska

Karl Schneider
Alaska Department of Fish and Game
Anchorage, Alaska

Richard Tenaza
Science Applications, Inc.
Boulder, Colorado

Bruce Wing
National Marine Fisheries Service
Auke Bay, Alaska

Kent Wohl
Bureau of Land Management
Anchorage, Alaska

Ed Wolf
Science Applications, Inc.
Boulder, Colorado

Rick Wright
State of Alaska, Governor's Office
Juneau, Alaska

APPENDIX 2

DEVELOPMENT SCENARIO FOR
THE POTENTIAL LOWER COOK INLET
OCS LEASE SALE: 1977

by

The BLM/Alaska OCS Office

NOAA Lower Cook Inlet Synthesis Workshop
16-18 November, 1977
Anchorage, Alaska

TABLE OF CONTENTS

Development Scenario For The Potential Lower Cook Inlet OCS Lease Sale

Michael L. Walker

INTRODUCTION

A proposed Federal Action, which is designed to meet the Department of the Interior's objectives for the management of marine minerals is the sale of oil and gas leases in the Lower Cook Inlet (Figure I). One hundred and fifty-two tracts (0.36 million hectares; 0.9 million acres) of OCS land are proposed for leasing action. The tracts are located offshore of the Kenai Peninsula and the west coast of the Lower Cook Inlet with distance to shore ranging from 6 to 22 miles. The tracts are situated in water depths that range from approximately 35 meters to 80 meters. The sale is tentatively scheduled to be held in February of 1977.

PURPOSE

The purpose of this paper is to examine the petroleum development scenario as it was described in the Lower Cook Inlet Draft Environmental Impact Statement (DEIS), and where possible to translate it into map form.

It is necessary to clarify the purpose of the DEIS and the meaning of our potential petroleum development scenario. The simply stated intent of the DEIS for the Lower Cook Inlet is to aid the Secretary of the Department of Interior during his decision making process and to act as a disclosure document to inform the public of a proposed major federal action. The method elected to develop the DEIS revolves around the concept of a petroleum development scenario which leads to a maximum impact assessment.

For example, the resource and production assumptions are "high case" and made for the purpose of estimating maximum impact assessment. This leads to an analysis of maximum resource conflict and/or competition. An analogy might be when you look through a stereoscope, elevation differences are accentuated with the highest points highlighted. This specific intent in maximizing the potential impacts reduces the value of the EIS as a local planning document because it is not the "most likely case" and therefore, not a prediction or forecast of the future.

Michael L. Walker is a staff regional planner with the Alaska Outer Continental Shelf Office, Bureau of Land Management, Department of Interior.

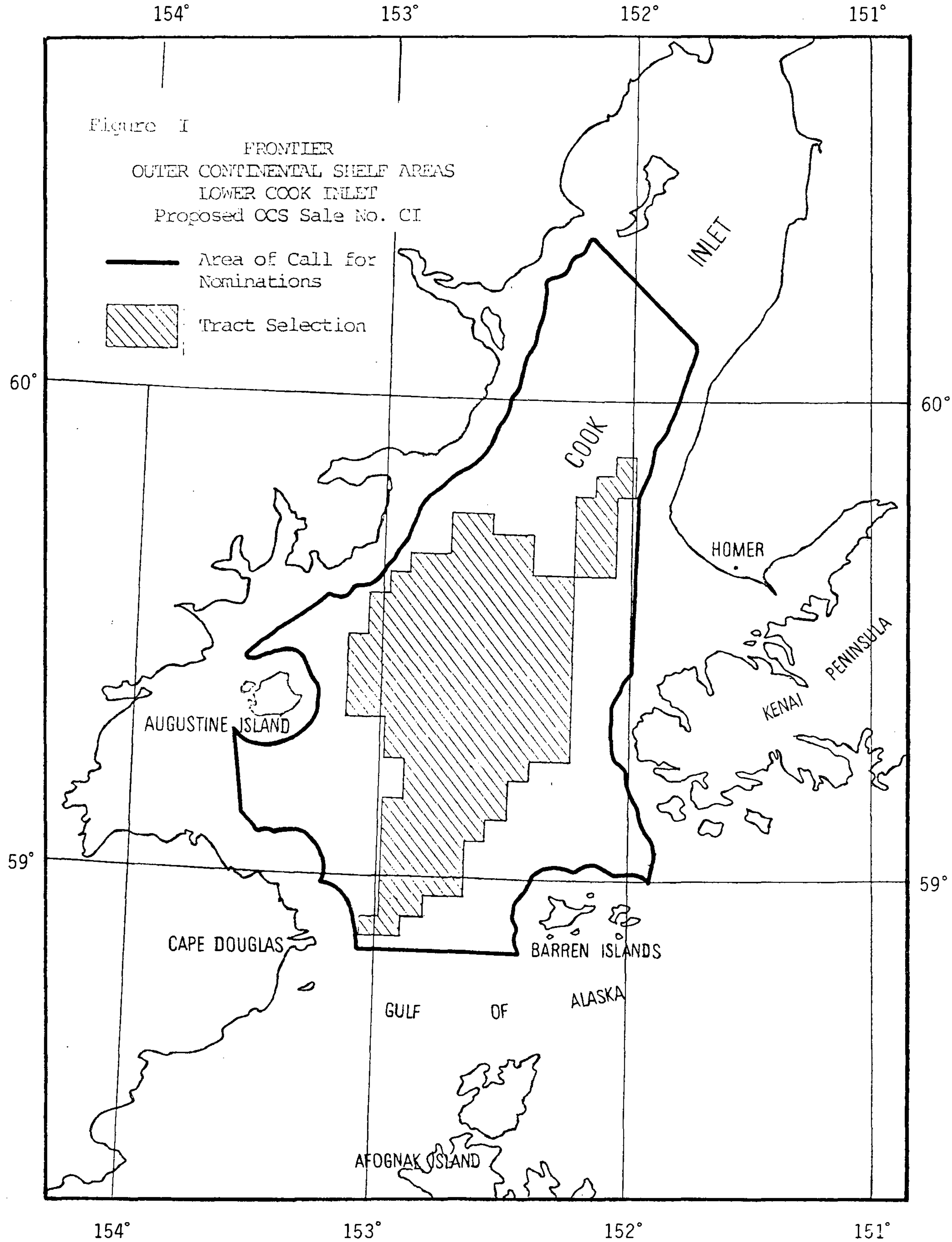


Figure I
FRONTIER
OUTER CONTINENTAL SHELF AREAS
LOWER COOK INLET
Proposed OCS Sale No. CI
Area of Call for Nominations
Tract Selection
154°
153°
152°
151°
60°
59°
INLET
COOK
HOMER
KENAI
PENINSULA
AUGUSTINE ISLAND
CAPE DOUGLAS
BARREN ISLANDS
GULF OF ALASKA
AFOGNAK ISLAND

THE HIGH CASE PETROLEUM DEVELOPMENT SCENARIO

Petroleum development in the Lower Cook Inlet depends in large part upon the volume of recoverable oil and gas resources, current technology, economic incentives, and the availability of capital, manpower, and equipment. Because the proposed sale would be only the second ever held on the Alaska OCS, and because development data from the first sale are not yet available, detailed information useful for projecting future production activities is lacking. The resources supply and production and development timetable assumptions which follow are based on interpretation of geologic data, and the anticipated development requirements, largely based on upper Cook Inlet derived data.

Resource Supply and Production Assumptions

The scenario assumes the sale area would produce 2.6 billion barrels of oil and 3.3 trillion cubic feet of gas.

The estimated peak volume of crude oil produced would be 930,000 bbls/day or 340,000,000 bbls/year, and the peak gas production would be 465 million cf/day or 170 billion cf/year.

Development Timetable Assumptions

Exploratory drilling would begin the year after leases are issued and would be substantially completed at the end of the eighth year (Reference Table I).

- Onsite platform installation would begin during the fourth year after the lease sale and continue through the ninth year.
- Peak oil production would occur approximately eight years after the lease sale.
- The life expectancy of the oil and gas fields would be about 25 years, and the last platforms might be removed about 40 years after production has commenced.

TABLE I

Development Timetable

Year	Exploratory Drilling (# of wells)	Development Drilling (# of wells) Oil	Gas	Service	Number of Platforms Set	Miles of Pipeline Constructed	Number of Terminals	Number of Production Treatment Facilities	Number of LNG Plant	Production Oil Mil bbls	Production Gas Bil cf
1977	5										
1978	11										
1979	21										
1980	21	30	0	0	3	75					
1981	11	60	0	0	3	75	1	1		40	
1982	8	120	0	0	6	60				120	25
1983	4	120	10	0	6	45	1	1		220	40
1984	3	60	10	20	3	45			1	340	65
1985		30		20	2					290	130
1986				20						250	170
1987				20						210	170
1988										180	170
1989										160	170
1990										130	170
1991										110	170
1992										100	170
1993										80	170
1994										70	170
1995										60	170
1996										50	170
1997										42	170
1998										38	170
1999										32	170
2000										28	170
2001										22	130
2002										18	120
2003										10	110
2004											75
2005											50
TOTAL	84	420	20	80	23	300	2	1	1		

- At assumed peak production, 23 platforms would be required -- 21 oil platforms and 2 gas platforms.

- Exploratory wells would number 84, which includes 24 expendable delineation wells.

- There would be pipelines totalling 300 miles in length, of which 100 miles would be constructed onshore and 200 miles would be submarine.

- The annual production would be transported from production platforms to shore by pipeline and from shore storage to market areas by tanker. Future pipeline management studies will delineate specific pipeline corridors.

- No petroleum refineries are expected to be constructed in Alaska as a result of the sale.

- No manufacturing of platforms is anticipated to occur in Alaska.

- There would be one liquefied natural gas (LNG) plant constructed around 1984.

Onshore Facilities Development Assumptions

Many variables will affect the types and locations of facilities required to support the exploration, development, and production of oil and gas resources, if discovered, and a number of facility combinations is possible. Among these variables are included the policies and controls of local, regional, State, and Federal governments, and those of private, corporate, institutional, and industrial landholders.

In order to address biophysical and socioeconomic impacts of the proposed sale, it is first necessary to qualify certain assumptions from within a framework of feasible alternatives. The sites shown in Figure II generally represent the ranges of feasible alternatives suggested by the U.S. Geological Survey and the Alaska OCS Office. This range of potential industrial sites is the assured onshore development scheme and represents one conditional and qualified example of a possible development scenario. It is not intended to imply or suggest specific onshore development for the impact area, and <u>should not be considered as a prediction or forecast</u> of the site-specific allocation of these facilities. Any regional development scheme and all site-specific facilities would be subject to all existing Federal, State, and local regulations, land use plans, policies, or controls.

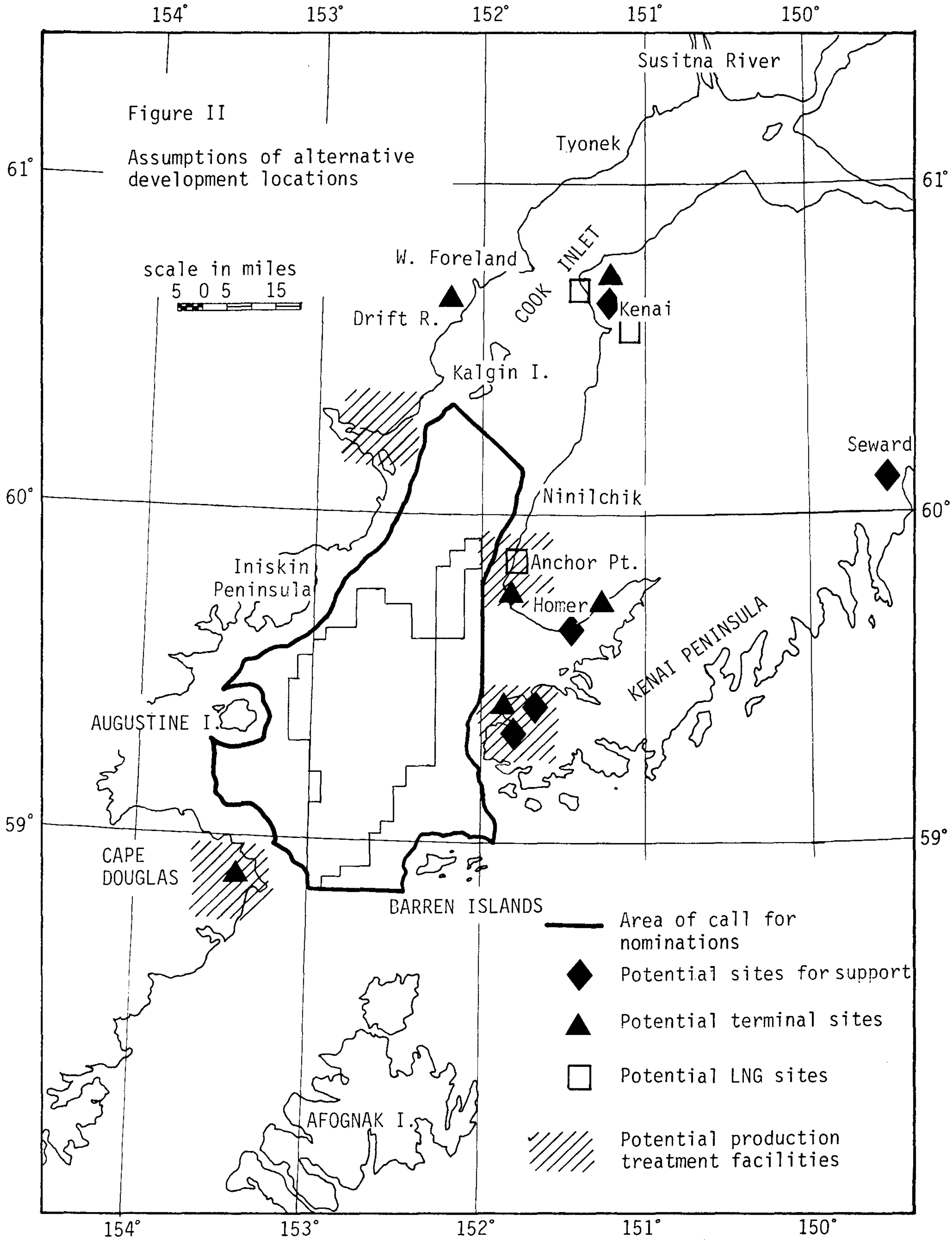


Figure II
Assumptions of alternative development locations
scale in miles
5 0 5 15
154°
153°
152°
151°
150°
61°
60°
59°
Susitna River
Tyonek
W. Foreland
COOK INLET
Kenai
Drift R.
Kalgin I.
Seward
Ninilchik
Iniskin Peninsula
Anchor Pt.
Homer
KENAI PENINSULA
AUGUSTINE I.
CAPE DOUGLAS
BARREN ISLANDS
AFOGNAK I.
Area of call for nominations
Potential sites for support
Potential terminal sites
Potential LNG sites
Potential production treatment facilities

- The location of support and supply facilties, crude oil terminal sites, and onshore production treatment facilities would depend mainly upon the location of producing fields in relation to the physical environment. Potential support and supply facilities would likely be located at Homer, Nikiski, the Seldovia Port Graham area, and Seward. Potential onshore crude oil terminal and treatment sites are the Seldovia - English Bay - Port Graham area and the Cape Douglas area for any discoveries in the southern part of the sale area. For discoveries in the northern part of the sale area, potential sites are the Anchor Point area and the west side of the Inlet. The present terminal and storage facilities at Nikiski and Drift River might also be used for production from oil and gas fields in the northern part of the sale area. For the purposes of this DEIS, two new onshore terminals, and two production treatment facilities (may or may not be with terminals) are assumed with all other production going to existing facilities.

A summary of the above basic assumptions are listed in Table II.

TABLE II

Summary of Basic Assumptions

Activity	This Proposed Sale
Sale acreage offering	865,000 acres (350,000 hectares)
Anticipated sale	692,000 acres (280,000 hectares)
Recoverable oil (maximum)	2.6 billion barrels 1/
Recoverable gas (maximum)	3.3 trillion cubic ft. 1/
Peak production oil	930,000 bbls/day 1/ 340 million bbls/year 1/
Peak production gas	465 million cf/day 1/ 170 billion cf/year 1/
Platforms	23 (21 oil; 2 gas) 1/
Wells	604 (84 exploratory; 80 service; 440 production)
Pipelines	300 miles (200 miles offshore; 100 miles onshore) 1/
Pipeline burial excavation volume	3000 to 8000 yards/mile 1/
Onshore pipeline acreage required	630 acres (255 hectares) permanent right-of-way
Onshore oil terminal facilities number and acreage required	2; 240 acres (97 hectares); 120 acres (49 hectares) each 1/
Support/supply facilities number and acreage required	3; 120-240 acres (49-97 hectares); 40-80 acres (16-32 hectares) each 1/
LNG plant and terminal	1; 60-120 acres (24-49 hectares)
Production treatment facilities	2; 160 acres (65 hectares); 80 acres (32 hectares) each
Total direct land requirements	1339-1519 acres (542-615 hectares)
Petroleum refineries	0 1/
Platform fabrication	0 1/
Supply and support boats	6-24
Annual crude shipped by tanker	Up to 340 million bbls/year 1/

THE EXISTING ONSHORE ENVIRONMENT

This discussion will be brief and consider the existing space use in the Cook Inlet along with a look at the area with the greatest community development potential.

Existing Space Use

The regional space uses identified in the Cook Inlet area are shown in Graphic 12. Even though the surface space of the Cook Inlet area is the most developed in the State of Alaska, it is still preponderantly under-developed and in its natural state. Uses range from intensively urban uses to extensively subsistences uses.

Presently about 20 percent of the surface space of the Kenai Peninsula Borough is in private ownership. Major urban concentrations are in Anchorage and the Kenai-Soldotna area. Other important urban areas are in Homer, Seward, and the industrial complex at Nikiski. Rural developments are heavily concentrated along the major road systems.

Major oil and gas development exists in the upper Cook Inlet. There are basically five oil and three gas producing fields, 14 offshore platforms, and a pipeline network to gather and distribute the oil and gas production (Graphic 1). The largest major pipeline which is used to move crude has a 20 inch diameter and is located on the west side of the Cook Inlet from Granite Point to the Drift River Terminal.

The Drift River Terminal handles approximately 3/4 of the total oil produced in the upper Cook and is presently at about 75 percent capacity. The Trading Bay facility is a production treatment facility. The Granite Point facility is also a production treatment facility, but much smaller.

The Nikiski Marine Terminal complex (Figure III) includes the following: (a) Collier Carbon and Chemical Company terminal and plant of which there are plans to double production; (b) Phillips/Marathon LNG plant and a terminal designed specifically for loading the production to tankers; (c) Kenai Pipe Line Company terminal (same as Standard Dock); (d) Rig Tenders dock which is a support and supply base designed primarily to handle barges and offshore platform service vessels; (e) Tesoro Alaska refinery; (f) Standard Oil Company of California refinery; and (g) it is possible that in the near future, the Pacific Alaska LNG Company will install an additional LNG plant and terminal south of the Collier Ammonia and Urea Plant.

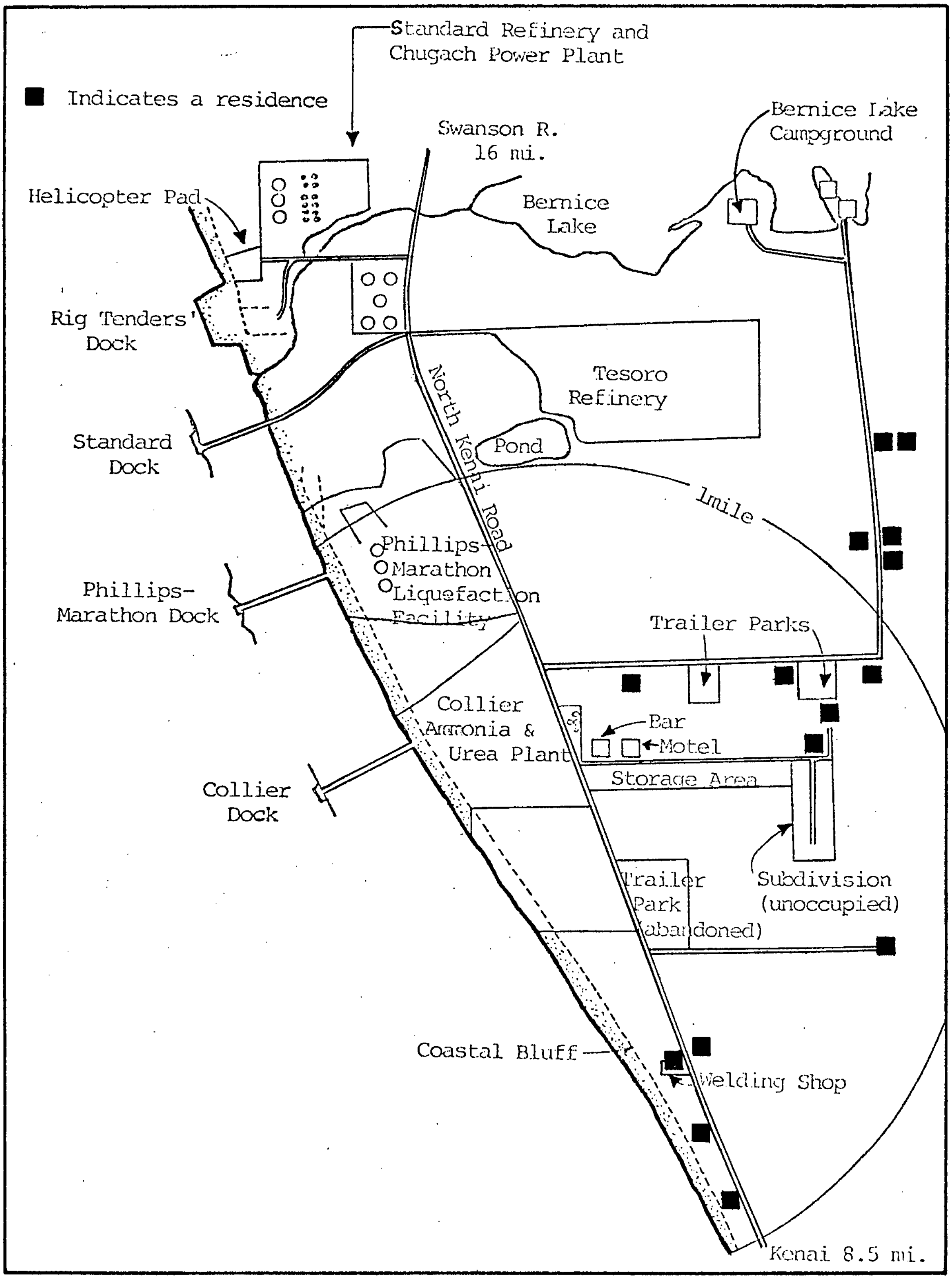


Figure III Nikiski marine terminal complex, land-use map.

Community Development Potential

The Joint Federal State Land Use Planning Commission has done work classifying the land surface of the Cook Inlet area as to its capabilities and potential use for urban and rural development. The lowland portion of the western Kenai Peninsula along with the Yentna, Susitna, and Matanuska drainage areas appear to have the greatest development potential in the Cook Inlet area (Figure IV). The actual major urban and rural concentrations on the Kenai Peninsula have developed in the same general areas (Graphic 12).

The principal basis of this classification was soil survey information. The principal soil features which limit the capability of the land for highway location and building development can be interpreted as limitations for physically suitable settlement.

POTENTIAL LOCATIONS OF IMPACTS RESULTING FROM THE PETROLEUM DEVELOPMENT SCENARIO

Sites for Support and Supply Bases

The most likely areas for support bases in the Cook Inlet during the initial exploration phase were assumed to be Nikiski for vessel support and Homer for air support. For field development, support and supply facilities would be developed and expanded at those sites nearest the offshore development activity to reduce logistic lines to a minimum. The most likely impact areas for permanent support and supply bases would be Nikiski, Homer, or the Seldovia-Port Graham area, as well as presently undeveloped sites (Figure V).

Platform Sites

Geological and geophysical information which is available to the federal government is proprietary and unuseable for making inferences concerning the locations of the assumed oil and gas resources. Therefore, the supposition of the petroleum development scenario is that the locations of the assumed 23 platforms will be evenly distributed throughout the potential lease sale area (Figure V).

Crude Oil Terminal Sites

It was assumed that the most likely locations for crude oil terminals would be Drift River, Nikiski, the Anchor Point-Homer area, the southwestern portion of the Kenai Peninsula (a coastal arc from Seldovia to Portlock), and other as yet unidentified sites (Figure V).

If discoveries occurred in the northern portion of the sale area, there is the possibility of offshore and onshore pipelines being layed from the discovery point to the existing terminals.

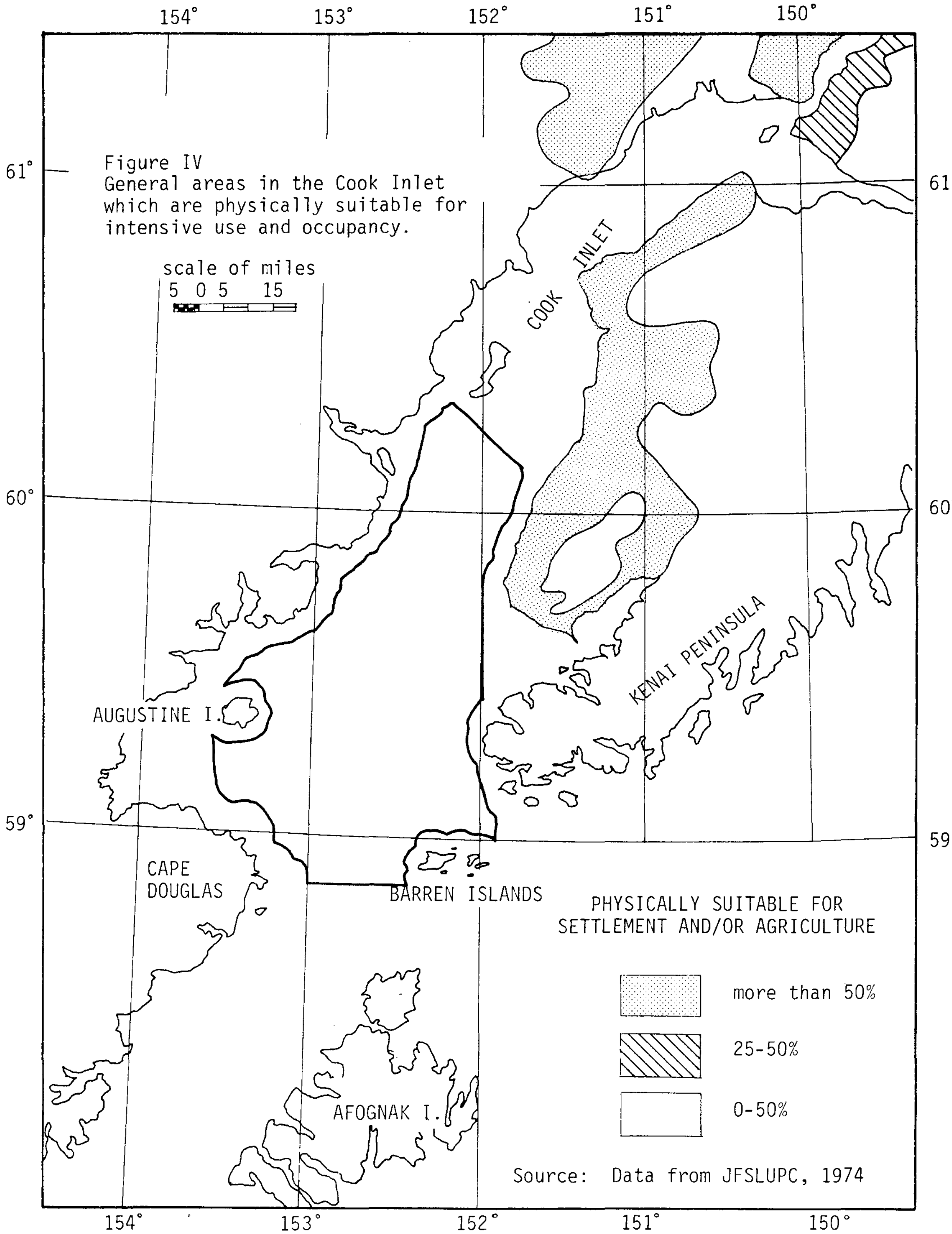
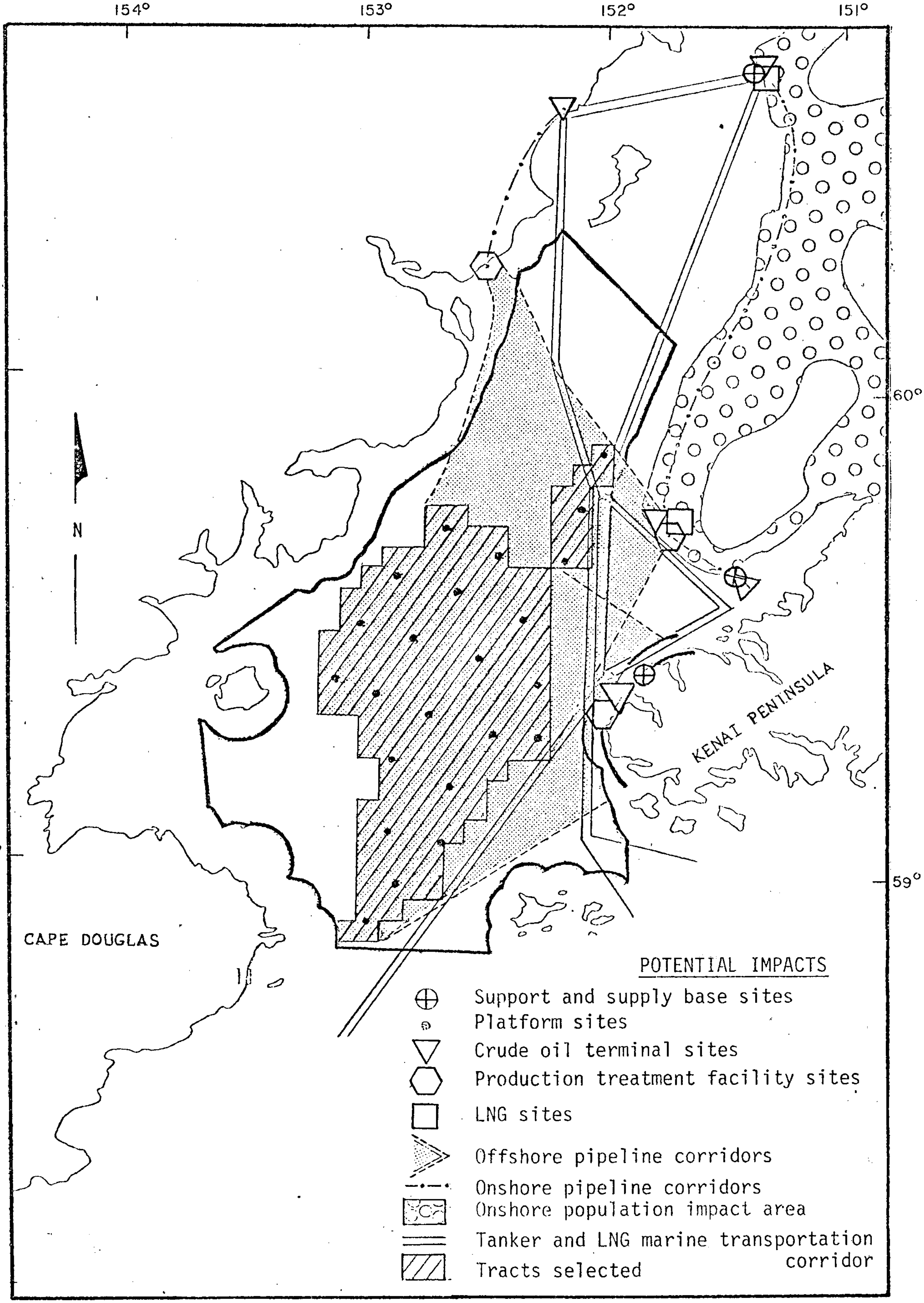


Figure IV
General areas in the Cook Inlet which are physically suitable for intensive use and occupancy.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CAPE DOUGLAS
KENAI PENINSULA
POTENTIAL IMPACTS
Support and supply base sites
Platform sites
Crude oil terminal sites
Production treatment facility sites
LNG sites
Offshore pipeline corridors
Onshore pipeline corridors
Onshore population impact area
Tanker and LNG marine transportation corridor
Tracts selected

Production Treatment Facilities

It was assumed that all potential production treatment facilities would occur at the locations of the crude oil terminals. The two exceptions would be the potential facilities in the Anchor Point and Redoubt Point areas. These two facilities would be separate from the crude oil terminal locations (similar to Trading Bay or Granite Point facilities).

LNG Sites

The petroleum development scenario indicated the Nikiski and Anchor Point areas as possible locations of the assumed LNG plant. Of the two sites, the Anchor Point area would have a higher probability due to the present high density of marine traffic at Nikiski.

Pipeline Corridors

The location of the specific areas within the lease sale in which producing fields will be discovered is unknown. Therefore, the pipeline corridors can only be very generally approximated as originating from the entire lease sale area to the potential crude oil terminals and production treatment facility sites (Figure V).

Distribution of Net Population Impact

The net population impact was defined as all additional people (direct and indirect employees, dependencies, and other associated non-workers) who will establish their primary residence in the impacted region. It was estimated that during 1983, the peak year for population increases, that the Kenai-Cook Inlet census division will receive approximately 11,000 additional people or about two-thirds of the total population impact (Reference Section III.G.2. of the EIS for the Cook Inlet). It is felt that the majority of this population impact will occur in the previously defined lowland portion of the Western Kenai Peninsula (Figure IV).

Surface Marine Transportation Impacts

The major surface marine competitors for space will be the exploration drilling vessels, support and supply boats, and crude oil and LNG tankers. The locational patterns will be determined primarily by the location of the producing fields, the onshore support facilities, and the potential markets. An estimate of the possible range of these patterns is given in Figure V.

Oil Introduction to the Marine Environment

One conclusion is that the previously discussed activities will have a certain likelihood of causing pollution to the marine environment. The estimated oil introduction to the Cook Inlet as a result of the maximum impact assessment scenario is described in Table III.

TABLE III

Anticipated Annual Oil Introduction to the Marine Environment During Peak Production Resulting From the Proposed Sale

Location	Sources	Maximum Annual Spillage Barrels	Cumulative 25 Year Total Barrels*
Lower Cook Inlet	Pipeline accidents	5,800	48,000
	Formation water*	780	19,500
	Spills from platform fires	9,900	82,000
	Overflow, malfunction, or rupture	185	1,500
	Minor spills (less than 50 bbls)-all sources	550	13,750
	SUBTOTAL	17,215	164,750
Transportation Route	Tankers	54,400	450,000
	TOTAL	71,615	614,750

Source: CEQ, 1974.

*The cumulative totals are not based on peak year production spillage rates, but on the yearly projected production.

An estimated maximum of 17,215 barrels of oil will be spilled (Table III) in the Lower Cook Inlet region during the year of peak production. This does not include the 2,100 barrels spilled from a projected blowout of one well sometime during the life of production. A total of 54,400 barrels will be spilled by tankers either in this area, along the transportation routes, or at their destination. Over the 25 year production life, about 600,000 barrels would be spilled using the total projected yearly production.

SUMMARY

Figure V entitled, Potential Locations of Impacts Resulting from the Petroleum Development Scenario," is a general spatial expression of the maximum development case. It 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 the DEIS and FEIS for the Lower Cook Inlet.

APPENDIX 3

COOK INLET BIOTA

ECOLOGY AND PROBABLE OIL INTERACTIONS

- Benthic Biota
- Fish
- Birds
- Mammals

Compiled by SAI staff from
Synthesis Meeting inputs and
the published literature

Ecology and Probable Oil Interactions -- Cook Inlet Benthic Biota

Species or Biotic Group	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Ecological Uses of Area by Biotic Group	Potential Oil - Biota Interactions
Kelp	Exposed rocky intertidal, subtidal (<30 m)	2,3,4,5	Spring - Summer Growing Season	Attachment, Photosynthesis, Nutrient uptake	Direct coating of plants and substrate; acute absorption; toxicity to young plants
Eelgrass	Shallow, protected embayments	2,3,4	Spring - Summer Growing Season	Attachment, Photosynthesis, Nutrient uptake	Direct coating of plants and substrate; acute absorption; toxicity to young plants
King Crab - adults	Littoral zone to 360 m	1	Summer shallow Winter deep	Feeding, Migration, Commercial catch	Tainting of catch, ingestion; substrate contamination; toxicity of larvae and adults
- spawning	Littoral zone	2,3	April	Molting, Reproductive and soft shell period	
- larvae	Semipelagic to benthonic	2,3	February - June		Ingestion, toxicity
Tanner Crab - adults	Littoral zone to 550 m	1	Summer shallow Winter deep	Feeding, Migration, Commercial catch	cf. King Crab
- spawning	Littoral zone	2,3	April	Molting, Reproductive and soft shell period	
- larvae	Semipelagic to benthonic	2,3	January - July	Feeding, Dispersal	
Dungeness Crab - adults	Bays, inlets, and open ocean to 100 m	3,4	Summer shallow Winter deep	Feeding, Migration, Commercial catch	cf. King Crab
- spawning	Intertidal to 50 m	3	September		
- larvae	Semipelagic to benthonic	3	May - December	Feeding, Dispersal	

- continued -

Species or Biotic Group	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Ecological Uses of Area by Biotic Group	Potential - Oil Biota Interactions
Pandalid Sprimp - adults (4 spp)	Littoral zone to 420 m	1,2,3,4		Feeding, Commercial catch	
- spawning	Shallow bays	3	September		cf. King Crab
- larvae	Semipelagic to benthic (35 m)	3	March - September	Feeding, Dispersal	
Scallops - adults	Benthic; sand-gravel bottom with some mud; 50-130 m	1,3	Year long	Attachment, Majority of life history	Substrate modification; ingestion; toxicity
- spawning	Benthic; sand-gravel bottom with some mud; 50-130 m	1,3	June - July		
- larvae	Planktonic	1,3	June - August	Feeding, Dispersal	
Razor Clams - adults	Intertidal, shallow subtidal surfswept sand beaches	2,3,5	Year long	Infaunal burial, Majority of life history, Commercial & sports catch	Smothering; substrate modification; ingestion; toxicity
- spawning	Intertidal, shallow subtidal surfswept sand beaches	2,3,5	Mid July - Mid September		
- larvae	Planktonic	2,3,5	July - November	Feeding, Dispersal	
Intertidal/Subtidal Benthos	Intertidal and shallow subtidal shores of inlet	1,2,3,4,5	Year long	Complete life cycle, planktonic reproductive stages usually in spring, summer	Smothering; substrate modification; ingestion; toxicity
Deeper Water Benthos	Offshore inlet bottom	1,2,3	Year long	Complete life cycle, planktonic reproductive stages usually in spring, summer	Substrate modification; ingestion; toxicity

*1 - Central Lower Cook Inlet
2 - Kachemak Bay
3 - Kamishak Bay
4 - Kennedy Entrance
5 - Kalgin Island
6 - Upper Cook Inlet

Ecology and Probable Oil Interactions -- Cook Inlet Fisheries

Species or Biota Group	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Area Use by Biotic Group	Potential Oil Biota Interaction
Salmonidae (Adults)					
Sockeye	Congregate in Estuaries	Nearshore; Anadromous Streams with Lakes; 2,5,6	Early June - Early August	Spawning migration	Behavioral; Block access to spawning streams
Pink	Congregate in Estuaries	Nearshore; Anadromous Streams; Intertidal; 2,3,4,5,6	Late July - Late August even years	Spawning; spawning migration	Behavioral; Block access to spawning areas; Toxic to spawn
Chum	Congregate in Estuaries	Nearshore; Anadromous Streams; Intertidal; 2,3,4,5,6	Early July - Late August	Spawning; spawning migration	Behavioral; Block access to spawning areas; toxic to spawn
Coho	Congregate in Estuaries	Nearshore; Anadromous Streams; 2,3,4,5,6	Late June - Mid September	Spawning migration	Behavioral; Block access to spawning areas
	Pelagic	Throughout Cook Inlet	Fall, Winter, Spring	Feeding	Deplete food source; Behavioral
Chinook	Congreate in Estuaries	Nearshore; Anadromous Streams; 2,5,6	Late May - Late August	Spawning migration	Behavioral; Block acess to spawning streams
	Pelagic	Throughout Cook Inlet	Fall, Winter, Spring	Feeding	Deplete food source; Behavioral
Steelhead	Congregate in Estuaries	Nearshore; Anadromous Streams; 2,3,5,6	Late June - Late October	Spawning migration	Behavioral; Block access to spawning stream
	Estuaries	NEarshore; 2,3,4,5,6	Fall and Early Winter	Feeding; overwintering	Additional stress on spent spawners
Char	Congregate in Estuaries	Nearshore; Anadromous Streams; 2,3,4,5,6	Late June - October	Spawning migration	Behavioral; Block access to spawning streams
	Estuaries	Nearshore; 2,3,4,5,6	Fall and Early Winter	Feeding; Migration to overwintering streams	Block access to overwintering streams with lakes; Added stress to spent spawners

- continued -

Species or Biota Group	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Area Use by Biotic Group	Potential Oil Biota Interaction
Salmonidae (Adults, cont.)					
Commercial Fisheries	Offshore	5	Early June - Mid September	Commercial harvest	Taint catch; Foul nets
	Nearshore, estuaries	2,3,4,5,6	Early June - Mid September	Commercial harvest	Taint catch; Foul nets
Sport Fisheries	Nearshore, estuaries	3	Summer - Fall	Sport catch; Recreation	Loss of aesthetic appeal
Salmonidae (Juveniles)					
Sockeye	Enter estuary	Nearshore; surface; 2,5,6	April - Late July	Smolting; Feeding	Toxicity, Reduced food supply; Behavioral
	Seaward migration	Offshore to Gulf of Alaska	4 to 6 weeks after entering the estuary	Outmigration	Toxicity, Behavioral
Pink	Enter estuary	Nearshore; surface; 2,3,4,5,6	April - June	Smolting; Feeding	Toxicity, Reduced food supply; Behavioral
	Seaward migration	Offshore to Gulf of Alaska	90 days after entering estuary	Outmigration; Feeding	Toxicity; Behavioral
Chum	Enter estuary	Nearshore; estuary; 2,3,4,5,6	April - Early July	Smolting; Feeding	Toxicity. Reduced food supply; Behavioral
	Seaward migration	Offshore to Gulf of Alaska	Appx. 90 days after entering estuary	Outmigration; Feeding	Toxicity; Behavioral
Coho	Enter estuary	Nearshore; surface; 2,3,4,5,6	May - Late October	Smolting; Feeding	Reduced food supply; Behavioral
	Seaward migration	Offshore		Outmigration; Feeding	Behavioral
Chinook	Enter estuary	Nearshore; surface; 2,5,6	Late June - Mid July	Smolting; Feeding	Reduced food supply; Behavioral
	Seaward migration	Offshore		Outmigration; Feeding	Behavioral

- continued -

Species or Biota Group	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Area Use by Biotic Group	Potential Oil Biota Interaction
Salmonidae (Juveniles cont.)					
Steelhead	Enter estuary	Nearshore; surface; 2,3,5,6	April - June	Smolting; Feeding	Reduced food supply; Behavioral
	Seaward migration	Offshore to Gulf of Alaska		Outmigration; Feeding	Behavioral
Char	Enter estuary	Nearshore; surface; 2,3,4,5,6	Early April - Late June; September - October	Smolting; Seeking overwintering streams; Feeding	Toxicity, Reduced food supply; Behavioral; Block access to overwintering streams
Salmonidae (Eggs & Hatching)					
Pink	Intertidal	2,3,4,5,6	July - May	Incubation; Hatching; Emergence	Smothering; Toxicity
Chum	Intertidal	2,3,4,5,6	July - May	Incubation; Hatching; Emergence	Smothering; Toxicity
Clupeidae (Adults)					
Herring	Rocky beach	Intertidal; shallow subtidal; 2,3	May - Mid June	Spawning	Inhibit spawning; Toxic to spawn
	Benthic overwintering	Near bottom; appx. 50 fathoms; 1	Late Fall through Winter	Overwintering; No feeding	Behavior
	Pelagic	Near surface; 2,3,4,5,6	Spring - Fall	Feeding	Reduced food supply; Food chain
Commerical Fisheries	Nearshore	Nursery intertidal; shallow subtidal; 2,3	May - Mid June	Commercial harvest	Taint catch; Foul net
Clupeidae (Eggs & Larvae)					
Herring	Rocky beach	Intertidal; shallow subtidal; 2,3	May - June	Incubation; Hatching	Toxicity; Smothering; Reduced health

- continued -

Species or Biota Group	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Area Use by Biotic Group	Potential Oil Biota Interaction
Clupeidae (Eggs & Larvae, cont.)					
Herring (cont.)	Nearshore	Nursery intertidal; shallow subtidal; 2,3	May - Late Fall	Feeding	Reduced food supply; Toxicity
Pleuronectidae					
Halibut (adults)	Demersal	Throughout Cook Inlet; Highest in 3	May - August	Feeding	Behavior
Commercial Fisheries	Demersal	2,3,4,5	May - August	Commercial harvest	Taint catch
Sport Fisheries	Demersal	3	May - August	Sport catch; Recreation	Taint catch
Gadidae					
Pacific Cod	Pelagic	Nearshore; shallow water	Spring - Summer	Feeding	Food chain; Behavior; Reduced food supply
Hexagrammidae					
Lingcod (adults)	Nearshore	Rocky; shallow subtidal	December - March	Spawning	Toxic to spawn; Inhibit spawning
Lingcod (eggs)	Nearshore	Rocky; shallow subtidal	December - March	Incubation; Hatching	Behavior of male; Smothering; Toxicity
Lingcod (larvae)	Nearshore	Rocky; shallow subtidal	January - Late June	Feeding	Toxicity; Reduced food supply

*1 - Central Lower Cook Inlet; 2 - Kachemak Bay; 3 - Kamishak Bay; 4 - Kennedy Entrance; 5 - Kalgin Island; 6 - Upper Cook Inlet.

Characterization of Principal Bird Species of Lower Cook Inlet

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
					FOR ALL BIRDS: Severe oiling causes death from exposure. Even small quantities of oil transferred to egg reduces their hatchability. Destruction or contamination of foods and habitat by oil. Human garbage might favor increase in gull population. Human disturbance around nesting colonies would lower reproductive success and, if severe enough, might eliminate entire colonies.
Sooty shearwater	Offshore	1,3,4	May - October	Summer feeding ground	
Short-tailed shearwater	Offshore	1,3,4	Mid May - Mid November	Summer feeding ground	
Fork-tailed storm petrel	Spring & summer: offshore Fall & winter: inshore	?	Summer	Summer feeding and breeding grounds	
Cormorants	Inshore waters, rocky coasts	4	Fall	For entire life cycle	
Canada and snow geese	Inshore and intertidal	3,5,6	April and late August - September, spring and fall migration	Feeding and staging during spring and fall migration	
Dabbling ducks (mainly mallard and pintail)	Inshore and intertidal; mudflats	2,3,5,6, particularly Redoubt Bay-Kalgin Is. area	Fall migration; lesser peak during spring migration	Mallard: entire life cycle Other: feeding and staging during migration	
Sea ducks	Inshore, offshore	2,3,5	Spring and summer	Greater scaup & common eider: entire life cycle Others: migration and winter feeding grounds; non-breeders may spend the summer	

- continued -

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
BIRDS (cont.)					See previous page for potential hazards for all birds
Sandhill crane	Intertidal	5 (Redoubt Bay, Kalgin Is.)	March - April and September - October, spring and fall migration	Migration	
Bald eagle and peregrine falcon	Intertidal, inshore	3,4	Year long	Inshore and intertidal fishing (eagle only) and hunting (both species)	
Whimbrel, least sandpiper, northern phalarope	Intertidal	2,3,5	March - April, spring migration	Feeding and staging in spring migration	
Rock sandpiper	Intertidal		October, fall migration	Fall migration, feeding	
Dunlin, western sandpiper	Intertidal	2,3,5	March - April and October, spring and fall migration	Feeding and staging in spring and fall migration	
Glaucous-winged gull	Intertidal, offshore, inshore	1,2,3,5	Spring, summer, fall (smaller numbers present in winter)	For entire life cycle	
Mew gull	Intertidal, offshore, inshore	1,2,3,5	November - April (present in low numbers May - October)	Winter feeding ground. Non-breeders present in summer	

- continued -

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
BIRDS (cont.)					See previous page for potential hazards for all birds
Black-legged kittiwake	Inshore and offshore	1,2,3,5	Spring, summer, fall (low numbers present in winter)	Mainly for breeding and summer feeding	
Pigeon guillemot	Inshore	2,3,5,4	Spring - Summer	Breeding, summer feeding	
Marbled and Kittlitz's murrelets	Inshore and, particularly in fall and winter, offshore	3,4	Year long	For entire life cycle	
Horned and tufted puffins	Offshore and inshore	4	May - September (absent in fall and winter)	Breeding, spring and summer feeding	
Common murre	Inshore and offshore	1,2,3,4,5	April - September but present all year	For entire life cycle, though numbers decrease in winter	
Northern crow	Intertidal	3,4	Fall and winter but present all year	Intertidal and beach zone foraging	

*1 - Central Lower Cook Inlet
2 - Kachemak Bay
3 - Kamishak Bay
4 - Kennedy Entrance
5 - Kalgin Island
6 - Northern Lower Cook Inlet

Characterization of Principal Mammal Species of Lower Cook Inlet

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
Harbor seal	Feed mainly in waters less than 55 m depth; haul out on beaches, sandbars rocks.	Summer: 5,6 Winter: 1,2,3	Pupping season, June - July	For entire life cycle	Food chain contamination; possible acute effects from oiling; contamination of hauling and pupping areas. Human disturbance (e.g., aircraft) could lower breeding success by disrupting rookeries and causing death of pups.
Steller's sea lion	Feed mainly in littoral zone waters; haul out, breed and pup on rocky coasts and islands	4 (Barren Islands) Secondarily, 2,3	Pupping season, June - September (Barren Islands)	For entire life cycle, with breeding/pupping mainly on the Barren Islands	
Sea Otter	Littoral zone waters	2,3,4	Year long	Entire life cycle	Oiling of pelage causes loss of thermal insulation followed by death from exposure
Beluga whale	Inshore waters and river mouths	Summer: 5,6 Winter: 1,2,3	Calving season; probably March - May Year long resident	For entire life cycle	Possible food chain contamination; acute effects, if any, unknown
Harbor porpoise, Dall porpoise, Killer whale, Minke whale	Inshore and offshore waters	1,2,3,4	Summer for Minke whale; unknown for others, perhaps year long	Minke whale: summer feeding. Others unknown, perhaps entire life cycle	Possible food chain contamination; acute effects, if any, unknown
Other cetaceans	Inshore and offshore waters	4	Summer	Migration and feeding around Barren Islands and mouth of Cook Inlet	Possible food chain contamination; acute effects, if any, unknown

- continued -

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
Brown (Grizzly) bear	Coastal brush, tundra, spruce forest and intertidal habitats	West side of Lower Cook Inlet at Redoubt, Tuxedni, Iniskin, Iliamna, Ursus, and Lower Kamishak Bays	Calving season, January - February	Intertidal foraging and fishing	Contamination of foods
Black bear	Similar to Grizzly	Kachemak and Kamishak Bays	Calving season, January - February	Intertidal foraging and fishing	Contamination of foods
River Otter	Rivers and intertidal zone	Kachemak and Kamishak Bays	Pupping season, spring	Littoral zone feeding	Death from exposure following oiling of pelage; contamination or destruction of foods

*1 - Central Lower Cook Inlet
2 - Kachemak Bay
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