Environmental Assessment of the Alaskan Continental Shelf Lower Cook Inlet Interim Synthesis Report

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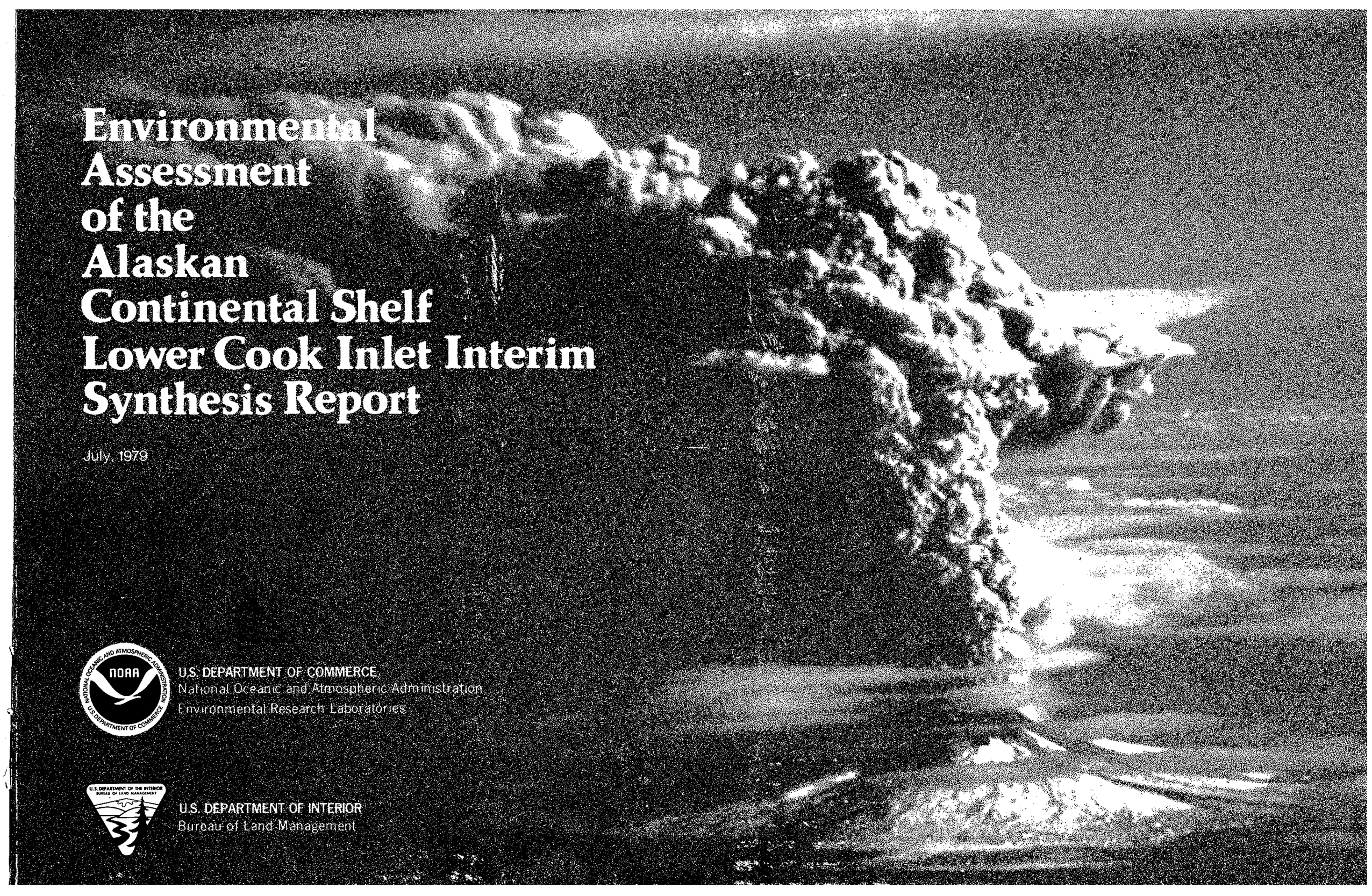

U.S. DEPARTMENT OF COMMERCE
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Environmental Assessment of the Alaskan Continental Shelf

LOWER COOK INLET
INTERIM SYNTHESIS REPORT

Prepared under the Guidance of the
Outer Continental Shelf Environmental Assessment Program

by

Science Applications, Inc.
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July 1979

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NOTICES

This interim report has been reviewed by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration's Outer Continental Shelf Environmental Assessment Program Office, and approved for publication. Approval does not necessarily signify that the contents reflect the views and policies of the Department of Commerce.

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SYNTHESIS REPORT UPDATING

This volume represents an INTERIM edition of the Lower Cook Inlet Synthesis Report and is intended to present a multidisciplinary overview of information relevant to possible Alaskan Outer Continental Shelf oil and gas development. OCSEAP-supported research is still continuing in the Lower Cook Inlet region, making additional relevant information continually available.

A data synthesis meeting will be planned in the near future, at which time OCSEAP Principal Investigators and others familiar with the Lower Cook Inlet Region, will be asked to update and refine the interpretations presented here.

In order to assist with this updating procedure, it is requested that the users of this Report inform the following of major omissions or errors or of any new relevant information:

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Foreword

Expeditious development of the Outer Continental Shelf (OCS) is essential to energy requirements of the United States. The OCS oil and gas deposits can provide a large national source of petroleum during a time when it is greatly needed. In each OCS area for which development is proposed, extensive environmental studies must be conducted before such development can safely proceed. As manager of the Alaskan Outer Continental Shelf leasing program, the Bureau of Land Management (BLM) has asked the National Oceanic and Atmospheric Administration (NOAA) to conduct the Outer Continental Shelf Environmental Assessment Program (OCSEAP).

This program presently focuses on nine lease areas on the Alaska Outer Continental Shelf, ranging from the subarctic Northeast Gulf of Alaska to the arctic Beaufort Sea. This vast geographic area involves extreme environmental conditions. The harsh environment and resultant severe working conditions are largely responsible for the scarcity of marine environmental information on the Alaskan OCS, much less than on any other shelf and coastal area of the United States. The existence of oil under the shelf, the demand for new domestic sources of energy, and the recognition of the lack of basic environmental information have accented the need for a well-developed research program.

An essential part of a research program is the reporting of its results. OCSEAP is reproducing and widely distributing the quarterly and annual reports received from each project as well as some specialized technical summaries. A listing of these reports, as well as the reports themselves, may be secured from OCSEAP's Writer/Editor, NOAA, Rx4, Boulder, CO 80303. More importantly, OCSEAP is producing synthesis reports such as this for each lease area. This current synthesis organizes all available marine environmental information pertinent to OCS development for the given lease area, tailoring the presentation to needs of the users.

A synthesis chapter is provided to tie the scientific and technical information chapters together. It presents a picture of the operation and vulnerability of the environmental system in such a way that the user, or "decision maker", will have a sound basis for tract selection, location of pipelines or other facilities, stipulations, and regulations, or know where problems exist.

The task of gathering, selecting, analyzing and presenting needed pertinent information for nine lease areas will take years to accomplish; yet the user needs information immediately. In order to resolve this dilemma and to secure a wide review of the information before finalization of the work, OCSEAP provides "interim" syntheses, intending to update them regularly to permit incorporation of data from current studies. These reports will be discussed at future meetings with OCSEAP staff and contract scientists to expedite the updating. The final synthesis, to be published when the OCSEAP scientific community has completed its studies in this lease area, will thus be a product tailored to current and future needs of decision makers.

Rudolf J. Engelmann, Director

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Successful completion of this Interim Synthesis Report reflects the enthusiastic support received from the entire OCSEAP community. Special thanks are extended to the respective staffs of the OCSEAP Program and Project Offices, Principal Investigators and Bureau of Land Management, Anchorage Office, for their continuing support, advice and encouragement.

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Contributions from others, whose names may have been inadvertently omitted from the lists above, are also gratefully acknowledged.

Table of Contents

NOTICES ii

SYNTHESIS REPORT UPDATING ...iii

FOREWORD v

ACKNOWLEDGMENTS vi

TABLE OF CONTENTS ix

LIST OF FIGURES x

1. INTRODUCTION 1

2. CONTAMINANTS 11

Task A Existing Distribution and Concentration of Potential Contaminants Associated with Petroleum Development 13

3. SOURCES 25

Task B Contaminants and Environmental Disturbances That May Accompany Petroleum Exploration and development 27

4. HAZARDS 51

Task C Geological Hazards to Petroleum Exploration and Development in Lower Cook Inlet 53

5. TRANSPORT 71

Task D Transport of Contaminant Discharges 73

6. RECEPTORS ...103

Task E Biological Populations and Ecological Systems ...105

7. EFFECTS ...197

Task F Effects of Hydrocarbon and Trace Element Contaminants on Individuals, Populations, and Ecological Systems ...198

8. SYNTHESIS ...199

A Synthesis of Environmental Information Concerning Potential OCS Oil and Gas Development in Lower Cook Inlet ...201

GLOSSARY ...221

REFERENCES ...233

A more detailed Table of Contents appears on the back of each of the blue pages marking the start of a new chapter.

List of Figures

INTRODUCTION

Figure 1.1 Proposed lease areas of the Alaskan outer continental shelf (NOAA, 1976). . . . 4

Figure 1.2 Locality map and gazetteer for the Lower Cook Inlet region. . . . 7

Figure 1.3 Lower Cook Inlet region, showing tracts involved in OCS Oil and Gas Lease Sale CI held in October 1977 (see Chapter 3 for additional details). . . . 8

Figure 1.4 Lower Cook Inlet-Kodiak Shelf region, showing the area included in the BLM Resource Report Request for proposed OCS Oil and Gas Lease Sale 60, presently scheduled for September, 1981 (see Chapter 3 for additional details). . . . 9

CONTAMINANTS

Figure A.1.1a A comparison of the average tar levels in the world's oceans and in Alaskan waters (Shaw, RU #275, Annual Report, 1977). . . . 14

Figure A.1.2a Hydrocarbons in sediments from Lower Cook Inlet. "A" and "B" are hydrocarbons with gas chromatographic retention times between tetradecane and dotriacontane from the first and second fractions of column chromatography. The latter fraction is substantially contaminated with biogenic non-hydrocarbon lipids, and the values are thus the upper bounds of hydrocarbon concentrations (Shaw and Lotspeich, 1977). . . . 14

Figure A.1.2b Sediment sampling locations for hydrocarbons (Brenner et al., RU #480, Annual Report, 1978). . . . 15

Figure A.1.2c Gravimetric data for Cook Inlet sediment samples collected in 1976 and 1977 (Brenner et al., RU #480, Annual Report, 1978). . . . 15

Figure A.1.3a Hydrocarbon content of algae and molluscs collected in Cook Inlet. "A" and "B" are hydrocarbons with gas chromatographic retention times between tetradecane and dotriacontane from the first and second fractions of column chromatography. The "B" fraction is contaminated with biogenic non-hydrocarbon lipids, and the values presented are the upper bounds of hydrocarbon concentrations (Shaw and Lotspeich, 1977). . . . 16

Figure A.2.1a Distribution of methane (nl/l, STP) in the surface waters during July 1977. For clarity, concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977). . . . 17

Figure A.2.1b Distribution of ethane (nl/l, STP) in the surface layers during July 1977. For clarity, concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977). . . . 18

Figure A.2.1c Distribution of ethene (nl/l, STP) in the surface layers during July 1977. For clarity, concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977). . . . 19

Figure A.2.1d Ethane/ethene ratio in the surface layers during July 1977. For clarity some ratios have been omitted (Cline, RU #153, Quarterly Report, Jul - Sep, 1977). . . . 20

Figure A.2.1e Distribution of propane (nl/l, STP) in the surface layers during July 1977. For clarity concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977). . . . 21

Figure A.3.1a Areas of sampling for subtidal and intertidal benthos and sediments for heavy metals analysis (Burrell, RU #162/163/288/293/310, Annual Report, 1978). . . . 22

Figure A.3.1b Level of heavy metals (µg/g dry weight) in Mytilus sp., Macoma sp., and Fucus sp. collected in Lower Cook Inlet during June 1977 (Burrell, RU # 162/163/288/293/310, Annual Report, 1978). . . . 22

Figure A.3.1c Level of heavy metals (mg/g dry weight) in selected organisms from Lower Cook Inlet during November 1977 (Burrell, RU #162/163/288/293/310, Annual Report, 1978). . . . 22

Figure A.3.2a Level of heavy metals in sediment extracts (mg/kg) at selected stations in Lower Cook Inlet (Burrell, RU #162/163/288/293/310, Annual Report, 1978). . . . 23

SOURCES

Figure B.1.1a Locations of platforms and pipelines in Upper Cook Inlet (from BLM, 1977). . . . 29

Figure B.1.1b Drift River Terminal (after NOS hydrographic chart #16660, 1976). . . . 30

Figure B.1.1c Nikiski Marine Terminal Complex (from BLM, 1977). . . . 30

Figure B.1.1d Results of OCS Sale No. CI, October 1977 (Warren, LCSM, 1978). . . . 31

Figure B.1.1e Areas for which biological surveys were required (Warren, LCSM, 1978). . . . 32

Figure B.1.3a Locations of current and proposed exploratory drilling rigs (Warren, LCSM, 1978). . . . 34

Figure B.1.3b Current and proposed exploratory drilling rigs (Petroleum Information, 1978). . . . 35

Figure B.1.3c Average Case Petroleum Development Scenario (Warren, LCSM, 1978). . . . 36

Figure B.1.3d Template platform (figure courtesy of Brown and Root, Inc., Houston, Texas). . . . 37

Figure B.1.3e Possible locations for tanker terminals and associated onshore development (Warren, LCSM, 1978). . . . 38

Figure B.1.3f A lay barge with an articulated stinger (after BLM, 1977). . . . 39

Figure B.1.3g Possible patterns of tanker use of Lower Cook Inlet (Warren, LCSM, 1978). . . . 40

Figure B.1.3h Projections of Nikiski and Anchorage traffic (SAI, 1976). . . . 41

Figure B.2.1a Sources of oil spills in Lower Cook Inlet based on the Average Case Scenario projection of 32 million barrels predicted per year during peak production (BLM, 1977). . . . 44

Figure B.2.1b Oil spills in Upper Cook Inlet (BLM, 1977). . . . 45

HAZARDS

Figure C.1.1a Epicenter plot of all earthquakes listed on the NOAA/EDS file with magnitudes of 6 or greater, by depth category. Plot produced by NOAA/EDS. . . . 53

Figure C.1.1b List of major earthquakes (magnitude ≥6) recorded in Lower Cook Inlet between 1900 and 1977. Epicenters are plotted in Fig. C.1.1e. Maximum Mercalli intensities associated with the earthquakes are also listed. Data are extracted from NOAA/EDS earthquake file; refer to U.S. Department of Commerce, 1976, for a further description of the file and its data sources. . . . 53

Figure C.1.1c Epicenter plot of all earthquakes since 1964 with focal depths of 70 km or less. Data are from NOAA/EDS earthquake file and do not contain local Alaska network data. Plot produced by NOAA/EDS. . . . 54

Figure C.1.1d Epicenter plot of all earthquakes since 1964 with focal depths greater than 70 km. Data are from NOAA/EDS earthquake file and do not contain local Alaska network data. Plot produced by NOAA/EDS. . . . 55

Figure C.1.1e Epicenter plot of all earthquakes with focal depths of 70 km or less. Data are from local Alaska network which began operation in 1976. Plot produced by NOAA/EDS. . . . 56

Figure C.1.1f Epicenter plot of all earthquakes with focal depths greater than 70 km. Data are from local Alaska network which began operation in 1976. Plot produced by NOAA/EDS. . . . 57

Figure C.1.2a Earthquake recurrence curves for two areas in the vicinity of Lower Cook Inlet (from Meyers et al., 1976). . . . 58

Figure C.1.2b List of b values of frequency/magnitude relationships for the Lower Cook Inlet region. Earthquake data are from 75 km radius circles about whole degree coordinates. Only magnitudes greater than 4 were included (from Meyers et al., 1976). . . . 58

Figure C.1.2c Recurrence curve for Alaskan seismic network earthquakes, 1 October 1977 to 28 February 1978. Regression equation is based only on data points through which the curve is drawn (data from Pulpan and Kienle, RU #251, Annual Report, 1978). . . . 59

Figure C.1.3a Plots of empirical relationships among magnitude, maximum intensity, and distance to limit of perceptibility of felt effects (equations from Meyers et al., 1976). . . . 60

Figure C.1.3b Isoseismal map for 1964 Prince William Sound earthquake (from Meyers et al., RU # 352, April 1976). . . . 60

Figure C.1.3c Tsunamis observed around Lower Cook Inlet (from Cox and Pararas-Carayannis, 1976). . . . 61

Figure C.1.4a Areas used for projection of hypocenters on to vertical planes. The Benioff Zone is perpendicular to the long sides of the rectangles (from Pulpan and Kienle, RU #251, Annual Report, 1978). . . . 61

Figure C.1.4b Earthquake hypocenters projected on to vertical planes perpendicular to the Benioff Zone. Refer to Fig. C.1.4a for locations of sections (from Pulpan and Kienle, RU #251, Annual Report, 1978). . . . 61

Figure C.1.6a Index map for locations of active volcanoes near Lower Cook Inlet. . . . 63

Figure C.1.6b Lower Cook Inlet volcanoes (from State of Alaska, 1974; Kienle and Forbes, 1976). . . . 63

Figure C.2.1a Faults in the vicinity of Lower Cook Inlet (modified from Magoon et al., 1976). . . . 65

Figure C.3.1a Bathymetry of Lower Cook Inlet (from Hampton and Bouma, RU #327, Annual Report, 1978). . . . 67

Figure C.3.2a Generalized isopach map of Quaternary sediments in Lower Cook Inlet (from Bouma et al., 1978). . . . 67

Figure C.4.2a Distribution of bedforms in Lower Cook Inlet (modified from Hampton and Bouma, RU #327, Annual Report, 1978). . . . 69

Figure C.5.2a Oil spill vulnerability of various coastal types in Lower Cook Inlet (from Michel et al., 1978). . . . 70

TRANSPORT

Figure D.1.1a Net surface circulation in Lower Cook Inlet, based primarily on data collected during the spring and summer (Burbank, 1977). . . . 75

Figure D.1.1b Debris accumulations in Central Lower Cook Inlet and coastal areas of the Kamishak Bay region. The survey is preliminary and based on limited data (Burbank, 1977). . . . 76

Figure D.1.1c Salinity profile along hydrographic line across Lower Cook Inlet near Ninilchik. Data is from R/V Acona cruise 065, 21 to 29 May 1968 (after Kinney et al., 1970; Burbank, 1977). . . . 77

Figure D.1.1d Net surface circulation during the fall within Cook Inlet as inferred from ERTS imagery (Burbank, 1977). . . . 78

Figure D.1.2a Co-amplitude lines (in cm) and co-phase lines (in degrees) for the semidiurnal principal lunar tide (M_2) of Cook Inlet, Alaska (Mungall, 1973). . . . 79

Figure D.1.2b Current amplitudes (in cm/sec) for the semidurnal princpal lunar tide (M_2) of Cook Inlet, Alaska (Mungall, 1973). . . . 80

Figure D.1.3a Distributions of surface temperature and salinity in Lower Cook Inlet for three different periods during spring and summer (Schumacher et al., RU #138, Annual Report, 1978). . . . 81

Figure D.1.3b Gauged river input (R) into Cook Inlet, showing both annual mean input ($\bar{R}$) and input during 1973. These figures were compiled from USGS streamflow records from the Kenai River at Soldotna, the Knik River near Palmer, the Matanuska River at Palmer, the Susitna River at Gold Creek, the Talkeetna River near Talkeetna, and the Skwentna River near Skwentna. . . . 82

Figure D.1.3c Vertical distributions of density (ot) at a section (see insert) across Lower Cook Inlet during summer 1973 (Schumacher et al., RU #138, Annual Report, 1978). . . . 83

Figure D.1.4a Net summer circulation in Lower Cook Inlet, based upon analysis of hydrographic and current meter data (Muench et al., 1978). . . . 85

Figure D.1.5a Drift bottle release sites, 1978 (ADF &G, 1978a). . . . 86

Figure D.1.6a Tidal influx surface current patterns off Kachemak Bay, 1120 hrs, 1 July 1977, by current-mapping radar (Barrick, RU #48, Annual Report, 1978). . . . 87

Figure D.1.6b Tidal outflux surface current patterns off Kachemak Bay, 1920 hrs, 1 July 1977, by current-mapping radar (Barrick, RU #48, Annual Report, 1978). . . . 87

Figure D.2.2a Net surface circulation in Kachemak Bay in spring and summer, with typical net surface current velocities (kts) indicated for various areas in the bay (1 kt = 50 cm/sec, approx.). Parentheses indicate where the velocity was determined from only one period of observation (Burbank, 1977). . . . 90

Figure D.2.2b Vertical cross-section of typical circulation in Kachemak Bay. The bathymetry for the model is taken from the actual bathymetry in inner Kachemak Bay along line A-B-C (Burbank, 1977). . . . 91

Figure D.3.1a Annual percentage probability of impact, cumulative for all 12 spill sites (Dames and Moore, RU # 436, Final Report, 1976). . . . 92

Figure D.6.1a Distribution of total suspended matter at the surface and at 5 m above the bottom, April 1977 (Feely et al., RU #152, Annual Report, 1978). . . . 94-95

Figure D.6.1b Distribution of total suspended matter at the sufrace and at 5 m above the bottom, June 1977 (Feely et al., RU #152, Annual Report, 1978). . . . 96-97

Figure D.6.1c Relative suspended load distribution in Lower Cook Inlet on 4 November 1972, based on interpretation of ERTS imagery (modified from Sharma et al., 1974; cited in Burbank, 1974. . . . 98

Figure D.6.2a Temporal variability of total suspended matter at the surface and 5 m above the bottom in Lower Cook Inlet (after Feely et al., RU #152, Annual Report, 1978). . . . 99

Figure D.6.3a Concentration of Cook Inlet crude oil accommodated by suspended particulate matter, as a function of the initial oil loading (after Feely et al., RU #152, Annual Report, 1978). . . . 99

Figure D.6.3b Particle size distributions for surface suspended matter in Lower Cook Inlet, and for oil/SPM aggregates resulting from laboratory interaction studies (after Feely et al., RU #152, Annual Report, 1978). . . . 100

RECEPTORS

Figure Ea Diagram of the interactions within nearshore communities with and without sea otter populations (Palmisano and Estes, 1977). . . . 106

Figure E.1.1a Distribution and range expansion patterns of sea otter populations around the Kenai Peninsula and Lower Cook Inlet (Schneider, RU #240, Final Report, 1976; pers. comm.). . . . 112

Figure E.1.2a Pinniped sightings (Pitcher and Calkins, RU #229, Annual Report, 1977). . . . 113

Figure E.1.2b Distribution of northern sea lions and harbor seals in Cook Inlet (from various sources, see text). . . . 114

Figure E.1.3a Sightings of cetaceans in Cook Inlet (Fiscus, Braham, and Mercer, RU #68, Final Report, 1976; Fay, pers. comm.). . . . 115

Figure E.1.4a Distribution of bears around Cook Inlet (ADF&G, 1973). . . . 116

Figure E.1.4b Tentative summary of use of Cook Inlet by marine and terrestrial mammals. . . . 117

Figure E.2.2a Identification of prey from the stomachs of 309 sea otters from Amchitka Island (Kenyon, 1969). . . . 118

Figure E.2.2b Identification of the prey (as % of total prey items) from the stomachs of northern sea lions (N=71) and harbor seals (N=165). . . . 119

Figure E.2.2c Prinicipal food types and feeding strata of cetaceans (Pike, 1962; Nemoto, 1970; Nishiwaki, 1972). . . . 119

Figure E.3.1a Summary of habitat preference, status, and abundance of marine coastal birds. . . . 121

Figure E.3.2a Estimates of breeding populations of Cook Inlet bird colonies (Erikson, 1977). . . . 122

Figure E.3.2b Distribution of bird colonies in Cook Inlet (Erikson, 1977). . . . 122

Figure E.3.3a Distribution of coastal birds by habitat features, February 1976 (Arneson, RU #3, Annual Report, 1977). . . . 123

Figure E.3.3b Distribution of coastal birds by habitat features, May 1976 (Arneson, RU #3, Annual Report, 1977). . . . 123

Figure E.3.3c Distribution of coastal birds by habitat features, June 1976 (Arneson, RU #3, Annual Report, 1977). . . . 124

Figure E.3.3d Distribution of coastal birds by habitat features, September and October 1976 (Arneson, RU #3, Annual Report, 1977). . . . 124

Figure E.3.4a Location of aerial pelagic bird survey transects, 1976 (Erikson, 1977). . . . 125

Figure E.3.4b Marine bird densities, March 1976 (Erikson, 1977). . . . 125

Figure E.3.4c Marine bird densities, May 1976 (Erikson, 1977). . . . 126

Figure E.3.4d Marine bird densities, June 1976 (Erikson, 1977). . . . 127

Figure E.3.4e Marine bird densities, September 1976 (Erikson, 1977). . . . 128

Figure E.3.4f Relative pelagic bird densities, Lower Cook Inlet, 1975 and 1976. Data for combined shipboard and aerial transects (see text for references). . . . 128

Figure E.3.4g Relative pelagic bird densities, Kachemak and Kamishak Bays, 1976 (Erikson, 1977). . . . 129

Figure E.3.4h Relative pelagic bird densities, inner Kachemak Bay, 1976 (Erikson, 1977). . . . 129

Figure E.3.5a Major waterfowl utilization of Cook Inlet (Erikson, 1977). . . . 130

Figure E.3.6a Tentative summary of use of Lower Cook Inlet by principal marine and coastal birds. . . . 131

Figure E.4.1a Breeding phenologies for 14 species of marine and coastal birds. Data from several RU #341/342 reports; see text for references. . . . 133

Figure E.4.1b Reproductive success of marine birds. . . . 134

Figure E.4.2a Diet of five species of marine birds, Kodiak area, 1977 (Sanger, Hironaka and Fukuyama, RU #341, Annual Report, Appendix III, 1978). . . . 135

Figure E.4.2b Diet of three species of marine birds, Gulf of Alaska (Danger and Baird, RU #341/342, Annual Report, Appendix III, 1978). . . . 136

Figure E.4.2c Seasonal variation in the diet of five species of marine birds, Kodiak area, 1977. Shaded areas represent total fish consumption (Sanger, Hironaka and Fukuyama, RU #341, Annual Report, Appendix III, 1978). . . . 136-137

Figure E.4.2d Food habits of diving ducks (data from Cottam, 1939; Cottam and Knappen, 1939). . . . 137

Figure E.4.2e Diet of horned and tufted puffin chicks, Gulf of Alaska (Manuwal and Boersma, RU #341, Annual Report, Appendix VI, 1978; Manuwal, pers. comm.). . . . 138

Figure E.5.1a Population estimates, 1956 through 1972, of total run size of adult salmonids by Statistical Area and the relative contribution of each species to the total run (modified from Stern, RU #353, Quarterly Report, Oct -Dec, 1976). . . . 140

Figure E.5.1b Summary of coastal movements of adult salmonids (modified from Stern, RU #353, Quarterly Report, Oct - Dec, 1976). . . . 140

Figure E.5.1c Summary of the distribution and mean catch per 20-minute trawl for demersal fish (summarized from Blackburn, RU #512, Final Report, 1978). . . . 142

Figure E.5.1d Catch per unit effort of demersal fish by depth interval and month in Lower Cook Inlet, June through September 1976 and March 1977 (summarized from Blackburn, RU #512, Final Report, 1978). . . . 142

Figure E.5.1e Distribution of saffron cod and longfin smelt (modified from Blackburn, RU #512, Final Report, 1978). . . . 145

Figure E.5.3a Monthly abundance of fish larvae (English RU #424, Apr - Oct, 1977). . . . 147

Figure E.5.3b Annual abundance of fish larvae per sampling station (English, RU #424, Apr - Oct, 1977). . . . 147

Figure E.5.5a Areas of commercial and sport fishing (modified from ADF&G, 1976a). . . . 150

Figure E.5.5b Salmon catch in Lower Cook Inlet, 1954 to 1978 (from ADF&G, 1976b; 1978a). . . . 151

Figure E.5.5c Salmon catch by district and species, 1954 to 1978 (from ADF&G 1976b; 1978a). . . . 152

Figure E.5.5d Commercial herring catch in Kachemak (southern) and Kamishak districts from 1969 to 1978 (data from ADF&G, 1976b; 1978a). . . . 153

Figure E.5.5e Commercial halibut catch in Lower Cook Inlet (IPHC Statistical Areas 261 and 272; data from ADF&G, 1978a). . . . 153

Figure E.5.5f Summary of Resurrection Bay pink salmon sport harvest (modified from ADF&G, 1976b). . . . 154

Figure E.5.5g Summary of the relative sport catch of pink salmon in Resurrection Bay, 1967 through 1975 (adapted from ADF&G, 1976b). . . . 154

Figure E.6.1a Feeding classifications of 12 species of demersal fish predators from Kodiak Island and Lower Cook Inlet collected during ADF&GOCS studies, June 1976 to March 1977 (from Simenstad, RU #512, Final Report, 1978; Feder, RU #281/5/303, Annual Report, 1977). . . . 155

Figure E.6.1b Principal prey of juvenile pink salmon captured in Kachemak Bay, 26 to 28 July 1976, by beach seine and tow net (from Blackburn, RU #512, Final Report, 1978). . . . 155

Figure E.6.2a Hypothetical food web for Lower Cook Inlet (Feder, RU #281/5/303, Annual Report, 1977). . . . 156

Figure E.6.2b Food web of great sculpin (Feder, RU #281/5/303, Annual Report, 1977). . . . 157

Figure E.6.2c Food web of Pacific cod (Feder, RU #281/5/303, Annual Report, 1977). . . . 158

Figure E.6.2d Food web of halibut (Feder, RU #281/5/303, Annual Report, 1977). . . . 158

Figure E.7.1a Distribution of king crab (ADF&G, 1976a; 1978a; Gusey, 1975). . . . 159

Figure E.7.1b Annual catch of king crab in Cook Inlet (ADF&G, 1976a; 1978a). . . . 159

Figure E.7.1c Distribution of Tanner crab (ADF&G, 1976a; 1978a). . . . 160

Figure E.7.1d Annual catch of Tanner crab in Cook Inlet (ADF&G, 1976a; 1978a). . . . 160

Figure E.7.1e Distribution of Dungeness crab (ADF&G, 1976a; 1978a). . . . 160

Figure E.7.1f Annual catch of Dungeness crab in Cook Inlet (ADF&G, 1976a; 1978a). . . . 161

Figure E.7.1g Distribution of shrimp (ADF&G, 1976a; 1978a; Gusey, 1975). . . . 161

Figure E.7.1h Annual catch of shrimp in Cook Inlet (ADF&G, 1976a; 1978a). . . . 161

Figure E.7.1i Distribution of razor and hardshell clam beaches (ADF&G, 1976a; 1978a). . . . 162

Figure E.7.2a Lower Cook Inlet benthic sampling stations, 1976 (Feder and Jewett, RU #281/5/303, Annual Report, 1978). . . . 163

Figure E.7.2b Densities of infaunal and epifaunal invertebrates from 13 Lower Cook Inlet van Veen grab stations, April 1976 (Feder and Jewett, RU #281/5/303, Annual Report, 1978). . . . 163

Figure E.7.2c Dominant epifaunal species in Lower Cook Inlet during April and October, 1976 (Feder and Jewett, RU #281/5/303, Annual Report, 1978). . . . 164

Figure E.7.2d Number, weight, and density (g/m^2) of epifaunal invertebrate phyla of Lower Cook Inlet as obtained by Agassiz trawl, 1976 (Feder and Jewett, RU #281/5/303, Annual Report, 1978). . . . 164

Figure E.7.2e Geological facies and station locations in Kachemak Bay (Driskell, 1977). . . . 165

Figure E.7.2f Distribution of major taxa among sediment facies in outer Kachemak Bay (Driskell, 1977). . . . 165

Figure E.7.3a Summary of life history information for various commercially important benthic invertebrates in Lower Cook Inlet (ADF&G, 1976a). . . . 167

Figure E.7.3b Life histories for commercially important crustacean larval stages (ADF&G, 1976a). . . . 167

Figure E.7.3c Distribution of king crab and shrimp spawning areas in Lower Cook Inlet (ADF&G, 1976a). . . . 168

Figure E.7.3d Growth data for six species of clam in Lower Cook Inlet (Feder and Jewett, RU #281/5/303, Annual Report, 1978). . . . 171

Figure E.7.4a Food web of king crab. Bold lines indicate major food sources based on frequency of occurrence (Feder, RU #281/5/303, Annual Report, 1977). . . . 171

Figure E.7.4b Food web of Tanner crab. Bold lines indicate major food sources based on frequency of occurrence (Feder and Jewett, RU #281/5/303, Annual Report, 1978). . . . 172

Figure E.8.1a Distribution of geological substrate types (aerial reconnaissance, May 1976) (Lees, RU #417, Final Report, 1978). . . . 174

Figure E.8.1b Distribution of geomorphological units (Hayes et al., 1977). . . . 175

Figure E.8.1c Vulnerability of coastal environments to oil spill damage (Hayes et al., 1977). . . . 176

Figure E.8.2a Characteristic biota by substrate type in the littoral and shallow sublittoral zone of Lower Cook Inlet (Lees, RU #417, Final Report, 1978). . . . 177

Figure E.9.1a Distribution of type and density of algal cover (aerial reconnaisance, May 1976) (Lees, RU #417, Final Report, 1978). . . . 178

Figure E.9.1b Relative cover of algal species in Lower Cook Inlet, June through August 1976 (Lees and Rosenthal #27, Final Report, 1977; Lees, RU #417, Final Report, 1978). . . . 179

Figure E.9.1c Relative densities of major infaunal taxa from sandy beaches in Lower Cook Inlet, May through July 1976 (Lees, RU #417, Final Report, 1978). . . . 179

Figure E.9.2a Seasonal biomass estimates of brown seaweeds in Kachemak Bay (Lees, RU #417, Quarterly Report, Oct - Dec, 1977). . . . 180

Figure E.9.2b Seasonal density comparisons of common infauna of sandy substrate at Homer Spit and Deep Creek, 1977 (Lees, pers. comm.). . . . 180

Figure E.10.1a Plankton sampling stations, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977). . . . 181

Figure E.10.1b Settled volumes of zooplankton, mean of all samples, upper 25 m, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977). . . . 181

Figure E.10.1c Zooplankton species and major groups, Kachemak Bay, Alaska, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977). . . . 182

Figure E.10.1d Densities of zooplankton, Kachemak Bay, Alaska, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977). . . . 182

Figure E.10.1e Comparison of day and night estimates of zooplankton abundance from the upper 25 m of the water column in Kachemak Bay (Station 6) and other Lower Cook Inlet stations (Stations 2 through 8a) (Damkaer, RU #425a, Annual Report, 1977). . . . 182

Figure E.10.2a Larval stages of commercially important invertebrates and periods when they are present in Cook Inlet (English, RU #424, Annual Report, 1978). . . . 183

Figure E.10.2b Stations of greatest abundance for larval invertebrate stages in Lower Cook Inlet. . . . 183

Figure E.10.2c Average depth distribution of king crab zoeae, Kachemak Bay, April through June 1972 (Haynes and Wing, 1977). . . . 184

Figure E.10.2d Mean catch of postlarval king crab per tow from bottom skimmer samples (Sundberg and Clausen, 1977). . . . 185

Figure E.11.1a Abundance of major groups of phyto - plankton for nine stations, 1976 (Larrance et al., RU #425b, Final Report, 1977). . . . 186

Figure E.11.1b Comparison of nitrate and incident radiation levels (A) with Chlorophyll a concentrations and primary productivity (B) in Lower Cook Inlet. Values are averages for nine stations (Larrance et al., RU #425b, Final Report, 1977). . . . 187

Figure E.13.1a Total monthly accumulations of fish eggs collected in Lower Cook Inlet. No data were collected during January, March, June, September, November, and December (English, RU #156/424, Quarterly Report, Apr - Jun, 1977). . . . 187

Figure E.13.1b Tentative egg identifications by size in Lower Cook Inlet (English, RU #156/424, Annual Report, 1977). . . . 188

Figure E.15.1a Relative microbial activity in water samples as measured using glutamic acid during the April cruise. The units are ng/liter/h (Morita and Griffiths, RU #190/E, Annual Report, 1977). . . . 189

Figure E.15.1b Respiration percentage in water samples as measured using glutamic acid during the April cruise (Morita and Griffiths, RU #190/E, Annual Report, 1977). . . . 190

Figure E.15.1c Nitrogen fixation rates in sediment samples collected during the November cruise. The unit of measurement is ng nitrogen fixed/g dry wt./h (Griffiths and Morita, RU #190, Annual Report, 1978). . . . 192

Figure E.15.2a Most probable numbers of hydrocarbon utilizers in Cook Inlet, April 1977 samples. Solid bars = water, open bars = sediment (Atlas, RU #29, Annual Report, 1978). . . . 193

Figure E.15.2b Crude oil degradation potential measurements in sediments collected during the April cruise. Units are DMP/g dry wt. (Griffiths and Morita, RU #190, Annual Report, 1978). . . . 194

Figure E.15.3a Relative concentrations of Desulfovibrio sp. in sediments analyzed during April (Griffiths and Morita, RU #190, Annual Report, 1978). . . . 195

Figure E.16.1a Physiological tolerance ranges for water and sediment isolates, summer 1975 (Atlas, RU #30, Annual Report, 1978). . . . 195

Figure E.16.1b Diversity indices ($\bar{H}$) for heterotrophic bacterial populations isolated at 4°C from Cook Inlet (Atlas, RU #30, Annual Report, 1978). . . . 196

Figure E.16.1c Percent of strains in clusters scored positive for ability to utilize any hydrocarbon or hydrocarbon mixture. . . . 196

SYNTHESIS

Figure 8.1 Locations of active volcanoes in relationship to lease tracts, onshore facilities, and projected pipeline corridors. . . . 202

Figure 8.2 Distribution of sandwaves in Lower Cook Inlet in relation to lease tracts and projected pipeline corridors. . . . 203

Figure 8.3 Natural regions of Cook Inlet. . . . 204

Figure 8.4 Kachemak Bay. . . . 205

Figure 8.5 Major biological resources and habitats in Kachemak Bay. . . . 206

Figure 8.6 Kennedy Entrance. . . . 207

Figure 8.7 Major biological resources and habitats in Kennedy Entrance. . . . 207

Figure 8.8 Lower Central Region, Lower Cook Inlet. . . . 208

Figure 8.9 Major biological resources and habitats in the Lower Central Region, Lower Cook Inlet. . . . 208

Figure 8.10 Kamishak Bay. . . . 209

Figure 8.11 Major biological resources and habitats in Kaligin Island Region. . . . 210

Figure 8.12 Kalgin Island Region. . . . 211

Figure 8.13 Major biological resources and habitats in the Kalgin Island Region. . . . 212

Figure 8.14 Habitats at risk from pipeline cooridors and potential shore based facilities. . . . 213

Figure 8.15 Habitats at risk from pipeline corridors and potential shore based facilities. . . . 216

Figure 8.16 Habitats at risk from tanker routes. . . . 219

INTRODUCTION

Keith B. Macdonald, SAI

ORIGINS

The Alaskan Outer Continental Shelf Environmental Assessment Program (OCSEAP) was instituted in May 1974, when the Bureau of Land Management (BLM), manager of the Outer Continental Shelf leasing program, requested that the National Oceanic and Atmospheric Administration (NOAA) initiate a program of environmental assessment in the Northeastern Gulf of Alaska (NEGOA) in anticipation of possible oil and gas lease sales in the region early in 1976. These studies, outlined in the document "Environmental Assessment of Northeastern Gulf of Alaska - First Year Program," were initiated in July 1974.

In October 1974, BLM requested a major expansion of the environmental assessment program to encompass five additional areas of the Continental Shelf of Alaska during the FY 1975-1976 period. Conferences involving about 300 scientists were held to develop an understanding of the existing data, which were judged to be based primarily on fragmentary studies and to lack continuity in time and space. After this intensive planning effort a program proposal entitled "Environmental Assessment of the Alaskan Continental Shelf, First 18-Month Program - Gulf of Alaska, Southeastern Bering and Beaufort Seas, April 1975," was published. Subsequently, in response to a BLM request in December 1975, OCSEAP scientific efforts were extended into the northern Bering Sea, Chukchi Sea, and Lower Cook Inlet, as described in "Environmental Assessment of the Alaskan Continental Shelf -- Extended FY 1976 Study Program, February 1976."

In December 1976, a Program Development Plan (NOAA, 1976), which brings into one document the planned program for all nine proposed lease areas of the Alaskan OCS, including work underway and planned, was completed. The nine proposed lease areas, extending from the NEGOA in the south to the Beaufort Sea in the north, as shown in Figure 1.1. Subsequent changes in BLM proposed leasing schedules and information requirements have resulted in revisions and "fine tuning" of this plan.

OBJECTIVES

The protection of the marine and coastal environment is a direct outgrowth of the National Environmental Policy Act of 1969. The overall objective of OCSEAP is to develop meaningful data, in a usable form and timely manner, so that any required preventive or corrective actions can be taken before serious or irreversible impacts occur.

Specific objectives of the BLM environmental studies program for all OCS areas, including Alaska, are:

1. To provide information about the OCS environment that will enable the Department of the Interior and BLM to make sound management decisions regarding the development of mineral resources on the federal OCS.

2. To acquire information that will enable BLM to identify those aspects of the environment that might be impacted by oil and gas exploration and development.

3. To establish a basis for prediction of impact on the environment of OCS oil and gas activities.

4. To acquire impact data that may result in modification of leasing regulations, operating regulations, and OCS operating orders, to permit more efficient resource recovery with maximum environmental protection.

In response to these objectives, OCSEAP identified six TASKS, which together provide a sound basis for evaluating the potential environmental impacts of OCS oil and gas development:

A. EXISTING CONTAMINANTS - Determination of the pre-development distribution and concentration of potential contaminants commonly associated with oil and gas development.

B. SOURCES - Determination of the nature and magnitude of contaminant inputs and environmental disturbances that may be assumed to accompany exploration and development on the Alaskan continental shelf.

C. HAZARDS - Identification and estimation of the potential hazards posed by the environment to petroleum exploration and development.

D. TRANSPORT - Determination of the ways in which contaminant discharges move through the environment and how they are altered by physical, chemical and biological processes.

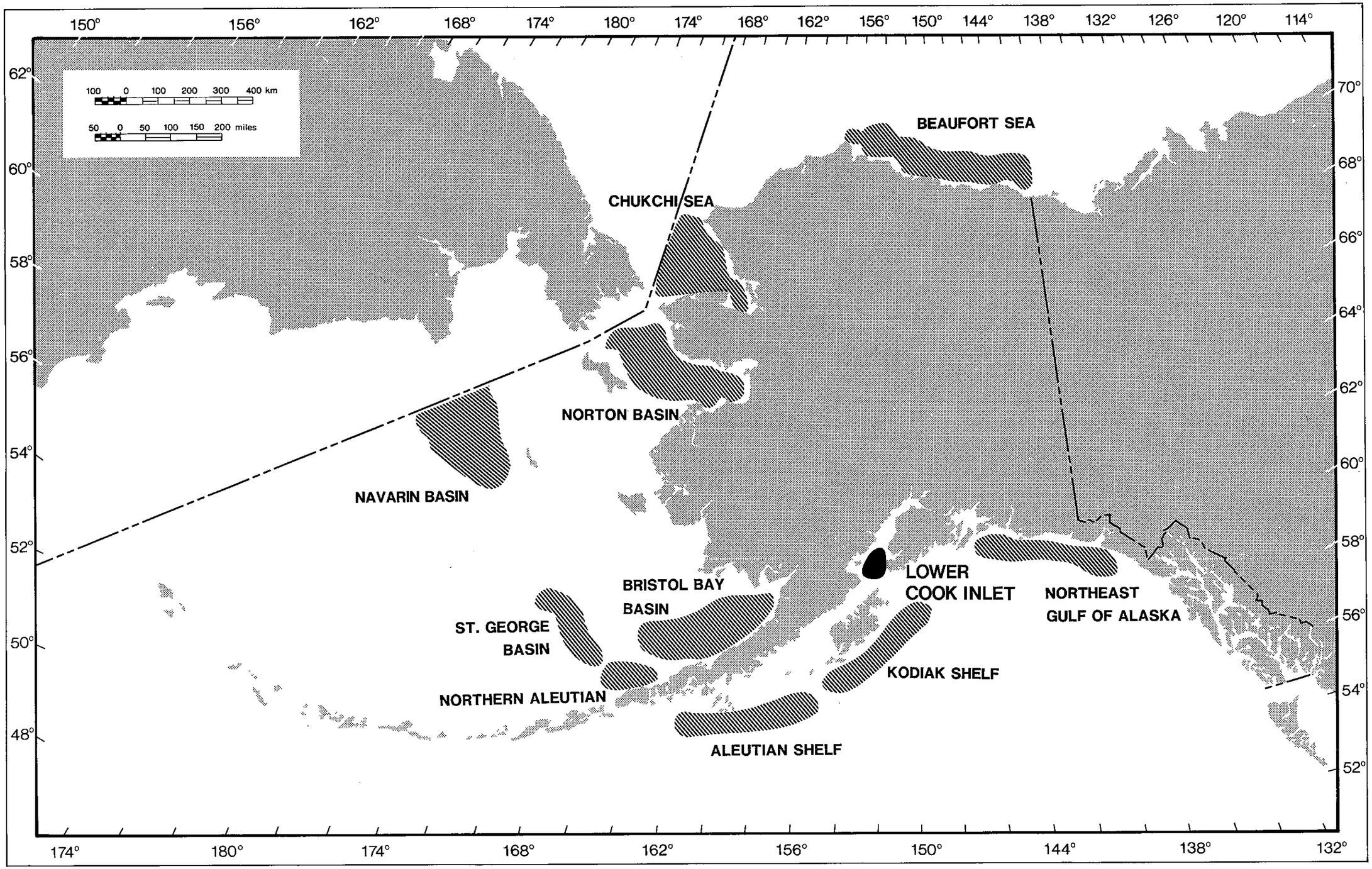
E. RECEPTORS - Reconnaissance and characterization of the biological populations and ecological systems that are subject to impact from petroleum exploration and development.

F. EFFECTS - Determination of the effects of hydrocarbon and trace element contaminants on individuals, populations, and ecological systems.

TASKS, SUBTASKS AND DATA PRODUCTS

Each of the OCSEAP tasks listed above is divisible into several SUBTASKS - smaller, more specific questions.

Subtask under Hazards (Task C), for example, require separate determinations of OCS geological hazards resulting from: (a) earthquakes, (b) surface and near-surface faulting, (c) seafloor instability, (d) coastal erosion, (e) ice gouging phenomena, etc. The OCSEAP Program Development Plan (1976) includes


150°
156°
162°
168°
174°
180°
174°
168°
162°
156°
150°
144°
138°
132°
126°
120°
114°
62°
60°
58°
56°
54°
52°
50°
48°
70°
68°
66°
64°
62°
60°
58°
56°
54°
52°
100 0 100 200 300 400 km
50 0 50 100 150 200 miles
BEAUFORT SEA
CHUKCHI SEA
NORTON BASIN
NAVARIN BASIN
BRISTOL BAY
BASIN
ST. GEORGE
BASIN
NORTHERN ALEUTIAN
LOWER
COOK INLET
NORTHEAST
GULF OF ALASKA
KODIAK SHELF
ALEUTIAN SHELF
174°
180°
174°
168°
162°
156°
150°
144°
138°
132°

some fifty-five such subtask questions and discusses each at length.

Analysis of subtasks reveals that in most cases specific DATA PRODUCTS need to be assembled to address a particular subtask. To adequately address the earthquake hazard subtask noted above, for example, relevant data products might include: (a) maps indicating epicenters and intensities, (b) maps contouring recurrence rates by magnitude, (c) maps correlating seismicity and near-surface faulting, (d) assessments of earthquake intensity/ground motion relationships and others.

The organizational concept behind these Interim Lease Area Synthesis Reports is to identify and present the most relevant data products, grouping them together by subtask. Each group of subtask data products is followed by a DATA EVALUATION section.

Related subtasks are grouped together to form a TASK DATA BASE which, in turn, provides supporting data and references for an integrated TASK SYNTHESIS. The task synthesis outlines task relevance to OCS development, integrates and highlights data available to address the task and identifies KEY CONSIDERATIONS of potential concern to decision makers.

In addition to separate chapters addressing each of the six tasks, the Lease Area Coordinator (the OCSEAP staff scientist with lead responsibility for planning and coordinating all studies and the synthesis for a given lease area) has prepared a SYNTHESIS CHAPTER that provides a summary perspective on the current state of knowledge for the lease area.

←

Figure 1.1 Proposed lease areas of the Alaskan outer continental shelf (NOAA, 1976).

REPORT FORMAT

The text format and graphics production system have been designed to permit new data and revised or more completely synthesized interpretations to be added without completely rewriting each report.

In contrast to the format of a typical "scientific paper" (i.e., Introduction - Methods - Results - Discussion - Conclusions), these reports stress the conclusions and key issues "up front," with the more detailed supporting data following. This should expedite the transfer of important information to the reader. A summary of the report format would thus be as follows:

CHAPTERS

1. INTRODUCTION
2. CONTAMINANTS (Task A)
3. SOURCES (Task B)
4. HAZARDS (Task C)
5. TRANSPORT (Task D)
6. RECEPTORS (Task E)
7. EFFECTS (Task F)
8. SYNTHESIS

GLOSSARY
REFERENCES

TASKS

TASK TITLE
TASK SYNTHESIS
- Relevance
- Summary
  - o Key Considerations

TASK DATA BASE
- Subtask A.1 Title
  - A.1.1 Data Product Title (Description)
  - A.1.2 Data Product Title (Description)
  - Data Evaluation
- Subtask A.2 Title
- Etc.

A comprehensive bibliography is provided and the text is fully referenced, to guide the reader directly to individual OCSEAP Principal Investigator (P.I.) reports and other published sources, should additional details be desired.

It is important to stress that in addition to OCSEAP-supported Research Units (RU's) these reports draw on a broad range of referenced, published sources to provide state-of-the-art answers to as many OCS development related questions as possible.

THE INDEXING SYSTEM

A straightforward alphanumeric INDEXING SYSTEM is used to simplify identification of subtask and data product text and figures associated with each task. As indicated above, the tasks underlying the research program are identified by the letters A through F; subtasks associated with each task are numbered consecutively (i.e., A.1, A.2, ...). Text sections describing successive data products within each subtask are also numbered consecutively (i.e., A.1.1, A.1.2, ...).

For simplicity, all graphics and data tabulations are referred to as FIGURES. Their numbers correspond with the sections of text in which they are described; successive figures are identified by letter subscripts. For example, Figures A.1.1a, A.1.1b and A.1.1c would all be described in text section A.1.1.

This alphanumeric indexing system allows rapid association of text and figures and will also permit new material to be added in the future without reindexing the entire report.

MAPS

Only two map projections are used throughout these reports. All lease area maps and associated local "blowups" (e.g. Figs. A.1.2b, A.2.1a and D.1.6a) utilize the Universal Transverse Mercator (UTM) system;

maps of Alaska (e.g., Fig. 1.1) are drawn on Albers' Conical Equal Area Projection.

The UTM is not strictly a projection, but rather a grid system based on the Transverse Mercator Projection. Central meridians are constructed every 6° of longitude running from 80°N to 80°S. Zones, extending 3° on both sides of the central meridian, are overlaid by a uniform rectangular grid. (The central meridians of the zones including Alaska are: 135°, 141°, 147°, 153°, 159°, 165°, 171°, 177° West, and 177°, 171° East.)

As a cylindrical, conformal projection the Transverse Mercator provides true angles of direction at all points within the grid and true North-South measuring lines (i.e. correlates straight line coordinates of a surveying grid with the curved line coordinates of the Earth). An important feature of the UTM grid is that each map grid square in each zone represents an area of the same size and shape as the earth's surface. These "blocks," 4,800 m on each side, are the LEASE BLOCKS identified by BLM for possible sale and development.

The UTM, quite suitable for a single lease area, is subject to increasing distortion if used for large areas; that is why the Albers' Conical Equal Area Projection has been chosen as more suitable to display the entire Alaskan region. Further information on both projections is presented in U.S. Dept. Army (1958), Greenhood (1964) and CIA (1977).

The coastline and latitude-longitude grids of the lease area maps were drawn by computer from World Data Base 2. Minor coastline corrections based on USGS and NOAA charts were made by hand. At the scales reproduced here, it can be assumed that the accuracy of the basemaps equals or exceeds that of the data plotted.

The National Ocean Data Center (NODC) in Washington, D.C., and the National Geophysical Solar-Terrestrial Data Center (NGSDC) in Boulder, Colorado, use these same computer drawn basemaps when preparing plots from the OCSEAP Computerized Data Base.

LOCALITY MAP AND GAZETTEER

A map of the Lower Cook Inlet region that includes all localities mentioned in the text (Fig. 1.2), is provided for the reader's convenience. Alphabetical and numerical lists of placenames are included.

COOK INLET: Alphabetical List of Placenames

87 Afognak Island
6 Akumvarick Bay
7 Amakdedori Beach
48 Anchor Point
9 Augustine Island/ Volcano
63 Barbara Point
55 Bear Cove
35 Beluga River
50 Bluff Point
8 Bruin Bay
2 Cape Douglas
58 China Poot Bay
70 Cape Elizabeth
41 Cape Kasilof
44 Cape Ninilchik
45 Cape Starichkof
18 Chinitna Bay
17 Chinitna Point
21 Chisik Island
42 Clam Gulch
12 Cottonwood Bay
45 Deep Creek
49 Diamond Gulch
5 Douglas River
3 Douglas Volcano
29 Drift River
16 Dry Bay
82 East Amatuli Island
74 East Chugach Island
37 East Forelands
69 Elizabeth Island
67 English Bay
53 Fox River
54 Fox River Flats
77 Gore Point
33 Granite Point
19 Gull Island
57 Halibut Cove
27 Harriet Point
51 Homer Spit
13 Iliamna Bay
20 Iliamna Volcano
14 Iniskin Bay
28 Kalgin Island
39 Kasilof
40 Kasilof River
62 Kasitna Bay
38 Kenai River
68 Koyuktolic Bay/Lagoon (Dogfish Bay)
56 Mallard Bay
52 Mud Bay
73 Nagahut Rocks
43 Ninilchik
83 Nord Island
34 North Foreland
15 Oil Bay
78 Outer Island
72 Perl Island
65 Point Pogibshi
24 Polly Creek
66 Port Graham
71 Portlock
30 Redoubt Bay
26 Redoubt Point
25 Redoubt Volcano
75 Rocky Bay
10 Rocky Cove
59 Sadie Cove
64 Seldovia Bay
1 Shakun Rock
4 Shaw Island
86 Shuyak Island
23 Snug Harbor
47 Stariski Creek
85 Sud Island
80 Sugarloaf Island
36 Susitna River
76 Taylor Bay
32 Trading Bay
61 Tutka Bay
22 Tuxedni Bay
79 Two Arm Bay
11 Ursus Cove
84 Ushagat Bay
83 West Amatuli Island
31 West Forelands
60 Yukon Island

COOK INLET: Numerical List of Placenames

1 Shakun Rock
2 Cape Douglas
3 Douglas Volcano
4 Shaw Island
5 Douglas River
6 Akumvarick Bay
7 Amakdedori Beach
8 Bruin Bay
9 Augustine Island/ Volcano
10 Rocky Cove
11 Ursus Cove
12 Cottonwood Bay
13 Iliamna Bay
14 Iniskin Bay
15 Oil Bay
16 Dry Bay
17 Chinitna Point
18 Chinitna Bay
19 Gull Island
20 Iliamna Volcano
21 Chisik Island
22 Tuxedni Bay
23 Snug Harbor
24 Polly Creek
25 Redoubt Volcano
26 Redoubt Point
27 Harriet Point
28 Kalgin Island
29 Drift River
30 Redoubt Bay
31 West Forelands
32 Trading Bay
33 Granite Point
34 North Foreland
35 Beluga River
36 Susitna River
37 East Forelands
38 Kenai River
39 Kasilof
40 Kasilof River
41 Cape Kasilof
42 Clam Gulch
43 Ninilchik
44 Cape Ninilchik
45 Deep Creek
46 Cape Starichkof
47 Stariski Creek
48 Anchor Point
49 Diamond Gulch
50 Bluff Point
51 Homer Spit
52 Mud Bay (Coal Bay)
53 Fox River
54 Fox River Flats
55 Bear Cove
56 Mallard Bay
57 Halibut Cove
58 China Poot Bay
59 Sadie Cove
60 Yukon Island
61 Tutka Bay
62 Kasitsna Bay
63 Barbara Point
64 Seldovia Bay
65 Point Pogibshi
66 Port Graham
67 English Bay
68 Koyuktolic Bay/Lagoon (Dogfish Bay)
69 Elizabeth Island
70 Cape Elizabeth
71 Portlock
72 Perl Island
73 Nagahut Rocks
74 East Chugach Island
75 Rocky Bay
76 Taylor Bay
77 Gore Point
78 Outer Island
79 Two Arm Bay
80 Sugarloaf Island
81 East Amatuli Island
82 West Amatuli Island
83 Nord Island
84 Ushagat Island
85 Sud Island
86 Shuyak Island
87 Afognak Island

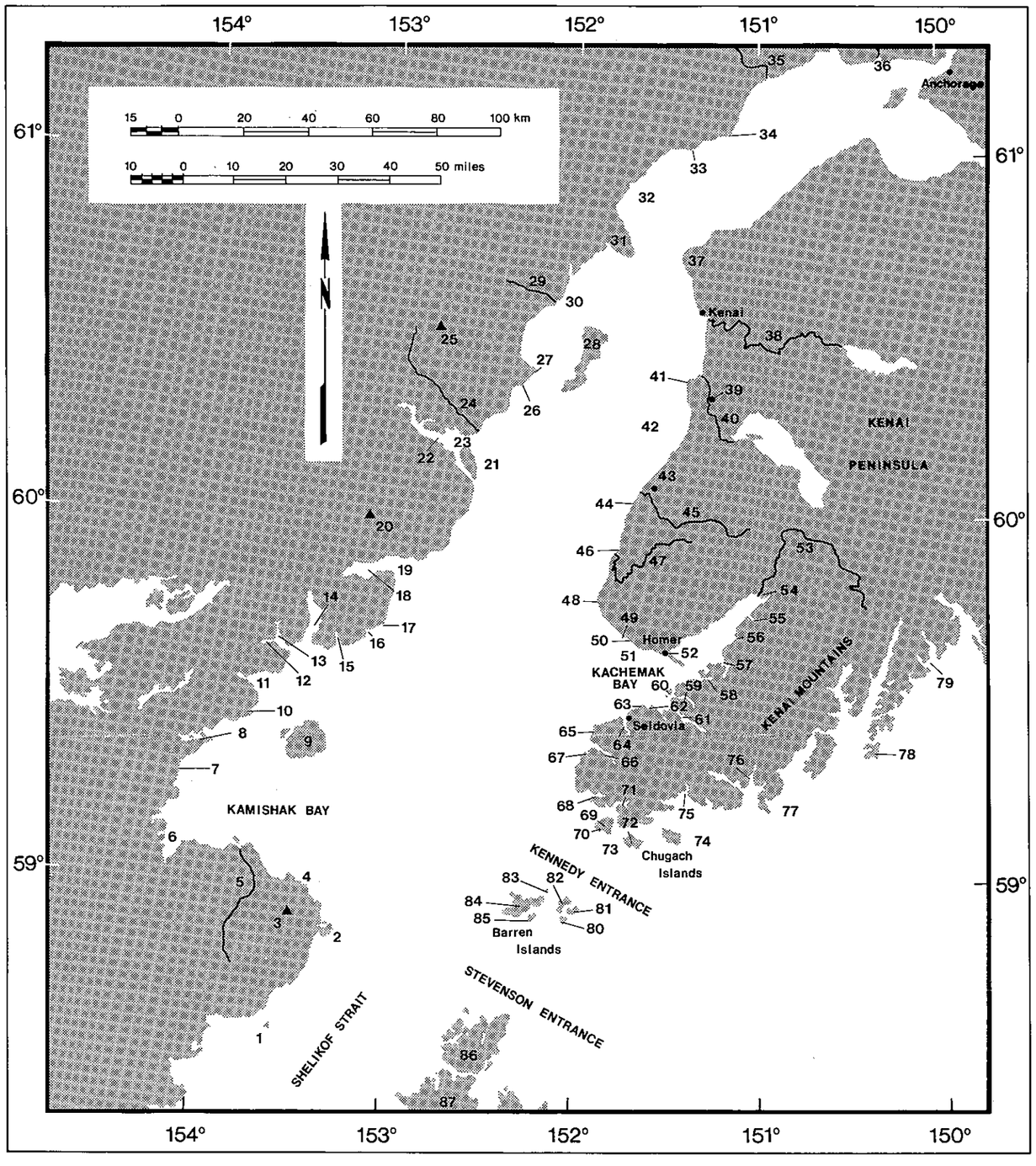


Figure 1.2 Locality map and gazetteer for the Lower Cook Inlet region.

Lower Cook Inlet was the site of the second Alaskan OCS Oil and Gas Lease Sale directed by the Department of the Interior's Bureau of Land Management. (The first was held in the Northeast Gulf of Alaska-NEGOA.) The Lower Cook Inlet Call for Nominations was published in the Federal Register on September 22, 1975. The selection of the tracts was officially announced and published in the Federal Register on March 2, 1976. Draft and Final Environmental Impact Statements (BLM 1977) were prepared, and Lower Cook Inlet Oil and Gas Lease Sale CI was finally held in October 1977. The sale resulted in the lease of 87 blocks totaling approximately 0.2 million hectares (0.5 million acres). The respective areas of the Call for Nominations, the tract selection and those tracts that were ultimately leased are shown in Figure 1.3. Further details concerning Lease Sale CI are provided in Chapter 3 of this report.

The steplike outline of the lease areas reflects the rectangular shape of most of the lease blocks. The boundaries of the regular lease blocks are 4,800 international meters on a side and contain 2,304 hectares. The regular boundaries are defined in terms of X and Y coordinates of the Universal Transverse Mercator Grid System based on the Clarke Spheroid of 1866. For identification and sale purposes the blocks are numbered starting with the first tier northerly of the equator as "N 1." The first range of blocks westerly of the central meridian of each UTM zone is designated "E 100." Thus, a block numbered "N 200-E 96" would be the 200th block northerly of the equator and the 5th block westerly of the central meridian of the respective UTM zone.

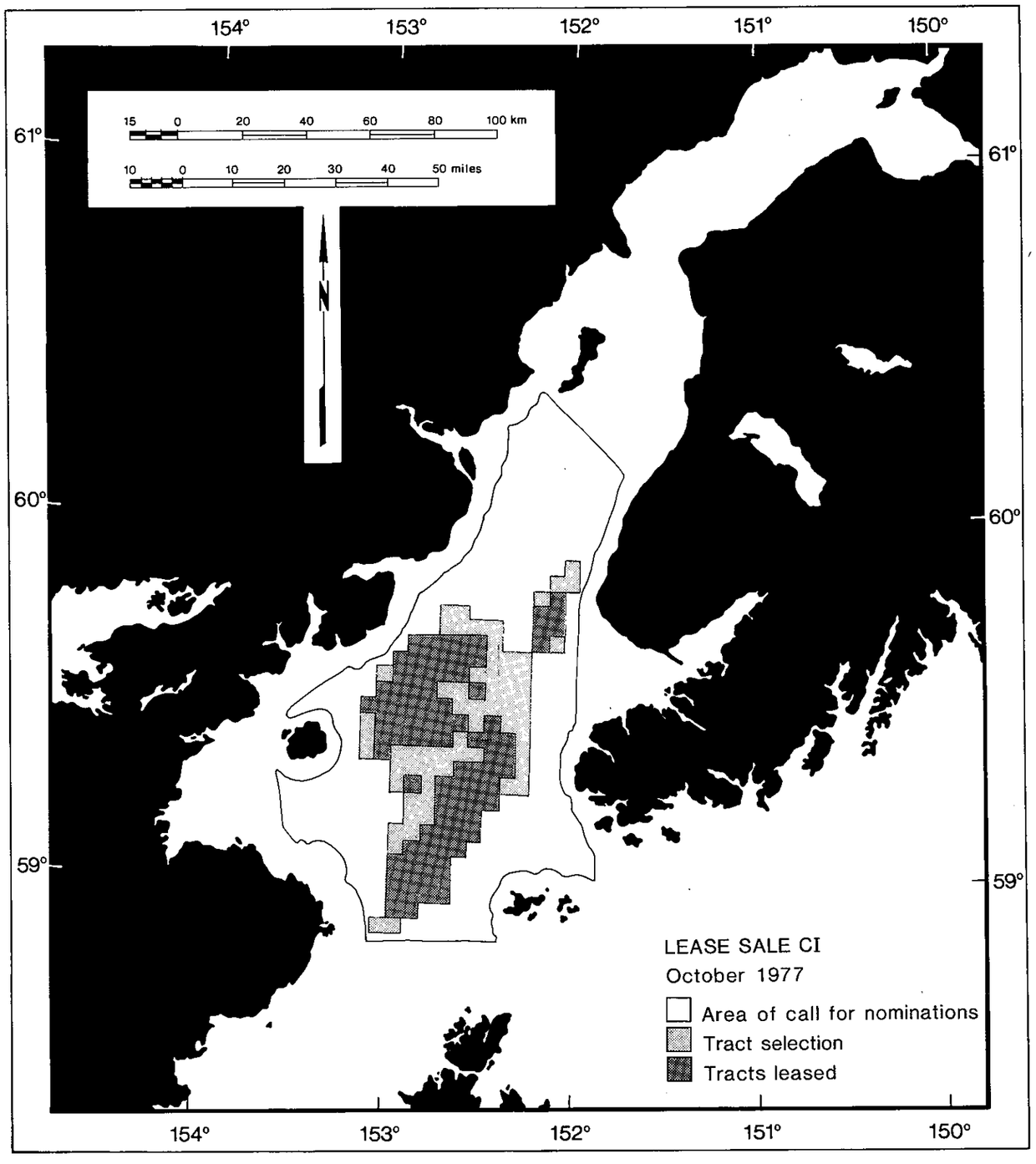


Figure 1.3 Lower Cook Inlet region, showing tracts involved in OCS Oil and Gas Lease Sale CI held in October 1977 (see Chapter 3 for additional details).

A second Federal lease sale (Sale 60) in Cook Inlet is presently scheduled for September 1981. Call for nominations was in December 1978, tract selection was scheduled for May 1979, and the draft EIS is due in August 1980. Shelikof Strait may be included in this sale but industry interest in that area is as yet unknown. Figure 1.4 shows the area of proposed Lease Sale 60 for which the BLM requested resource reports from other government agencies.

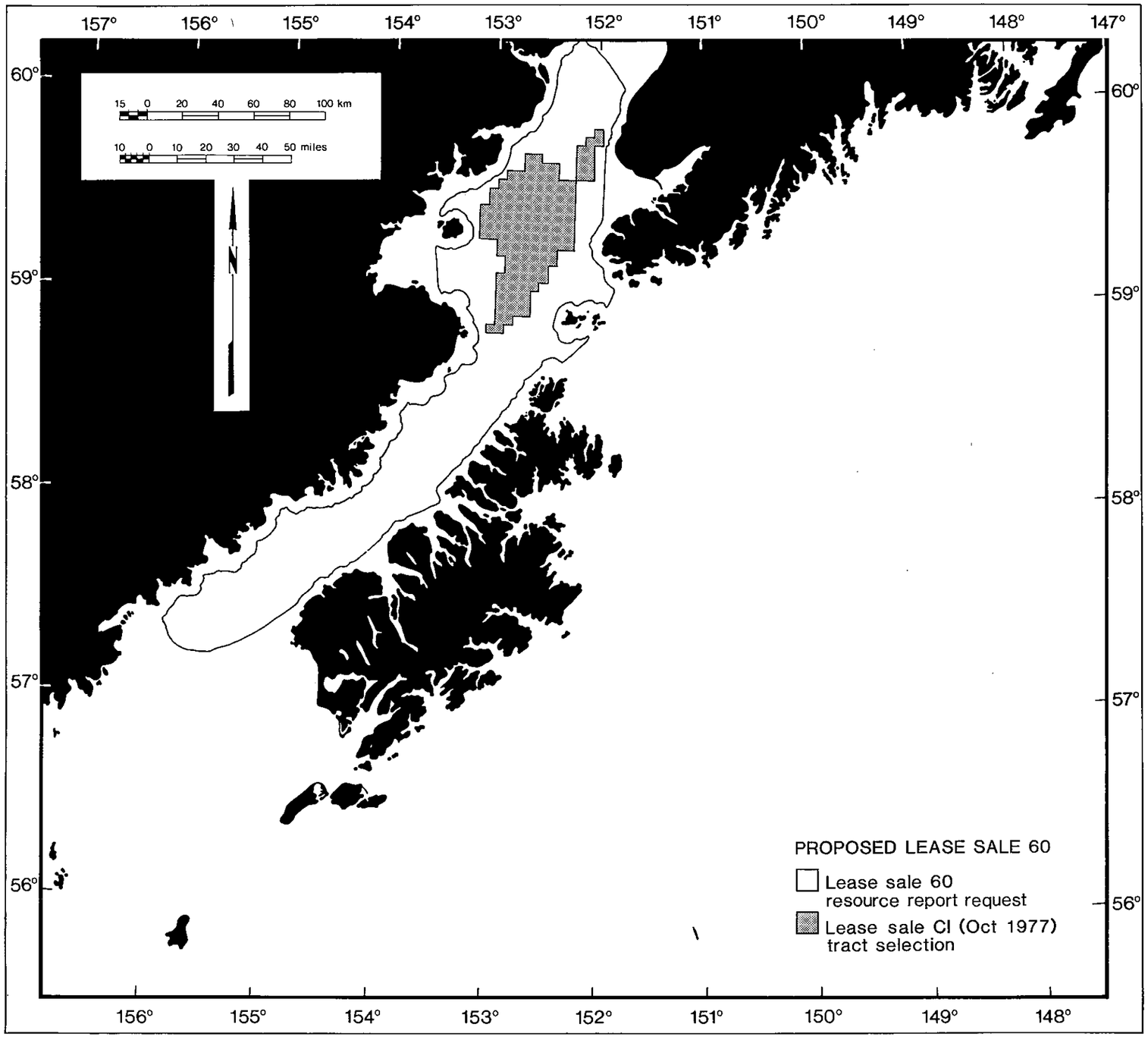


Figure 1.4 Lower Cook Inlet-Kodiak Shelf region, showing the area included in the BLM Resource Report Request for proposed OCS Oil and Gas Lease Sale 60, presently scheduled for September, 1981 (see Chapter 3 for additional details).

TASK A EXISTING DISTRIBUTION AND CONCENTRATION OF POTENTIAL CONTAMINANTS ASSOCIATED WITH PETROLEUM DEVELOPMENT

Kenneth W. Fucik, SAI

RELEVANCE

Some possible sources of petroleum hydrocarbons in Lower Cook Inlet are oil seeps, coal outcrops, atmospheric input, tankers and other marine traffic, waste discharges from urban areas, and offshore operations. One of the future goals of the OCSEA program is to assess the changes that have occurred as a result of offshore oil and gas development in Alaskan waters. To make these determinations, it is essential to identify the present levels of hydrocarbons in the environment and, if possible, their probable origins.

The low molecular weight aliphatic and aromatic hydrocarbons may be useful indicators of petroleum contamination due to their high solubility and low natural abundance. The value of these components as tracers will depend on a number of factors including the magnitude of the input, whether it is at depth or on the surface, and the prevailing hydrographic and meteorological conditions. The distribution of methane may also serve as a qualitative or semiquantitative measure of local circulation (Cline and Feely, RU #153, Annual Report, 1977).

Increases in the levels of petroleum-derived products are likely to occur as a result of the activities associated with exploration, production and transportation of oil and gas. Because some of the hydrocarbons common to petroleum are also manufactured by marine organisms, it is essential to establish background levels of naturally occurring hydrocarbons before an accurate assessment of anthropogenic input can be made. At the same time, the development of techniques that provide a means to trace the sources of hydrocarbon will be a valuable tool in future monitoring and assessment programs.

The heavy metals represent a potential health hazard to man through their toxicity. In gas and oil field operations, these metals can enter the marine environment through associations with formation waters, crude oil, or the sediments. These metals may be incorporated into the marine food web and eventually become available to man. Besides the hazards to man, the potential also exists that the metals will affect the biota, thereby resulting in system state changes in the areas where the contaminants are released. Determination of the existing levels of these metals in the water, sediments and biota of the Alaskan marine waters is required before any oil development begins so that future changes in metals concentrations can be accurately assessed.

SUMMARY

The Alaskan marine environment is essentially pristine with regards to petroleum contamination. Hydrocarbons in Lower Cook Inlet are primarily of biogenic origin although some evidence exists for the presence of petroleum hydrocarbons at low levels. The distribution of these petroleum hydrocarbons is not extensive and appears to be localized in the waters near Homer and in Trading Bay. No petroleum hydrocarbons could be detected in the water, sediments or biota of Kamishak Bay although this area has naturally occurring oil seeps in the vicinity of Chinitna, Oil and Iniskin Bays.

Kachemak Bay is an area of potential accumulation of spilled hydrocarbons. Organic carbon levels tend to be high in the sediments of this area, probably because of the hydrographic regime of the bay which restricts the exchange of water and materials with Lower Cook Inlet.

The distributions of the low molecular weight hydrocarbons in the water column probably reflect both the hydrographic conditions and biological activity in Lower Cook Inlet. Concentrations of petroleum-derived hydrocarbons is highest in the Inlet above the Forelands, indicating a source of petroleum in this area possibly a producing oil field located in this part of the Inlet. Additional petroleum may be entering Lower Cook Inlet from alleged seeps in Kamishak Bay and from coal outcrops and urban inputs in Kachemak Bay. Levels of biogenic hydrocarbons indicate a high biological activity in Kachemak Bay.

Sampling for metals concentrations in the water, sediment and biota of Lower Cook Inlet has been quite limited. In all instances, however, the metal concentrations have been low and have given no indications of excessive metals contamination. At the present time, it is probably safe to assume that Lower Cook Inlet is a relatively clean area with respect to the levels of metals contaminants.

KEY CONSIDERATIONS

- Hydrocarbons in the Inlet are primarily of biogenic origin; however, sources of potential petrogenic hydrocarbons have been suggested in Kachemak and Kamishak Bays and from north of the Forelands. Overall levels of petroleum hydrocarbons and heavy metals in Lower Cook Inlet are indicative of a near pristine environment.
- The hydrographic regime of Kachemak Bay tends to result in an accumulation of organic carbon in the sediments of the Bay.

- The existing data base is insufficient to predict rates of dispersion, transport, and accumulation of contaminants introduced into Lower Cook Inlet by OCS development.
- The extent to which the relatively untouched Lower Cook environment can accommodate the addition of contaminants without unacceptable change is unknown.

SUBTASK A.1 Distribution, Concentrations and Chemical Composition of Petroleum Hydrocarbon Contaminants

A.1.1 DISTRIBUTION OF PETROLEUM HYDROCARBONS IN THE WATER COLUMN

Only surface waters of Cook Inlet have been analyzed for petroleum hydrocarbons (Shaw, RU #275/276/294, Annual Report, 1977). All samples analyzed to date have shown levels to be less than 1 ppb (Fig. A.1.1a). Similar results were obtained by Kinney et al., (1970) in water and suspended sediment samples. These concentrations are consistent with hydrocarbon levels of other Alaskan marine waters (Bering Sea, Northwest and Northeast Gulf of Alaska) and are indicative of pristine waters.

Figure A.1.1a A comparison of the average tar levels in the world's oceans and in Alaskan waters (Shaw, RU #275, Annual Report, 1977).

Amount (mg/m^2)	Location	Source
2.17×10^{-3}	Alaskan waters	Shaw 1977
<0.01	Southwest Pacific	National Academy of Science 1975
0.1-10	North Atlantic	National Academy of Science 1975
	Mediterranean	National Academy of Science 1975
	Kuroshio Current system	National Academy of Science 1975
3.8	N. Pacific (west)	Wong, Green and Cretney (1974)
0.4	N. Pacific (eastern region along 35°N)	
0	N. Pacific (along 125°W)	

Surface tows were made at twenty Cook Inlet stations for the collection of floating tar. At only one station (CI10) was tar collected and this amounted to less than 0.1 mg. The average amount (2.17×10^{-3} mg/m^2) of tar collected in seventy-seven tows in Alaskan waters is quite low by world standards (Fig. A.1.1a).

A.1.2 DISTRIBUTION OF PETROLEUM HYDROCARBONS IN BOTTOM SEDIMENTS

Shaw (RU #275/276/294, Annual Report, 1977) has measured hydrocarbon levels in three sediment samples from Cottonwood Bay and Iniskin Bay, both of which are in the Kamishak Bay area. No petrogenic hydrocarbons were found in these samples, suggesting that the petroleum from seeps known to be in the region is not generally accumulating in the intertidal environment. A variety of normal alkanes and tricyclic diterpenoid hydrocarbons of terrestrial origin were found in sediments from the Homer area. These latter samples contained terpenes, which includes simonellite (a breakdown product of terrigenous origin) at concentrations of about 1 µg/g. This may indicate that if the area has been naturally exposed to aromatic hydrocarbons and the condition has existed for a considerable time, then the marine system around Homer may have adapted to the presence of very low levels of a few aromatic compounds (Shaw, RU #275, Annual Report, 1978).

Sediment samples from Mud Bay, Dogfish Bay, Douglas River, and Kasitsna Bay were analyzed for hydrocarbon concentrations (Shaw and Lotspeich, 1977). None of the features associated with petroleum were present in these samples and the hydrocarbons detected appeared to be of biogenic origin. The levels of hydrocarbons present in each sample (Fig. A.1.2a) seemed to be related to the sediment grain size for each area. That is, hydrocarbon levels increased with decreasing grain size. The order of decreasing concentrations was: Mud Bay (silt and clay), Dogfish Bay (fine sand and silt), Douglas River (fine sand), and Kasitsna Bay (sand). In general, the presence of the smaller sediment particles indicates calmer waters from which suspended organic materials will settle out, and this will favor the growth of organisms. Thus silts and clays typically contain more organic material, including hydrocarbons, than do sands.

Kinney et al. (1970) also examined hydrocarbon levels in the sediments of Cook Inlet. Hydrocarbons were below the level of detection (0.001 µg/g) except for one sample near Homer; the latter concentration was attributed to natural hydrocarbons.

Figure A.1.2a Hydrocarbons in sediments from Lower Cook Inlet. "A" and "B" are hydrocarbons with gas chromatographic retention times between tetradecane and dotriacontane from the first and second fractions of column chromatography. The latter fraction is substantially contaminated with biogenic non-hydrocarbon lipids and the values are thus the upper bounds of hydrocarbon concentrations (Shaw and Lotspeich, 1977).

	Hydrocarbon Concentration (µg/g)	
Location	A	B
Douglas River	4.5	4.5
Kasitsna Bay	0.45	0.46
Mud Bay	32.6	45.6
Dogfish Bay	8.8	11.8

Brenner et al. (RU #480, Annual Report, 1978) examined the subtidal sediments of Lower Cook Inlet for hydrocarbon in 1976 and 1977 (Fig. A.1.2b). The sediments were characterized by low hydrocarbon levels that showed little or no petroleum hydrocarbon contamination (Fig. A.1.2c). The biogenic sources of the hydrocarbons were primarily of a terrestrial origin with varying amounts of marine components.

The terrestrial input, derived from the surface waxes of higher plants, was predominant in the northern and eastern parts of Lower Cook Inlet. The marine input, which never exceeded that of the terrigenous source, was most pronounced in the southern and western parts of the inlet. In these regions, plant-wax hydrocarbons were being diluted by hydrocarbons from phytoplankton and zooplankton sources.

The highest hydrocarbon concentrations and percent organic carbon levels in the sediments were found at those stations in and near Kachemak Bay. A high plant-wax input to the bay comes from the rivers (mainly the Fox River) and the glaciers. This detrital material sinks to the bottom and supplies the dominant organic content of the sediments. The accumulations in the bay may be a function of restricted mixing between the bay and the rest of the inlet.

The lowest organics concentrations were found in the center of the inlet. Brenner et al. (RU #480, Annual Report, 1978) suggest that due to the counterclockwise motion of the currents entering through Kennedy Entrance and the stormy nature of the waves in the area the deposition rate is slow.

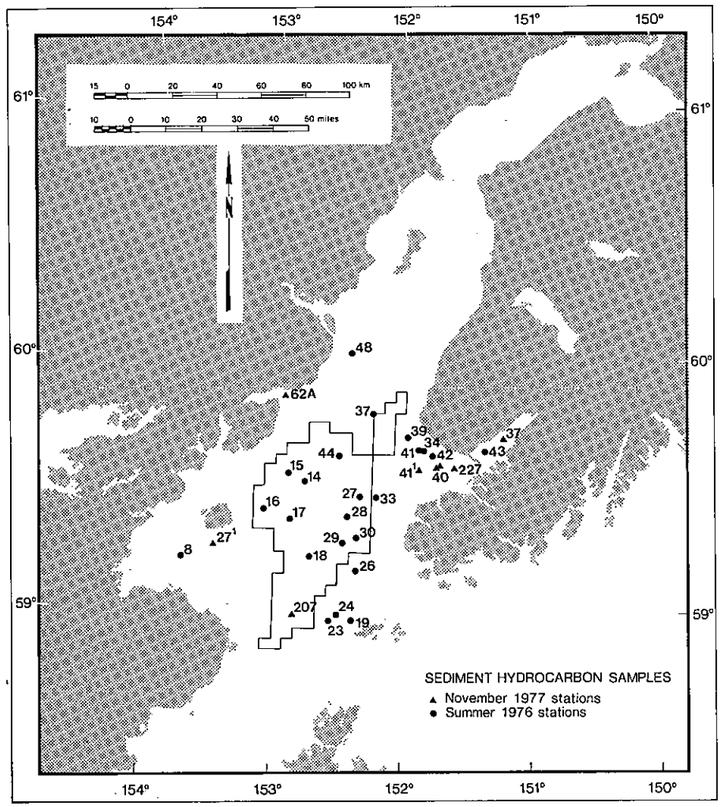


Figure A.1.2b Sediment sampling locations for hydrocarbons (Brenner et al., RU #480, Annual Report, 1978).

Figure A.1.2c Gravimetric data for Cook Inlet sediment samples collected in 1976 and 1977 (Brenner et al., RU #480, Annual Report, 1978).

Station	Depth (m)	Total Carbon %	Organic Carbon %	Dry Weight (gr)	Non Saponifiable Fr. (ppm)	Aliphatic Fr. (ppm)	Aromatic Fr. (ppm)
1976							
14	61	0.20	0.09	133.23	3.00	0.435	0.480
16	48	0.44	0.15	152.03	18.62	0.868	0.842
18	122	0.91	0.65	166.33	22.43	0.661	0.992
19	75	0.44	0.26	157.83	28.51	0.792	0.919
23	170	0.39	0.17	140.26	22.96	0.563	1.176
24	147	0.73	0.43	111.45	179.36	2.306	4.845
26	119	0.82	0.37	151.15	6.42	0.390	0.476
27	74	0.69	0.14	155.19	1.74	0.509	0.180
28	78	0.83	0.15	149.33	5.93	0.904	0.603
29	89	3.08	0.65	142.29	23.83	1.546	1.441
30	91	2.12	0.35	165.10	2.51	0.121	0.363
33	50	3.32	0.47	152.27	13.40	0.348	0.585
34	28	1.23	0.86	144.97	71.74	5.553	3.704
37	56	1.44	0.37	-	-	-	-
39	35	1.23	0.92	-	-	-	-
41	30	1.44	0.69	146.07	6.57	0.815	0.808
42	30	2.60	0.92	165.41	60.58	1.814	3.265
43	52	2.68	1.47	131.02	254.54	16.104	23.813
44	65	0.93	0.15	-	-	-	-
48	45	2.24	0.52	95.84	75.23	4.539	2.494
1977							
27	38	1.13	0.40	125.35	45.31	3.191	1.835
37	33	1.38	0.36	100.62	160.11	8.149	6.621
40A	82	1.03	0.66	127.74	45.87	2.583	2.583
40B	82	0.97	0.78	137.52	71.77	3.345	4.799
41	46	1.03	0.31	142.75	30.47	1.471	1.681
62A	16	0.87	0.44	116.45	79.43	5.582	3.349
207	165	0.72	0.53	131.34	55.43	2.969	4.188
227A	88	1.51	1.30	78.05	159.51	7.687	16.784
227B	88	1.39	1.07	88.52	148.78	7.795	9.602

A.1.3 DISTRIBUTION OF PETROLEUM HYDROCARBONS IN MARINE ORGANISMS

Samples of the alga Fucus distichus, and the bivalves Macoma balthica and Mytilus edulis were collected from four locations in Cook Inlet (Fig. A.1.3a) (Shaw and Lotspeich, 1977). Considerable variation was observed in the hydrocarbon levels in the organisms from different areas. In F. distichus this was believed to be the result of variation in the length of time plants were exposed during low tides. During exposed periods, the plants undergo dehydration which causes a rise in the hydrocarbon concentration present. The variation in bivalves may be due to changes in the animals' diets.

There was no indication of petroleum contamination in the algal samples. However, one sample of M. balthica collected at Mud Bay near Homer showed some evidence of petroleum in its tissues. The fraction 1 gas chromatogram of this sample showed normal hydrocarbons from docosane through dotriacontane (C_{22} to C_{32}). These peaks did not show the predominance of odd carbon chain lengths frequently found in biogenic hydrocarbons. Their relative abundance was more characteristic of petroleum hydrocarbons although the concentrations were not high. Also, the large unresolved envelope usually associated with petroleum was absent. The fraction 2 gas chromatograms appeared to be due to biogenic lipids.

One of two samples of M. edulis collected at Mud Bay also produced some evidence of petroleum. The fraction 1 gas chromatogram of this sample showed the unresolved envelope characteristic of weathered petroleum. This is an indication (though not proof) of low concentrations of petroleum.

Shaw (RU #275/276/294, Annual Report, 1978) collected samples of subtidal animals and intertidal plants for hydrocarbon analyses throughout Lower Cook Inlet. Low amounts of hydrocarbons were found in the shrimps and crabs examined. The pandalid shrimp contained pristane but the crangonid shrimp contained no hydrocarbons whatever. Most of the algal samples contained only biogenic hydrocarbons. However, Fucus distichus collected near a small boat harbor in Homer appeared to be contaminated with fuel oil. In addition, a complex of compounds associated with coal and peat deposits was found in Constantinia subulifera. This alga was collected at Diamond Gulch which is adjacent to Bluff Point, an area of coal outcrops. The number of these coal-associated aromatic compounds, which are structurally much less diverse than the aromatic hydrocarbons of petroleum, was small.

Figure A.1.3a Hydrocarbon content of algae and molluscs collected in Cook Inlet. "A" and "B" are hydrocarbons with gas chromatographic retention times between tetradecane and dotriacontane from the first and second fractions of column chromatography. The "B" fraction is contaminated with biogenic non-hydrocarbon lipids, and the values presented are the upper bounds of hydrocarbon concentrations (Shaw and Lotspeich, 1977).

LOCATION	HYDROCARBON CONCENTRATION (µg/g of wet tissue)					
	Fucus distichus		Macoma balthica		Mytilus edulis	
	A	B	A	B	A	B
Douglas River	8.7	6.4	10.7	38.7	1.7	26.2
Kasitsna Bay	20.7	29.3	2.6	44.5	1.0	13.7
Mud Bay	11.4	11.2	4.3	10.4	1.4,1.0	16.5,17.9
Dogfish Bay	50.0	12.6	1.6	29.3	2.7	28.1

DATA EVALUATION

The levels of hydrocarbons measured in the surface waters of Lower Cook Inlet are consistent with concentrations in other Alaskan offshore waters. These levels are indicative of a pristine environment. Therefore, additional hydrocarbon sampling in these waters is probably not warranted at this time.

The Cook Inlet sediment analyses show no apparent petroleum hydrocarbon contamination. These results are consistent with contaminant surveys in other areas of the Alaskan OCS. Therefore, it does not seem likely that additional baseline type surveys would provide much additional data. However, Shaw and Lotspeich (1977) argue that there may be seasonal and longer term variations in hydrocarbon levels whose magnitude is presently unknown. These authors suggest that several years of similar data would be needed to assess these natural variations.

Hydrocarbon sampling of plant and animal tissues in Lower Cook Inlet has been rather limited. In one instance, two samples from the same area gave somewhat different results for the presence of petroleum hydrocarbons. Variations in hydrocarbon content within animal tissues can be inherently large due to environmental conditions. Sampling and extraction procedures also provide some error. Therefore, the small number of samples analyzed may not be conclusive evidence for the absence of petroleum hydrocarbons. However, the results obtained to date are consistent with results obtained from sediment and water samples.

SUBTASK A.2 Seasonal Horizontal and Vertical Distribution of Methane, Ethane, Propane, Butane and Relevant Olefinic Homologs in the Water Column

A.2.1 SEASONAL DISTRIBUTION OF LIGHT HYDROCARBONS

Information on the distribution of low molecular weight hydrocarbons in Lower Cook Inlet has been provided primarily by Cline (RU #153, Quarterly Report, Jul-Sep, 1977) and Cline, Feely and Young (RU #153, Annual Report, 1978). The Inlet is characterized by a tongue of methane-deficient waters (100-200 nl/l that enter through Kennedy Entrance (Fig. A.2.1a). High concentrations are found north of Kachemak Bay, above the Forelands, and on the lateral shelf areas of the Inlet. The high methane concentrations observed north of the Forelands may be partly petrogenic in origin. Generally, higher methane levels are observed during July than in April, probably resulting from reduced biological activity in the spring. Concentrations approaching 900 nl/l in the near shore presumably reflect the influence of methane production from the bottom sediments. Methane distributions on the bottom were similar to those observed on the surface. Near bottom concentrations reached a maximum concentration of 1320 nl/l in Kachemak Bay in July. Values in excess of 800 nl/l were common in Kamishak Bay and near Ninilchik. Microbial production of methane from bottom sediments appears to be important in these areas. Kinney et al., (1970) also observed a similar distribution for methane in their studies in the Inlet.

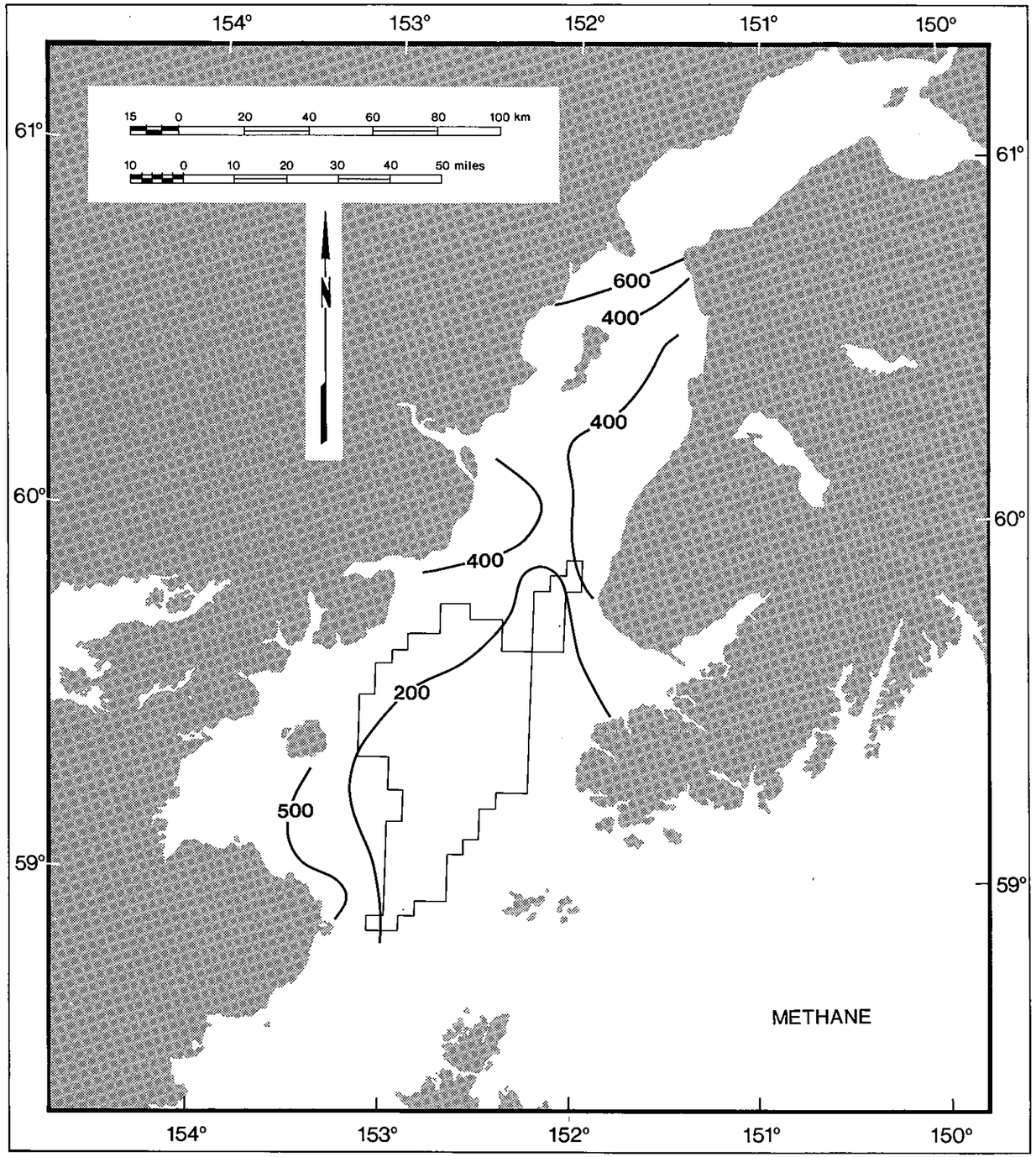


Figure A.2.1a Distribution of methane (nl/l, STP) in the surface waters during July 1977. For clarity, concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977).

Ethane concentrations are uniformly distributed through Lower Cook Inlet although slightly higher on the east side of the Inlet than on the west side (Fig. A.2.1b). This is related in part to the higher levels of ethene observed in this area. The high ethane and ethene levels are presumably related to the cyclonic circulation in the lower Inlet. The marine waters entering Cook Inlet on the east are probably more productive than the sediment laden waters moving south along the western shore.

The highest ethane concentration (7.7 nl/l) was measured north of the Forelands in Trading Bay. This is the location of the McArthur oil field. The ethane rich waters move south through the Forelands and pass to the east of Kalgin Island in response to the general estuarine circulation of the Inlet. Strong salinity gradients north and east of Kalgin Island represent a mixing zone for the low salinity waters of upper Cook Inlet and the marine water of the lower Inlet. Ethane distributions in this region strongly correlate with the salinity gradients. Near bottom distributions of ethane were analogous to those observed in the surface waters.

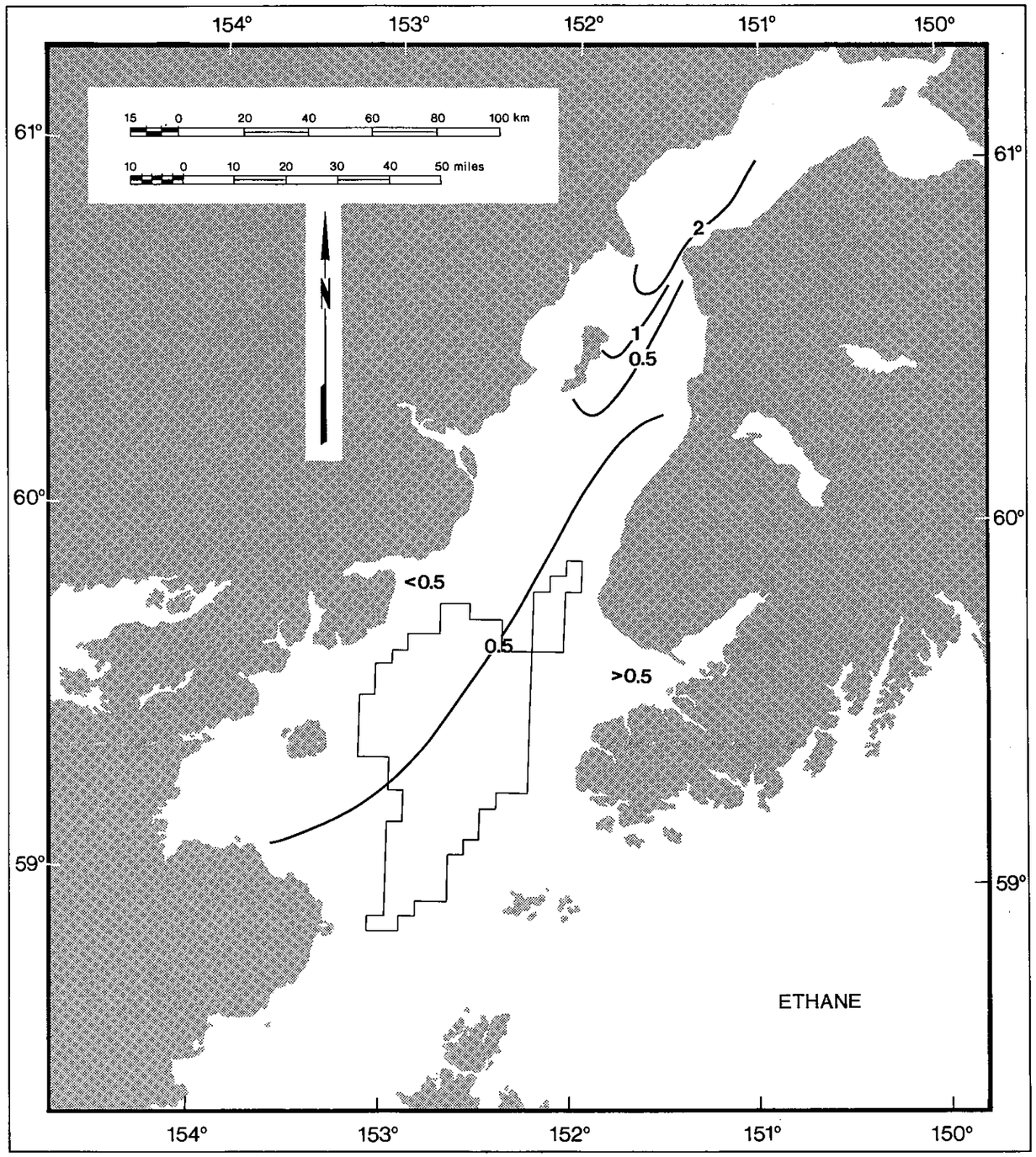


Figure A.2.1b Distribution of ethane (nl/l, STP) in the surface layers during July 1977. For clarity, concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977).

Ethene concentrations were generally greater in July (values greater than 2 nl/l) than in April (mean of 0.5 nl/l). Presumably, high ethene concentrations in Kachemak Bay and north of Anchor Point (Fig. A.2.1c) are related to high primary productivity levels (see E.11.1). The occurrence of near bottom concentrations less than those of the surface also indicates surface production. The near absence of ethene north of the Forelands during July indicated little biological activity.

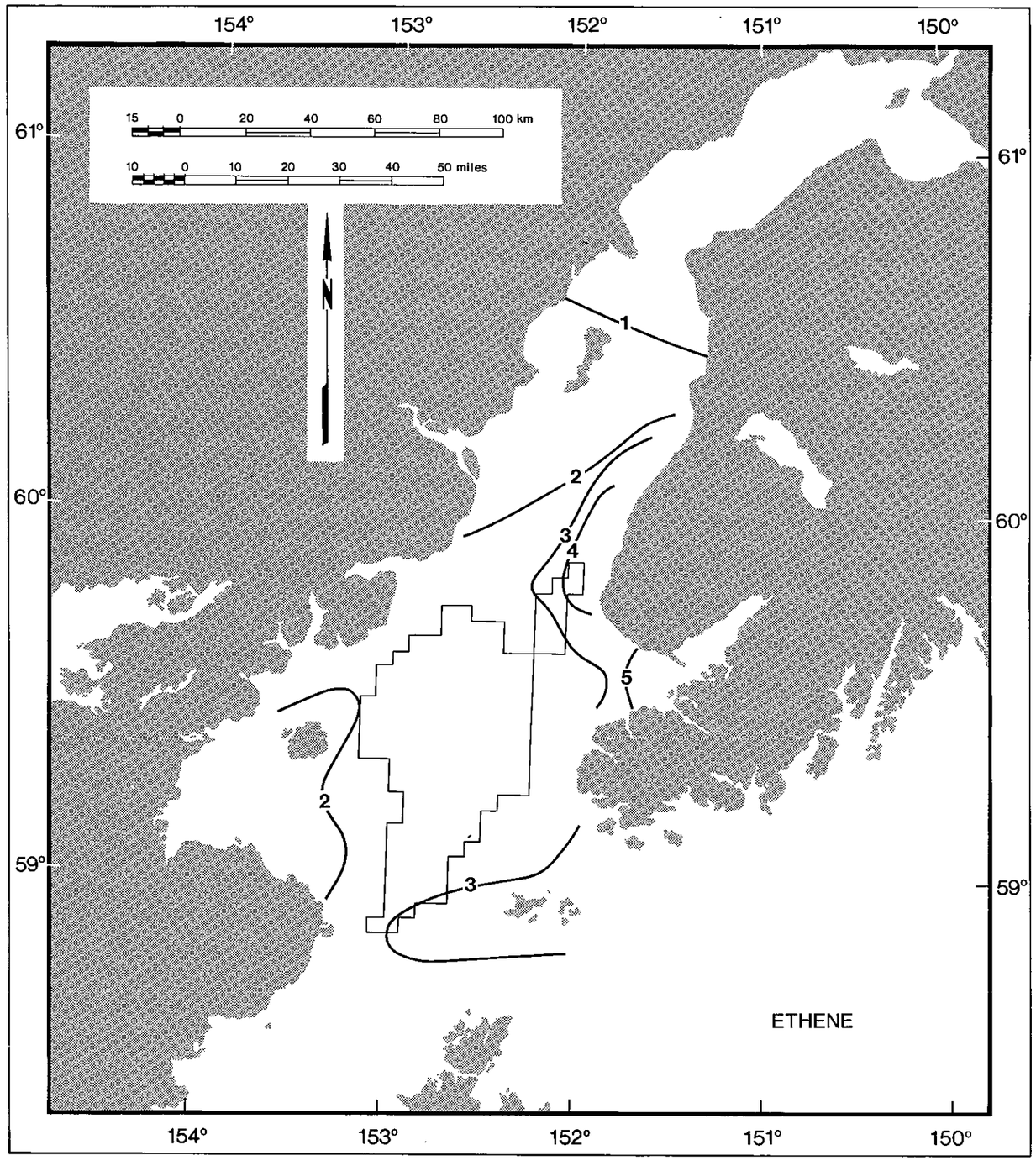


Figure A.2.1c Distribution of ethene (nl/l, STP) in the surface layers during July 1977. For clarity, concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977).

In 1976 and 1977 Cline (RU #153, Quarterly Report, Jul-Sep, 1977) and Cline et al. (RU #153, Annual Report, 1978) found the ethane/ethene ratio in Lower Cook Inlet to be about 0.2 (Fig. A.2.1d). Ratios in the waters north of Kalgin Island, however, were much higher (up to 16) and indicate natural or industrial sources of petroleum hydrocarbons. These authors have reported that ethane/ethene ratios up to 20 have been observed near a seep in Norton Sound.

A small increase in the concentration of ethane measured near the bottom of Kamishak Bay indicate that hydrocarbons may be entering the Bay from alleged seeps near shore in the Cape Douglas area. The highest concentration of ethane observed in the area was 1.0 nl/l which was somewhat higher than that observed in the southern part of the Inlet.

Concentrations of propane have been found to range from 0.1-0.4 nl/l in Lower Cook Inlet (Fig. A.2.1e). North of Kalgin Island concentrations reach a maximum of 4.4 nl/l, which may reflect a large input of this component north of the Forelands. Concentrations on the western side of the Inlet were generally less than 0.3 nl/l, but concentrations in excess of 0.4 nl/l were found on the eastern side. These distributions probably reflect both the circulation and biological activity of the Inlet. Bottom concentrations did not differ significantly from surface generalizations.

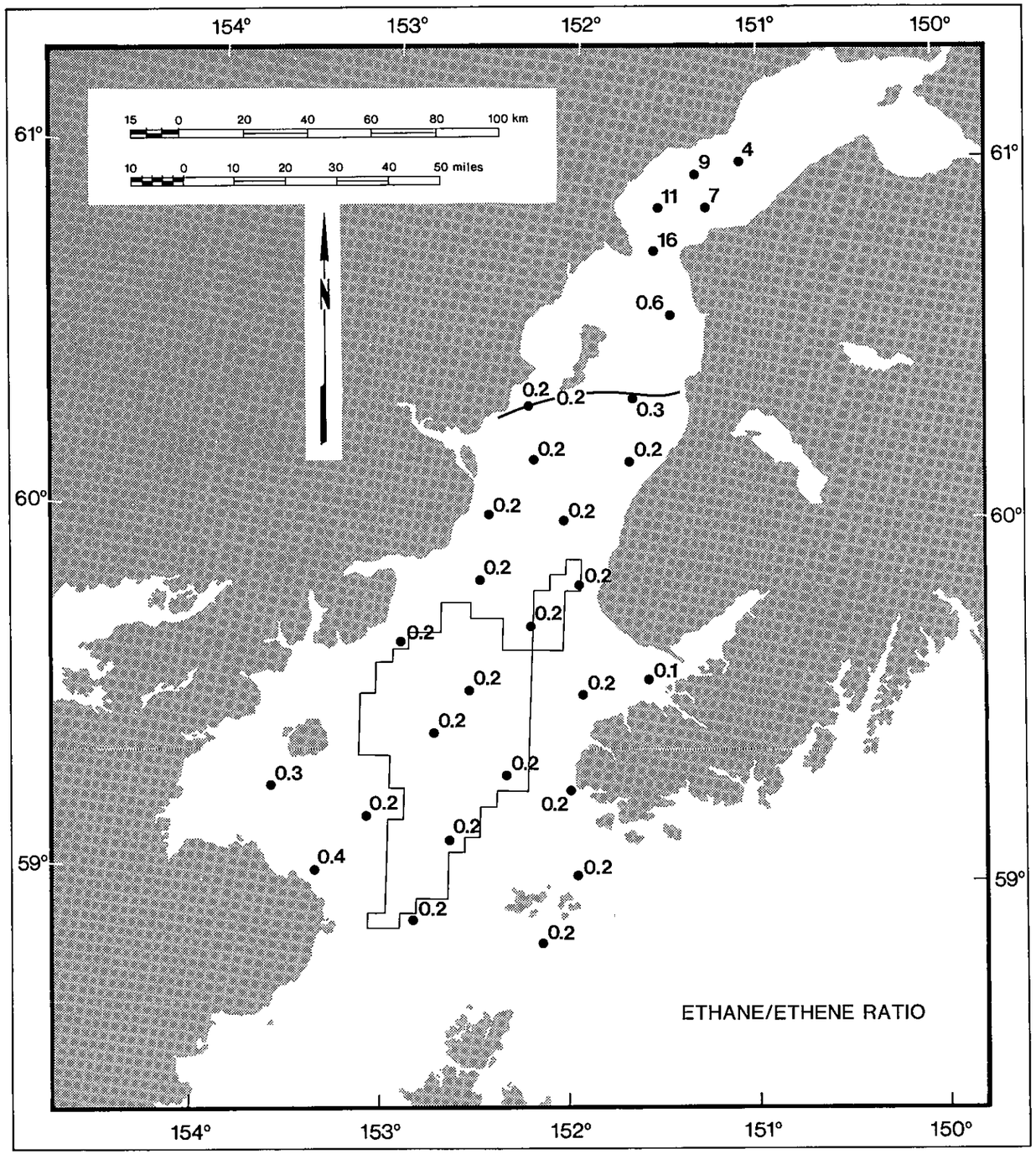


Figure A.2.1d Ethane/ethene ratio in the surface layers during July 1977. For clarity some ratios have been omitted (Cline, RU #153, Quarterly Report, Jul - Sep, 1977).

Propene levels (of biogenic origin) were generally higher in Lower Cook Inlet (0.5-0.7 nl/l) than above the Forelands (<0.1 nl/l). The highest concentration was measured in Kachemak Bay (2.5 nl/l). The levels in the lower inlet were generally higher than the propane levels. However, propene levels less than those of propane in Kachemak Bay indicate a petroleum source in this area.

The n- and i-butanes were generally at or below the detection limit of 0.05 nl/l. However, in July 1977, concentrations of the C_4 isomers approached 1 nl/l north of the Forelands. Their origin was probably thermogenic in nature, which would be consistent with the high concentrations of ethane and propane.

DATA EVALUATION

Results show that the concentrations of the LMWH are, for the most part, low throughout most of Cook Inlet. At these levels, even small increases in the input rate would be easily detected. Also, it appears that the ethane to ethene ratio is a reliable parameter by which thermogenic and biogenic hydrocarbon sources may be distinguished.

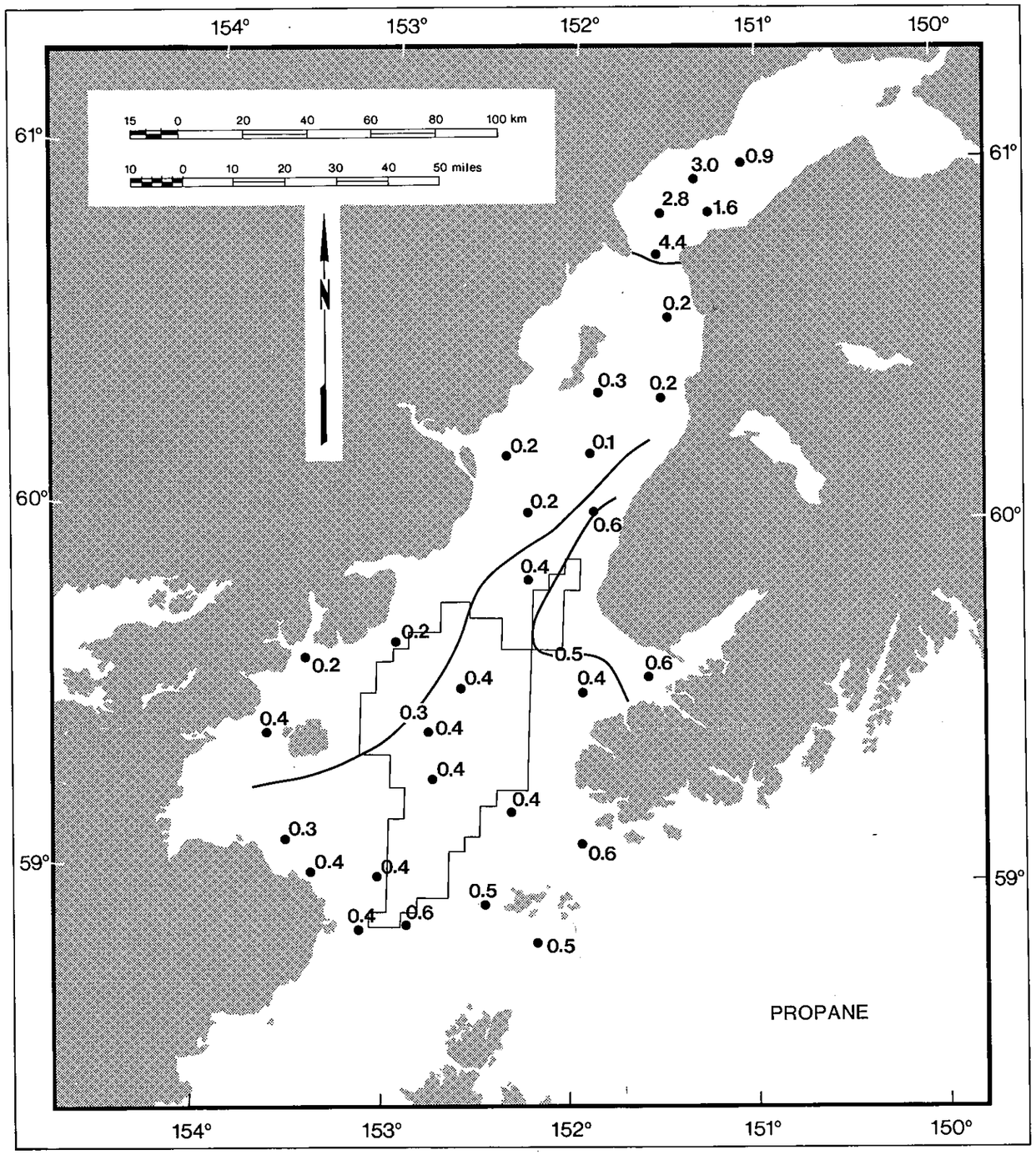


Figure A.2.1e Distribution of propane (nl/l, STP) in the surface layers during July 1977. For clarity concentrations are shown for only some stations (Cline, RU #153, Quarterly Report, Jul - Sep, 1977).

SUBTASK A.3 Distribution, Concentration and Total Content of Trace Metals

A.3.1 DISTRIBUTION OF TRACE METALS IN SELECTED MARINE ORGANISMS

Collections of Cook Inlet organisms for trace metals contents were made during two periods in June and November, 1977 (Fig. A.3.1a) (Burrell, RU #162/163/288/293/310, Annual Report, 1978). Fucus, Mytilis and Macoma balthica were collected in June in the vicinity of Homer and from both sides of the Inlet. The levels of metals in these organisms was low and comparable to values obtained from the Gulf of Alaska and S. Bering Sea (Fig. A.3.1b).

The second sampling period obtained tissue metals levels in Macoma calcarea, Tanner and Dungeness crabs, and sole (Fig. A.3.1c). Metals content in entire crabs and sole was low. Levels of Cd, Cu, Ni, and Pb were much higher in the clams than in the other organisms. This may be due to the clams deposit feeding habits in contrast to those of the carnivore species examined.

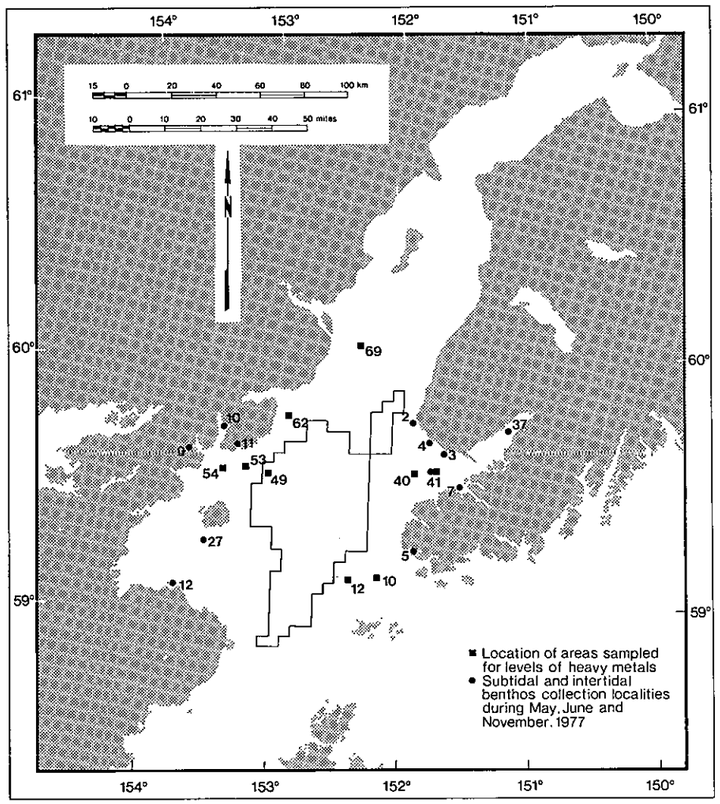


Figure A.3.1a Areas of sampling for subtidal and intertidal benthos and sediments for heavy metals analysis (Burrell, RU #162/163/288/293/310, Annual Report, 1978).

Figure A.3.1b Level of heavy metals (µg/g dry weight) in Mytilus sp., Macoma sp., and Fucus sp. collected in Lower Cook Inlet during June 1977 (Burrell, RU # 162/163/288/293/310, Annual Report, 1978).

Sample No.	Cd	Ni	Cu	Zn
		Mytilus		
01	2.5 ± 0	3.0 ± 0.8	11.0 ± 0	68 ± 30
02	3.3 ± 0	4.3 ± 0.5	5.5 ± 0.6	98 ± 0
03	2.5 ± 0	4.5 ± 0	6.5 ± 1.5	138 ± 20
04	4.5 ± 0.3	3.6 ± 0.9	8.0 ± 0	123 ± 20
05	3.3 ± 0	1.8 ± 0.7	5.5 ± 0.6	88 ± 12
07	1.7 ± 0.7	2.3 ± 0.4	4.0 ± 1.2	113 ± 15
11	1.0 ± 0	1.8 ± 0.6	8.0 ± 0	63 ± 7
12	2.5 ± 0	2.1 ± 0.7	5.7 ± 0.8	68 ± 15
		Macoma		
01	0.18 ± 0	13.0 ± 0.5	31.5	220 ± 30
07	0.03	13.7 ± 0.6	26 ± 2.5	190 ± 5
09	0.04 ± .01	12.9 ± 0.4	44 ± 2.5	340 ± 30
10	<0.03	10.0 ± 0.3	17 ± 4	220 ± 20
		Fucus		
01	5.2 ± 1.5	4.5 ± 1.5	9.2 ± 0.8	22 ± 3
03	10.1 ± 0.7	11.2 ± 1.0	10.0 ± 0.8	21 ± 1
04	12.2 ± 0.6	12 ± 3	5.8 ± 0.8	16 ± 4
05	9.3 ± 1.5	4.0 ± 1.0	5.5 ± 3	11 ± 1
09	8.4 ± 0.6	8.2 ± 1.0	10.8 ± 0.8	10 ± 0
10	7.0 ± 3	11 ± 2	8 ± 2	5 ± 0

Figure A.3.1c Level of heavy metals (mg/g dry weight) in selected organisms from Lower Cook Inlet during November 1977 (Burrell, RU #162/163/288/293/310, Annual Report, 1978).

Station No.	Sample	Cd	Ni	Cu	Zn	Pb
			Tanner Crab			
27	a	0.10 ± 0.03	<0.25	23.3 ± 1.5	148 ± 5	1.71 ± 0.04
	b	0.05 ± 0	<0.25	31.8 ± 3.5	137 ± 7	1.11 ± 0.18
	c	0.08 ± 0.03	<0.25	69.6 ± 2.9	115 ± 5	0.92 ± 0.07
40	a	0.08 ± 0.03	<0.25	17 ± 8	140 ± 40	0.92 ± 0.14
	f	<0.05	<0.25	14 ± 5	129 ± 17	1.05 ± 0.05
			Dungeness Crab			
40	b	<0.05	<0.25	32	185 ± 9	0.64 ± 0.09
	h	<0.05	<0.25	16 ± 5	202 ± 1	0.62 ± 0.10
			Macoma Calcarea			
27	-	1.2	5.7	230	115	16
37	d	3.1	1.6	130	65	5
	e	0.6	1.7	140	70	8
	f	-	2.0	230	50	15
	g	1.0	1.6	130	70	2
			Sole			
37a	Curl fin	<0.13	<0.25	-	27 ± 11	0.95 ± 0.1
40k	Flat head	<0.13	<0.25	-	25.0 ± 0.7	1.04 ± 0.12
			Crab organs and tissues			
	Eggs	<0.13	0.5	26	125	-
	Eggs	<0.13	0.5	28	250	-
	Gut	33.0	0.8	59	144	-
	Muscle	<0.13	0.6	25	200	-

A.3.2 DISTRIBUTION OF TRACE METALS IN BOTTOM SEDIMENTS

Because of the hydrographic regime in Cook Inlet, the average surface sediments in the lease area are relatively coarse and concentrations of extractable heavy metals released are generally lower than in other Alaskan coastal areas (Burrell, RU #162/163/ 288/293/ 310, Annual Report, 1978). Strong currents in the Inlet tend to carry fine grained sediments out of the central portion of Cook Inlet. Because of the coarseness of these sediments that remain, sediment samples suitable for analysis were obtained at only nine stations (Fig. A.3.1a). The results of these heavy metal sediment analyses are given in Fig. A.3.2a.

Figure A.3.2a Level of heavy metals in sediment extracts (mg/kg) at selected stations in Lower Cook Inlet (Burrell, RU #162/163/288/293/310, Annual Report, 1978).

Station	Cd	Cu	Ni	Zn	Fe	Mn
10	<0.25	3.6	1.8	10.5	500	70
12	<0.25	3.0	<1.2	5.2	690	136
40	<0.25	6.7	2.9	19.6	3230	420
41	<0.25	3.0	1.3	11.6	1125	40
49	<0.25	15.1	4.1	14.7	3310	100
53	<0.25	17.2	5.9	17.8	3685	112
54	<0.25	16.9	7.9	34.3	3830	113
62	<0.25	16.8	3.7	13.7	2810	176
69	<0.25	11.9	2.9	10.0	1240	62

DATA EVALUATION

The sampling of organisms for associated metals levels in Lower Cook Inlet has been somewhat limited because all of the organisms have been collected in nearshore areas. However, for these organisms no anomalous trends are indicated in the concentrations of the metals and the results are consistent with data obtained in other Alaskan marine waters.

Sampling of the sediments for metals content has been limited to a few sites in the coastal areas of the Inlet. The few samples recovered have shown no apparent metals contamination. The coarseness of the sediments prevented the collection of sediments from the central portion of the Inlet, thereby preventing a representative sampling of the area. Heavy metals within the water column are strongly partitioned onto the suspended sediments of the Inlet (Burrell, RU #162/163/288/293/310, Annual Report, 1978). Since these sediments are carried out of the central portion of the Inlet, it can resonably be concluded that metals have not accumulated to significant concentrations in the sediments of the central part of the Inlet. Similarly, it is likely that the benthic organisms in this area are free of abnormal metals concentrations.

TASK B CONTAMINANTS AND ENVIRONMENTAL DISTURBANCES THAT MAY ACCOMPANY PETROLEUM EXPLORATION AND DEVELOPMENT

Paul R. Becker, OCSEAP

RELEVANCE

Accurate information on contaminants and environmental disturbances resulting from petroleum exploration and development activities is required for adequate environmental assessment. Such information includes:

1. the location, nature, and timing of platform, pipeline, and facility development,

2. the probable quantity and physiochemical nature of contaminants released from potential sources,

3. the nature and severity of possible environmental disturbances likely to accompany exploration and development.

According to interagency agreement BLM is the principal source of this information to OCSEAP; other sources include the oil and gas industry, USGS, USEPA, USFS, and the Alaska Department of Fish and Game, Department of Community and Regional Affairs, and Department of Natural Resources. This information and data on transport, survey and effects, are used to derive estimates of habitats and species at risk within a lease area. In the early stages of an environmental study there is little information available for resource and development projections. As tract selection is followed by lease sale, exploratory drilling, and the formulation of development plans, however, initial projections are refined through the addition of information.

Oil and gas production has occurred in the upper portion of Cook Inlet (above the Forelands) for about the last ten years, and onshore development has occurred just below the Forelands at Nikiski and Drift River. Information resulting from Cook Inlet's history of OCS development and applied engineering options can provide more accurate projections of the effects of future OCS development in Lower Cook Inlet.

SUMMARY

The first Federal oil and gas lease sale of OCS lands in Cook Inlet, held in October 1977, resulted in the lease of 87 blocks totaling 495,307 acres. Five environmental stipulations placed on the lessees covered the use of recommended boat lanes, monitoring of exploratory drilling, use of bird scare devices in case of an oil spill, and the requirement for a development phase EIS.

Exploratory drilling from the 1977 sale was begun in the summer of 1978 by Marathon on Block 318 and by Phillips Petroleum on Block 668. The following blocks will probably be explored by 1980: 2, 274, 401, 789, and 970.

A second Federal lease sale is scheduled for March 1981. Shelikof Strait is included in the call for industry nominations; industry interest in this area will not be known until February, 1979, however.

The level and timing of offshore exploration and onshore development activities depend primarily on the amount and quality of petroleum discovered and the time required to make these discoveries. Both BLM and the oil and gas industry project that if oil is discovered in 1978-79, on-site platform installation could begin as early as 1981, oil production could begin six to eight years after the lease sale, and exploratory drilling would be essentially complete by the end of 1985.

If oil is discovered in commercial quantities, the "Average Case Scenario" projects that Lower Cook Inlet will produce 326 million barrels of oil and 330 billion cubic feet of gas, and that the life of the fields will be 26 years. The Drift River Terminal and Nikiski Marine Terminal complex will be used and possibly expanded, and onshore storage, treatment facilities, or terminal sites at Anchor Point, along the Kenai Peninsula, and at Redoubt Point are also possible. Except for Redoubt Point, the most obvious sites for development are on the east side of the Inlet.

Potential sources of hydrocarbons and associated contaminants are the offshore platforms, pipelines, shore facilities including tanker terminals, tankers and chemicals that might be employed in the cleanup if an oil spill occurred. Considering the history of oil spills in other geographical areas and the locations of the leased blocks in Lower Cook Inlet, it is probable that the most damaging effect of platforms would come from large-volume acute spills from fires or blow-outs. It is believed that low-volume chronic releases from formation waters and accidental small-volume spills (<50 barrels) would be dispersed fairly rapidly by the strong currents in the central lower Inlet.

The currents in central Lower Cook Inlet would also govern the dispersion of drilling muds and fines associated with drill cuttings. Large particles of drill cuttings would probably settle out near the platform. Effects on benthic communities would prob-

ably be localized. The strength of bottom currents and bottom sediment dynamics would determine whether cuttings accumulate in a mound. There is evidence that in areas of Cook Inlet where moving sand waves exist the cuttings could be quickly incorporated and dispersed into the sediments.

An additional potential problem associated with drilling platforms is entrainment of fish and shellfish larvae into cooling water. Such a problem is important only when drilling occurs in areas of high larvae concentration, areas of larval release and gyres.

Hydrocarbon release from tanker terminal operations would probably be small compared to those projected from platforms and pipelines. Since hydrocarbon accumulation at tanker terminals could cause localized concentrations of pollutants and could affect local populations of intertidal and shallow subtidal biota, they should also be considered.

An important potential result of construction or expansion of onshore facilities is permanent habitat destruction through filling of subtidal areas and maintenance dredging. This could be catastrophic to biological populations both locally and regionally.

Probably the most important environmental consideration (with the exception of geohazards) in selecting pipeline routes is the avoidance of unique biologically important areas in Cook Inlet. While the effects of laying pipeline may be transitory, leaks and breaks may release hydrocarbons on a sustained basis in such areas. Compared to spills from other sources, pipelines could introduce a significant amount of oil into Cook Inlet. Measurable effects of spills from pipeline would probably be localized.

A potential result of petroleum exploitation in Lower Cook Inlet is an increase in tanker traffic. There is an existing conflict with crab pot fishery in areas such as Kachemak Bay where formal, required shipping lanes have not been designated. Possible oil spills from tankers using routes in Lower Cook Inlet near the east shore would place at risk such biologically important areas as the outer Kenai Peninsula, Kachemak Bay, and Anchor Point.

DATA EVALUATION

Among the many difficulties associated with accurate projections of location, timing, and nature of platform, pipelines, and facility development within a lease area are the uncertainties involving the location of commercial quantities of oil and gas and the time to discover and identify the field. The location of commercial quantities also depends upon equipment and labor costs, oil prices, and attractiveness of development prospects elsewhere.

As exploration has already begun in Lower Cook Inlet, we know the location of tracts to be explored, the companies involved, and the drilling vessels to be employed. We have projections on the timing and location of exploratory drilling through 1980 and, if the most expensive tracts are drilled first, we can make some projections beyond this.

The accuracy of the average case scenario (Warren, remarks Lower Cook Synthesis Meeting (LCSM, 1978), Anchorage Alaska, January 1978) depends on the size of the field, whether oil and gas is discovered, and its location.

Projections on platform types, development activities, and the location of shore facilities at Lower Cook are probably more accurate than for many other lease areas in Alaska since there is a past history of exploration, development, and production in Cook Inlet. Shore facilities already at Drift River and Nikiski will probably be used for the lease area. It is unknown whether an onshore facility will be built at Anchor Point, or on the Lower Kenai Peninsula, although the BLM (Warren, LCSM, 1978) considers the latter a potential site.

The Kenai Peninsula should be considered as a site for shore facilities, particularly if discoveries are restricted to the southern portion of Lower Cook Inlet. Opposition to placing pipeline, landfall, and onshore facilities on the Kenai Peninsula stem from environmental concerns, socioeconomic implications of industrialization, the local opposition there, and questions concerning the seismic activity of faults which lie between the Peninsula and Cape Douglas.

The question of tanker routes is clear: the projected tanker routes (Warren, LCSM, 1978) follow existing voluntary tranport corridors and the pattern of established vessel movements to the Drift River Terminal and Nikiski.

Projections of sources and quantities of contaminants resulting from OCS activities, which are based primarily on information from the oil and gas industry, BLM, and the State of Alaska, and those concerning the environmental disturbance likely to accompany development are generalized. More accurate and specific information will result if and when oil is found in Lower Cook Inlet, the size of commercial quantities of crude oil and gas are known, and more specific development plans are formulated.

SUBTASK B.1 Development of Platforms, Pipelines, and Facilities

B.1.1 EXISTING OCS ACTIVITIES IN COOK INLET

Between 1959 and 1974 (the date of the last State sale) 1.9 million acres were leased. The Cook Inlet Basin has yielded the bulk of the oil and gas produced from State lands, 700 million barrels of oil and 743 billion cubic feet of gas up to 1976 (BLM, 1977). There are presently 14 offshore platforms and a pipeline network above the Forelands in Cook Inlet (Fig. B.1.1a).

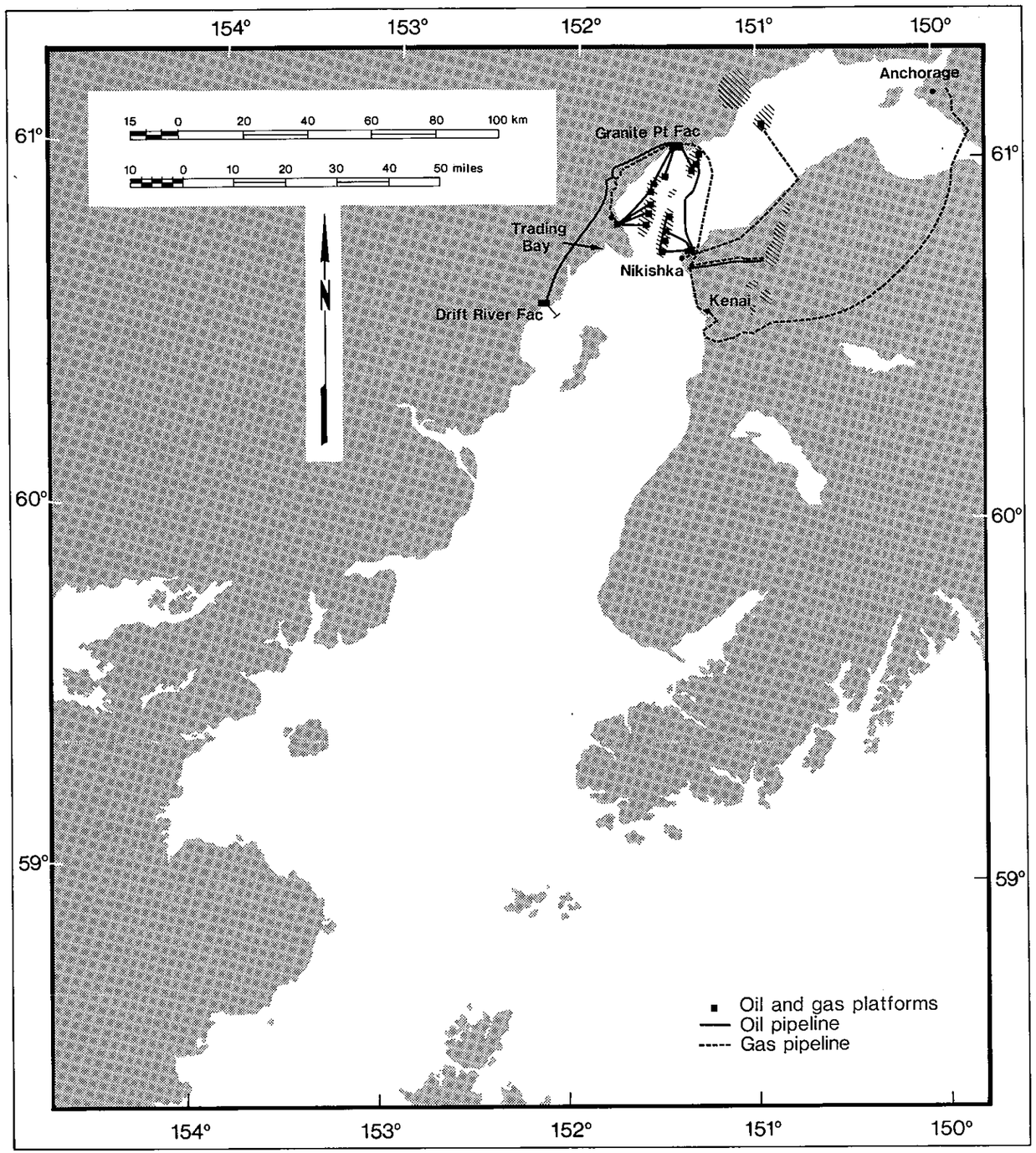


Figure B.1.1a Locations of platforms and pipelines in Upper Cook Inlet (from BLM, 1977).

In addition, the Drift River Terminal and the Nikiski Marine Terminal complex (Fig. B.1.1a) have been built in Lower Cook Inlet just below the Forelands. The Drift River Terminal (Fig. B.1.1b) is an offshore tanker terminal connected to onshore storage facilities by a submarine pipeline. A 20-inch onshore pipeline links these facilities to producing wells in Upper Cook Inlet at treatment facilities at Trading Bay and Granite Point. The Drift River Terminal handles approximately three-fourths of the total oil produced in Upper Cook Inlet and is presently at about 75 percent capacity (Warren, LCSM, 1978).

At the Nikiski Marine Terminal complex (Fig. B.1.1c) three marine terminals support the Collier Carbon and Chemical Company's ammonia and urea plant, Phillips/Marathon's LNG Plant, and the Kenai Pipeline Company (Standard Dock). Other facilities found here are the Tesoro Alaska Refinery, Standard Oil Company of California refinery, and a rig tenders' dock. The latter is a support and supply base for handling barges and offshore platform service vessels.

Expansion of the Nikiski Marine Terminal complex is planned. Collier expects to double production and Pacific Alaska LNG Company may install an additional LNG plant and terminal south of the Collier Ammonia and Urea Plant soon (SAI, 1976; Warren, LCSM, 1978).

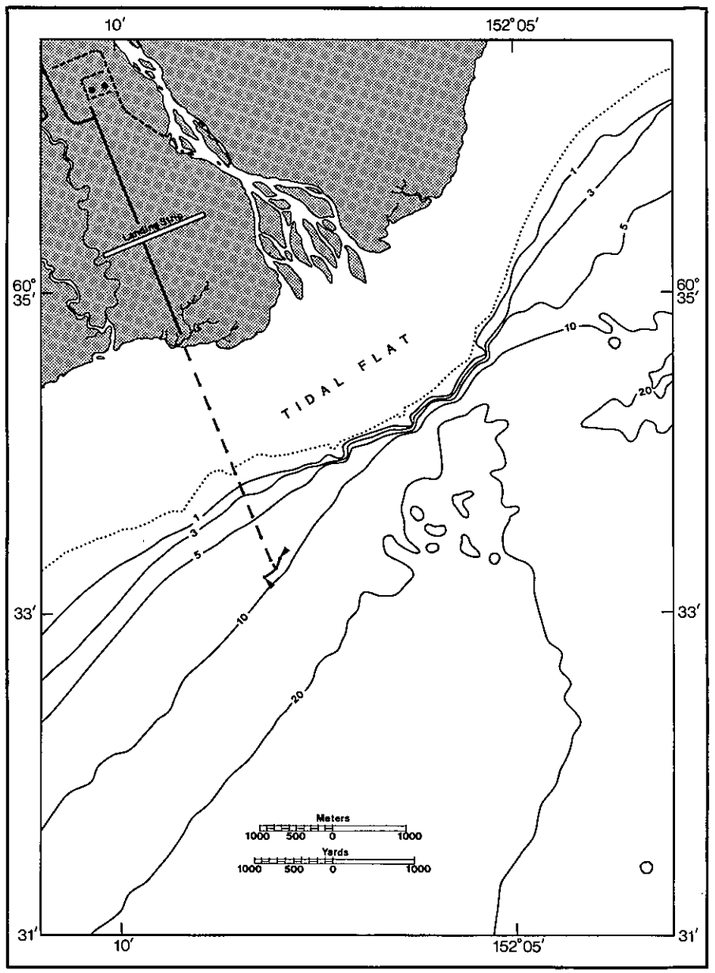


Figure B.1.1b Drift River Terminal (after NOS hydrographic chart #16660, 1976).

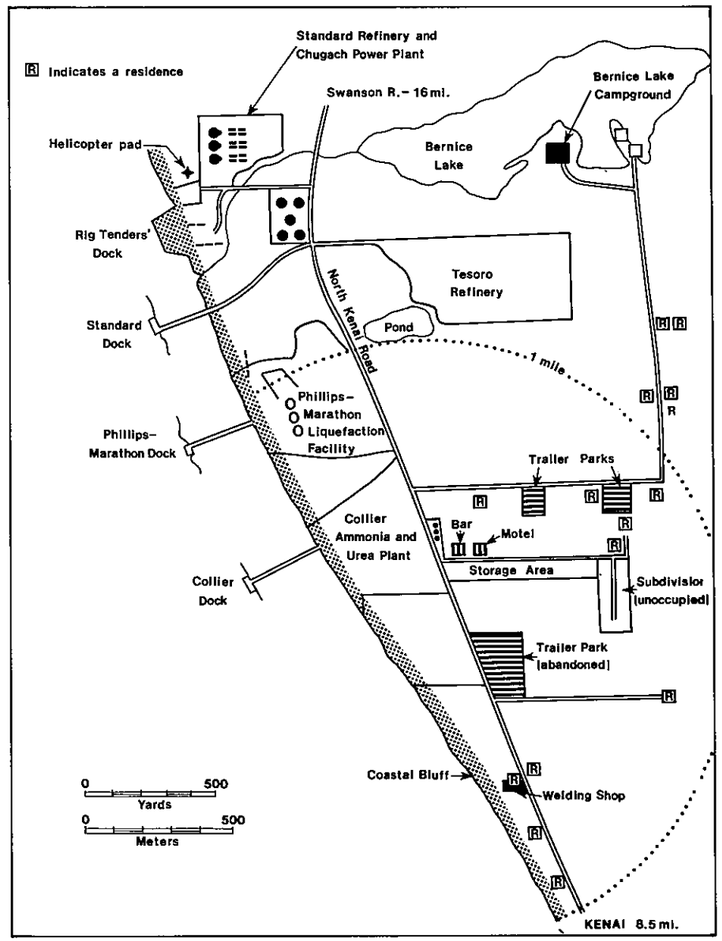


Figure B.1.1c Nikiski Marine Terminal Complex (from BLM, 1977).

Before the first OCS oil and gas lease sale of Federal lands in Cook Inlet in October 1977, 152 tracts were selected for environmental assessment (Fig. B.1.1d). Seventeen tracts along the Kenai Peninsula were eliminated from the sale for environmental reasons, leaving 135 tracts to be offered for sale.

Of these, 495,307 acres were leased and over $398 million was realized from the sale. Marathon and Phillips Petroleum began exploratory drilling the following summer.

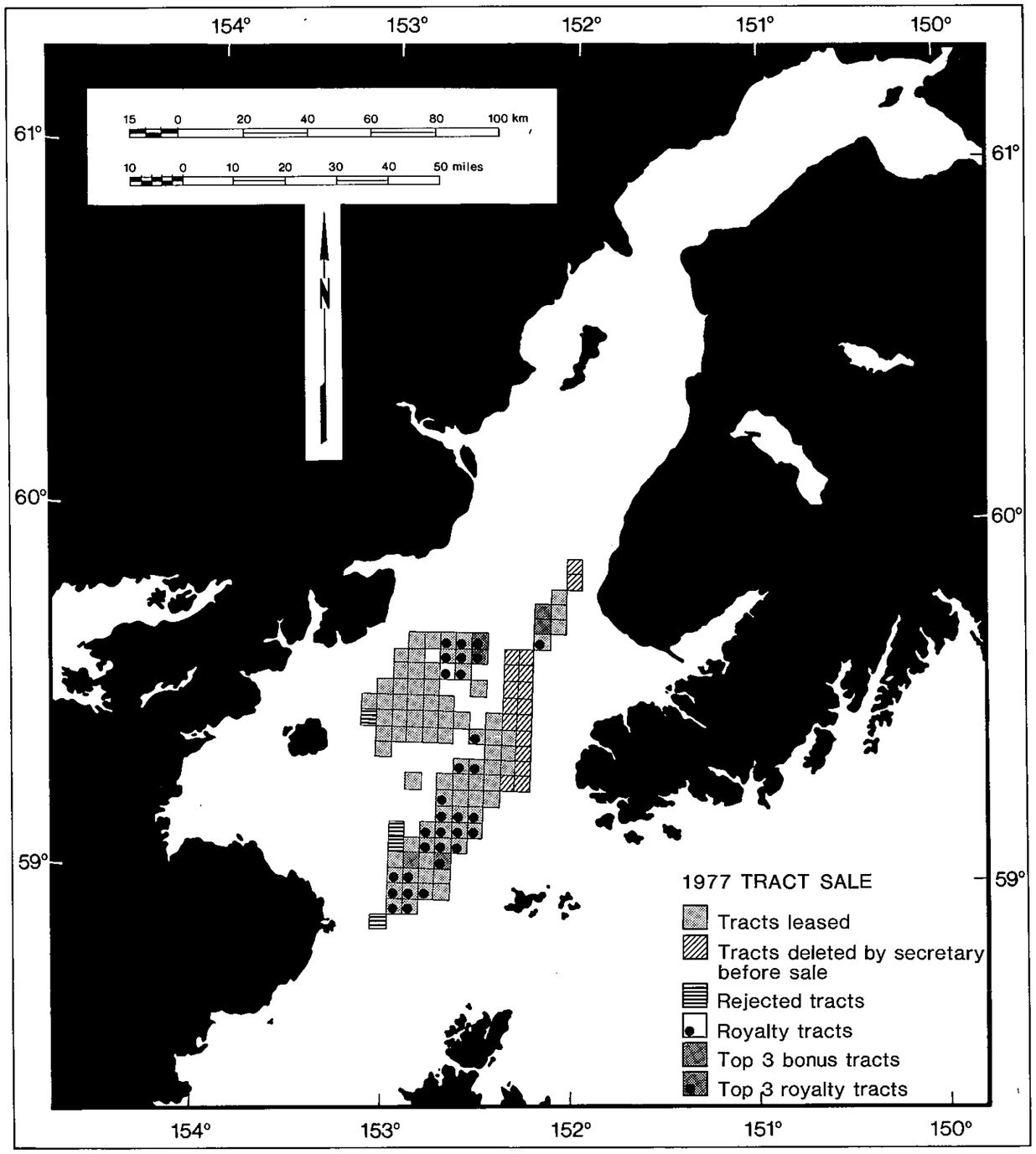


Figure B.1.1d Results of OCS Sale No. CI, October 1977 (Warren, LCSM, 1978).

Five of nine lease stipulations were environmental in nature (Warren, LCSM, 1978), requiring:

1. inclusion of an environmental training program for all personnel involved in exploration and development;

2. no barging except under special or emergency circumstances;

3. a limit on the use of boats and aircraft between May and September to prescribed distances and altitudes to protect seabird colonies and marine mammal rookeries;

4. approval of the Governor of Alaska and local jurisdictions to be obtained before beginning exploration;

5. surveys to be performed in certain areas to determine which biological communities may be adversely affected by a lease operation; the areas requiring biological surveys are shown in Fig. B.1.1e.

In addition to these stipulations, three new requirements have been placed on the lessees (Warren, LCSM, 1978):

1. the use of recommended boat traffic lanes established by the Coast Guard to transport supplies to the leased areas;

2. the use of bird scare techniques in the event of an oil spill;

3. the monitoring of exploratory drilling to determine the effects on aquatic life.

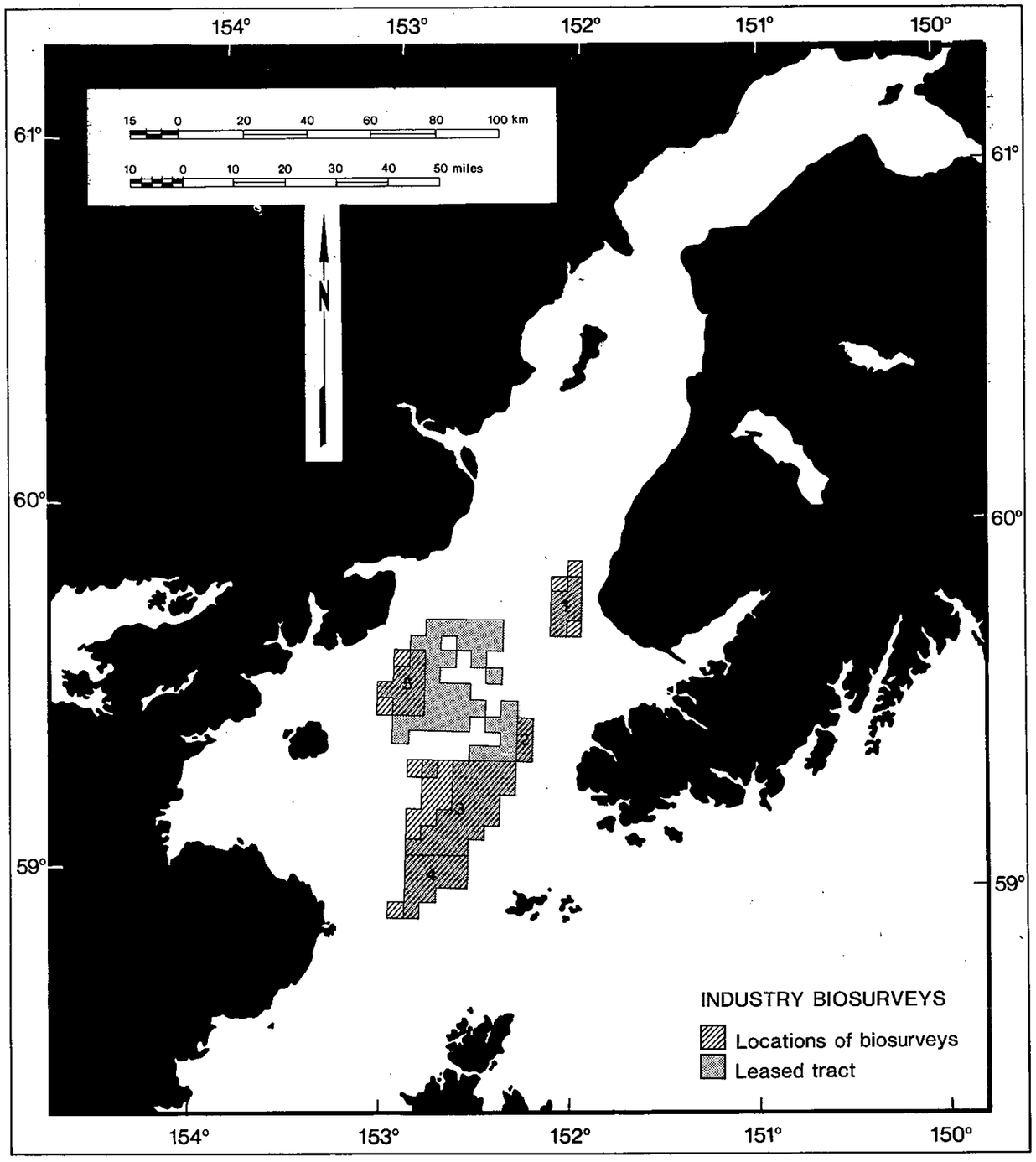


Figure B.1.1e Areas for which biological surveys were required (Warren, LCSM, 1978).

The Department of Interior will seek the advice of state and federal agencies to identify areas requiring the burial of pipelines, alternative methods for disposal of drilling muds and formation waters, and the reduction of boat and air traffic. An environmental impact statement will be required for the development phase in Lower Cook Inlet.

A second Federal lease sale (Sale 60) in Cook Inlet is scheduled for March 1981. Call for nominations was in December 1978 tract selection will be in May 1979 the draft EIS is due in February 1980 and final tract selection is scheduled for December 1980. Shelikof Strait may be included in this sale but industry interest in that area is as yet unknown.

B.1.2 PHASES OF OFFSHORE OIL AND GAS OPERATIONS

The activities of the oil and gas industry within a lease area consists of five phases: reconnaissance, exploration, development, production, and post-production.

Reconnaissance, which takes place before leasing, includes magnetic, gravitational, and seismic measurements to determine the location and depth of sedimentary structures that may bear oil and gas, as well as surface collections and coring. Besides locating potential sources of oil and gas, this information is used to find areas with fewest geological hazards to drilling, production platforms, and related structures.

The exploration phase includes exploratory drilling with mobile drilling platforms. Onshore bases provide services (pipe, equipment, men, etc.) to these drilling platforms. If exploration is successful additional wells are drilled to assess the extent of the discovery.

The development phase requires the largest labor force and involves expansion of service bases, construction of non-mobile platforms onshore, the positioning of the platforms offshore, and the drilling of numerous deviated wells (development drilling) from single production platforms. Concurrently, oil collection and storage systems, production treatment facilities, (for separating oil, gas, and water), gas processing plants, and tanker terminals are built. In fields of limited production, fewer onshore facilities are needed because crude oil is stored on the drilling platform and loaded directly into tankers. If extensive onshore storage is required, however, submarine pipelines must be laid between platforms and shore-based facilities.

The production phase begins with the flow of oil or gas from offshore platforms. Fewer workers are needed, as most activity is restricted to maintenance and inspection. During this phase additional drilling may be required to maintain adequate flows of oil and gas.

The post-production phase begins when the field is exhausted; this involves shutdown and dismantling of the platforms.

B.1.3 PROBABLE OCS EXPLORATION AND DEVELOPMENT IN LOWER COOK INLET

Of immediate environmental concern are the exploratory, development, and production phases. The information used to project exploration and development in Lower Cook Inlet comes from several sources (Lilly, LCSM, 1978; Goldman, LCSM, 1978; and Warren, LCSM, 1978). The projections of these authors differ because of the uncertainty of locating commercially exploitable quantities of oil and gas during exploration.

The potential level of offshore and onshore activity depends on the amount and quality of petroleum discoveries, the cost of equipment and labor, the price of oil, and the attractiveness of development prospects in other parts of the world (Kramer et al., 1978). Some basic factors that affect timing are (Lilly, LCSM, 1978):

1. delineation of field size, which requires one to two years.
2. EIS requirements; an EIS is required for the development phase in Cook Inlet.
3. completion of a four-phased Intergovernmental Planning Program before an operator can file a development plan. This program establishes interagency/industry regional working groups to evaluate management information regarding leasing and transportation of OCS oil and gas.
4. water depth; the deeper the water, the more time required for installation of a platform.
5. weather conditions; some phases of work may have to be seasonal.
6. drilling time, which depends on geological formation, the depth to formation, and whether a deviation well is required.

Assuming the discovery of oil in 1978-79, a time table for development in Lower Cook Inlet was projected by Lilly and Warren in remarks at the Lower Cook Synthesis Meeting, January 1978. The exploratory phase should be substantially completed by the end of 1985. The development phase would then begin with onsite platform installation in 1981. The production phase would begin between 1983 and 1985, six to eight years after the lease sale. This timetable should be considered as an optimistic minimum.

Reconnaissance, Continental Offshore Stratigraphic Test (C.O.S.T.) Well

Between June 7 and September 26, 1977, ARCO completed the Lower Cook Inlet C.O.S.T. well approximately 35 nautical miles west of Homer (Fig. B.1.3a). This well was drilled, using the Ocean Ranger semisubmersible rig, to obtain geological information on promising deep formations. Information on porosity and permeability characteristics was sought to determine the ease of extraction of oil or gas.

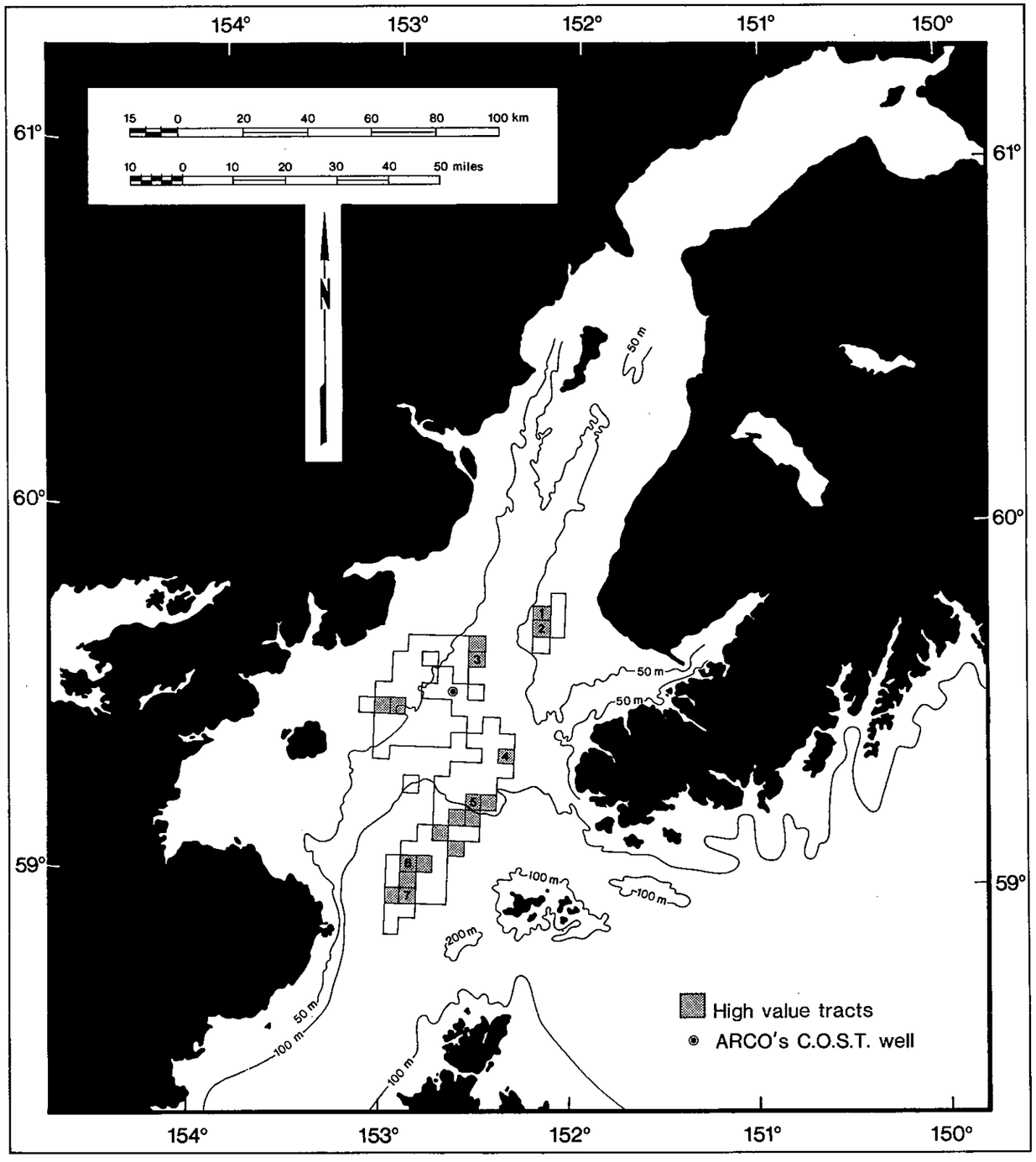


Figure B.1.3a Locations of current and proposed exploratory drilling rigs (Warren, LCSM, 1978).

Exploration

The locations of ongoing exploratory drilling and drilling projected through 1980 are shown in Fig. B.1.3a. The locations, companies involved, proposed drilling rigs, and projected starting dates (Petroleum Information, 1978) are given in Fig. B.1.3b. Since the oil and gas industry will probably explore the most expensive tracts first, exploratory drilling is expected to begin soon in the following clusters of blocks:

1. 358, 402
2. 572, 529
3. 799, 841, 842, 844, 929
4. 971, 1014, 1

The present exploratory drilling is being conducted using a drillship and a semisubmersible rig. Two additional exploratory rigs may be used in Cook Inlet in the future (Goldman, LCSM, 1978). Each rig requires two supply boats to haul supplies, to stand by in case of an emergency, and to haul anchors when a rig is moved. Support boats required during exploration are about 200 feet long. Helicopters such as an S-61 or a Bell 212 are needed to ferry personnel and some equipment to the offshore rigs (Goldman, LCSM, 1978).

The establishment of adequate service bases during the early stages of exploration is essential. In Lower Cook Inlet facilities and transportation support already exist at the Nikiski Marine Terminal Complex and at Kenai and Homer; these will be used during exploration (Goldman, LCSM, 1978). Expansion of Nikiski and/or development of other service bases will depend on the results of exploration.

Figure B.1.3b Current and proposed exploratory drilling rigs (Petroleum Information, 1978).

Lease Block	Map No.	Location	Water Depth (m)	Proposed Drilling Date	Probable Equipment	Company
274	1	40 km NW of Homer 21 km W of Anchor Pt.	46	8/79-1/80	ODECO Ocean Bounty semisubmersible rig	Phillips Petroleum
318	2	19 km SW of Anchor Pt. 37 km W of Homer	32	spudded 7/78 drilling started 8/78	Diamond M. Dragon drillship	Marathon
401	3	61 km W of Homer	63	5/78		ARCO
668	4	53 km SW of Homer	85	spudding 11/78 drilling to 3/79	ODECO Ocean Bounty semisubmersible rig	Phillips Petroleum
798	5	66 km SW of Homer	79	spudding 1/80 drilling to 5/80	ODECO Ocean Bounty semisubmersible rig	Phillips Petroleum
970	6	102 km SW of Homer	185	spudding 3/78 drilling to 8/79	ODECO Ocean Bounty semisubmersible rig	Phillips Petroleum
2	7	110 km SW of Homer	160	?	Diamond M. Dragon drillship	Marathon

If oil is discovered in 1978-79, exploratory drilling will probably be complete by the end of 1985 (Lilly, LCSM, 1978; Warren, LCSM, 1978).

Development

Projections of probable development are based on the "Average Case Petroleum Development Scenario" produced by BLM for Lower Cook Inlet (Warren, LCSM, 1978) using the results of the lease sale together with estimates of oil and gas production.

Among the assumptions used in the "Average Case Scenario" were: that the sale area would produce 326 million barrels of oil with a peak volume of 87,671 bbls/day, or 32 million bbls/year, and 330 billion cubic feet of gas with a peak volume of 52 million cf/day, or 19 billion cf/year and that the life expectancy of the oil and gas fields would be about 26 years. A diagram of the scenario is shown in Fig. B.1.3c.

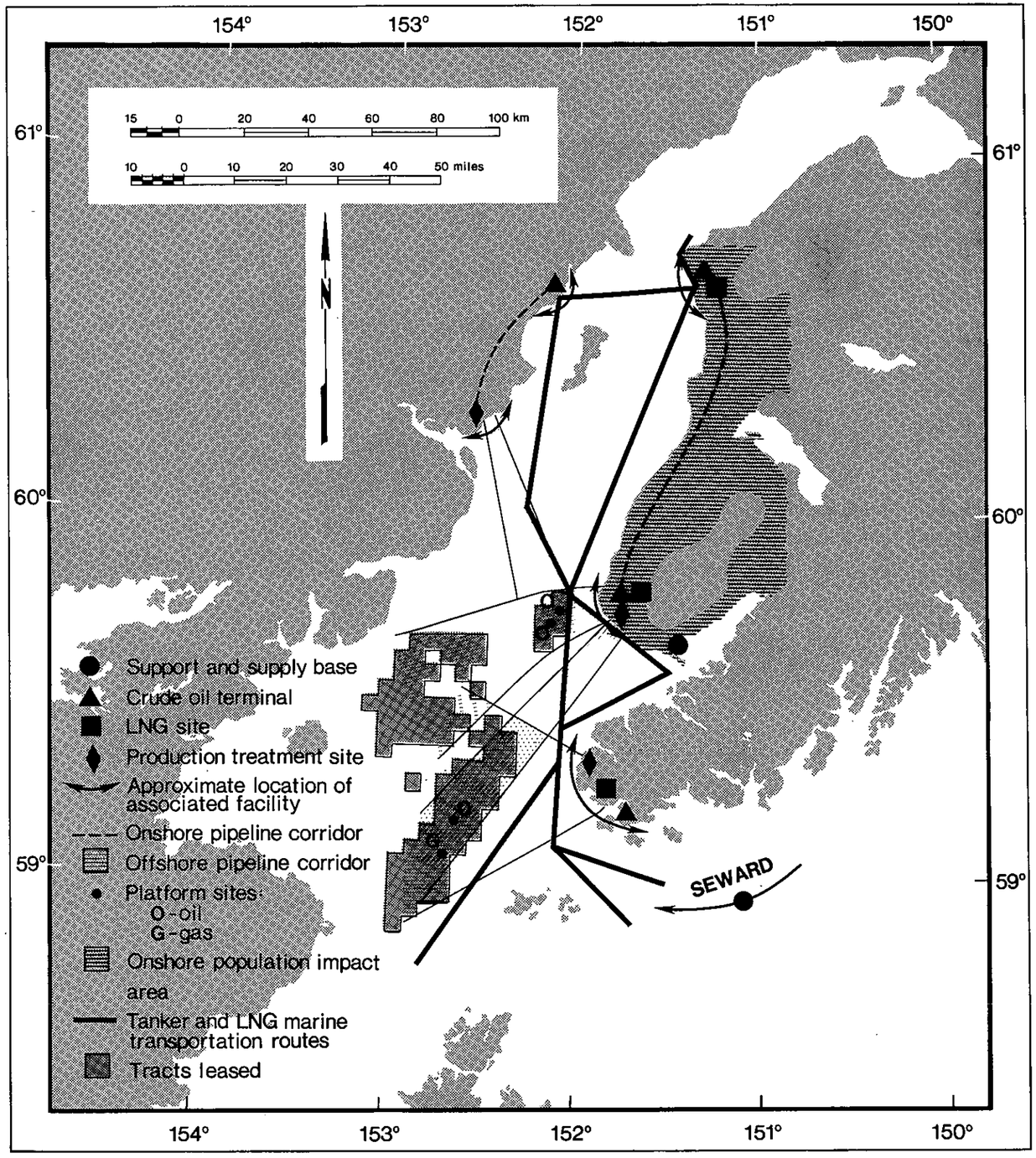


Figure B.1.3c Average Case Petroleum Development Scenario (Warren, LCSM, 1978).

Platforms

The three production platforms shown in Fig. B.1.3c are located within high-bonus bid and royalty tracts. The upper two correspond to exploratory drilling locations 2 and 5 in Fig. B.1.3b. If oil is discovered in 1978-79, onsite platform installation could begin as early as 1981 (Lilly, LCSM, 1978; Warren, LCSM, 1978).

Template platforms (Fig. B.1.3d) constructed in the Lower 48 and transported to Alaska will be used in Lower Cook (Goldman, LCSM, 1978). Once barged to the location, templates are set on the bottom, pilings driven through the template guides into the bottom, and the platform attached to the pilings. Because of the hard bottom in Lower Cook Inlet, these pilings would have to be drilled (Lilly, LCSM, 1978). In Cook Inlet as many as 20 to 30 development wells may be drilled from a single platform (BLM, 1977).

Several factors affecting platform design in Cook Inlet are wind, waves, currents, earthquakes, bottom sediment conditions, and ice loads (Lilly, LCSM, 1978). Industry (in consultation with Japanese geologists, who have monitored a subduction zone off Japan) has developed a seismic wave attenuation equation to be used in design aspects concerning earthquake hazards. Ice loads on rigs have not been a problem in upper Cook and should not cause design problems for the platforms in Lower Cook Inlet. Earthquake, storm, and other design criteria are described in Appendix 8 of BLM (1977).

The design of platforms for Lower Cook Inlet will not be started until oil or gas is discovered (Lilly, LCSM, 1978). Time required for design and installation will range from 30 to 54 months.

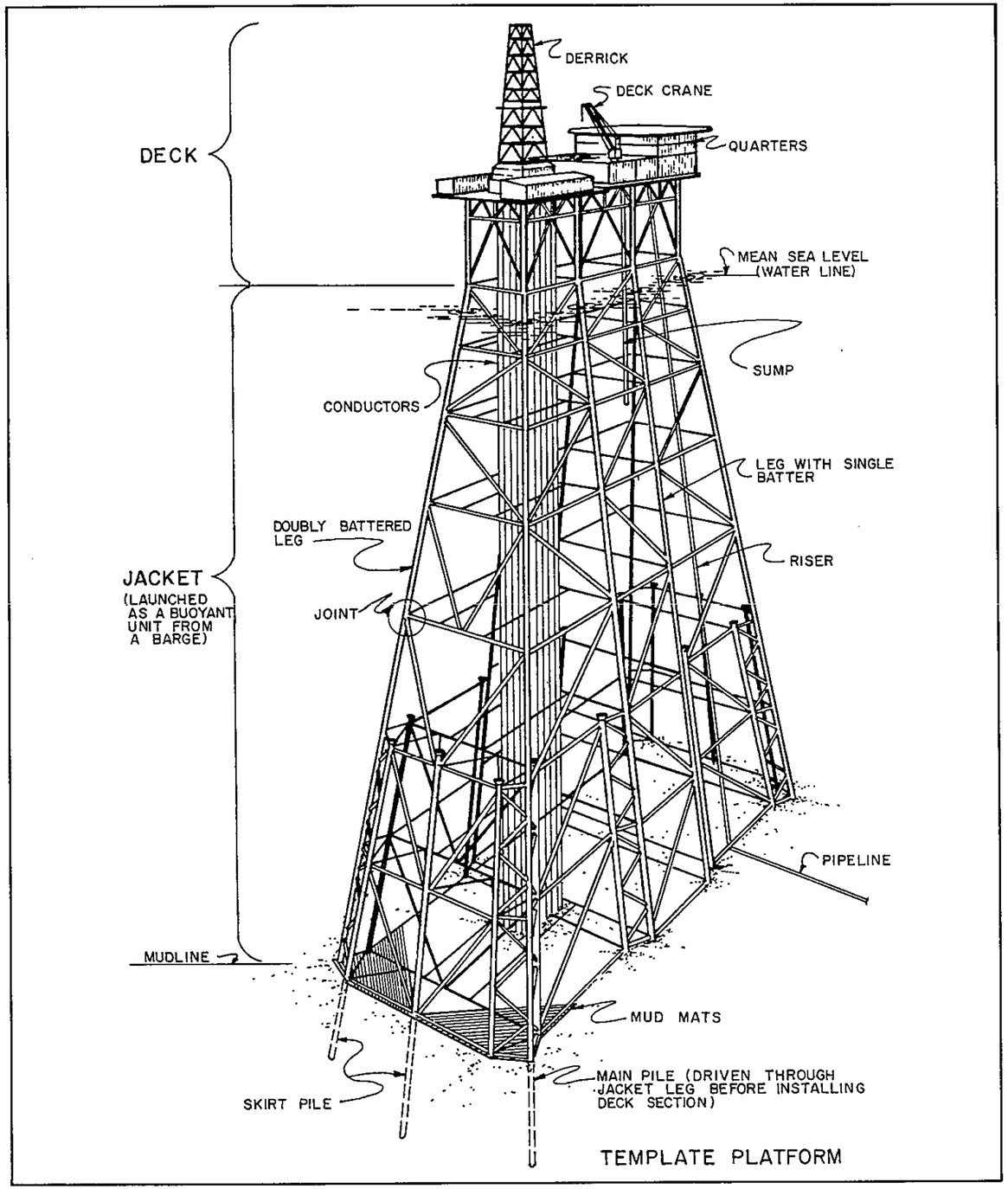


Figure B.1.3d Template platform (figure courtesy of Brown and Root, Inc., Houston, Texas).

Service Bases

Although ports such as Kenai and Homer, which do not contain service bases, play a role in supply of offshore needs during exploration, the burden will be assumed by the service base(s) during the development phase (Alaska Consultants, 1976). The location of producing platforms will determine the need, since the maximum operating distance from supply base to offshore rigs is 200 miles (Alaska Department of Community and Regional Affairs, 1977). Nikiski is assumed to be the primary local source of heavy supplies, with Seward as an alternate port of entry. The most likely areas for permanent support and supply bases are Nikiski, Homer, and the Seldovia-Port Graham area.

Tanker Terminals, and Onshore Collection and Separation Facilities

Possible locations for tanker terminals and associated onshore development are indicated in Fig. B.1.3e (Warren, LCSM, 1978). Development in Lower Cook Inlet may require expansion of the Nikiski and Drift River terminals. Other likely locations, if oil is discovered in the southern portion of Lower Cook Inlet, are the Anchor Point area and the area south of English Bay to Portlock.

With the exception of the Anchor Point and Redoubt Point areas, production treatment would take place at the terminals (Fig. B.1.3e). Also located there would be oil storage tanks, ballast water cleaning plants, and associated support facilities. Storage facilities would be designed to store 4 to 10 days' production of crude oil in case of transportation breakdown (Kramer et al., 1978).

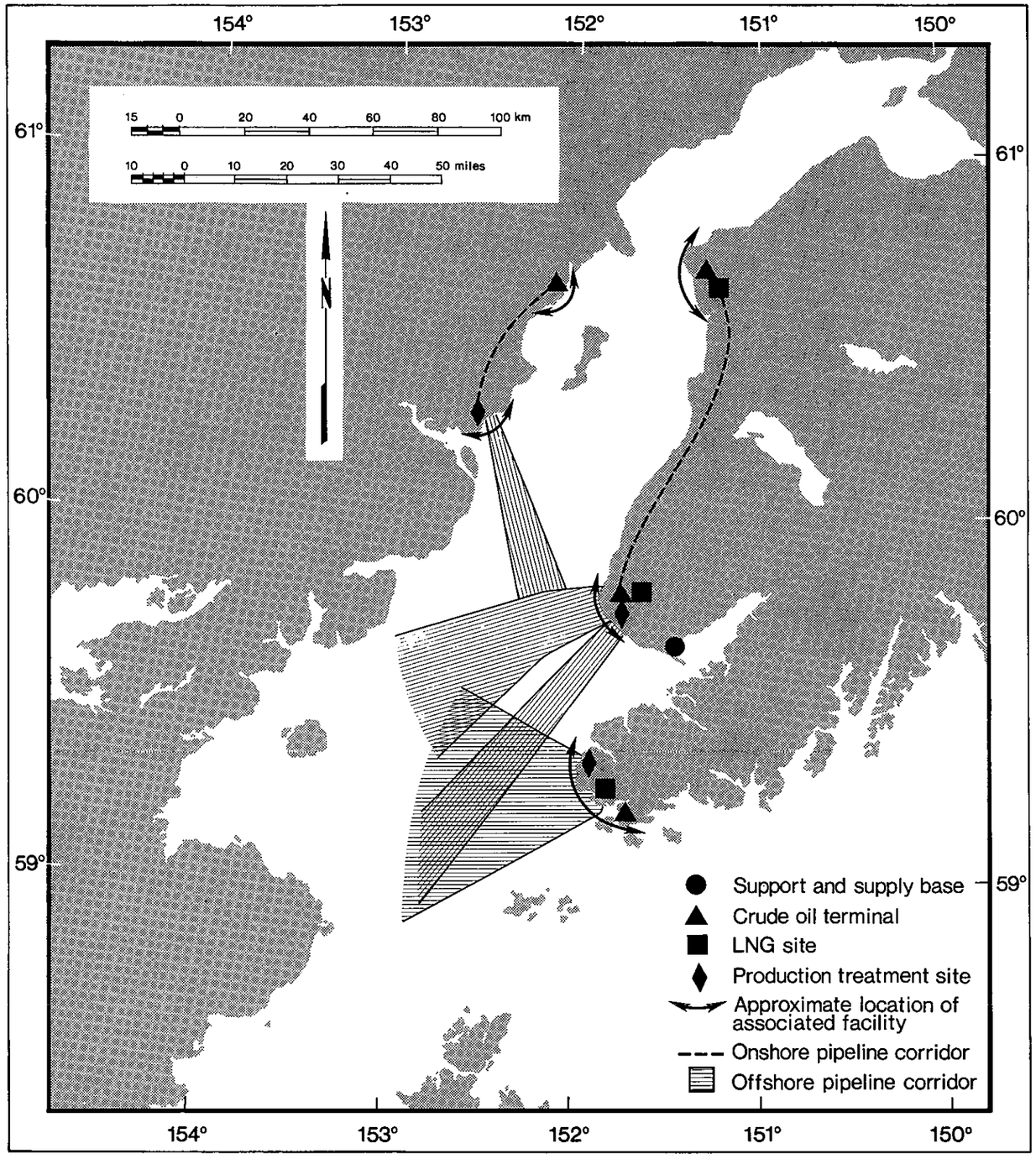


Figure B.1.3e Possible locations for tanker terminals and associated onshore development (Warren, LCSM, 1978).

Nikiski, southern Kenai Peninsula, and Anchor Point are possible locations for an LNG plant. If gas discoveries occur in the southern portion of Lower Cook Inlet, a gas pipeline could be built to Anchor Point or the southern Kenai Peninsula (Warren, LCSM, 1978).

Pipelines

Pipeline corridors will transport crude oil from the northeast or southeast lease sale area to crude oil terminals, production treatment facilities, and LNG plants (Fig. B.1.3e: from Warren, LCSM, 1978). The marine pipeline system will consist of a pressure source (production platform), gathering lines to a central compressor station, transmission lines, intermediate booster stations, landfall, and onshore destination. The latter may be a land pipeline if landfall is not at a treatment facility or terminal.

Factors to consider in designing the pipeline are bottom condition, internal pressure and connection requirements, buckling, and installation (Lilly, LCSM, 1978). Of particular importance in Cook Inlet are the location of dynamic sand waves and sand dunes, nearshore faulting, the slope of the bottom, and bottom currents (potential for scour). Moving sand bottoms in upper Cook Inlet have resulted in exposure and suspension of sections of pipelines, sometimes causing the pipes to flutter or move at right angles to the direction of the current (Goepfert, 1969). Such movement can result in breaks and/or leaks in the pipes.

To avoid areas of unsuitable bottom conditions, a pipeline can be diverted 20 to 25 percent from a straight path (Lilly, LCSM, 1978). This must be minimized, however, since the cost of a pipeline can be as high as $3 to 4 million per mile in Alaska (Kramer et al., 1978). The cost can also be reduced by laying the largest line possible, probably 30- to 36-inch diameter pipe of 5/8 to 1 inch wall thickness.

The pipeline will probably be laid by a lay barge (Fig. B.1.3f), which contains all facilities required to weld the pipe, x-ray joints, cover the weld with a protective coating, and lay the joined pipeline on the Inlet floor. Anchors hold the barge in place. As each section of the pipe is welded and passed over the stern, the barge moves forward. A buoyant pontoon called a stinger may be used to support the upper section of the pipeline.

Since OCS regulations require that pipelines be buried in water less than 62 m deep, almost all of the pipeline in Lower Cook Inlet will be buried. Minimum burial depth is one meter, except in shipping fairways and anchorage areas, where it is 3 m (Alaska Department of Community and Regional Affairs, 1977). In order to maintain flexibility, pipelines in earthquake-prone areas may not be buried (BLM, 1977).

Pipes may be buried by dredging, trenching, or jetting. Jetting is the most likely method to be used in Cook Inlet because of sandy substrate. A towline consisting of a strength member, water line, and airline extends from a barge down to a U-shaped jetting nozzle which straddles the pipeline. The nozzle directs high-pressure water and air ahead of and below the pipeline. As the sediment is blasted from underneath the pipeline, the jet is rolled forward, the pipeline sinks into the resulting trench and is buried by the sediment. In shallow waters, restoration of the bottom contour is rapid, but in deep waters it may take more than a year (BLM, 1977).

Besides jetting, rock outcrops may require dredging and some landfall areas could require blasting (Lilly, LCSM, 1978), although the ideal landfall is a gently sloping sandy beach.

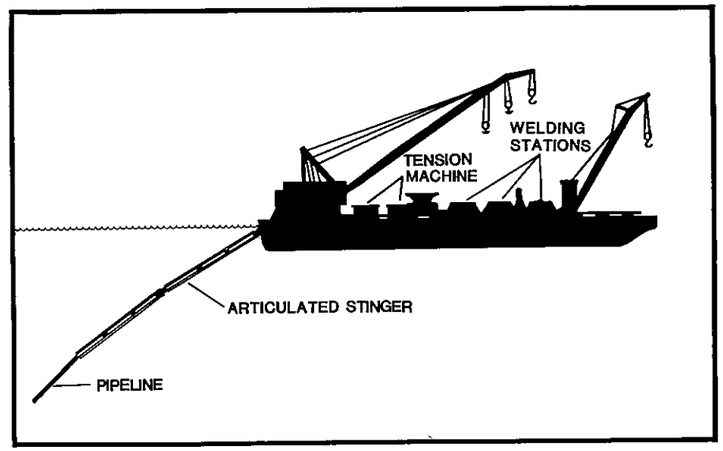


Figure B.1.3f A lay barge with an articulated stinger (after BLM, 1977).

Submarine pipelines require a 5-foot swath of seafloor and a wider area would probably be disturbed by the installation activities. Most barges can lay 50 miles of large-diameter pipe in a season -- May through October (Kramer et al., 1978).

Strong currents and tides in Cook Inlet may cause buckling of the pipeline (Lilly, LCSM, 1978). The internal fluid will determine how much weight is permitted on the pipe. Internal pressures may reach 1,000 psi for crude oil lines and 1,200 psi for gas lines (Lilly, LCSM, 1978). Most will be coated with concrete to keep them from floating out of the trench.

Production

The major components of the production phase are supply boat and tanker traffic. Daily helicopter flights would transport supplies and personnel between platforms and service bases. Direct tanker transport of crude oil from producing platforms could occur during early years of production (Kramer et al., 1978). The possibility of this depends on the quality (percent of water and gas) of the crude oil.

For prevention of catastrophic line breaks, automatic pressure-sensing recorders would be installed on both ends of the pipeline system. These have built-in alarm systems that shut down flow or alarm personnel if pressure in the lines drops more than 300 to 500 psi (BLM, 1977). Small leaks could be detected by routine patrolling by boat or aircraft. OCS regulations require patrolling at least every two weeks (BLM, 1977). A third system consists of volume-recording flow meters on each end of the pipeline system. Differences in input and output alert personnel. All three systems are required in OCS production (BLM, 1977). All major pipelines would include remote mainline block valves at intervals to isolate segments of the pipeline. The spacing of these valves is specified by the USGS.

The major competitors for harbor space during the production phase will be support and supply boats, and crude oil and LNG tankers. Patterns of use will be determined primarily by the location of producing fields or shore support facilities and the potential markets (Warren, LCSM, 1978; Fig. B.1.3g).

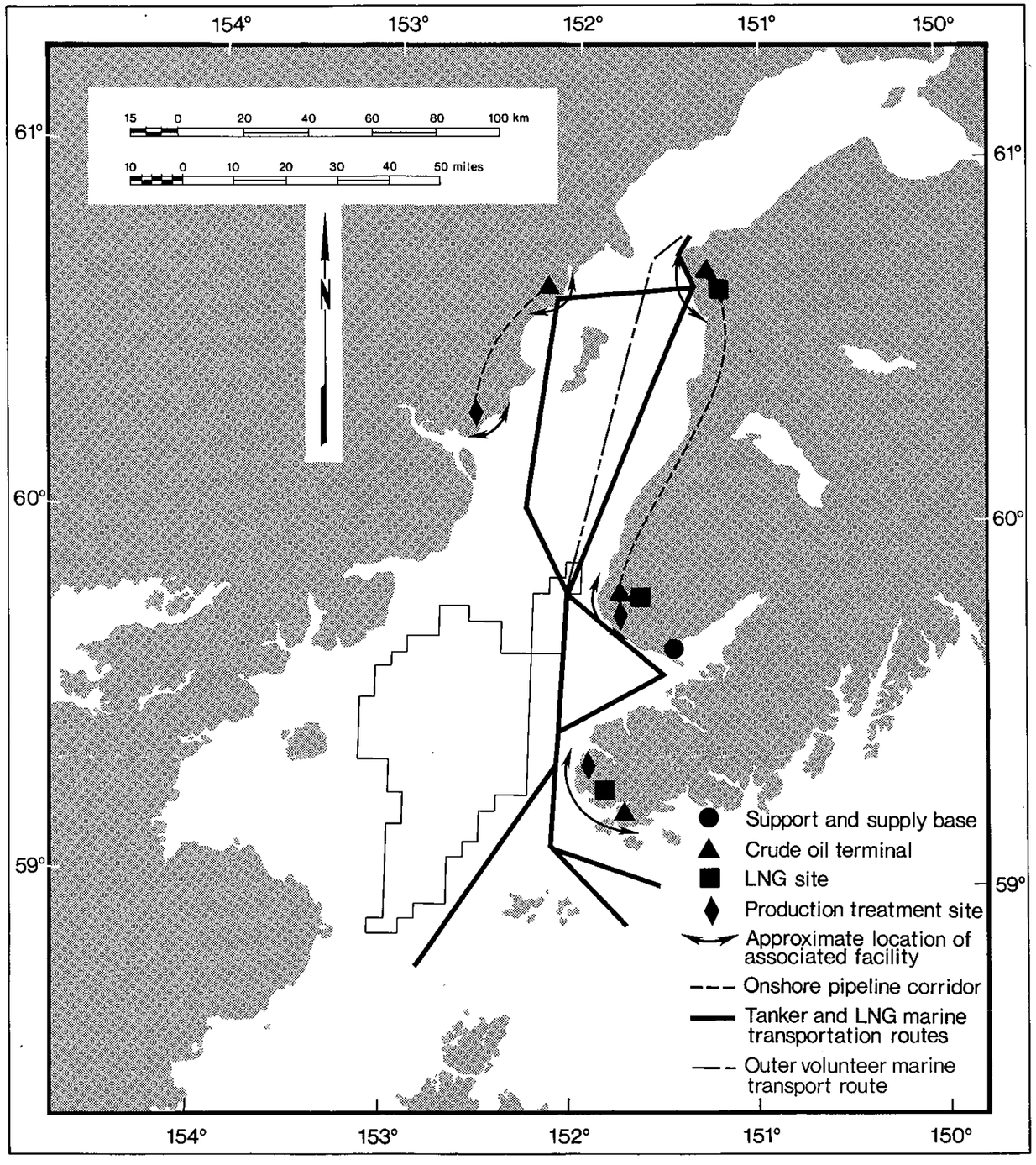


Figure B.1.3g Possible patterns of tanker use of Lower Cook Inlet (Warren, LCSM, 1978).

Nikiski will probably be the center of activity. The outer marine transport route, which runs from off Anchor Point northward through the center of the Inlet and past the Forelands, is used by Anchorage traffic except from December to March (SAI, 1976), when the inner route, nearer the eastern shore, is used due to ice conditions. Cargo vessels use the inner route year-round.

SAI's (1976) collision modeling exercise on risks associated with LNG plant construction at Nikiski (Fig. B.1.3h) did not consider increased traffic due to oil production in Lower Cook Inlet.

Figure B.1.3h Projections for Nikiski and Anchorage traffic (from SAI, 1976).

Type of Vessel	Size (tons)	Transits/Year
Anchorage Traffic Using Nikiski Route:		
Tanker	3,600-48,400	128
Cargo	2,100-32,000	937
TOTAL		1,065
Nikiski Traffic:		
Tanker	19,400-100,000	514
Cargo	13,900-32,000	184
Barges	3,500-13,200	366
Misc.	1,600	8
TOTAL		1,072

Plans to expand the Nikiski facility would have to take into account hazards to shipping. Ice floes can trap ships and move them against obstacles and, with strong tidal currents, break ships away from docks (SAI, 1976). On ebb tides, ice moving from north of the East Foreland is deflected westward away from Nikiski. Flood tides, on the other hand, move the ice flows from the south toward Nikiski, which has no natural barriers for protection.

Controlled breakaways (castoffs) due to ice, wind, or waves are considered normal at Nikiski (SAI, 1976). Of the breakaways at Nikiski, seven were classified as controlled and seven as uncontrolled with broken mooring lines. Six of the latter occurred during flood tides.

SUBTASK B.2 Quantity and Physical and Chemical Nature of Possible Contaminants

Possible Sources of Contaminants

Five potential sources of contaminants associated with OCS exploration, development and production in Lower Cook Inlet are offshore platforms, pipelines, shorebased facilities including tanker terminals, tanker routes, and the chemicals used to clean up major oil spills.

Offshore Platforms

Discharges from drilling platforms are regulated by the EPA through National Pollution Discharge Elimination System (NPDES) permits. Plans for exploratory drilling by the Ocean Bounty (CESC, 1978) list eight types of daily solid and liquid discharges from this drilling platform:

1. treated effluent from the sewage treatment system;
2. brine from the distillation unit;
3. seawater from the ballast system;
4. seawater and rainwater from the uncontaminated deck drains;
5. treated effluent from the oil/water separator;
6. drill cuttings mixed with sea water and drilling mud;
7. sea water, drilling mud, and cement from the drilling mud system; and
8. freshwater, water-soluble oil, and antifreeze from the blow-out preventer.

This list also applies to other exploratory rigs in Lower Cook Inlet.

Biological wastes originating at the platform are treated and disposed of according to USGS and the Coast Guard regulations (BLM, 1977). Brine from the distillation unit and seawater from the ballast system should contain no hydrocarbon contaminants. Waste oil and non-combustible refuse will be transferred to shore for disposal (CESC, 1978). Uncontaminated deck drains are in areas separate from the drilling space. These drains are checked when discharge occurs. Water in the drilling space (contaminated drains) drains into the oil/water separator and becomes part of this system's effluent. Estimated discharges from the separator of the Ocean Bounty are 1,500 to 2,400 gal/day (CESC, 1978). The maximum allowable oil and grease (EPA procedures) concentration is 72 mg/l. NDPES Permits require weekly monitoring of discharge.

I. Drill Cuttings and Drilling Muds

Drill cuttings composed of rock fragments and sediments will be left on the bottom if oil-free. If contaminated with free oil, they are to be transferred to shore for disposal, probably at the Kenai Peninsula Borough Oil and Hazardous Substances Waste Disposal Site in Sterling (CESC, 1978). Estimated discharge of drill cuttings mixed with sea water and some drilling muds is 12,200 gal/day. Turbidity would probably be restricted to the immediate vicinity of the platform; dispersal will depend on drilling procedures and the particle sizes of the cuttings. Coarse cuttings should fall quickly to the bottom; turbidity would be caused by fine sediments and associated drilling muds.

Drilling muds (or fluids) are an important part of the drilling program. The drilling mud is pumped down the drill pipe through the bit and returns through the annulus to the shale shaker, where drill cuttings are separated. Besides carrying drill cuttings, the mud also conditions the system and controls formation pressures to prevent blowouts.

Drilling mud is recycled because of its high cost, but because of incomplete separation, substantial amounts are discharged daily. Estimated discharge from the Ocean Bounty is 1,900 gal/day (CESC, 1978).

Drilling mud is discharged with the drill cuttings, when cleaning the shale shaker, while drilling the upper part of the hole before establishing circulation to the platform (spud-in) and when disconnecting the riser when the well is completed. The last two conditions occur only with mobile, floating platforms. Maximum discharge from the Ocean Bounty will be 42,000 gallons at spud-in and 84,000 gallons at completion. The maximum allowable is 1,260 gal/hr (CESC, 1978). The USGS requires monthly reports on the quantity of mud discharged.

Contaminants in drilling muds include pentachlorophenol, sodium hydroxide, ferrochrome lignosulfate, and barium sulfate (barite). The first two compounds are toxic to marine biota at concentrations greater than one mg/l. Both ferrochrome lignosulfate and barite, which contain toxic heavy metals, are not especially toxic to marine biota since they have low solubilities. The possibility of their alteration to soluble forms in sea water needs to be studied, as does the possible long-term uptake from sediments by benthic invertebrates.

Oil-based muds are used when abnormal formation pressures occur and during well completion to prevent blow-out. As NPDES permits allow no discharge of oil-based muds, they are usually disposed of onshore.

Whether biological populations are affected by turbidity due to disposal of drilling muds would depend upon concentrations of suspended solids and volume at the point of discharge, rate of dilution, and sensitivity of the organisms. Discharge limits of drilling muds for NPDES permits are 1,260 gal/hr; this rate would be allowed only during shaker cleaning, spudding-in, and well completion (CESC, 1978). The average discharge for the Ocean Bounty would be 1,900 gal/day or 80 gal/hr.

In their study of the drilling mud discharge from the ARCO C.O.S.T. well, Dames and Moore (1978) found that the turbulent wake of the rig Ocean Ranger in currents greater than 0.1 knot diluted discharges by 10,000:1 within 100 m of the rig. Since currents in Cook Inlet are usually greater than 0.1 knot, the 10,000:1 dilution factor holds for most of the lease area.

NPDES permits restrict concentration of suspended solids at the discharge point to four percent or less (CESC, 1978). With the 10,000:1 dilution factor of Dames and Moore, the concentration of suspended solids 100 m from the drilling rig would be about 4 ppm or 4 mg/l when discharge takes place at the maximum allowable limits. Background levels in Lower Cook Inlet for suspended solids are commonly 0.5 mg/l to 50 mg/l (Cline and Feeley, RU 152, Quarterly Report, Jul-Sep, 1978).

II. Formation Waters

Water may be separated from oil and gas on the offshore platform, at the production treatment facilities on shore, or both. It is assumed that some separation will take place at the platform, and formation water will either be reinjected into the formation or disposed of into the Inlet.

Although the percent of water in oil discovered in Lower Cook Inlet is unknown, Alaska Department of Natural Resources (1975) estimated that in upper Cook Inlet during a 7½-year period 651 million barrels of oil and 84 million barrels of water were produced (or about 10 percent water). It is projected that 50 percent of the produced water will be reinjected into the formation and 50 percent discharged in the Inlet (BLM, 1977). Because of incomplete separation of oil and water, formation water represents a chronic source of oil contamination.

Introduction of oil via formation water during peak production is relatively low as compared to accidental spills from platforms and pipelines (BLM, 1977). Formation water could cause the equivalent of 73 barrels of spilled oil per year based on the average case scenario projections of 32 million barrels per year peak production.

Other contaminants associated with formation waters are heavy metals and hydrogen sulfide. Because of the rapid dispersion of effluents, hydrogen sulfide, which can be extremely toxic, should be quickly oxidized.

III. Blowout Preventer (BOP)

The well control system, which includes the BOP, is probably the most vulnerable portion of any oil or gas well. USGS requires weekly testing of the BOP, which necessitates discharging the operating fluid (water/antifreeze mixed with hydraulic oil (BLM, 1977)) on the sea floor. The discharge is 12 gallons per well, 2 gallons of which is oil. Compared with other sources of chronic contamination, this amount is insignificant.

IV. Accidental Oil Spill

Accidental oil spills from OCS platforms are of several types: spills during platform operations, blowouts during drilling, and platform fires. Accidental spills (>50 barrels per incident) from overflows, malfunction, rupture, or failure of platform piping valves probably will account for about one percent of all oil spills occurring in Lower Cook Inlet during the life of the field. Minor spills of <50 barrels per incident could account for four percent (BLM, 1977). Based on the expected maximum annual oil production from the average case scenario, 32 million barrels (Warren, LCSM, 1978), and the projected spillage (BLM, 1977), accidental spillage could approximate 70 barrels of oil per year.

BLM (1977) estimates that each well will have one blowout, resulting in the spillage of 2,100 barrels of oil. Based on data from the Gulf of Mexico, the spillage rate from platform fires could be 0.0029 percent of the total production (BLM, 1977). If 326 million barrels of oil are produced during the life of the field (Warren, LCSM, 1978), spillage could amount to 928 barrels per year.

Acute environmental effects could be expected from any large oil spill originating from offshore platforms. Possible effects of hypothetical platform spills in Lower Cook Inlet were discussed by Calder (LCSM, 1978). Organisms coated by oil in the water column, floating on the surface, or stranded in the intertidal area or on beaches could suffer high mortality. Large kills would be a dramatic, but short-term effect. Depending on the circumstances of a spill the reproductive output of local populations could be barely affected, eliminated in the year of the spill, or greatly reduced for many years and thus prolong the effects of a spill. Continual reexposure to oil for a long period could result from redistribution of oil by physical factors or through the food chain. Current knowledge is inadequate to assess the probability and extent of these effects.

V. Pipelines

Most contamination from pipelines would come from oil leaks and accidental breaks. However, contamination through turbidity during laying of the pipeline would probably be insignificant since it would be restricted to the immediate vicinity of the laying operation.

On the basis of spillage rates in the Gulf of Mexico since 1970 (0.0017 percent) and an average case maximum annual production of 32 million barrels of oil (BLM, 1977), pipeline accidents could cause the release to 544 barrels of oil per year.

Pipeline breaks or leaks in Cook Inlet can be minimized by avoiding geological hazards such as active faults, extreme bottom erosion and deposition, which could result in pipeline buckling. Before a pipeline permit is issued the industry is required to survey the proposed pipeline route using side-scan sonar, sub-bottom profiling, and possibly TV; additional biological studies may be required.

VI. Shore Facilities Including Tanker Terminals

Chronic discharge of oil into areas around shore facilities and tanker terminals can be expected. Spillage at the Milford Haven terminal in the United Kingdom over a nine-year period amounted to 0.0011 percent of all oil moved (Brummage, 1973). This was

considered a well-controlled oil terminal operation. At that rate 3600 barrels spilled at the terminal sites could be expected for Lower Cook during the life of the field. The effect of this amount of oil would depend on how rapidly it could be dispersed.

In estimating spillages, an important factor is the number of ship-to-shore transfers (Clark and MacLeod, 1977). Spillage rates are higher with numerous small tankers than with a few large tankers. Another factor is the ease of operation. Tides and ice at Nikiski and Drift River during the winter increase the possibility of spillage. The projection of 3,600 barrels spilled is thus probably underestimated.

Additional contamination may come from disposal of biological wastes and dust and air from the exhaust of tankers and oil storage tanks. The magnitude of air contamination would depend on weather conditions and the rate of dispersal of hydrocarbon vapor and sulfur dioxide.

VII. Tanker Routes

An important potential source of oil contamination in Lower Cook Inlet is accidental oil spills from tankers. Some contamination could be caused by fuel leaks, but greater contamination would probably come from spilled cargo oil. More than 1000 barrels are spilled in tanker oil spills (BLM, 1977). Also, most large tanker spills occur within 50 miles of land because of their grounding or striking structures or other vessels. Following projected tanker routes (Fig. B.1.3g) tankers would come close to the east shore of Cook Inlet. The winter docking hazards at Drift River and Nikiski also increase the chance of a spill.

An annual maximum oil production of 32 million barrels (Warren, LCSM, 1978) and a spillage rate of 0.016 percent for tankers (CEQ, 1974) would result in 5,120 barrels spilled per year during peak production along the transportation route. These spills are projected for the entire route, only a portion of which is in Lower Cook Inlet. The spillage will of course increase if the volume of oil produced in Lower Cook Inlet increases.

VIII. Comparison of Sources of Spilled Oil from Production

The estimated probable annual spillage of oil from platforms, pipelines, tanker terminals, and tankers en route is presented in Fig. B.2.1a. These figures are based on spillage rates from other geographical areas. Comparison of the percentages show that the two major sources of spilled oil are pipelines (leaks and accidental breaks) and large-volume single spills from platforms. Chronic contamination from formation water and small-volume single spills at the platform probably will have little effect. Their importance will depend upon activities at the platform and the rate of dispersal. Since the blocks presently leased are in areas of strong currents, dispersal at most platforms should be rapid.

The annual spillage projected for tanker terminals is an average of the total projected spillage over the life of the field (26 years) and the spillage rate of Brummage (1973). Detrimental effects will probably be restricted to the immediate vicinity of the terminal depending on currents. Biological zones at risk are the intertidal and shallow subtidal, two important and productive areas of Lower Cook Inlet. Effects of contamination in these zones probably will be more easily seen than offshore in deeper areas.

One of the most important sources, if not the single most important source, of spilled oil for Cook Inlet will be tankers en route. This is because tanker spills are of large volume and usually occur near shore. The tanker routes in Cook Inlet will lie close to the eastern shore and very close to such biologically important areas as the outer Kenai Peninsula, Kachemak Bay, and the clam beaches above Anchor Point. These areas appear to be more at risk from tanker spills than from any of the other sources mentioned.

Figure B.2.1a Sources of oil spills in Lower Cook Inlet based on the Average Case Scenario projection of 32 million barrels predicted per year during peak production (BLM, 1977).

Source	Spill Volume BBLS/Year	Percent
Offshore Platforms		
Formation Water	73	4
Accidental (> 50 BBLS)[1]	17	1
Accidental (< 50 BBLS)	70	4
Platform Fires	928	52
Pipelines	544	31
Tanker Terminals	138	8
TOTAL	1,770	
Tanker Spills along route	5,120	

[1] Estimated spillage of 2,100 bbls from one blowout during the life of the field is not included.

IX. Cleanup Procedures

Oil spills may be treated with dispersing agents or surface collecting agents. The agents authorized for use in the Gulf of Alaska, which will probably also be used in Lower Cook Inlet, are Corexit 9527 and Corexit OC-5 (GOACO, 1977). Corexit OC-5 is a surface collecting agent used to contain oil slicks. It is a blend of surfactants in a hydrocarbon-based solvent. Corexit 9527 increases the solubility of oil and hastens its dispersion. This product is diluted with fresh water when used on low-paraffin oil of low to medium viscosity, and with a hydrocarbon-based solvent such as kerosene when used on oil of high viscosity. Dispersing agents may increase vertical mixing of spilled oil as well as its solubility, thus making it more available to organisms of the water column and the subtidal benthos.

Synergistic detrimental effects of oil and dispersants on developing fish eggs and larvae have been documented in the laboratory (Wilson, 1976). Detrimental effects of Corexit 9527 on fertilization and development of fish eggs were demonstrated by Lonning and Hagstrom (1975).

Oil Spills from Upper Cook Inlet

Spill data from the Alaska Department of Natural Resources for upper Cook Inlet for the period 1965 to 1975 are shown in Fig. B.2.1b (BLM, 1977). The number of oil industry spills was about three times that from other sources, but the total volume of industry-related spills was only half that from other sources. Average spill volumes from industry sources declined from 1971 to 1975. BLM (1977) attributed the decline to more stringent offshore operating regulations and continued improvement of offshore technology.

Cline et al. (RU 512, Annual Report, 1978) and Cline and Feeley (RU 512, Quarterly Report, Jul-Sep, 1978) reported petrogenic aliphatic hydrocarbons in Trading Bay just south of the southernmost platform at the West Foreland. The highest level of methane here was 1560 nl/l, that of ethane was 8.3 nl/l, and that of propane was 4.4 nl/l. Background levels north of the platforms were less than 200 nl/l, 2nl/l, and 0.2 nl/l, for methane, ethane and propane, respectively. Ethane concentrations were low here, 0.2-0.6 nl/l, suggesting a nonbiological source. These hydrocarbons could have originated west of the existing platforms from a production platform, capped wells, or natural seeps and been spread eastward by prevailing currents. Further study is needed to discover their source.

Figure B.2.1b Oil spills in Upper Cook Inlet (BLM, 1977).

	SOURCE				
	Oil Industry		Known		Unknown
Year	Spill Volume BBLS	Incidents	Spill Volume BBLS	Incidents	Incidents
1965	160	1			0
1966	4855	28	30	2	13
1967	1824	48	10,000	1	26
1968	1070	49	389	17	18
1969	918	21	6,243	10	12
1970	1039	23	3,984	9	31
1971	72	12	1,794	6	15
1972	19	8	32	7	1
1973	24	6	29	8	1
1974	19	25	268	7	4
1975	11	2	18	4	3
TOTAL	10,011	223	22,817	74	124

SUBTASK B.3 Potential Environmental Disturbance Accompanying Development

Drilling Platforms

Some environmental disturbances could arise from the release of hydrocarbons and related contaminants from drilling platforms.

In addition, benthic communities could be destroyed by the increase in suspended particles (turbidity) caused by the disposal of drill cuttings and drilling muds. Other potential problems are interference with commercial fishing activities and the entrainment of planktonic larvae of fish and shellfish with the intake water of drilling rigs.

BLM (1977) estimates 700 barrels of drilling mud per well are dumped over the life of the well which, for exploratory wells, is about six months. From the location of tracts which were sold in Lower Cook Inlet, one would expect rapid dispersal of suspended materials because of the strong currents. At the C.O.S.T. well in Lower Cook Inlet, within a few meters of the discharge point, drilling muds were well below concentrations expected to cause mortalities in the most sensitive species (pink salmon fry) tested (Dames and Moore, 1978). NPDES permits restrict suspended solids concentrations at the discharge point to 4 percent or less which, based on a measured dilution factor of 10,000:1 (Dames and Moore, 1978) would amount to 4 ppm at a distance of 100 meters from the discharge point. Thus, at least in the case of the C.O.S.T. well, any effects of turbidity would be localized to the drilling platform site. Although the test organisms did not include larval stages of other fish and shellfish, which might be even more sensitive than pink salmon fry, 4 ppm lies at the low end of the range of background levels for existing suspended

solids concentrations in Lower Cook Inlet (0.5 mg/l to 50 mg/l or more; Cline and Feely, RU 512, Quarterly Report, Jul-Sep, 1978).

Maximum discharges of drilling muds occur during spud-in of a well and at completion (280,000 mg/l). Maximum discharges during C.O.S.T. well completion resulted in toxic levels within a few meters of the discharge for periods of up to three hours (Dames and Moore, 1978). It would probably be difficult to demonstrate any adverse effects on biological populations through field measurements during such a short time.

Benthic communities could be destroyed by direct burial by drill cuttings. BLM (1977) estimates that for each exploratory and production well there would be 763 m^3 and 388 m^3, respectively, of drill cuttings disposed of. The long-term effects of this material would depend upon the strength of bottom currents, the dynamics of bottom sediments, and the ability of benthic communities to recolonize the substrate.

In the Lower Cook Inlet C.O.S.T. well, 3,460 barrels of drill cuttings (dry volume) were disposed of (Dames and Moore, 1978). Drill cuttings accumulated near the drilling rig at from 5.5×10^{-3} to 1.25 $g/hr/m^2$. Strong currents and extensive reworking of the sandy bottom prevented accumulation of a mound of material, and by time of completion of the well, drill cuttings were mixed into the sediment to a depth of 8 to 9 cm. Benthic communities, which were dominated by polychaetes and amphipods, were highly variable in their response, but no statistically significant changes in benthic communities were found near the drilling rig.

Interference with commercial fishing activities is of particular concern for Kachemak Bay and Lower Cook Inlet (Trasky et al., 1977). It is one of the major effects of oil exploitation on the Gulf Coast of Louisiana (St. Amant, 1971). Interference includes both competition for dock space, labor, and the loss of gear from drilling platforms.

Gear may be lost from drilling platforms when nets and lines become entangled with the mooring systems of exploratory rigs. The moorings are designed to limit the horizontal displacement of vessels to 10 percent of the water depth. They are composed of chain systems with anchors, wirelines, and dynamic positioning devices. Although this is only a problem when drilling rigs are installed in principal fishing areas, the western portion of the tracts leased in Lower Cook Inlet lies in a section of a major harvest area for King and Tanner Crabs (see Chapter 8). Because of the number of rigs presently projected (see Subtask B.1), interference with fishing will probably be serious in Lower Cook Inlet.

Because of the possibility of entrainment of larval fish and shellfish into drilling rigs (Trasky et al., 1977), one of the environmental stipulations recommended for permits issued for OCS exploratory drilling in Lower Cook Inlet requires operators to draft cooling water from depths of 5 meters from March 15 to September 1. Some drilling rigs use more than 1,000,000 gallons of cooling water per day, with discharge temperatures of -1 to 4° C (EPA, 1977). Problems could arise where drilling is conducted in areas of larval release or in areas of larvae concentration (gyres); it is difficult to assess the effect of this removal on commercial stocks in Lower Cook Inlet. Such an assessment requires a good understanding of population stability, natural mortality rates, and long-term production potential of all commercial stocks in Lower Cook Inlet.

One possible effect of a drilling platform is an improvement in fish habitat by providing surfaces for the attachment of food organisms. Fish appear to concentrate around producing platforms in the Gulf of Mexico, but it is not known whether this is an increase in production or a concentration of existing individuals. Platforms in the Gulf of Mexico provide surfaces to which food organisms may attach and diversify the niche availability there. It is questionable whether installing drilling platforms will improve fish habitat in Lower Cook Inlet, where niche diversity is already quite high.

Shore-Based Facilities

Construction or expansion of shorebased facilities such as tanker terminals, oil treatment facilities, and storage facilities could result in chronic hydrocarbon release during normal operations, acute accidental oil spills during tanker loadings, increase in suspended particles and habitat destruction during dredging, habitat removal by landfills, alteration of current patterns, and alteration of normal beach erosion and deposition patterns.

The water depth required for channels and docking at tanker terminals is 55 to 65 feet, with a 2,300- to 2,800-foot turn-around space (Kramer et al., 1978). This will necessitate dredging and pile-driving. Selection of suitable sites should include consideration whether dredging will be a one-time operation or whether periodic maintenance dredging will be required. The latter possibility poses more hazard to the environment.

Landfills may be required. These may cause removal of habitats, probably the most important factor other than the release of contaminants in the development of shorebased facilities. Every effort should be

made to minimize the permanent destruction of habitat in Lower Cook Inlet.

The alteration of nearshore current patterns should be minimized. Maintenance of an adequate water exchange between docking facilities and the Inlet promotes the dispersal of hydrocarbons released during normal operations and prevents water stagnation with low oxygen concentrations. Alteration in patterns of beach erosion and deposition can result in loss of beach habitat or subtidal and intertidal habitats. All of these potential problems can be prevented by good planning and design.

Pipelines

Turbidity from laying pipeline would probably have little effect on benthic communities. They could be destroyed by removal and burial, however. If the substrate were not changed substantially, recovery might be expected to take place fairly rapidly.

If the total area of Lower Cook Inlet is 3,600 square miles, a hypothetical 200-mile-long pipeline with a disturbance of 25 feet on each side would affect two square miles, or about 0.05 percent of the total bottom area (Becker, LCSM, 1978). Considering that recolonization would be by migration of larvae and motile adults from the undisturbed to the disturbed areas, and that the ratio of boundary to surface area would be high, recovery should be rapid.

The only result of pipeline laying which could have long-term deleterious effects would be the disturbance or destruction of a unique and locally restricted community or habitat. Such an area could recover slowly or not at all. Laying of a pipeline through such an area could also present the risk of oil leaks. To prevent this, the USGS Conservation Divison may require the industry to conduct biological surveys along a proposed pipeline route before a permit to lay the pipeline is issued. These surveys should also identify highly productive or unique habitats associated with landfall areas which should be avoided.

Tanker Routes

The increased movement of tanker and other shipping traffic in Lower Cook Inlet causes problems for commercial fishing operations, especially the crab pot fishery. Where specific shipping lanes have been designated, crab pots can be placed in areas where they are least likely to be struck by a moving vessel. In important fishing grounds, such as Kachemak Bay, where there are no designated shipping lanes, crab pot losses from large ships can be substantial. Losses of crab pots from ships already occur in Kachemak Bay and, without designated shipping lanes, will probably increase as tanker traffic increases. The projected tanker routes in Subtask B.1 are commonly used routes only and are not necessarily designated shipping lanes.

Biological Disturbances, Aircraft and Boat Traffic

Unless precautions are taken, increased aircraft and boat traffic could disturb normal activities of colonial nesting birds and marine mammals. Boats and low-flying aircraft passing close to cliff-nesting birds may cause abandonment of nests, egg losses, and consequent lowered production of young. These effects can be avoided by requiring aircraft or boats to stay at a designated distance from a colony. Since existing bird colonies in Cook Inlet are not near leased tracts, there will probably not be a problem. This is also true of mammal rookeries. As a safeguard, however, one of the nine stipulations attached to each lease sold in Lower Cook Inlet specifies the distances and altitudes of boats and aircraft near bird colonies and mammal rookeries between May and September.

The effect of increased boat traffic on marine mammals such as whales is unknown. Whether whales that frequent Lower Cook Inlet will avoid the area because of increased boat traffic is not known and will be very difficult to ascertain.

Ongoing studies of beluga and bowhead whales in the Mackenzie Estuary indicate that periods of heavy barge traffic can impede whale movements to some extent (Fraker, 1977). In 1976 distribution patterns were changed for periods of a few hours when a barge tow passed up to 1.5 miles away. In 1977, when barge traffic was reduced, whale movements were not restricted (Fraker, 1977).

TASK C GEOLOGICAL HAZARDS TO PETROLEUM EXPLORATION AND DEVELOPMENT IN LOWER COOK INLET

Robert E. Peterson, SAI

RELEVANCE

Modern technological developments have permitted geologists to measure some features of the earth's crust to such a degree that they are confident not only of understanding a certain process, but also, in some cases, of predicting future results of that process. The current hypothesis of plate tectonics is an excellent example. This hypothesis describes the earth's crust as a dynamic system, with new material generated at mid-ocean ridges, transported great distances by sea floor spreading, and consumed at subduction zones and trenches, such as the Aleutian Trench.

The plate tectonics hypothesis helps to explain the occurrence of earthquakes and volcanoes, two primary geological hazards to human activities in many parts of the world. The State of Alaska and its surrounding continental shelf are located in a particularly dynamic region, with the Pacific lithospheric plate being thrust under the North American plate at a rate of about 6 cm/yr. The mechanical grinding of these plates against each other results in earthquakes, and as the Pacific plate descends to deeper (and hotter) regions, the melting of rocks produces magma which rises to the surface to form volcanoes. Present knowledge of crustal dynamics permits scientists to delineate zones of intense earthquake and volcanic activity as part of the plate tectonics model. Significant progress, in terms of a human development time scale, is being made in predicting the rates and intensities of these two geologic phenomena.

Evidence for the destructive potential due to earthquake and volcanic activity occurs regularly; witness the recent earthquake in Tabas, Iran, with the loss of 15,000 lives, and the ash clouds and glowing avalanches generated during recent eruptions of Mt. Augustine in Alaska and Volcano Fuego in Guatemala. The risk in Alaska to large offshore structures, pipelines, and onshore developments pertaining to the petroleum industry is immediate, and the fullest use of recent advances in geology should be made to assess that risk.

Hazards due to tectonic activity are not the only ones resulting from geological processes. Rapid erosion and deposition of seafloor sediments may adversely affect pipelines, for instance, as may slumping and sliding of unstable sediments. Dispersion of sediments in the water column, along the seafloor and along coastlines may be intimately involved with the fate of spilled oil. A thorough understanding of geological processes in an area of anticipated petroleum industry development is essential for full assessment of the effect this development will have on the environment, and of the effects the environment might have on the development.

SUMMARY

The potential geological hazards to petroleum industry development in Lower Cook Inlet are earthquake seismicity, tsunamis, volcanic eruptions, and the migration of sand-sized sediment along the seafloor. Though no active faults have been positively identified on the seafloor of the Inlet, shallow faulting is occurring as demonstrated by the distribution and frequency of shallow earthquakes.

A substantial earthquake record exists for the Lower Cook Inlet region. Data are collected by stations of the Worldwide Standard Seismograph Network and by a local Alaskan network of seismograph stations set up as part of OCSEAP. This local network is particularly important in assessing Lower Cook Inlet seismicity. At present, all earthquakes of magnitude 2 or greater should be detected in the area. Epicenter plots of shallow focus earthquakes (i.e. less than 70 km depth) do not show obvious correlations with geologic structures and faults, except for an increase in shallow seismicity near some volcanoes. The epicenters of deeper focus earthquakes (greater than 70 km depth) reveal a well-defined pattern associated with the Benioff Zone of the subducting Pacific lithospheric plate.

Destructive effects of past earthquakes near Lower Cook Inlet have been due primarily to tsunami (seismic sea wave) generation and resultant damage to harbor facilities. The risk of damage due to ground rupture and ground shaking will increase in direct proportion to the increase in offshore structures, pipelines, and onshore facilities, i.e., damage will be proportional to industrial development in this area of very intense seismic activity.

Augustine Island is an active volcano of the explosive eruption type. Its most recent eruption in 1976 generated violent explosions with large ash clouds, pyroclastic ash flows with nuées ardentes, and lava flows. Hazards to industrial facilities from this volcano include large debris falls, corrosive rains, noxious gas clouds, and seismic seawaves. The distance to which a nuée ardente may travel offshore during a violent eruption is unknown.

The hazards posed by Redoubt volcano are flash floods breaking out of the summit crater as the result of over-accumulation of meltwater. A glacier and the seasonal accumulation of snow are melted by heat from the volcano at the summit crater. Flood waters could reach the Drift River and ultimately pose a risk to the Drift River Tanker Terminal.

Because of vigorous tidal currents in Lower Cook Inlet, bedforms consisting of sand-sized sediment probably migrate along the seafloor. The rates of migration are poorly understood, and research is continuing on that subject. Bedform migration may have serious implications for offshore platform installations and seafloor pipelines. In addition, the geotechnical properties of the sediments (shear strength, porosity and permeability, bearing capacity, and potential for spontaneous liquefaction) remain to be determined. Overly steep or unstable slopes do not appear to be a hazard in Lower Cook Inlet.

Classification of the shoreline around the Inlet into erosional, depositional, or neutral categories, with an "oil spill vulnerability" value assigned to each, indicates that a significant portion of the shoreline, especially the protected bays, are highly susceptible to long-term contamination by accidentally spilled oil.

KEY ISSUES

- Lower Cook Inlet is a region of intense tectonic activity, which results in a high frequency of earthquakes. The possibility exists for a major earthquake occurring sometime during the development and operation of an oil field.
- Volcanism associated with the subduction zone will pose a continuing threat to structures and personnel.
- It is doubtful that earthquakes can be accurately predicted in the near future. However, research shows promise for limited capability to predict impending volcanic eruptions in Lower Cook Inlet.
- The migration of seafloor sediments as bedforms may pose serious problems in the design of offshore offshore drilling platforms and submerged pipelines.
- A significant amount of Lower Cook Inlet coastline is highly vulnerable to long term contamination by pollutant oil, primarily because of the dynamics of coastal sedimentation.

SUBTASK C.1 Seismic and Volcanic Activity

C.1.1 EARTHQUAKE RECORD: HISTORICAL AND INSTRUMENTAL

The historical (or pre-instrumental) earthquake record for Alaska and the Aleutian Islands extends back to 1786 (U.S. Dept. of Commerce, 1973). The earliest documented event occurred near 59.0° N, 154.0° W in the vicinity of Lower Cook Inlet. The historical record is by no means a complete record of seismic activity, since it includes only the larger events which occurred in populated areas. Even in populated areas, numerous earthquakes felt by natives or prospectors may not have been recorded.

During the early 1900's, seismograph stations began producing a record of earthquake activity which was more complete but still limited by unsophisticated instruments, inadequate geographical coverage, and crude calculating procedures. Completion of the Worldwide Standard Seismograph Network (WWSSN) in about 1963 and routine computer processing of earthquake signals have resulted in a fairly complete and accurate record of events.

Meyers et al. (1976) have estimated that the record for earthquakes in Alaska is essentially complete for magnitudes greater than 7 since 1899, for magnitudes greater than 6 since 1928, and for magnitudes greater than 4 since 1964. The seismograph network installed as part of the OCSEAP effort early in 1976 permits collection of a nearly complete record of events greater than magnitude 2 in the vicinity of Cook Inlet and Kodiak Island (Dr. Kienle, Bering Sea - Gulf of Alaska Geological Studies Review Meeting, Menlo Park, CA, Jan. 31 - Feb. 3, 1978).

Figure C.1.1a Epicenter plot of all earthquakes listed on the NOAA/EDS file with magnitudes of 6 or greater, by depth category. Plot produced by NOAA/EDS.

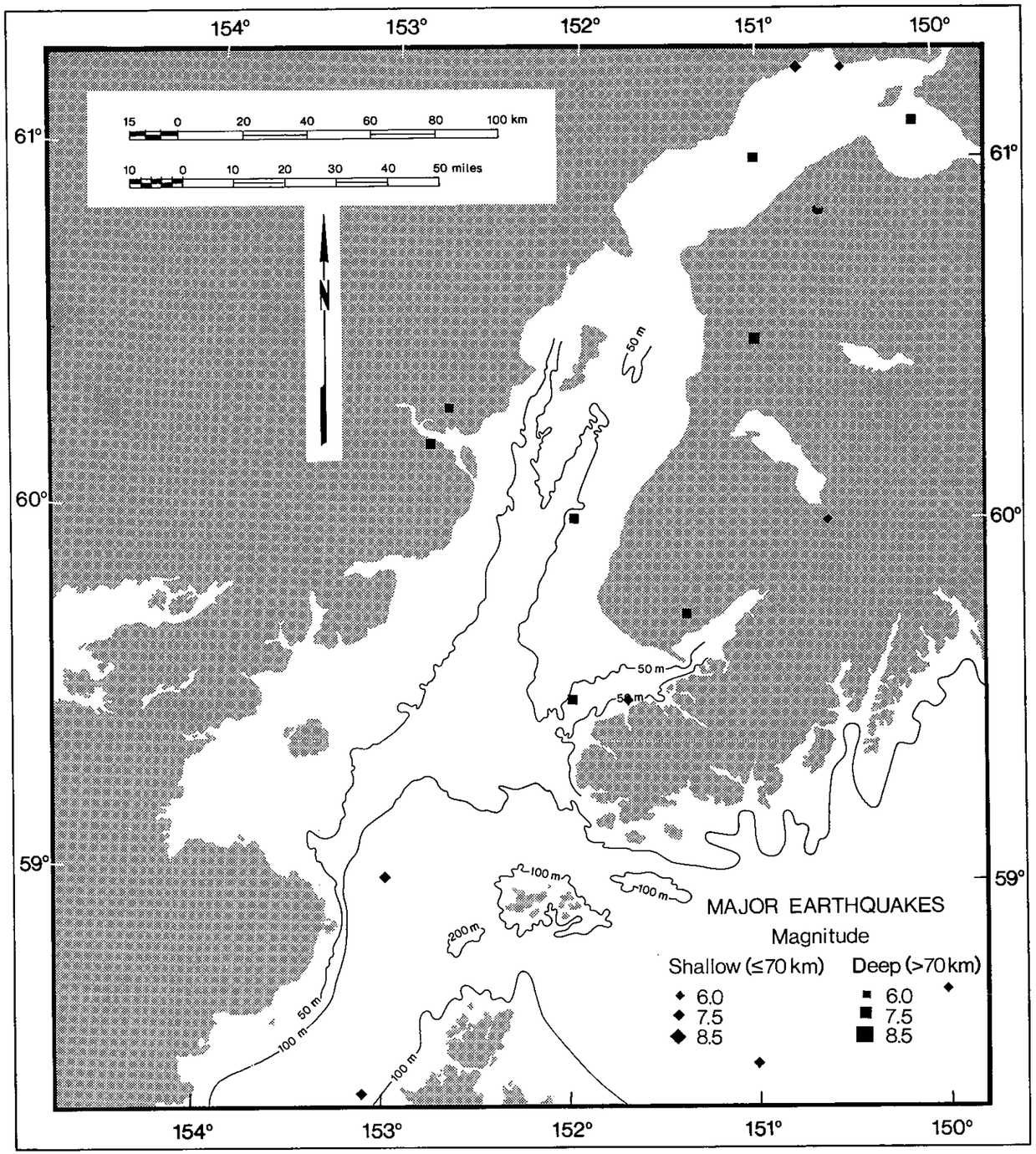


Fig. C.1.1a shows all seismic events of magnitude 6 or greater, or intensity 9 or greater, by depth class. Nearly equal detection capability exists for these larger events throughout the entire time span of the NOAA data file. Fig. C.1.1b is a tabulation and description of the events plotted on Fig. C.1.1a.

Figure C.1.1b List of major earthquakes (magnitude ≥6) recorded in Lower Cook Inlet between 1900 and 1977. Epicenters are plotted in Fig. C.1.1e. Maximum Mercalli intensities associated with the earthquakes are also listed. Data are extracted from NOAA/EDS earthquake file; refer to U.S. Department of Commerce, 1976, for a further description of the file and its data sources.

DATA SOURCE*	YEAR	MO	DAY	HR	MIN	SEC	LAT	LONG	DEPTH (km)	MAGNITUDES			INT MAX
										BODY WAVE	UNSPECIFIED	LOCAL (RICHTER)	
EQR	1909	09	19	20	00	00.0	60.600N	149.270W			7.40		V
G-R	1911	09	22	05	01	24.0	60.500N	149.000W	60		6.90		VIII
G-R	1912	06	07	09	55	54.0	59.000N	153.000W	25		6.40		V
G-R	1912	06	10	16	06	06.0	59.000N	153.000W	25		7.00		
G-R	1931	12	24	03	40	40.0	60.000N	152.000W	100		6.25		IV
G-R	1933	04	27	02	36	04.0	61.250N	150.750W	25		7.00		VII
G-R	1933	06	13	22	19	47.0	61.000N	151.000W	25		6.25		V
G-R	1933	06	19	18	47	43.0	61.250N	150.500W	25		6.00		V
G-R	1934	06	18	09	13	50.0	60.500N	151.000W	80		6.75		V
G-R	1940	10	11	07	53	10.0	59.500N	152.000W	25		6.00		
G-R	1941	07	30	01	51	21.0	61.000N	151.000W			6.25		VI
G-R	1942	12	05	14	28	40.0	59.500N	152.000W	100		6.50		
G-R	1943	11	03	14	32	17.0	61.750N	151.000W	25		7.30		V
G-R	1944	08	14	11	07	23.0	59.000N	155.000W	100		6.25		
G-R	1945	11	03	22	09	03.0	58.500N	151.000W	50		6.75		
G-R	1949	09	27	15	30	45.0	59.750N	149.000W	50		7.00		V
ISS	1951	06	25	16	12	37.0	61.100N	150.100W	128		6.25		V
USE	1954	10	03	11	18	46.0	60.500N	151.000W	100		6.75		VIII
USE	1958	01	24	23	17	29.0	60.000N	152.000W	60		6.50		IV
CGS	1959	04	19	15	03	26.0	58.000N	152.500W			6.25		
ISS	1959	12	26	18	19	08.0	59.740N	151.380W			6.25		
CGS	1961	09	05	11	34	37.3	60.000N	150.600W	43		6.13		VI
CGS	1962	05	10	00	03	40.2	62.000N	150.100W	72		6.00		V
CGS	1963	06	24	04	26	37.9	59.500N	151.700W	52	5.70	6.75		VII
CGS	1964	03	28	04	54	07.0	59.800N	149.400W	25	6.10			
CGS	1964	03	28	06	43	57.4	58.300N	151.300W	25	6.10			
CGS	1964	03	28	07	10	21.4	58.800N	149.500W	20	6.10	6.20		
CGS	1964	03	28	08	33	47.0	58.100N	151.100W	25	5.60	6.50		
CGS	1965	09	04	14	32	46.7	58.200N	152.700W	10	6.20	6.88		
CGS	1965	12	22	19	41	23.1	58.400N	153.100W	51	6.50	6.88		V
USE	1968	04	23	20	29	14.5	58.700N	150.000W	23	6.30	6.13		
CGS	1968	11	15	00	07	09.7	58.326N	150.367W	26	5.10	6.38		
USE	1968	12	17	12	02	15.0	60.200N	152.800W	86	5.90	6.50		VI
USE	1970	01	16	08	05	39.6	60.300N	152.700W	91	5.60	6.00		V
AGS	1975	01	01	03	55	12.9	61.854N	149.483W	60			6.10	

*EQH: Earthquake History of the United States
ISS: International Seismological Summary
CGS: Coast and Geodetic Survey
G-R: Gutenberg and Richter
USE: United States Earthquakes
AGS: Alaskan Geological Survey

Of the three major destructive earthquakes which have occurred in Alaska during the 20th century, one, the Prince Williams Sound earthquake of 1964, caused damage to population centers around Lower Cook Inlet. That earthquake, one of the most violent ever recorded, was studied extensively (National Academy of Sciences, 1972). Damage in Lower Cook Inlet, primarily to port and harbor facilities, was the result of tsunamis caused either by the main shock or by major landslides extending into the waters of the Inlet.

In order to describe the distribution of seismicity in Lower Cook Inlet, plots have been made of the instrumental earthquake record using the earthquake file of the NOAA Environmental Data Services, which includes the earthquake data of the Alaskan network set up under OCSEAP in 1976.

The data file was broken down into several categories. Figures C.1.1c and d are plots of all epicenters since 1964 to be found in the NOAA file, excluding the local Alaskan network data. The year 1964 was chosen for two reasons: first, epicenter locations prior to that time are less reliable, and second, detection of the smaller events is incomplete for the pre-1964 period. By restricting the data in this way, the plots are more representative of the actual distribution of seismicity of various magnitude events (mag. 4 or greater). The separation by depth (above and below 70 km) distinguishes the Benioff zone earthquakes from others.

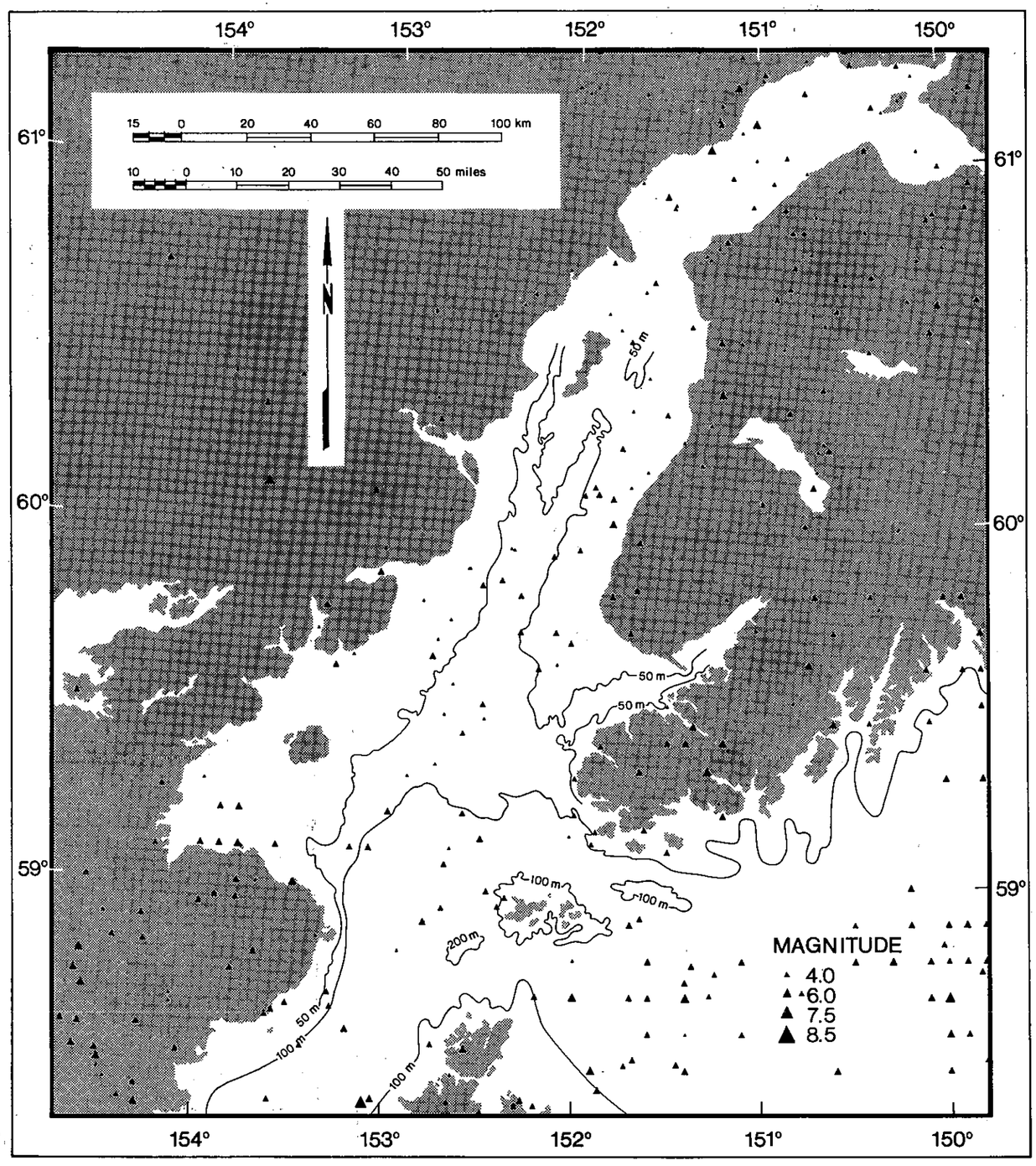


Figure C.1.1c Epicenter plot of all earthquakes since 1964 with focal depths of 70 km or less. Data are from NOAA/EDS earthquake file and do not contain local Alaska network data. Plot produced by NOAA/EDS.

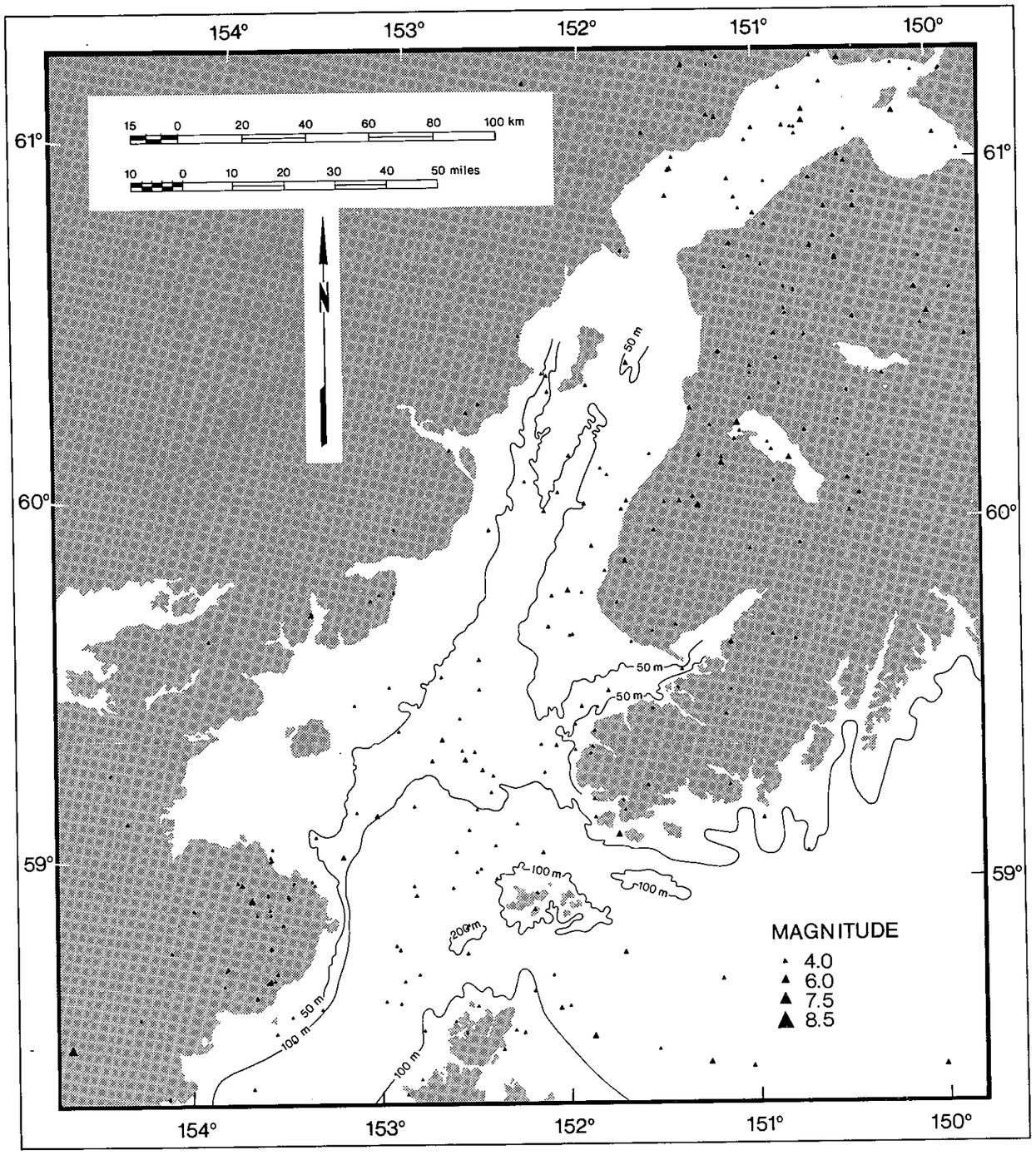


Figure C.1.1d Epicenter plot of all earthquakes since 1964 with focal depths greater than 70 km. Data are from NOAA/EDS earthquake file and do not contain local Alaska network data. Plot produced by NOAA/EDS.

Figures C.1.1e and f show the distribution of shallow and Benioff zone seismicity as detected by the local Alaskan network, which is sensitive to events of much smaller magnitude than those displayed in Figs. C.1.1a and b. Note that the period of observation is considerably shorter for the Alaskan network, which began operating in 1976.

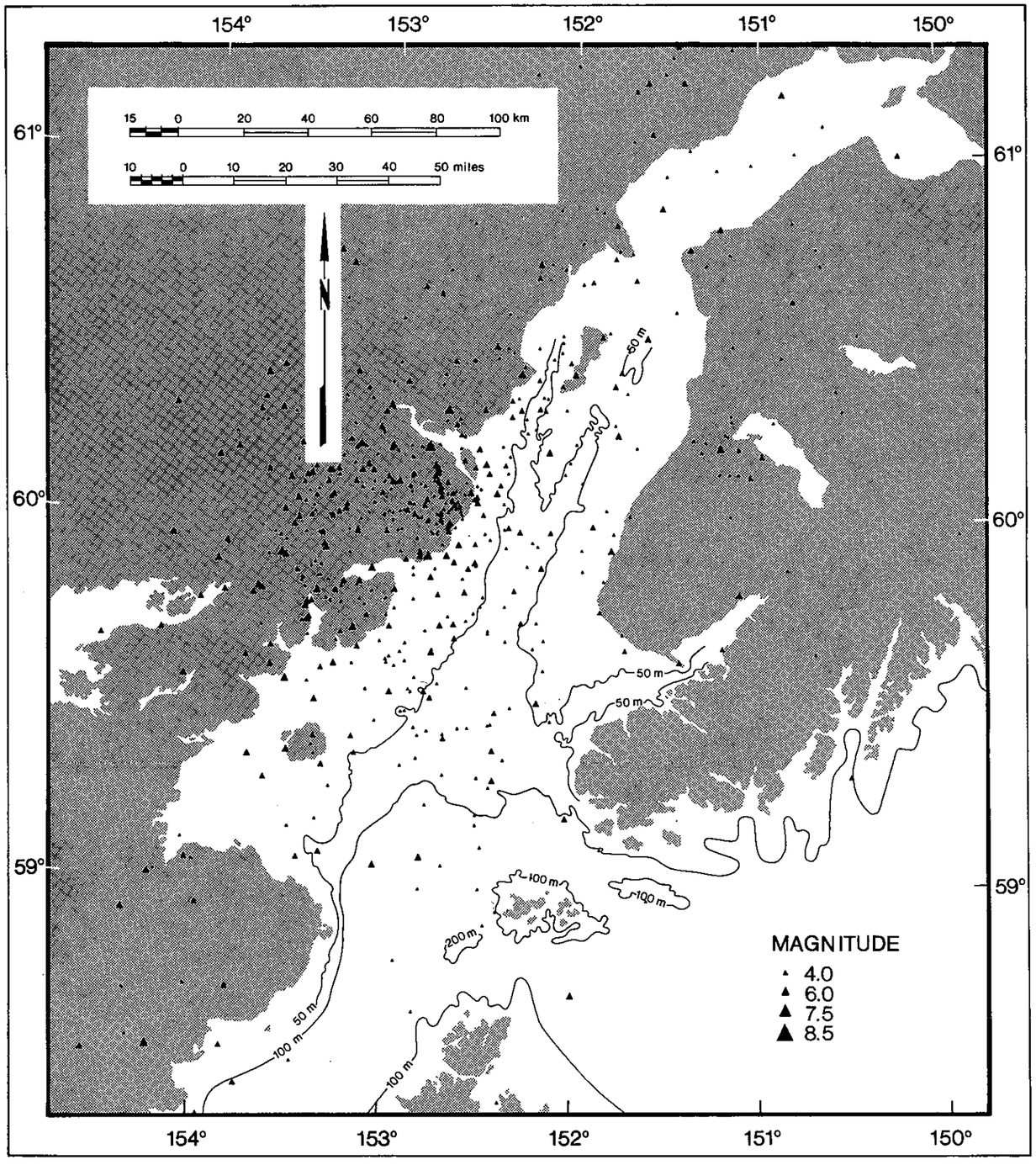


Figure C.1.1e Epicenter plot of all earthquakes with focal depths of 70 km or less. Data are from local Alaska network which began operation in 1976. Plot produced by NOAA/EDS.

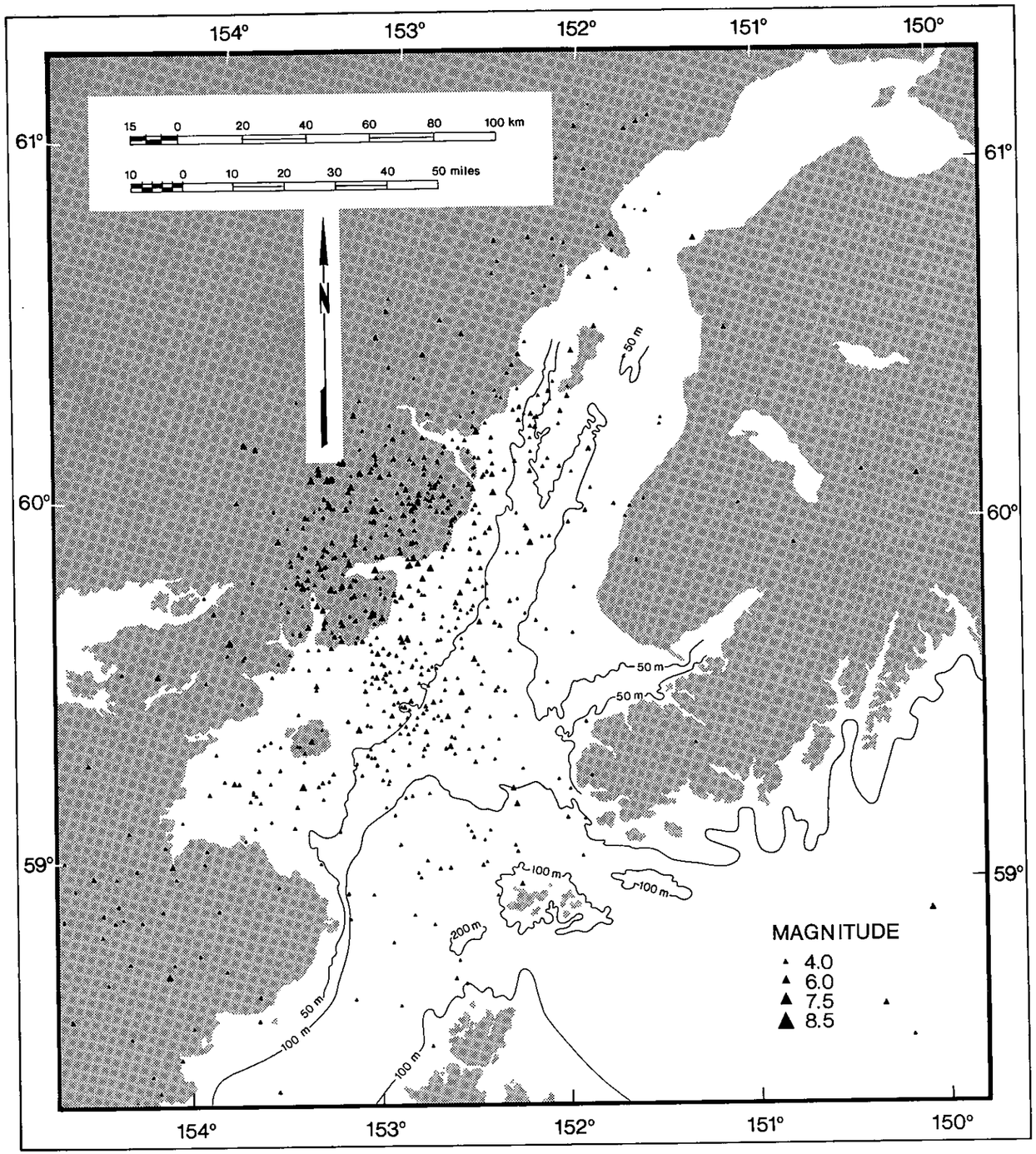


Figure C.1.1f Epicenter plot of all earthquakes with focal depths greater than 70 km. Data are from local Alaska network which began operation in 1976. Plot produced by NOAA/EDS.

C.1.2 EARTHQUAKE RECURRENCE INTERVALS

The analysis of the frequency of occurrence of instrumentally recorded earthquakes is commonly used to estimate earthquake recurrence intervals. A major assumption in this approach is that the physical processes responsible for past earthquakes will not change with time, nor will the rate at which they occur change. This assumption is believed to be valid because geological time scales are so much longer than human time scales.

The frequency distribution of earthquakes as a function of magnitude has been used to describe the recurrence rate of earthquakes. This distribution follows the empirical formula

$$\log N = a - bM$$

where N is the cumulative number of events per year greater than magnitude (M), and a and b are the intercept and slope of the equation when graphed on semi-logarithmic scales. The b value is the rate parameter of interest. It has been shown to vary as a function of geographical region, time depth of focus, type of shock (foreshock, aftershock, etc.), and level of stress in the rocks (see Wyss, 1973, for a further discussion of the physical meaning of b values).

Meyers et al. (1976) have calculated b values for earthquakes of magnitude 4 or greater which occurred within a circle of 75 km radius about points at whole degree increments. Examples of frequency distributions for areas near Lower Cook Inlet are shown in Fig. C.1.2a, and a list of b values for the Inlet region is shown in Fig. C.1.2b. Since many of the source parameters of earthquakes, as described in the preceeding paragraph, were not considered in this analysis, the b values represent an average of the effects of several physical parameters which influence the b value; hence, this data should not be used to estimate the recurrence of specific magnitudes for discrete time intervals.

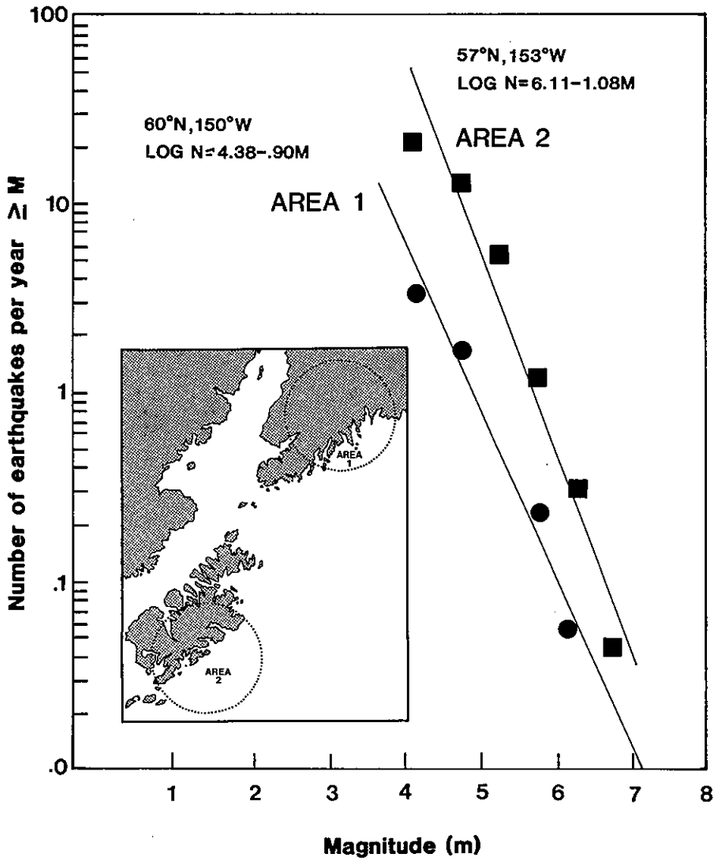


Figure C.1.2a Earthquake recurrence curves for two areas in the vicinity of Lower Cook Inlet (from Meyers et al., 1976).

Figure C.1.2b List of b values of frequency/magnitude relationships for the Lower Cook Inlet region. Earthquake data are from 75 km radius circles about whole degree coordinates. Only magnitudes greater than 4 were included (from Meyers et al., 1976).

GEOGRAPHICAL COORDINATES		Recurrence Curve: INTERCEPT (a value)	Recurrence Curve: SLOPE (b value)
62N	149W	3.54	.77
62N	150W	4.16	.87
62N	151W	4.59	.93
62N	152W	3.73	.77
62N	153W	2.28	.56
61N	149W	2.21	.51
61N	150W	3.62	.74
61N	151W	3.63	.74
61N	152W	4.16	.86
61N	153W	3.95	.90
61N	154W	2.63	.65
60N	149W	4.51	.87
60N	150W	4.38	.90
60N	151W	3.09	.63
60N	152W	4.19	.80
60N	153W	5.19	.99
60N	154W	5.60	1.11
60N	155W	3.36	.81
59N	149W	5.30	1.04
59N	150W	5.09	1.01
59N	151W	4.57	.90
59N	152W	4.12	.83
59N	153W	4.13	.87
59N	154W	4.75	.96
59N	155W	5.19	1.07
58N	149W	4.65	.97
58N	150W	5.64	1.09
58N	151W	5.53	1.03
58N	152W	5.05	.93
58N	153W	4.32	.84
58N	154W	4.29	.84
58N	155W	3.46	.75

In an attempt to assess the small-magnitude detection capability of the Alaskan seismic network set up during the OCSEAP program, a recurrence curve was generated for this report using all recorded events between October 1, 1977, and February 28, 1978 (Fig. C.1.2c). Data values were taken from Pulpan and Kienle (RU #251, Annual Report, 1978).

Two characteristics of this curve may be observed: first, if it is assumed that the cumulative frequency distribution of earthquakes of various magnitudes follows a logarithmic distribution, then the seismic network has probably detected all the events of magnitude 2 or greater in this area, but only some of those smaller than 2. This agrees with the description of the network provided by Dr. Kienle (Bering Sea-Gulf of Alaska Geological Studies Review Meeting, Menlo Park, CA, Jan 31-Feb 3, 1978). He indicated that the detection threshold is about magnitude 1.5 for events inside the network, with some exceptions. The threshold would be somewhat higher for events outside the network. Second, the linear trend of the data points for earthquakes greater than magnitude 2 has a b value of 0.84, which is similar to the values for curves of magnitude 4 and greater shown in Fig. C.1.2b. Hence, the Alaskan network data, which cover a very short observation period, are providing b values similar to the values from the NOAA earthquake file, which spans a much longer period of time. A longer period of observation by the local network is required to determine whether these results are real or coincidental.

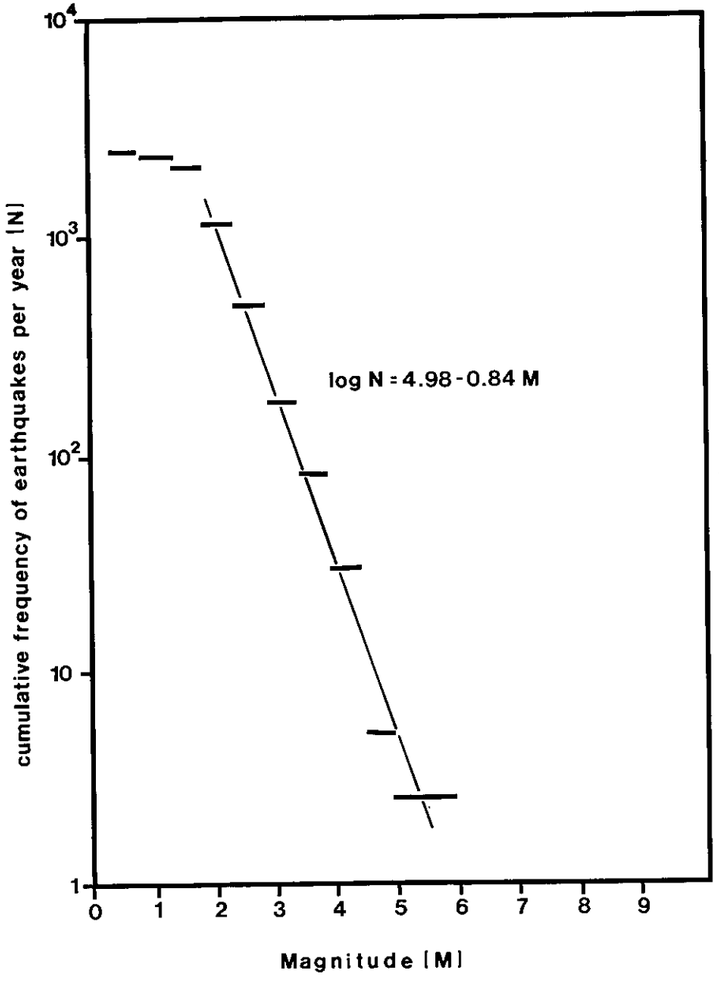


Figure C.1.2c Recurrence curve for Alaskan seismic network earthquakes, 1 October 1977 to 28 February 1978. Regression equation is based only on data points through which the curve is drawn (data from Pulpan and Kienle, RU #251, Annual Report, 1978).

C.1.3 ATTENUATION OF EARTHQUAKE ENERGY

The energy released as elastic shock waves at an earthquake hypocenter is dissipated by geometrical spreading and adsorption by geological formations through which the waves pass. A subjective measure of the degree of attenuation at a distance from the hypocenter is referred to as intensity. It is an evaluation of "felt" effects of the earthquake, i.e., the physical damage and psychological response of the population.

The scale used today in the U.S. to quantify intensity is the Modified Mercalli Scale of 1931 (Wood and Neumann, 1931; Brazee, 1978). Surveys are made in the area experiencing an earthquake, and contours (called isoseismals) are drawn connecting observation points of equal intensity.

Presently, there are no means of assigning intensities to offshore areas. The effects felt at the seafloor surface may be quite different from those on land, due to the differences in geological formations which attenuate the seismic waves near the seafloor surface.

A study by Meyers et al. (1976) of all Alaskan data relating earthquake magnitude to the intensity felt at some distance from the epicenter allows engineers to estimate the effects on potential construction caused by various magnitude events in unpopulated areas, where no intensity data exist. The empirical relationships which Meyers et al. (1976) derived are:

$$I_{max} = 1.2824 + 1.2027\ (M),$$

where I_{max} is the maximum intensity to be expected near the epicenter of a magnitude (M) earthquake, and

$$\ln (D) = 2.347 + 0.368\ (I_{max}),$$

where D is the distance in km from the epicenter to the limit of perceptibility for the felt effects of the earthquake (i.e., intensity about III). These relationships are graphed in Fig. C.1.3a.

One major earthquake in the vicinity of Cook Inlet (the Prince William Sound earthquake of March 27, 1964, which resulted in severe damage to Anchorage) has resulted in enough observations of intensity to allow drafting of an isoseismal map (Fig. C.1.3b). Note that Lower Cook Inlet experienced an intensity of VII, the effects of which would be as follows (Brazee, 1978):

> "Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars."

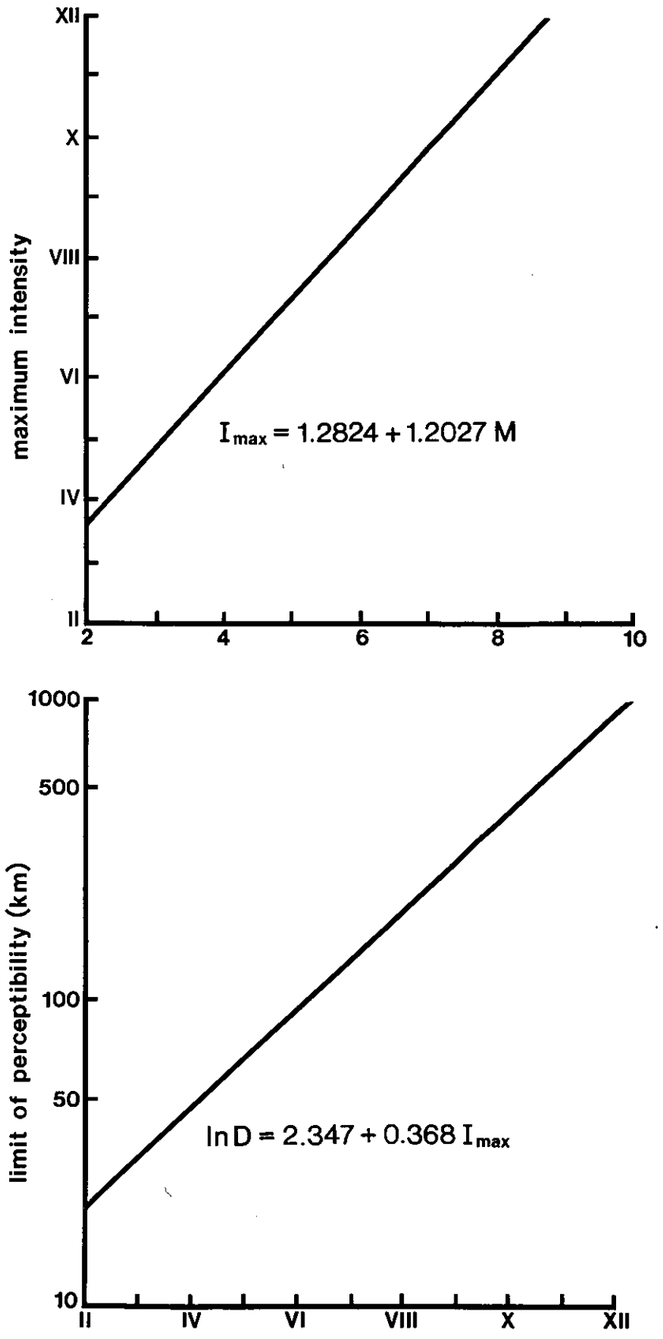


Figure C.1.3a Plots of empirical relationships among magnitude, maximum intensity, and distance to limit of perceptibility of felt effects (equations from Meyers et al., 1976).

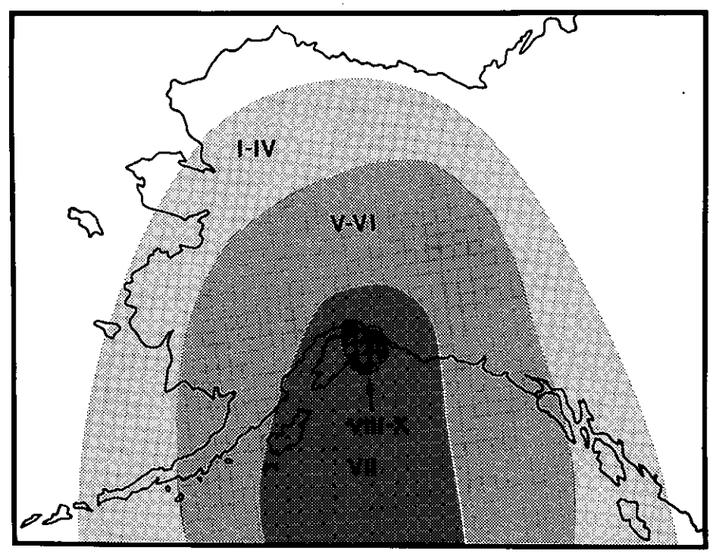


Figure C.1.3b Isoseismal map for 1964 Prince William Sound earthquake (from Meyers et al., RU # 352, April 1976).

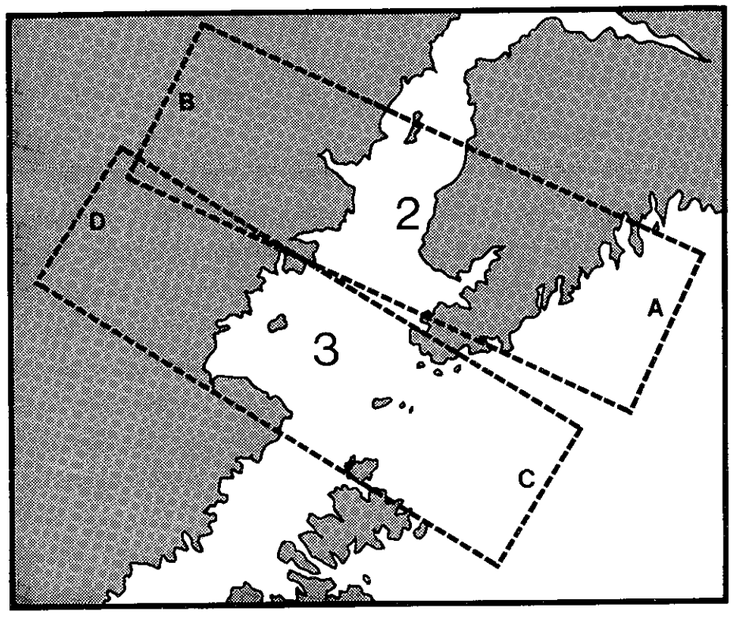
Earthquake-generated seismic waves which pass through the oceans may result in tsunamis, waves which can build to considerable heights as shorelines are approached. As attenuation of seismic energy by seawater is very low relative to geologic formations, tsunamis may travel great distances from their earthquake sources. As they approach shorelines, the speed at which they travel (up to 400 knots) decreases, while their height increases. Damage to shorelines and structures thereon can be considerable.

Cook Inlet has experienced several tsunamis in recent history. Figure C.1.3c lists the towns reporting a tsunami as well as the earthquake thought to be the source.

Figure C.1.3c Tsunamis observed around Lower Cook Inlet (from Cox and Pararas-Carayannis, 1976).

Location	Earthquake or Volcanic Eruption	Remarks
Port Graham, Kenai Pen.	Mt. Augustine eruption Oct. 6, 1883	Height of wave 7.5 to 9 m.
Seldovia, Kenai Pen. Afognak Is.	"Great Alaska Quake" Prince William Sound Mar. 27, 1964 Mag. 8.3	"Great damage to villages and boats." Height of wave 1.2 m at Seldovia, and 6.1 m at Kodiak where damage was described as "disastrous."
Snug Harbor	Peru Oct. 17, 1966 Mag. 7.5	Height of wave 0.1 m; no damage reported; only location in Alaska where noted.

Figure C.1.4a Areas used for projection of hypocenters on to vertical planes. The Benioff Zone is perpendicular to the long sides of the rectangles (from Pulpan and Kienle, RU #251, Annual Report, 1978).



C.1.4 EARTHQUAKES AND GEOLOGIC FAULTS

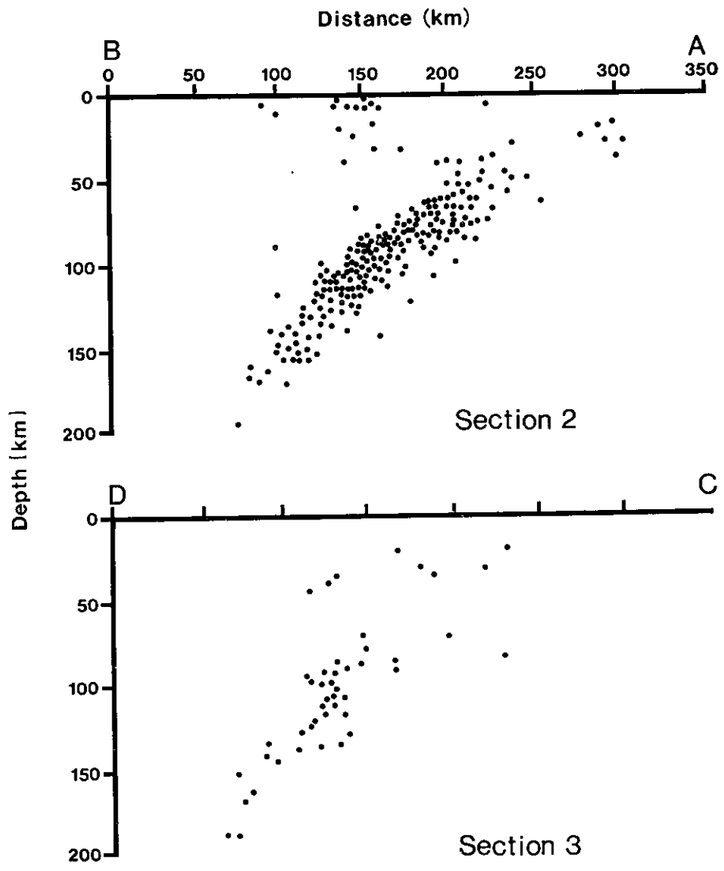
The association of earthquakes and geological faulting is divided into two categories. The first includes deep earthquakes associated with a Benioff zone in an area of crustal subduction and is of somewhat more academic interest than the second. It will, however, serve to provide an appreciation for the tectonic activity of this region. The second association, that of known or inferred surface or near-surface faulting and earthquake epicenters, is of more immediate importance in planning for offshore development by the petroleum industry.

Deep Earthquakes

Pulpan and Kienle (RU #251, Annual Report, 1978) show plots of earthquake epicenters projected onto vertical planes. These cross sections are perpendicular to the Benioff Zone and transect Lower Cook Inlet. They are reproduced in Figs. C.1.4a and b. The Benioff Zone is clearly defined at depths between 50 and 200 km. The thickness of the zone appears to be 30 to 40 km; however, since the Benioff zone curves gently across the sampling band, and since hypocenters are projected along straight lines to a common plane at the middle of the band, the zone appears thicker than it really is. This major geologic fault zone reveals the subduction of the Pacific lithospheric plate under the North American plate. A convergence rate of 5 to 7 cm/yr is estimated for these two plates (Le Pichon, 1968).

Seismicity is not evenly distributed along the Benioff zone. Below Iliamna volcano the Benioff zone activity is particularly intense and was the source area for many larger earthquakes during the past year (Pulpan and Kienle, RU #251, Annual Report, 1978).

Figure C.1.4b Earthquake hypocenters projected on to vertical planes perpendicular to the Benioff Zone. Refer to Fig. C.1.4a for locations of sections (from Pulpan and Kienle, RU #251, Annual Report, 1978).



Shallow Earthquakes

Earthquakes with focal depths less than 50 km have been classed as "shallow" events by Pulpan and Kienle (RU #251, Annual Report, 1978). For the epicenters shown in Figs. C.1.1a-e, a depth of 70 km has been chosen to delineate "shallow" events, to conform to NOAA/EDS convention (U.S. Dept. of Commerce, 1978).

The depth division is somewhat arbitrary, but not totally so, since it is in the depth range 50 to 70 km that the earthquakes associated with the Benioff zone become apparent.

In Lower Cook Inlet, shallow events are distributed fairly uniformly (see Figs. C.1.1a and c), with several exceptions. No preferred association with the mapped major fault systems can be demonstrated, although several linear trends of epicenters are apparent and may be associated with minor surface faulting identified previously (Bouma and Hampton, 1976).

The association of epicenters and surface faulting cannot be interpreted in an absolute sense, primarily because the surface expression of a fault may bear little relation to the fault geometry at depth. Uncertainties in locating the hypocenter of an earthquake -- especially its depth -- add to the difficulties in establishing an association.

Shallow seismicity is associated with active volcanism, notably at Douglas, Augustine, and Iliamna volcanoes (Pulpan and Kienle, RU #251, Annual Report, 1978). Clusters of shallow seismic activity have been observed near Mt. Katmai and Mt. Magiek, located to the southwest of the Lower Cook lease areas. It is postulated that this seismicity is associated with magma chambers under the volcanoes (Pulpan and Kienle, RU #251, Annual Report, 1978).

C.1.5 INTERPRETIVE ASSESSMENT OF EARTHQUAKE RISKS

Earthquakes produce a variety of effects that must be considered in any hazard analysis for a region. A generalized list of effects for Lower Cook Inlet includes the following:

	Effect	Resulting Damage
1)	Ground Shaking	collapse of structures, weakening and future collapse, failure of unstable terrain (landslides), failure of dams (flash floods)
2)	Ground Rupture	water and sewer line failure (contamination of water supplies), gas and oil line failure (fires), electrical line failure (fires, power outages) disruption of transportation lines
3)	Tsunamis	destruction of port facilities and boats
4)	Population trauma	panics, injuries, loss of life, crime (looting)

The proximity of Lower Cook Inlet lease areas to the active subduction zone of the Alaskan margin and its attendant seismicity places the region in a high earthquake risk category. While a quantitative seismic risk analysis is currently underway (Pulpan and Kienle, RU #251, Annual Report, 1978), several semi-quantitative and qualitative comments can now be made.

Recurrence estimates from statistical analyses for the instrumentally recorded earthquakes in the Lower Cook Inlet region (Figs. C.1.2a, b, and e) suggest an event of minimum magnitude between 5.8 and 6.5 every 10 years and an event of minimum magnitude between 6.9 and 8.3 every 100 years.

Very large, destructive earthquakes (magnitude greater than 8) have occurred near Lower Cook Inlet, with the major damage resulting from tsunamis rather than ground shaking. However, since the tectonics of the region suggest the possibility for a very large earthquake to occur anywhere around the western Gulf of Alaska, the risk of damage caused by severe ground shaking around Lower Cook Inlet is indeed present.

The risk of disastrous destruction due to an earthquake during the exploratory phase of oil industry development is probably lower than during the later production and transportation stages. This is because the semi-submersible exploratory drilling rigs (e.g., Wills et al., 1978) are less susceptible to seismic waves than are structures permanently attached to the ground, such as pipelines and tanker terminals.

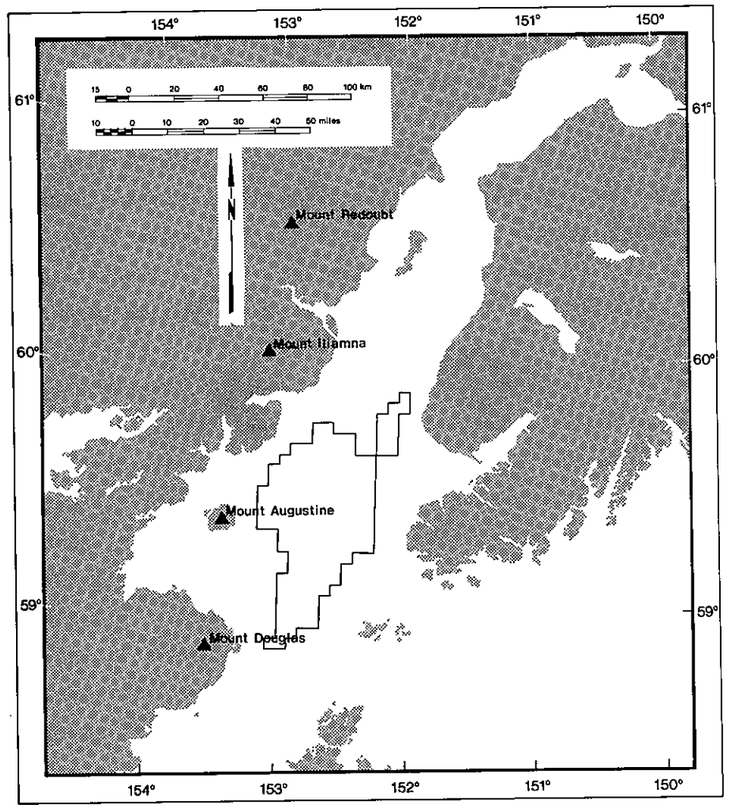
Finally, frequent low magnitude earthquake activity can increase the risk already posed by the unstable ice/mud dams on the Drift River, which are primarily hazards induced by volcanism. Ironically, the low magnitude events seem to be reliable precursors to volcanic eruptions, and their detection by the local Alaskan seismic network thus helps to reduce the hazards of volcanic eruption.

C.1.6 VOLCANIC ACTIVITY

The hazards resulting from volcanic activity in and around Lower Cook Inlet are greater than in other lease areas because of several currently active volcanoes. This volcanic activity is directly related to the subduction of the Pacific lithospheric plate under the North American plate, the tectonic phenomenon which also results in the abundance of earthquakes and the alignment of topographical features in the region.

The volcanoes which deserve study with regard to potential hazards are Augustine, Redoubt, Iliamna, and Douglas (Fig. C.1.6a). Only Douglas has no known recorded activity, with the exception of occasional steam emission. Augustine is the most recently active

Figure C.1.6a Index map for locations of active volcanoes near Lower Cook Inlet.



volcano and is potentially the most hazardous to people and structures in the area. It has received more study than the other volcanoes, in part because of the development of OCSEAP. Figure C.1.6b is a summary of the activity of the Cook Inlet volcanoes.

Scientists at the Geophysical Institute of the University of Alaska had been studying Augustine for 5 years prior to the 1976 eruption and thereby have had the opportunity to describe precursor, eruptive, and posteruptive phases of the eruptive cycle. The significant precursor activity observed was an increase

Figure C.1.6b Lower Cook Inlet volcanoes (from State of Alaska, 1974; Kienle and Forbes, 1976).

Volcano		History of Activity
Augustine	1976	Explosive eruption
	1963-64	Explosive eruption
	1935	Minor eruptions
	1902	Minor eruptions
	1895	Smoke, steam
	1885	Smoke, steam
	1883-84	Explosive eruption which generated a 10-meter tsunami at Port Graham
	1812	Minor eruptions
Redoubt	1966-68	Minor eruptions, explosions at summit caused breach in crater, resulting in flash floods into Drift River Valley
	1933	Smoke, steam
	1918	Smoke, steam
	1902	Minor eruptions
	1778	Minor eruptions
Iliamna	1952-53	Smoke, steam
	1947	Smoke, steam
	1933	Smoke, steam
	1876	Smoke, steam
	1867	Ash eruption
	1786	Smoke, steam
	1778-79	Minor eruption
	1768	Smoke, steam
Douglas		No known historic activity except for intermittent steam emission.

in microearthquakes during the 4 months preceding the eruption (Kienle and Forbes, 1976). Other geophysical measurements, including leveling, gravity, magnetotellurics (conductivity), and earth magnetism, did not point to an impending eruption. An infrared (heat-sensitive) survey did reveal an anomalous temperature increase in a fumarole at which a new crater ultimately formed.

The main eruption began on January 23 and consisted of major explosions and ash falls characteristic of a vent-clearing phase. Pyroclastic ash flows and associated nuées ardentes, and additional explosions continued into early February. Extrusion of lava began about February 12, heralding the decline of explosive activity. A second extrusive phase occurred between April 13 and 18, 1976, and was the last of the major eruptive phases (Kienle and Shaw, 1977). Posteruptive stages at Augustine consist of gas and steam expulsion, and relatively quiet seismicity.

Research on the activity of Redoubt volcano is continuing. It has less potential for the violent, explosive activity exhibited by Augustine. Eruptions of Redoubt have tended to occur within several years following eruptions of Augustine (Pulpan and Kienle, RU #251, Annual Report, 1978), suggesting the existence of a possible common "triggering" mechanism. During its most recent eruptive phase, increased heat at the summit crater caused melting of snow and ice accumulations, which ultimately resulted in flash floods and debris slides moving down the flanks of the mountain into the Drift River. Some of the debris slides formed ice and mud dams on the river.

Iliamna has shown the mildest activity of all the Cook Inlet volcanoes, with the most recent indication of an eruptive phase being the emission of smoke in 1952 and 1953. Fumaroles near the summit are the only evidence of its active nature today (Selkregg, 1974). An area of intense earthquake activity in the Benioff zone (relative to other parts of this zone in the Western Gulf of Alaska) occurs near Iliamna volcano, although the significance of this association is not well understood (Pulpan and Kienle, RU #251, Annual Report, 1978).

C.1.7 INTERPRETIVE ASSESSMENT OF VOLCANIC RISK

The phenomena associated with volcanic eruptions that should be considered in assessing the volcanic hazards in Lower Cook Inlet have been described by Evans et al. (1972). Briefly, they are:

1) Violent, explosive eruptions, resulting in directed blasts, nuées ardentes, large debris falls, and seismically induced effects, such as tsunamis.

2) Hazardous atmospheric phenomena, including turbulent ash clouds, ash falls, corrosive rains, noxious gas clouds, and lightning discharges.

3) Pyroclastic flows, lava flows, and mudslides.

4) Breakout of ice-dammed lakes or summit craters, resulting in flash floods in river valleys.

Most of the above phenomena are possible with eruptions of either Augustine or Redoubt. Pulpan and Kienle (RU #251, Annual Report, 1978) feel that the most immediate threat to offshore structures would be pyroclastic flows from Augustine. Some geophysical evidence suggests that these flows may travel at least 5 km offshore. They are also capable of generating significant seawaves as they enter the sea. Nuées ardentes associated with pyroclastic flows may detach from the pyroclastic flow and travel at high speeds downslope and out across the surface of the Inlet. These clouds pose a grave danger to persons or structures in their paths. At present, the distance they may travel outward from Augustine is uncertain. Large, flying debris from explosions may fall on structures at distances up to 10 km from the volcano.

The hazard posed by Redoubt does not result from violent explosive activity, but rather from the accumulation of water at the summit caused by heating of the glacier ice and snowfall. Breaching of the summit crater resulted in flash flooding of the Drift River in 1966 and the formation of several ice and mud dams on that river (Post and Mayo, 1971). If additional damming occurs due to more mudslides, a large reservoir could form in the Drift River valley. Were that dam then to be breached, it could have dire consequences for anything downstream, such as the Drift River Tanker Terminal.

DATA EVALUATION

The historical earthquake record for the region around Lower Cook Inlet appears to be as complete as is possible, although additional intensity information may still be in old newspapers or other documents in Alaska and the Soviet Union. Data recorded by the recently completed Alaskan network are particularly important in assessing geological hazards, especially the identification of active faults and the recording of precursor activity to volcanic eruptions. The network can detect nearly all events of magnitude 2 and above in the vicinity of Lower Cook Inlet.

The published data on frequency/magnitude relationships (Meyers et al., 1976) are not suitable for estimating recurrence intervals for predictive purposes. More detailed selection of earthquake source parameters is required for b value studies. Proper selection of source parameters in b value analysis may lead to better predictive capability through the identification of foreshock sequences and areas of high stress accumulation.

Data from the local network become increasingly important as the time span during which the network operates increases. Any interruption of its operation during the next few years would be wasteful of the initial investment which started the network.

Strong motion records of large earthquakes are not available for the region. Data of this nature are important in the design of earthquake-resistant structures. Strong motion accelerometers have been installed recently at 3 seismic stations in the Alaskan network (Pulpan and Kienle, RU #251, Annual Report, 1978).

The program to monitor Mt. Augustine volcano in Lower Cook Inlet is now producing data which allow the anticipation of an eruption by perhaps 4 months and researchers feel they are approaching actual prediction capability (Pulpan and Kienle, RU #251, Annual Report, 1978). Information is lacking with regard to the distances to which submarine pyroclastic flows and airborne nuées ardentes may travel offshore during an eruption of Augustine. Aerial photographic surveys of snow volume at the summit of Redoubt will provide information concerning the heat flux from the volcano, which is important for anticipating outbursts of meltwater from the summit crater.

SUBTASK C.2 Surface and Near-Surface Faults

C.2.1 MAPPED FAULTS SURROUNDING LOWER COOK INLET

Lower Cook Inlet is bordered by two NE-SW fault systems: the Bruin Bay Fault on the NW and the Border Ranges Fault on the SE (Fig. C.2.1a). The Bruin Bay Fault is a high-angle reverse fault whose fault plane dips 60° towards the northwest in the vicinity of Kamishak Bay (Magoon et al., 1976); there is evidence suggesting that the stratigraphic displacement may reach 3000 m (Detterman and Hartsock, 1966, cited in Magoon et al., 1976). This fault may have been active during the late Jurassic period (about 150 million years ago) and again about 25 million years ago. The fault forms the western boundary of the region in which petroleum reserves are thought to occur (Magoon et al., 1976).

The Border Ranges Fault, which crosses the Kenai Peninsula and continues southwest through Afognak Island, represents the boundary between the Pacific lithospheric plate and the North American plate (MacKevett and Plafker, 1974, cited in Magoon et al., 1976). The last movement on this fault occurred during the late Mesozoic or early Tertiary, about 65 million years ago (Magoon et al., 1976).

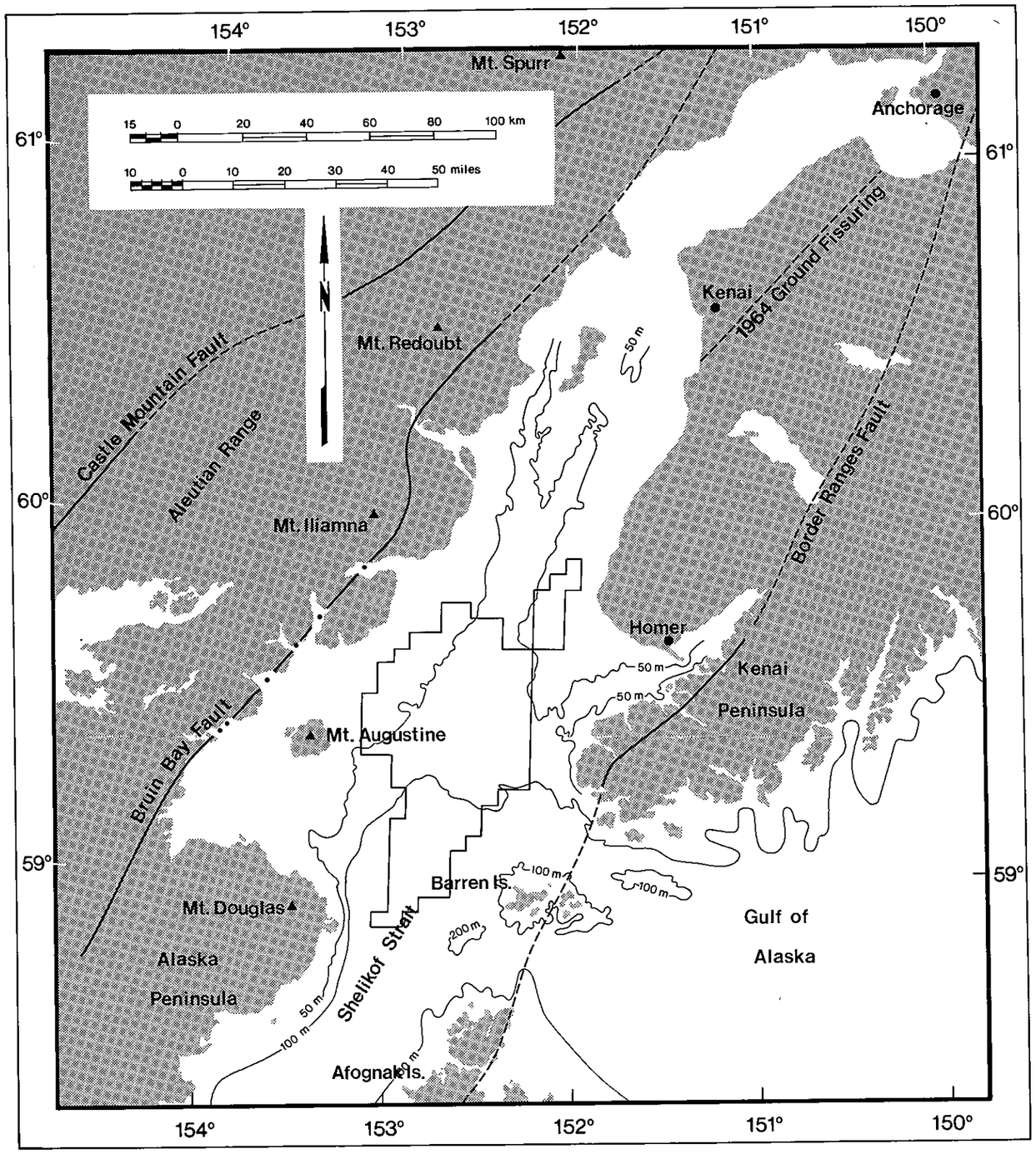


Figure C.2.1a Faults in the vicinity of Lower Cook Inlet (modified from Magoon et al., 1976).

The northern side of Cook Inlet is bordered by the Castle Mountain Fault, along which lineations and offsets in Pleistocene (less than 2 million years old) glacial deposits give evidence of recent movement (Evans et al., 1972). Movement along the fault probably accounts for the numerous small earthquakes in the region.

The 1964 Prince William Sound earthquake resulted in extensive ground fissuring on the Kenai Peninsula. The fissuring lies on a trend which extends to the southwest through Lower Cook Inlet. While there is no direct evidence that an active fault underlies this fissuring, it is a possibility (Foster and Karlstrom, 1967, cited in Magoon et al., 1976).

C.2.2 SEAFLOOR FAULTS INFERRED FROM SEISMIC PROFILING

No significant surface faulting within the lease area of Lower Cook Inlet has yet been identified from seismic reflection studies (Hampton and Bouma, RU #327, Annual Report, 1978). Those investigators note that minor faulting may be present in Lower Cook, but that surface expressions of the faults would be rapidly obliterated by moving seafloor sediment. In a preliminary report on seismic reflection surveys Bouma and Hampton (1976, Plate 5) indicate numerous minor faults, especially on the south and west sides of Augustine Island and between Kenai Peninsula and Shuyak Island, but faults could not be correlated between adjacent tracklines, which were spaced between 8 and 12 km (Hampton and Bouma, RU #327, Annual Report, 1977a).

SUBTASK C.3 Natural Seafloor Instability

C.3.1 BATHYMETRY

The bathymetry of Lower Cook Inlet is shown in Fig. C.3.1a. The northern portion of the lease area has depths generally between 50 and 70 m while the portion south of a line connecting Augustine to the Kenai Peninsula contains a prominent south-facing slope that extends to depths of 150 to 170 m. Southwest of Barren Island, on the Inlet side of the Stevens Entrance, there is a depression with depths exceeding 200 m. The Inlet is divided on a roughly north-south line by an axial trough, or depression, which is particularly obvious between Chinitna Bay and Anchor Point on the north and also east of Augustine, where the trough crosses the aforementioned prominent slope.

The most recent mapping of the bathymetry has been done by Petty-Ray Geophysical Inc. and augmented by the U.S. Geological Survey (Hampton and Bouma, RU #327, Annual Report, 1978). Those investigators are using bathymetry to delineate physiographic units relative to depth zones and bottom features. Refer to Subtask D.7 for additional discussion of the seafloor topography.

C.3.2 THICKNESS OF UNCONSOLIDATED SEDIMENTS

A generalized isopach map of unconsolidated sediments (Fig. C.3.2a) has been constructed from the seismic survey made in 1976 (Hampton and Bouma, RU #327, Quarterly Report, Oct-Dec 1977b). The "thickness" of the unconsolidated sediment is measured from the seafloor down to an angular unconformity which is visible on most of the seismic reflection records. This angular unconformity apparently separates underlying deformed Tertiary rocks from glacially derived unconsolidated sediments deposited during the waning of the last ice age.

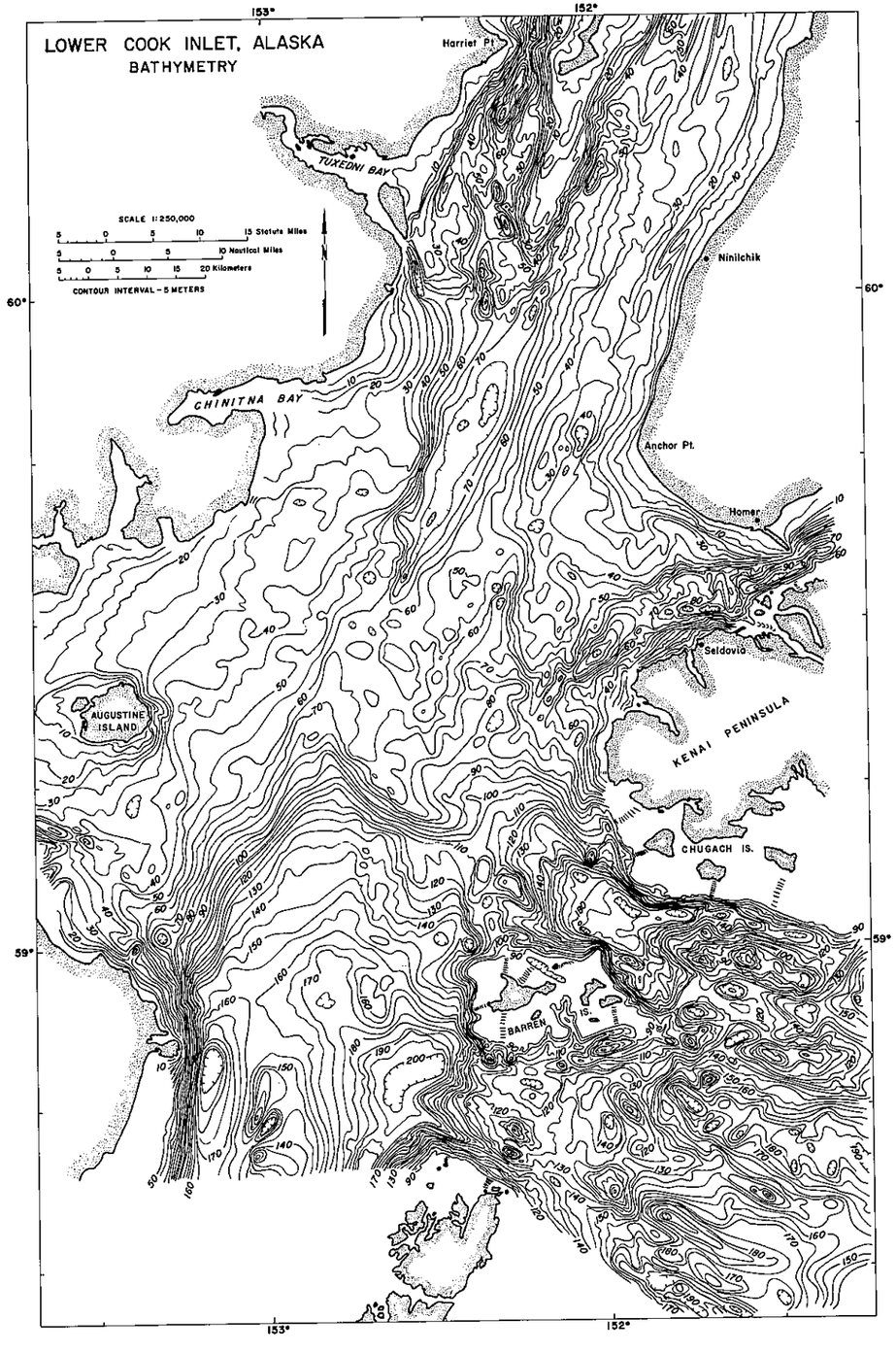
The isopach map (Fig. C.3.2a) is a generalization for the following reasons: first, many small basins and highs (thick and thin areas of sediment) are present but don't appear because of the contour interval selected and second, the thickness is estimated from the travel time required for the seismic energy waves to pass through the sediments. As the wave velocity in sediments is variable, an average value must be assumed for the conversion to thickness. Hence, the contours portrayed on Fig. C.3.2a should be interpreted only as approximate thickness values.

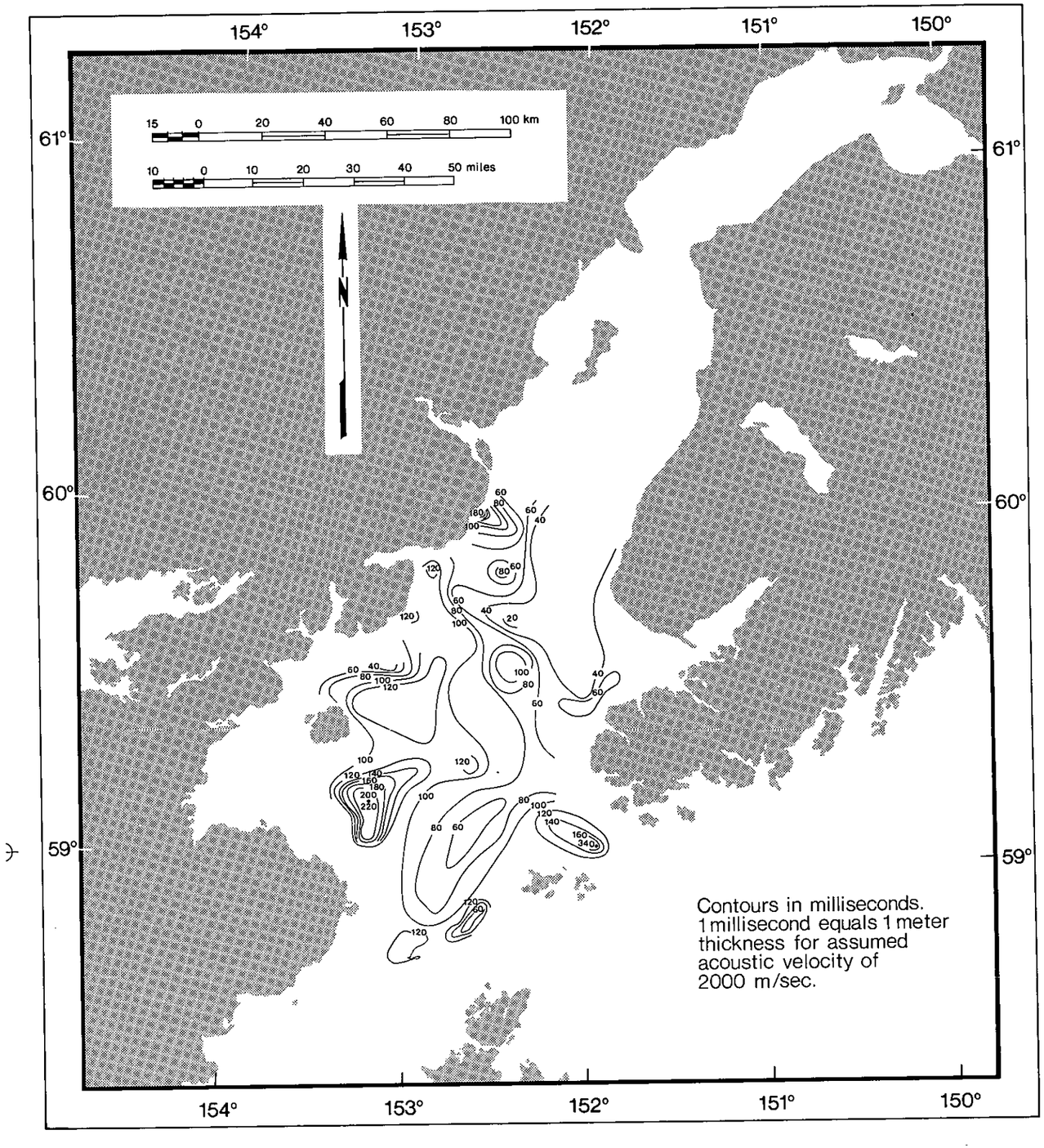
C.3.3 GEOTECHNICAL PROPERTIES OF SEDIMENTS

The sediments of Lower Cook Inlet are gravelly sands with minor amounts of silts and clays (Sharma and Burrell, 1970). They are predominantly reworked glacial sediments from the last major ice advance, and include material supplied currently by rivers, especially fine-grained material such as clay minerals. However, the strong tidal currents and occasional severe storms create an energetic sedimentological environment that precludes the deposition of significant amounts of fine-grained sediments (Hein et al., 1977). These deposits are characterized by good sorting by size and the reworked character of lithic fragments (i.e., rock fragments of varying composition brought in during the last ice age). The sediments were initially deposited under shallower sealevel conditions than exist today (Bouma and Hampton, 1976).

Figure C.3.1a Bathymetry of Lower Cook Inlet (from Hampton and Bouma, RU #327, Annual Report, 1978).

Figure C.3.2a Generalized isopach map of Quaternary sediments in Lower Cook Inlet (from Bouma et al., 1978).


LOWER COOK INLET, ALASKA
BATHYMETRY
153°
152°
60°
59°
Harriet Pt.
TUXEDNI BAY
Ninilchik
CHINITNA BAY
Anchor Pt.
Homer
Seldovia
AUGUSTINE ISLAND
KENAI PENINSULA
CHUGACH IS.
BARREN
SCALE 1:250,000
15 Statute Miles
10 Nautical Miles
20 Kilometers
CONTOUR INTERVAL - 5 METERS


154°
153°
152°
151°
150°
61°
60°
59°
15 0 20 40 60 80 100 km
10 0 10 20 30 40 50 miles
Contours in milliseconds.
1 millisecond equals 1 meter
thickness for assumed
acoustic velocity of
2000 m/sec.

No data are available on the engineering characteristics of the sediments in Lower Cook Inlet. Measurements of sediment shear strength, porosity and permeability, bearing capacity, etc., would be necessary before planning construction of offshore structures. The potential for liquefaction of sediments in response to earthquake-induced ground shaking would have to be studied carefully as well, prior to any offshore construction.

C.3.4 ASSESSMENT OF HAZARDS DUE TO SEAFLOOR INSTABILITY

The risk due to slumping or sliding of seafloor sediment is low in Lower Cook Inlet. No evidence of slope failure having occurred in the past has been observed (Hampton and Bouma, RU #327, Annual Report, 1978).

The risk of sediment load-bearing capacity being exceeded due to spontaneous liquefaction of the sediment must be more fully assessed, especially because of the high level of earthquake activity, which may instigate spontaneous liquefaction.

SUBTASK C.4 Seafloor Erosion & Deposition

C.4.1 AREAS OF INTENSE EROSION AND DEPOSITION

The significance of potential hazards due to intense erosion or deposition has yet to be determined. Sediment transport is occurring within the Inlet, and is directly related to the strength of the currents, which in turn is related to the bathymetry and width of the various parts of the Inlet (Bouma and Hampton, 1976). Those investigators suggest that the surface sediment is a lag deposit, formed under higher energy conditions than exist today, and that little net transport of sediment into or out of the Inlet is presently occurring.

The areas in which there may be a net accumulation of sediment are the bays around the Inlet, such as Tuxedni, Chinitna, and Kachemak. These may be sediment sinks for fine-grained suspended material since currents and waves are weaker in these bays, permitting particulates to settle out of suspension.

C.4.2 LARGE SCALE MOBILE BEDFORMS

There is movement of sand along the bottom of Lower Cook Inlet due to the migration of various bedforms such as sand ripples, sand ribbons, and large sand waves, some of which have heights of 5 to 10 m and wavelengths of 500 to 1000 m (Hampton and Bouma, RU #327, Annual Report, 1978). The migration of these bottom features is primarily due to strong tidal currents, but is also partly due to wind waves during storm conditions. The rate at which the large bedforms migrate may be about 10 cm/day and depends on current velocities. Given the accuracy of modern day navigation equipment, this rate requires that several years of observations of bedform positions be made before trajectories of their movements can be well established (Hampton and Bouma, RU #327, Annual Report, 1978).

A map showing the distribution of bedforms is presented in Fig. C.4.2a. The elongate dimension is generally aligned parallel to the direction of tidal currents, especially in the case of sand ribbons and large sand ridges (Bouma et al., 1977). Frequently, small bedforms will be found superimposed on larger ones, and the two bedforms will indicate opposite directions of current flow. This implies that the time frames of movement for the various sized bedforms may be quite different. For instance, small or medium-sized features may be responding to the daily tidal currents, while some larger features may only respond to major storm activity.

C.4.3 ASSESSMENT OF EROSION, DEPOSITION, AND BEDFORM HAZARDS

Rapid erosion and deposition of sediments may pose hazards to the development of the petroleum industry in Lower Cook Inlet. Once offshore structures are completed, the effects of scouring by strong currents on pilings and pipelines must be monitored. Scouring may lead to a weakening of structural supports and to the fluttering of pipelines, which become suspended due to removal of underlying sediment along portions of the pipeline (Goepfert, 1969).

A potential hazard to some types of submerged equipment may be abrasion caused by high concentrations of suspended material in strong currents impinging on the equipment (Visser, 1969). This could cause the removal of corrosion resistant coatings and electrical insulation.

The migration of bedforms around Lower Cook Inlet can also pose hazards. The effects are again principally on offshore structures and pipelines. In placing pilings into the seafloor, the depth to which they are set should exceed the depth of the migrating material, which may mean sinking pilings as deep as

60 m (Evans et al., 1972; refer to Fig. C.3.2a). Migrating sand waves could also result in the suspension of sections of pipelines that lie on the seafloor, causing severe structural strain (Hampton and Bouma, RU #327, Annual Report, 1978; Goepfert, 1969). This action is distinct from the effects of scouring in that sand waves migrate through an area whether a pipeline is present or not, but scouring action is initiated by turbulence, induced by current flow around the pipeline itself.

DATA EVALUATION

The movement of bedforms in Lower Cook Inlet and the potential for erosion/deposition problems due to the vigorous tidal circulation in the Inlet, have been cited as potentially significant hazards to industrial development (e.g. Bouma et al., 1978b). The current ideas of OCSEAP principal investigators concerning these phenomena do not reflect all the data which have been collected, since some seismic lines run by industry are proprietary. The investigators of RU #327 are attempting to obtain the industrial data, and they intend to collect additional data on bedform migrations during the 1978 and 1979 field seasons (Hampton and Bouma, RU #327, Annual Report, 1978).

Complementary data were collected by the investigators of RU #430 during the 1978 field season through the use of GEOPROBE tripods resting on the seafloor (Cacchione and Drake, RU #430, Quarterly Report, Apr-Jun, 1978). These instrument systems record oceanographic parameters such as currents, salinity, temperature, and light transmission for periods of days, weeks or months, as desired.

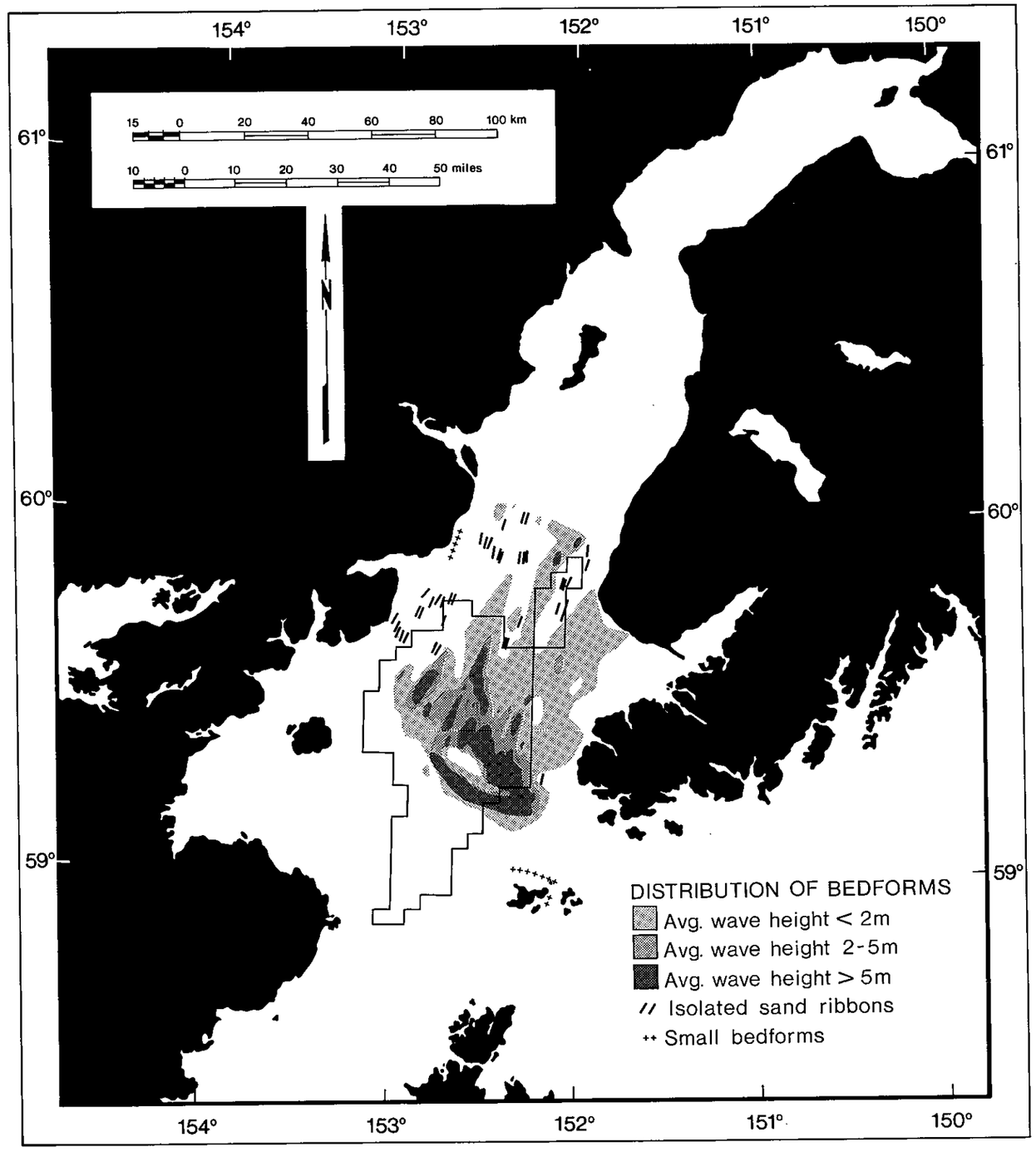


Figure C.4.2a Distribution of bedforms in Lower Cook Inlet (modified from Hampton and Bouma, RU #327, Annual Report, 1978).

SUBTASK C.5 Coastline Sediment Dynamics

C.5.1 DESCRIPTION OF THE COASTAL ZONE

The beaches and nearshore zones of Lower Cook Inlet are not currently being investigated by an OCSEAP research unit. The Alaskan Department of Fish and Game, however, has supported research in this area in response to potential petroleum industry development. Most of the present knowledge concerning the dynamics of nearshore and beach sedimentation comes from that research effort and is summarized in this section (Hayes et al., 1976).

The coastline is characterized by "ria" morphology, with numerous narrow, funnel-shaped bays extending into the land, similar to the fiords of the Norwegian coast but less pronounced. Chinitna, Tuxedni, and Port Graham Bays are examples of ria morphology. Many of these bays have complex intertidal zones with extensive mudflats and salt marshes. Other coastline features include wave-cut beaches and scarps in glacial till deposits and bedrock, and depositional features such as deltas and sand spits.

Hayes and co-workers have classified about 1200 km of Lower Cook Inlet coastline into erosional (45 percent), neutral or stable (38 percent), or depositional (17 percent) areas (Hayes et al., 1976, Table 4; Fig. E.8.1b). They have further subdivided these generalized classifications into 16 specific morphological descriptions.

C.5.2 HAZARDS ASSOCIATED WITH COASTAL SEDIMENT DYNAMICS

From the literature presently available, no areas of severe erosion or deposition have been identified around the shoreline of Lower Cook Inlet. However, sediment transport does occur in various areas along the coastline, and, if construction sites are planned for those areas, site-specific studies of the resulting influence on sediment dynamics will be required.

Identifying areas of sediment erosion and deposition is critical for predicting the effects of oil spills, as sediment dynamics will strongly influence the residence time of pollutant oil along the coasts and in the bays.

Based on the effects of actual oil spills on similar coastal features in other areas, Hayes et al. (1976) derived an "oil spill vulnerability" index. This index is basically a longevity scale for spilled oil and does not include chemical or biological weathering effects. Lower Cook Inlet is considered to be a high-risk area since many parts of its shoreline have a high susceptibility rating. Figure C.5.2a lists the percentages of various classes of shoreline and their associated oil spill vulnerability risk, and Fig. E.8.1c shows the distribution of highly vulnerable areas.

Figure C.5.2a Oil spill vulnerability of various coastal types in Lower Cook Inlet (from Michel et al., 1978).

Coastal Type	Percent Shoreline	Discussion	Vulnerability Index (1-10)
A1a High rock scarps	8	Oil easily removed by wave erosion; some problems in gravel beach areas	1-2
A1b Low rock scarps	28	Generally low-risk area except where depositional berms exist; gravel and boulder low-tide terraces subject to long-term oil residuals; burial possible on beach faces	2-4
A1c Scarps on dip slopes	5	Same as A1a	1-2
A2a-b Scarps in glacial and deltaic deposits	4	Same as A1b	2-4
B1a-b Embayed shorelines	38	Long-term oil spill damage due to low wave energy; fewer problems at mouth than at head of embayment where salt marshes are present	8-10
C1a Lobate fan deltas	1.5	Low wave energy and coarse grain size would allow oil to remain for years; fresh-water plume could keep oil off delta during spring runoff	6-8
C1b Arcuate-cuspate fan deltas	6	Oil eroded in 6 mos. to year; penetration and burial possible; if buried, would remain longer	4-6
C1c Arcuate-cuspate asymmetrical fan deltas	1	Lower wave energy than C1b; coarse grain size increase oil residence time (1½ years in Chile)	6-8
C2a-d Spits	5.4	Mostly mixed sand and gravel beaches; 6 mos. to year residence time; penetration and burial very possible	4-6
C3a Bayhead beach-ridge plains	2	Longevity variable depending on composition of beaches; gravel beaches more susceptible than sand; oil accumulates here	4-6
C3b Tide-dominated bayhead systems	1	Very sensitive area due to broad expanse of salt marsh and tidal flats; lower intertidal areas would be flushed by tidal currents; oil may not enter if fresh-water run-off high	8-10

TASK D TRANSPORT AND ALTERATION OF CONTAMINANT DISCHARGES

Edwin J.C. Sobey, SAI

RELEVANCE

The most significant question about a potential oil spill is the areal extent of the oil after a given period of time. In the marine environment many forces contribute to the movement of oil, and accurate predictions of trajectories are thus difficult.

Oil can be distributed by several means or combinations of means. Winds and currents are the primary advective transporters of oil which is floating on the surface. Oil which is incorporated into ice floes and aggregates of suspended matter follows trajectories quite different from those controlled by winds or currents. In nearshore regions, the transport of oil is even more difficult to forecast because of the complex interactions of waves, beach sediment dynamics, and recontamination from land surfaces.

SUMMARY

The surface circulation in Lower Cook Inlet is characterized by an influx of Gulf of Alaska seawater through Kennedy Entrance, a meeting and mixing of this flow in the central Inlet with a relatively fresh and turbid outflow from Upper Cook Inlet, a southerly flow of the mixture along the western side of the Inlet, and outflow from Lower Cook through Shelikof Strait. This circulation pattern can be termed a counterclockwise gyre, with significant northward and westward transport. Several secondary gyres occur in the larger bays such as Kamishak and Kachemak.

Surface circulation in Lower Cook has two other important features. The first is upwelling along the southwest tip of Kenai Peninsula; the upwelled water enters Kachemak Bay and promotes high productivity in the waters of the outer bay. The second feature is convergence, or frontal zones, which form as Gulf of Alaska water encounters freshwater outflow from the upper inlet. These zones, termed "rips," are locations of debris and pollutant accumulation; debris has been observed to remain in the rips for weeks.

During spring and summer, Gulf of Alaska seawater travels as far north as the latitude of Ninilchik before it turns west and mixes with Upper Inlet outflow. Seawater characteristics north of that latitude are the result of tidal mixing. During the fall, Gulf of Alaska water travels farther to the north, perhaps as far as the North Forelands, due to the decrease in outflow from the Upper Inlet. Hence, surface circulation is influenced to a great degree by the seasonally varying outflow of freshwater from the Upper Inlet.

The main driving forces for surface circulation are the tides, which are semi-diurnal with high tides of unequal height each day. Typical ranges between successive high and low waters are from 12 to 18 feet, with wider ranges in the upper reaches of the Inlet, and along the eastern side (due to the Coriolis effect). Tidal currents of 2 to 3 knots have been measured at Kennedy Entrance, and 8 knots at the Forelands. Ebb velocities are greater than those of flood because of augmentation by net outflow from the Upper Inlet.

Temperature, salinity, and density distributions vary seasonally, and are strongly influenced by variations in freshwater outflow and by seasonal changes in the winds. Surface salinities in Lower Cook range from 26 to 32 ^{o}/oo, varying with location and season.

Studies using surface drifters and radar-tracked drogues in Lower Cook Inlet supply supporting evidence for the circulation patterns. Some moored current meter data which have been collected reveal the dominant influence of the tides and also of some current events with periodicities of 3 to 4 days.

The circulation in Kachemak Bay is fairly well known. The outer bay has a pair of counter-rotating gyres with surface velocities of up to 1/5 knot. Very high biological productivity occurs in these gyres because of the intrusion of upwelled, nutrient-rich water originating along the southwest tip of Kenai Peninsula. The inner bay has a pair of counterclockwise gyres; mixing of intruding seawater (along the bottom) and surface freshwater runoff occurs in the inner bay.

Limited results obtained from oil spill trajectory models suggest that buoyant material (floating oil) released in central Lower Cook will either accumulate along the western side of the inlet or be transported out of the inlet via Shelikof Strait. The deep circulation is too poorly known to use in predicting trajectories for non-buoyant pollutants.

Preliminary results from experiments conducted to determine the accommodation capacity of suspended matter in Cook Inlet indicate that the capacity increases with increasing initial oil concentration and with decreasing temperature. Aggregates of oil and suspended matter tend to be spherical and larger than naturally-occurring particles. The size distribution of suspended matter does not change during the formation of oil/suspended matter aggregates, although the median size increases. Oil/suspended matter aggregates could settle at higher rates than naturally-occurring suspended matter in Lower Cook Inlet.

The north-northwest winds of winter together with

the net surface circulation pattern cause the transport of ice from Upper Cook Inlet southward along the western coast. The ice forms on the mud flats in Upper Cook Inlet and eventually moves to the deeper waters of Lower Cook Inlet. Sediments are incorporated into the ice which forms on the mud flats, and these floes are a source of some of the suspended matter observed along the western side of Lower Cook Inlet. The ice often accumulates in Kamishak Bay. Ice floes up to 320 m across and up to 12 m thick have been observed; these are large enough to be hazards.

KEY CONSIDERATIONS

- Few data exist on the distribution and transport of sea ice in Cook Inlet. Ice may be a major transporter of sediments and spilled oil. It influences the distribution of sea birds by limiting the open water available to them and scours intertidal zones, disrupting attached plants and benthic organisms. Floes can be hazards to ships or structures in Cook Inlet.

- The limited wind data collected over water in Lower Cook Inlet suggest that offshore observations differ from those made at adjacent land sites. Additional data are needed to compare with large-scale meteorological conditions to ascertain how local winds are modified and to determine the influence of local winds on the surface circulation.

- Upwelling occurs in Lower Cook Inlet. Since this process is important in supplying nutrients to primary producers, further study is imperative.

- Spilled oil and other contaminants are likely to accumulate along the western coast from Tuxedni Bay to Ursus Cove and temporarily along rips. Some transport out of the Inlet through Shelikof Strait is likely.

- The general pattern of summer circulation is fairly well understood. However, the variability and intensity of its major features and the nature and location of minor features need to be determined.

- Winter data on the circulation of Lower Cook Inlet are not available, and thus seasonal variations in the circulation patterns are not known.

SUBTASK D.1 Offshore Circulation Patterns and Water Masses

D.1.1 GENERAL DESCRIPTION OF CIRCULATION

General descriptions of the circulation pattern and water masses of Lower Cook Inlet were made by Burbank (1977) and ADF&G (1978b). The following information is from Burbank (1977) unless otherwise stated.

The net surface circulation in Lower Cook Inlet (Fig. D.1.1a) is representative of conditions to be expected during spring and summer, when winds are moderate and from the south and freshwater runoff is high. Gulf of Alaska seawater enters Lower Cook Inlet through Kennedy Entrance and flows north and northwestward. Along the southwestern coastline of the Kenai Peninsula (northwest of the Chugach Islands) the flow diverges, causing coastal upwelling. This nutrient-rich water flows along the coastline and into outer Kachemak Bay; its circulation is discussed in Subtask D.2.

The main surface flow of Gulf of Alaska water continues north past Kachemak Bay to Anchor Point, where it turns westward due to the topography of the seafloor. A part of this flow is diverted strongly to the west, while the remainder continues north and northwestward to the latitude of Ninilchik. Here it mixes with a strong surface outflow from Upper Cook Inlet, and is then diverted to the west.

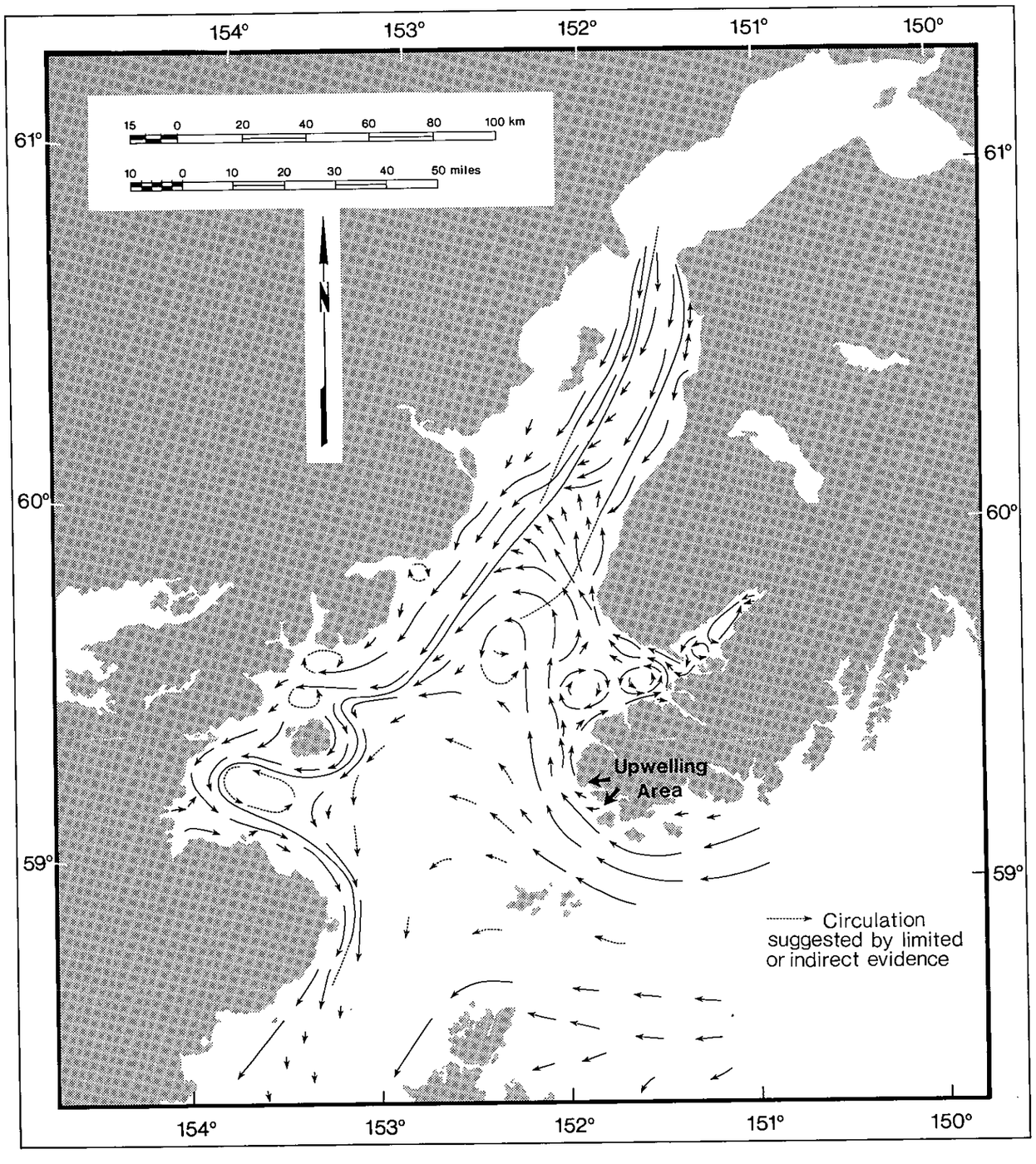


Figure D.1.1a Net surface circulation in Lower Cook Inlet, based primarily on data collected during the spring and summer (Burbank, 1977).

About mid-channel, at the latitude of Ninilchik, the westward flow meets the strong southerly flow of turbid water of relatively low salinity from Upper Cook Inlet. This convergence produces a frontal zone known as the Mid-Channel Rip (Fig. D.1.1b), which is clearly revealed by the accumulation of floating debris. Since some westward transport of surface water occurs across nearly all of Lower Cook Inlet, the Mid-Channel Rip also extends the length of the Inlet. A second, less intense convergence zone (East Rip) occurs on the east side of the Inlet. The convergence along these frontal zones is strongest during flood tide, as the northward intrusion of seawater forces itself between the major outflow of Upper Inlet water on the west and the smaller outflow on the east; convergence is most dynamic on the Mid-Channel Rip, however, and has the greatest significance for Lower Cook circulation. A third frontal zone, the West Rip, is present east of Kalgin Island, between the Mid-Channel Rip and the island (Fig. D.1.1b).

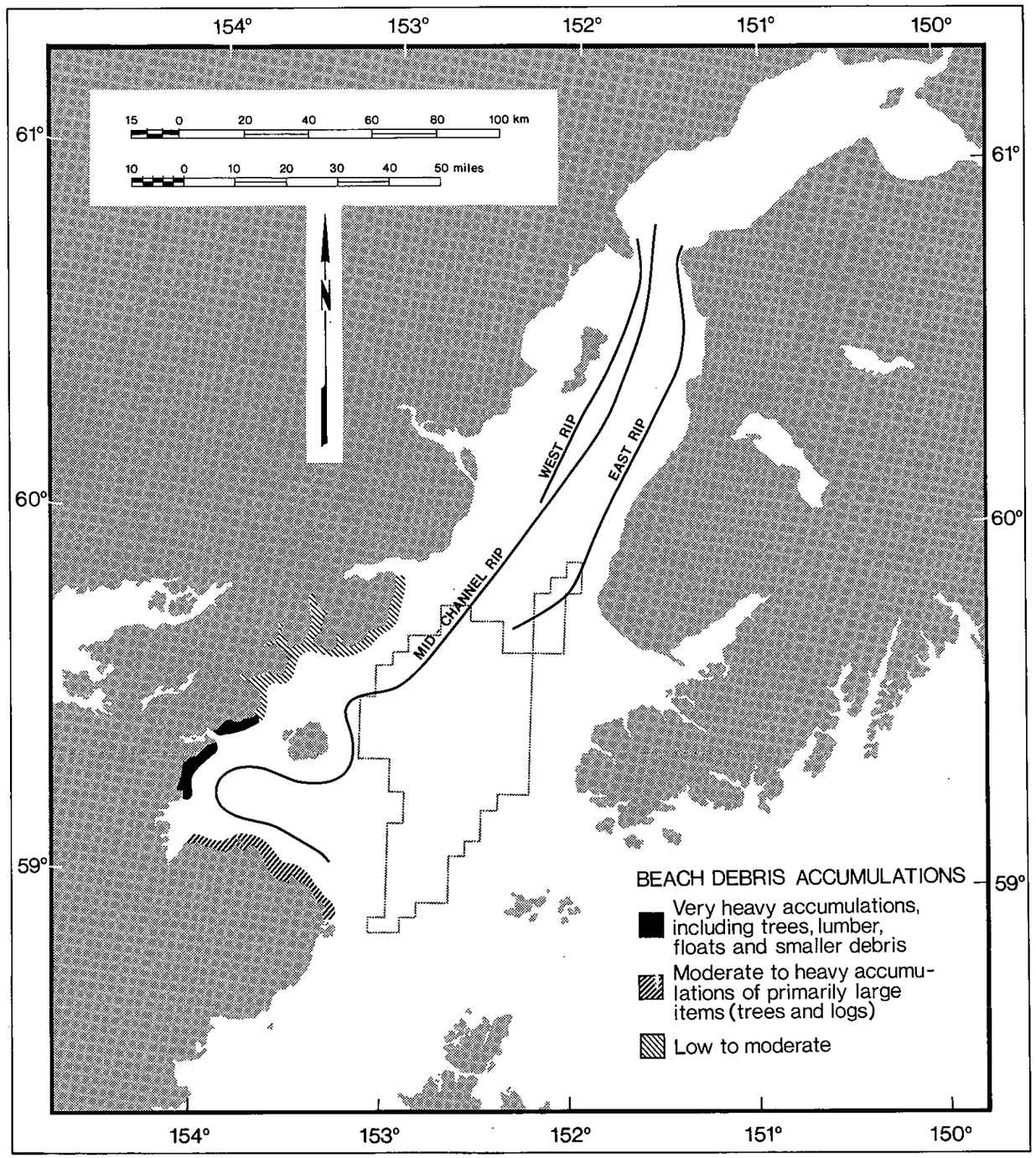


Figure D.1.1b Debris accumulations in Central Lower Cook Inlet and coastal areas of the Kamishak Bay region. The survey is preliminary and based on limited data (Burbank, 1977).

The inflowing surface seawater descends under the less dense outflow of Upper Inlet water at the convergence zones, as revealed by a salinity cross section of the Inlet along 60°N (Fig. D.1.1c). Seawater that flows below the outflowing Upper Inlet water comes to the surface on the western side of Kalgin Island Shoal (Burbank, 1974; Gatto, 1976).

Contrasting current directions and velocities on either side cause considerable horizontal shear along these convergence zones. The tidal currents on the east side of the Mid-Channel Rip are strongest during flood, and those on the west during ebb (Wright, 1974). The ebb flow is probably augmented by the mean flow out of the Upper Inlet.

Analyses of distribution patterns of temperature, salinity, and suspended load suggest that the net northward transport of Gulf of Alaska seawater does not extend past the latitude of Ninilchik during summer. The seawater characteristics observed north of this latitude result from progressive mixing by tidal action. As the northward extent of seawater characteristics is controlled by the volume of freshwater runoff added to the upper inlet, the extent varies seasonally. Figure D.1.1d is probably typical of the northern intrusion of seawater during the fall, when freshwater runoff is minimal.

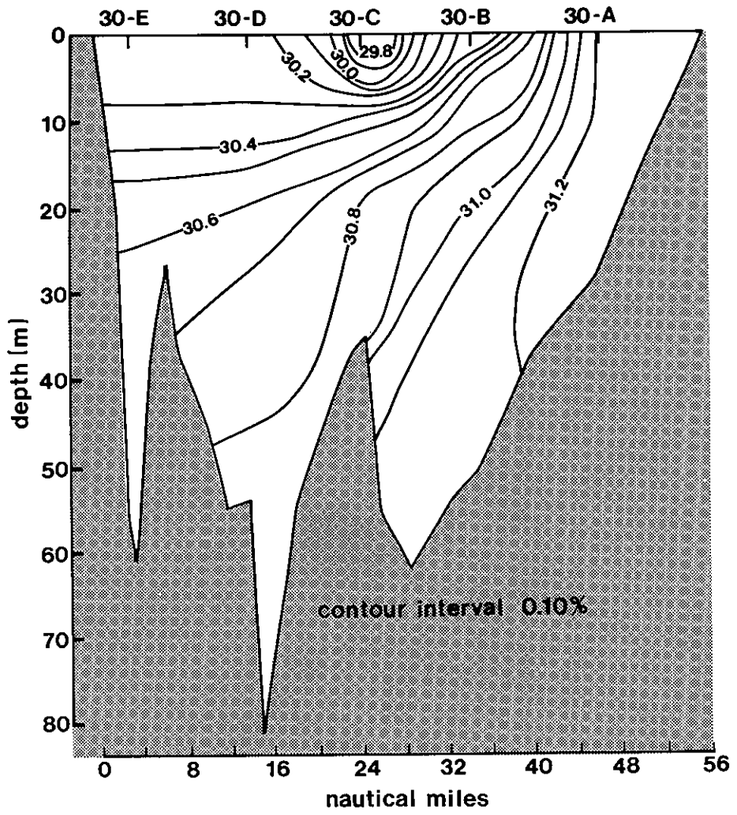


Figure D.1.1c Salinity profile along hydrographic line across Lower Cook Inlet near Ninilchik. Data is from R/V Acona cruise 065, 21 to 29 May 1968 (after Kinney et al., 1970; Burbank, 1977).

Intense mixing of seawater and turbid Upper Inlet outflow occurs along the Mid-Channel Rip between the latitudes of Anchor Point and Kasilof. This mixture is now carried south along the western side of Lower Cook Inlet past Augustine Island and across Kamishak Bay. After mixing, the salinity of the main flow has been reduced from 32 °/oo (Gulf of Alaska seawater) to 28-29 °/oo, and the suspended load increased from about 2 mg/l to 10-20 mg/l. Circulation to the east of Kamishak Bay is poorly known, but it appears to be sluggish, with some net transport of surface water to the west.

After passing Kamishak Bay, the flow continues into Shelikof Strait, where it remains primarily on the western side. (Gulf of Alaska seawater which has entered Lower Cook through Stevenson Entrance flows south along the eastern side of Shelikof Strait, and a mid-channel rip has been observed there as well.) The flow then exits the Strait and is dispersed offshore.

Circulation during seasons other than spring and summer is not well-documented. During the fall (Fig. D.1.1d) the circulation pattern south of Anchor Point is basically the same; however, some differences occur north of Anchor Point because of more northerly winds and reduced outflow from the Upper Inlet.

Seasonal variability in the freshwater contribution to the Inlet from precipitation and melting of snow and ice, in the transport by the Alaska Stream, and in meteorological conditions will all affect the circulation patterns in Lower Cook Inlet. It is likely that the general features of the circulation are similar throughout the year, but that current velocities, net transport, and exact positions of flow vary somewhat.

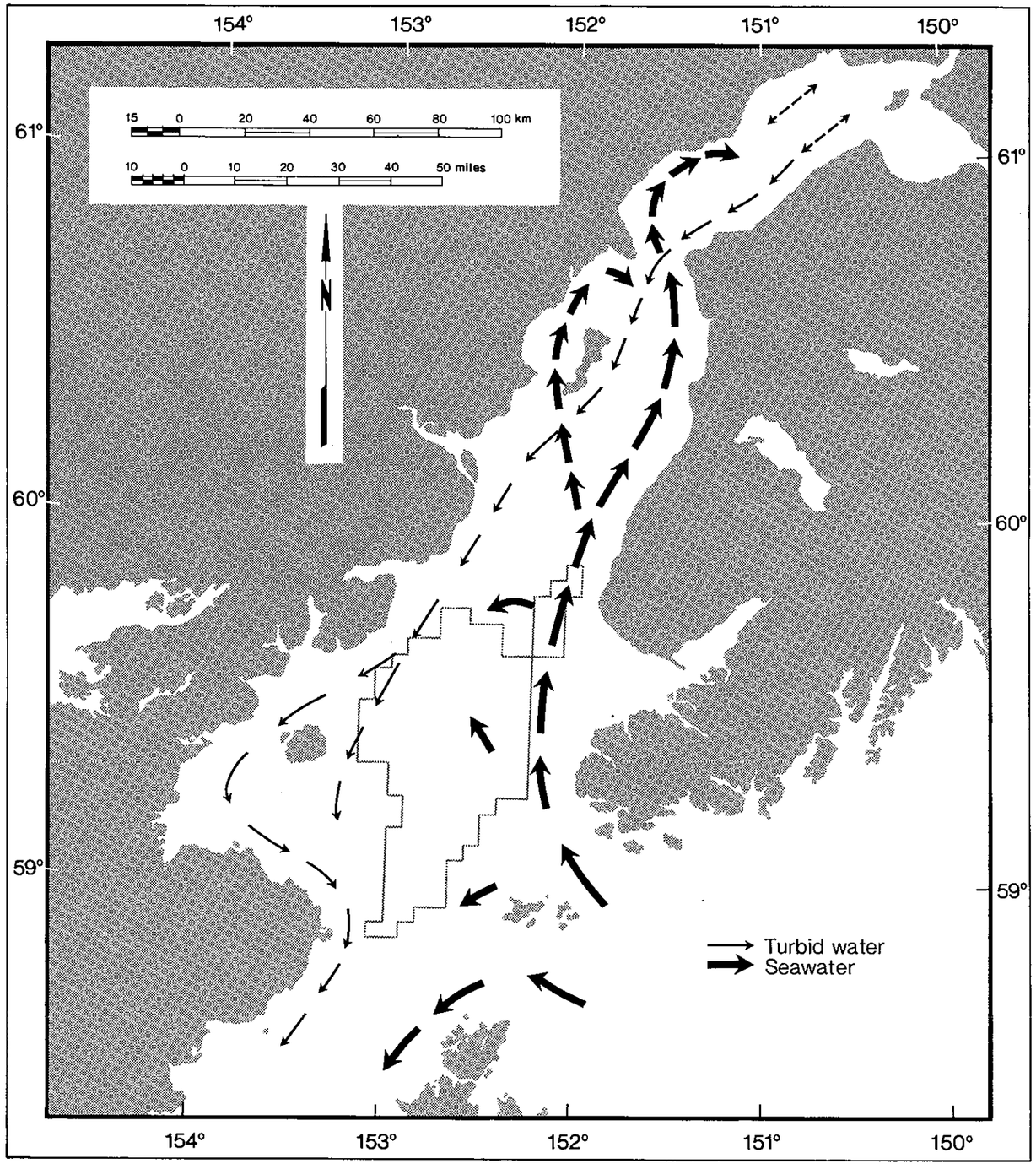


Figure D.1.1d Net surface circulation during the fall within Cook Inlet as inferred from ERTS imagery (Burbank, 1977).

D.1.2 TIDES

Tidal currents dominate the currents in Lower Cook Inlet. About 85 percent of the variance in currents is associated with tidal activity. The tides are predominantly semi-diurnal (two highs and two lows in a 24 hour period) and display a diurnal inequality (successive high and low tides are not equal in height).

As the tides propagate northward up Lower Cook Inlet, the mean range increases with distance from the entrance. Near the entrance to Cook Inlet (at Port Chatham) the mean tidal range is 12.0 feet. At Cape Ninilchik it is 16.5 feet, and at the Kenai River entrance it is 17.7 feet. Mean tidal ranges along the western shore of Lower Cook Inlet also increase to the north. Ranges on the eastern side, however, are two to four feet greater than those on the western side at equivalent latitudes. For example, the mean range at the Kenai River entrance, on the eastern side, is 2.3 feet greater than at the Drift River entrance, on the western side (NOS, 1978). The Coriolis effect (an apparent force due to the earth's rotation) causes these differences in tidal ranges. Co-amplitude and co-phase lines for the semidiurnal principal lunar tide (M_2) tide are shown in Fig. D.1.2a.

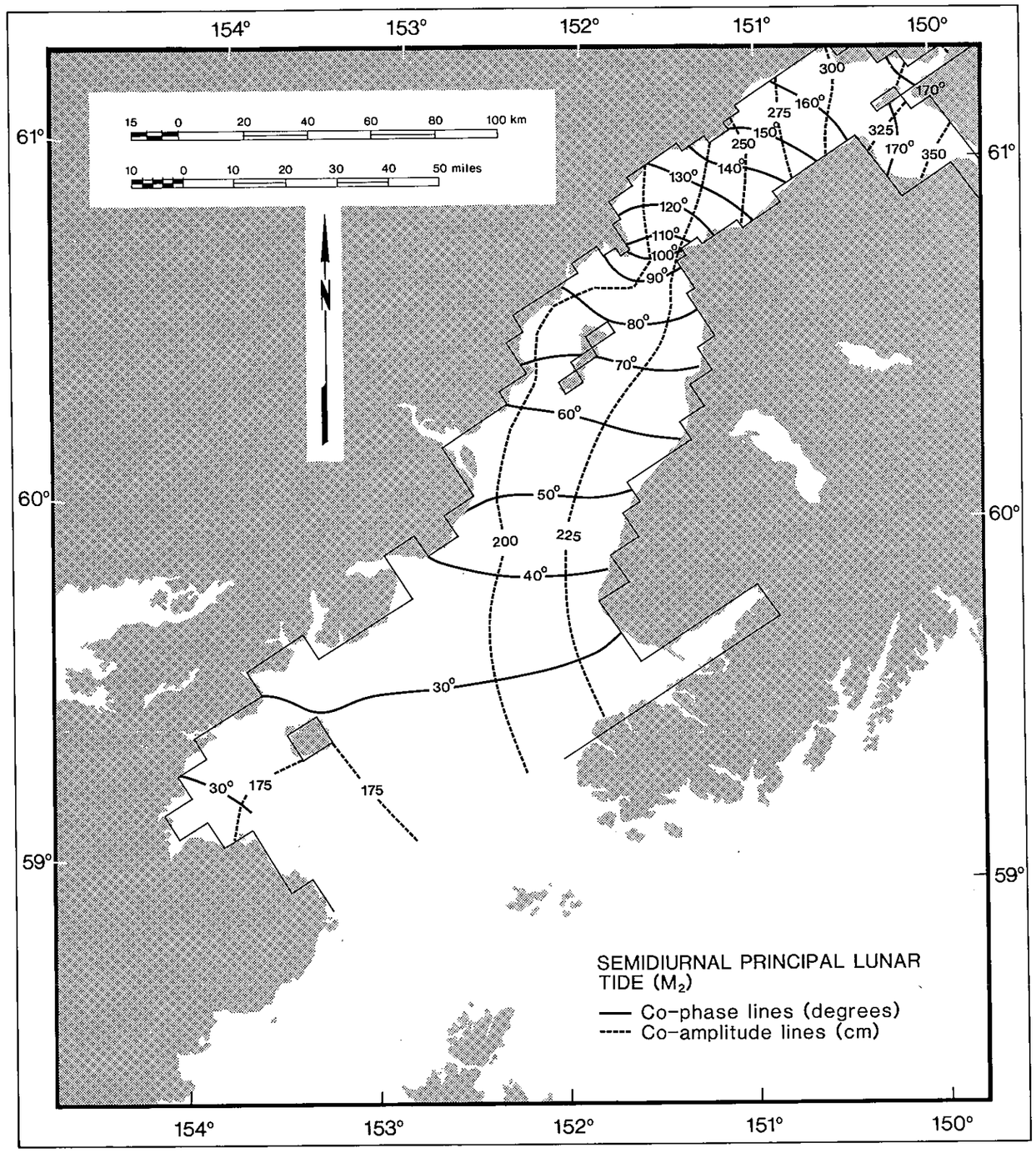


Figure D.1.2a Co-amplitude lines (in cm) and co-phase lines (in degrees) for the semidiurnal principal lunar tide (M_2) of Cook Inlet, Alaska (Mungall, 1973).

Tides propagate northward nearly contemporaneously along the eastern and western sides of Lower Cook Inlet. High tides occur at Drift River Entrance 13 minutes earlier than at Kenai River Entrance. Low tides at Drift River precede those at Kenai River by 14 minutes (NOS, 1978).

Tidal currents reach 2-3 knots at the entrance to Lower Cook Inlet. Speeds greater than 8 knots have been reported at narrows, such as the Forelands (Gatto, 1976). The amplitude of the current associated with the M_2 tidal component (Fig. D.1.2b) has relative maximum values between the Forelands, between Kalgin Island and the west coast of the Inlet, off Cape Douglas, and northeast of Chinitna Bay. Strong tidal currents exist along the eastern part of Lower Cook Inlet north of Anchor Point. The weakest tidal currents are found southeast of Augustine Island (Mungall, 1973; Muench et al., 1978).

Energy from the tides is dissipated largely by bottom friction. Sand waves and ridges indicate a strong near-bottom current regime in central Lower Cook Inlet (Bouma and Hampton, 1976).

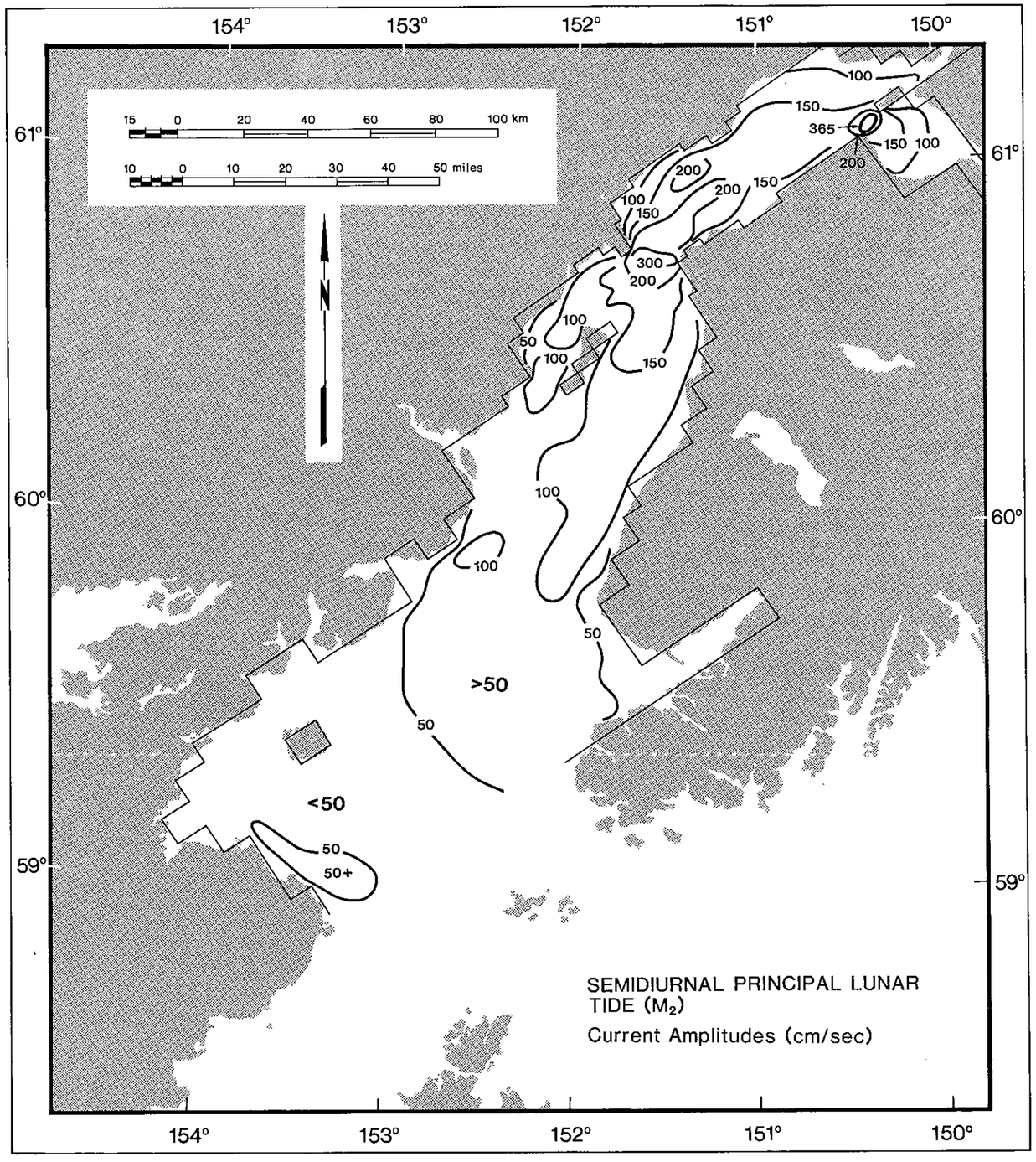
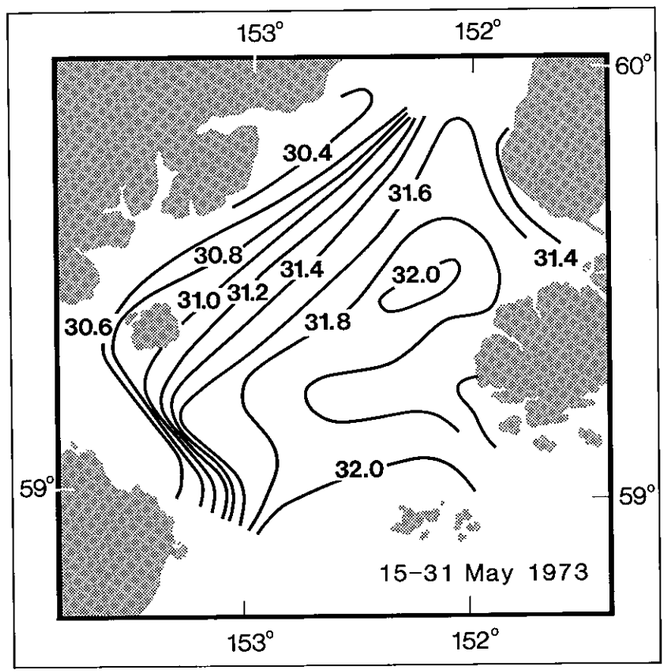


Figure D.1.2b Current amplitudes (in cm/sec) for the semidurnal princpal lunar tide (M_2) of Cook Inlet, Alaska (Mungall, 1973).

D.1.3 DISTRIBUTION OF SEASONAL TEMPERATURES AND SALINITIES

Seasonal changes in the surface values of temperature, salinity, and density occur in Cook Inlet. Freshwater runoff has a strong influence on the salinity distribution throughout Cook Inlet. The shallow waters of the Upper Inlet allow temperatures there to fluctuate seasonally to the extent that the surface temperature gradient, measured along the axis of the Inlet, changes sign. The combination of higher temperatures and lower salinities along the edges of the Inlet in summer produces an enhanced horizontal gradient in density, which may result in increased baroclinic currents.

Schumacher et al. (RU #138, Annual Report, 1978) present salinity, temperature, and density data for Lower Cook Inlet during spring and summer. Surface salinities (Fig. D.1.3a) decrease from east to west except during the late summer (28 August to 10 September 1973), when there is a mid-Inlet salinity maximum. The lowest salinities also occur during the late summer, as soon as the freshwater input to Cook



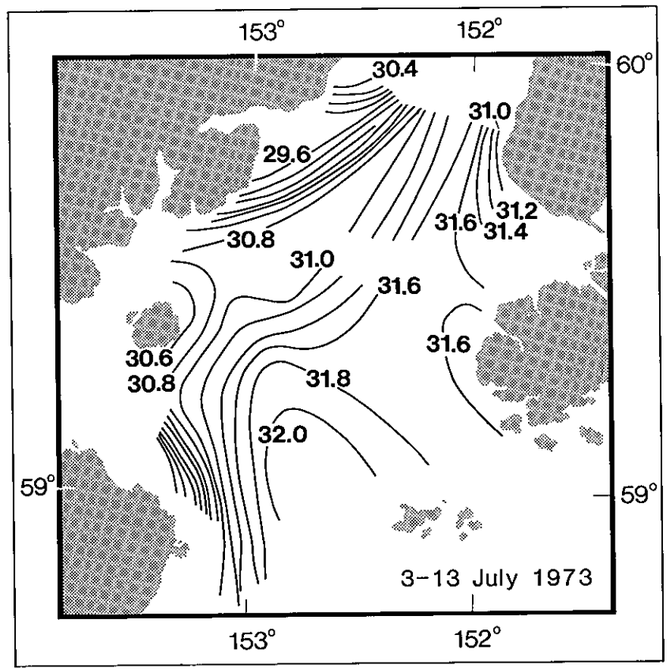
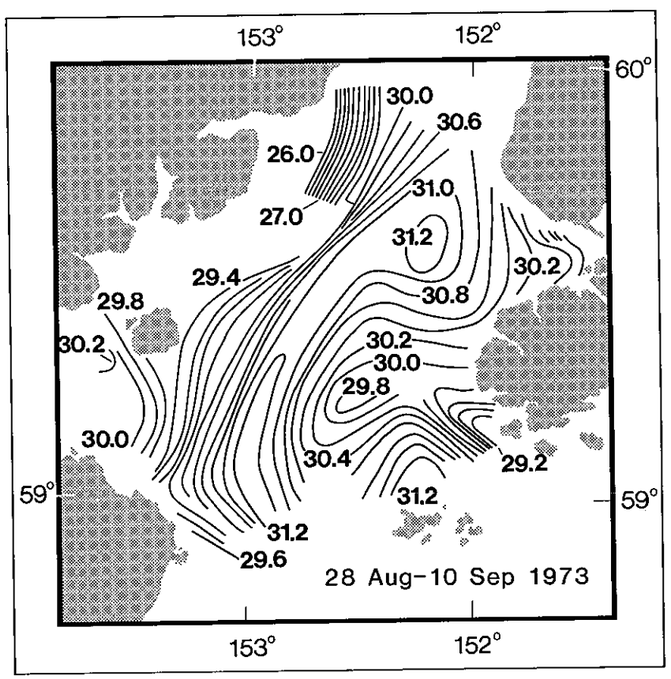


Figure D.1.3a Distributions of surface temperature and salinity in Lower Cook Inlet for three different periods during spring and summer (Schumacher et al., RU #138, Annual Report, 1978).



Inlet has peaked (Fig. D.1.3b). The relatively high salinity of Kamishak Bay water during August and September (Fig. D.1.3a) suggests some isolation of the water from the rest of the Inlet. The low salinity of the water at the Kennedy Entrance could be caused by dilution of Gulf of Alaska seawater by runoff from the southeast coast of the Kenai Peninsula.

The Upper Inlet has the lowest surface temperatures in spring and the warmest temperatures in the late summer. The water stays longer in Upper Cook Inlet than in Lower Cook Inlet, due to lower advection and replacement rates. In winter the Upper Inlet waters are subjected to longer periods of low atmospheric temperatures; in summer, the longer residence time allows the water to be warmed by insolation (Muench et al., 1978).

During May the warmest temperatures occur in the western part of the Inlet. A mid-Inlet tongue of cooler water separates warmer regions during July, August, and September.

During spring and summer the water of lowest density is found along the eastern and western edges of Lower Cook, as revealed by a section across the mouth of the Inlet (Fig. D.1.3c). A well-defined dome of high density water occurs in the center of the

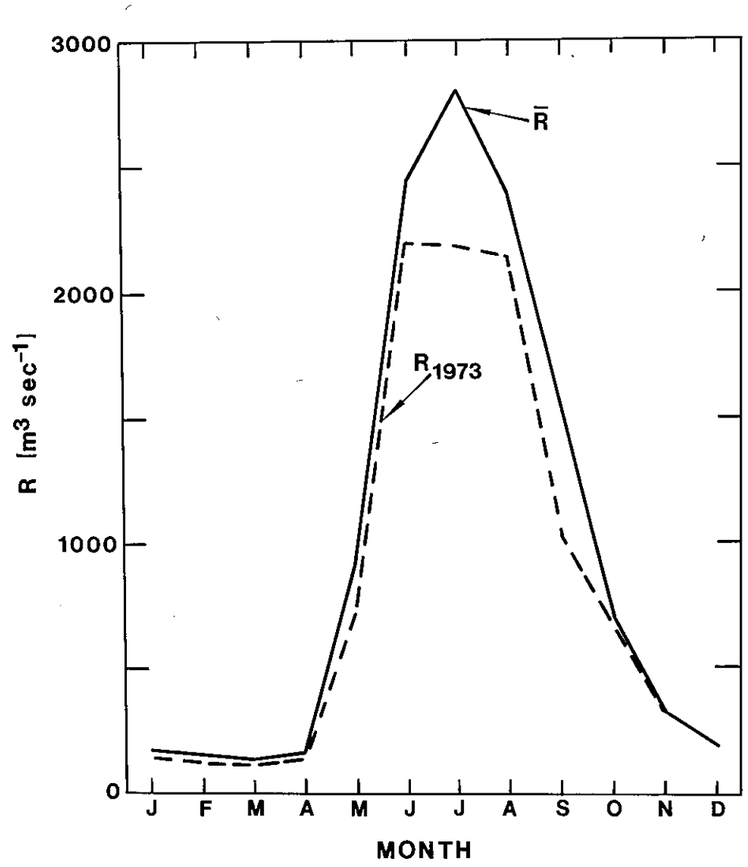


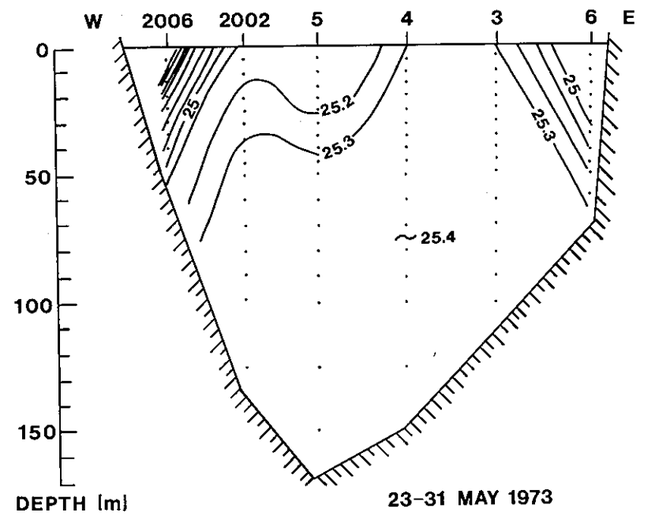
Figure D.1.3b Gauged river input (R) into Cook Inlet, showing both annual mean input ($\bar{R}$) and input during 1973. These figures were compiled from USGS streamflow records from the Kenai River at Soldotna, the Knik River near Palmer, the Matanuska River at Palmer, the Susitna River at Gold Creek, the Talkeetna River near Talkeetna, and the Skwentna River near Skwentna.

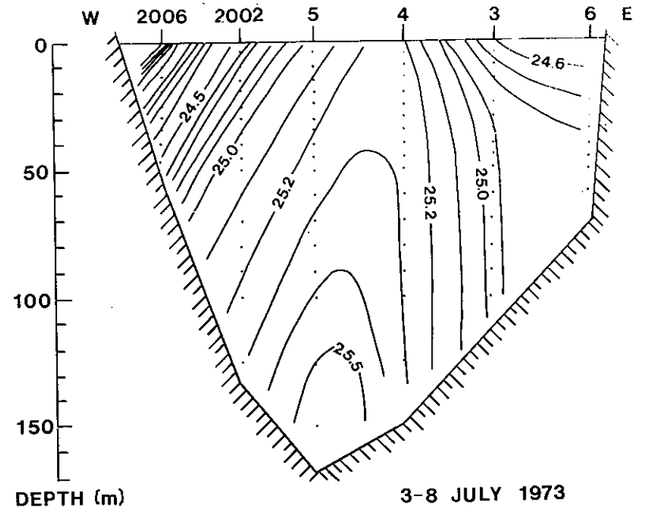
month in July. The baroclinic currents to be expected from this density distribution would support a counterclockwise circulation (see Fig. D.1.1a). This dome shifts to the west by September, and the density throughout the section decreases. Horizontal density gradients increase, and hence a greater baroclinic shear would be expected between shallow and deep currents.

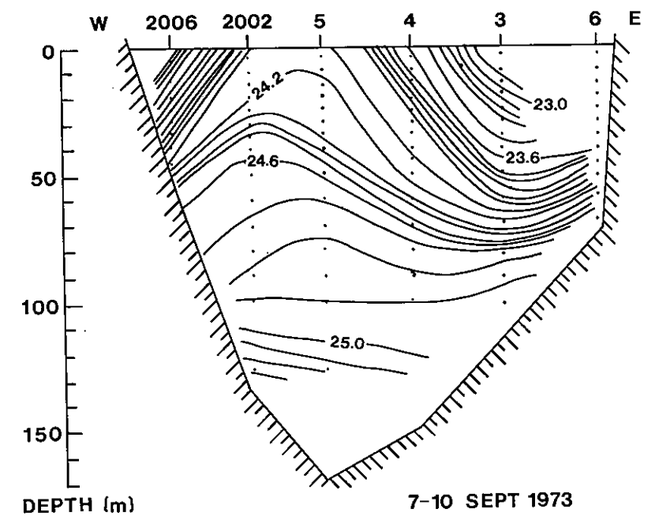
Unfortunately, as there are no hydrographic data from the winter months, a complete seasonal description of Lower Cook Inlet is not possible. The data shown here, however, do reveal the seasonal influence of freshwater runoff on currents.

The distribution of surface salinities is consistent with the description of surface circulation presented by Burbank (1977, Fig. D.1.1a). Water of lower salinity is advected to the south along the western side of Lower Cook Inlet. This band of low salinities, which originates in the upper part of the Inlet, also follows bathymetry (Muench et al., 1978). It appears to exit the Inlet after rounding Cape Douglas.

Salinities in Kamishak Bay in September are higher than any possible source waters, suggesting slow circulation and perhaps high evaporation in this area.







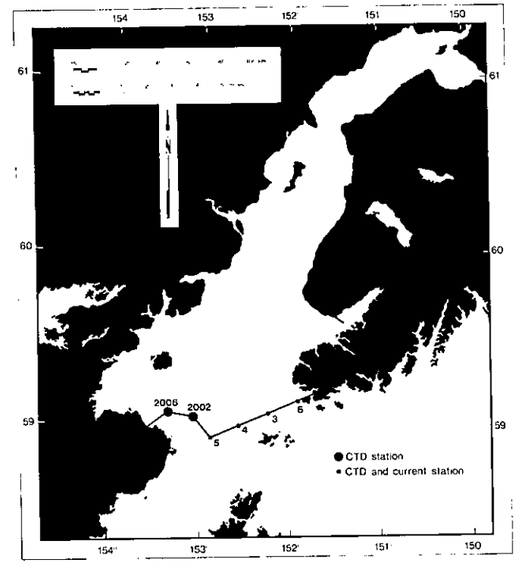


Figure D.1.3c Vertical distributions of density (ot) at a section (see insert) across Lower Cook Inlet during summer 1973 (Schumacher et al., RU #138, Annual Report, 1978).

D.1.4 MOORED CURRENT METER OBSERVATIONS

Analysis of moored current meter records is continuous (Schumacher et al., RU #138, Annual Report, 1978). Short time series records were obtained by the National Ocean Survey (Schumacher et al., RU #138, Annual Report, 1978). More recent data have been reported by Muench et al. (1978).

The circulation in Lower Cook Inlet is dominated by the semidiurnal tides and by oceanographic events with time scales of three to four days. Analysis of several current meter records for the amplitude of the M_2 tidal component (Muench et al., 1978) revealed that the strongest tidal amplitudes occur in Kennedy Entrance and across Lower Cook Inlet north of Anchor Point. A tidal amplitude null zone was found about one-third of the way across the Inlet, east of Augustine Island. In general, amplitudes are largest where the flow is laterally restricted and weakest where the restriction is minimal.

Filtering the current meter records to remove tidal effects reveals that the next strongest influence on circulation is the 3-to-4-day time scale events, which have associated current speeds as high as 50 cm/sec. The events are probably caused by meteorological events (Muench et al., 1978).

Current records which have either been low-pass filtered or averaged indicate much smaller velocities than the unfiltered records. The mean currents are in agreement with geostrophic current estimates calculated from hydrographic data.

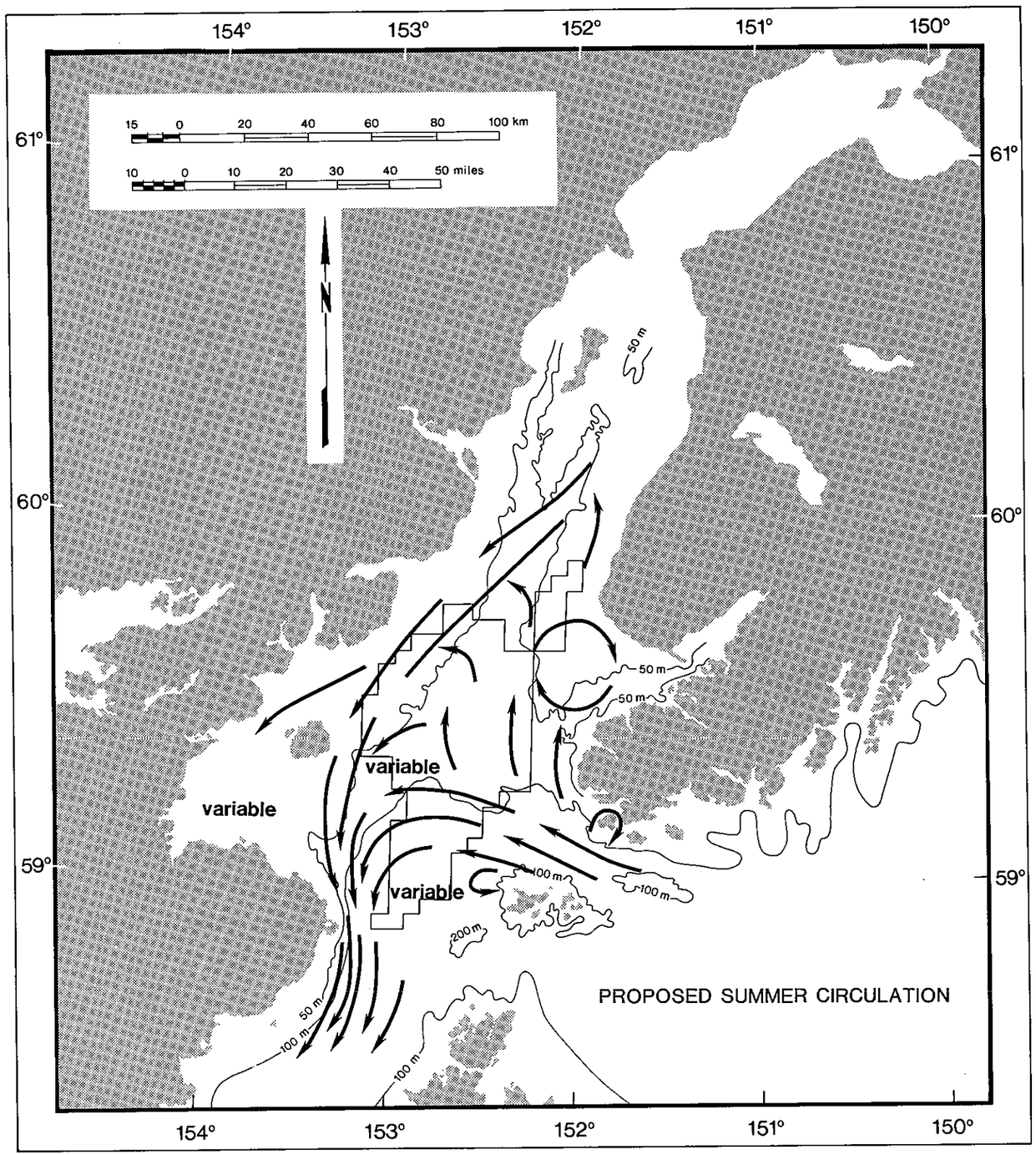
Analysis of the most recent current meter data is not complete, but the following observations were made by Muench et al. (1978): a concentrated ribbon of currents exits Lower Cook Inlet just offshore of Cape Douglas; the position of this ribbon may vary laterally; in Kennedy Entrance, the flow is to the west and seems to parallel the bathymetry, as determined by hydrographic observations; off Anchor Point, the mean current is weak and to the northeast.

Muench et al. (1978) have proposed a model of the net summer circulation in Lower Cook Inlet based on an analysis of hydrography and current meter data (D.1.4a). Gulf of Alaska water enters Lower Cook Inlet through Kennedy Entrance. Part of this water flows to the west, forming a counterclockwise flow, and exits the Inlet after passing to the east of Cape Douglas. A weak flow of relatively cold and saline Gulf of Alaska seawater moves northward along the eastern shore. Part of it becomes entrained in the southward flow of Upper Inlet water moving along the western side of the Inlet. The water in this southward flow is less saline and warmer than Gulf of Alaska water due to freshwater runoff and heating in the Upper Inlet. This water flows past Cape Douglas in a concentrated band and enters Shelikof Strait.

Upwelling may occur in the counterclockwise flow in the central part of Lower Cook Inlet. If so, it is probably a major source of nutrients for organisms in the area.

The general features of the summer circulation pattern described by Burbank (1977; Fig. D.1.1a) and of the circulation predicted by modeling hydrography and current meter data (Muench et al., 1978; Fig. D.1.4a) are quite similar. Both show water flowing into Lower Cook Inlet through Kennedy Entrance and spreading to the west and north. Water originating in the Upper Inlet flows south along the western side of Lower Cook and exits beyond Cape Douglas into Shelikof Strait. Muench et al. (1978) show the westward flowing Gulf of Alaska water paralleling the prominent slope across central Lower Cook, while Burbank (1977) shows the westward flow extending farther to the north during its counterclockwise motion. Since the data used in each study were from independent sources, confidence in the general similarity of the patterns is increased.

Figure D.1.4a Net summer circulation in Lower Cook Inlet, based upon analysis of hydrographic and current meter data (Muench et al., 1978). →



D.1.5 DRIFT BOTTLE STUDIES

Drift bottle studies can supply information on circulation. But as the actual trajectories of drift bottles and their time in transit to recovery locations are not known, estimates of advection speed cannot be made. The following descriptions of drift bottle releases and recoveries during 1978 are from ADF&G (1978a).

The distribution of recovery locations of bottles released in early July from the Marathon Diamond M site off Anchor Point is bi-polar (Fig. D.1.5a). About half of the recoveries were made north of the release site, on the north side of Kalgin Island and along the coast south of the East Foreland. Surface flow in this region (as shown in Fig. D.1.1a) is opposite to the currents inferred from drift bottle results. The remaining bottles were recovered on the western shore of Cook Inlet, between Ursus Cove and Amakdedori Beach. To arrive here, the drift bottles had to cross the Mid-Channel Rip and the southwesterly flow shown in Figs. D.1.1a and D.1.4a.

While the two regions of recovery are widely separated, all of the drift bottles probably traveled northward from the release site. It is difficult to believe that a drift bottle could reach the western shore without first having traveled to the north and then to the west.

Bottles released from the ARCO Raven site in July were recovered at Augustine Island and at Amakdedori Beach. These drift bottles also had to cross the Mid-Channel Rip. One other bottle was found on the west side of Kodiak Island.

In August bottles were released at the ARCO Hawk site. Twenty-seven were found between Ursus Cove and the southern coast of Kamishak Bay. The circulation patterns shown in Fig. D.1.1a suggest that the drift

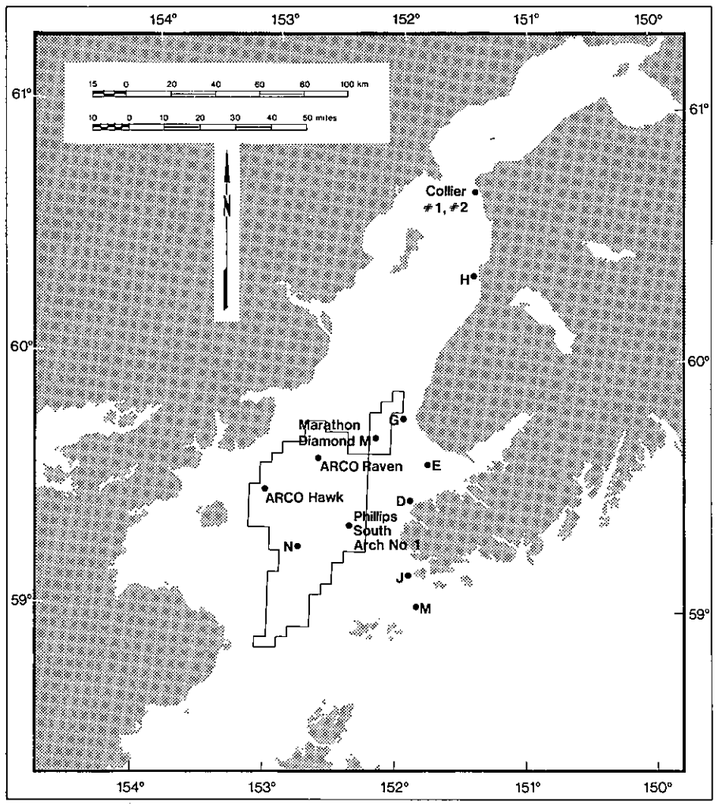


Figure D.1.5a Drift bottle release sites, 1978 (ADF &G, 1978a).

bottles released at this site should have been advected to the south before beaching; four recoveries were made on Rocky Point, on the western coast of lower Kodiak Island.

A pattern of recoveries similar to that for the ARCO Hawk site occurred for bottles released in August at the Phillips South Arch No. 1 site. Three bottles were found due west of the release point along Amakdedori Beach. Two others were found on Rocky Point.

Two releases were made off the Collier dock south of the East Foreland. The first release site was 0.16 km offshore of the dock. Thirty-eight drift bottles were found north of the release site and two were found on Kalgin Island. Circulation patterns for this region suggest that the net flow is to the south. The bottles recovered a few kilometers north of the release site could have been transported there by a flood tide. It is not clear how the two bottles got to Kalgin Island across the net southward currents. Perhaps they were advected northward past the East Foreland on the flood tide, and they had enough westward momentum to reach Kalgin Island while being advected southward by the mean flow or by the ebbing tide. The second release was made 0.46 km off the Collier dock. The recoveries from this release fit more closely the expected southward net flow.

Burbank (1977) describes and interprets other drift bottle study results. These studies were conducted during August to September (1974) and April to June (1976). Two releases were made in Kachemak Bay in 1974 at release sites D and E. The primary recovery sites were along Homer Spit, near Anchor Point, near Amakdedori Beach, and along the west coasts of Shuyak, Afognak, and Kodiak Islands. One bottle was found on the southern end of Kalgin Island.

Only a few bottles were recovered from a release off Anchor Point in 1974, and all but one were found in the vicinity of Anchor Point. The exception was recovered in Spiridon Bay on the west side of Kodiak Island.

A wide distribution of recoveries resulted from a release at station H in 1974. The area from Ursus Cove to Amakdedori Beach and Augustine Island was a principal landing site. However, the area with the most recoveries (about 65) was the coastline south of the release points. Bottles were found as far south as English Bay, on the eastern side of the Inlet, and just west of Homer Spit. The net flow according to the circulation models is southward from the release site. However, for drift bottles to get south of Cape Starichkof they had to be either advected southward by tidal flow, or transported around the counterclockwise gyre of Lower Cook Inlet and advected northwards to the recovery sites at English Bay, Homer Spit, and Anchor Point.

Two releases were made in 1976 in Kennedy Entrance. The major recovery locations were Ursus Cove, Amakdedori Beach, near Cape Douglas, and along both sides of Shelikof Strait. Unexpected recoveries were made on Spruce Island (northeast of Kodiak Island) and on the eastern sides of Shuyak and Afognak Islands, possibly because drift bottles were carried out of Cook Inlet by an ebb tide.

Recoveries were made on the west side of Augustine Island, on Amakdedori Beach, and along the west coast of Shelikof Strait after a release from site N in 1976. One drift bottle was found in Kiliuda Bay on the east side of Kodiak Island.

Most of the drift bottle recovery sites are in agreement with the previously described circulation patterns in Lower Cook Inlet, although some of the recovery locations seem anomalous. It is likely that drift bottles would accumulate along the Mid-Channel Rip, since it is a zone of surface convergence and debris accumulation. However, the Rip is a transient feature and may not have been well-developed when these releases were made and hence drifts may pass to the west across the Rip zone. Tidal currents also need to be considered in comparisons of drift bottle recovery locations and general circulation patterns. The general patterns are based on mean flow, with tidal currents averaged out, whereas the trajectory that a bottle might follow could be influenced to a large degree by tidal currents.

D.1.6 CURRENT MEASUREMENTS MADE WITH A CURRENT-MAPPING RADAR

Two sets of current mapping radar data (Barrick, RU #48, Quarterly Report, Oct-Dec, 1977; Annual Report, 1978) show the strong tidal influence in the eastern part of Lower Cook Inlet. The data described here were collected off Kachemak Bay in sampling periods about eight hours apart. Data in the first plot (Fig. D.1.6a) were obtained 2.5 hours before high tide on 1 July 1977. During this flood tide, the currents are fairly uniform to the north except at the mouth of Kachemak Bay. There appears to be an inflow into the Bay along the southern coast and possibly an outflow south of Homer. During the ebb stage (Fig. D.1.6b) the flow is southerly, and the current vectors closest to shore have an offshore component. A comparison of these instantaneous current measurements to the net surface circulation (D.1.1a) shows that the tidal flow dominates the circulation off Kachemak Bay.

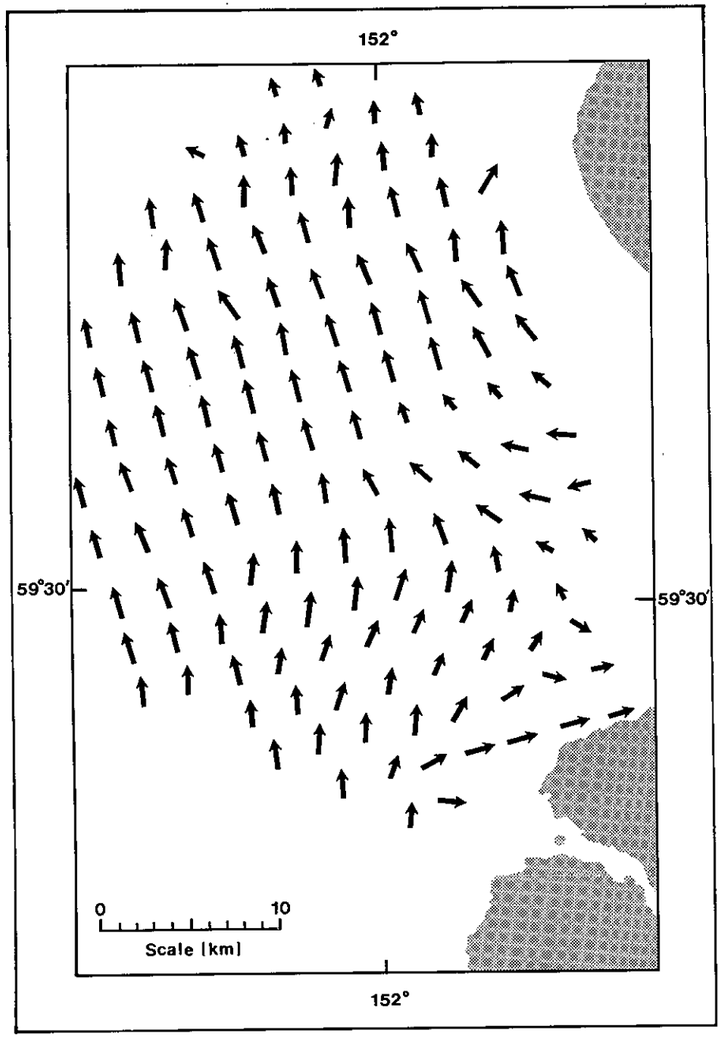


Figure D.1.6a Tidal influx surface current patterns off Kachemak Bay, 1120 hrs, 1 July 1977, by current-mapping radar (Barrick, RU #48, Annual Report, 1978).

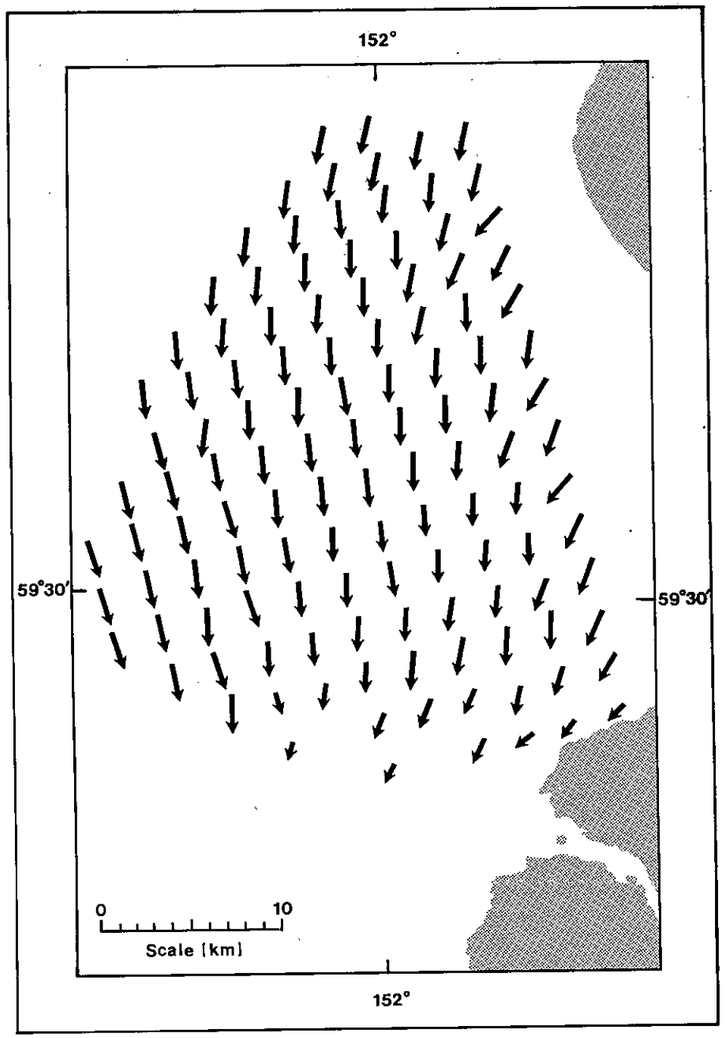


Figure D.1.6b Tidal outflux surface current patterns off Kachemak Bay, 1920 hrs, 1 July 1977, by current-mapping radar (Barrick, RU #48, Annual Report, 1978).

D.1.7 MEASUREMENTS OF LOCAL WIND FIELDS

Although measurements of wind fields in Lower Cook Inlet have not been reported, Reynolds (RU #367, Annual Report, 1978) presents wind records from the Anchorage airport for 1973 to 1977. No strong seasonal signal appears in records of wind speed; summer winds seem to be slightly stronger. A clear seasonal signal is present in wind direction: summer winds are from the south or south-southwest and winter winds are from the north or northwest. These dominant directions are aligned with the orientation of the 915-m elevation contour surrounding Cook Inlet. This orientation differs from that of the crest of the Kenai Mountains and probably reflects the steering of the planetary boundary layer which is typically 600-900 m deep. Winds in summer are generally more consistent in direction than in other seasons.

The few wind observations actually made over Lower Cook Inlet show little correlation with winds reported at coastal stations. Reynolds (unpublished data, PMEL/NOAA, 1977, reported in Muench et al., 1978) compared wind data taken at an environmental buoy in central Lower Cook Inlet with data at surrounding coastal stations. He attributed the lack of correlation to topography which alters the flow at the coastal sites.

Generalized wind patterns have been computed for Lower Cook Inlet based on Putnins' classification (1966) of atmospheric pressure types (Dames and Moore, RU #436, Final Report, 1976). From Putnins' 22 types, eight patterns were selected, each representing a different basic direction of wind flow. Mean wind speeds were estimated for each of the eight patterns by comparing these data with wind speeds observed at land stations (Putnins, 1969). Estimates were also made of the frequency of occurrence of each weather type for four months of the year. This analysis provided a climatology for Lower Cook Inlet that was used in subsequent oil spill simulations. Since it has been found that winds over Lower Cook Inlet differ from winds at adjacent land stations and from geostrophic winds (Reynolds, unpublished data, NOAA/PMEL, 1977, reported in Muench et al., 1978), the climatology probably does not accurately represent meteorological conditions over Lower Cook Inlet.

SUBTASK D.2 Nearshore and Kachemak Bay Circulation and Water Masses

D.2.1 GENERAL DESCRIPTION OF CIRCULATION

The nearshore circulation of Lower Cook Inlet, and that of the major bays, such as Kachemak and Kamishak, is more complex than that off shore because of the influences of coastal topography, river runoff, large tidal ranges, and variable winds. Figure D.1.1a shows some of the features of nearshore circulation as derived from data collected during the spring and summer. The following description is taken primarily from Burbank (1977).

Along the southwest coast of the Kenai Peninsula, northwest of the Chugach Islands, upwelling occurs. The mechanism of this upwelling has not been described in the literature, but it probably is driven by the strong flow of Gulf of Alaska water through Kennedy Entrance. The upwelled water differs from Gulf of Alaska water in its low suspended load and its much higher nutrient content. This clear, nutrient-rich upwelled water stays close to shore as it moves northward and enters outer Kachemak Bay. Here it contributes a significant volume to the surface waters and probably results in the extremely high productivity observed in the outer bay.

Part of the nearshore flow continues around the shoreline of the outer bay, turns north under topographic influence just west of Homer Spit (where it also mixes with outflow from the inner bay), and continues northwestward towards Anchor Point. This nearshore flow moves north to about the latitude of Ninilchik, where it meets with low salinity, high-suspended-load coastal water (whose source is Kenai and Kasilof River runoff) flowing south (Fig. D.1.1a). The mixed flows are diverted westward and are entrained with the main offshore circulation.

The nearshore circulation along the western side of the Inlet is dominated by the strong southerly flow of turbid and low-salinity water, as previously described. Eddies form in the major bays, especially Kamishak Bay. North and south of Augustine Island prominent eddies form in which debris from the North Pacific accumulates. Analysis of drift bottle recoveries (refer to section D.1.5) and beach accumulation of debris typical of that observed in the Mid-Channel Rip, suggest that the nearshore circulation in Kamishak Bay is not sufficiently vigorous to prevent the bay from becoming a sink for drifting debris and pollutants.

D.2.2 CIRCULATION IN KACHEMAK BAY

The typical surface circulation of Kachemak Bay is shown in Fig. D.2.2a. The most recent summary of circulation in the bay is by Burbank (1977) and the following is taken from that reference unless otherwise cited.

Surface circulation in outer Kachemak Bay consists of two counter rotating gyres, with the western gyre rotating clockwise. These surface waters are composed of a mixture of upwelled coastal water, Gulf of Alaska seawater, and freshwater runoff from the upper bay. The area is extremely productive biologically. The current velocities for these gyres, as shown in Fig. D.2.2a, are typical but not necessarily mean velocities.

Variations in the size of the two gyres and in their current velocities are caused by variations in winds, tidal ranges, and freshwater runoff. Hence, the circulation characteristics can vary daily, monthly, and seasonally. Also, the gyres may disappear completely during the fall when intense storms move in from the south.

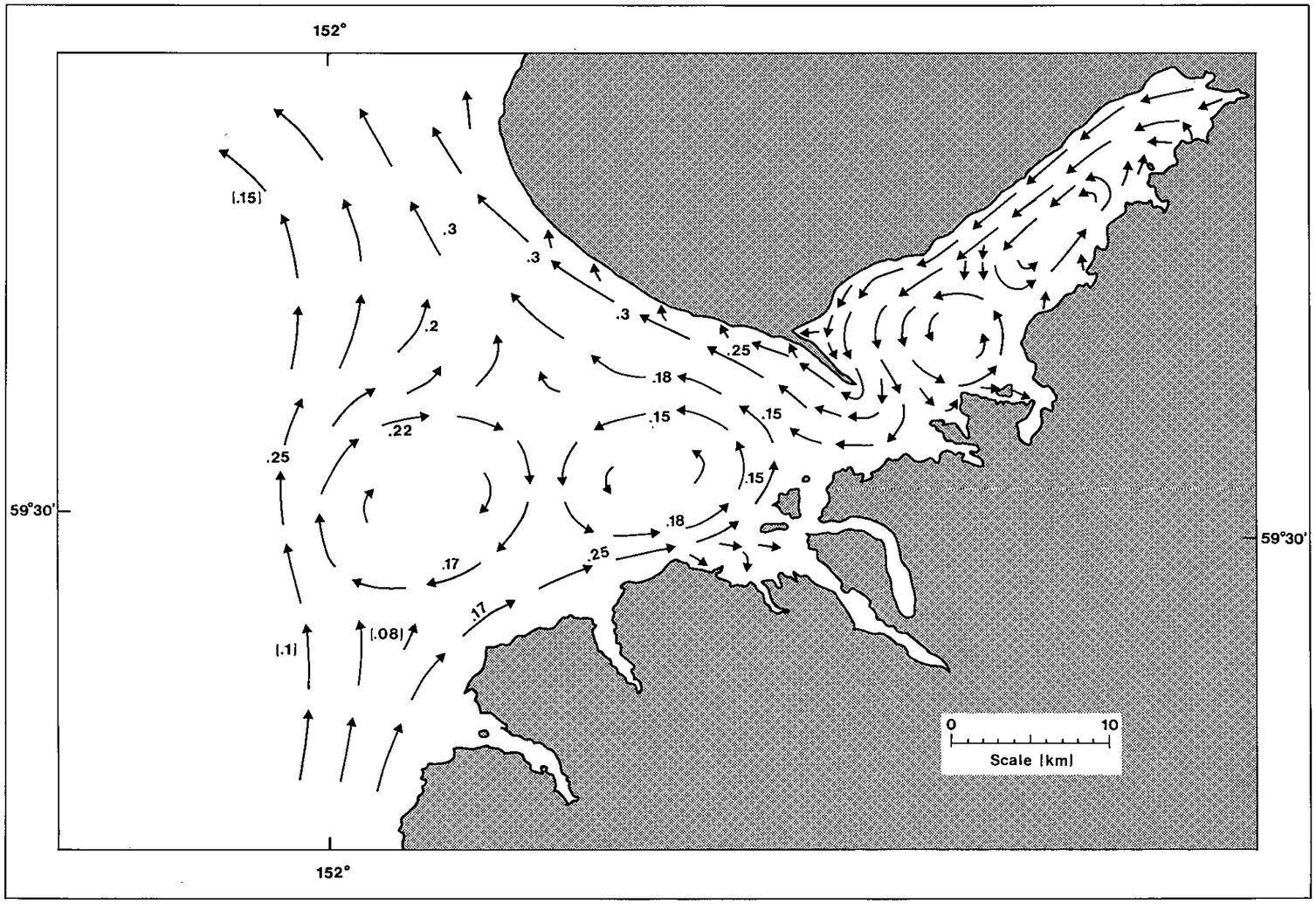


Figure D.2.2a Net surface circulation in Kachemak Bay in spring and summer, with typical net surface current velocities (kts) indicated for various areas in the bay (1 kt = 50 cm/sec, approx.). Parentheses indicate where the velocity was determined from only one period of observation (Burbank, 1977).

Information on the subsurface circulation in outer Kachemak Bay is limited. Some intrusion of saline water from Cook Inlet probably occurs (Fig. D.2.2b), although the effect of Cook Inlet circulation on that of Kachemak Bay is unclear. Burbank's (1977) estimates current velocities at depths of 15 to 30 m, based on drogue studies, indicate that typical subsurface velocities are about half the surface velocities in the outer (clockwise) gyre, and essentially the same as surface values in the inner (counterclockwise) gyre.

Drifting debris from the Gulf of Alaska is not commonly found in Kachemak Bay. This suggests that Kachemak Bay would not act as a sink for floating pollutants (from Lower Cook Inlet) as Kamishak Bay might. However, pollutants introduced directly into Kachemak Bay might stay in the surface gyres for long periods; drogues have been tracked in the gyres for up to 15 days when observations were discontinued.

Inner Kachemak Bay has been described as a positive, partially-mixed estuary. Freshwater outflow from Fox River runoff mixes with saline inflow along the bottom of the estuary (Fig. D.2.2b).

Drift bottle studies have not shown any net transport of surface waters from the outer bay to the inner bay, although the studies were not conducted during periods of minimal freshwater runoff. For further details of the circulation of the inner bay refer to Burbank (1977).

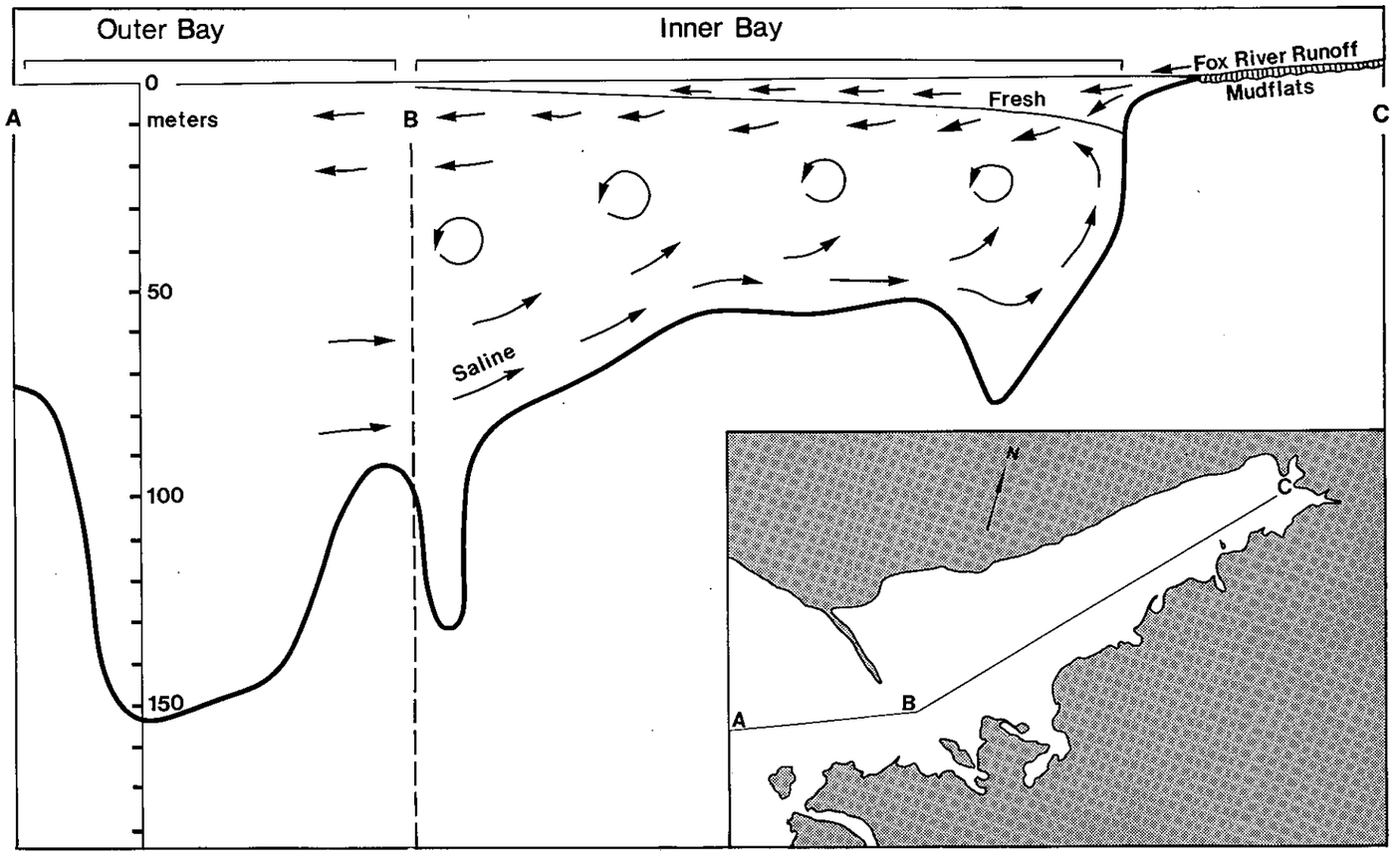


Figure D.2.2b Vertical cross-section of typical circulation in Kachemak Bay. The bathymetry for the model is taken from the actual bathymetry in inner Kachemak Bay along line A-B-C (Burbank, 1977).

SUBTASK D.3 Oil Spill Trajectories

D.3.1 RESULTS OF ANALYSIS BY MODELS

Dames and Moore (RU #436, Final Report, 1976) studied the probable effect of an oil spill on a coastal area. Twelve potential oil spill sites were selected and 32 trajectories were constructed for each site. Conditions included four tidal stages and eight wind patterns. The trajectories were computed as the sum of tidal and net surface currents and wind-induced motion. Tidal currents were estimated from data collected by the 1973 to 1974 NOAA cruises to Lower Cook Inlet. Simulated spills were initiated at four different times of the tidal cycle. Net currents were estimated from the literature (e.g., Burbank, 1974, and ADF&G, 1976a). Eight wind patterns were selected from Putnins' (1966) classification of atmospheric pressure distributions. The simulations of each trajectory were stopped when it encountered a boundary cell or when twelve tidal cycles had been completed.

Figure D.3.1a represents the cumulative potential effect for all twelve sites. The probabilities of impact for each cell or grid, for each spill site, were summed and then divided by the number of spill sites. The percentages shown represent the probability that a particular cell will be insulted in the course of one year, assuming that one spill occurs per year and that it could occur with equal probability at any of the twelve sites.

Approximately 10 percent of the total number of trajectories simulated did not contact a boundary cell within twelve tidal cycles (6.21 days). Also, 34

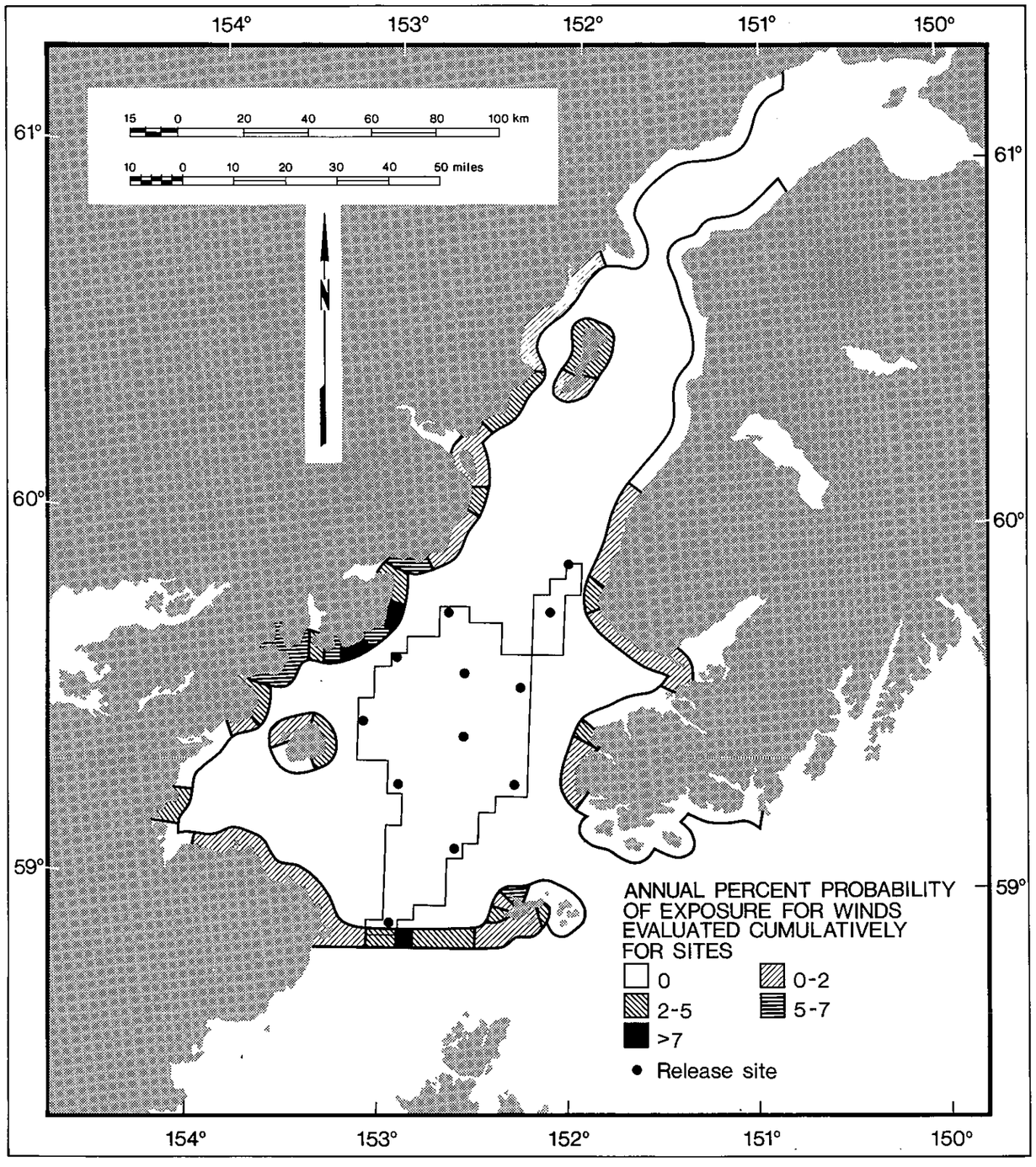


Figure D.3.1a Annual percentage probability of impact, cumulative for all 12 spill sites (Dames and Moore, RU # 436, Final Report, 1976).

percent of the trajectories passed through open-water boundary cells. Thus, about 56 percent of the trajectories did touch land areas within the temporal and spatial limits of the simulation.

The only land areas with probabilities of impact greater than 5 percent are from Ursus Cove to just south of Tuxedni Bay (on the western coast), and on the Barren Islands. As might be expected from the general circulation pattern, areas east and north of the spill sites are unlikely to be affected. However, almost any land area in Lower Cook Inlet could be insulted by oil spilled from the several release points.

Although there were no simulated impact locations on the eastern side of Lower Cook Inlet north of Ninilchik, drift bottle studies (Burbank, 1978) have shown that oil could reach this coastline from releases made off Anchor Point. Except for this difference, the drift bottle studies confirm the general results of the simulation study: buoyant material, released on the surface in central Lower Cook Inlet, tends either to be advected out of the Inlet and into Shelikof Strait or to accumulate along the western coast of Lower Cook Inlet.

An analysis by Kinney et al. (1970; reported in Gatto, 1976) calculated the flushing time for Cook Inlet. They estimated that hydrocarbon pollutants in Cook Inlet would be reduced by 90 percent in ten months.

DATA EVALUATION

Few direct observations of currents in Cook Inlet have been reported, but several studies of currents are now under way. The generalized net circulation in Lower Cook Inlet is fairly well understood. The distributions of temperature, salinity, and suspended matter support the general circulation pattern. Most of the hydrographic data have been collected in non-winter months; more winter data are needed for a complete seasonal description.

Verification of the data produced by current-mapping radar is difficult since there is no accurate calibration standard. Barrick (1978) compared his Eulerian observations with surface drogues (Lagrangian), and the correlation of velocities was high (r^2=0.92). Thus, these data are at least as precise as data obtained by tracking surface drifters.

Few measurements of atmospheric parameters over Lower Cook Inlet have been made. This information is needed to determine how the circulation responds to variations in meteorological conditions.

The usefulness of the Dames and Moore (RU #436, Final Report, 1976) simulations is limited for several reasons. Currents and winds in Lower Cook Inlet are not well understood in detail, and the data used in the simulations were limited. More observations of currents and winds (over the Inlet and not just along the shoreline) are needed. The model is being re-run to include new current meter data. Oil slicks can pass through an area several times, recontaminating the area; the model does not include this possibility. The influence on oil transport of oil weathering and spreading and interactions with sea ice have not been considered. Furthermore, the model was developed to simulate only instantaneous spills; the chronic spillage of oil was not considered.

SUBTASK D.4 Bottom Sediments and their Interaction with Oil and Biota

D.4.1 SEDIMENT GRAIN SIZE PROPERTIES

Prior to the initiation of OCSEAP programs in Lower Cook Inlet, the only published information on sediment grain sizes was that of Sharma and Burrell (1970). They described the surface sediments of Lower Cook as gravelly sands with small amounts (averaging 6 percent by weight) of silt- and clay-sized material.

The size distributions of 11 surface sediment samples collected during the 1976 field season by RU #327 investigators were determined. Although the texture data points available thus far are too few to make a grain size distribution map (Hampton and Bouma, RU #327, Annual Report, 1978), several generalizations may be made. The surface sediments of the central portion of Lower Cook are mostly sand-sized, with small amounts of larger pebbles and smaller silt- and clay-sized materials. The mean grain size decreases from north to south, while the size sorting of the sediments improves in that direction. Probably the sediments are progressively sorted and winnowed as they are transported by currents from the north to the south (Bouma et al., 1978a), but more samples are needed to test this hypothesis.

D.4.2 COASTAL MORPHOLOGY, BEACH MATERIALS, AND OIL SPILL VULNERABILITY

These topics are discussed in Subtasks C.5 and D.6.

D.4.3 INTERACTION BETWEEN OIL AND BOTTOM SEDIMENT: IMPLICATIONS REGARDING BIOTA

(In preparation)

SUBTASK D.5 Bottom Sediment Dynamics

This topic is discussed in Subtask C.4, and, to a lesser extent, in Subtask D.7.

Investigations into the mechanisms of entrainment and transport of bottom sediment, and their relationship to physical oceanographic processes, are under way. Data are being collected during the 1978 field season (Cacchione and Drake, RU #430, Quarterly Report, Apr-Jun, 1978).

SUBTASK D.6 Suspended Particulate Matter and Its Interaction with Oil

D.6.1 DISTRIBUTION OF SUSPENDED PARTICULATE MATTER

Data on suspended particulate matter (SPM) in Cook Inlet are few, but OCSEAP investigators are gathering more. Burrell et al. (1967) presented preliminary data on the distribution of SPM in Upper Cook Inlet; Sharma and Burrell (1970) expanded upon this preliminary work and included some data for part of Lower Cook Inlet; and Sharma et al. (1974) and Burbank (1974), related the distribution of SPM to ERTS imagery in Lower Cook Inlet. SPM data for Lower Cook were most recently summarized by Feely et al. (RU #152, Annual Report, 1978) and, unless otherwise noted, that is the reference for the following description.

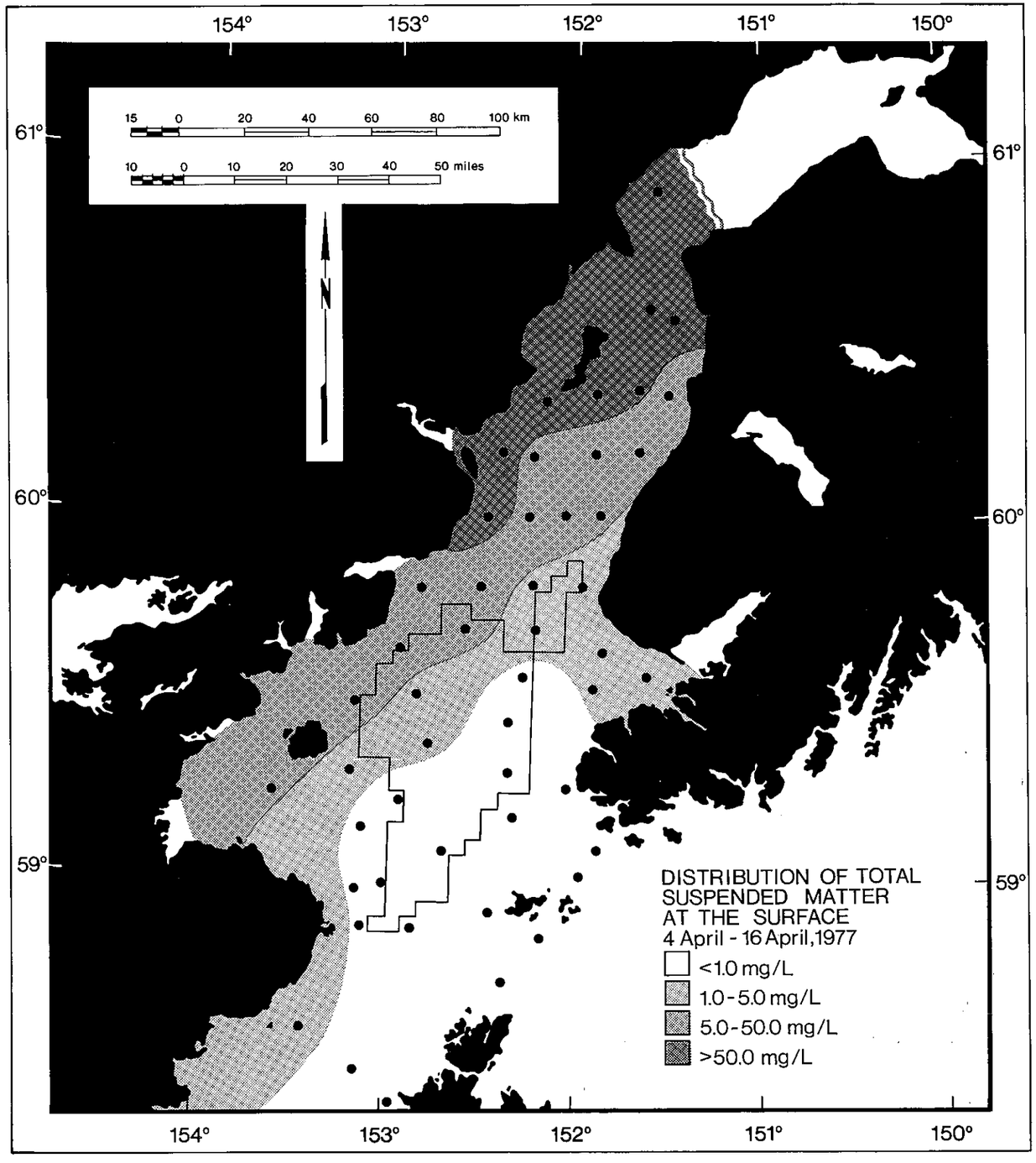


Figure D.6.1a Distribution of total suspended matter at the surface and at 5 m above the bottom, April 1977 (Feely et al., RU #152, Annual Report, 1978).

Cook Inlet circulation is driven primarily by tides, with the resulting currents modified by Coriolis effects and bottom topography and basin morphology (see Subtask D.1; Burbank, 1974). A net inward movement of Gulf of Alaska ocean water occurs at the Kennedy (and possibly Stevenson) Entrance. This water moves up the eastern side of the Inlet, and contains between 0.5 and 5 mg/l SPM. In the upper part of the Inlet the water mixes with freshwater runoff -- primarily from the Matanuska, Knik, Susitna, and Beluga Rivers -- which contains high concentrations of glacial rock flour. This increasingly turbid mixture moves south along the western side of the Inlet, and typically contains between 5.0 and 100 mg/l SPM, with highest concentrations near the Forelands and Tuxedni Bay. From here it moves to the southwest and leaves Lower Cook through Shelikof Strait.

Figures D.6.1a and b show the distribution of SPM at the surface and at 5 m above the seafloor for samples collected in spring and summer (Feely et al., RU #152, Annual Report, 1978). The plots reveal no significant differences between the surface and near-bottom distributions, suggesting that cross-channel SPM gradients exist throughout the water column. Similar concentrations and geographical distributions in surface samples were reported by Sharma et al. (1974).

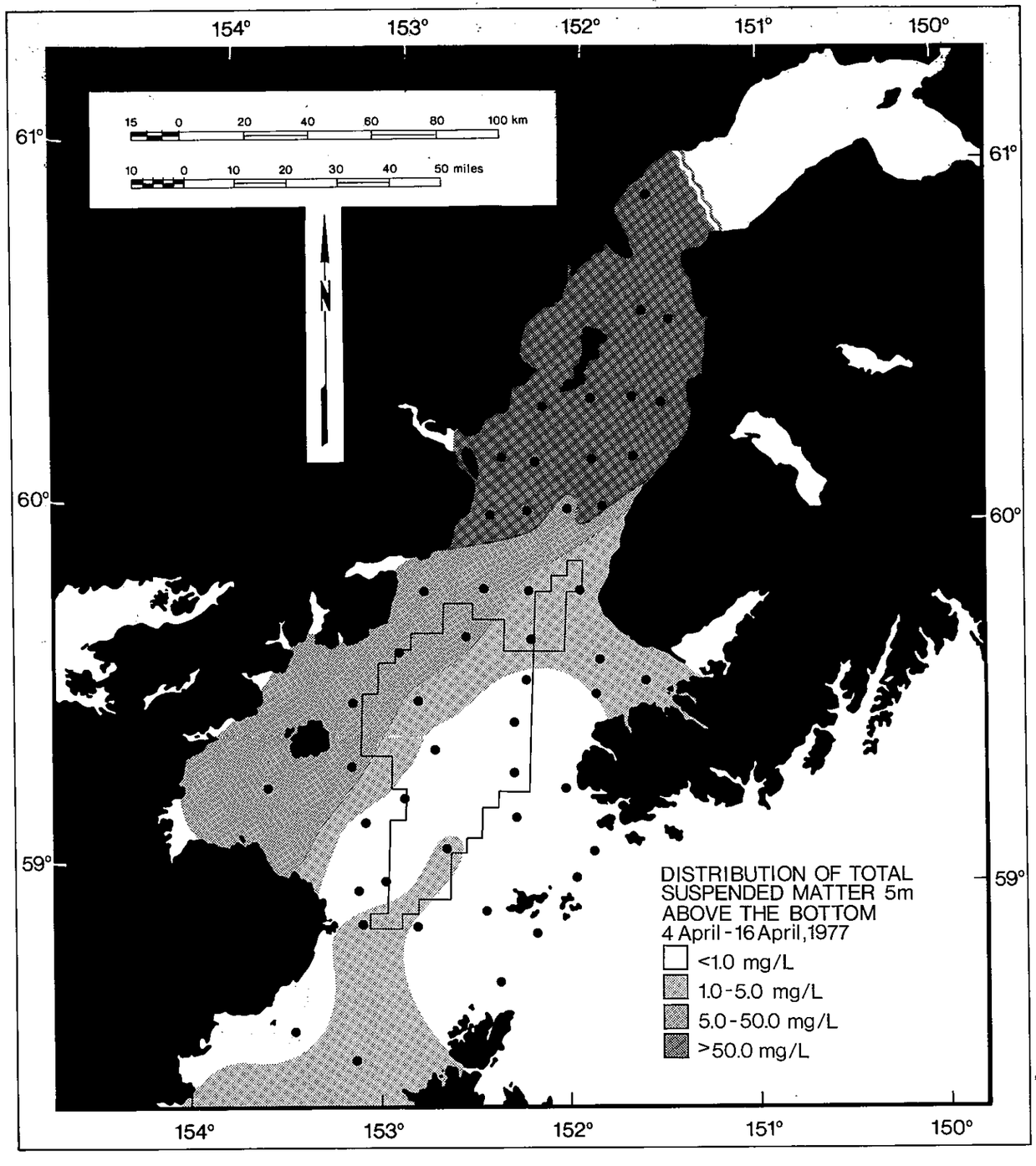


Figure D.6.1a (continued)

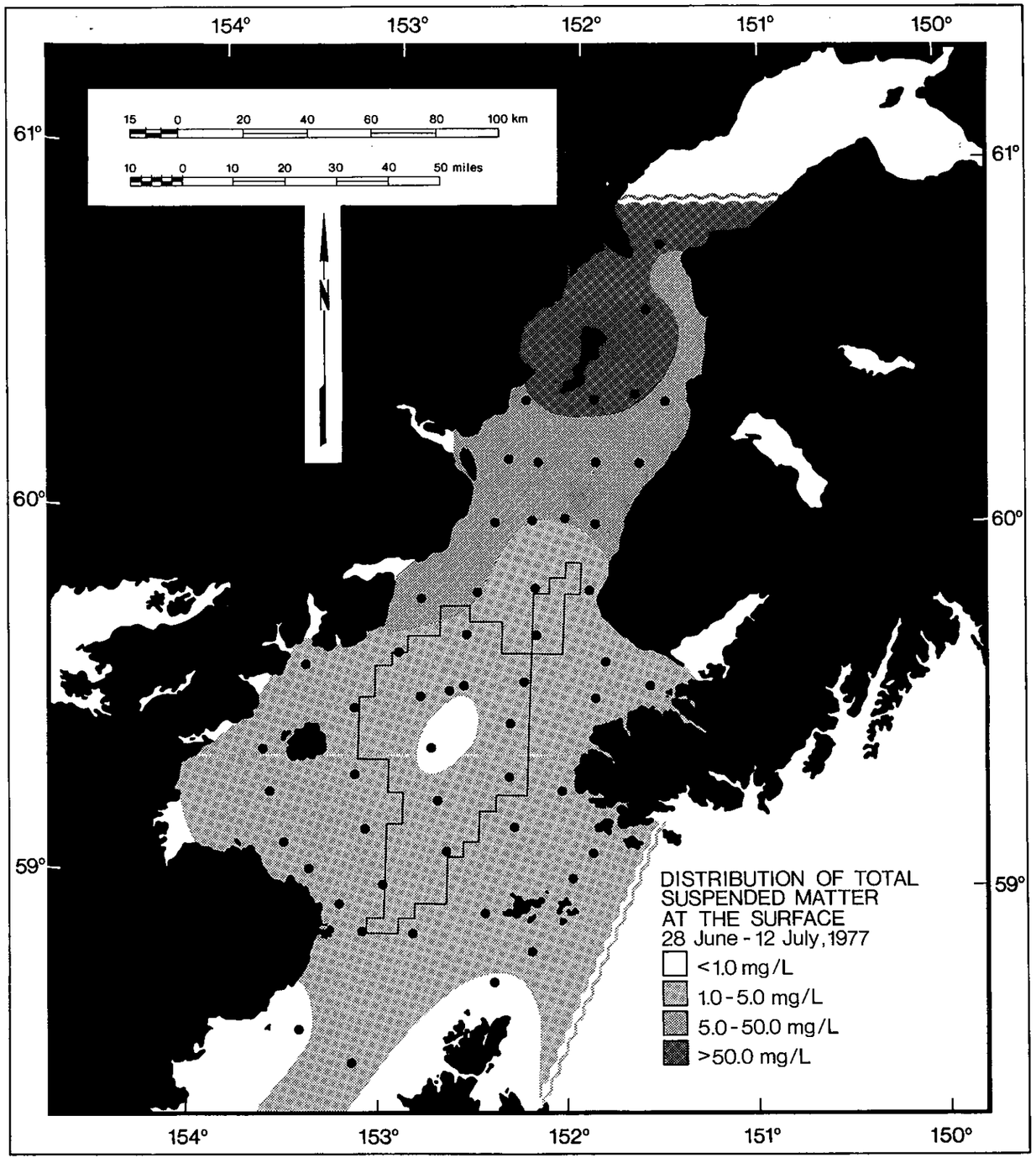


Figure D.6.1b Distribution of total suspended matter at the sufrace and at 5 m above the bottom, June 1977 (Feely et al., RU #152, Annual Report, 1978).

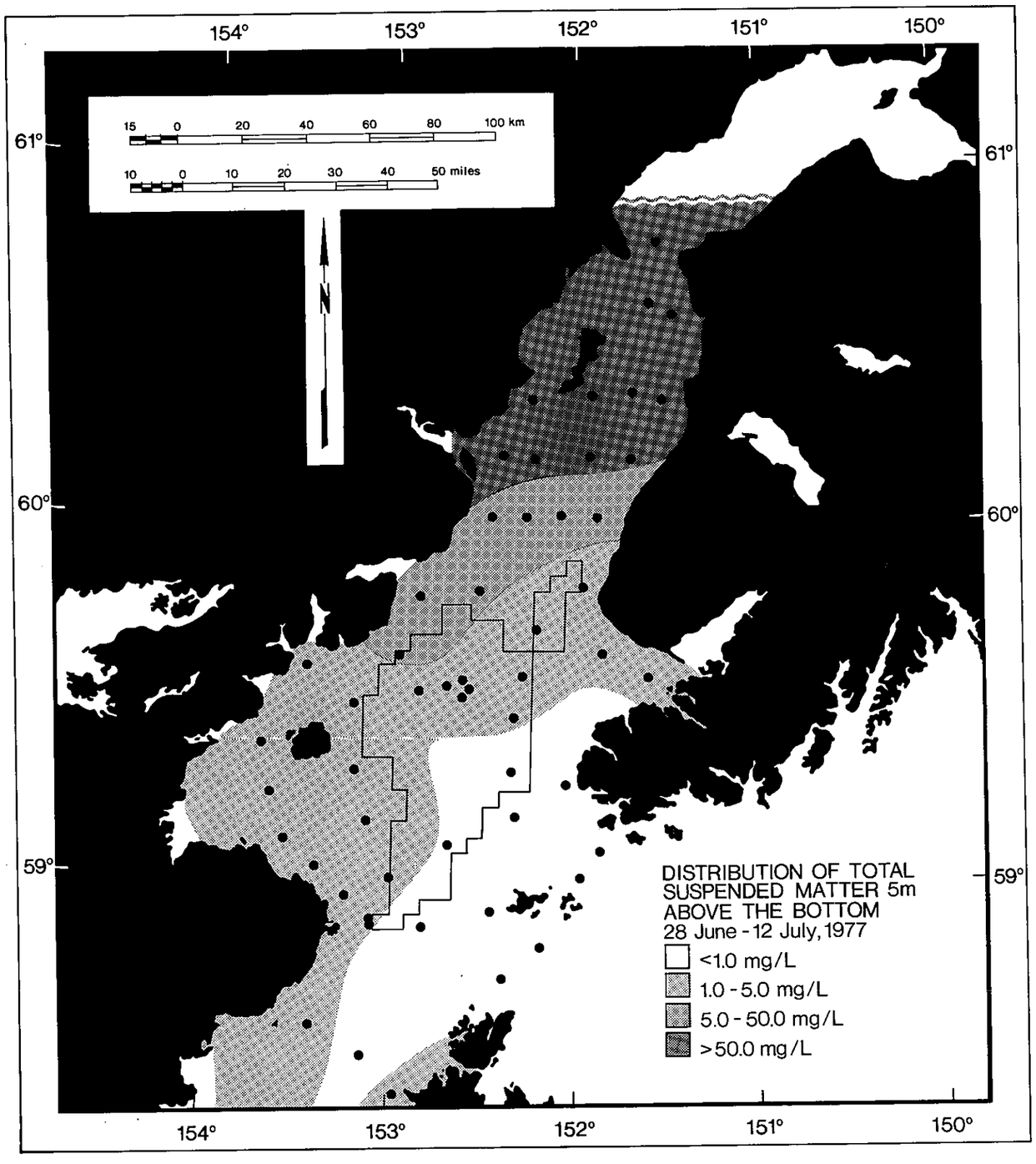


Figure D.6.1b (continued)

Burbank's (1974) study of the correlation between SPM and ERTS imagery produced a similar distribution pattern (Fig. D.6.1c).

Seasonal variations in SPM distribution in Lower Cook Inlet are indicated by changes in horizontal concentration gradients. These gradients are lower (less steep) in the late summer and fall than in the early spring and summer (Feely et al., RU #152, Annual Report, 1978). Those investigators cite three possible causes for seasonal variability: (1) variability in introduction of SPM from land runoff, (2) increased water column stability and lateral mixing in the late summer and fall, and (3) increased productivity on the western side of the Inlet during the summer.

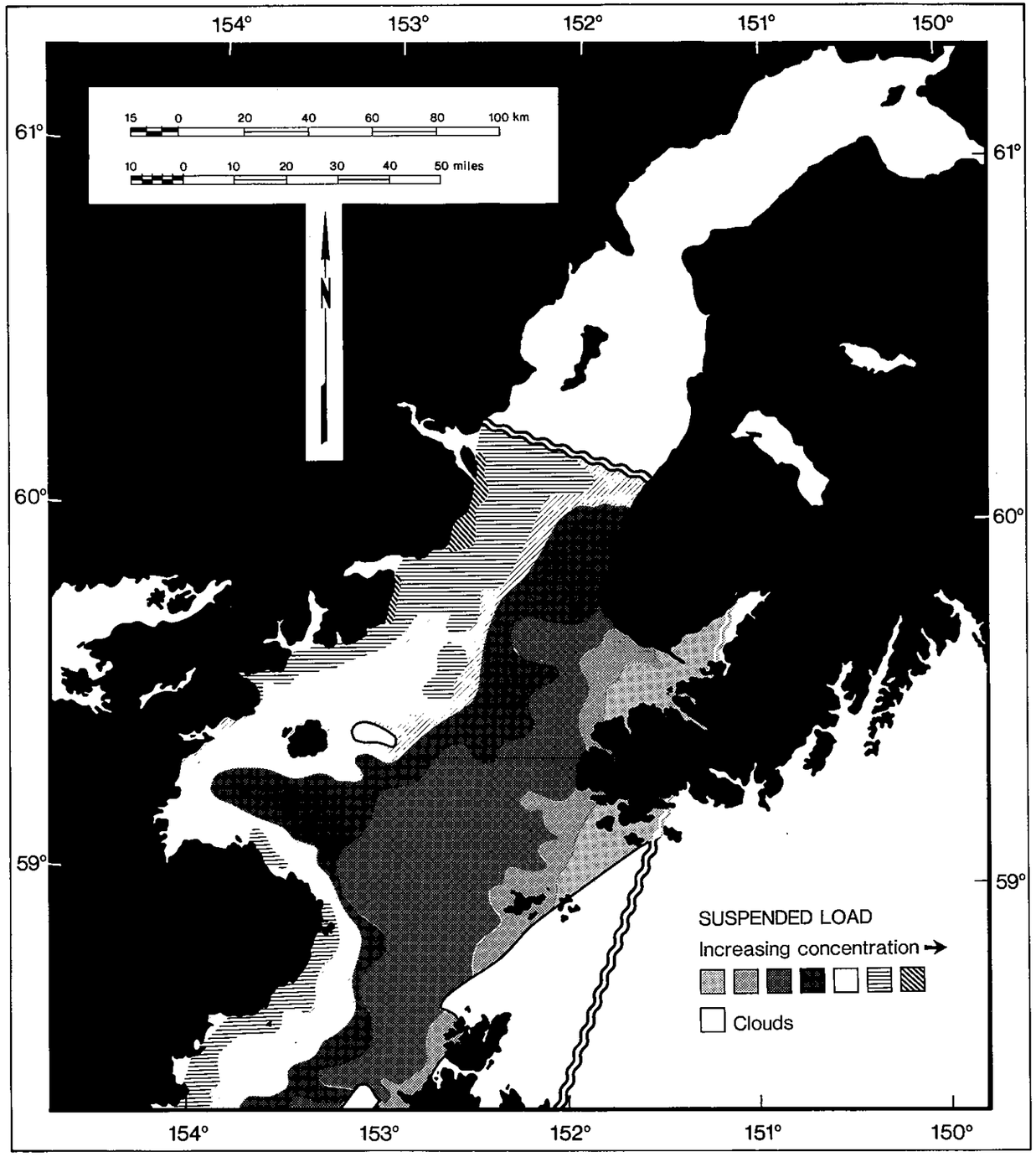


Figure D.6.1c Relative suspended load distribution in Lower Cook Inlet on 4 November 1972, based on interpretation of ERTS imagery (modified from Sharma et al., 1974; cited in Burbank, 1974.

D.6.2 TRANSPORT OF SUSPENDED PARTICULATE MATTER

The horizontal gradient of the direction and velocity of SPM transport follows the seawater circulation pattern in Lower Cook. Vertical transport of SPM (or SPM flux to the seafloor) can be inferred from two sets of data (described below); both suggest that the large amounts of SPM observed in Upper Cook Inlet pass through Lower Cook Inlet with little or no net sedimentation at the seafloor.

First, the sediments in the central part of Lower Cook are unconsolidated coarse-grained Pleistocene sands (Bouma and Hampton, 1976) and bear no resemblance to the materials in suspension. This indicates that sedimentation of the observed SPM at present is minimal. Second, SPM concentration is highly correlated with salinity, which suggests that dilution by seawater inflow from the Gulf is the process controlling horizontal gradients of SPM and not removal of SPM by sedimentation to the seafloor. Though sedimentation may be occurring in coastal embayments, the magnitude of this sediment flux relative to the total SPM in Lower Cook is unknown.

Two series of observations, of 36 and 26 hours duration, from the northern part of Lower Cook west of Tuxedni Bay (Feely et al., RU #152, Annual Report, 1978), reveal the association between SPM concentration and tidal motions, especially for the surface concentrations of SPM (Fig. D.6.2a). Surface SPM concentration reaches a maximum shortly after maximum tidal current velocity. Near the bottom, the periodicity is not so evident, because it is obscured by variations in SPM due both to resuspension of bottom sediment and to advection of SPM with tidal currents.

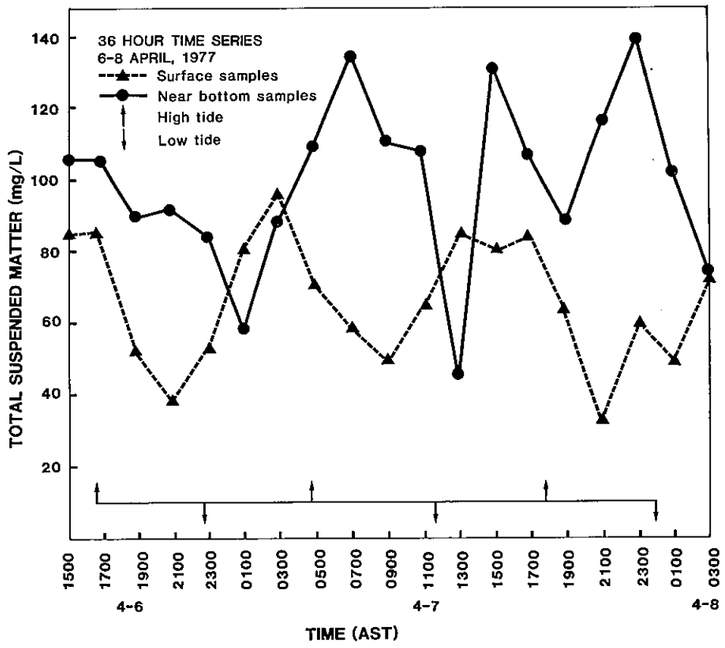


Figure D.6.2a Temporal variability of total suspended matter at the surface and 5 m above the bottom in Lower Cook Inlet (after Feely et al., RU #152, Annual Report, 1978).

D.6.3 OIL/SPM INTERACTION

Experiments have been conducted to determine the accommodation capacity of SPM from Lower Cook Inlet for Cook Inlet crude oil (Feely et al., RU #152, Annual Report, 1978). Preliminary results indicate that the quantity of oil that SPM can accommodate increases in proportion to the initial concentration of oil, with constant salinity and temperature (Fig. D.6.3a). The investigators also confirmed an increase in the oil accommodation ability of the SPM with decrease in temperature as found by Baker et al., (1978).

Particle size distribution studies of Lower Cook Inlet SPM, and of oil/SPM aggregates produced during laboratory experiments reveal a median diameter of 1.9

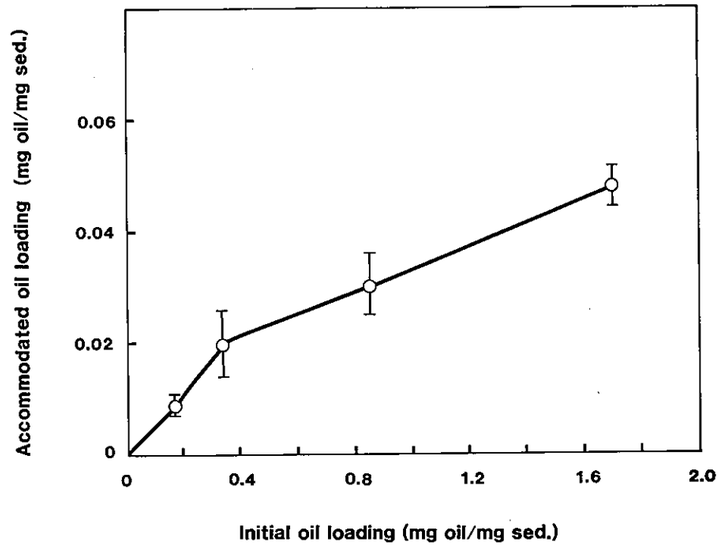


Figure D.6.3a Concentration of Cook Inlet crude oil accommodated by suspended particulate matter, as a function of the initial oil loading (after Feely et al., RU #152, Annual Report, 1978).

μm (range 0.1 to 35.0 μm) for natural SPM and 7.5 μm (range 5.0 to 45 μm) for oil/SPM aggregates. Microscope study of the aggregates showed them to be spherical. As the size of the oil/SPM aggregates increases, the shape of the size distribution remains similar to the shape for natural SPM (Fig. D.6.3b), suggesting that oil/SPM aggregates maintain an optimum size distribution independent of oil loading.

Feely et al. (RU #152, Annual Report, 1978) note that these oil/SPM aggregates should therefore settle at rates proportional to their size and density, which in Lower Cook Inlet "could mean (settling) rates which are higher than expected for ambient suspended matter."

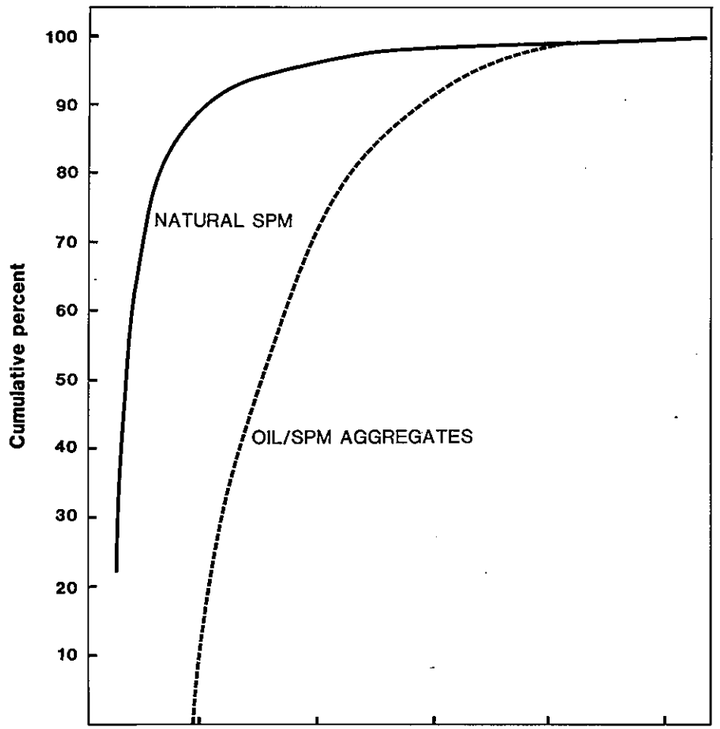


Figure D.6.3b Particle size distributions for surface suspended matter in Lower Cook Inlet, and for oil/SPM aggregates resulting from laboratory interaction studies (after Feely et al., RU #152, Annual Report, 1978).

D.6.4 SOURCES OF SPM

The Gulf of Alaska ocean water which flows into Lower Cook Inlet typically contains 0.5 mg/l SPM, and is rich in biogenic particles compared to lithogenous particles. Terrigenous SPM, predominantly glacial rock flour, is added in Upper Cook Inlet by the freshwater inflow from several major rivers, especially the Susitna and Knik, which account for 70 to 80 percent of the freshwater input (Rosenberg et al., 1967, cited in Burbank, 1974).

During the summer primary productivity along the western side of the Inlet increases SPM by the addition of biogenic particles. The percentage by weight of biogenic particles remains in the range of 5 to 20 percent, however, with lithogenous particles comprising the remaining major portion.

During the winter, Upper Cook Inlet becomes heavily iced. In spring the ice breaks up and drifts towards the lower part of the Inlet, carrying with it large amounts of fine and coarse sediments picked up from the tide flats (Burbank, 1974). The ice melts as it moves down the Inlet and drops its load of sediment, which adds to the SPM. The magnitude of this sediment transport is unknown.

DATA EVALUATION

The SPM distribution and concentration data collected by OCSEAP investigators thus far appear to be of sufficient resolution and precision for studying oil/SPM interaction. Additional field work is needed to better identify ultimate sinks for Lower Cook Inlet SPM. Likely sinks may be the coastal embayments, but insufficient data exist to determine their role in the SPM budget.

Experimental data on oil/SPM interaction are very promising, and it is hoped that additional experiments under a variety of temperature, salinity, and oil-loading conditions (to approximate the range in Cook Inlet) will provide valuable information for mitigating the environmental effects of spilled oil.

SUBTASK D.7 Seafloor Topography

The bathymetry of Lower Cook Inlet is discussed in Section C.3.1, and is shown in Fig. C.3.1a. The bottom features visible today are primarily the result of glacial action during the Pleistocene Age and do not reflect current sedimentation processes occurring in the Inlet. It is possible that a glacier existed in Cook Inlet during the Pleistocene, and that the prominent curving slope ("ramp") in the southern half of Lower Cook is a glacial cirque. A large proportion of the unconsolidated material on the Inlet floor may therefore have been derived from moraines.

In addition to the influence glacial action has had in shaping the seafloor of Cook Inlet, tectonic forces have also changed the topography. The relative high between Augustine Island and Kenai Peninsula (Augustine-Seldovia Arch) is a structural feature associated with tectonism (Magoon et al., 1976). The entire Cook Inlet could be described as a graben structure, i.e., a block of crust bounded by faults (Bruin Bay and Border Ranges; see Fig. C.2.1a) that has been downdropped (Evans et al., 1972). Pleistocene glacial features have been superimposed on the primary structural features.

The depths observed today are greater than in glacial times, when sea level was lowered considerably. During the 1964 Great Alaska Earthquake, the seafloor of Cook Inlet tilted towards the southeast and subsided more than two feet along the southeastern margin (Plafker, 1969, Plate I).

While the surface circulation of Lower Cook Inlet has received recent attention (cf. Burbank, 1977), little is known about the near-bottom circulation. On the basis of grain size and grain surface texture data, it is believed that currents are winnowing the

bottom sediments and transporting them in a southerly direction (Bouma et al., 1978a). The alignment of sand ridges and sand ribbons is parallel to current flow (see Fig. C.4.2a), and submarine television observations have revealed sand moving at velocities of 10 to 14 cm/sec (Bouma et al., 1977a). Bottom currents causing this sand motion may be as great as 50 cm/sec, or about 1 knot (Bouma et al., 1978a).

In general, ocean water floods into the Inlet with the tides through Kennedy Entrance and is steered along the prominent slope between Augustine Island and the Kenai Peninsula, the glacial cirque-like feature mentioned above. It ultimately turns south, following the topography, towards Shelikof Strait. Part of this main tidal flood branches off to the north of the cirque and splits again, with one branch moving into Kachemak Bay and the other continuing up the east side of Cook Inlet (Bouma et al., 1978a).

SUBTASK D.9 Ice Dynamics and its Effects on Transport of Oil and Safety of Structures

D.9.1 ICE DYNAMICS

Ice forms in Upper Cook Inlet in early December and usually breaks up by late April. Much of the ice is formed from river water freezing on the tidal flats of Upper Cook Inlet. The currents and winter winds both tend to move ice southward through the Forelands, past Kalgin Island and down the west coast of Lower Cook Inlet. South of the Forelands ice is open pack with small floes (Peyton, pers. comm.).

The pack ice can extend as far south as Cape Douglas along the western shore and as far south as Anchor Point along the eastern shore. It is at its maximum in late January. In general, the ice concentration in the central and eastern parts of the lower inlet are low. Ice accumulates densely in Kamishak Bay as far offshore as Augustine Island. Although some ice in Kamishak Bay is formed locally, most drifts down from the upper Inlet (Gatto, 1976).

Ice floes in Cook Inlet may be as large as 320 m across and 1 m thick. Ice as thick as 12 m reported in Upper Cook Inlet is the result of successive freezing on tidal flats, forming layer upon layer of ice (Gatto, 1976). Pressure ridges up to 6 m have been observed (Blenkarn, 1970).

No studies have been made to date on either the hazards of ice to structures or the transport of oil by ice in Lower Cook Inlet. Oil uptake and transport by ice would occur if the two substances were brought into contact. It seems equally obvious that damage to vessels or structures could occur if contact were made with ice floes of the size reported in Cook Inlet. The area where these problems are most likely is the western third of the Inlet.

DATA EVALUATION

Although it lies south of regions known to have sea ice problems, Lower Cook Inlet can have sea ice (actually fresh water ice formed on salt flats in Upper Cook Inlet). However, data sufficient for a detailed analysis of ice dynamics have not been collected.

To assess the vulnerability of offshore structures and equipment (and thus to assess probabilities of oil being spilled), information on the extent of the ice and forces upon it must be gathered.

TASK E BIOLOGICAL POPULATIONS AND ECOLOGICAL SYSTEMS

Joseph G. Strauch, Jr., Edward G. Wolf, and Kenneth W. Fucik, SAI

RELEVANCE

OCSEAP's underlying objective is the protection of the environment compatible with oil and gas development. Alaskan ecosystems have evolved over millions of years with minimal human influence. Many of the interactions in these systems are not understood; it is often difficult to assign them precise quantitative values, anticipate the impact of human activities, and determine to what extent such perturbations are inevitable.

With increasing industrial expansion and rapid population growth resulting in a greatly increased need for food, living space, and energy, the world is rapidly losing areas of natural habitat. In Alaska there is still an opportunity to plan for development so that environmental damage is minimized or, in some areas, completely avoided. The data base necessary for such planning, however, is scanty. Task E is an ambitious program whose goal is to make up this lack.

Before the effects of oil and gas development on the marine biota of Alaska can be predicted its distribution and interactions must be determined. Information on distribution, as well as on the breeding biology, feeding behavior, physical requirements, and physiology of different species can be used to estimate their vulnerability at particular locations and times of the year.

The cycling of nutrients and energy through biological communities is dependent on complex predator-prey relationships or food webs. Microbes, plankton, and larger species are all integral members of these food webs. Both marine and terrestrial species may be important members of the same food web. The loss or drastic reduction in population of even one key member of these webs would have detrimental effects on many other species. The details of these interrelationships are little understood, and many key species have not yet been unidentified.

The fishing industry is an important component of the economy of the State of Alaska. In addition, Japan, Russia, and Korea exploit a large portion of the Alaskan fisheries. The recent establishment of a 200-mile territorial limit will require wise management of oil and gas development based on broad ecological studies if serious political and resource-conflict problems are to be avoided.

The information presented below represents a significant increase over previous knowledge of Alaskan ecosystems. Of necessity much of it is preliminary, incomplete, and descriptive. It is, however, a first step toward an understanding of what needs to be done. Some OCSEAP research on the dynamics of these natural systems is already in progress, but much more is required. Work to date has demonstrated the rich and pristine nature of the Alaskan marine environment. If this information helps planners to better preserve this heritage, the effort expended in its gathering will have been a good investment.

CONCLUSIONS

Mammals

Included are current distributional data on the mammals of Cook Inlet. Except for the sea otter, Enhydra lutris, there are few studies of the mammal populations of Cook Inlet and little knowledge is available for most of them, thus the information presented here is preliminary.

Sea Otter

The sea otter populations of Cook Inlet are expanding in numbers and range, as are those of the Kodiak Archipelago (Schneider, RU #240, Final Report, 1976), into regions occupied before almost total destruction of them by commercial hunting at the turn of the century. The population along the southern coast of the Kenai Peninsula now appears to have stabilized, while populations in and near Kachemak and Kamishak Bays are still spreading. The most recent information (Schneider, RU #240, Final Report, 1976) indicates that approximately 2000 to 3000 sea otters occupy the Inlet.

Considerable evidence, both from California (Estes and Palmisano 1974) and the Aleutian Islands (Palmisano and Estes 1977; Simenstad, Estes, and Kenyon 1978), indicates that the sea otter is a key species in determining the structure of nearshore communities. Sea otters control herbivorous invertebrate populations and indirectly affect wave exposure and the composition of the rocky intertidal community (Fig. Ea). In areas with dense sea otter populations sea urchins, limpets, and chitons are reduced to sparse populations of small individuals; macroalgae flourish, providing food and shelter for a variety of organisms, especially crustaceans; wave exposure is reduced, siltation increases, and overall productivity is high. In contrast, similar areas with few or no sea otters have dense populations of large herbivores; macroalgae are severely overgrazed; bare rocky substrates are exposed to wave action; and overall productivity is low.

Sea otters are especially vulnerable to the effects of petroleum development in the Inlet. Because they rely on their dense pelage for insulation, fouling of it leads to almost certain death. Sea otters

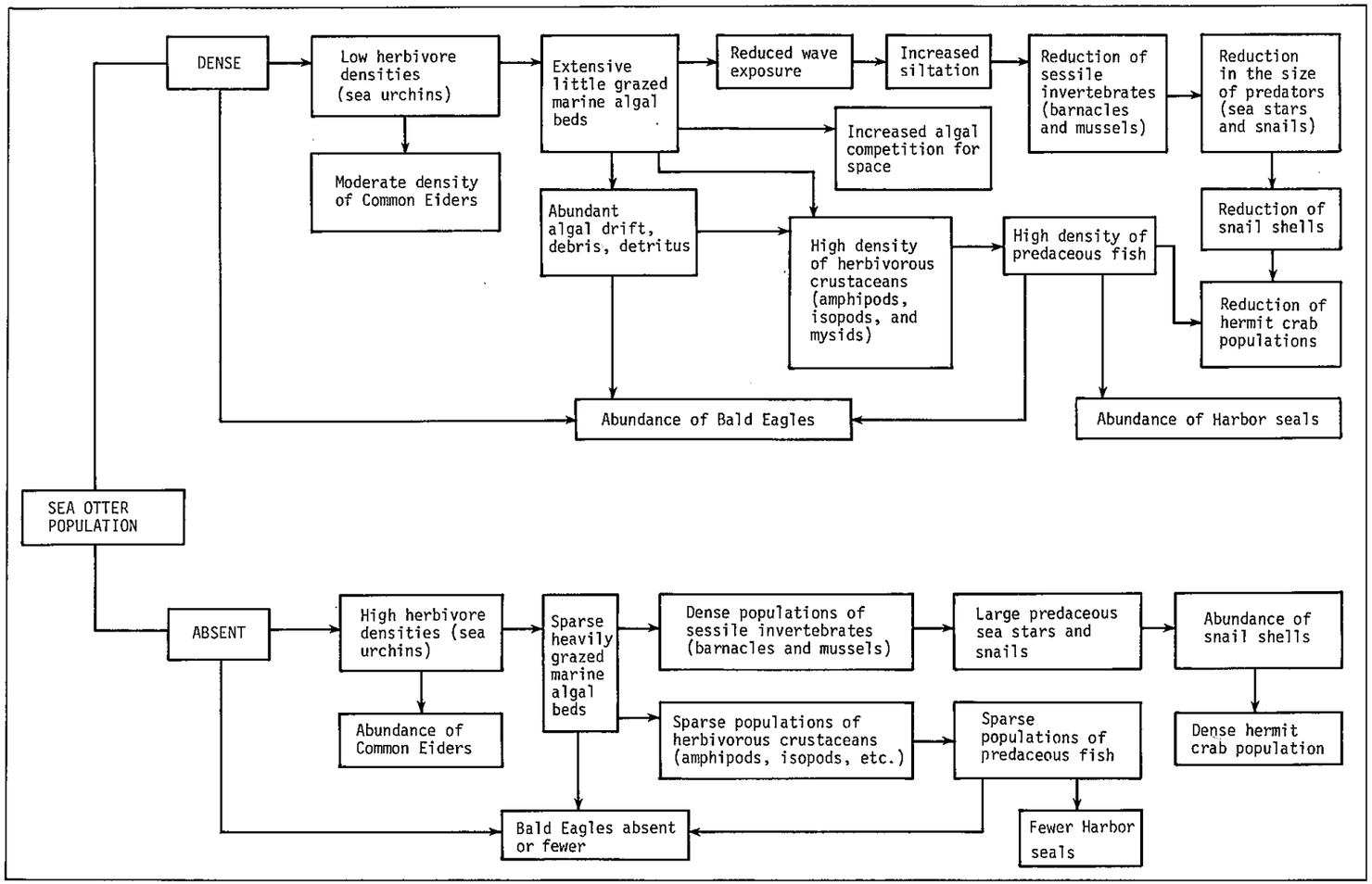


Figure Ea Diagram of the interactions within nearshore communities with and without sea otter populations (Palmisano and Estes, 1977).

have a basal metabolic rate about 2.5 times that of other mammals of their size. Captive animals support their metabolic rate by consumption of about 25 percent of their body weight daily. The species thus is also vulnerable to any reduction in its food supply. Oil pollution would probably cause the death of many sea otters, endangering some of the Inlet populations and seriously retarding the repopulation of former sea otter habitat.

Pinnipeds

Northern sea lions (Eumetopias jubatus) and harbor seals (Phoca vitulina) occur in the Inlet, but the area apparently is not as attractive to these species as is the Gulf of Alaska. There are no major haulout areas or rookeries of the northern sea lion within the Inlet (Calkins and Pitcher, RU #243, Annual Report, 1977), but one of the major rookeries in the Gulf of Alaska is on the Barren Islands, which lie just outside of Kennedy Entrance (see the Kodiak Interim Synthesis Report for details). The harbor seal is distributed along the shoreline of most of the Inlet, with many scattered areas of high density (ADF&G, 1973); however, no systematic census of this population has been made. A high count of about 1200 was found on Augustine Island in September, 1976 (Pitcher and Calkins, RU #229, Annual Report, 1977). A large population of harbor seals is also found on the Barren Islands.

The effects of oil pollution on pinnipeds are poorly understood. Geraci and Smith (1977) have shown that direct contact with oil causes eye irritation in seals and that ingestion of oil can cause liver damage. Their experimental conditions were similar to those which would be expected during a large oil spill. The effects of low-level chronic pollution are unknown. Harbor seals are known to panic easily when disturbed by humans or low-flying aircraft. If this occurs during the pupping season, young pups separated from their mothers during a panic face almost certain death (Johnson, RU #229, Annual Report, Appendix I, 1977). Geraci and Smith (1977) suggest that seals stressed by adverse environmental conditions, such as a low food supply, may be selectively affected by oil spills.

Cetaceans

Fiscus, Braham and Mercer (RU #68, Final Report, 1976) record the occurrence of seven species of cetaceans in Cook Inlet. Except perhaps for the beluga whale (Delphinapterus leucas), current knowledge of these species consists of little more than miscellaneous sightings, which are of little value in estimating their spatial and temporal distributions. The minke whale (Balaenoptera acutorostrata) and Dall porpoise (Phocoenoides dalli) are the only species other than the beluga known to occur more than incidentally in the Inlet. The harbor porpoise (Phocoena phocoena) may also occur in large numbers. The beluga is believed to be a permanent resident of the Inlet (population about 500) (Fiscus et al., RU #68, Final Report, 1976). Sightings in May through September are almost entirely restricted to the upper Inlet. No information on their seasonal movements is available, but in other areas the species is known to move to deeper waters in the winter. The Cook Inlet population is believed to be near the maximum size which can be supported by the local environment (Rausch, 1975, cited in BLM, 1977). This population appears to be completely isolated from the nearest beluga population in Bristol Bay, about 1200 miles away (Sergeant and Brodie, 1969; Harrison and Hall, 1978). It is highly unlikely that animals from other populations would move into the Inlet if the Cook population were destroyed or drastically reduced.

Little is known of the effect of petroleum on cetaceans. Their smooth skin and thick blubber suggest that oil would not adhere to them nor interfere with their thermal regulation. Direct contact with oil may irritate their eyes, as it does in pinnipeds, and, if inhaled through their blowholes, it may contaminate their lungs and lead to pneumonia. It is believed that the open-water cetaceans can avoid the effects of oil spills by quickly moving to uncontaminated areas. Species such as the beluga, however, which depend on shallow waters, could be exposed to contaminated prey or forced into less hospitable deeper waters (Blood, 1977).

Terrestrial Mammals

Several species of terrestrial mammals, especially bears, forage on the Cook Inlet coast line. The major threat to these mammals may be contamination of their food supply. Perhaps the most important users of the coastline are brown (Ursus arctos) and black (U. americanus) bears. Both species forage along the shore and in the intertidal zone (ADF&G, 1973). Brown bears are common along the western shore of the Inlet, mainly in areas where brushy growth, tundra, or barren ground border the shoreline (AEIDC, 1974). They make intensive use of stream mouths, especially during fish runs (ADF&G, 1973). Historically, human activities in areas utilized by brown bears have inevitably led to conflict between man and bear, with the resulting destruction of bear populations. Black bears tend to use the shoreline only in forested regions; intensive use is reported for the region north of Tuxedni Bay. Of the large black bear population in the inland regions around Cook Inlet, only a relatively small number use shoreline habitat. Thus, it appears that oil pollution would have little impact on this species. Black bears also seem to be more adaptable to human disturbance than brown bears.

Birds

About 95 species of birds use the marine habitats of Cook Inlet (Erikson, 1977). During the summer breeding loons, grebes, waterfowl, raptors, shorebirds, and perching birds are scattered along the coast wherever suitable nesting habitats are found.

The colonial breeding bird population of Cook Inlet has been estimated to be at least 115,000 (Erikson, 1977). It includes about 67,000 gulls and about 45,000 alcids, with black-legged kittiwakes (Rissa tridactyla) and common murres (Uria aalge) as the most abundant species. An additional 350,000 birds (mostly alcids) nest on the Barren Islands just to the south of the Inlet (see Kodiak Interim Synthesis Report for details). No estimates on the size of the breeding populations of the burrow-nesting storm petrels and small alcids, or of non-colonial species, are available. Almost all of these species feed on the open water and are highly vulnerable to oil contamination of their food and plumage.

The 58 known Cook Inlet bird colonies are concentrated around the Kenai Peninsula (about 15,000 birds) and on the west coast of the Inlet from the southern part of Kamishak Bay to Tuxedni Bay (about 100,000 birds) (Erikson, 1977). Regular human activity near or in colonies will have detrimental effects on their productivity. Frightening birds from their nests can cause desertion and increased predation by gulls.

Winter

The ice-free waters from Kachemak Bay to Gore Point, as well as abundant marine invertebrate populations, make Lower Cook Inlet an important wintering area for about thirty species of marine birds (Erikson, 1977). Only a few species use the open leads in the extensive ice pack along the western side of the Inlet. In February 1976 diving ducks, found mainly on the open water near beaches and unprotected shoreline, and shorebirds, found on mud and sand substrates in bays, made up the bulk of the bird populations (Arneson, RU #3, Annual Report, 1977).

Spring

The bird populations of the Inlet increase dramatically in the spring as thousands of migrants pass through or arrive for the summer. About five times as many birds were recorded in May as in February. Diving ducks (found mainly on open water near beaches or intertidal areas in bays or along unprotected shoreline) shorebirds (found mainly on mud and sand substrates on bays) and gulls (found widely distributed on a variety of substrates) account for the vast majority of the birds observed (Arneson, RU #3, Annual Report, 1977). Most of the staging areas used by waterfowl during this season (Fig. E.3.5a) are considered as highly vulnerable to oil spills (Hayes, Brown and Michael, 1977; see Fig. E.8.1c). Pelagic surveys show diving ducks, gulls, and alcids to be the most abundant offshore birds.

Summer

The inshore bird population of the Inlet declines in the summer as wintering birds and migrants depart for their breeding grounds. Non-breeding diving ducks and breeding gulls and alcids are the most abundant species. Large flocks of shearwaters move into and feed in offshore waters. Densities of pelagic birds often reach 100 or more birds/km^2 in outer Kachemak Bay and near Kennedy Entrance. Breeding concentrations of ducks are found in the Trading-Redoubt Bays area and on the Fox River Flats.

Fall

In the fall migrant and wintering species (mainly waterfowl and shorebirds) reappear, and summering species (mainly shearwaters, gulls, and alcids) leave the area. Dabbling ducks and diving ducks (found mainly on the water near beaches or intertidal areas in bays or along unprotected shorelines) and gulls (found in a variety of habitats) are the most abundant species. Maximum pelagic bird densities have been observed in September (Lensink and Bartonek, RU #337, Annual Report, 1976).

Effects of Pollution

Two major categories of hazards to bird populations in Cook Inlet can result from the exploration for and production of petroleum. The most dramatic and visible is the oiling, death, and littering of beaches with large numbers of birds as a result of oil spillage from platforms, pipelines, terminal and storage facilities, and tankers.

Birds are vulnerable to many effects of oil pollution. Even small amounts of oil fouling plumage can destroy its buoyancy, waterproofing and insulating qualities. Affected birds may drown, starve, or die from exposure. Miller, Peakall and Kinter (1978) reported that ingestion of crude oil causes cessation of growth in young gulls because of alteration in the intestinal transport of nutrients. Gorman and Simms (1978), on the other hand, report that the ingestion of crude oil had no effect on the growth of young chickens, ducks, and gulls and suggest that the experimental birds used by Miller et al. had already finished their natural growth before initiation of the experiment.

While major oil spills have obvious, often spectacular effects, minor pollution events associated with petroleum development, production, and transport may also have important consequences. Most oil-caused mortality of seabirds in Danish waters was found to be the result of generally unnoticed pollution (Joensen, 1972). The soiling of eggs by oil usually causes death of the embryos. The contamination and destruction of prey also have direct immediate and long-range effects on birds (Erickson, 1963). The tendancy of birds to concentrate in small areas could magnify the effect of even a small spill.

The second category of bird hazards involves human disturbances to birds. Drilling rigs in foraging areas or in major migratory pathways and aircraft and vessel traffic and construction activities near coastal nesting and foraging habitat. When adult birds are frightened from their nests by vessel or aircraft noises or by foot traffic, they leave their eggs and young vulnerable to exposure and predation. Repeated disturbance to a seabird colony can cause long-term reduction of productivity (Birkhead, 1977).

Fish

Ecologically and economically important demersal, pelagic and anadromous fin fish populations are found throughout Lower Cook Inlet. Numerically dominant species include pink and sockeye salmon, walleye pollock, Pacific herring, Pacific sand lance, and arrowtooth flounder. All life stages are found throughout the proposed lease area; however, data on abundance and distribution of juvenile and larval stages are generally limited to salmon.

Seasonally, the late spring and summer months are most important because of nearshore aggregations of larval and juvenile forms and adult spawners. Commercial and sport harvest are also greatest during these periods. Oil spills near shore at this time would likely foul catch gear and result in poor harvests as well as kill larvae and juveniles.

Commercial catch statistics (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; ADF&G, 1976b) and Blackburn's (RU #512, Final Report, 1978) baseline

survey indicate that the nearshore regions from the Forelands throughout Kachemak Bay contain the greatest concentrations of fin fish in Lower Cook. On the west side, Kamishak Bay is most important.

Salmon, Pacific halibut and Pacific herring are the most important species harvested commercially. Other flatfish are also caught. The sport harvest is rapidly expanding; salmon, steelhead trout, Dolly Varden and Pacific halibut are the major species caught.

Dominant Species

Nearshore salmonid abundance and distributions and the major migratory routes of maturing salmonids returning to natal streams are well established. Many demersal and pelagic species move up and down the continental shelf for spawning and feeding, but their general behavior throughout the year is poorly understood.

The nearshore region of Lower Cook is an important spawning area for several pelagic, demersal and anadromous species. In the summer maturing salmonids congregate at the mouths of natal streams before migrating upstream to spawn (ADF&G, 1976b). In late spring and summer Pacific herring, chum and pink salmon, and some demersal species spawn in intertidal and shallow subtidal regions (ADF&G, 1976b). Some flatfish are thought to spawn near shore in Lower Cook Inlet in winter and spring.

Few major spawning sites for species other than Pacific herring and salmon have been identified. The abundance of flatfish eggs and larvae in the Kachemak and Kamishak Bays indicates that these areas may be used extensively for spawning.

Larval Distribution

Larvae are most abundant in Kachemak and Kamishak Bays, peaking in April and May and July through August (English, RU #424, Annual Report, 1977).

Juvenile Distribution

Large numbers of juvenile smelt, salmon, herring and sand lance feed in the nearshore areas of Lower Cook during spring and summer. Although juveniles of other species occur in Lower Cook, quantitative data on distribution, abundance and seasonality are scarce.

Migratory pathways have been poorly defined; however, juvenile salmonids are known to follow nearshore routes when moving out of the Inlet. Other species show a seasonal movement across the shelf. Fishes other than salmon may move out of the Inlet at certain times.

Seasonal Productivity

Summer is the most productive season for commercial fishing, with sizable catches of salmon during June, July, and August. Pacific halibut are also taken during this period.

Catch statistics are abundant for salmon; data on the harvest of other species are few. Catches of "other species" are influenced by the size of salmon harvests and market values of the catch.

The major commercial fishing areas are the nearshore salmon fisheries. Halibut are taken primarily along the east coast from Kenai to Homer and in Kamishak Bay. Herring are taken near shore in Kachemak and Kamishak Bays.

The summer sport fishery is expanding in Lower Cook. In the lower Inlet marine sport fishing is limited to the east side in the Kachemak Bay region. Sport fishing for anadromous species occurs near shore along the entire east side, particularly near the mouths of major streams.

Food Dependences

The diets of juvenile forms of major fish species occurring in Lower Cook Inlet include insects, invertebrate and fish larvae, and small crustaceans. Stomach contents from juvenile pink salmon, Oncorhynchus gorbuscha, consisted mainly of calanoid and harpacticoid copepods, fish larvae, and insects. Composition of the stomach contents of adult demersal fish species varied according to where they fed. Benthic invertebrates such as molluscs (Macoma, Spisula), crustaceans (Crangon dalli, Pandalus borealis, Chionoecetes bairdi) echinoderms, and hydroids as well as small fish predominate in the diets of cod, sole, and greenlings. Few specific data are available for the pelagic species of Lower Cook Inlet, though crustaceans and fish appear to be major components of their diets.

In an attempt to identify key prey species in fish diets, theoretical food webs have been constructed. These models can be manipulated to predict how stress on one part of the ecosystem will affect the whole. They are thus highly useful in predicting the effects of oil spills.

Food webs constructed from stomach analyses for three species of demersal fish (Myoxocephalus sp., Gadus macrocephalus, Hippoglossus stenolepis) indicate that crangoid shrimp, the Tanner crab, C. bairdi, and several fish species are key species in their diets. These conclusions are generally supported by other available data.

Benthic Community

The benthic invertebrates of Lower Cook Inlet are major components of the food web which supports several commercially important fish and shellfish species (see Fig. E.6.2a). Data on population dynamics and life histories generally are available only for commercially important species. Community structure can usually be correlated with substrate type. Overall, crustaceans dominate benthic communities, with polychaetes usually dominant in infaunal communities. The largest commercial catch of crustaceans is taken in Kachemak Bay. Since sediments would serve as the primary sink for hydrocarbons in marine environments, the benthos would be particularly vulnerable to oil spills.

Littoral Habitat and Biota

Six basic intertidal substrates were identified and have been listed in order of increased vulnerability to oil spills: pavement or bedrock; beach or reef; sand beach; mudflats; sand/gravel flats; gravel/cobble beach and boulder field.

With the exception of Kachemak Bay, the substrate of the eastern side of the Inlet, consists mainly of gravel and cobble. In contrast, habitat diversity on the western side is much greater because of greater substrate diversity and differences in turbidity, salinity and wave exposure (Lees, RU #417, Final Report, 1978).

In comparing the biotic diversity of the two coasts, tidal and subtidal communities of the eastern shore were more diverse. This anomaly has been attributed to increased stress on the western shore during cold weather. Stress factors include high turbidity derived primarily from glacial flour runoff, sedimentation, lower salinity, and ice abrasion. The Cook Inlet circulation system is the primary cause of the exposure of the western shore to these stresses. Thus, while diverse mature assemblages of organisms exist on the eastern shore, the west side of the Inlet, in spite of greater habitat diversity, has less diverse assemblages of pioneer and juvenile species such as barnacles and light algal coverage.

The littoral communities have been divided by Lees (RU #417, Final Report, 1978) into four vertical zones each with a composition of dominant flora/fauna generally distinct from adjacent zones. These zones are the upper intertidal (that area above mean sea level, MSL); the middle intertidal (that area between MSL and the mean lower low water, MLLW); the lower intertidal (that area from MLLW to extreme low water, ELW); and the shallow subtidal zone. Though the presence or absence of a given species in a zone is dependent on many factors, tolerance to varying periods of exposure is of key importance in vertical distribution. The varying tolerance of the organisms to the range of conditions (desiccation, temperature changes, varying salinity, etc.) presented by tidal changes promotes the development of a diverse community throughout the tidal range. Changes in water levels during the tidal cycle make these communities particularly susceptible to contaminants, since the entire intertidal area becomes exposed to surface-confined pollutants such as the lighter oils. Ecological damage to entire communities could occur.

The complexity of organization of the littoral zone ecosystem is increased because more than one substrate or habitat type is found in each vertical zone. At least four distinct habitats have been designated according to substrate type (Lees, RU #417, Final Report, 1978): rocky, sand, mud, and mixed. Thus the littoral zone is a mosaic of distinct communities, each with varying levels of tolerance to contaminants. The rocky intertidal habitat generally shows a transition from a barnacle-dominated community in the upper littoral zone to a macrophyte-dominated one in the lower intertidal. Soft substrates exhibit less dramatic changes in community composition, with the general intertidal zone dominated by suspension and deposit feeders, such as the bivalves Mya and Macoma and a polychaete Nephtys.

The duration of exposure to contaminants also depends on substrate type. Whereas exposed areas such as the rocky intertidal may suffer from contaminant exposure only for short periods, soft substrates are sinks for many contaminants, and effects on infaunal communities there are of much longer duration.

Finally, though very few data are available, the lowest reaches of the rocky intertidal and nearshore eelgrass beds are critical to the life cycle of such commercially important species as the king crab, Paralithodes camtschatica and Dungeness crab, Cancer magister, (Lees, RU #417, Final Report, 1978; Anonymous, 1975). Until more is known of the critically important seasons and habitats in the life cycle of these and other valuable species, realistic predictions of their vulnerability to the effects of oil and gas development will not be possible.

Plankton

The distribution and production of phytoplankton are strongly influenced by chemical and hydrographic conditions. Dominant species appear to be distributed according to light and nutrient levels. The timing of bloom periods is influenced to a large degree by stabilization of the water column. The highest productivity within the Inlet is found in Kachemak Bay.

The patterns of phytoplankton production and nutrient dynamics within Kachemak Bay suggest a long residence time of water within this bay.

Zooplankton populations within Lower Cook Inlet are dominated by crustaceans, particularly copepods. Periods of maximum zooplankton abundance coincide closely with phytoplankton blooms. Meroplanktonic invertebrates are present through much of the year, but periods of maximum abundance vary temporally and spatially depending on the species.

Kachemak Bay is the richest area of Lower Cook Inlet in numbers of organisms, but its zooplankton populations are less diverse. This is believed to be caused by the inability of deep-water plankters to adapt to the shallower conditions in the Bay. Because of the unique hydrography of Kachemak Bay, the periods of maximum zooplankton abundances there differ from those in the rest of the Inlet. Cook Inlet zooplankton population dynamics correspond fairly closely with zooplankton population cycles in the more marine waters of the Gulf of Alaska.

A major constituent of the meroplankton are pelagic fish eggs, many from species of commercial importance. Most planktonic eggs from Lower Cook Inlet were those of flatfish. They were most abundant in or near Kachemak and Kamishak Bays. Areas of least abundance were in Northern Cook Inlet and near the middle of the Inlet between Kachemak and Kamishak Bays. The distribution observed was attributed to currents and the exisence of discrete spawning beds.

Planktonic eggs are dispersed by currents; this means of dispersal makes them highly vulnerable to being smothered by oil-laden surface water and prevents their escape from contaminated areas.

Microorganisms

Microbial populations in marine waters are important in many ways. As a food source for numerous marine species, bacteria also have a significant role in recycling matter through the ecosystem. In polluted areas bacteria which degrade hydrocarbons are potentially valuable in the degradation and removal of contaminants from the system. Certain pathogenic bacteria represent a health hazard to man.

At present, the distributions of the heterotrophic and chemotrophic microorganisms in Cook Inlet have been mapped. Very little data exist for pathogenic organisms, however. The distributions of the heterotrophic organisms seem to be closely correlated with hydrographic and associated chemical patterns in the Inlet. This may be caused by the association of the microbes with suspended particles being transported from the upper portions of the Inlet. Hydrocarbon-degrading organisms are most abundant in areas of known hydrocarbon contamination by petroleum.

The responses of Cook Inlet bacterial populations to environmental stresses have been studied only peripherally. Experimental exposure to oil reduced the number of colonies and microbial respiration rates. However, laboratory studies and data from the Beaufort Sea suggest that the effect was short-lived and decreased with extended exposures.

KEY CONSIDERATIONS

- The offshore Inlet is nearly pollution-free and historically has experienced very little change in environmental conditions. For this reason many organisms may be unable to cope with sudden environmental changes.
- Because of the currents entering and leaving Cook Inlet, areas along the southern coast of the Alaska Peninsula and the Aleutian Islands would be affected by any major release of contaminants into the Inlet.
- Kachemak Bay is an important area for hatching and recruitment of fish and invertebrates; it is heavily used by migrant and wintering bird populations.
- Sea otters are a key species in determining nearshore community structure. The current increase in their populations in the Inlet could be retarded or halted by oil pollution, since they are particularly vulnerable to oil contamination.
- Because of complex food web interrelationships, oil spills affecting one species could affect organisms occupying other trophic levels.
- Petroleum hydrocarbons and heavy metals could accumulate in some sediments, leading to long-term exposure to benthic organisms, several of which are either key members of food webs or of commercial importance.
- Petroleum hydrocarbons and heavy metals can be accumulated at least temporarily within the body tissues of most fish and invertebrates. This type of contamination may seriously disrupt food webs, change the population dynamics of many organisms, and enter human food supplies.
- Cook Inlet supports an important fishery; nearshore waters are nursery grounds for many species. Larval and juvenile fish and crustaceans, especially those concentrated in the upper layers of inshore waters and tidal areas, are particularly susceptible to pollution. Depending on the location and time of the year, oil spills could destroy entire year classes, which in turn could reduce populations far into the future. Species such as pink salmon, which use the inlet for spawning, nursery, and feeding grounds, are especially vulnerable. The

effects of chronic pollution, certain to occur during the projected life of the oil field, are not well understood but may lead to the reduction in numbers and vigor of some populations. There is a large potential for resource-conflict between the oil and gas industry and commercial and sports fisheries.

- The Cook Inlet beluga whale population is probably isolated from other populations of the species and may be genetically distinct. It is unlikely that any reduction in population would be compensated by migrants from other areas.

SUBTASK E.1 Seasonal Density Distribution, Critical Habitats, Migratory Routes, and Breeding Locales for Marine Mammals

E.1.1 SEA OTTER

At the turn of the century, sea otter (Enhydra lutris) populations in and near Cook Inlet were reduced to remnants in Prince William Sound, the Kodiak Archipelago, and Kamishak Bay. The recovery of these populations was slow until the 1960's, when observations indicated rapid increases in numbers, followed by the spread to new areas (Schneider, RU #240, Final Report, 1976). The southern shore of the Kenai Peninsula was probably repopulated by animals from expanding populations in Prince William Sound and perhaps the Barren Islands (Fig. E.1.1a). During the 1960's populations grew and extended around the western end

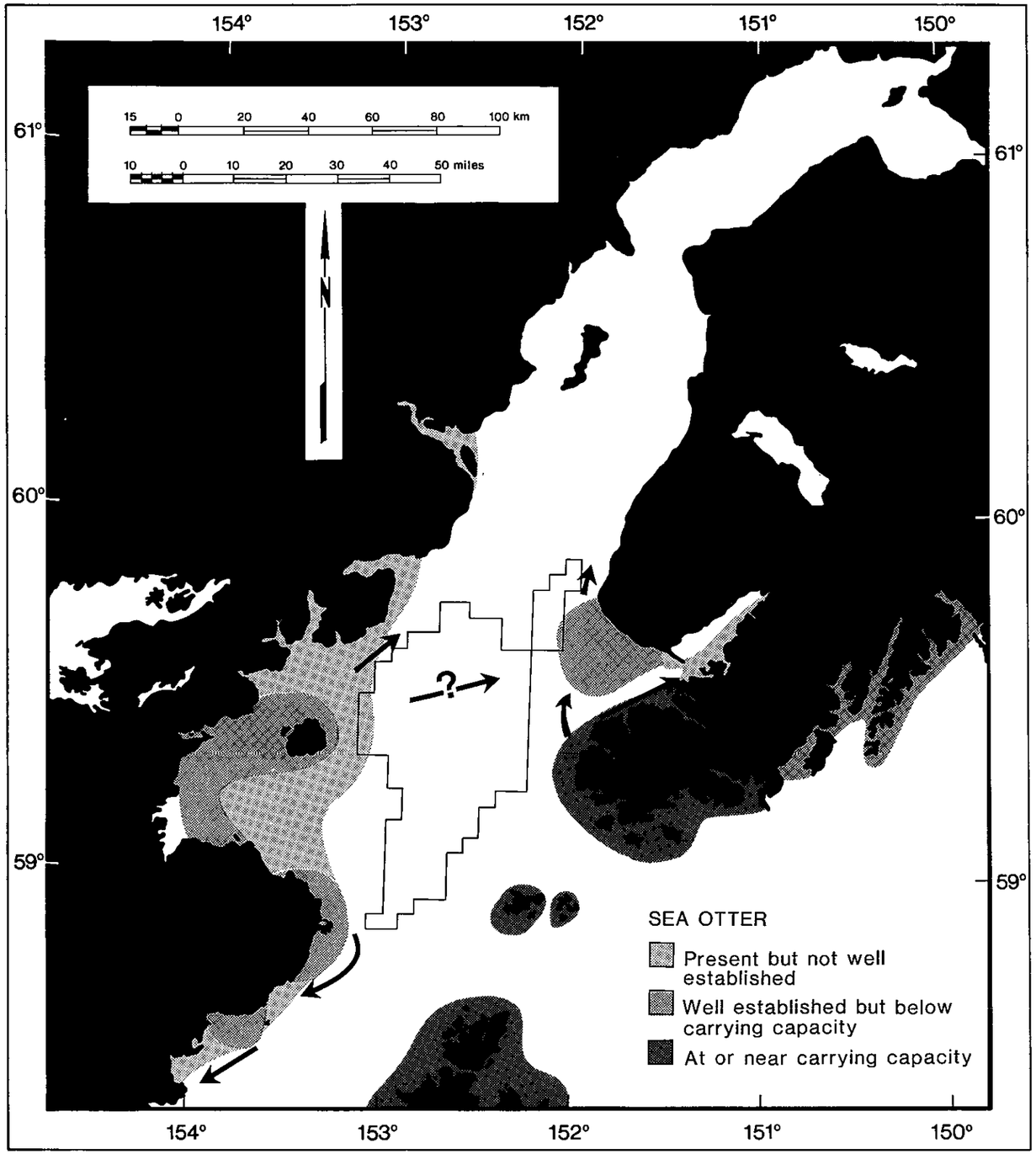


Figure E.1.1a Distribution and range expansion patterns of sea otter populations around the Kenai Peninsula and Lower Cook Inlet (Schneider, RU #240, Final Report, 1976; pers. comm.).

of the Kenai Peninsula into southern Kachemak Bay. No major changes were reported for this population between 1970 and early 1975, although reports of sightings increased in Kachemak Bay. In 1975 there was an increase of sightings in the area between Homer and Anchor Point, where a survey in 1976 found a "substantial number of sea otters . . . dispersed over a large area." Available data indicate that a similar growth and spread of the Kamishak Bay population also occurred during the 1960's. This population appears to have spread from around Augustine Island to the north and also to the southwest around Cape Douglas to the vicinity of the Shakun Rocks. Since potential sea otter habitat extends across Cook Inlet, the Kachemak and Kamishak Bay populations may eventually become continuous. At this time it is difficult to predict the eventual northern limit of these populations. Although good population estimates are not available for these areas, Schneider (RU #240, Final Report, 1976) reckoned there were at least 750 otter around the Kenai Peninsula, about 400 in the north Kachemak Bay population, between 500 and 1000 in Kamishak Bay, and another 500 to 1000 southwest of Cape Douglas.

The distribution of sea otters within Cook Inlet closely matches that of the macroalgal cover (Lees, RU #417, Final Report, 1977; Fig. E.9.1a). While historic data are lacking it appears that the same interactions between sea otters and macroalgae reported elsewhere (Estes and Palmisano, 1974; Palmissano and Estes, 1977; Simenstad, Estes and Kenyon, 1978) are taking place in the Inlet.

Sea otters are rather sedentary in their habits and use Cook Inlet for their entire life cycle. They are especially vulnerable to oil spills since fouling of their pelage leads to death through loss of insulation (Fig. E.1.4b).

E.1.2 PINNIPEDS

Five regularly used haulout areas of northern sea lions (Eumetopias jubatus) have been identified along the southern coast of the Kenai Peninsula west of Two Arm Bay (Calkins and Pitcher, RU #243, Annual Report, 1977) (Fig. E.1.2b). Almost 5000 animals, most of them on Outer Island, were found in June 1976 (Fig. E.1.2a). Several other haulout areas and a major rookery occur on the Barren Islands (see the Kodiak Synthesis Report). They use the area for their entire life cycle with a pupping and breeding season extending from late May to mid-July (Fig. E.1.4b). Harbor seals (Phoca vitulina) occur along almost the entire Cook Inlet shoreline (ADF&G, 1973; Fig. E.1.2b). A concentration of 1,175 animals was found on Augustine Island in September, 1976 (Pitcher and Calkins, RU #229, Annual Report, 1977; Fig. E.1.2a). They use the area for their entire life cycle with a pupping and breeding season from mid-May to mid-July (Fig. E.1.4b).

Both species of pinnipeds are vulnerable to contamination of their food supplies, and in varying degrees, by human disturbance of any kind (Fig. E.1.4b).

Figure E.1.2a Pinniped sightings (from Pitcher and Calkins, RU #229, Annual Report, 1977).

Northern sea lion	October 1975	March 1976	June 1976
Outer Island	2,904	1,528	3,847
Gore Point	2	200	535
Perl Island	-	8	33
Cape Elizabeth	-	68	124
Nagahut Rocks	-	68	344
Totals	2,906	1,872	4,883

Harbor seal	October 1975	Jun-Jul 1976	September 1976
East Chugach Island	18	-	-
Elizabeth Island	35	-	-
Sadie-Cove - Tutka Bay	23	-	-
Halibut Cove - China Poot Bay	15	-	-
Rocky Bay	-	176	-
Fox River	-	45	-
Iniskin Bay	-	57	-
Augustine Island	-	-	1,175
Taylor Bay	-	24	-
Yukon Island	-	-	250
Totals	91	302	1,425

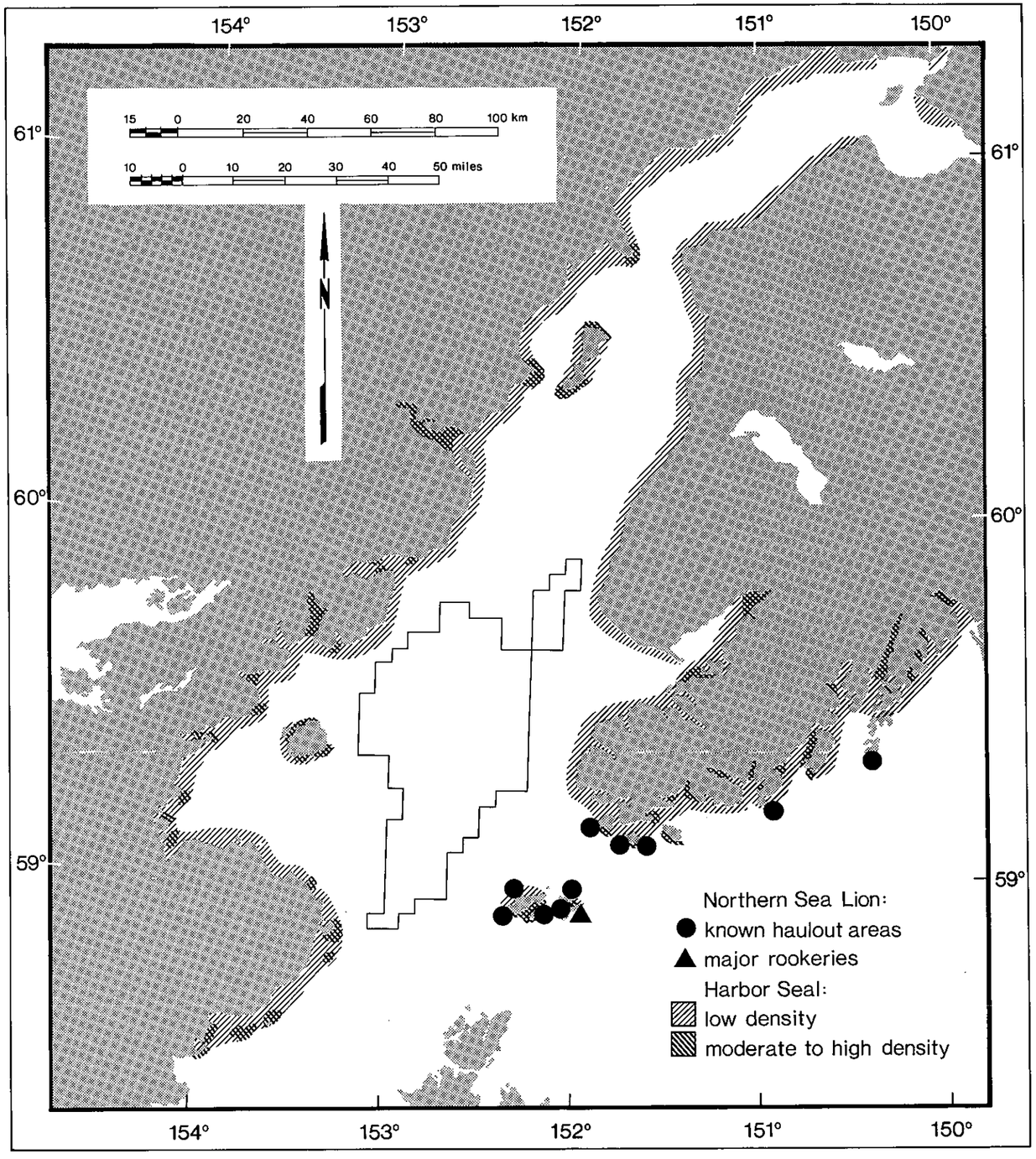


Figure E.1.2b Distribution of northern sea lions and harbor seals in Cook Inlet (from various sources, see text).

E.1.3 CETACEANS

Seven species of cetaceans, gray whale (Eschrichtius robustus), minke whale (Balaenoptera acutorostrata) fin whale (B. physalus), killer whale (Orcinus orca), harbor porpoise (Phocoena phocoena), Dall porpoise (Phocoenoides dalli), and beluga (Delphinapterus leucas) have been reported from Cook Inlet (Fiscus et al., RU #68, Final Report, 1976).

Sightings for May-September are shown in Fig. E.1.3a. The minke whale and Dall porpoise are the only species other than the beluga documented to be of more than incidental occurrence in the Inlet. The harbor porpoise, which is shy of man and occurs in habitats difficult to census in large boats, may be numerous in the Inlet. May-September sightings of the beluga are almost entirely confined to the inner part of the Inlet (Fig. E.1.3a). Calkins and Pitcher (RU #243, Annual Report, 1978) report 92 belugas about midway between Cape Ninilchik and Kalgin Island on January 11, 1978. They found 182 belugas in the Inlet south of East and West Forelands on March 1 and 2, 1978, mostly associated with shallow bays or shoals. The Cook Inlet beluga population is probably geographically isolated from the nearest population in Bristol Bay (Sergeant and Brodie, 1969; Harrison and Hall, 1978). In extensive aerial surveys south of the Alaska Peninsula, from Kodiak west to the Aleutian Islands, Harrison and Hall (1978) observed no belugas. In the Gulf of Alaska belugas have been sighted near Kodiak in March and July, near Prince William Sound in March, and in Yakutat Bay in May (Harrison and Hall, 1978).

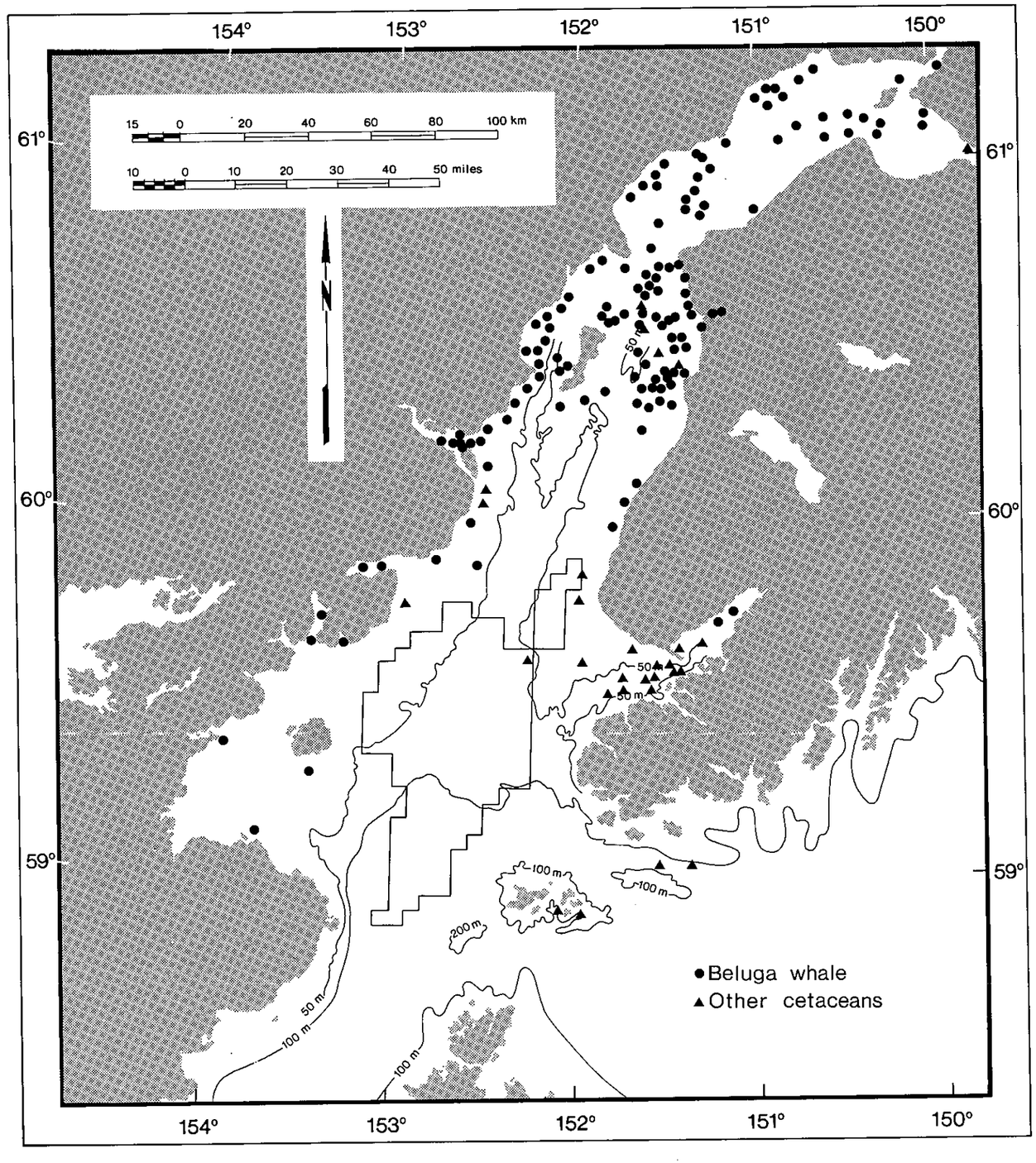


Figure E.1.3a Sightings of cetaceans in Cook Inlet (Fiscus, Braham, and Mercer, RU #68, Final Report, 1976; Fay, pers. comm.).

E.1.4 TERRESTRIAL MAMMALS

The brown bear (Ursus arctos) is found along the entire west coast of Cook Inlet and makes intensive use of many of the stream mouths, especially during the salmon runs in the area (ADF&G, 1973; Fig. E.1.4a). Almost any increase in human activity in this area will lead to conflicts between humans and bears. Although large black bear (U. americanus) populations occur inland around Cook Inlet, this species makes relatively little use of the shoreline (ADF&G, 1973) (Fig. E.1.4a). Most of its coastal use is restricted to small areas around Kachemak Bay and along the shore of the Inlet north of Tuxedni Bay. Black bears are more adaptable to human activity than are brown bears.

Murie (1959) reports that river otters (Lutra canadensis), red (Vulpes fulva), and Arctic (Alopex lagopus) foxes make heavy use of the coastal and marine environments. Both species of foxes depend on a diet of beach fleas, clams, crabs, marine birds, and fish and other beach carrion. River otters are reported to frequent salt water and often swim to islands near the coast. River otters are also susceptible to fouling of their pelage (Fig. E.1.4b).

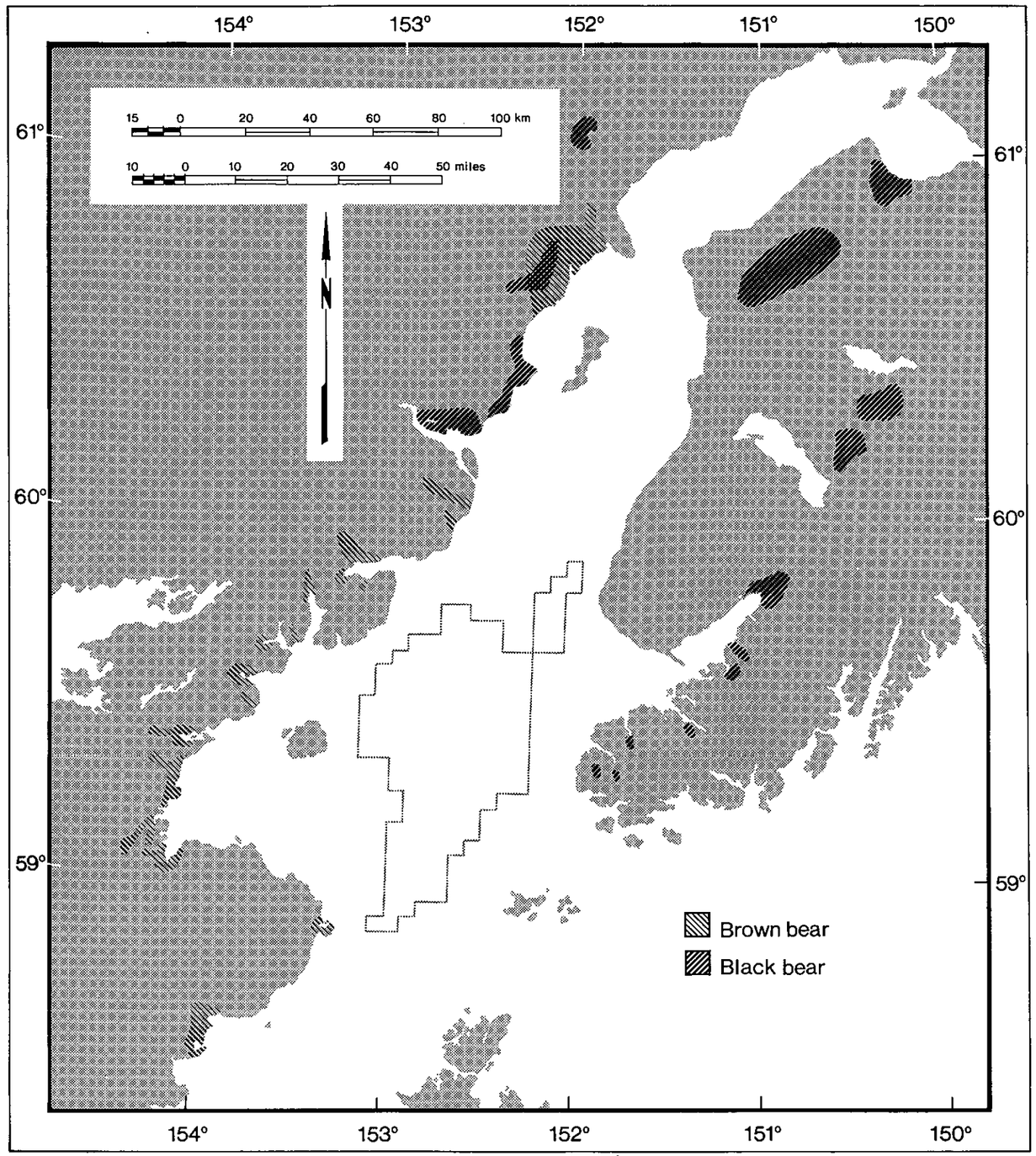


Figure E.1.4a Distribution of bears around Cook Inlet (ADF&G, 1973).

Figure E.1.4b Tentative summary of use of Cook Inlet by marine and terrestrial mammals.

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
Marine mammals:					
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
Northern sea lion	Feed mainly in littoral zone waters; haul out, breed and pup on rocky coasts and islands	4 (Barren Islands)	Pupping and breeding season, late May - mid-July (Barren Islands)	For entire life cycle, with breeding/pupping mainly on the Barren Islands	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
Harbor seal	Feed mainly in waters less than 55 m depth; haul out on beaches, sandbars, rocks	2, 3, 5	Pupping season, mid-May - mid-July	For entire life cycle	
Harbor porpoise, Dall porpoise, Killer whale, Minke whale	Inshore and offshore waters	1, 2, 4	Summer for minke whale; unknown for others	Minke whale-summer feeding; others unknown	Possible food chain contamination; acute effects, if any, unknown
Beluga whale	Inshore waters and river mouths	Summer: 5, 6	Calving season; probably March - May Year-long resident	For 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
Terrestrial mammals:					
Brown (grizzly) bear	Coastal brush, tundra, spruce forest and intertidal habitats	West side of Lower Cook Inlet	Calving season, January - February	Intertidal foraging and fishing	Contamination of foods
Black bear	Coastal forest	Kachemak Bay & NW shore	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; 3 - Kamishak Bay; 4 - Kennedy Entrance; 5 - Kalgin Island; 6 - Northern Lower Cook Inlet

DATA EVALUATION

The mammal populations of Cook Inlet have not been intensively studied, and relatively little knowledge concerning most of them is available. Much of the information presented above is tentative and in part extrapolated from other areas. A major source of such data is ADF&G (1973).

Information on sea otter populations is based on recent systematic surveys concentrated in areas where range expansion is occurring (Schneider, RU #240, Final Report, 1976). Since survey efforts were not evenly distributed, population size estimates are probably low.

The data reported here for pinnipeds are from surveys concentrated on Gulf of Alaska populations which incidently included Cook Inlet sites. Apparently northern sea lions do not make much use of the Inlet for haulout areas and rookeries (ADF&G, 1973; Calkins and Pitcher, RU #243, Annual Report, 1977). On the other hand, the Inlet, especially the western shoreline and Kachemak Bay, is an important area for the harbor seal. Present information on the size and distribution of the Cook Inlet harbor seal population is inadequate to estimate its vulnerability to the effects of oil and gas development.

The use of Cook Inlet by cetaceans is poorly documented. There has been no systematic census of their populations nor study of their seasonal movements in the Inlet.

SUBTASK E.2 Population Dynamics and Trophic Relationships of Marine Mammals

E.2.1 POPULATION DYNAMICS

Sea Otter

The Lower Cook Inlet population of sea otter was reduced to a very low level at the turn of the century. Under protection the species has recovered and some areas have become saturated. Animals from the saturated areas are now recolonizing the former range (Schneider, RU #240, Final Report, 1976; pers. comm.). Sea otters breed throughout the year, with a peak in births and breeding activity in the fall and winter. The present distribution of this population is discussed in Subtask E.1.

PINNIPEDS

Life history studies for the northern (Steller) sea lion and harbor seal are currently in progress in the Gulf of Alaska (Calkins and Pitcher, RU #243, Annual Report, 1977; Pitcher and Calkins, RU #229, Annual Report, 1977).

Northern sea lion females become sexually mature at 3 to 5 years of age, males at about 4 years of age. Ninety percent of all females 5 years or older were found to be pregnant. Pupping takes place from late May to mid July with a peak early in June (Calkins and Pitcher, RU #243, Annual Report, 1977).

This species is polygynous, males control breeding territories and may inseminate many females during the breeding season. In species with similar social systems only a few males survive to reproductive maturity (LeBoeuf, 1974). Mortality of a significant percentage of the breeding males, even though it might represent a small percentage of the total male population, could drastically affect the breeding population. Data on the vulnerability of the breeding males are needed.

Harbor seal females become sexually mature at 5 to 8 years of age, males at about 7 years of age. About 87 percent of all females 5 years or older were found to be pregnant. Pupping takes place from mid-May to late June with a peak in mid-June. About 36 percent of females and 50 percent of males were immature (Pitcher and Calkins, RU #229, Annual Report, 1977).

Cetaceans

Few data on the population dynamics of cetaceans are available. All of the larger species have been over-exploited, and their populations have declined to levels such that many are now recognized as endangered (Nishiwaki, 1972; Scheffer, 1972; Rice, 1974). These species must be considered as extremely vulnerable to any human disturbance.

Figure E.2.2a Identification of prey from the stomachs of 309 sea otters from Amchitka Island (Kenyon, 1969).

Prey Item	% Volume	Minimum Frequency of Occurrence
Annelids	1	2
Crustaceans	<1	5
Molluscs	37	16
Echinoderms	11	58
Tunicates	<1	4
Fish	50	35

E.2.2 TROPHICS

Sea Otter

Kenyon (1969) found that sea otter feeding habitat on Amchitka Island was limited to the intertidal and sublittoral regions within the 60 m depth contour. From the examination of 309 sea otter stomachs he found that about 98 percent of their diet consisted of molluscs, echinoderms, and fish (Fig. E.2.2a). The species has a relatively high metabolic rate for its size (Morrison, Rosenmann, and Estes, 1977) which is supported by a daily food consumption of from one-fifth to one-fourth of body weight. Estes and Palmisano (1974) estimated that sea otters on Amchitka eat about 35,000 kg/km^2/yr of animal biomass. Sea otters thus are key members of nearshore marine communities and are important factors in determining community structure.

Pinnipeds

Seals eat a variety of invertebrates and fish. Generally, small schooling fish such as herring (Clupeidae) are swallowed whole under water while larger prey are consumed at the surface, where they are reduced to small pieces by violent shaking (Spalding, 1964).

In a large sampling effort Calkins and Pitcher (RU #243, Annual Report, 1978) report on the stomach contents of 193 sea lions collected in the Gulf of Alaska. Overall, they found the species eats about 6 percent invertebrates, 93.9 percent fish, and 0.1 percent mammals by volume, with capelin and pollock (Theragra chalcogramma) being the fishes most commonly eaten. In the Kodiak area they report that the species eats about 54 percent capelin and 25 percent pollock (Fig. E.2.2b). The remains of a harbor seal

Figure E.2.2b Identification of the prey (as % of total prey items) from the stomachs of northern sea lions (N = 71) and harbor seals (N = 165).*

Prey Species	Northern Sea Lion	Harbor Seal
Invertebrates		
Gastropods	-	0.1
Cephalopods	1.4	30.3
Crustaceans	0.4	4.4
Unid. Invertebrate	0.1	tr
Fishes		
Skates	6.6	3.8
Salmon	1.7	-
Herring	-	tr
Capelin	54.0	22.8
Eulachon	-	6.1
Pollock	24.8	7.1
Other Gadids	8.1	6.4
Eelpouts	0.1	0.3
Rockfish	-	2.3
Greenlings	-	0.1
Cottids	0.1	5.5
Pacific Sandfish	-	0.2
Ronquil	-	0.2
Pacific Sandlance	-	1.7
Pleuronectids	0.7	8.0
Moray Eels	-	-
Unid. Fish	0.3	0.5
Mammals		
Harbor Seal	1.7	-

*Data on Northern Sea Lions and Harbor Seals are from animals collected in the Kodiak Area (Calkins and Pitcher, RU #229, Annual Report, 1978; Pitcher and Calkins, RU #243, Annual Report, 1978).

were found in one of the 71 stomachs they examined from the Kodiak area. Spalding (1964) reports that sea lions feed mostly during darkness.

Harbor seals feed during daylight, mostly in nearshore waters (Spalding, 1964). Pitcher and Calkins (RU #229, Annual Report, 1978) report that their diet in the Gulf of Alaska is about 30 percent invertebrates and 70 percent fish. In the Kodiak area they found octopus (30 percent) and capelin (23 percent) to be the major prey (Fig. E.2.2b).

Cetaceans

The prey of the cetaceans found in the Gulf of Alaska are fairly well known (Pike, 1962; Nemoto, 1970; Nishiwaki, 1972). Baleen whales eat mostly large quantities of planktonic species (amphipods, copepods and euphausiids) and some benthic species, while the toothed whales eat mainly cephalopods and fish (Fig. E.2.2c). Baleen whales exhibit two feeding patterns: swallowing, in which large patches of clumped prey are swallowed at one time; and skimming, in which dispersed prey are caught by swimming with the mouth open for extended periods. Gray and sei whales apparently use both methods; minke, fin, blue, and humpback whales are swallowers, and right whales are skimmers. Swallowers rely on heavy patches of prey, such as euphausiids and gregarious fish, while the skimmers rely on more sparse plankton patches. Skimmers may be more vulnerable to contamination since they must process large volumes of water per volume of food ingested.

Crude estimates of dietary needs (Brodie, 1975) and estimates of current cetacean populations in the North Pacific (Scheffer, 1972; Fiscus, Braham and Mercer, RU #68, Final Report, 1976) indicate that

Figure E.2.2c Prinicipal food types and feeding strata of cetaceans (Pike, 1962; Nemoto, 1970; Nishiwaki, 1972).

Species	Principal Food Types	Feeding Strata
Gray Whale	amphipods copepods	Benthic-ocean floor Surface-photic zone
Minke Whale	fish euphausiids	Surface-photic zone
Sei Whale	copepods	Surface-photic zone
Fin Whale	euphausiids copepods fish	Surface-photic zone
Blue Whale	euphausiids	Mid-Water
Humpback Whale	euphausiids fish	Surface-photic zone
Right Whale	copepods	Surface-photic zone
Killer Whale	fish cetaceans pinnipeds	Surface-photic zone
Harbor Porpoise	fish	Surface-photic zone
Dall Porpoise	fish cephalopods	Surface-photic zone
Beluga	fish	Benthic-ocean floor Surface-photic zone
Sperm Whale	cephalopods fish	Benthic-ocean floor Mid-water

baleen whales consume about 50,000 metric tons of food per day. An estimate of the consumption rate of toothed whales is confounded by several factors. Toothed whales are about four times as abundant as baleen whales in the North Pacific, but on the average, they tend to be smaller, lay down smaller fat supplies, feed at the same rate throughout the year, and pursue faster prey.

Belugas probably eat almost any type of aquatic or marine animal of appropriate size. Food items as small as shrimp and as large as 10 lb cod have been found in stomachs of belugas along with a variety of other fish and invertebrates (Fraker, Sergeant and Hoek, 1978). Perhaps the most comprehensive food study of belugas was done by Vladykov (1947). He found that their diet, in the St. Lawrence River, consisted of at least 50 different kinds of fish and invertebrates, including capelin, cod, sturgeon, sandlance, plaice, marine worms, shrimp, octopus and squid. The contributions of Lower Cook Inlet to the food supply of toothed whales is unknown, but the area is thought to be an important feeding area for some species.

Terrestrial Mammals

Brown bears spend the winter in their denning areas at higher elevations. In the spring they move to lower elevations, especially to coastal areas, to make use of limited herbaceous forage. From July through September, and on some streams until November, brown bears concentrate on all of the salmon streams along the west coast of the Inlet. This food resource is thought to be critical to the maintenance of this high density population (ADF&G, 1973).

DATA EVALUATION

The growth and spread of sea otter populations in Lower Cook Inlet are well documented. However, there is no information on the sex and age structure nor fecundity and survival schedules of the population. This information is necessary to predict the response of the populations to new sources of mortality.

Lower Cook Inlet pinniped populations are not well documented, but there is now good information on the sex structure of northern sea lion and harbor seal populations around Kodiak. Fecundity rates are also fairly well established for these two species, but there is little information on mortality rates. Thus additional information is needed before it can be estimated what their potentials are to maintain themselves, when faced with chronic or acute attrition. There are few data on the population dynamics of cetaceans.

The diets of the common marine mammals of the Gulf of Alaska have been fairly well documented for the warmer months, but not for the winter. The work of Calkins and Pitcher (RU #243, Annual Report, 1978) and Pitcher and Calkins (RU #229, Annual Report, 1978) has shown that there are differences in dietary detail from place to place within the Gulf of Alaska for northern sea lions and harbor seals. Seasonal shifts in the diets and feeding habitats of some species of pinnipeds have been suggested by several authors. Feeding habitat requirements for pinnipeds and cetaceans are not well known. Information on possible critical feeding habitats is necessary to estimate the vulnerability of these species to environmental contamination.

SUBTASK E.3 Seasonal Density Distribution, Critical Habitats, Migratory Routes, and Breeding Locales for Principal Marine Bird Species.

E.3.1 AVIFAUNA

About 95 species of marine and coastal birds are found in Cook Inlet (Erikson, 1977). Of these, about 69 species are common to abundant, about 20 species are uncommon, and about 6 species are rare (Fig. E.3.1a). Approximately 75 species find their preferred habitats within the Inlet. Although not every species fits the pattern, in general, loons, grebes, cormorants, raptors, gulls, some species of alcids, and passerines are resident in the Inlet. Geese and some species of shorebirds occur only as migrants. Fulmars, shearwaters, storm petrels, swans, dabbling ducks, some species of shorebirds, terns, and some species of alcids occur mainly as summer residents. Diving ducks occur chiefly as winter residents, but significant numbers occur as non-breeding summer residents. Seventeen species use only open-water habitats, 34 only shorelines habitats, while 44 species use a combination of both open-water and shoreline habitats.

Figure E.3.1a Summary of habitat preference, status, and abundance of marine coastal birds.

Family	Species	Habitat Preference[a] OW	IW	RS	SB	SC	CF	S[c]	A[d]
Gaviidae	Common Loon	2[b]	1					R	C
	Yellow-billed Loon	2	1					WR	R
	Arctic Loon	2	1					M	U
	Red-throated Loon	2	1					R	C
Podicipedidae	Red-necked Grebe		1					R	C
	Horned Grebe		1					R	C
Procellariidae	Northern Fulmar	1	2					SR	C
	Sooty Shearwater	1	2					SR	A
	Short-tailed Shearwater	1	2					SR	U
Hydrobatidae	Fork-tailed Storm Petrel	1	2					SR	U
Phalacrocoracidae	Double-crested Cormorant	2	1	1		1		R	C
	Pelagic Cormorant	2	1	1		1		R	C
	Red-faced Cormorant	2	1	1		1		R	C
Anatidae	Trumpeter Swan		2		2		2	SR	C
	Whistling Swan		2		2		2	M	C
	Canada Goose	2	1	2	1		1	SR	C
	Black Brant	2	1	2	1		2	M	U
	Emperor Goose		1		1		2	M	R
	White-fronted Goose	2	2	2	1		1	SR	C
	Lesser Snow Goose	2	1		1		1	M	C
	Mallard		1	2	1		1	R	A
	Gadwall		2		1		1	SR	U
	Pintail	2	1	2	1		1	SR	A
	Green-winged Teal		1	2	1		1	SR	A
	American Wigeon		2	2	1		1	SR	C
	Northern Shoveler		2	2	1		1	SR	C
	Canvasback		2		2		1	M	U
	Greater Scaup		1	2	1		1	R	C
	Common Goldeneye	2	2	1				WR	C
	Barrow's Goldeneye		2	2	1			WR	C
	Bufflehead		1		2			WR	C
	Oldsquaw	2	1					WR	A
	Harlequin Duck		1	1	2			R	C
	Steller's Eider		1	2	2			WR	C
	Common Eider		1	1	2			R	C
	King Eider		1	2				WR	U
	White-winged Scoter	2	1	2	2			R	A
	Surf Scoter	2	1	2	2			R	A
	Black Scoter	2	1	2	2			R	C
	Common Merganser		1	2	2			R	U
	Red-breasted Merganser		1	2	2		2	R	C
Accipitridae	Bald Eagle			1	1	1	2	R	C
	Marsh Hawk				2		1	SR	C
Falconidae	Peregrine Falcon			1	2	2	1	R	C
Gruidae	Sandhill Crane						1	SR	C
Haematopodidae	Black Oystercatcher			1	2	1		SR	C
Chardriidae	Semipalmated Plover			2	1			M	C
	American Golden Plover			2	1		1	M	U
	Black-bellied Plover			2	1		1	M	C
Scolopacidae	Whimbrel						1	SR	C
	Bristle-thighed Curlew				1			M	R
	Spotted Sandpiper			2	1		2	SR	C
	Wandering Tattler			1	2			SR	U
	Greater Yellowlegs			2	1		1	SR	C
	Lesser Yellowlegs			2	1		1	SR	C
	Surfbird			1	2			M	A
	Red Knot			2	1			M	U
	Rock Sandpiper			2	1			WR	C
	Pectoral Sandpiper			2	1		1	M	C
	Sharp-tailed Sandpiper				1		2	M	C
	Baird's Sandpiper				1		1	M	U
	Least Sandpiper			2	1		1	SR	C
	Dunlin			1	1		1	M	C
	Semipalmated Sandpiper				1		1	SR	U
	Western Sandpiper			2	1		1	SR	A
	Ruddy Turnstone			1	2			M	C
	Black Turnstone			1	2			SR	C
	Dowitcher (both species)			2	1		1	SR	C
	Hudsonian Godwit			2	1		1	M	U
	Common Snipe				2		1	SR	C
Phalaropodidae	Northern Phalarope	1	1				2	M	C
Laridae	Glaucous Gull		2	1	1	1		WR	R
	Glaucous-winged Gull	1	1	1	1	1	1	R	A
	Herring Gull		1	1	1			R	U
	Mew Gull	2	1		1		1	R	A
	Bonaparte's Gull		1	2	1			M	C
	Black-legged Kittiwake	1	1	1	1	1		SR	A
	Sabine's Gull		1					M	R
	Arctic Tern	1	1	1	1	2		SR	A
	Aleutian Tern	2	1		2			M	U
Alcidae	Common Murre	1	1			1		R	A
	Thick-billed Murre	1	1			1		?	R
	Pigeon Guillemot	1	1	1		1		R	C
	Marbled Murrelet	1	1					R	C
	Kittlitz's Murrelet	1	1					R	C
	Ancient Murrelet	1	2					SR	U
	Parakeet Auklet	1	2					SR	U
	Rhinoceros Auklet	1	2					SR	U
	Horned Puffin	1	1			1		SR	C
	Tufted Puffin	1	1			1		SR	C
Corvidae	Black-billed Magpie			1				R	C
	Common Raven							R	C
	Northwestern Crow			1		2		R	C
Fringillidae	Savannah Sparrow				2		2	SR	C
	Fox Sparrow	2	2					SR	C
	Song Sparrow	1	2					R	C

[a] Habitat Codes:
OW: Offshore water
IW: Inshore water
RS: Rocky shores
SB: Sea beaches and tidal flats
SC: Sea cliffs
CF: Coastal floodplains

[b] Habitat Preference:
1: Primary Preference
2: Secondary Preference

[c] Status Codes:
R: Resident
M: Migrant
SR: Summer resident
WR: Winter resident

[d] Abundance Codes:
A: Abundant: regularly seen in proper habitat or in very large numbers
C: Common: regularly seen in proper habitat
U: Uncommon: not observed regularly in proper habitat
R: Rare: regular in region, but in small numbers

E.3.2 BREEDING MARINE BIRDS

Glaucous-winged gulls (Larus glaucescens) make up about 14 percent, black-legged kittiwakes (Rissa tridactyla) about 44 percent, common murres (Uria aalge) about 26 percent, and other alcids about 13 percent of the approximately 115,000 colonial birds which breed in Cook Inlet (Erikson, 1977) (Fig. E.3.2a,b). Most of the colonies and about 87 percent of the total breeding population are located on the west coast of the Inlet between the southern part of Kamishak Bay and Tuxedni Bay. On the east coast colonies are found on all shores of the Kenai Peninsula. The west coast colonies are most important (in terms of population size) for most of the colonial species in the Inlet, but the east coast colonies have larger populations of pelagic (Phalacrocorax pelagicus) and red-faced (P. urile) cormorants, pigeon guillemots (Cepphus columba), and tufted puffins (Lunda cirrhata).

Figure E.3.2a Estimates of breeding populations of Cook Inlet bird colonies (Erikson, 1977).

Species	REGION					
	Kenai Peninsula	Kachemak Bay	Kamishak Bay	Iliamna-Chinitna Bays	Tuxedni Bay Region	Totals
Pelagic Cormorant	206	222	84	96	30	638
Red-faced Cormorant		62	30			92
Double-crested Cormorant			186	62	500	748
Cormorant sp.	410		284	54		748
Common Eider	6	2	707	42	300	1,057
Black Oystercatcher			7	30	6	53
Glaucous-winged Gull	470	270	1,774	11,097	3,072	16,683
Black-legged Kittiwake	1,260	3,320	750		45,000	50,330
Common Murre		2,642	2,500		25,000	30,142
Horned Puffin	4	14	2	47	5,000	5,067
Tufted Puffin	5,858	604	*	2,123	1,000	9,585
Pigeon Guillemot	46	32		33		111
Parakeet Auklet					6	6
Rhinoceros Auklet					2	2
Totals	8,260	7,168	6,324	13,584	79,916	115,262

*present

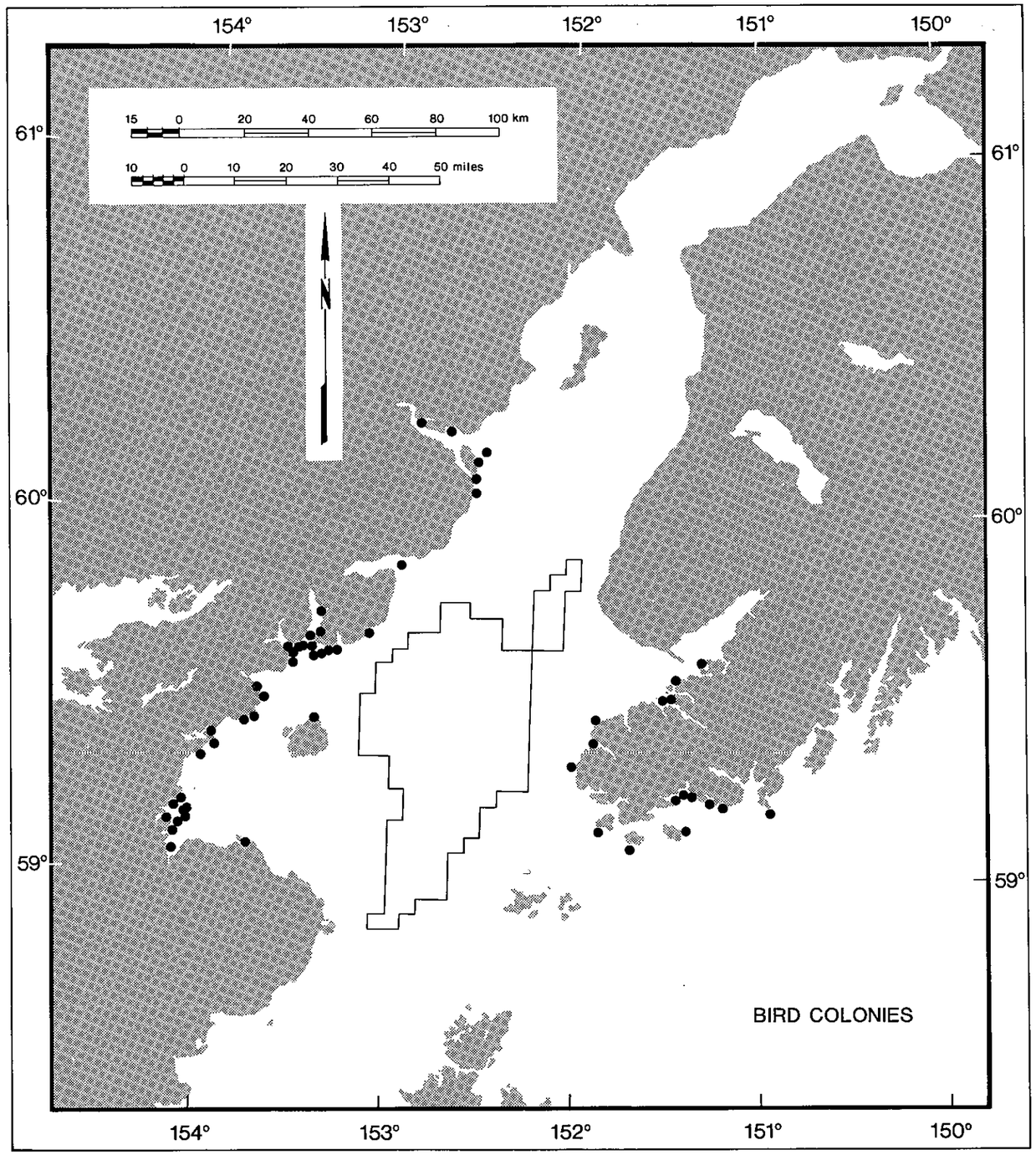


Figure E.3.2b Distribution of bird colonies in Cook Inlet (Erikson, 1977).

E.3.3 BIRD HABITAT

The distribution of Cook Inlet birds according to habitat features was estimated in four surveys in 1976 (February, May, June, and September-October) (Arneson, RU#3, Annual Report, 1977).

In February about 80 percent of the birds recorded were diving ducks and shorebirds (Fig. E.3.3a). The ducks were found mostly on the open water near beaches in bays or along unprotected shoreline. The shorebirds were found on mud and sand substrates in bays.

In May, as migrants and summer residents arrived, about five times as many birds were recorded as in February (Fig. E.3.3b). The largest increase in numbers occurred in dabbling ducks, shorebirds, and gulls. Swans, geese, and cranes, not found in February, moved into the Inlet. In May about 88 percent of the birds recorded were diving ducks, shorebirds, and gulls. The diving ducks were found mostly on the open water near beaches or intertidal areas in bays or along unprotected shoreline. The shorebirds were found mostly on mud and sand substrates in bays. The gulls were widely distributed over a variety of substrates, mainly on the unprotected shorelines of islands.

February 1976

	Water Type				Physiographic Features						Substrate Type				
	Bay, Fiord or Embayment	Unprotected Shoreline	Lagoon	Other	Beach or Sandspit	Intertidal Area	Island	Coastal Floodplain	Delta	Other	Water	Mud, Sand or Both	Sand, Gravel, Rock or Combination	Ice	Approximate Totals
Loons & Grebes	43	21	3	-	62	-	-	-	5	-	67	-	-	-	67
Cormorants	146	308	4	-	296	-	162	-	-	-	393	-	65	-	458
Dabbling Ducks	1343	-	159	-	1388	-	-	-	114	-	1442	60	-	-	1502
Diving Ducks	8971	3352	377	137	10,670	318	867	-	1186	463	13,043	139	28	288	12,837
Raptors	39	10	3	-	35	8	5	-	2	2	1	2	14	1	52
Shorebirds	4328	309	2	-	3883	627	44	-	85		87	3588	107	200	4639
Gulls	101	1295	36	-	1395	8	5	-	20	4	963	5	18	15	1432
Alcids	194	64	21	-	243	-	3	-	4	29	274	-	-	-	279
Perching Birds	563	242	-	-	1	162	195	-	72	1	3	2	34	7	805
Totals	15,728	5601	605	137	17,973	1123	1281	-	1488	499	16,273	3796	266	511	22,071

May 1976

	Water Type				Physiographic Feature						Substrate Type				
	Bay, Fiord or Embayment	Unprotected Shoreline	Lagoon	Other	Beach or Sandspit	Intertidal Area	Island	Coastal Floodplain	Delta	Other	Water	Mud, Sand or Both	Sand, Gravel, Rock or Combination	Ice	Approximate Totals
Loons & Grebes	62	49	11	5	102	13	8		2	4	123	-	-	-	129
Cormorants	512	666	20	-	279	87	207	1	1	622	473	-	474	-	1198
Swans & Geese	1163	630	1	5044	156	66	1046	4600	970	-	155	4902	1205	-	6838
Dabbling Ducks	1877	429	281	4609	846	1619	1148	2517	910	156	4574	1277	15	-	7196
Diving Ducks	21,568	9133	1249	1245	12,005	17,298	2609	330	534	416	31,617	-	1447	-	33,195
Raptors	16	14	4	4	15	12	5	3	1	2	4	6	9	-	38
Cranes	-	2	-	213	2	-	20	45	148	-	2	193	-	-	215
Shorebirds	14,595	7651	258	149	1655	14,924	1728	4058	215	73	59	18,728	1742	-	22,653
Gulls & Terns	8455	31,744	996	1017	5828	3823	25,958	577	1586	4392	2590	3250	3242	8	42,212
Alcids	97	398	28	2	186	4	265	-	-	70	484	-	41	-	525
Perching Birds	44	9	65	-	78	36	2	-	-	1	7	-	49	-	118
Totals	48,389	50,725	2913	12,288	21,152	37,882	32,996	12,131	4367	5736	40,088	28,356	8224	8	114,317

Figure E.3.3a Distribution of coastal birds by habitat features, February 1976 (Arneson, RU #3, Annual Report, 1977).

Figure E.3.3b Distribution of coastal birds by habitat features, May 1976 (Arneson, RU #3, Annual Report, 1977).

In June, as migrants and winter residents left the area for their breeding grounds, the number of birds in the Inlet decreased (Fig. E.3.3c). Most of the swans, geese, dabbling ducks, cranes, and shorebirds found in May had left the area. Only gulls and alcids showed a noticeable increase in numbers. Tubenoses were first recorded in June. In June diving ducks and gulls accounted for about 89 percent of the birds recorded. The diving ducks were found in the same habitats as in February and May. Gulls were found widely distributed in a variety of habitats.

In September-October, as summer residents left the area and migrants and wintering species arrived, the number of birds in the Inlet decreased to about 60 percent of the numbers found in June (Fig. E.3.3d). The numbers of tubenoses, diving ducks, gulls, and alcids all declined. Those of geese, dabbling ducks, and shorebirds rose. Together, dabbling ducks, diving ducks, and gulls accounted for about 86 percent of the total number of individuals recorded. The dabbling ducks were found mainly on the water near beaches or intertidal areas in bays and along unprotected shoreline. The diving ducks used the same habitats as in previous months, and gulls were still distributed over a variety of habitats. The most common raptor found along the inlet coast is the bald eagle (Haliaeetus leucocephalus), a permanent resident found in a variety of habitat types.

June 1976

	Water Type					Physiographic Features					Substrate Type			
	Bay, Fiord or Embayment	Unprotected Shoreline	Lagoon	Other	Beach or Sandspit	Intertidal Area	Island	Coastal Floodplain	Delta	Other	Water	Mud, Sand or Both	Sand, Gravel, Rock or Combination	Approximate Totals
Loons & Grebes	19	80	1	10	36	6	5	3	50	7	107			155
Tubenoses	1	1005	-	-	2	-	1004	-	-	-	1006			1006
Cormorants	156	1602	-	3	544	91	1091		30	9	904	13	848	1761
Swans & Geese	11	78	-	7		69	5	17	5		89	2		97
Dabbling Ducks	754	478	-	1059	138	870	164	958	85	76	1841	437		2291
Diving Ducks	19,656	10,303	521	146	20,277	7408	2841	55	14	44	29,581	87	132	30,626
Raptors	18	20	4	2		8	10	3	5	-		3	12	44
Cranes	5	1	-	7			5	6	1	-	1	6		13
Shorebirds	184	268	-	65	130	138	14	72	163	-	147	115	23	517
Gulls, Terns & Jaegers	15,222	35,039	138	4791	21,481	9,476	17,295	901	6245	245	1999	16,339	14,563	55,190
Alcids	67	5223	31	-	171	-	5115	-	-	-	5042		264	5321
Perching Birds	54	12	3	26	37	-	7	6	6	-		6	1	95
Totals	36,147	54,109	698	6116	42,816	18,066	27,556	2021	6604	381	40,717	17,008	15,843	97,116

Figure E.3.3c Distribution of coastal birds by habitat features, June 1976 (Arneson, RU #3, Annual Report, 1977).

September–October 1976

	Water Type					Physiographic Features						Substrate Type				
	Bay, Fiord or Embayment	Unprotected Shoreline	Lagoon	Other	Beach or Sandspit	Intertidal Area	Delta	Island	Coastal Floodplain	Delta	Other	Water	Mud, Sand or Both	Gravel, Rock or Both	Ice	Approximate Totals
Loons & Grebes	54	96	1	1	125	7	5	15	-	5	-	151		1		152
Tubenoses	2	1			3	-	-	-	-	-	-	3				3
Cormorants	878	1792	129		704	129	27	1921	-	27	18	1062	2	1735		2799
Geese	369	132		2158	4	2142	381	132	-	381	-	4	2523	132		2659
Dabbling Ducks	7358	2859	1806	1090	4436	4957	3644	12	60	3644	-	10,218	2480	123		13,113
Diving Ducks	6516	4390	907	199	9602	1465	239	686	-	239	-	10,912	61	39		12,012
Raptors	22	14	3	1	22	5	3	10	-	3	-	3	12	12		40
Shorebirds	1327	202	11	35	1421	13	80	103	3	80	-	35	248	1320		1620
Gulls	8704	9416	3346	907	11,221	6780	2226	2047	-	2226	99	4572	10,809	4900	53	22,373
Alcids	18	20			25		-	13	-	-	-	38		1		38
Perching Birds	396	173	139	1	393	139	13	163	1	13	-	132		297		709
Totals	25,644	19,095	6342	4392	27,956	15,637	6618	5102	64	6618	117	27,130	16,135	8560	53	55,518

Figure E.3.3d Distribution of coastal birds by habitat features, September and October 1976 (Arneson, RU #3, Annual Report, 1977).

E.3.4 PELAGIC SURVEYS

Several workers (Lensink and Bartonek, RU #337, Annual Report, 1976; Erikson, 1977; Gould, RU #337, Annual Report, Part I, 1977; Wiens, Heinmann, and Hoffman, RU #108, Final Report, 1978) have reported the results of pelagic bird surveys in Cook Inlet. The most systematic of these have been by Erikson (1977) who made four surveys in 1976 over the same transect lines (Fig. E.3.4a).

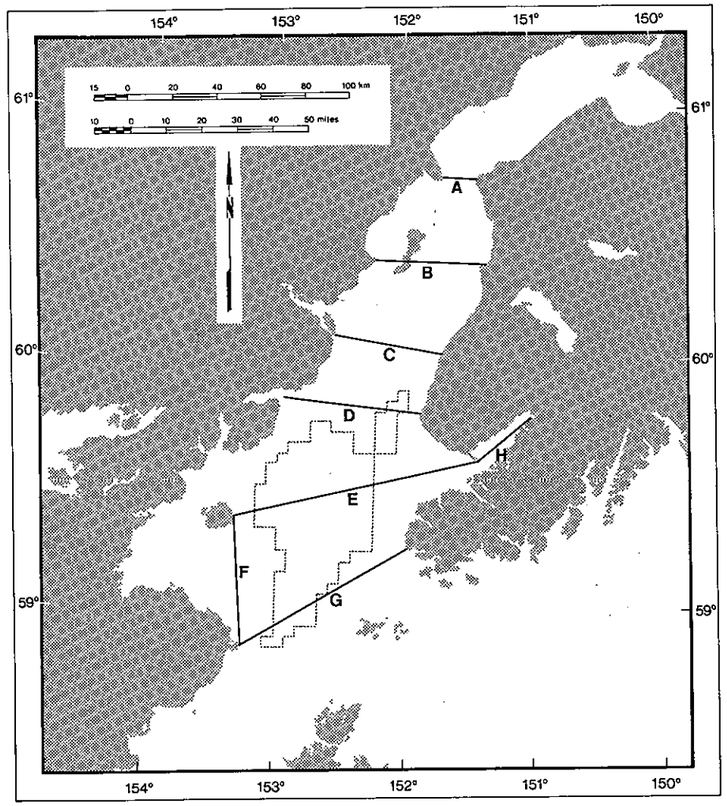


Figure E.3.4a Location of aerial pelagic bird survey transects, 1976 (Erikson, 1977).

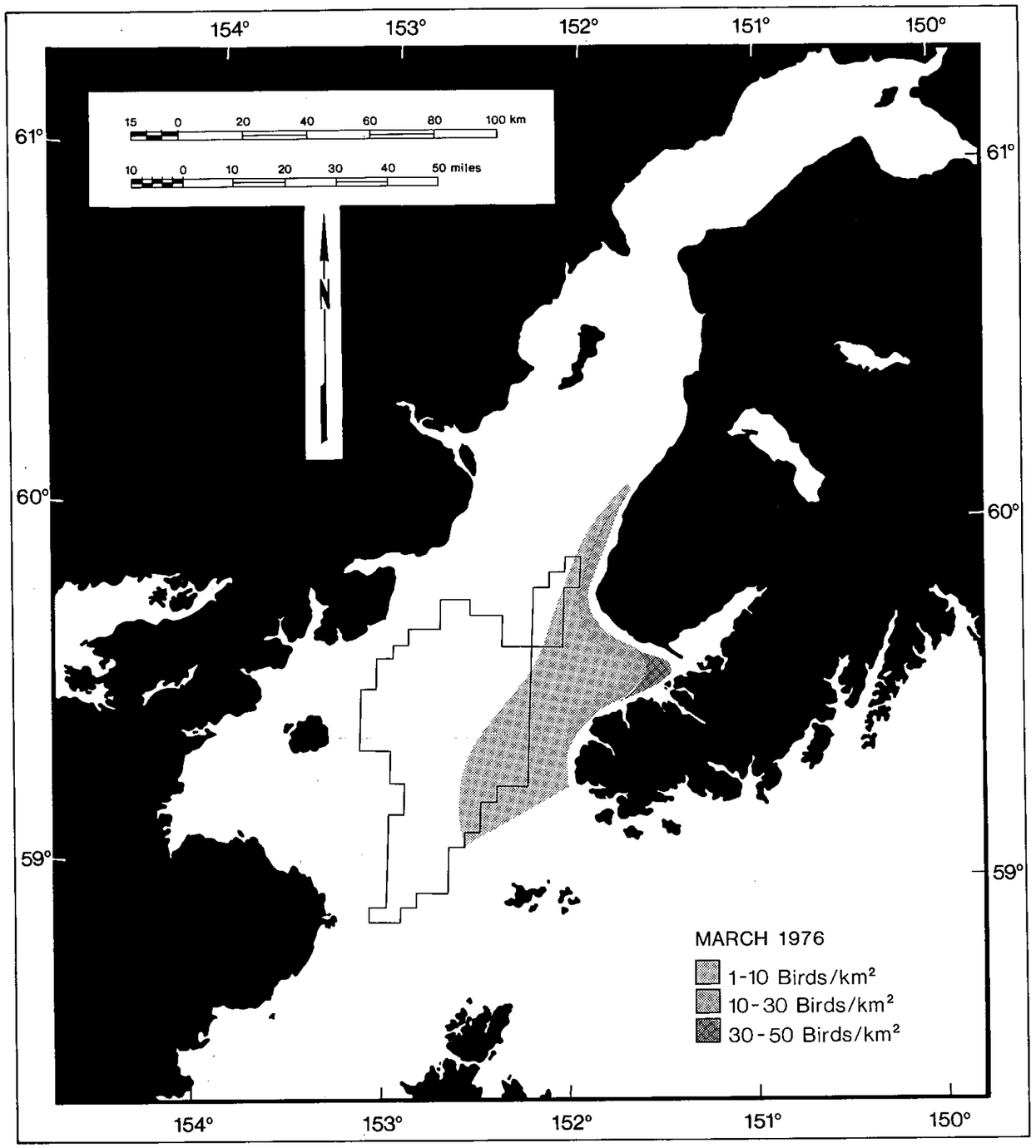


Figure E.3.4b Marine bird densities, March 1976 (Erikson, 1977).

Maximum bird concentrations in the Inlet are usually found around Kachemak Bay and Kennedy Entrance (Erikson, 1977; Fig. E.3.4b-e). In March bird densities of at least 0.1 birds/km^2 were found only along the eastern portion of the Inlet. Maximum densities of 30 to 50 birds/km^2 (mostly ducks and gulls) were found in the mouth of Kachemak Bay (Fig. E.3.4b). In May bird densities of 0.1 birds/km^2 were found throughout most of the Lower Inlet. Densities of 10 birds/km^2 or more were found across most of the mouth of the Inlet, reaching 50 or more birds/ km^2 in the eastern portion (Fig. E.3.4c). Alcids, followed by gulls and diving ducks, were the most abundant species recorded.

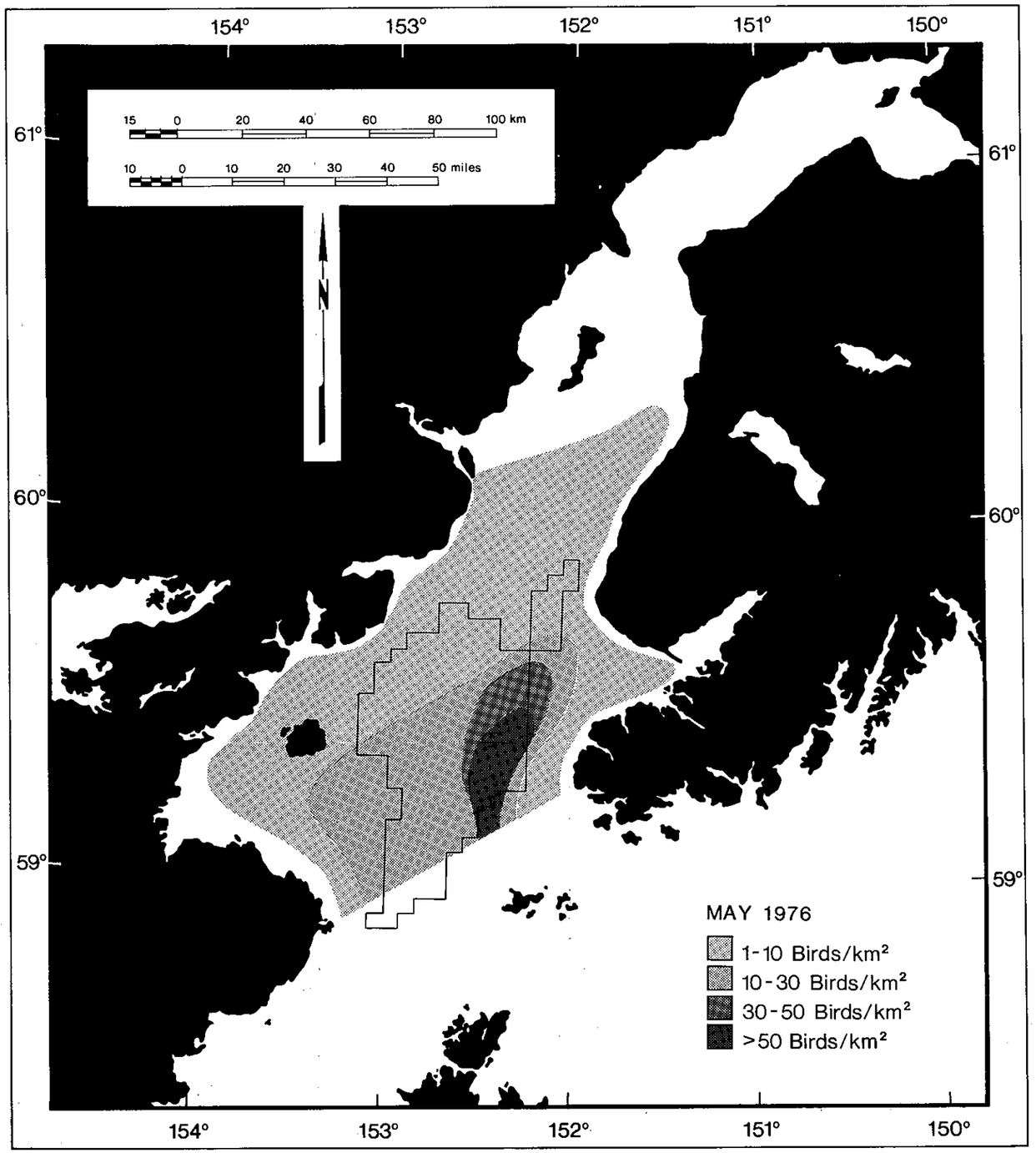


Figure E.3.4c Marine bird densities, May 1976 (Erikson, 1977).

In June and September bird densities of 0.1 birds/km^2 persisted throughout most of the Lower Inlet (Fig. E.3.4d,e). Densities of 10 or more birds/km^2 were then found only along the eastern portion of the Inlet from Kennedy Entrance north almost to Anchor Point. Foci of densities of 50 or more birds/km^2 were found in the mouth of Kachemak Bay and off the tip of the Kenai Peninsula. Shearwaters, are the most common species in these areas of concentration, followed by gulls and alcids (Erikson, 1977).

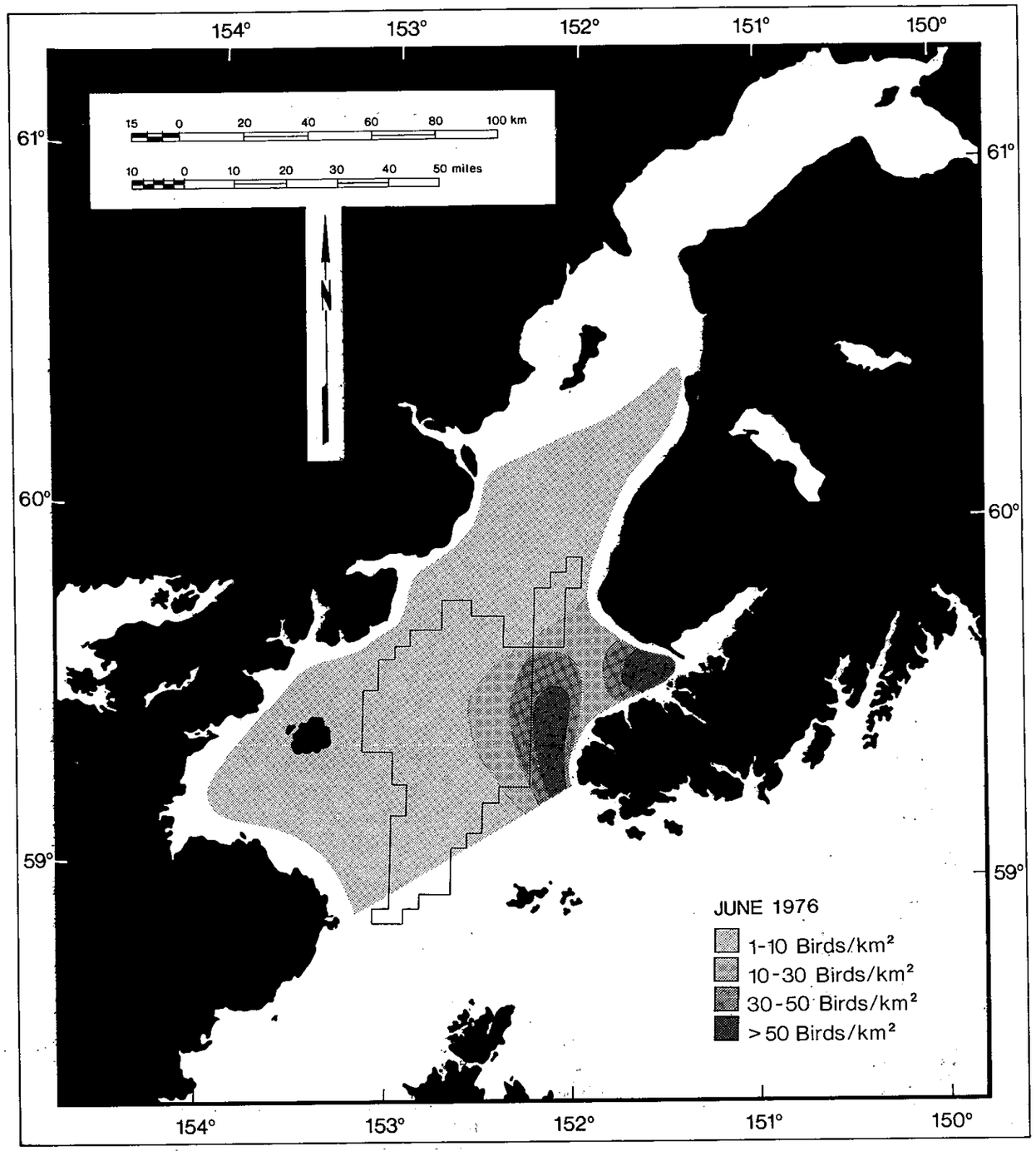


Figure E.3.4d Marine bird densities, June 1976 (Erikson, 1977).

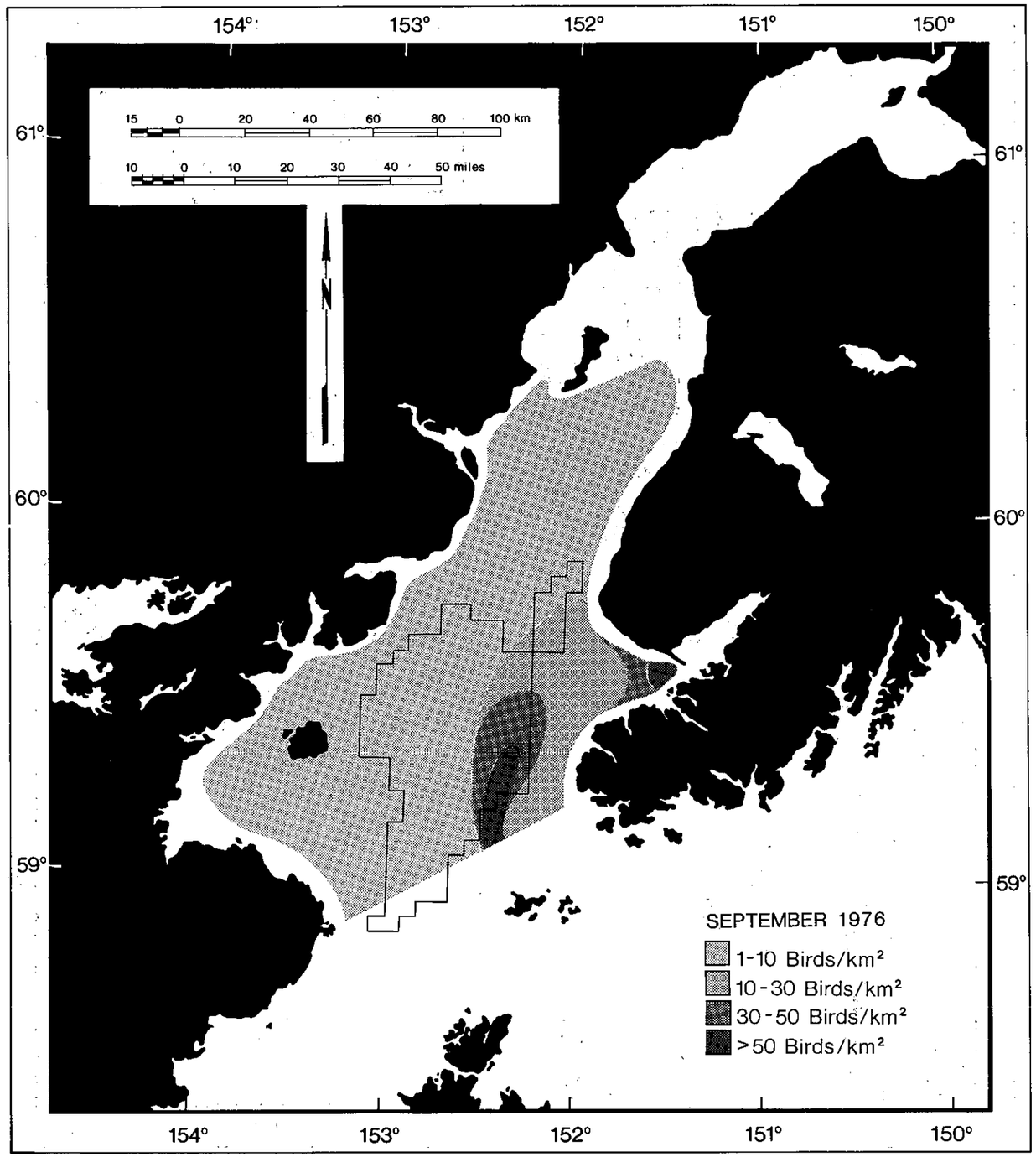


Figure E.3.4e Marine bird densities, September 1976 (Erikson, 1977).

Estimated relative densities of pelagic birds by species group from combined shipboard and aerial transects (Lensink and Bartonek, RU #337, Annual Report, 1976; Erikson, 1977; Gould, RU #337, Annual Report, Part I, 1977; Wiens, Heinmann, and Hoffman, RU #108, Final Report, 1978) are given in Fig. E.3.4f. The most abundant pelagic birds are shearwaters, diving ducks, gulls and alcids.

Figure E.3.4f Relative pelagic bird densities, Lower Cook Inlet, 1975 and 1976. Data for combined shipboard and aerial transects (see text for references).

	Jan.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
Seabird	0	0	0	0	t	0	0	0	0	0
Loon	0	0	0	+	t	0	0	t	+	0
Grebe	0	0	0	t	0	0	0	t	0	0
Northern Fulmar	t	0	0	0	t	+	t	t	+	+
Shearwater	0	0	0	+	+++	+	+	++++	+	++
Storm-petrel	0	0	0	0	t	t	t	t	0	0
Cormorant	0	+	+	+	0	t	0	t	0	0
Dabbling Duck	0	0	+	+	0	0	0	t	0	0
Diving Duck	0	+++	+	+	+	t	0	+	+	0
Raptor	0	t	0	t	0	0	0	0	0	0
Shorebird	0	t	0	+	t	t	0	t	t	0
Jaeger	0	0	0	0	0	t	t	0	+	0
Glaucous-winged Gull	t	+	+	+	+	+	t	t	+	0
Black-legged Kittiwake	t	t	+	+	+	+	+	+	+	+
Other Gull	t	t	+	+	t	t	0	t	+	0
Tern	0	0	0	+	t	t	t	0	0	0
Murre	+	++	+	+	++	t	t	+	+	+
Guillemot	0	0	+	+	t	0	0	0	0	0
Puffin	0	0	0	t	++	t	+	t	+	+
Small Alcid	0	+	+	+	t	t	0	t	0	0
Passerine Bird	0	0	+	0	0	t	0	0	0	0
Unidentified Bird	0	t	0	t	t	0	0	t	0	+

0 = no birds, t = <1 bird/km^2, + = 1-9 birds/km^2, ++ = 10-29 birds/km^2, +++ = 30-99 birds/km^2, ++++ = 100+ birds/km^2

High concentrations of pelagic birds were found in outer Kachemak Bay in March, April, and June (Erikson, 1977) (Fig. E.3.4g). The maximum concentration reported (116.9 birds/km^2) occurred in mid-March, but this declined as diving ducks and alcids left the area in early April. Concentrations rose again in June when shearwaters appeared in the area and alcid densities again increased. Densities in the inner portion of the bay (east of Homer Spit) were moderate in spring and early summer when gulls were the most numerous species (Fig. E.3.4h). In June the density increased with increasing numbers of gulls and reached a recorded maximum in September when large numbers of ducks appeared in the area. Bird densities in outer Kachemak Bay were recorded as being about three to five times higher than those in Kamishak Bay in April (61.1 vs. 21.7 birds/km^2) (Erikson, 1977) and November (19.1 vs 4.3 birds/km^2) (Arneson, RU #3, Quarterly Report, Oct-Dec, 1977). Ducks were the most common species in both areas in April and November, but in April more alcids were found in Kachemak Bay and more gulls were found in Kamishak Bay.

Figure E.3.4g Relative pelagic bird densities, Kachemak and Kamishak Bays 1976 (from Erikson, 1977).

	Kachemak Bay			Kamishak Bay
	March	April	June	April
Loon	0	t	t	0
Shearwater	0	0	++	0
Cormorant	+	t	0	t
Duck	+++	+++	t	++
Phalarope	0	0	+	0
Glaucous-winged Gull	+	+	+	+
Black-legged Kittiwake	0	t	+	0
Other Gull	0	t	t	t
Tern	0	0	t	0
Murre	+++	++	++	t
Guillemot	+++	+	t	0
Murrelets	+	t	+	0
Puffin	0	0	+	0
Unidentified Alcid	t	+	++	t

0 = no birds
t = <1 bird/km^2
+ = 1-9 birds/km^2
++ = 10-29 birds/km^2
+++ = 30-99 birds/km^2

Figure E.3.4h Relative pelagic bird densities, inner Kachemak Bay 1976 (from Erikson, 1977).

Species	March	May	June	September
Sea Bird	0	0	0	+
Loon	0	0	t	t
Storm-Petrel	0	0	0	t
Cormorant	0	t	0	t
Duck	t	t	t	+++
Phalarope	0	0	0	t
Glaucous-winged Gull	+	+	+	t
Black-legged Kittiwake	0	0	+	++
Other Gull	+	t	+	+
Tern	0	t	+	0
Murre	0	0	0	+
Small Alcid	0	t	0	t

0 = no birds
t = <1 bird/km^2
+ = 1-9 birds/km^2
++ = 10-29 birds/km^2
+++ = 30-99 birds/km^2

E.3.5 WATERFOWL

The major waterfowl breeding areas in Lower Cook Inlet are found at Trading (262.1 birds/km^2) and Redoubt (193.4 birds/km^2) Bays and on the Fox River Flats (119.4 birds/km^2) (Timm, 1976, as reported in Erikson, 1977; Fig. E.3.5a). An estimated 29,369 birds breed in the Trading-Redoubt Bay areas compared to only 765 birds on the Fox River Flats. In June, 1976, concentrations of nonbreeding scoters were found on Akumwarvick Bay (2,450), Bruin Bay (714), Iniskin Bay (6,693), and inner Kachemak Bay (11,296) (Erikson, 1977; Fig. E.3.5a). Four surveys in late March and April showed white-winged scoter (Melanitta deglandi) concentrations of about 111 birds/km^2 over an area of approximately 90 km^2 in the northwest corner of Kachemak Bay. Erikson (1977) suggests that this flock of about 10,000 birds traditionally winters in this area. In the spring many areas are used as staging areas by geese and ducks (Fig. E.3.5a) as they migrate through the area. ADF&G (1978a) estimates that over four million waterfowl and shorebirds pass through the Inlet each spring.

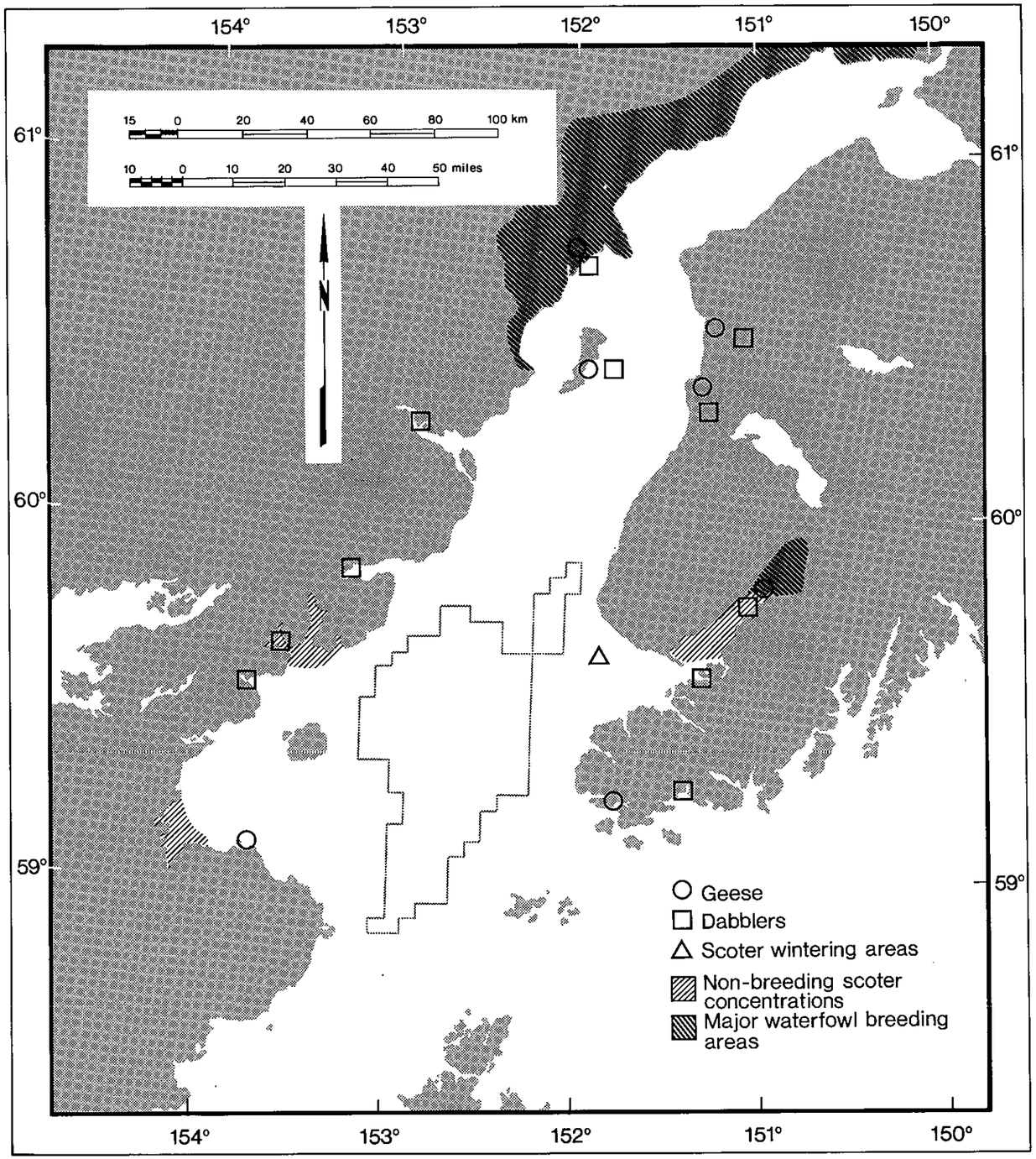


Figure E.3.5a Major waterfowl utilization of Cook Inlet (Erikson, 1977).

E.3.6 BIRD USE SUMMARY

Cormorants, mallards (Anas platyrhynchos), some diving ducks, bald eagles, peregrine falcon (Falco peregrinus), glaucous-winged gull, common murre, marbled (Brachyramphus marmoratum) and Kittlitz's murrelet (B. brevirostre) and northwestern crow (Corvus caurinus) use Cook Inlet for their entire life cycles (Fig. E.3.6a). Shearwaters (Puffinus sp.) use the Inlet as a summer feeding ground. Storm petrels, black-legged kittiwakes, guillemots, and puffins use the Inlet mainly for breeding and feeding during the summer, but small numbers are present throughout the year. Geese, most dabbling ducks, cranes, most shorebirds, and other gulls use the Inlet mainly during migration, diving ducks occur throughout the year, mostly as non-breeders. All of the bird species are vulnerable to direct fouling of their plumage by oil and to contamination or destruction of their food supplies. Embryos of breeding species usually die if eggs are soiled by oil. Human disturbance, such as noise, close approach of aircraft and boats, movement within colonies, can cause lower reproductive success or even desertion of nests and colonies. An increase of gull populations with increased availability of human garbage would expose many breeding species to higher predation of eggs and young.

Figure E.3.6a Tentative summary of use of Lower Cook Inlet by principal marine and coastal birds.

Species	Principal Habitat	Areas of Peak Occurrence*	Season of Peak Occurrence	Habitat Use	Potential Hazards During Petroleum Development
					FOR ALL BIRDS:
Sooty Shearwater	Offshore	1,3,4	May-Oct	Summer feeding ground	Severe oiling causes death from exposure.
Short-tailed Shearwater	Offshore	1,3,4	Mid May-Mid Nov	Summer feeding ground	Even small quantities of oil transferred to eggs reduces their hatchability.
Fork-tailed Storm Petrel	Spring & summer: offshore Fall & winter: inshore	?	Summer	Summer feeding & breeding grounds	
Cormorants	Inshore waters, rocky coasts	4	Fall	For entire life cycle	Destruction or contamination of foods and habitat by oil.
Canada & Snow Geese	Inshore & intertidal	3,5,6	Apr & late Aug-Sep, spring & fall migration	Feeding & staging during spring & fall migration	Human garbage might favor increase in gull population.
Dabbling Ducks (mainly mallard & pintail)	Inshore & 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 & staging during migration	Human disturbance around nesting colonies would lower reproductive success and, if severe enough, might eliminate entire colonies.
Diving Ducks	Inshore, offshore	2,3,5	Year long	Greater scaup & common eider: entire life cycle; Others: migration & winter feeding grounds; non-breeders may spend the summer	----------
Bald Eagle & Peregrine Falcon	Intertidal, inshore	3,4	Year long	Inshore & intertidal fishing (eagle only) & hunting (both species)	
Sandhill Crane	Intertidal	5 (Redoubt Bay, Kalgin Is.)	Mar-Apr & Sep-Oct, spring & fall migration	Migration	
Whimbrel, Least Sandpiper, Northern Phalarope	Intertidal	2,3,5	Mar-Apr, spring migration	Feeding & staging in spring migration	
Rock Sandpiper	Intertidal		Oct, fall migration	Fall migration, feeding	
Dunlin, Western Sandpiper	Intertidal	2,3,5	Mar-Apr & Oct, spring & fall migration	Feeding & staging in spring & 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	Nov-Apr (present in low numbers May-Oct	Winter feeding ground, Non-breeders present in summer	
Black-legged Kittiwake	Inshore & offshore	1,2,3,5	Spring, summer, fall (low numbers present in winter)	Mainly for breeding & summer feeding	
Common Murre	Inshore & offshore	1,2,3,4,5	Apr-Sep but present all year	For entire life cycle, though numbers decrease in winter	
Pigeon Guillemot	Inshore	2,3,4,5	Spring-Summer	Breeding, summer feeding	
Marbled & Kittlitz's Murrelets	Inshore & particularly in fall & winter, offshore	3,4	Year long	For entire life cycle	
Horned & Tufted Puffins	Offshore & inshore	4	May-Sep (absent in fall & winter)	Breeding, spring & summer feeding	
Northwestern Crow	Intertidal	3,4	Fall & 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

DATA EVALUATION

The broad outlines of the bird populations of Cook Inlet are fairly well established. Recent information on distribution and numbers is available in Erikson (1977). Distributional and abundance data are the result of recent aerial and shipboard surveys (Lensink and Bartonek, RU #337, Annual Report, 1976; Erikson, 1977; Gould, RU #377, Annual Report, Part I, 1977; Wiens, Heinmann and Hoffman, RU #108, Final Report, 1978), as is some of the habitat data (Arneson, RU #3, Annual Report, 1977). Much information is from the general literature, especially Isleib and Kessel (1973).

Population estimates for colonies are the result of ship and/or aerial surveys made in May and June, 1976 (Erikson, 1977). Data may be biased against smaller colonies (1,000 or less) and those of burrow-nesting species such as storm petrels and small alcids. Data on non-colonial species such as ducks, shorebirds, and songbirds, which may be as numerous as some colonial species, are lacking. Not included in these estimates are the Barren Islands bird colonies, which include about 350,000 birds (mostly alcids). Of the species listed, only the black-legged kittiwake has been found to be somewhat more numerous in the Inlet than it is on the Barren Islands. Overall, the Inlet populations are somewhat less than 10 percent of the Kodiak-Barren Islands populations (Lensink and Bartonek, RU #338/343, Quarterly Report, Apr-Jun, 1976).

Habitat data are the results of only four aerial surveys in 1976 and thus may not give a representative picture of the use of the Inlet by birds. The observation of 1-2 million small shorebirds on Fox River Flats on May 11, 1976 (Arneson, RU #3, Annual Report, 1977), for instance, is not reflected in these data. The data, however, clearly show that bays with open water are extremely important for the large numbers of diving sea ducks which use the Inlet throughout the year. Equally important for wintering and migrant shorebirds are the mud and sand substrates.

The pelagic survey data reported here are for the most part not the result of systematic surveys of the Inlet. The data of RUs 108 and 337 were recorded as part of larger surveys of the Gulf of Alaska and only incidentally included areas in Cook Inlet. Those of Erikson (1977) are from four 1976 surveys conducted over the same routes. Erikson's data are probably the best available for the Inlet, but they do not include the winter months.

There are several problems with the pelagic data. The results of shipboard surveys differ considerably from those of aerial surveys. The source of this disagreement is difficult to establish, since the various surveys were taken over different routes and by different observers using different techniques. Until a simultaneous shipboard and aerial census is made along the same transect routes there will be no basis for comparing the results from different methods. The data of Erikson (1977) indicate that aerial surveys tend to underestimate shearwater, diving duck, and alcid densities.

The major breeding areas for ducks identified here have long been known to be important (ADF&G, 1973). The areas of scoter concentrations in winter and summer need to be verified by further observations, as do the major migratory waterfowl staging areas. Almost all of the areas identified as important for waterfowl have been rated as environments highly vulnerable to oil spills by Hayes, Brown, and Michel (1977).

SUBTASK E.4 Population Dynamics and Trophics of Marine and Coastal Birds

E.4.1 POPULATION DYNAMICS

General information on the breeding phenologies of Alaskan marine and coastal birds has long been available (Gabrielson and Lincoln, 1959). As one proceeds northward from the equator the length of the summer, and hence, the breeding season of birds, becomes shorter. The reproductive period of more northerly populations of a species is usually compressed and may be several weeks shorter than that of more southerly populations. Superimposed on this geographic trend are local year-to-year fluctuations in the weather and food supply. An unseasonably late spring may delay the start of breeding, while a poor food supply may lead to slower growth or increased mortality of young, or may even prevent breeding altogether. Natural populations can compensate for these year-to-year uncertainties. In late seasons the breeding effort of a colony is usually more highly synchronized and compressed into a shorter period; when conditions are favorable, individual pairs (and the population as a whole) produce greater numbers of more vigorous young, thus offsetting poor years. True marine species tend to have low fecundity but high survivorship (Ashmole, 1971); thus a pair may enjoy many breeding seasons, and the success or failure of a particular season is not as critical for individual fitness or maintenance of a population as it is for shorter-lived species. On the other hand, such populations increase very slowly, and recovery from significant mortality of the breeding population may take many generations.

Details of the long-term population trends and year-to-year fluctuations in breeding effort and success of local populations or colonies of most Alaskan species are generally known. Studies of the population dynamics of marine and coastal birds have been carried out on the Barren Islands near Cook Inlet (Manuwal and Boersma, RU #341/342, Annual Report, Part VII, 1977; RU #341, Annual Report, Appendix VI, 1978), at Chiniak Bay, Kodiak Island (Nysewander and Hoberg, RU #341, Annual Report, Appendix V, 1978), and at Sitkalidak Strait, Kodiak Island (Baird and Moe, RU #341, Annual Report, Appendix IV, 1978).

Breeding Phenologies

The breeding phenologies recorded for 14 species of marine and coastal birds on the Barren Islands and Chiniak Bay and Sitkalidak Bay, Kodiak Island in 1976 and/or 1977 (references cited above) are shown in Fig. E.4.1a. Egg laying for all species took place between 10 May and 10 July. Common eiders (Somateria mollissima), black oystercatchers (Haematopus bachmani), mew gull (Larus canus), parakeet auklet (Cyclorrhynchus psittacula), and rhinoceros auklet (Cerorhyncha monocerata) laid earliest, while black-legged kittiwakes, common murres, and horned puffins (Fratercula corniculata) laid latest. Hatching started around 14 June and continued to about 16 August. Fledging started around 15 July and was still in progress when research teams left the study sites in September or October. The period from laying of the first egg to fledging of the first chick varied from about 40 to about 100 days, being longest for the cormorants and puffins, and shortest for the terns. The young of the common eider and the black oystercatcher left the nest soon after hatching.

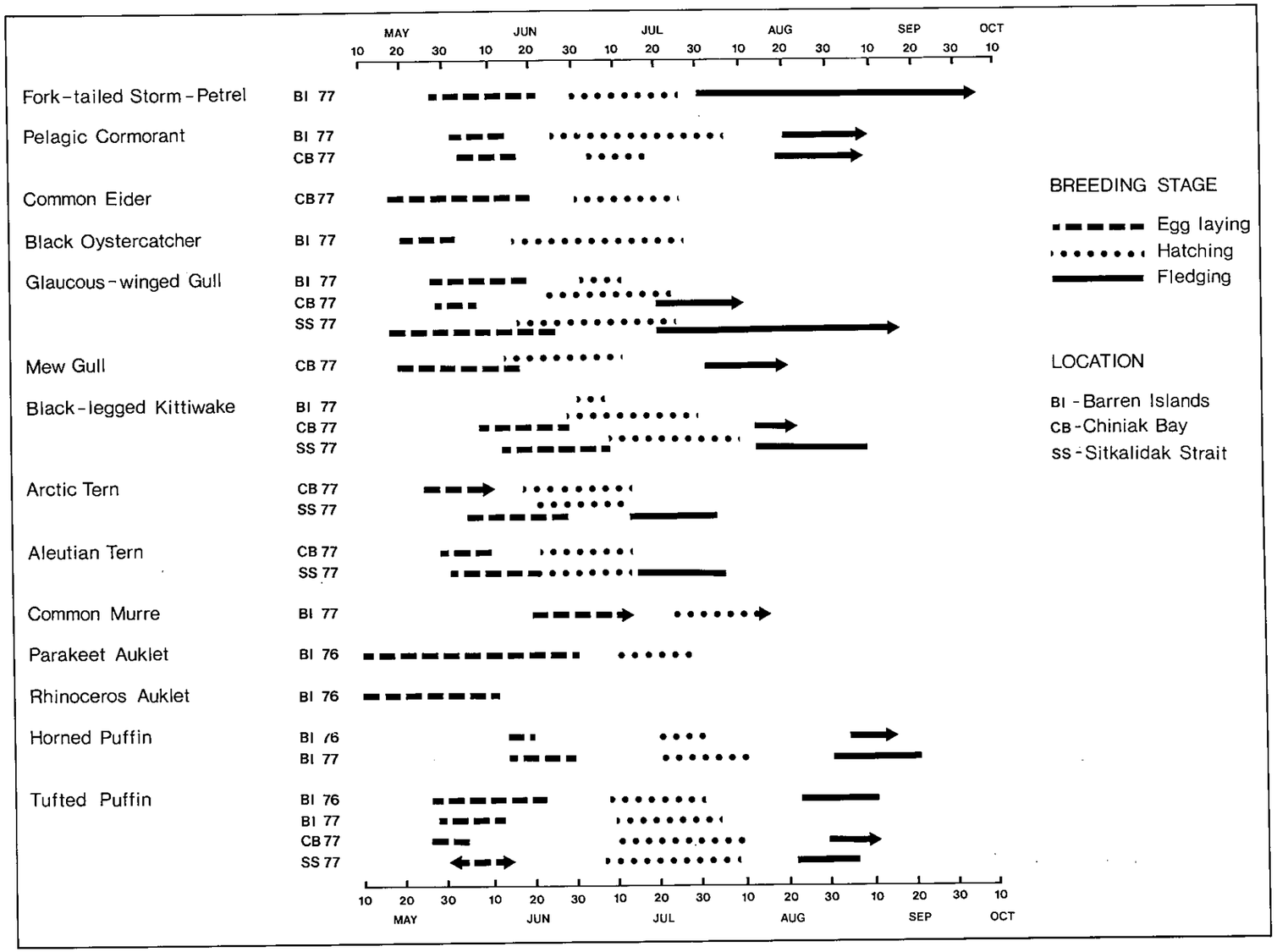


Figure E.4.1a Breeding phenologies for 14 species of marine and coastal birds. Data from several RU #341/342 reports; see text for references.

Two years of data are available only for the two species of puffins on the Barren Islands. Their breeding dates were almost identical for the two years. In 1977 the various species breed at similar dates at each of the three study sites. Minor exceptions are glaucous-winged gulls which breed about a week earlier at Sitkalidak Strait than at the other two sites, and Arctic terns (Sterna paradisaea) which breed about a week later at Sitkalidak Strait than at Chiniak Bay.

Compared to Bering Sea marine bird populations, those breeding in the Kodiak Area tend to begin nesting earlier, but the young fledge at about the same time.

Breeding Success

Data on the breeding success of ten species of marine and coastal birds for 1976 and/or 1977 on the Barren Islands, Chiniak Bay, and Sitkalidak Strait are given in Fig. E.4.1b. The productivity (young fledged per breeding pair) varied over a range of 0.26 to 1.74. There are too few data to suggest any strong differences between years or locations. Similar data for other areas in the Gulf of Alaska (Hatch et al., RU #341, Annual Report, 1978) indicate that productivity was about 12 percent higher in 1977 in the Kodiak area than it was in the Aleutian area.

The productivity of kittiwakes reported for 1977 is about 88 percent of that found by Coulson and White (1961) for a rapidly growing kittiwake population in Britain. The nesting success of the pelagic cormorant (Phalacrocorax pelagicus) and the black oystercatcher are essentially the same as reported by Drent et al (1964) for coastal British Columbia. About 51 percent of the eggs laid in the colonies studied failed to produce fledged young. Often the cause of mortality was unknown; an egg or nestling merely disappeared. At the Kodiak Island study sites the eggs of gulls and terns were regularly collected for food by natives. The predation of the eggs and chicks of other species by gulls appears to be lower on Kodiak than it is in the Aleutian area. The apparent depression of gull populations by native egging thus may be benificial to other birds. Bald eagles apparently prey regularly on colonies near their nests (Nysewander and Hoberg, RU #341, Annual Report, Appendix V, 1978). River otters are locally quite destructive to eggs and young (Manuwal and Boersma, RU #341, Annual Report, Part VII, 1977; Appendix VI, 1978; Nysewander and Hoberg, RU #341, Annual Report, Appendix V, 1978) but are not major causes of overall mortality. Storms and continued bad weather were observed to cause significant mortality to the chicks of fork-tailed storm-petrels (Oceanodroma furcuta) pelagic cormorants, mew gulls, black-legged kittiwakes, terns and puffins.

Figure E.4.1b Reproductive success of marine birds.

Species	Location[a]	Year	Number of[b] Active Nests Observed	Clutch Size	Eggs Hatched/ Eggs Laid	Chicks Fledged/ Chicks Hatched	Chicks Fledged/ Eggs Laid	Productivity (Young/Pair)
Fork-tailed Storm-Petrel	BI	1977	100	1.00	0.84	0.58	0.49	0.49
Fork-tailed Storm-Petrel	BI	1978	85	1.00	0.73	0.94	0.68	0.68
Pelagic Cormorant	BI	1977	63	2.84	0.64	0.57	0.36	1.02
Pelagic Cormorant	BI	1978	61	3.64	0.29	0.66	0.19	0.70
Pelagic Cormorant	CB	1977	25	3.48	0.69	0.62	0.42	1.48
Black Oystercatcher	BI	1977	12	3.00	0.92	0.64	0.58	1.74
Glaucous-winged Gull	BI	1977	44	2.46	?	?	0.54**	1.33
Glaucous-winged Gull	BI	1978	25	2.52	0.35	0.18	0.06	0.16
Glaucous-winged Gull	CB	1977	33	2.64	0.86	0.61	0.53	1.39
Glaucous-winged Gull	SS	1977	89	1.55	0.70	0.46-0.93	0.32-0.65	0.50-1.01
Mew Gull	CB	1977	60	2.63	0.84	?	?	1.00*
Black-legged Kittiwake	BI	1977	49	1.76	0.83	0.51	0.42	0.74
Black-legged Kittiwake	BI	1978	46	1.41	0.28	0.39	0.11	0.15
Black-legged Kittiwake	CB	1977	177	1.91	0.84	0.90	0.76	1.46
Black-legged Kittiwake	SS	1977	114	1.59	0.70	0.76	0.54	0.86
Arctic Tern	CB	1977	97	2.18	?	?	?	<1.53*
Arctic Tern	SS	1977	23	2.05	0.58	0.22-0.85	0.14-0.52	0.26-1.09
Aleutian Tern	SS	1977	126	1.60	0.65	0.28-0.88	0.19-0.58	0.29-0.92
Horned Puffin	BI	1976	14	1.00	0.79	0.36	0.28	0.28
Horned Puffin	BI	1977	14	1.00	0.93	0.69	0.64	0.64
Horned Puffin	BI	1978	18	1.00	0.88	0.75	0.66	0.66
Tufted Puffin	BI	1976	40	1.00	0.40	0.68	0.32	0.32
Tufted Puffin	BI	1977	56	1.00	0.50	0.78	0.39	0.39
Tufted Puffin	BI	1978	25	1.00	0.84	0.79	0.68	0.47***
Tufted Puffin	CB	1977	25	1.00	0.88	0.91	0.80	0.80
Tufted Puffin	SS	1977	67	1.00	0.61	0.88	0.54	0.54

a Locations: BI = Barren Islands
CB = Chiniak Bay, Kodiak Island
SS = Sitkalidak Strait, Kodiak Island

b An active nest was known to contain at least one egg

* indirect estimate (see Nysewander and Hoberg, RU #341, Annual Report, Appendix V, 1978)

** indirect estimate (see Manuwal and Boersma, RU #341, Annual Report, Appendix VII, 1978)

*** estimate from undisturbed study plot (Manuwal, pers. comm.)

Human activity in and near colonies often resulted in frightening away adult birds and exposing eggs and young to predation. A common theme in the reports of workers on bird colonies in the Gulf of Alaska is the high incidence of nest abandonment by puffins because of human disturbance. Birkhead (1977) observed that regular visits to measure chicks of the common murre greatly increased mortality. While the restricted activities of OCSEAP investigators have probably had little effect on these populations sustained human activity on or near their colonies will wreak havoc among them.

E.4.2 TROPHICS

An understanding of the feeding ecology and diet of marine and coastal birds gives insight into the roles that various species play in local ecosystems. However, specific dietary information is required to identify their roles in food webs and in nutrient and energy cycles. Specializations in prey and habitat requirements are often determined from trophic data. Currently little information is available on the ability of birds to shift their diet or the kind of habitat in which they feed when food availability changes suddenly. Many species have been observed to change their diet with the seasonal waxing and waning of prey populations, to have different food preferences in different geographic regions, and to exploit different feeding habitats during migration. These differences, however, occur gradually in time and space and have a high degree of predictability. A sudden and unpredictable change, as in the case of the sudden reduction of food when El Niño occurs along the Peruvian coast (Ashmole, 1971), may result in massive mortality in marine birds.

Diet of Adults

Figure E.4.2a displays composite dietary information for five species of marine birds from near Kodiak Island in 1977 (Sanger, Hironaka, and Fukuyama, RU #341, Annual Report, Appendix III, 1978). Figure

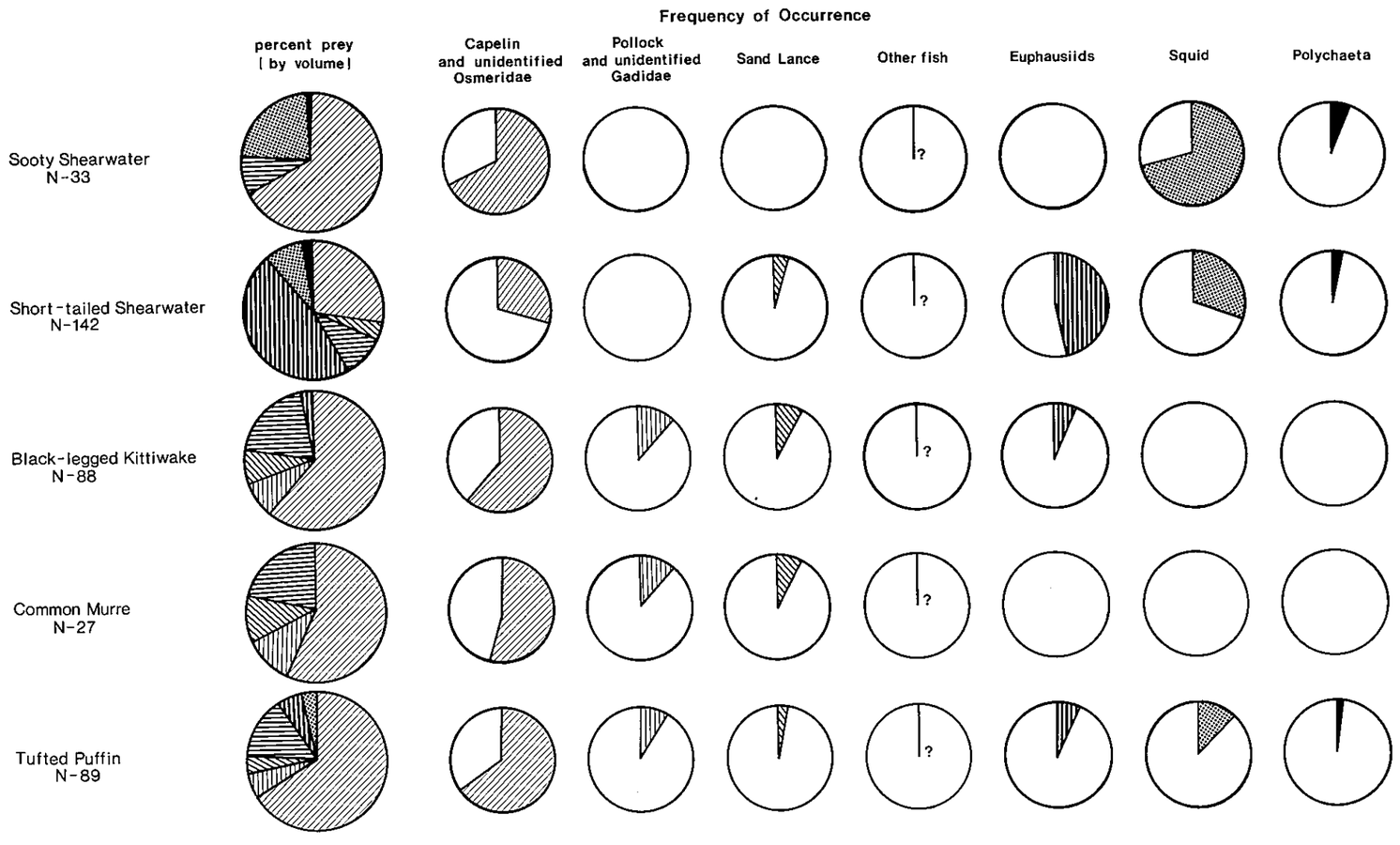


Figure E.4.2a Diet of five species of marine birds, Kodiak area, 1977 (Sanger, Hironaka and Fukuyama, RU #341, Annual Report, Appendix III, 1978).

E.4.2b shows similar, but less detailed information, for three other species from the Gulf of Alaska (Sanger and Baird, RU #341/342, Annual Report, Part XIV, 1977). On the basis of percent volume and frequency of occurrence, fish, especially capelin (Mallotus villosus), are the major prey of six species. Euphausiids are the major prey of short-tailed shearwaters, and squid are most important for thick-billed murres. Thus fish support the majority of the species, but because short-tailed shearwaters are so numerous, euphausiids may actually support greater numbers of individuals (Sanger et al., RU #341, Annual Report, Appendix III, 1978). In contrast to these results, Wehle (1976) found that horned and tufted puffins ate mostly squid around Buldir Island in the western Aleutians.

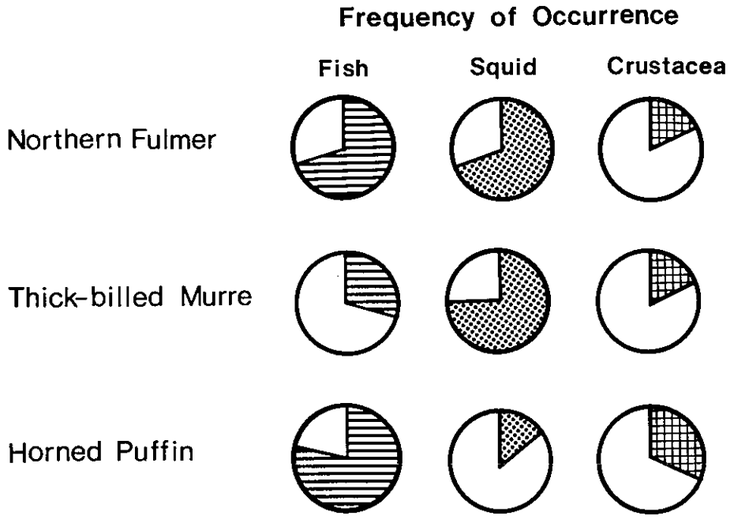
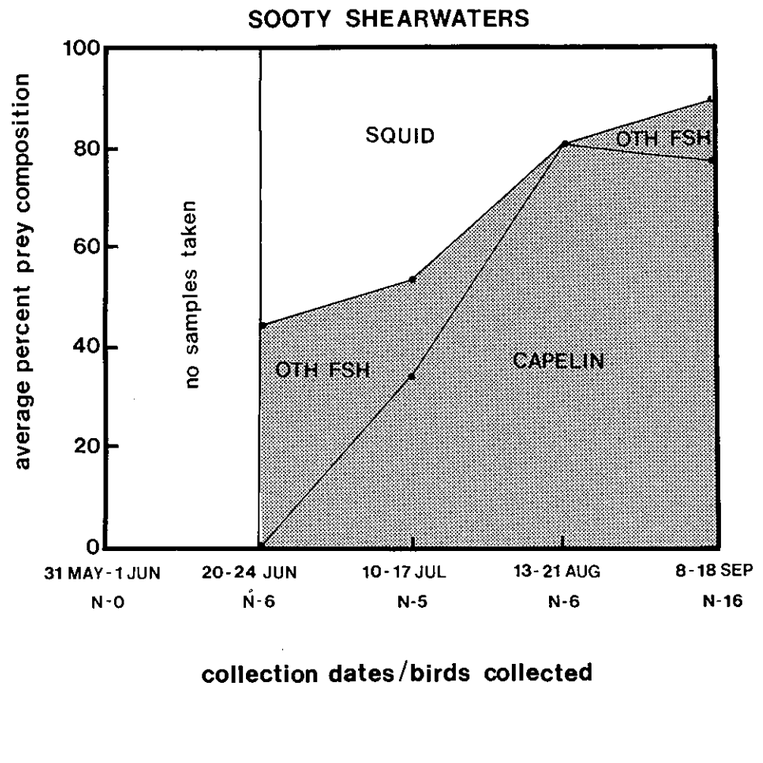


Figure E.4.2b Diet of three species of marine birds, Gulf of Alaska (Danger and Baird, RU #341/342, Annual Report, Appendix III, 1978).

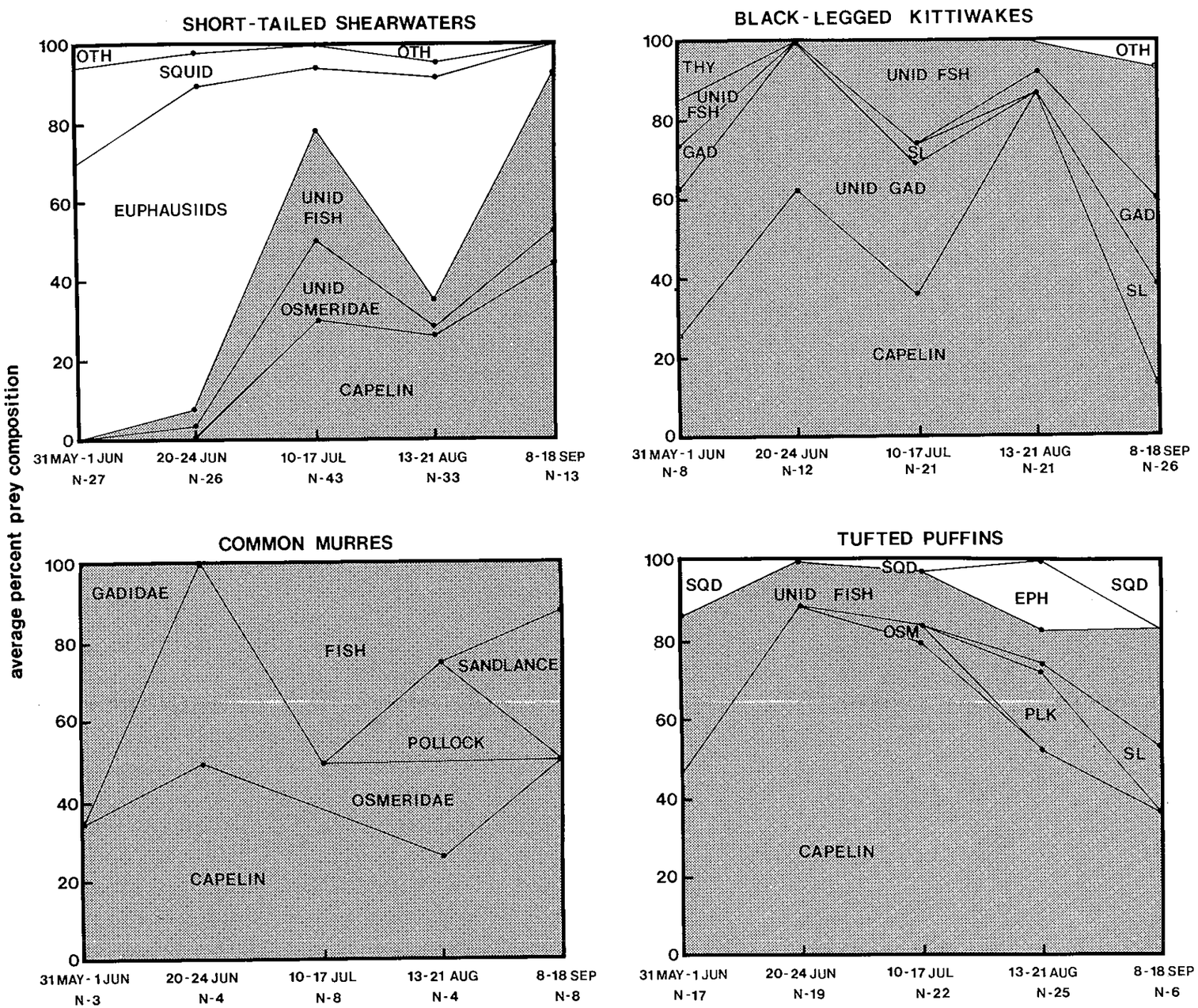
The diets shown in Fig. E.4.2a are composites of five sampling periods. The variation in diets for these sampling periods (from the end of May to mid-September, 1977) is shown in Fig. E.4.2c. Because of the small sample sizes and the large proportions of unidentified fish, there is little basis for identifying seasonal trends in the diets of these bird species. For the shearwater species, however, it does appear that the proportion of fish in the diet increases through July and August.



ABBREVIATIONS

EPH	EUPHAUSIIDS	OTH	OTHER
FSH	FISH	SL	SANDLANCE
GAD	GADIDAE	SQD	SQUID
PLK	POLLOCK	THY	THYSANOESSA
OSM	OSMERIDAE	UNID	UNIDENTIFIED

Figure E.4.2c Seasonal variation in the diet of five species of marine birds, Kodiak area, 1977. Shaded areas represent total fish consumption (Sanger, Hironaka and Fukuyama, RU #341, Annual Report, Appendix III, 1978).



The overall diets of diving ducks, wintering in Lower Cook Inlet, are given in Fig. E.4.2d. Bottom-dwelling molluscs and crustaceans are the major food items of eleven of the twelve types of ducks listed. The dependence on these food resources is probably greater than indicated, because the data represent samples taken throughout the year and include birds taken on their inland breeding habitats (Cottam, 1939; Cottam and Knappen, 1939). Oil spills which destroyed the bottom fauna would be detrimental to wintering ducks regardless of the time of year in which they occurred.

Figure E.4.2d Food habits of diving ducks (data from Cottam, 1939; Cottam and Knappen, 1939).

Species	Percent Volume of Total Diet						
	Pondweeds	Misc. plant	Molluscs	Insects	Crustaceans	Fishes	Misc. Animals
Scaup (sp.)	19	25	39	7	7		
Goldeneye (sp.)	9	17	10	28	32	3	1
Bufflehead	7	14	16	41	17	4	1
Oldsquaw	2	10	16	11	48	10	3
Harlequin Duck		1.5	25	10	57	2.5	4
Steller's Eider	3	10	19	13	45	2	8
Common Eider		4	82	2	7		5
King Eider		5	46	5	19		25
Spectacled Eider	7	16	42	32	3		
White-wing Scoter		6	75	2	13	2	2
Common Scoter	5	5	65	3	17	3	3
Surf Scoter	3	9	61	10	10	3	4

Diet of Young

The diets of horned and tufted puffin chicks are shown in Fig. E.4.2e. Food samples were obtained by forcing chicks to regurgitate, collecting food samples left in the burrows by adults when their chicks were prevented from eating (by taping their beaks shut), and by capturing feeding adults (Manuwal and Boersma, RU #341, Annual Report, Appendix VI, 1978; D. Manuwal, pers. comm.). Capelin and Pacific sand lance (Ammodytes hexapterus) were heavily utilized as food by both species. Early in the 1978 season tufted puffin chicks were fed mainly on an unidentified species of fish (D. Manuwal, pers. comm.). The heavy use of capelin, an oil-rich species, parallels the preferential use of oil-rich spratts (Sprattus sprauus) by common puffins (Fratercula arctica) to feed their young (Harris and Hislop, 1978). Harris and Hislop (1978) reckon that puffins obtain the best return for effort expended by feeding their young a few large oil-rich species. They also report that young puffins are easy to raise in the laboratory when fed exclusively on spratts, but all die if fed exclusively on whiting (Merlagius merlangus), a fish with a higher protein, but lower fat content.

Feeding Area

Observations on the feeding grounds of birds of Lower Cook Inlet area are few but are available for several species around the Semidi Islands (Leschner and Burrell, RU #341/342, Annual Report, Part II, 1977) and around Ugaiushak Island (Wehle et al., RU #341/ 342, Annual Report, Part IV, 1977). Pigeon guillemots fed within several hundred meters of shore at both locations; the species is well-known as a littoral feeder (Bédard, 1976). Cormorants fed primarily within 2 km of shore, horned puffins concentrated within 3 km of shore (Ugaiushak), black-legged kittiwakes near shore and out of sight of land (Ugaiushak); murres fed more than 0.5 km from shore (Ugaiushak), parakeet auklets occasionally fed in riptides near islands, but usually over 1 km offshore (Semidis); tufted puffins were rarely seen feeding near land (Semidis), while rhinoceros auklets were never observed feeding near land (Semidis). Wehle (1976) reported that around Buldir Island horned puffins tended to feed in shallower waters usually within 2 km of the island, while tufted puffins fed in deeper water up to at least 15 km from land.

Wiens, Heinemann, and Hoffman (RU #108, Final Report, 1978) found that most marine bird feeding flocks in Alaskan waters occur within 5 km of land, usually in areas of greatest coastline complexity. Baird and Moe (RU #341, Annual Report, Appendix IV, 1978) reported that in Sitkalidak Strait feeding flocks usually formed along convergence currents especially in areas where there was a rapid change in bottom topography. Bédard (1976) suggests that coastline and slope configuration, water circulation, and seasonal and local events (tidal rips, fronts, etc.) may be more important than simple distance from land in determining the feeding locations of marine birds. Hunt (RU #83, Annual Report, 1978) reported that around the Pribilof Islands foraging birds were concentrated within ten nautical miles of the islands and in the vicinity of the 200-meter shelf break.

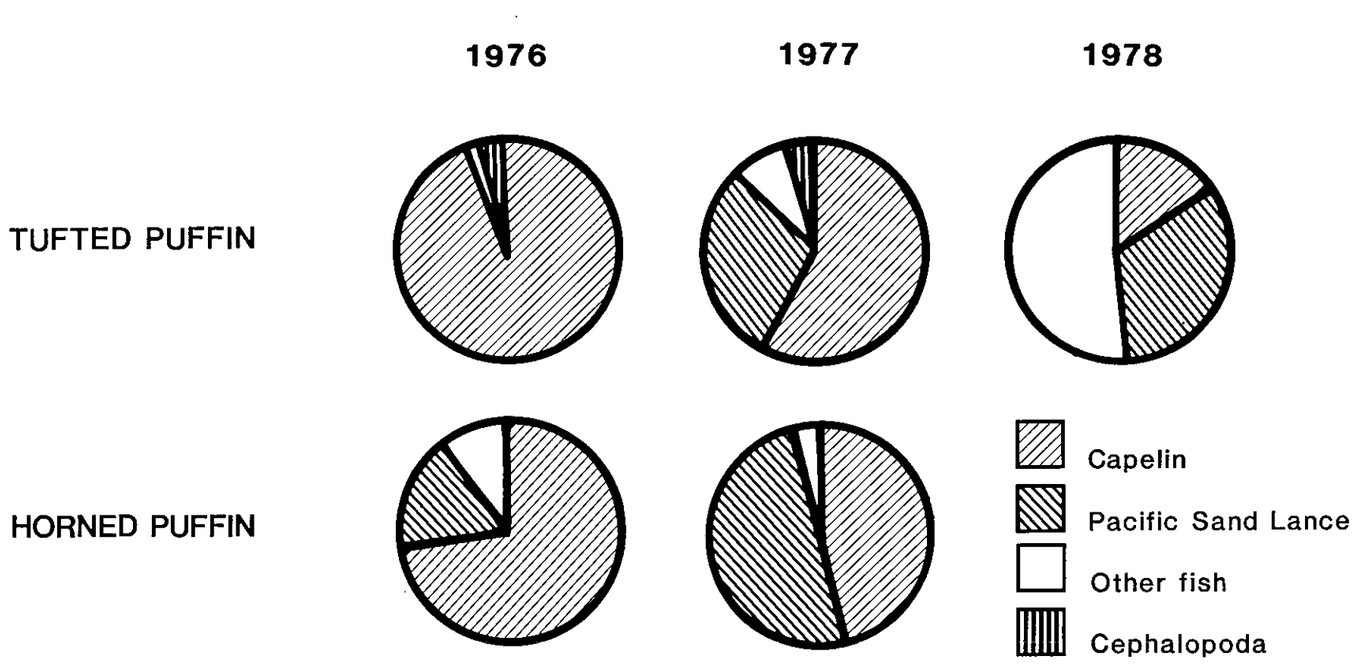


Figure E.4.2e Diet of horned and tufted puffin chicks, Gulf of Alaska (Manuwal and Boersma, RU #341, Annual Report, Appendix VI, 1978; Manuwal, pers. comm.).

DATA EVALUATION

The breeding phenologies of the colonial breeding species of Lower Cook Inlet have not been studied. Several species, however, have been studied in the Kodiak area where breeding chronology is probably quite similar.

The prediction of long-range population trends requires several years' data on fecundity, mortality schedules, and the age of first reproduction. Current OCSEAP studies have not gathered data on these population parameters. Without this information there is no way that the variations in breeding success reported for different years or localities can be used to estimate whether Alaskan bird populations are stable, growing, or declining, nor how they might respond to increased mortality rates resulting from development.

The gathering of such data would take perhaps a decade of intensive effort and probably would involve only a few species and sites. If such a program were continued into the production phase of the lease area, almost as many years would be required to determine whether population changes were taking place. Measurements of population parameters, however, are available for the same or similar species in other areas. Using those data, the effects of different mortality regimes for these populations could be simulated and the level of perturbations they could withstand without unacceptable change could be estimated.

The overall non-winter diets of a few species of Alaskan marine or coastal birds have been determined. Sample sizes are generally too small to identify seasonal shifts in diet. Information on the food of nestlings is mostly qualitative. While it appears that the diets of the young and adults are different, it is not known whether adults gather food for themselves and their young in the same habitat or whether they exploit one habitat for their young and another for self-maintenance. Much work is needed to determine the feeding habitat requirements of most species. Data for the winter months in particular are needed.

SUBTASK E.5 Distribution and Abundance of Pelagic and Demersal Fish, Relative Seasonal Distributions, Critical Habitats

E.5.1 DISTRIBUTION, ABUNDANCE AND MIGRATORY ROUTES OF DOMINANT FISHES

Salmonids

Five species of Pacific salmon (pink, Oncorhynchus gorbuscha; chum, O. keta; coho, O. kisutch; sockeye, O. nerka; and chinook, O. tshawytscha) are found throughout Cook Inlet during late spring and early summer. Other salmonids common in Lower Cook are Dolly Varden (Salvelinus malma) and steelhead trout, (Salmo gairdneri). Common names of fish are those approved by the American Fisheries Society (Bailey et al., 1970). From 1925 to 1972, the average number of maturing adults entering Cook Inlet per year was about 4.7 million individuals; estimates of the potential run size exceed 11 million fish (Stern, RU #353, Quarterly Report, Oct-Dec, 1976). Sockeye and pink salmon are most abundant, respectively contributing 43 and 34 (the average of 54 in even years and 14 in odd years) percent to the spawning run.

The year's breeding cohort of salmonids has been observed in marine waters as early as December, but it usually begins to enter the Inlet in early May. Most of the spawners enter natal streams during the summer. Those individuals which spawn in the upper areas of the Inlet reach peak abundance first.

Within the Inlet, ADF&G Fisheries Management Statistical Area 244 (Fig. E.5.1a) is most important to the spawning run. From 1956 to 1972 the average run in this area was about 2.7 million fish or 57 percent of the maturing adults entering Cook Inlet. Another important area is the region southeast of Kalgin Island, where sockeye, coho, pink and chum salmon concentrate in large numbers before migrating to natal streams in other parts of the Inlet (Stern, RU #353, Quarterly Report, Oct-Dec, 1976).

Maturing salmonids usually approach coastal streams from a counter-clockwise direction along the coastal margins of the Gulf of Alaska. Within the Inlet (Fig. E.5.1b) migratory pathways of maturing adults are not rigidly fixed and much searching occurs before the fish enter natal streams; the cause of these deviations are unknown (Stern, RU #353, Quarterly Report, Oct-Dec, 1976). For example, sockeye bound for the Kenai and Kasilof Rivers move northward well past their natal streams before turning southward along the eastern shore (Stern, RU #353, Quarterly Report, Oct-Dec, 1976). This may be a response to southwest winds, prevailing currents, and tides. Tagging studies of maturing adults indicate that most fish entering Cook Inlet remain there. Some fish tagged in outer Prince William Sound were later found in Cook Inlet.

Pink Salmon

Pink salmon are common throughout the Gulf of Alaska and may be found seasonally in most bays and streams of Cook Inlet. Females spawn in the summer, entering natal streams from June through September. Groups of individuals migrate on an odd/even year basis, spending only one summer at sea; no genetic interchange occurs between different runs (ADF&G, 1976b). From 1956 to 1972, the average even-year run (2.5 million fish) dominates pink salmon and total salmon abundance in Cook Inlet. Only in Statistical Areas 242 and 248 did odd-year run abundance approach even-year estimates. Maturing pink salmon are most

Figure E.5.1a Population estimates, 1956 through 1972, of total run size of adult salmonids by Statistical Area and the relative contribution of each species to the total run (modified from Stern, RU #353, Quarterly Report, Oct -Dec, 1976).

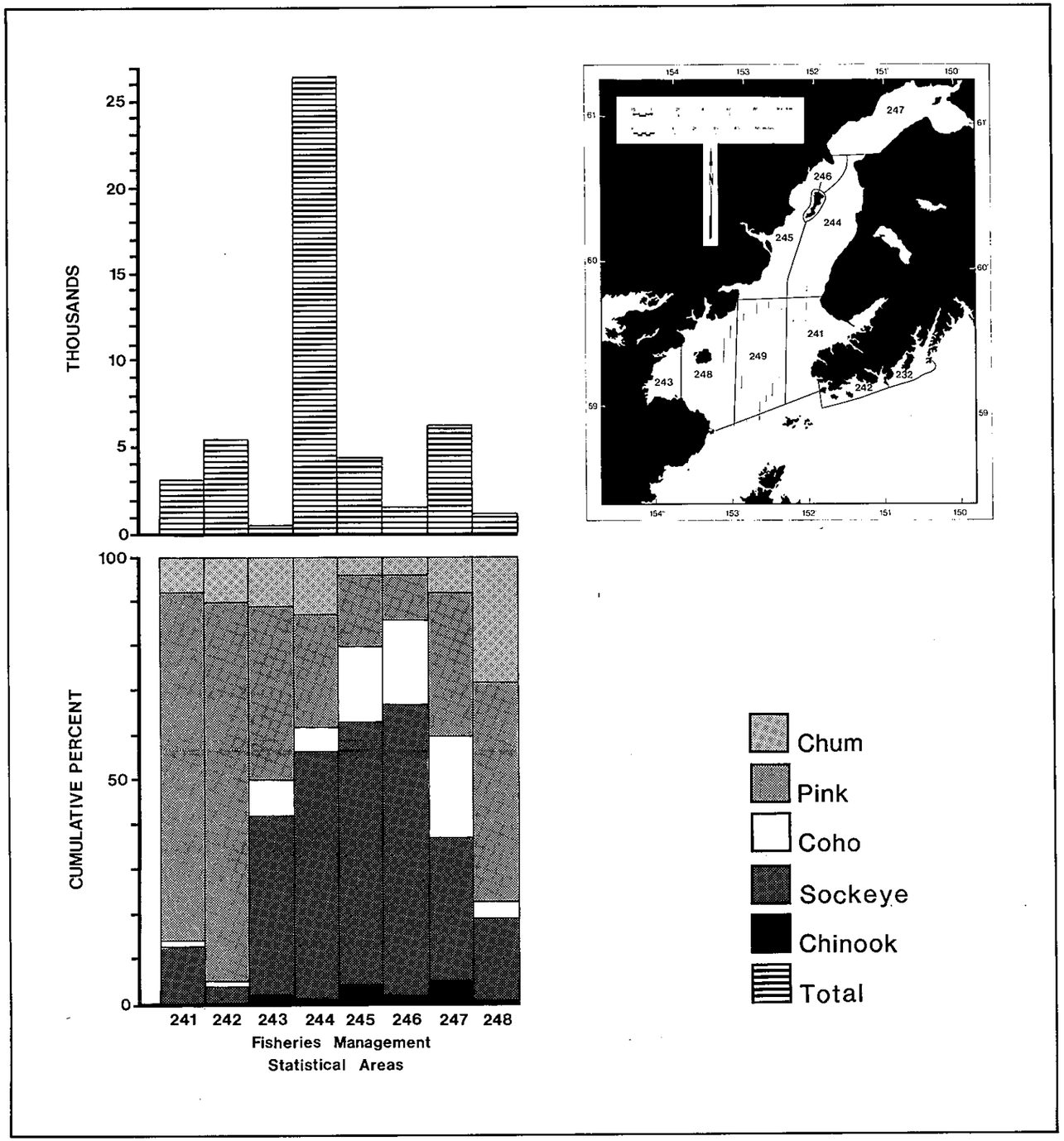
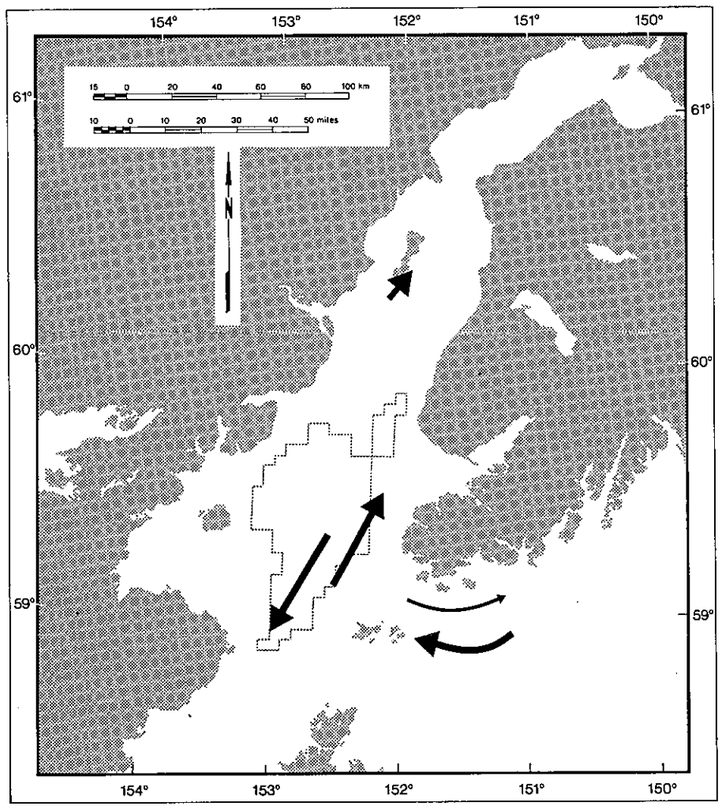


Figure E.5.1b Summary of coastal movements of adult salmonids (modified from Stern, RU #353, Quarterly Report, Oct - Dec, 1976).



numerous in the Kenai and Kasilof River systems (Statistical Area 244), but only the even-year run is significant. They also constitute a major portion (>50 percent) of the spawning run in Statistical Areas 241, 242 and 248. During spawning adults are commonly found in short coastal streams and often in the intertidal zone (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; ADF&G, 1976b).

Sockeye Salmon

Within Cook Inlet, sockeye salmon are most numerous in Statistical Area 244; they were also abundant in Statistical Areas 245, 246 and 247. These areas contain river-lake systems, which are essential to reproductive success of sockeyes. The Susitna, Kenai, and Kasilof River systems are most important to this species. Their spawning migration begins in early June and continues into late August (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; ADF&G, 1976b).

Chum Salmon

Chum salmon are most numerous in Statistical Area 244; however, their relative abundance is highest in Statistical Area 248 where they account for about 30 percent of the average salmon. In Cook Inlet maturing chum move into fresh-water spawning areas in early July, with migration from the marine environment continuing into September. Like pink salmon, adults typically spawn in outlet areas of small coastal streams, rarely leaving the zone of tidal influence. Chum salmon spend two to four years at sea before returning to spawn (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; ADF&G, 1976b).

Chinook Salmon

Chinook salmon are the least abundant salmon species in Cook Inlet. They are most common in the central and upper areas of the Inlet north of Anchor Point. The Susitna, Kenai, and Kasilof Rivers are most important to chinook salmon production. Maturing adults enter the nearshore zone in mid-May and the migration continues into early August. Juveniles usually spend one to two years in the natal stream and an additional two or three years at sea (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; ADF&G, 1976b).

Coho Salmon

Coho salmon are distributed throughout Cook Inlet but are most abundant in Statistical Areas 244 and 247. In Statistical Area 247 this species comprises about 25 percent of the total salmon spawning run. The run begins in late July or early August and may continue into December. Coho salmon spend one to two years at sea before returning to natal streams (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; ADF&G, 1976b).

Dolly Varden Char

Dolly Varden were most numerous in nearshore regions, especially in catches on the eastside of the Inlet. This species occurred infrequently in offshore catches. Average catches per unit effort (CPUE) greater than 10 fish/beach seine haul were recorded north of Anchor Point and in Kachemak Bay during May-June, in Kachemak Bay in July, and southwest of Tutka Bay in August. The highest average catch rate on the west side was 9 fish/beach seine haul in May-June (Blackburn, RU #512, Final Report, 1978).

Steelhead Trout

Spawning migrations of steelhead trout take place along the coast of the lower Kenai Peninsula in the fall, with actual spawning occurring in March and April (ADF&G, 1976b).

Demersal Fish

Data on the distribution and relative abundance of various demersal fish species in Lower Cook Inlet indicate that demersal species are found throughout the sampling area during all months sampled (Blackburn, RU #512, Final Report, 1978; Figs. E.5.1c and d). CPUE was highest during August, particularly in the 101-125 m depth zone. CPUE's were greatest in the 2650 m depth zone during July, in the 76-175 m zone during August, and in the 176-200 m depth zone in March. Blackburn's data generally agree with the known behavioral patterns of many demersal fish species; i.e., most species migrate into deeper water during the fall and winter months.

Catch data for the flatfish group from demersal fish surveys conducted by the National Marine Fisheries Service (NMFS; formerly the Bureau of Commercial Fisheries) from 1950 to 1971 are summarized by Gusey, 1975. In general, the average catch rates of flatfish on the inner shelf (1-99 m) of Cook Inlet were the lowest of any recorded in similar depth zones in the Gulf of Alaska. Average flatfish CPUE's were 60 kg/hr trawled (1-90 m), 102 kg/hr (91-181 m), and 99 kg/hr (182-273 m). The average flatfish catch for all depths was 206 kg/hr trawled.

Figure E.5.1c Summary of the distribution and mean catch per 20-minute trawl for demersal fish (summarized from Blackburn, RU #512, Final Report, 1978).

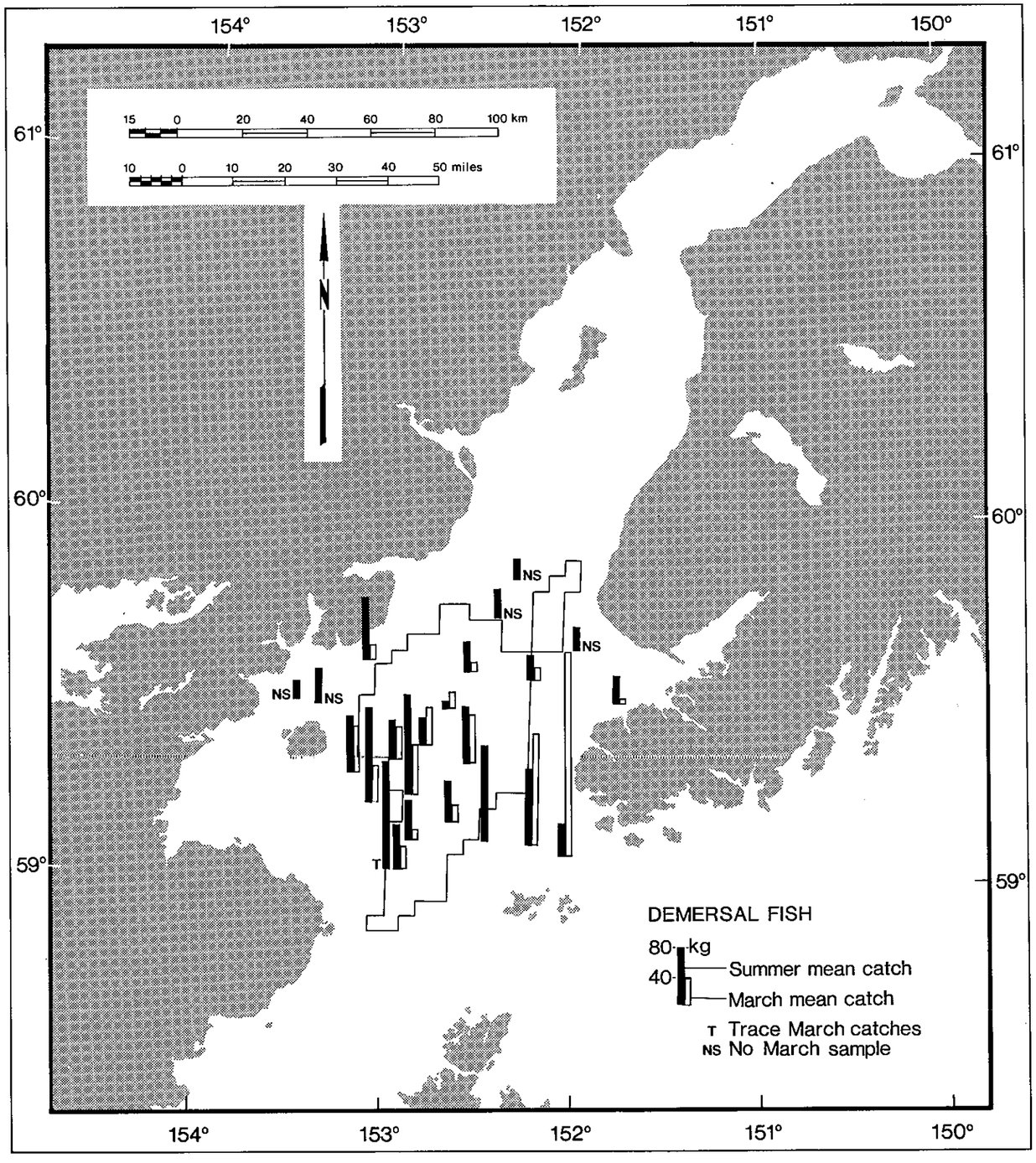


Figure E.5.1d Catch per unit effort of demersal fish by depth interval and month in Lower Cook Inlet, June through September 1976 and March 1977 (summarized from Blackburn, RU #512, Final Report, 1978).

Depth (m)	CPUE (kg)				
	June	July	August	September	March
0- 25	-	-	-	36.7	-
26- 50	60.3	164.4	10.7	38.1	14.5
51- 75	34.6	34.2	60.9	78.1	45.4
76-100	25.3	70.3	136.3	95.6	66.9
101-125	-	95.9	237.4	-	-
126-150	-	45.8	114.6	40.5	47.1
151-175	-	38.3	218.3	-	-
175-200	-	80.4	16.4	-	277.1

Arrowtooth Flounder

Arrowtooth flounder (Atheresthes stomias) were the most abundant flatfish species caught in NMFS surveys in Lower Cook Inlet (Gusey, 1975) but were only fifth in flatfish abundance in Blackburn's (RU #512, Final Report, 1978) survey. The abundance reported by NMFS in Lower Cook was also less than catch levels recorded by Ronholt, Shippen and Brown (1978) in the Gulf of Alaska. This species was most abundant in the southern portion of the lease area.

Flounders were caught in all depth zones sampled by trawl in spring through fall. Catch rates ranged from less than one to more than 17 kg/20 min. otter trawl; highest CPUE's occurred during July and August in water depths of 101 to 175 m. Catch rates decreased in September and were low (<3 kg/20-min. trawl) in March. No flounders were caught in nearshore beach seine hauls (Blackburn, RU #512, Final Report, 1978).

Pacific Halibut

Pacific halibut (Hippoglossus stenolepis) are distributed throughout Cook Inlet from March through August and have been reported as far north as the Forelands (ADF&G, 1976a; Blackburn, RU #512, Final Report, 1978). Catch rates were highest (>20 kg/20-min. trawl) in the southern and central regions of the lower Inlet during March; summer catches were greatest in the central, western, and northern regions of the lower Inlet (Blackburn, RU #512, Final Report, 1978). Exploratory trawls by the NMFS indicate that halibut concentrations were highest in Kachemak Bay (ADF&G, 1976a).

Halibut were caught in most depth zones sampled, but deep water (>126 m) summer trawls captured less than 1 kg/20 min. trawl. Most abundant catches in June (37 kg/20-min. trawl) and July (45 kg/20-min. trawl) were at depths of 26-50 m while in August (42.6 kg/20-min. trawl) they were at depths of 76 to 100 m. Catches were low (<12 kg/20 min. trawl) during September and March; however, the highest catches in March occurred at depths greater than 50 m (Blackburn, RU #512, Final Report, 1978).

Catch rates reported by Gusey (1975) averaged 36 kg/hr trawled in depths of 1 to 90 m and 28 kg/hr trawled at depths of 91 to 181 m, or 29 kg/hr trawled for all depths sampled. These catch rates are similar to those recorded by Blackburn (RU #512, Final Report, 1978).

Pacific halibut in Lower Cook generally move into deeper water during winter and into the shallow zones in summer. Because of the bathymetry of Lower Cook, these movements are toward the lower Inlet during the winter.

Yellowfin Sole

The yellowfin sole (Limanda aspera) population in Cook Inlet is the largest reproducing population of this species east of the Bering Sea. The species is most numerous in the southeastern Bering Sea and is the second most abundant demersal fin fish species in Cook Inlet (Blackburn, RU #512, Final Report, 1978). In the Gulf of Alaska yellowfin sole occur only incidentally in survey catches of demersal fish.

Within Cook Inlet, Blackburn, (RU #512, Final Report, 1978) found that concentrations of this species decreased with increasing water depth, with less than 1 kg/20-min. trawl caught in water more than 101 m deep. This species was most abundant east and southeast of Augustine Island, with few caught in the central, northern, and eastern regions of the lower Inlet.

Though yellowfin sole is usually most abundant in September, the highest CPUE (90.7 kg/20-min. trawl) recorded were taken in July. Individuals were rarely caught in water deeper than 100 m and have never been recorded in the northern areas of Lower Cook. The distribution of this species in shallow water (<26 m) is not well known, since sampling in these depths has been limited (Blackburn, RU #512, Final Report, 1978).

The species is found in shallow water in spring and summer and moves into deeper regions in the fall and winter. Blackburn (RU #512, Final Report, 1978) reports that sole were most abundant in the shallow waters of western Kamishak Bay in June and July. In August and September they move into the region southeast of Augustine Island, where they were found to be most abundant in March.

Starry Flounder

Starry flounder (Platichthys stellatus) were abundant in trawls in September, less so in June, July, August, and March. They were most common in beach seine catches, indicating a preference for nearshore areas. Largest catches were on the west side of the Inlet, particularly in Kamishak Bay (Blackburn, RU #512, Final Report, 1978).

Unlike most other flatfish species, starry flounder move into shallow water during the winter and are most abundant in deeper regions during the summer.

Rock Sole

Rock sole (Lepidopsetta bilineata), were common in both nearshore beach seine hauls and in otter trawls throughout the lower Inlet. They occurred in all areas of the Inlet but were most abundant in the southern portions.

Nearshore abundance, 2.6 fish/beach seine haul, was greatest in Seldovia Bay. The CPUE, by trawl, was highest (30.2 kg/20-min. tow) in depths of 176 to 200 m zone near Kennedy Entrance. Trawl catch rates were greatest in August, September, and March, with moderate catches (12 to 18 kg/20-min. tow) in depths of 51 to 100 m (Blackburn, RU #512, Final Report, 1978).

Other Flatfish Species

Butter sole (Isopsetta isolepis) were abundant in the central Inlet at water depths of 25 to 100 m. Flathead sole (Hippoglossoides elassodon) were found throughout the Inlet but did not occur nearshore. Largest numbers were taken in the southwestern region of the Inlet. Rex sole (Glyptocephalus zachirus) were most abundant east and southeast of Augustine Island. These species are usually found in shallow water areas during the summer and in deeper regions during the winter (Blackburn, RU #512, Final Report, 1978).

Walleye Pollock

Walleye pollock (Theragra chalcogramma) were the most abundant demersal fin fish in Lower Cook, occurring in 72 percent of the trawls (Blackburn, RU #512, Final Report, 1978), at all stations and depths sampled (18 to 192 m) were most abundant at depths greater than 76 m and in the southern portion of the lower Inlet, where trawl catch rates exceeded 80 kg/20-min. tow north of Cape Douglas.

This species was most abundant in July and August. Average CPUE's ranged from 0 kg/20-min. tow at 26 to 50 m to 163 kg/20-min. tow at 151 to 175 m; concentrations were greatest in water depths of 76 to 200 m. Catch rates were low in September, and few were caught in June and March (Blackburn, RU #512, Final Report, 1978).

Walleye pollock migrate over the shelf, occurring in shallower areas during summer and seeking deep water regions in winter.

Pacific cod

Pacific cod (Gadus macrocephalus) were most abundant in summer in northern and southern regions of Lower Cook. They were abundant in catches taken near Kennedy Entrance in March; in all other areas few or none were caught.

In June, a greater abundance (9 to 10 kg/20-min. tow) were taken in depths of 51 to 100 m; fewer were taken at these depths during other months. During July and August average catch rates were low at shallower depths, with the highest catches (>30 kg/20-min. tow) recorded in depths of 151 to 175 m. In March the highest average CPUE (>30 kg/20-min. tow) was in depths of 176 to 200 m (Blackburn, RU #512, Final Report, 1978).

Other Demersal Species

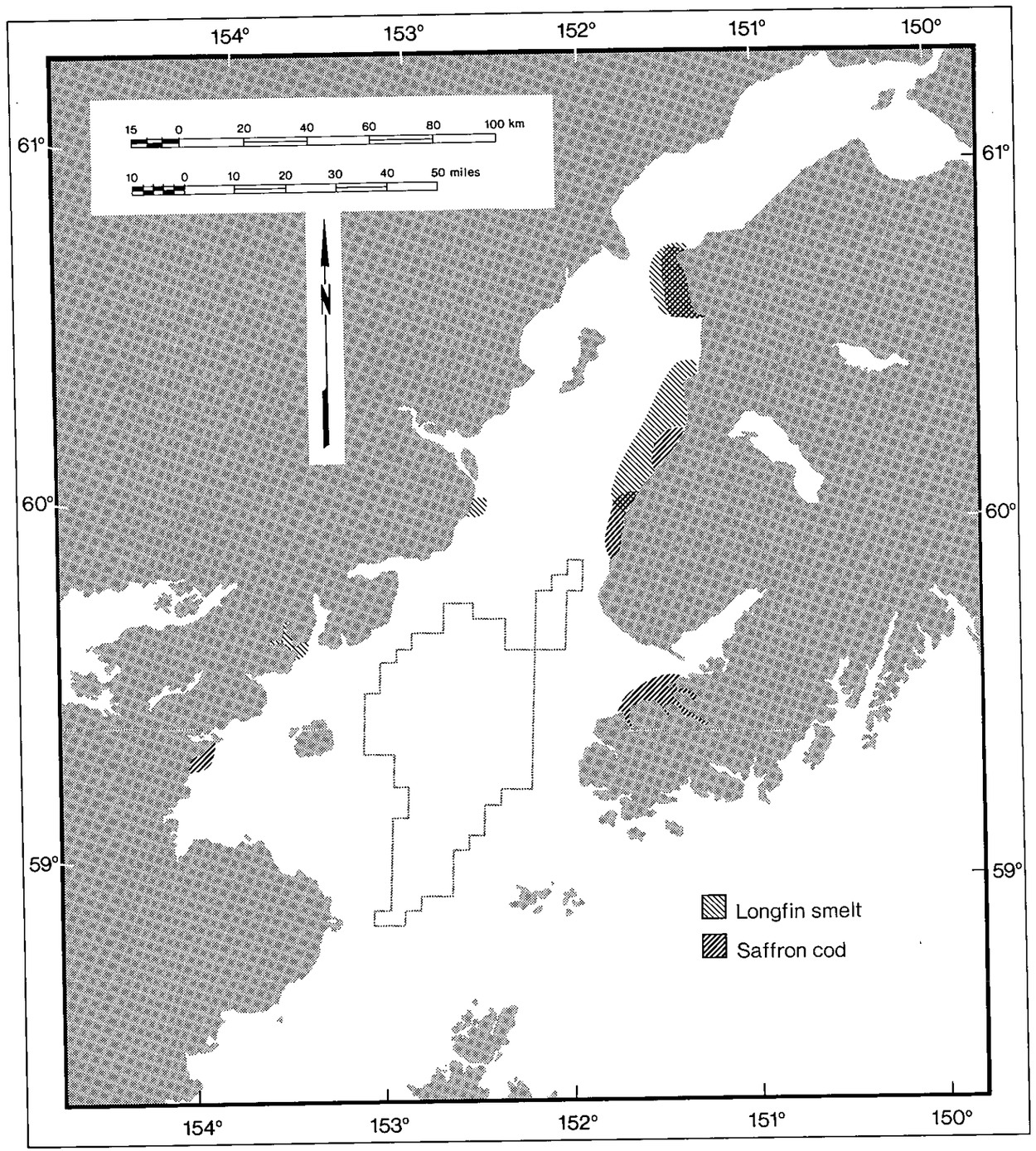
Saffron cod (Eleginus gracilis) were common in coastal zones from Cape Ninilchik to the east Forelands (Fig. E.5.1e). This species is abundant in the northern part of Lower Cook, where it appears to spawn (Blackburn, RU #512, Final Report, 1978). Some cod were also caught in Kamishak Bay and in the Seldovia area.

Sturgeon poacher (Agonus acipenserinus) accounted for 89 percent of all poachers caught. They were found at most depths and at all locations sampled by trawl. Poacher densities were greatest in the western areas of the Inlet, particularly east and southeast of Augustine Island. Poachers were most abundant in March (Blackburn, RU #512, Final Report, 1978).

Saffron cod and poachers appear to migrate into shallow water during the winter and offshore in the summer.

Yellow Irish lord (Hemilepidotus jordani) were fourth in abundance of demersal fin fish taken by otter trawls. They were generally found only in the southern part of the Inlet, with the highest catch rates (>40 kg/20 min. tow) near Kennedy Entrance (Blackburn, RU #512, Final Report, 1978). Average CPUE's for this species were highest (>50 kg/20-min. tow) in July and August in depths of 101 to 125 m. In March average catch rates exceeding 200 kg/20-min. tow occurred in depths of 176 to 200 m (Blackburn, RU #512, Final Report, 1978).

Figure E.5.1e Distribution of saffron cod and longfin smelt (modified from Blackburn, RU #512, Final Report, 1978).



Non-Salmonid Pelagic Species

Pacific Sand Lance

Blackburn (RU #512, Final Report, 1978) reported Pacific sand lance (Ammodytes hexapterus) to be the most numerous species in the nearshore zone. They occurred in all areas sampled during each sampling period. In May-June, they were most abundant (508 fish/beach seine haul) in Kachemak Bay; in August catches were greatest (95 fish/beach seine haul) north of Anchor Point. The species was less abundant (<0.1 to 22 fish/beach seine haul) on the west side of the Inlet; catches there were greatest in July. Sand lance were least abundant (<100 fish/beach seine haul) near shore in July and August; they increase in abundance (100 fish/tow net haul) off shore during these months (Blackburn, RU #512, Final Report, 1978). Tow net catches were also much lower (0.2 to 31 fish/tow net haul) on the west side. In September, catches were higher (289 fish/beach seine haul) near shore; catches were still high (373 fish/tow net haul). The clustering of catches suggests that sand lance are highly schooled (Blackburn, RU #512, Final Report, 1978).

Size and age differences of sand lance catches indicate that there are several distinct populations in Lower Cook Inlet (Blackburn, RU #512, Final Report, 1978). The Kachemak Bay population appears to be distinct from fish caught on the east side of the Inlet north of Anchor Point and on west side. A third group appears to enter Kachemak Bay in late August.

Nearly all sand lance taken belong to age 0 or 1 age-classes with only one fish older than age 1 caught (Blackburn, RU #512, Final Report, 1978).

Pacific Herring

Herring (Clupea harengus pallasi) were the second most numerous demersal species taken in the nearshore region. ADF&G (1976a) reports that herring are sporadically distributed throughout the Inlet, with the highest concentrations occurring in the Kamishak and Kachemak Bay areas. Although Blackburn (RU #512, Final Report, 1978) caught this species only in coastal areas, shrimp trawlers occasionally report large catches of herring during the winter in the deep waters of Kachemak Bay. Herring were caught throughout the nearshore areas of Lower Cook except in the region southwest of Tutka Bay. Catch rates were highest (156 fish/beach seine haul) in Kachemak Bay in September; the next highest average rate (22 fish/beach seine haul) was taken north of Anchor Point in May-June and in September on the west side of the Inlet. Catch rates for tow net samples (offshore) were highest (53 fish/tow net haul) in September on the west side of the Inlet. Average CPUE's were also high (37 fish/tow net haul) in Kachemak Bay in September; average catches were moderate (15 to 26 fish/tow net haul) for all months along the east side of Lower Cook north of Anchor Point.

Other Non-Salmonid Pelagic Species

Longfin smelt (Spirinchus thaleichthys), were found only in the nearshore zone from north of Ninilchik to the Forelands, south of Chisik Island, and in Iliamna Bay (Fig. E.5.1e). They were most abundant on the east side of the Inlet near the Kenai River, a major spawning stream for this species.

Capelin (Mallotus villosus) were most abundant on the west side of the Inlet, particularly in Kachemak Bay. Abundance and frequency of occurrence of this species were greatest in offshore catches; they were most numerous in September tow net hauls (offshore). Blackburn (RU #512, Final Report, 1978) did not catch any capelin north of Anchor Point on the east side of the Inlet.

Surf smelt (Hypomeus pretiosus) were uncommon in both nearshore and offshore areas. They were most abundant in Kachemak Bay in September and occurred most frequently in catches from exposed coastal areas.

E.5.2 MAJOR SPAWNING SEASONS AND AREAS OF DOMINANT SPECIES

Cook Inlet has been identified as an essential spawning area for several pelagic and anadromous fishes. During the spring and summer larger numbers of salmon, steelhead trout, Dolly Varden char, Pacific herring, smelts, and others come to the coastal areas of Cook Inlet to spawn. Maturing anadromous salmonids and smelt migrate into natal streams; some salmonids also occupy intertidal areas of low salinity (ADF&G, 1976b). Little is known about the utilization of the Inlet by demersal species for spawning.

All suitable streams in Cook Inlet are used for spawning by one or more salmonid species. The Susitna, Kenai, and Kasilof River systems are the major salmon spawning streams in Cook Inlet. Chum, coho, king, and sockeye salmon spawn in the Susitna River drainage, while the Kenai and Kasilof River basins are used by all salmon except chums. The short coastal streams of Kamishak and Kachemak Bays are preferred by chum and pink salmon. Coho are distributed fairly evenly throughout coastal areas of the Inlet. The major spawning streams for anadromous Dolly Varden are located on the Kenai Peninsula; some also exist on the west side of the Inlet. Dolly Varden populations do not occur in the upper Inlet. Steelhead trout are found in several streams on the lower Kenai Peninsula.

Blackburn (RU #512, Final Report, 1978) concluded that anadromous longfin smelt spawn in the Kenai River, based on catches of larvae and juveniles in the Kenai River area of Cook Inlet during the summer. Longfin smelt spawn in October; their eggs incubate over winter and hatch in May and June.

Pacific herring spawn on attached vegetation and stabilized substrate in intertidal and shallow subtidal rocky coast regions. Depending on water temperature, spawning may occur any time from May through mid-June. In Cook Inlet herring spawn mostly in Kachemak and Kamishak Bays. The abundance of juvenile and larval herring north of Anchor Point suggest that areas along the east side are used for spawning (ADF&G, 1976a; Blackburn, RU #512, Final Report, 1978).

In the Kamishak Bay District (see Fig. E.5.5c) herring have been observed spawning in Oil, Dry, and Bruin Bays, in Ursus Cove, off Augustine Island, and on shallow reefs along the southern margins of Kamishak Bay. Some deep-water (subtidal) spawning has been reported from southern Kamishak Bay. The principal spawning sites in the Kachemak (Southern) District, are Mallard Bay, Bear Cove, and along Homer spit (ADF&G, 1976a).

E.5.3 SEASONAL DISTRIBUTION AND ABUNDANCE OF LARVAL STAGES

Although the fishing industry traditionally has been a major component of Alaska's economic sector, details of the life cycles and larval stages of many species of fish remain unknown. Studies are needed to fill gaps in the knowledge of critical stages in the life cycles of commercially and ecologically important fish to better predict the possible effects of oil development on larvae populations.

Larvae of flathead sole, eulachon (Thaleichthys pacificus), longfin smelt, capelin, walleye pollock, Pacific cod, Pacific herring, and Pacific sand lance have been tentatively identified from Lower Cook Inlet (English, RU #424, Quarterly Report, Apr-June, 1977).

Larvae of Pacific sand lance and gadids (cod and pollock) were most abundant in April-May, those of Pacific herring, capelin and osmerids (smelt and eulachon) were most abundant in July-August, while those of flatfish were most abundant in May and July (Fig. E.5.3a).

The distribution of samples with 5 or more larvae per 10 m^2 is shown in Fig. E.5.3b. Larvae of flatfish, cod, and pollock were confined to areas near Kennedy Entrance. Those of capelin, smelt, and eulachon were absent from the Inlet during most of the sampling period but were abundant at most or all stations in July-August. Similarly, Pacific sand lance larvae were widely distributed during all sampling dates except July-October. Pacific herring were found only in Kamishak Bay and in the northern part of the lower Inlet.

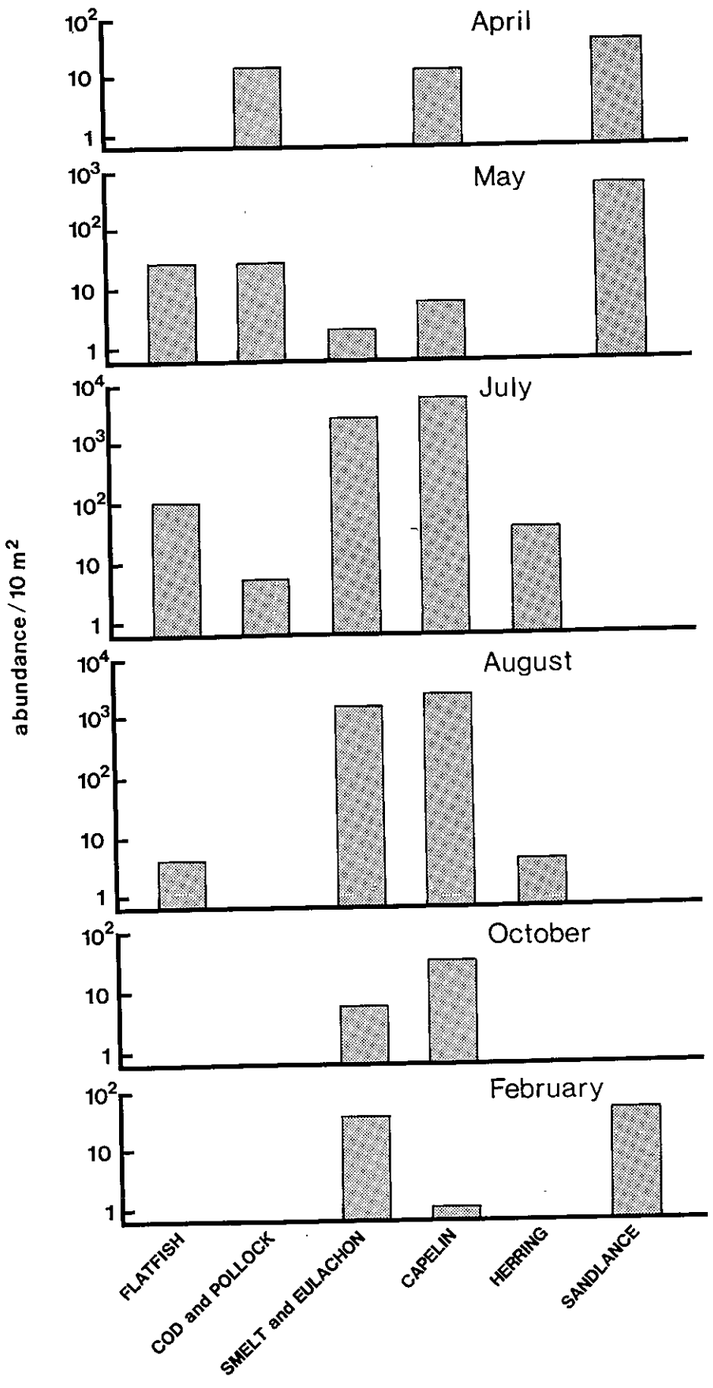


Figure E.5.3a Monthly abundance of fish larvae (English RU #424, Apr - Oct, 1977).

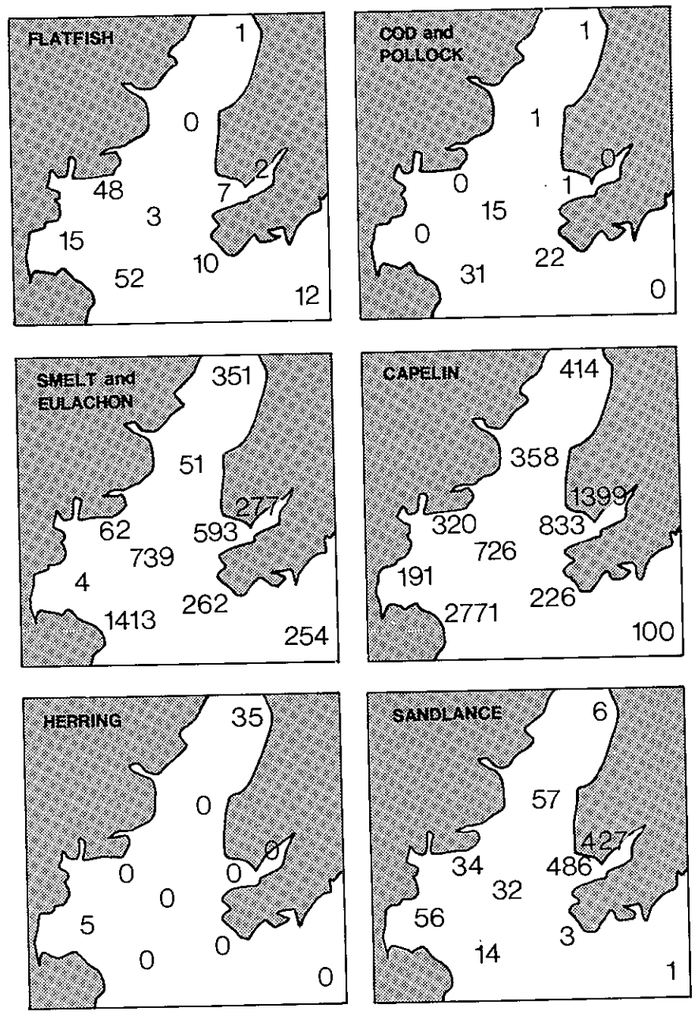


Figure E.5.3b Annual abundance of fish larvae per sampling station (English, RU #424, Apr - Oct, 1977).

E.5.4 SEASONAL DISTRIBUTION AND ABUNDANCE OF JUVENILE FISHES

Information on seasonal distribution and abundance of juvenile life stages of most fish species in the Lower Cook Lease area is lacking. The available data do not show clear spatial and temporal patterns. During the spring and summer large numbers of juvenile fish enter the nearshore zones from natal streams (salmon, trout, smelt), offshore over-wintering areas (flatfish, herring), and intertidal hatching areas (herring, smelt, salmon, greenlings).

Salmonids

On the basis of estimated adult escapement, Stern (RU #353, Quarterly Report, Oct-Dec, 1976) reckoned that the average yearly abundance of juvenile salmonids migrating into the estuarine areas of Cook Inlet is in excess of 100 million fish (1925-1974). Juvenile pink salmon of even-year spawning adults are most numerous, with the average yearly population estimated at 75.9 million. Chum salmon fry were second in abundance, with the 50-year average exceeding 26 million individuals. Odd-year pink and sockeye smolts are the next most numerous, averaging more than 20 million fish each. More than four million coho salmon juveniles enter Cook Inlet from natal streams; the 50-year average for chinook salmon smolts is estimated to be about one million individuals.

Chum Salmon

Chum fry were most numerous in beach seine hauls from the west side of the Inlet especially in Iniskin Bay, Iliamna Bay, Ursus Cove, and in the nearshore zone at the mouth of Bruin Bay. Catch rates and frequency of occurrence of juvenile chums peaked in August and then decreased significantly in September (Blackburn, RU #512, Final Report, 1978). The presence of 40-mm juveniles, the size of fry at emergence from the gravels, in catches made as late as mid-August indicate that fry enter the estuaries from natal streams over several months.

Pink Salmon

Juvenile pinks were caught throughout the Inlet in both beach seines and tow nets in both nearshore and nearsurface pelagic zones. In Cook Inlet pink fry were least abundant along the eastern shoreline north of Anchor Point. The Kenai and Kasilof Rivers, on the east side of the Inlet, and rivers north of the Forelands, however, contribute substantially to pink fry abundance. Blackburn (RU #512, Final Report, 1978) reports that juvenile pink salmon abundance is greatest in the years following the spawning of the dominant even-year population.

Catch rates and frequency of occurrence of juvenile pinks on the west side of the Inlet and southwest of Tutka Bay on the Kenai Peninsula were greatest in beach seine hauls in July; offshore tow net catches were highest in August. Pink fry abundance was greatest in Bruin Bay, Ursus Cove, and Rock Cove in July and August.

In Kachemak Bay pink fry abundance in beach seine hauls was highest in late May, while catches from tow net hauls did not peak until the later half of June, indicating an offshore movement by the fry (Blackburn, RU #512, Final Report, 1978). Pink salmon fry remained in shoreline nursery areas about 45 days before moving into the open waters of the bays and estuaries. Most juvenile pinks had left Kachemak Bay by late July having moved out of the upper bay even earlier (Blackburn, RU #512, Final Report, 1978). Residence times agree with those reported by Stern (RU #353, Quarterly Report, Oct-Dec, 1976) for pink fry in the Kodiak Area.

Stern (RU #353, Quarterly Report, Oct-Dec, 1976) reported that juvenile pinks begin to leave for the open ocean in late June, concentrating near the mouths of bays by August and September. The outward migration peaks in August and lasts through September. It should be noted that streams in Kamishak and Kachemak Bays produce only a small portion of the total Cook Inlet pink salmon run.

Sockeye Salmon

Sockeye smolts were most common in the northern and west side areas of Lower Cook Inlet, but some are also produced in streams emptying into Kamishak Bay. Catch abundance in beach seine hauls and tow net catches was highest in July although the number of fish in the tow net catch was low (10 total, 9 in July).

Chinook Salmon

Chinook salmon smolts were the second most abundant salmon species caught. In late June they were most abundant in Kachemak Bay, especially in Halibut Cove. Some chinook juveniles were also caught north of Anchor Point on the east side of the Inlet. On the west side they were common near the mouths of Iniskin and Iliamna Bays. Juvenile chinook salmon were also caught in purse seines off shore; they were most abundant in catches made at 13 and 18 km from shore. Near shore, they were most abundant from late May to early June as beach seine haul data show.

Coho Salmon

Juvenile coho salmon were most abundant in Kachemak Bay. They were caught almost exclusively in beach seines near shore. Their frequency of occurrence was highest along the east shore of Cook Inlet north of Anchor Point.

Dolly Varden

While Blackburn's data (RU #512, Final Report, 1978) do not distinguish between adult and juvenile abundance and distribution, he does report that Dolly Varden were abundant in all nearshore areas of Lower Cook during all sampling periods. Catches of Dollys were equally highest in all regions sampled in the May-June and July sampling periods. Numerically, Dolly Varden char were the third most abundant species caught in the beach seine hauls.

Excluding char, juvenile salmonids in the Gulf of Alaska migrate near shore, counterclockwise along the western Gulf (Stern, RU #353, Quarterly Report, Oct-Dec, 1976). Migratory pathways have not been clearly defined in Cook Inlet, but it is expected that the outmigrants remain near shore, joining the Gulf of Alaska migration beyond Kennedy Entrance and/or south of the Shelikof Straits. They follow the continental shelf southwest of Kodiak Island until fall when they disperse off shore and move south (Stern, RU #353, Quarterly Report, Oct-Dec, 1976; Royce, Smith and Hartt, 1968).

Non-Salmonids

There are few data on the abundance of juvenile pelagic non-salmonids. Blackburn (RU #512, Final Report, 1978), however, reports that juvenile herring, smelt, and sandfish can be found in most of the nearshore areas of Lower Cook Inlet during spring and summer. Distributions are patchy, probably because of the schooling behavior of these species.

Data on flatfish and demersal roundfish are few. White-spotted and masked greenling juveniles were common in tow net and beach seine hauls throughout the Inlet (Blackburn, RU #512, Final Report, 1978). In addition, smaller or younger age-classes of flatfish generally occurred in the nearshore areas. Juveniles of flatfish caught near shore include Pacific halibut, yellowfin sole, starry flounder, and flathead sole.

Documentation of flatfish migrations in Cook Inlet is limited to data indicating a seasonal movement across the shelf. Most species appear to seek deeper waters during the winter, moving into shallow areas in the spring and summer (Blackburn, RU #512, Final Report, 1978).

E.5.5 SEASONAL PRODUCTIVITY OF SELECTED COMMERCIAL AND SPORT FISHERIES

Commercial Fisheries

The primary fishery in Cook Inlet is the commercial salmon fishery, but a sport fishery is rapidly expanding (Fig. E.5.5a). In addition to salmon, halibut and herring are also of major commercial importance. Some ground fish, such as flounder, rockfish, and sole, are also taken.

In 1974 the salmon catch in Cook Inlet exceeded 4,600 mt with a value of $6.9 million to the fishermen. It comprised about 28 percent of the central region and 11 percent of state catch revenues (ADF&G, 1971, 1974).

Other species of fin fish landed in the Cook Inlet, statistically grouped as "other fish," include Pacific halibut, Pacific herring (including roe and eggs-on-kelp), steelhead trout, rockfish, other bottom fish, and a group of miscellaneous species. In 1974 the total Cook Inlet catch of "other fish" was about 3,000 mt, with a value of $1.4 million to the fishermen. The 1971 catch, in contrast, was about 4,500 mt and was valued at $2.9 million. The Cook Inlet catch represented 15 percent of the state's "other fish" revenues for 1971 but only 9 percent for 1974 (ADF&G, 1971, 1974).

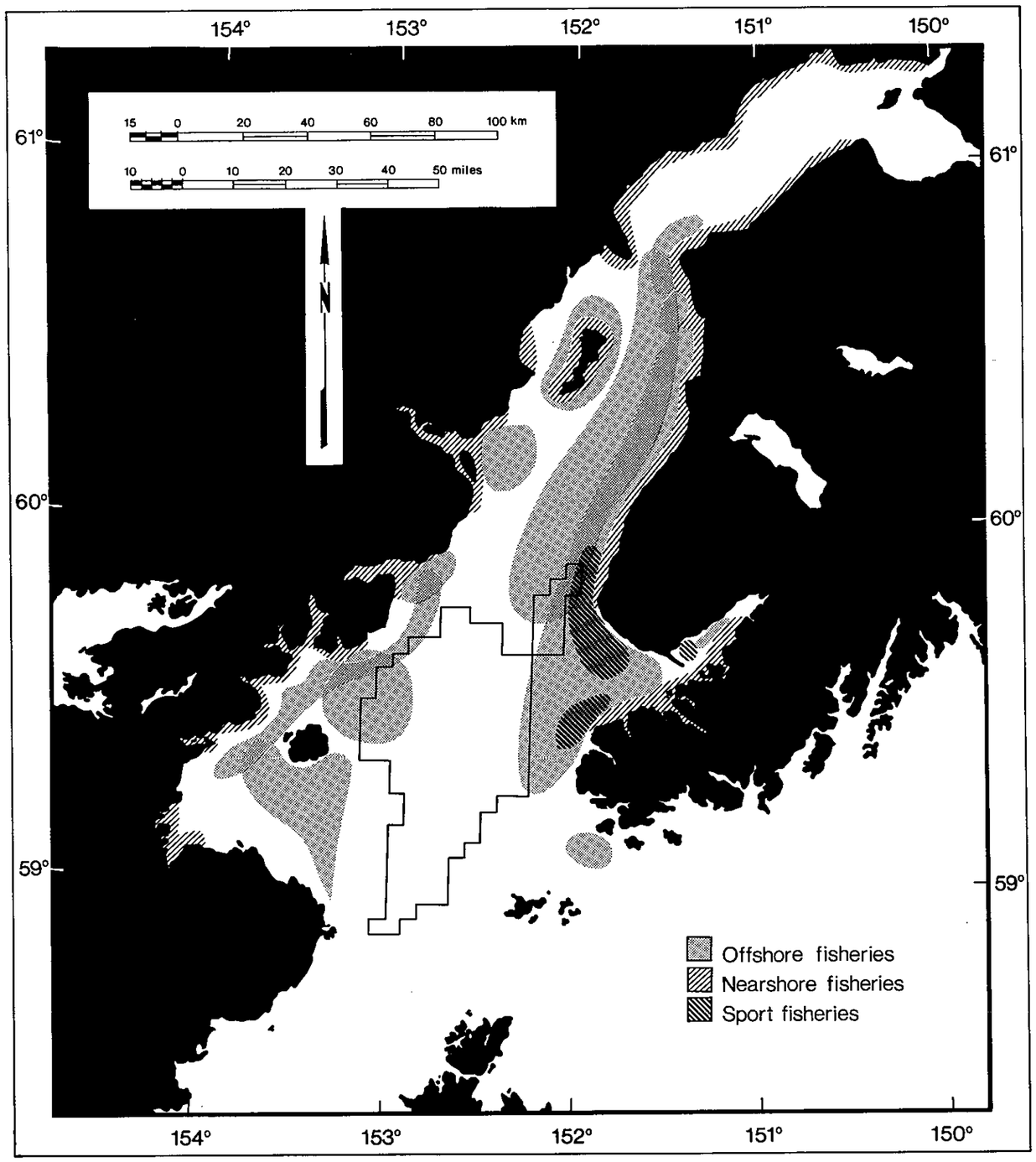


Figure E.5.5a Areas of commercial and sport fishing (modified from ADF&G, 1976a).

Historical data for Cook Inlet show about equal catches of even-year pink and sockeye salmon. For the period 1925-72, the average annual catch was approximately 1.7 million even-year pink salmon and 1.4 million sockeye salmon. Numerically, these two species have constituted about 80 percent of the Cook Inlet salmon catch. For the same period the average catch of chum salmon, third in abundance, was approximately 400,000 fish (Stern, RU #353, Quarterly Report, Oct-Dec, 1976).

Historical salmon catches for the Lower Cook region and the Kachemak (Southern) and Kamishak Districts are plotted in Figs. E.5.5b and E.5.5c. These data illustrate the annual variability in catches, the high catches in the Kachemak District, and the numerical dominance of pink salmon. Chum salmon catches are greater in the Kamishak District.

In early June, chinook are the first salmon to appear in the commercial catch in Cook Inlet. The other Pacific species begin to appear in catches in late June and early July. Peak catches for all species generally occur in July; chinooks, however, are also common in June, and pinks are abundant until mid-August (Stern, RU #353, Quarterly Report, Oct-Dec, 1976).

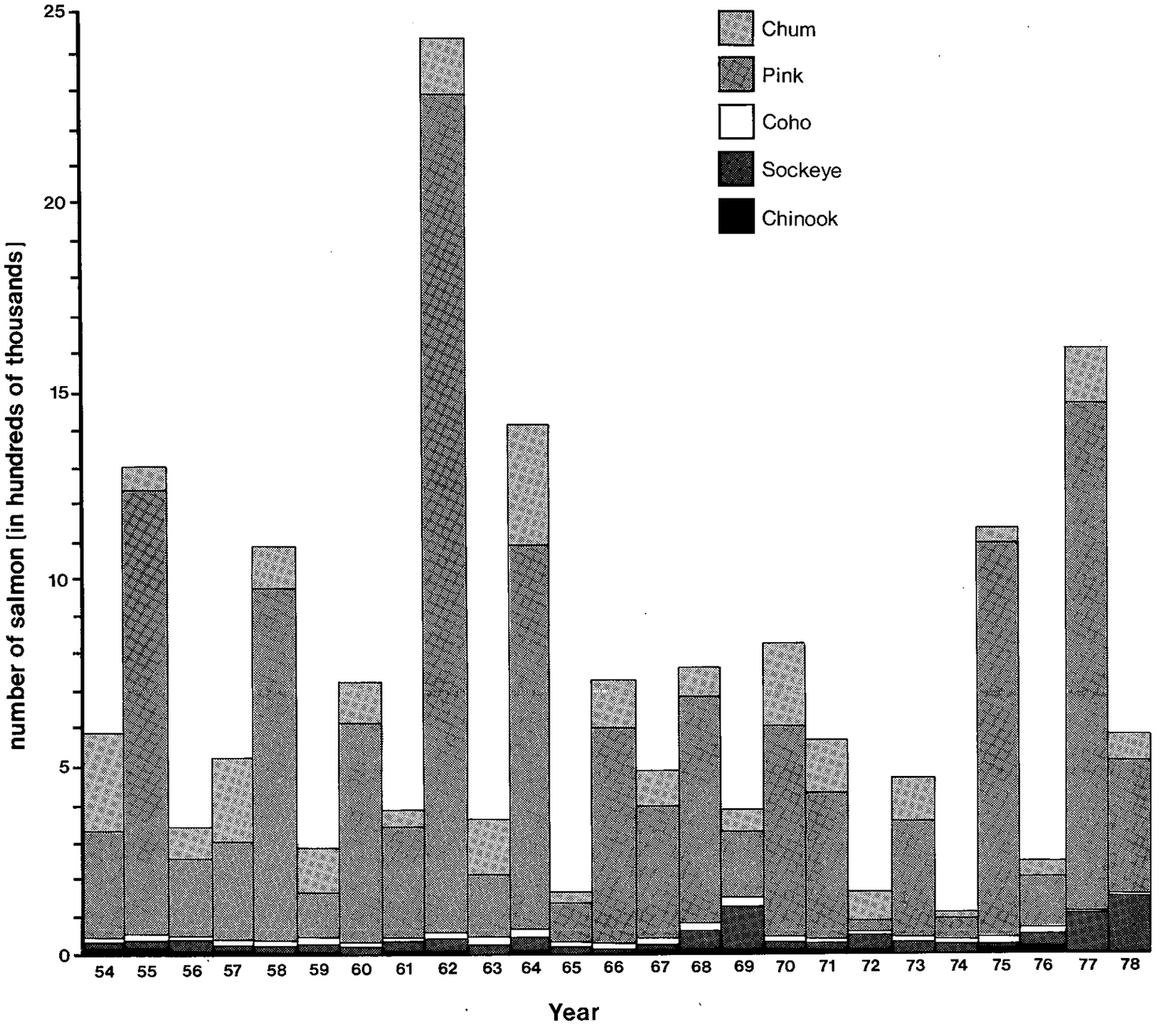
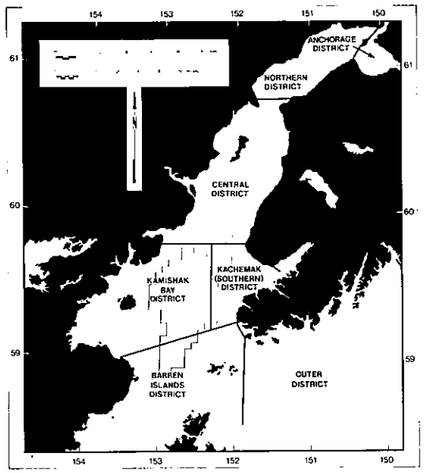
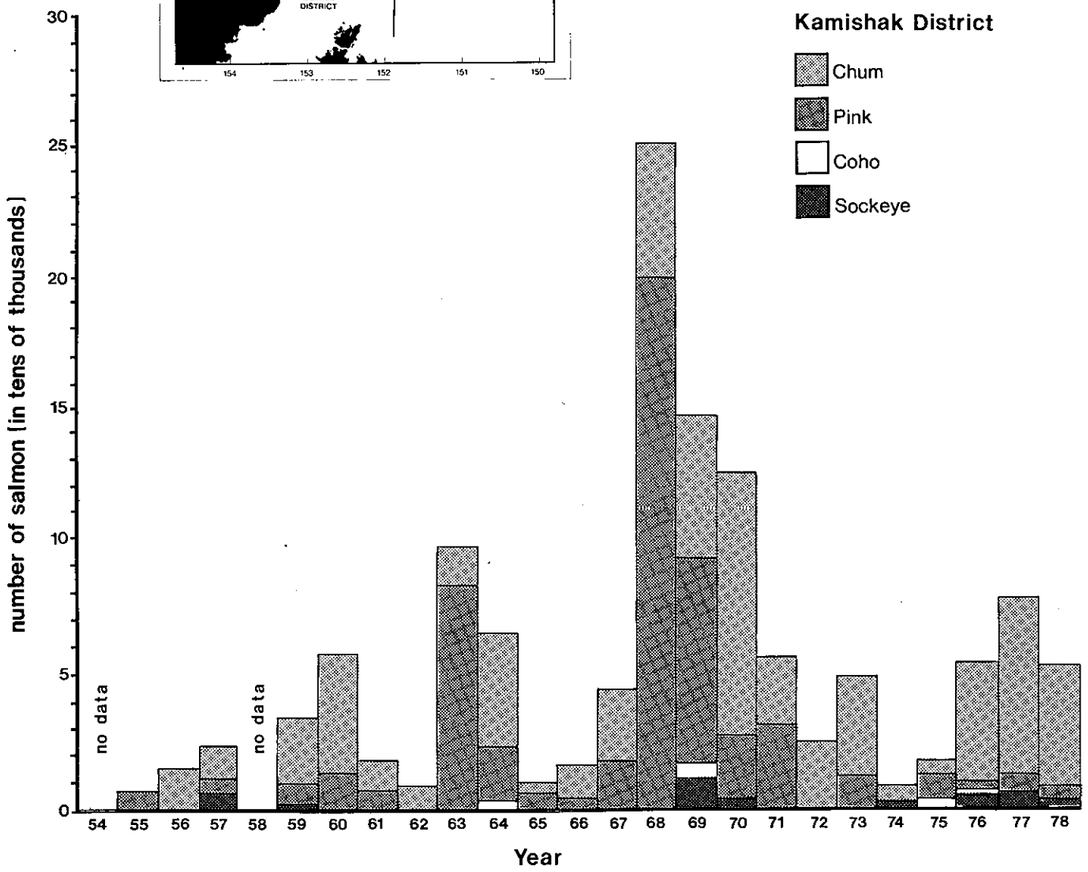


Figure E.5.5b Salmon catch in Lower Cook Inlet, 1954 to 1978 (from ADF&G, 1976b; 1978a).





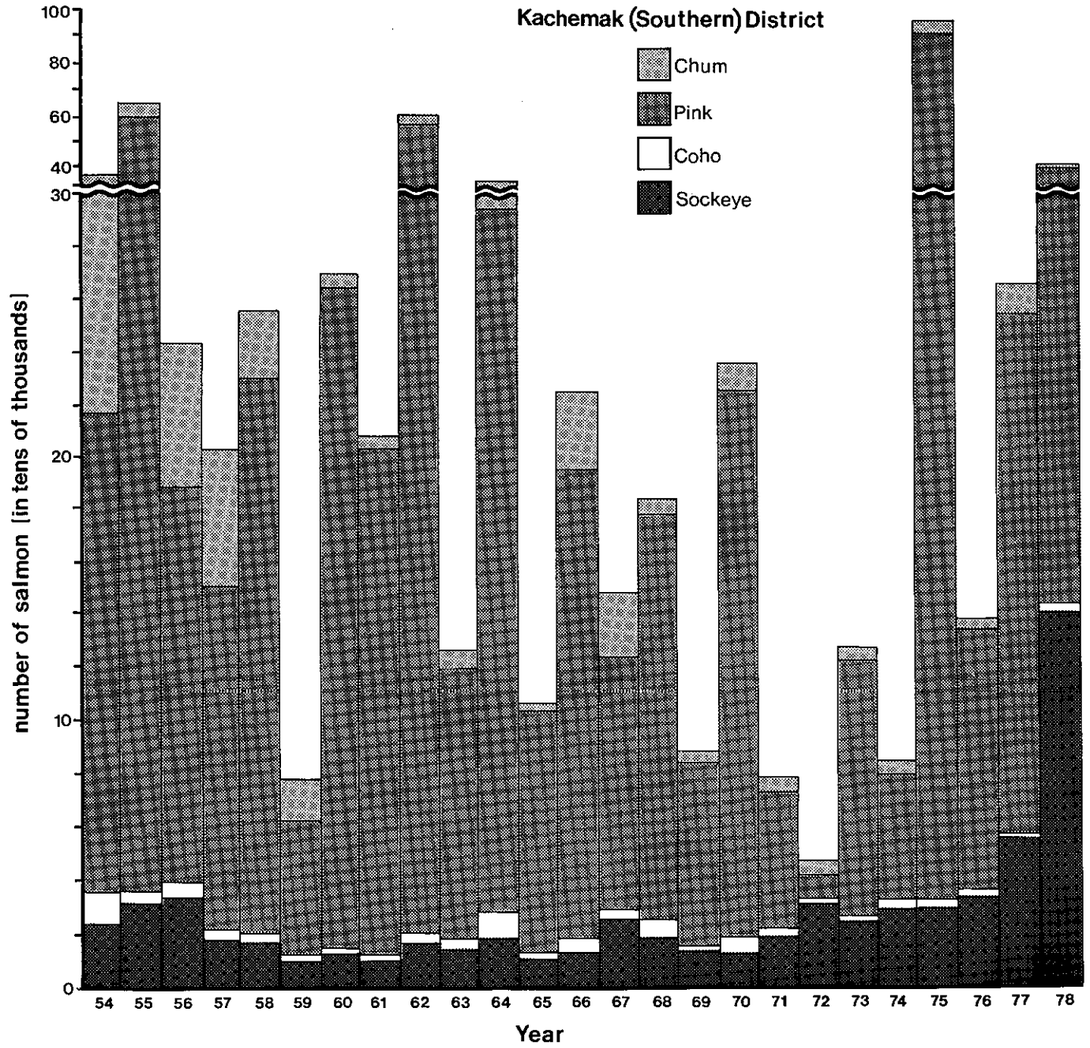


Figure E.5.5c Salmon catch by district and species, 1954 to 1978 (from ADF&G 1976b; 1978a).

Previously, herring were pickled or used as meal and as bait, but these commercial uses were discontinued when market value declined. The use of herring roe as food by the Japanese caused the resumption of commercial herring fishing in 1969. Herring populations along both coasts of the southern Kenai Peninsula were the first to be exploited (Fig. E.5.5d). Commercial catches have decreased on the east side of the Inlet; in 1976 the catch from this area was less than one metric ton. The commercial herring catch in the Kamishak Bay region peaked at 4,262 mt in 1976, but in 1978 was only 364 mt. Small catches (5 to 33 mt) have been made north of Anchor Point on the east side of the Inlet (ADF&G, 1976a; Blackburn, RU #512, Final Report, 1978).

The dominant ground fish caught commercially is halibut. Halibut catch statistics for Lower Cook are included in the International Pacific Halibut Commission's statistical area 3A (Cape Spencer to Kupreanof Pt.; ADF&G, 1976a). The catch in 1974 in statistical area 3A was about 4350 mt; the Cook Inlet halibut catch contributed less than 10 percent of the total. For the years 1973 to 77, the commercial halibut catch for Cook Inlet ranged from 337 mt in 1975 to a high of 472 mt in 1977 (Fig. E.5.5e; ADF&G, 1978a).

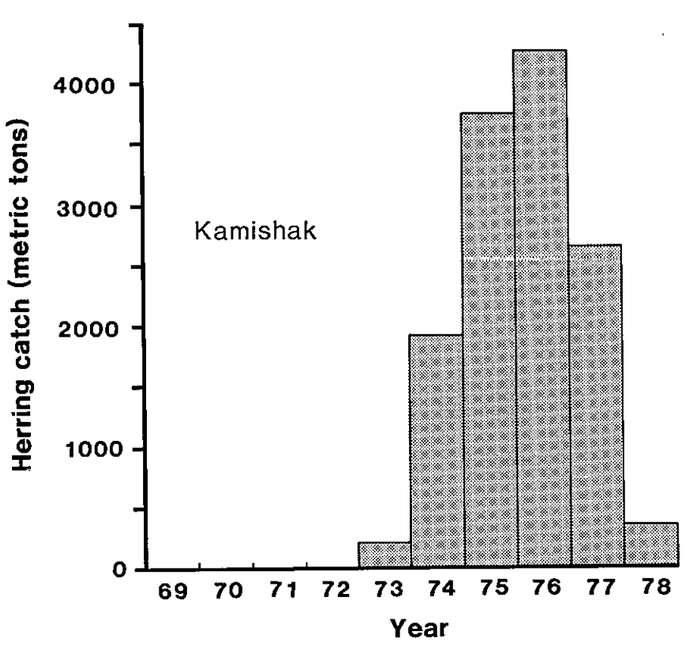
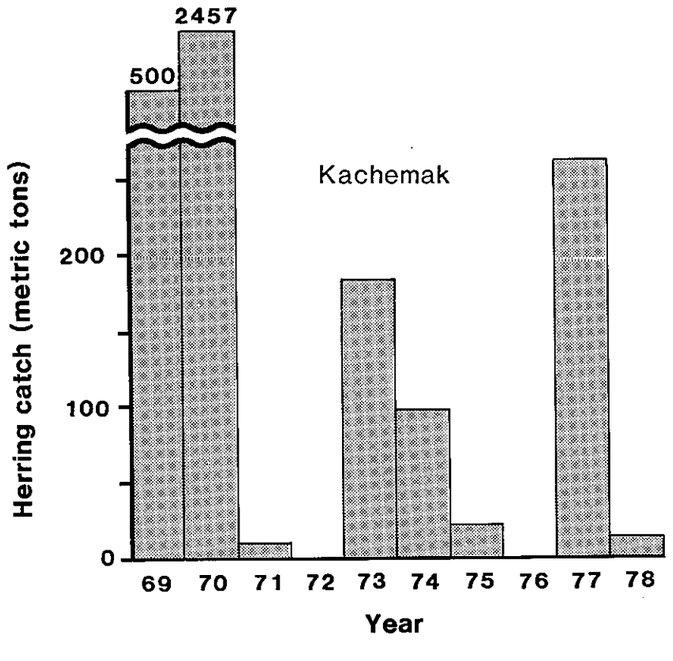


Figure E.5.5d Commercial herring catch in Kachemak (southern) and Kamishak districts from 1969 to 1978 (data from ADF&G, 1976b; 1978a).



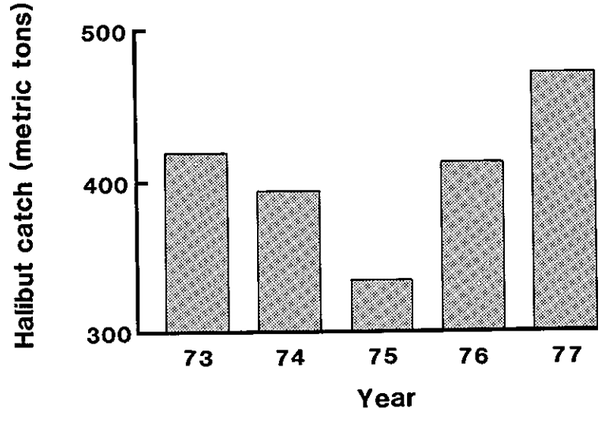


Figure E.5.5e Commercial halibut catch in Lower Cook Inlet (IPHC Statistical Areas 261 and 272; data from ADF&G, 1978a).

Sport Fishing

With the human population growth in the Anchorage-Kenai Peninsula region has come an increase in recreational fishing. Species sought include Dolly Varden in June, pink salmon in July, and coho in August and September. Pacific cod and Pacific halibut are also taken (ADF&G, 1976a). The increase in sport fish harvest is exemplified by data from Resurrection Bay on the west coast of the Kenai Peninsula (Fig. E.5.5f). The sport fish harvest is probably increasing in the Homer area also. Figure E.5.5g shows the weekly sport catch of pink salmon in Resurrection Bay; a similar harvest probably occurs in the Homer region.

Subsistence Fishing

A subsistence fishery exists in Lower Cook Inlet but no statistics are available (ADF&G, 1976a). Salmon are the usual target species.

DATA EVALUATION

Salmonids

The Alaska Department of Fish and Game annually monitors spawning and escapement levels of salmon; reliable counting systems are located on only a few river systems, however. This agency also collects data on egg viability and hatch success. The International North Pacific Fishery Commission has studied the migrations of maturing adults. Thus there is considerable information on salmon available.

Demersal Fish

International Pacific Halibut Commission trawl surveys provide good historical data on halibut abundance and distribution. Information on other species is spotty, often being collected incidentally to other work. Catch records probably do not reflect true population fluctuations, since they are easily influenced by variations in market value, competition with foreign fisheries, and other factors.

Blackburn has conducted the most extensive survey of Lower Cook demersal fish resources. His data, however, are sometimes difficult to use for comparisons because he used different gear and different time periods in sampling different areas of the Inlet. Additional data are needed to confirm spawning areas of most species. Other than the general movement of demersal fish over the shelf, little is known of their migratory habits.

Non-Salmonid Pelagic Species

Data are limited to Blackburn's nearshore beach and tow net catches. Information on spawning areas, seasonal distribution and abundance, and use of Inlet pelagic waters is lacking.

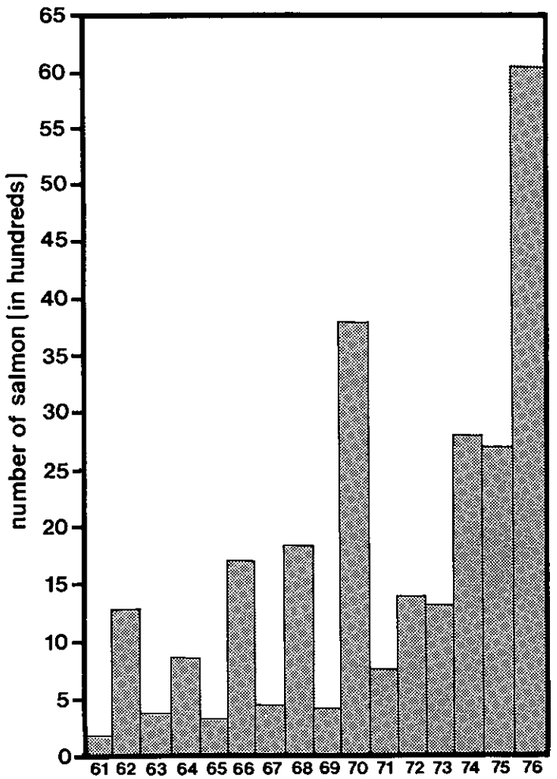


Figure E.5.5f Summary of Resurrection Bay pink salmon sport harvest (modified from ADF&G, 1976b).

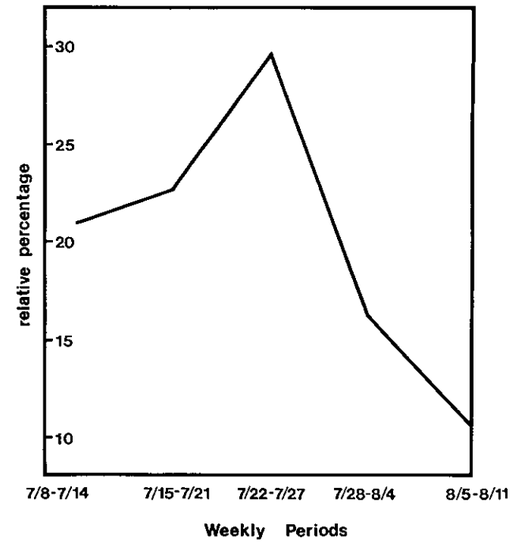


Figure E.5.5g Summary of the relative sport catch of pink salmon in Resurrection Bay, 1967 through 1975 (adapted from ADF&G, 1976b).

SUBTASK E.6 Food Dependencies and Natural Histories of Commonly Occurring Species of Pelagic and Demersal Fish.

E.6.1 FOOD HABITS

Bivalves (Macoma and Spisula), crustaceans (Crangon dalli, Pandalus borealis, and Chionoecetes bairdi), and fish (capelin and snake prickleback) were the major food items of nine species of demersal fish from Cook Inlet (Feder, RU #281/5/503, Annual Report, 1977; Fig. E.6.1a) as determined by analysis of stomach contents.

Simenstad (RU #512, Final Report, 1978) has summarized the condition, abundance, biomass and composition of prey organisms in 500 stomachs for 12 species of demersal marine and estuarine fishes in Lower Cook Inlet and Ugak and Alitak Bays on Kodiak Island and distinguished three types of feeding behavior. He suggests that prey resources available to fishes in the two regions may be distinct. Fish in Lower Cook Inlet appear to exploit benthic organisms (polychaetes, gastropods, bivalves), while those of Kodiak Island prey primarily on the smaller demersal fish. The composition of crustacean (shrimp, mysiid, euphausiid and amphipod) prey was similar in both regions. These results agree with the general feeding preferences found by others.

Blackburn (RU #512, Final Report, 1978) showed diet to be related to size class in an analysis of stomach contents of juvenile pink salmon, O. gorbuscha. Juveniles consume insects, fish larvae, ostracods, Brachyura zoea, gammarid amphipods, and harpacticoid and calanoid copepods (Fig. E.6.1b) Copepods and polychaetes were the principal food of juvenile pink salmon less than 80 mm long. Ostracods, insects, amphipods and fish eggs were also important. Juveniles longer than 80 mm preferred Brachyura zoea, insects, and fish larvae. Generally, differences in prey selectivity are related to age, size, and habitat of the predator and to the availability of particular prey. For example, a small fish in a nearshore area is more likely to encounter harpacticoid copepods and insects than fish larvae, which are more abundant offshore.

Figure E.6.1a. Feeding classifications of 12 species of demersal fish predators from Kodiak Island and Lower Cook Inlet collected during ADF&G-OCS studies, June 1976-March 1977 (from Simenstad, RU #512, Final Report, 1978; Feder, RU #15, Annual Report, 1977).

Species	Principal Prey Organisms
Planktivore	
Gadus macrocephalus Theragra chalcogramma Hemilepidotus jordani Atheresthes stomias Hippoglossoides elassodon Isopsetta isolepis Microstomus pacificus	Shrimp Mysids Euphausiids Amphipods Fishes Polychaetes Bivalves Gastropods Crabs Brittle stars
Benthivore	
Lepidopsetta bilineata	Amphipods Polychaetes Gastropods Bivalves Mysids Shrimp
Piscivore	
Gymnocanthus sp. Myoxocephalus sp. M. polyacanthocephalus Limanda aspera Hippoglossus stenolepis Trichodon trichodon	Fishes Shrimp Polychaetes Euphausiids Mysids Crabs Bivalves

Figure E.6.1b. Principal prey of juvenile pink salmon captured in Kachemak Bay July 26-28, 1976, by beach seine and tow net (from Blackburn, RU #512, Final Report, 1978).

Prey	Fork Length 58-69 mm (N=7)	70-79 mm (N=19)	80-89 mm (N=32)	90-102 mm (N=14)
Ostracoda	+			
Copepoda				
Calanoida	+			
Harpacticoida		+		
Amphipoda				
Gammaridea		+		
Brachyura zoea			+	
Insecta	+	+	+	
Polychaeta	+	+		
Teleostei eggs		+		
Teleostei larvae			+	+

E.6.2 FOOD WEBS

Feder (RU #281/5/503, Annual Report, 1977) constructed a theoretical food web of benthic organisms and demersal fishes (Fig. E.6.2a) based on data from benthic and epibenthic studies and analyses of stomach contents of several species of demersal fish from Lower Cook Inlet. He also constructed specific food webs for great sculpin (Myoxocephalus sp.; Fig. E.6.2b), Pacific cod (Fig. E.6.2c) and halibut (Fig. E.6.2d).

Crangoid shrimps (especially Crangon dalli) were found to be the major food of Lower Cook Inlet fishes. Other important prey species were the shrimp Pandalus borealis, Tanner crab Chionoecetes bairdi, and numerous species of small fish.

Of the three species of demersal fish, the great sculpin has the least varied diet, preferring mainly predator and/or scavenging crustaceans. Pacific cod relies principally on crangoid shrimps and Tanner crab. Halibut supplements its main diet of Tanner crab with numerous fish species. No pelagic fish are included in these food webs as they usually feed in the water column above the benthos.

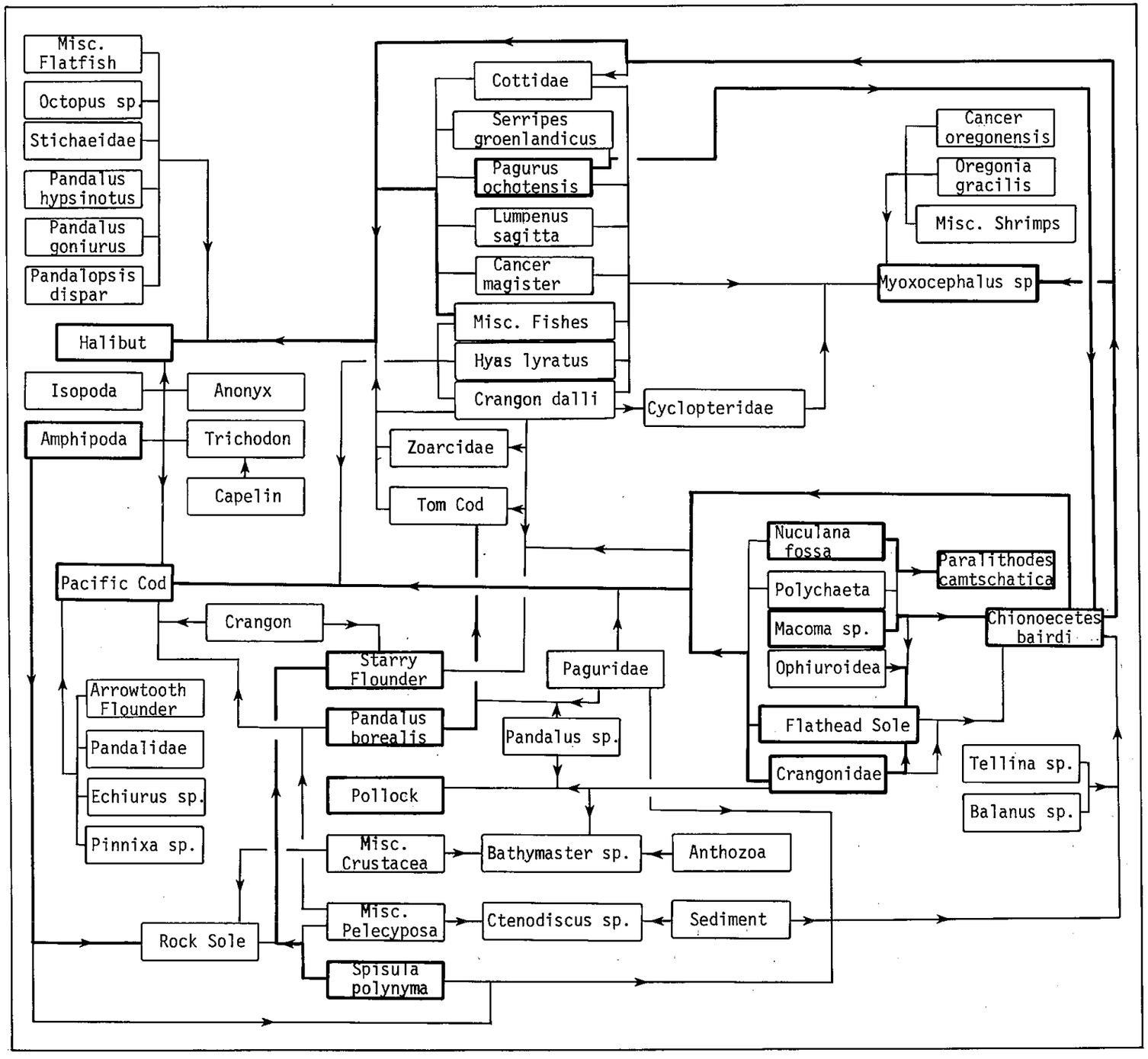


Figure E.6.2a Hypothetical food web for Lower Cook Inlet (Feder, RU #281/5/303, Annual Report, 1977).

DATA EVALUATION

Food preference data for Lower Cook Inlet are few, emphasize demersal fish species, and do not represent all seasons. Feder's study (RU #281/5/503, Annual Report, 1977) was confined to October 1976. Simenstad's report (RU #512, Annual Report, 1978) mixes results from the Kodiak Island region and Lower Cook Inlet, from nearshore and offshore sampling areas, and from different types of sampling equipment (otter trawls and beach seines). Direct comparison between the findings of different workers are difficult since they do not analyze or present their data in a standardized form.

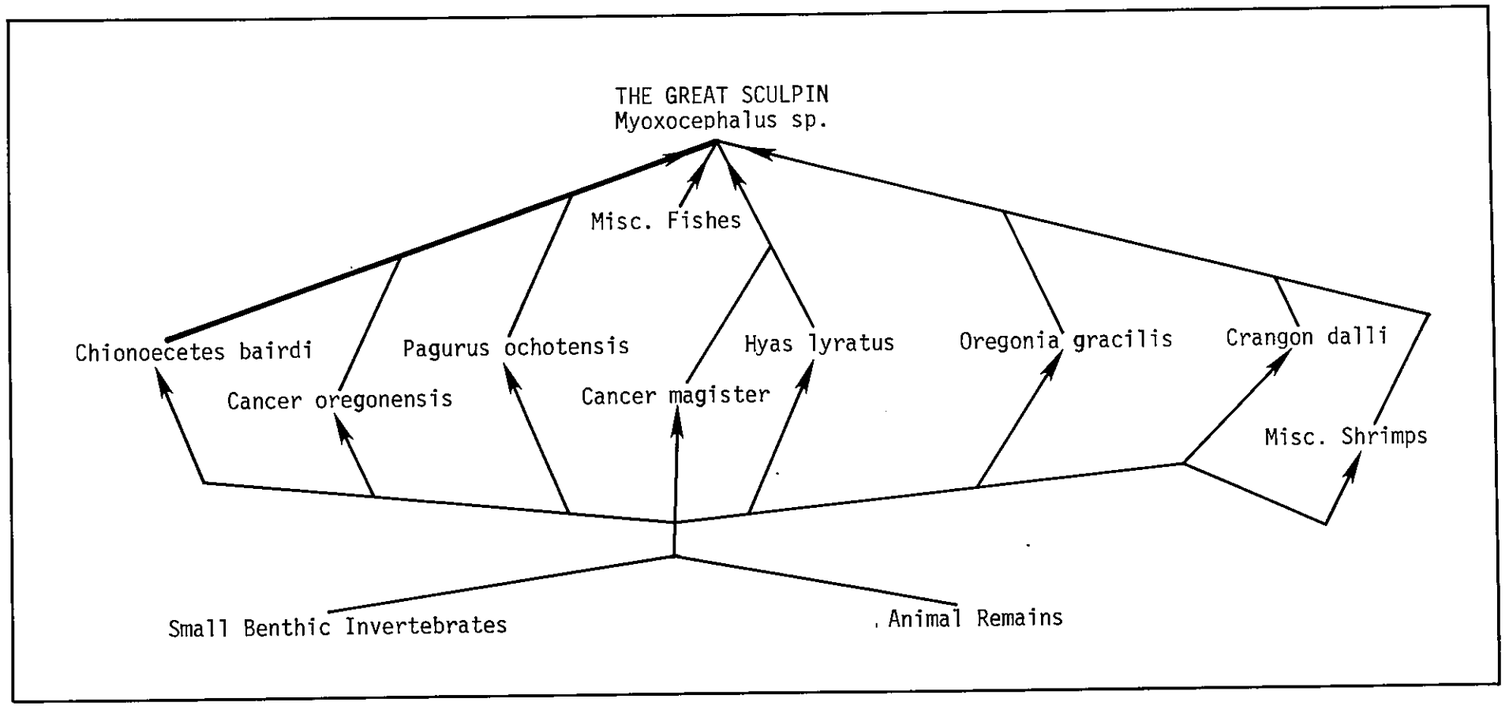


Figure E.6.2b Food web of great sculpin (Feder, RU #281/5/303, Annual Report, 1977).

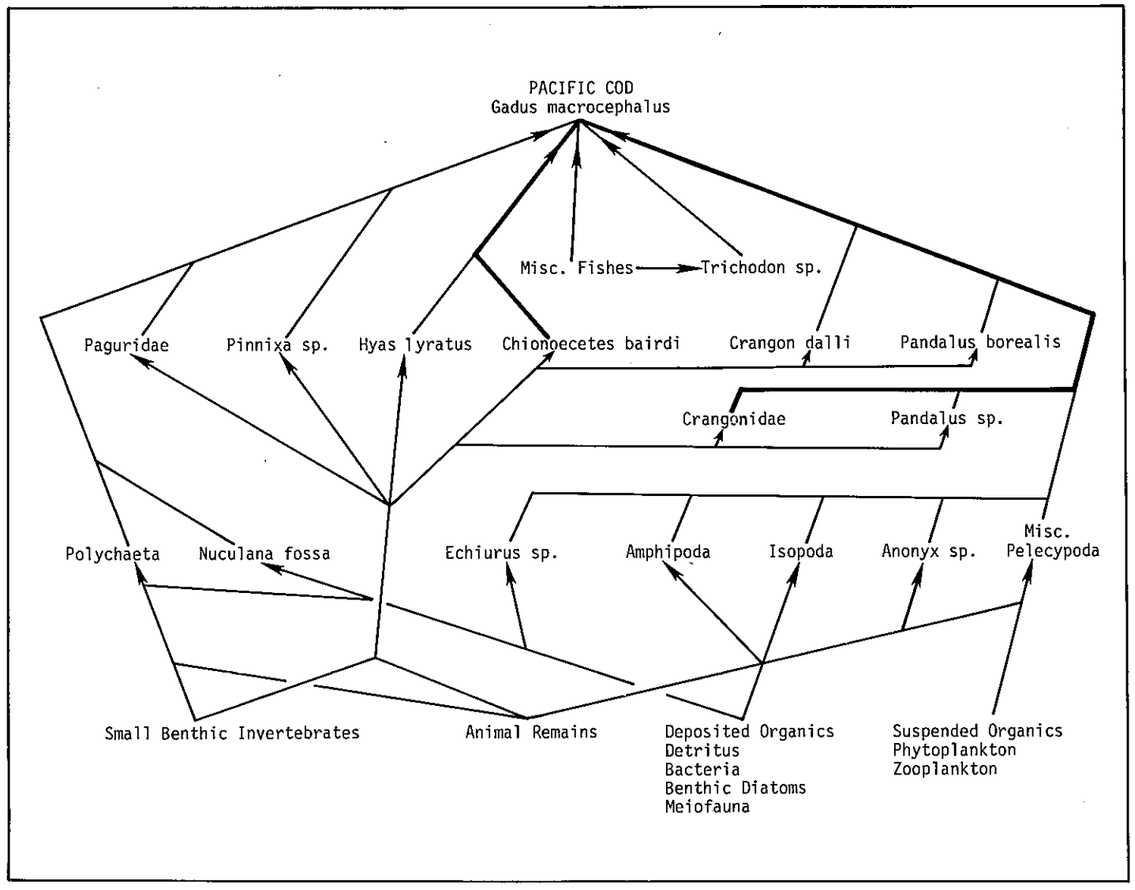


Figure E.6.2c Food web of Pacific cod (Feder, RU #281/5/303, Annual Report, 1977).

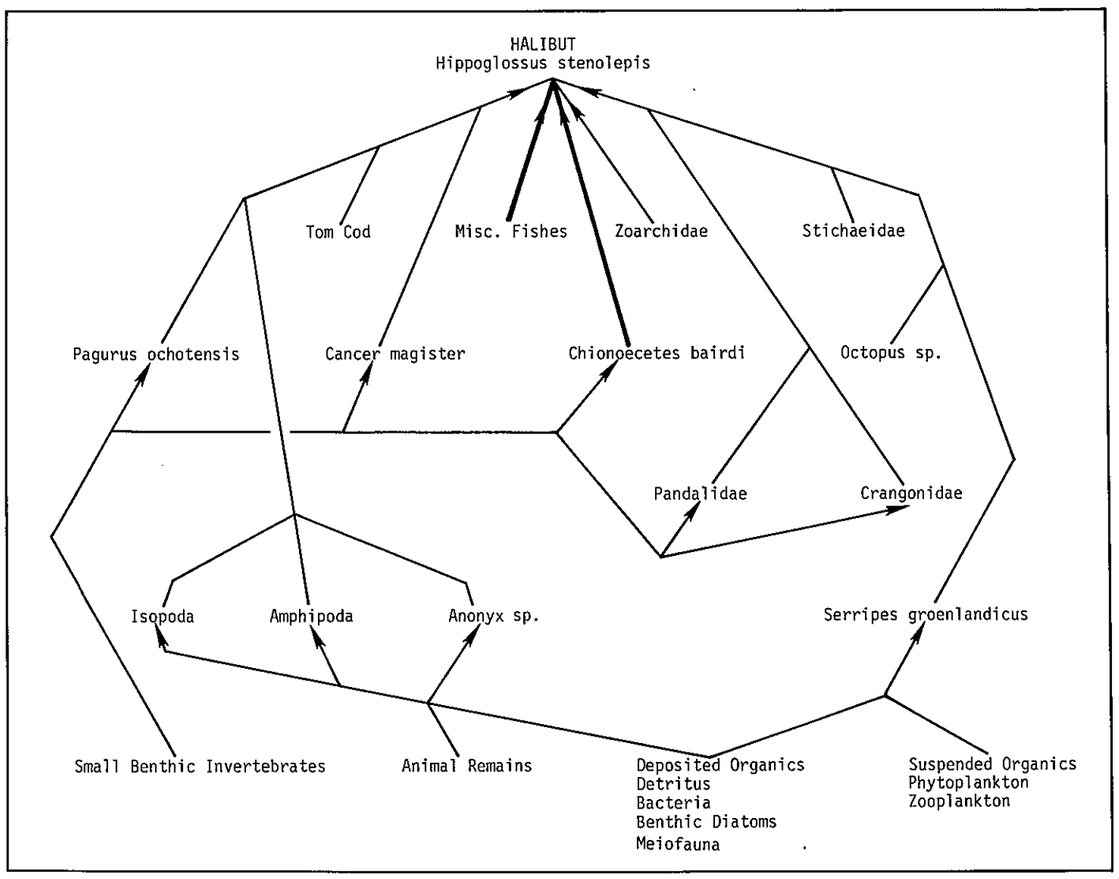


Figure E.6.2d Food web of halibut (Feder, RU #281/5/303, Annual Report, 1977).

SUBTASK E.7 Distribution, Abundance, Diversity, and Productivity of the Benthic Community

E.7.1 DISTRIBUTIONS OF COMMERCIALLY IMPORTANT SHELLFISH (CRABS, SHRIMP AND SHELLFISH)

The commercial fishery in Cook Inlet is based primarily on king, Tanner and Dungeness crabs, shrimp, scallops and razor clams. Information on these fisheries is mainly derived from ADF&G (1976a; 1978a) and Davis (1977).

King Crab

The king crab (Paralithodes camtschatica) is found throughout Cook Inlet south of Anchor Point (Fig. E.7.1a) in depths to about 366 m. The greatest numbers are found in the deepwater region midway between Augustine Island and the Barren Islands (ADF&G, 1976a). The favored habitats appear to be sand or mud substrates.

The commercial crab fishery began in Cook Inlet in 1951 and has remained relatively stable since 1960. In the years immediately following the 1964 earthquake the harvest was low because of reduced fishing effort. Between 1960 and 1977 the annual harvest averaged 2052 mt (Fig. E.7.1b; ADF&G, 1976, 1978). The 1977-78 catch was well below average largely because of two successive weak year-classes in 1976 and 1977 (ADF&G, 1978a). Prior to 1961, nearly all of the king crab catch came from Kachemak Bay. Since 1961 an equally large fishery has been developed in Kamishak Bay. Smaller fisheries are also found in the Barren Islands, Outer, and occasionally Eastern districts. Commercial fishing is generally confined to depths less than 183 m. The commercial fishing season is from August 1 to March 15, with the following harvest guidelines for each district (ADF&G, 1976a; 1978a):

Kachemak (Southern) District	
Aug 1 - Dec 31	455 metric tons
Jan 1 - Mar 15	227 metric tons
Kamishak District	1364 metric tons
Outer and Eastern Districts	227 metric tons.

The largest catches are made during the summer and winter (Gusey, 1975; ADF&G, 1978a). The value of the king crab catch has steadily increased over the last ten years. The 1977 catch was worth about $1.8 million to commercial fishermen (ADF&G, 1978a).

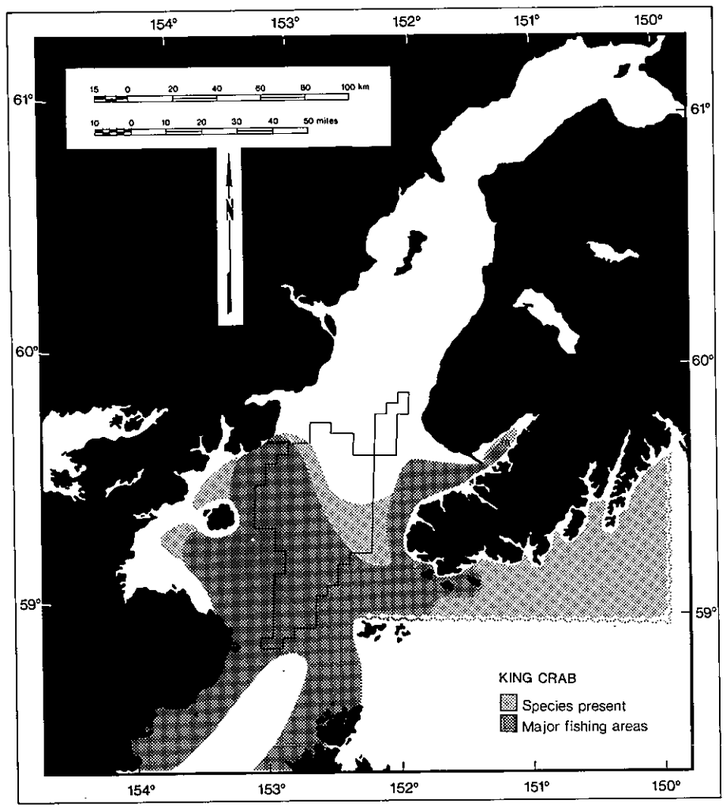


Figure E.7.1a Distribution of king crab (ADF&G, 1976a; 1978a; Gusey, 1975).

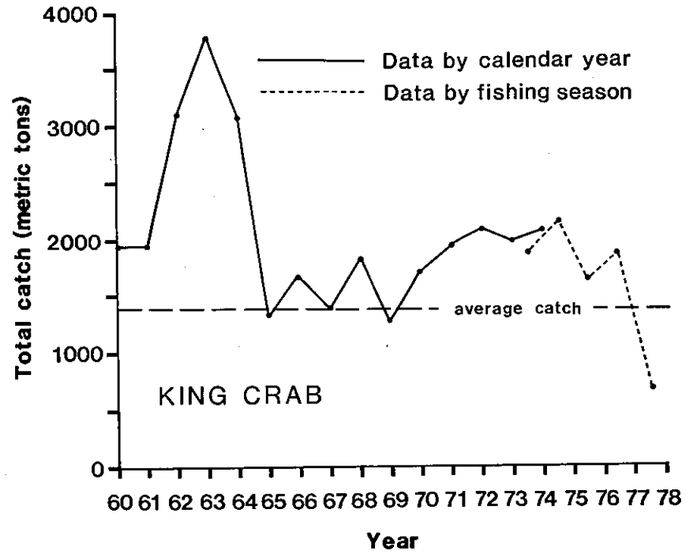


Figure E.7.1b Annual catch of king crab in Cook Inlet (ADF&G, 1976a; 1978a).

Tanner Crab

Tanner crabs, Chionoecetes bairdi, are found throughout Cook Inlet south of Anchor Point and into the Eastern and Outer districts (Fig. E.7.1c) at all water depths from the littoral zone to 550 m.

The Tanner crab fishery has existed on a sustained basis in Cook Inlet only since 1968. The fishing season runs from December 1 to April 30 in the Kachemak, Outer, and Eastern Districts and from December 1 to May 31 in the Kamishak District. Harvest guideline levels for each district are as follows:

Kachemak (Southern) District	1364 metric tons
Kamishak and Barren Island District	2045 metric tons
Outer and Eastern Districts	1591 metric tons

The catch has averaged 2015 mt since the 1968-69 season (ADF&G, 1978a). The largest catches were made in the deep water region (unspecified depths) midway between Augustine Island and the Barren Islands (ADF&G, 1976a). Catch statistics for the various districts from the 1968-69 through the 1977-78 fishing seasons are shown in Fig. E.7.1d. The 1977-78 catch was worth $2 million to commercial fishermen (ADF&G, 1978a).

Dungeness Crab

The Dungeness crab (Cancer magister) is distributed in all shallow (<60 m) areas in Lower Cook and in the Outer and Eastern Districts (Fig. E.7.1e). They inhabit the bays, estuaries and open ocean waters near the coast from the intertidal zone to water depths of 90 m and favor sand or sand-mixed substrates. A major concentration of large crabs exists off the Bluff Point area near Kachemak Bay.

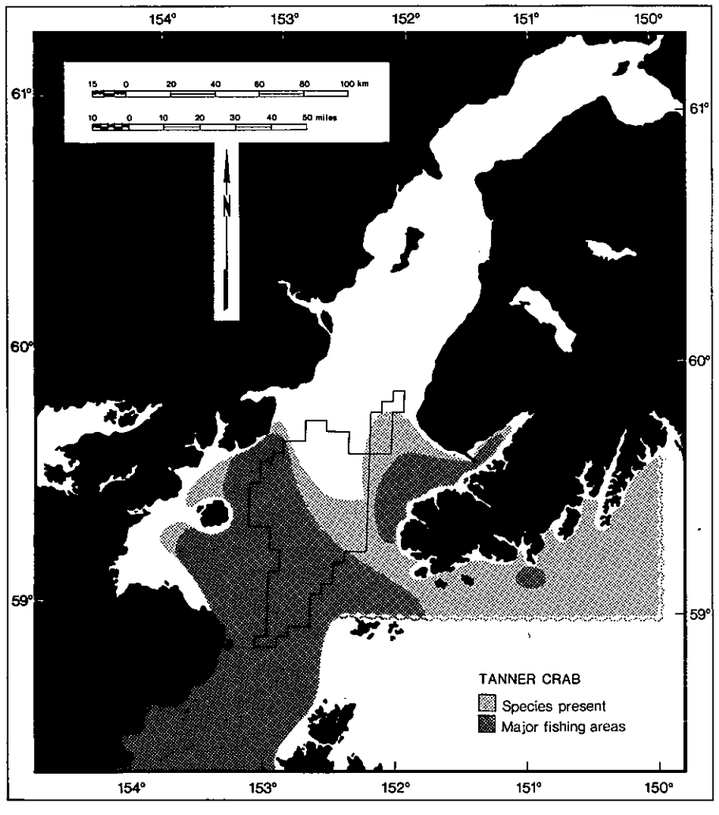


Figure E.7.1c Distribution of Tanner crab (ADF&G, 1976a; 1978a).

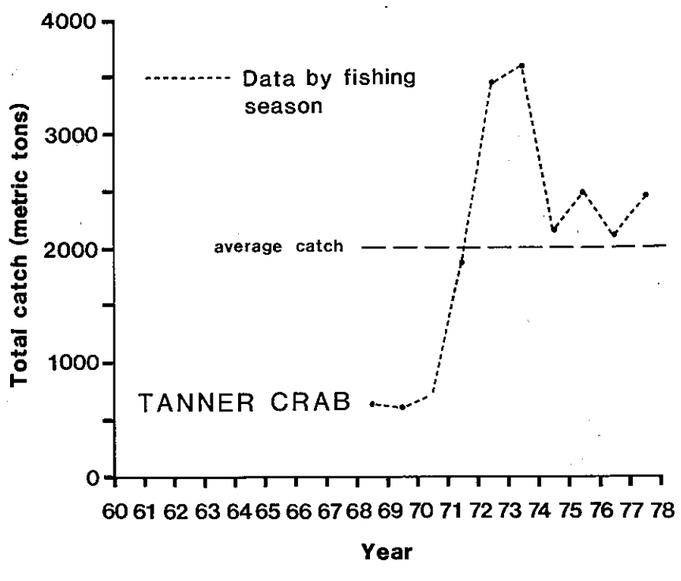


Figure E.7.1d Annual catch of Tanner crab in Cook Inlet (ADF&G, 1976a; 1978a).

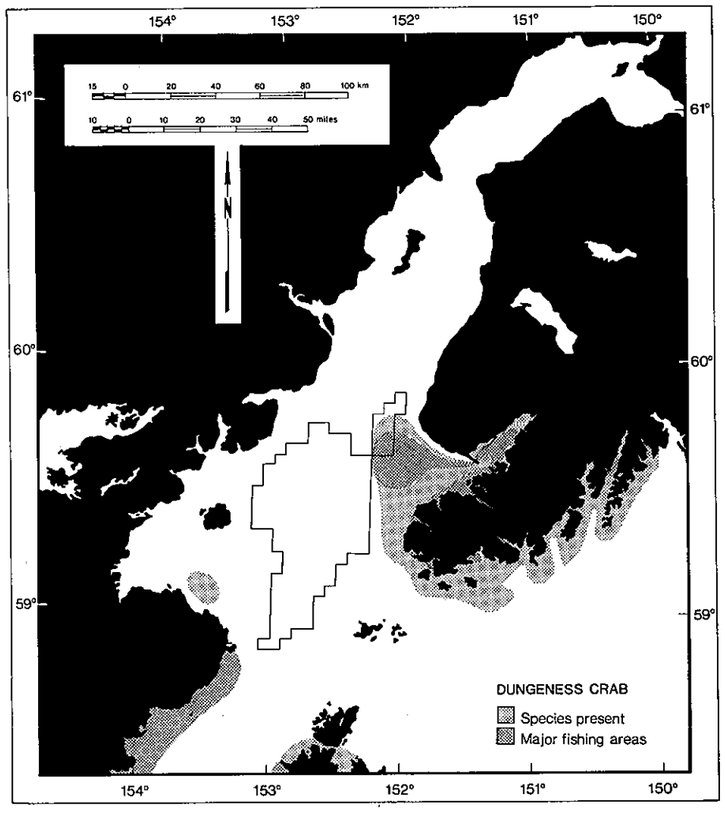


Figure E.7.1e Distribution of Dungeness crab (ADF&G, 1976a; 1978a).

The Dungeness crab fishery began on a sustained basis in 1961 and peaked at 757 mt in 1963 (Fig. E.7.1f). It declined following the 1964 earthquake and has since fluctuated, depending on U.S. West Coast market conditions. The catch has averaged 144 mt since 1961 (ADF&G, 1976a; 1978a). Most of the commercial catch is made in the Kachemak District (Fig. E.7.1e). No harvest guidelines have been set for Dungeness crab. The 1977 catch was worth about $28,000 to commercial fishermen.

Shrimp

Shrimp (pandalids) are found in all districts of Cook Inlet south of Anchor Point as well as in the Outer and Eastern Districts (Fig. E.7.1g). Major concentrations are found in Kachemak Bay and in the deep waters off Cape Douglas. Cook Inlet shrimp fisheries are based on pink (Pandalus borealis), humpy (P. goniuris), coonstripe (P. hyspinotus) and sidestripe (Pandalopsis dispar) shrimp. Nearly all shrimp catches have occurred in Kachemak Bay; a minor fishery has developed in recent years in the Outer district. The catch has averaged 1460 mt since 1962 and 2366 mt since 1970 (ADF&G, 1976a; 1978a; Fig. E.7.1h).

The trawl fishery season extends from June 1 through March 31, but there is no closed season for the shrimp pot fishery. Catch quotas for Kachemak Bay inside a line from Point Pogibshi to Anchor Point are set at 2545 mt per year. The 1977-78 catch was worth $1,175,000 to commercial fishermen (ADF&G, 1978a).

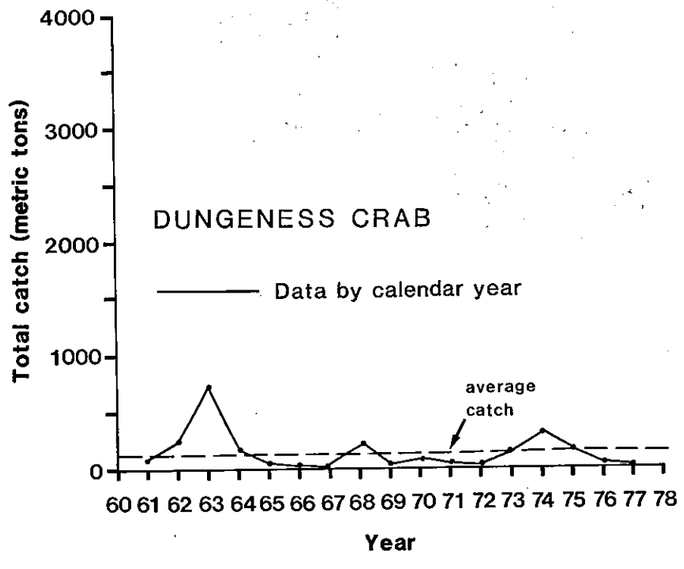


Figure E.7.1f Annual catch of Dungeness crab in Cook Inlet (ADF&G, 1976a; 1978a).

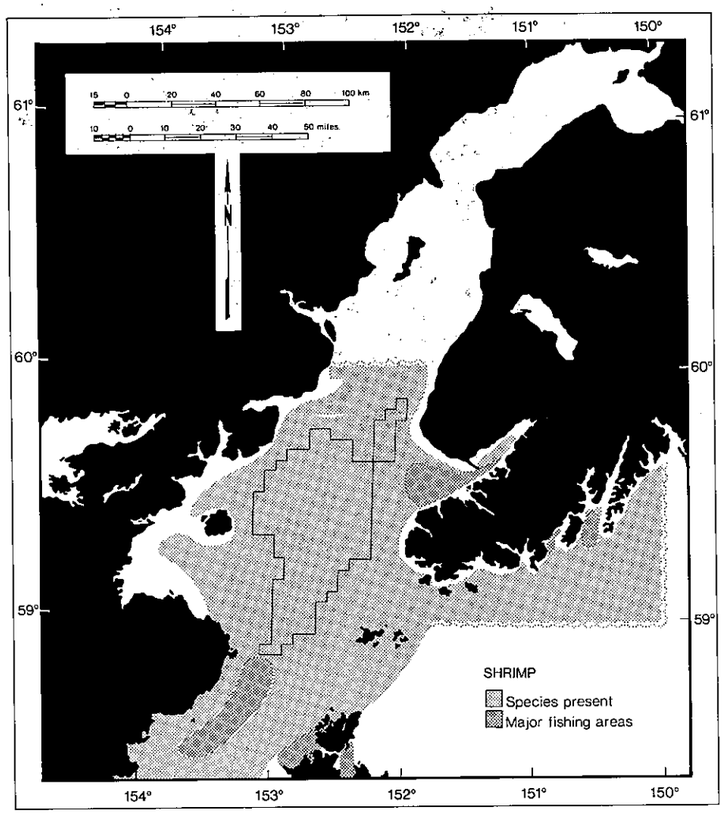


Figure E.7.1g Distribution of shrimp (ADF&G, 1976a; 1978a; Gusey, 1975).

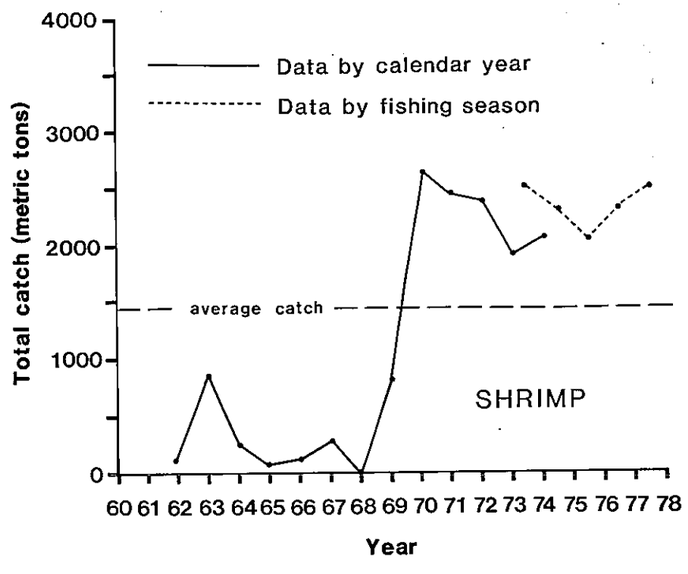


Figure E.7.1h Annual catch of shrimp in Cook Inlet (ADF&G, 1976a; 1978a).

Razor Clam

Razor clams (Siliqua patula is the dominant species) are present on sandy beaches throughout Lower Cook Inlet (Fig. E.7.1i). A small commercial razor clam fishery exists at Polly Creek north of Tuxedni Bay and there is believed to be commercial potential in Chinitna Bay (ADF&G, 1978a). A substantial commercial "hand-dig" fishery existed at Polly Creek until the early 1960's. Increased federal and state regulations for processing the product, poor market conditions, and the 1964 Alaskan Earthquake combined to cause a decline of the fishery. In recent years the harvest has been minimal. The commercial value of the 1973 catch was $5,300 (ADF&G, 1976a). Extensive recreational and subsistence digging of razor clams still occurs along beaches from Cape Starichkof to Cape Kasilof on the east side of Lower Cook Inlet. In recent years nearly one million clams per year have been harvested from these beaches.

There is presently no closed season for clam harvesting but commercial fishery is allowed only on Polly Creek on the west side of Cook Inlet. Almost all of the annual harvest occurs from May through July.

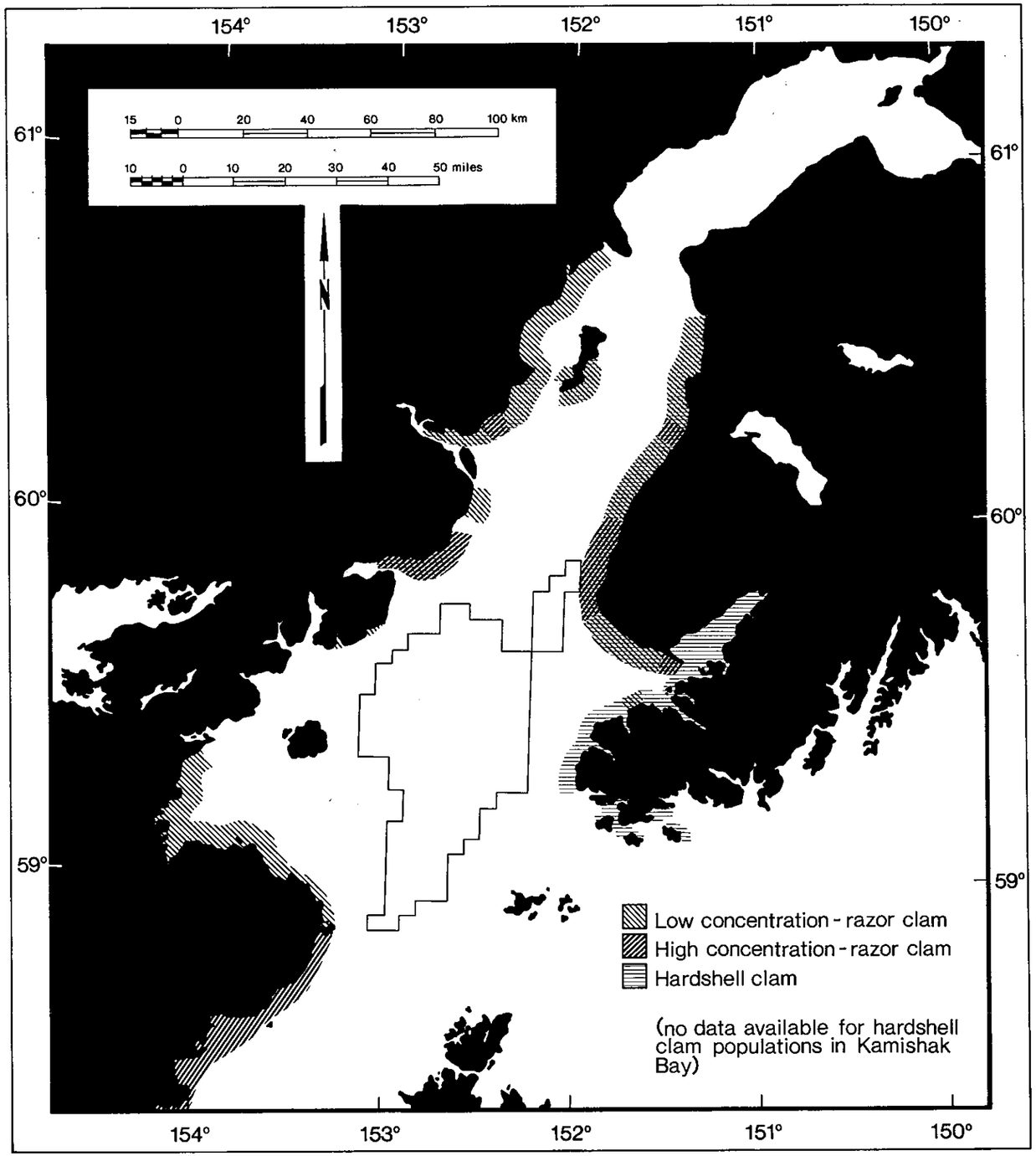


Figure E.7.1i Distribution of razor and hardshell clam beaches (ADF&G, 1976a; 1978a).

Hardshell Clams

Hardshell clams are distributed throughout Cook Inlet from the Kenai River south (Fig. E.7.1i). There is a small butter clam fishery in the Inlet. Distributions vary with species.

E.7.2 SEASONAL DISTRIBUTIONS AND ABUNDANCE FOR IMPORTANT BENTHIC SPECIES

Lower Cook Inlet

Feder and Jewett (RU #5/281/303, Annual Report, 1978) characterized infaunal and epifaunal populations at 74 stations in Lower Cook Inlet (Fig. E.7.2a). The van Veen grab, pipe dredge, and clam dredge were all used to collect infaunal species.

Forty-eight stations were sampled with the van Veen sampler in April 1976, of which 12 were resampled in October. Only 13 of the April stations were analyzed, however. Two hundred eleven species were identified in these grabs, with polychaetes comprising the largest group (93 species). Other important groups were Mollusca (64 species), Arthropoda (Crustacea-33 species) and echinoderms (8 species). The highest density was 732 g/m^2 at station 45; 80 percent of this sample consisted of the sand dollar Echinarachnius parma (Fig. E.7.2b). The lowest density was 6.2 g/m^2 at station 69.

The pipe dredge was used at 40 stations in April and 58 in October. Thirty-seven stations were occupied once, and 32 were occupied twice. The most frequently occurring taxa were hydroids, polychaetes, annelids and ten species of clams (Glycymeris subobsoleta, Nuculana foesa, Nucula tenuis, Cyclocardia ventricosa, Astarte esquimalti, A. alaskensis, Psephidia lordi, Macoma calcarea, Spisula polyneyma, Tellina nuculoides).

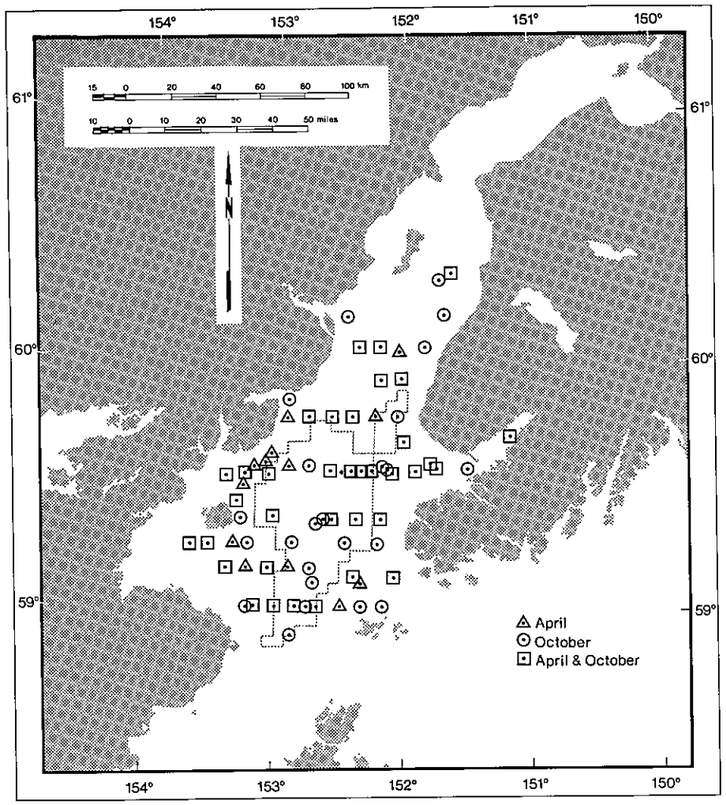


Figure E.7.2a Lower Cook Inlet benthic sampling stations, 1976 (Feder and Jewett, RU #281/5/303, Annual Report, 1978).

Figure E.7.2b Densities of infaunal and epifaunal invertebrates from 13 Lower Cook Inlet van Veen grab stations, April 1976 (Feder and Jewett, RU #5/281/303, Annual Report, 1978).

Station	Density	
	Individuals/m^2	g/m^2
6	2137	163
18	1334	48
27	1600	22
31	406	241
33	2050	129
40	2988	68
42	452	558
45	532	732
46	300	320
48	630	261
49	1014	84
54	1371	38
69	15	6

Six stations were sampled with the clam dredge. Sixty-two species of invertebrates were identified in these grabs, including 3.63 kg of a cockle (Clinocardium californiense) at station 40A and nine large pink neck clams (Spisula polynyma) in April at station 41. Station 41 also yielded 19 blue mussels (Mytilus edulis) in October.

In all, 76 species of bivalves were collected by grab and pipe dredge. Deposit-feeding species were dominant in the western side of Cook Inlet and in inner Kachemak Bay, whereas suspension feeders were most abundant in the sandier areas of outer Kachemak Bay. Horse mussels (Modiolus modiolus) were common in areas of water currents (stations 3, 58-60).

Epifaunal organisms were sampled by a non-quantitative bottom skimmer (26 stations) and by Agassiz, try-net, and eastern otter trawls (25 stations). The highest epifaunal abundance and biomass were found at western and southwestern stations south of Anchor Point.

Figure E.7.2c Dominant epifaunal species in Lower Cook Inlet during April and October, 1976 (Feder and Jewett, 1978).

Species	Maximum Density (g/m^2)	Maximum Number	Station	Month Obtained
Chionoecetes bairdi	6.5[a]	-	25 5-8b[d]	Oct
Hyas lyratus	-	1032[a]	40[a]	Oct
Oregonia gracilis	-	29[b]	8	Apr
Pagurus ochotensis	0.08[a]	54[a]	-	Oct
Elassochirus tenuimanus	0.09[a]	26[b]	44[a]	Apr
Crangon dalli	0.01	7200	-	-
Neptunea lyrata	3.4	78	53	Oct
Fusitriton oregonensis	0.04	-	-	-
Echinarachnius parma	585.5[c]	-	45	Apr
Paralithodes camtschatica	18.1[b]	12[b]	6	Oct

[a] Eastern otter trawl
[b] Agassiz trawl
[c] van Veen grab
[d] mainly juveniles

Catches were dominated by six species of crabs (Chionoecetes bairdi, Paralithodes camtschatica, Hyas lyratus, Oregonia gracilis, Pagurus ochotensis, Elassochirus tenuimanus), two species of gastropods (Neptunia lyrata, Fusitriton oregonensis), a shrimp (Crangon dalli) and a sand dollar (Echinarachnius parma) (Fig. E.7.2c). Dominant organisms were Arthropoda (Crustacea), molluscs, and echinoderms. Higher catches were made in April than in October (Fig. E.7.2d).

The average invertebrate densities from ten Agassiz trawl stations in April and seven stations in October were 3.2 and 3.3 g/m^2, respectively. The average density from 16 eastern otter trawl stations was 3.0 g/m^2. By comparison, an average density of 205.4 g/m^2 was obtained with the grab sampler.

Figure E.7.2d Number, weight, and density (g/m^2) of epifaunal invertebrate phyla of Lower Cook Inlet as obtained by Agassiz trawl, 1976 (Feder and Jewett, RU #281/5/303, Annual Report, 1978).

	April 1976				October 1976			
Phylum	Number	Weight (kg)	% Total Wt.	g/m^2	Number	Weight (kg)	% Total Wt.	g/m^2
Porifera	2	0.107	0.094	0.003	-	-	-	-
Cnidaria	23	0.619	0.542	0.018	1	0.002	0.003	0.0001
Annelida	25	0.031	0.027	0.001	17	0.017	0.024	0.0008
Mollusca	700	17.812	15.588	0.507	60	1.049	1.529	0.0514
Arthropoda: Pycnogonida	-	-	-	-	8	0.003	0.004	0.0002
Crustacea	4061	82.414	72.123	2.342	2981	67.354	98.195	3.3049
Ectoprocta	5	0.188	0.165	0.005	-	-	-	-
Brachiopoda	20	0.135	0.118	0.004	-	-	-	-
Echinodermata	290	12.718	11.130	0.362	78	0.166	0.242	0.0081
Chordata: Urochordata	5	0.245	0.214	0.007	1	0.001	0.002	0.0001
TOTAL	5131	114.269	100	3.249	3146	68.592	100	3.3656

The major epifaunal invertebrate was the Tanner crab, which was obtained mainly by trawling. Tanner crabs found at stations 5 through 8B were mostly juveniles. Large specimens were found at the most western and southwestern stations. The highest catch was made at station 25 (6.5 g/m^2). One thousand thirty-two Hyas lyratus, a crab similar to the Tanner crab, were caught in October at station 40A; 75 percent were females with eggs. The most abundant catch of O. gracilis (29) came in April at station 8.

King crabs were found north of Augustine Island and off Anchor Point in April but were more widely distributed in October. Catches were light during both April and October. The highest catch was made at station 6 in October (12 crabs: density 18.1 g/m^2).

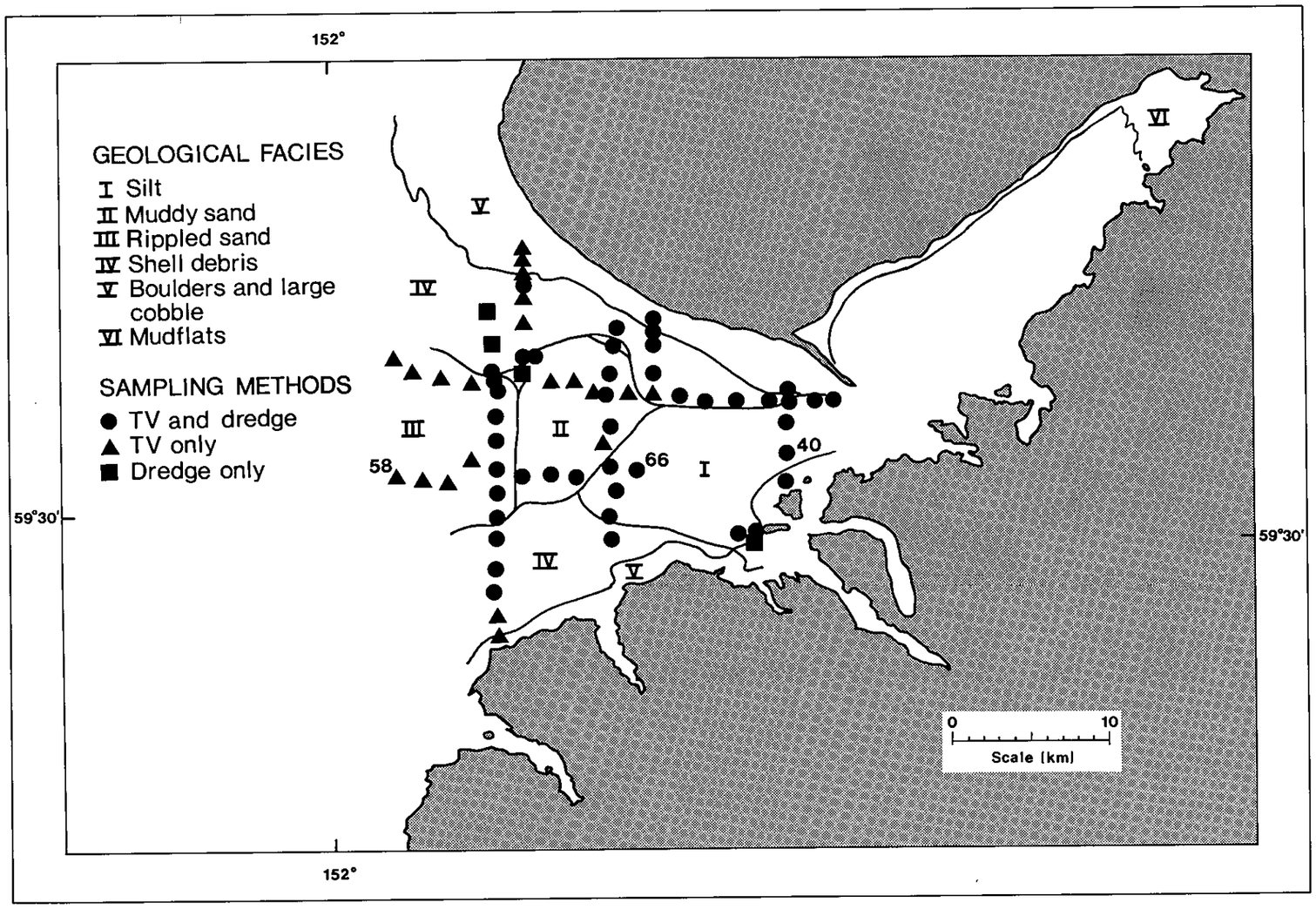


Figure E.7.2e Geological facies and station locations in Kachemak Bay (Driskell, 1977).

Kachemak Bay

The most comprehensive recent studies on benthic populations in Kachemak Bay are those of Driskell (1977). He identified bay six major geological facies in the outer bay consisting of four major substrate types: rock, sand, silt and shell debris (Fig. E.7.2e), and their characteristic infaunal assemblages (Fig. E.7.2f).

Figure E.7.2f Distribution of major taxa among sediment facies in outer Kachemak Bay (Driskell, 1977).

	Sediment Facies				
	Northern Shell	Southern Shell	Sand	Muddy-Sand	Silt
Number of Stations	17	4	8	9	11
Depth (m)[1/]	12-34	29-65	25-64	28-65	34-141
TAXA:					
Total Mollusca	79	21	22	43	21
Mean - Molluscan taxa/station	10.3	6.3	6.5	10.7	3.7
Total Polychaetes	23	10	11	16	22
Mean - Polychaete taxa/station	5.0	4.0	3.0	4.8	5.3
Total Bryozoans	34	4	1	1	1
Total Misc. Taxa	28	18	11	16	15
Total - All Taxa	163	47	45	76	59
Mean taxa/station	29.2	20.0	13.9	22.6	13.5

[1/] Corrected to MLLW

Habitat Assemblages

Northern Shell Debris Assemblage

In the northern shell debris assemblage, samples from 17 dredge stations yielded 163 taxa. Molluscs, with 79 species, were the most diverse group; bryozoan species were also numerous. The bivalves, Astarte spp. Liocyma fluctuosa, and Yoldia myalis, were most abundant in the eastern region, while Cyclocardia spp. and the snail Oenopota viridula were most common at the western stations. Bryozoans were most diverse at the western stations; Carbasea carbasea, Dendrobeania murrayana and Flustrella gigantea were the most common species.

Species of Aphroditoidea (scaleworms) and Oweniidae (collar worms) were most common at the western stations. Lumbrinerids and maldanids were found primarily at the eastern stations. Common crustaceans were barnacles (Balanus spp.), the crabs H. lyratus and O. gracilis in the western regions, hermit crabs (Paguridae), and a small number of brittle stars (Ophiuroidea).

Southern Shell Debris Assemblage

The southern shell debris assemblage yielded 47 taxa from four dredge stations. The richest group was Mollusca with 21 species; polychaetes and bryozoans were of lesser importance. Characteristic species included a bivalve (Glycymeria subobsoleta), which was most numerous although most were juveniles, a clam (Cyclocardia crebricostata), and small adult king crab.

Sand Assemblage

Forty-five taxa were found at eight stations in the sand region. Molluscs again were the most diverse group, with 22 species. Polychaetes were also common. The red neck clam, Spisula polynyma, was the dominant species at most stations in this facies but did not occur at the northern and southern extremes. Also common were the white clam (Axinopsida serricata) and the basket cockle (Clinocardium nuttalii) particularly at the northern end.

At the southern end of this region was a discrete population of Tellina lutea, T. modesta, and T. nuculoides. Polychaetes, particularly members of the family Orbiniidae, were found in half the samples and were densest at the southern stations. Gammarid amphipods had a similar distribution. Adult sand dollars (Echinarachnius parma) were found throughout this facies. Sea cucumbers were abundant on the remnants of an old Modiolus bed at station 58; also present were numerous sea stars, urchins, and anemones.

Muddy Sand Assemblage

Seventy-six taxa were obtained from 9 dredge samples. Molluscs were again the most diverse group with 43 species. Polychaetes were also common. Characteristic bivalve species were the clams Axinopsida serricata, Nuculana fossa, Pandora grandis, N. tenuis, Psephidia lordi, Spisula polynyma and Yoldia seminuda. Several snail species were also abundant in this region.

Sand dollars, Echinarachnius parma, were mostly juveniles and were concentrated at the northern stations. Also common were the sea pen, Ptilosarcus gurneyi, and the Pacific scallop, Pecten caurinus. The sea pen was found at most stations, although its distribution appeared to be patchy. The scallops were seen only in the northern stations and were usually associated with the sea pens.

Silt Assemblage

The silt facies yielded 59 taxa from 11 stations. Polychaetes were the most diverse group, followed closely by molluscs with 21 species. This facies had somewhat impoverished faunal populations with low diversity. Several species of minute clams, which were collected nearly exclusively on the western reaches of this facies, accounted for most of the individuals. Various shrimp species and Tanner crabs were found at nearly every station, and Pacific herring (Clupea harengus) were common at station 40. The most impoverished area was at station 66, where only shrimp, herring, demersal fish, and three taxa of polychaetes were taken.

Boulder-Large Cobble Assemblage

This facies is common in intertidal and subtidal regions of outer Kachemak Bay down to approximately 10 fathoms. Because of operational hazards to sampling gear and vessels, however, the faunas of this facies were not sampled.

Of all the habitat assemblages, the northern shell debris assemblage was the richest. Over 80 percent of the total species was found in the northern shell debris and sand assemblages. The silt and muddy sand assemblages had 29.5 percent and 38 percent, respectively.

Molluscs were more diverse in the muddy sands primarily because more snails were found there; they were least diverse in the silt assemblage. Overall, they comprised 36 to 57 percent of the total taxa in the various assemblages. Polychaetes comprised 14 to 37 percent of the total taxa. They were most diverse in the silty regions and least diverse in the northern shell region. Bryozoa flourished in the northern

shell debris but were less abundant in the southern shell facies. Because of their requirement for a hard substrate, they were poorly represented in the other assemblages.

E.7.3 LIFE HISTORIES FOR KEY BENTHIC SPECIES

King Crab

King crabs follow distinct annual migration patterns associated with their mating season. In Cook Inlet they move inshore in spring and summer and offshore to deeper waters in fall and winter (Fig. E.7.3a; ADF&G, 1976a). The inshore spawning period in Kachemak Bay extends from late December through May with the peak movement occurring in April (Fig. E.7.3b). Molting and spawning occur at this time.

Figure E.7.3a Summary of life history information for various commercially important benthic invertebrates in Lower Cook Inlet (ADF&G, 1976a).

Species	Spawning Time	Age at Maturity	Migrations	Diet
King crab	Late Dec-May	5	inshore (spring and summer) offshore, (fall and winter)	molluscs, polychaetes
Tanner crab	Jan-?	-	inshore (spring and summer) offshore (fall and winter)	varied
Dungeness crab	May-Oct?	2-3	limited	crustaceans, molluscs, worms, seaweed
Pandalid shrimp	Sep-Oct	$1\frac{1}{2}$-$2\frac{1}{2}$	onshore-offshore	amphipods, copepods, isids, limpets, annelids, shrimp
Weathervane scallop	Jun-early Jul	3-4	unknown, probably limited	detritus, plankton
Razor clams	Jul-mid Sep	3	unknown, probably limited	detritus, plankton
Butter clams	spring-summer at water temp. 20°C	up to 15-20	unknown	detritus, plankton

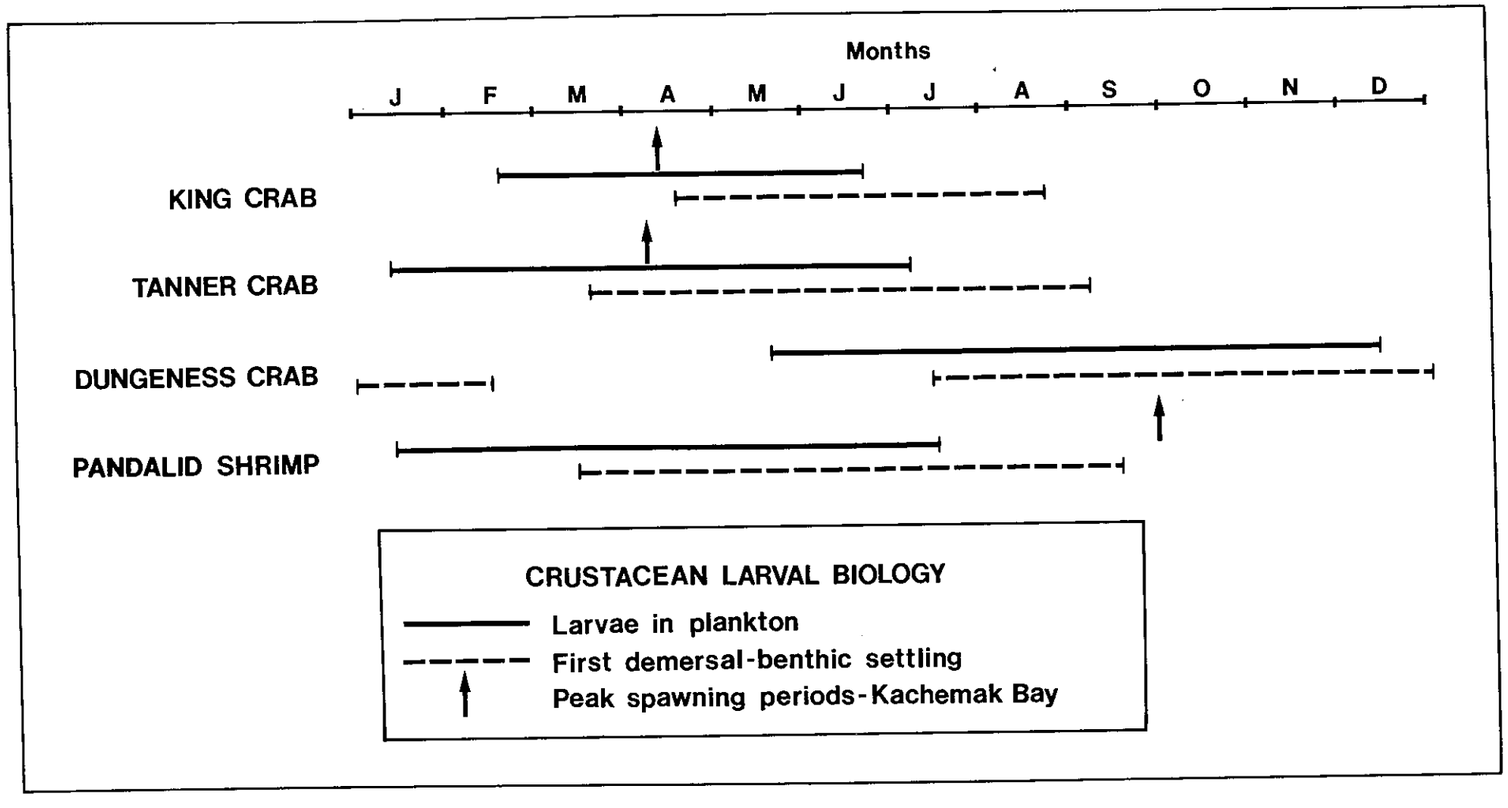


Figure E.7.3b Life histories for commercially important crustacean larval stages (ADF&G, 1976a).

Known spawning areas in Lower Cook Inlet are shown in Fig. E.7.3c. Crabs are found at an average depth of 40 m during this period. The offshore feeding migration takes place from September through November. The crabs forage slowly toward deep water rather than moving there directly.

Mating usually occurs on kelp-covered rocky areas (Powell and Grey, 1964). A male mates with several females. Fecundity increases with size of the female, the largest producing 400,000 eggs. Gravid females carry ova for 11 months before the zoea (larvae) are hatched. After five or six molts (over a 60 to 120-day period) larvae metamorphose into benthic-dwelling juveniles (Weber and Miyahara, 1962; Eldridge, 1972a). Juveniles live solitary, secretive lives on rocky substrates until they are two to three years old. They are distributed from the intertidal to "deep waters" (AEIDC, 1974). At two or three years of age they begin to move about actively and aggregate, forming dense pods of up to several thousand individuals (Bright, 1967; Rietze, 1975). Older juveniles again disperse, and their social behavior becomes similar to that of adults. In the summer and fall, they move farther offshore to feed, returning to shallower depths in the spring. King crabs reach maturity in their fifth or sixth year (Rietze, 1975). Most studies have shown that king crabs are segregated by sex and age-class on their offshore feeding grounds, which they inhabit from late summer to early winter (literature cited in Pereyra et al., 1976).

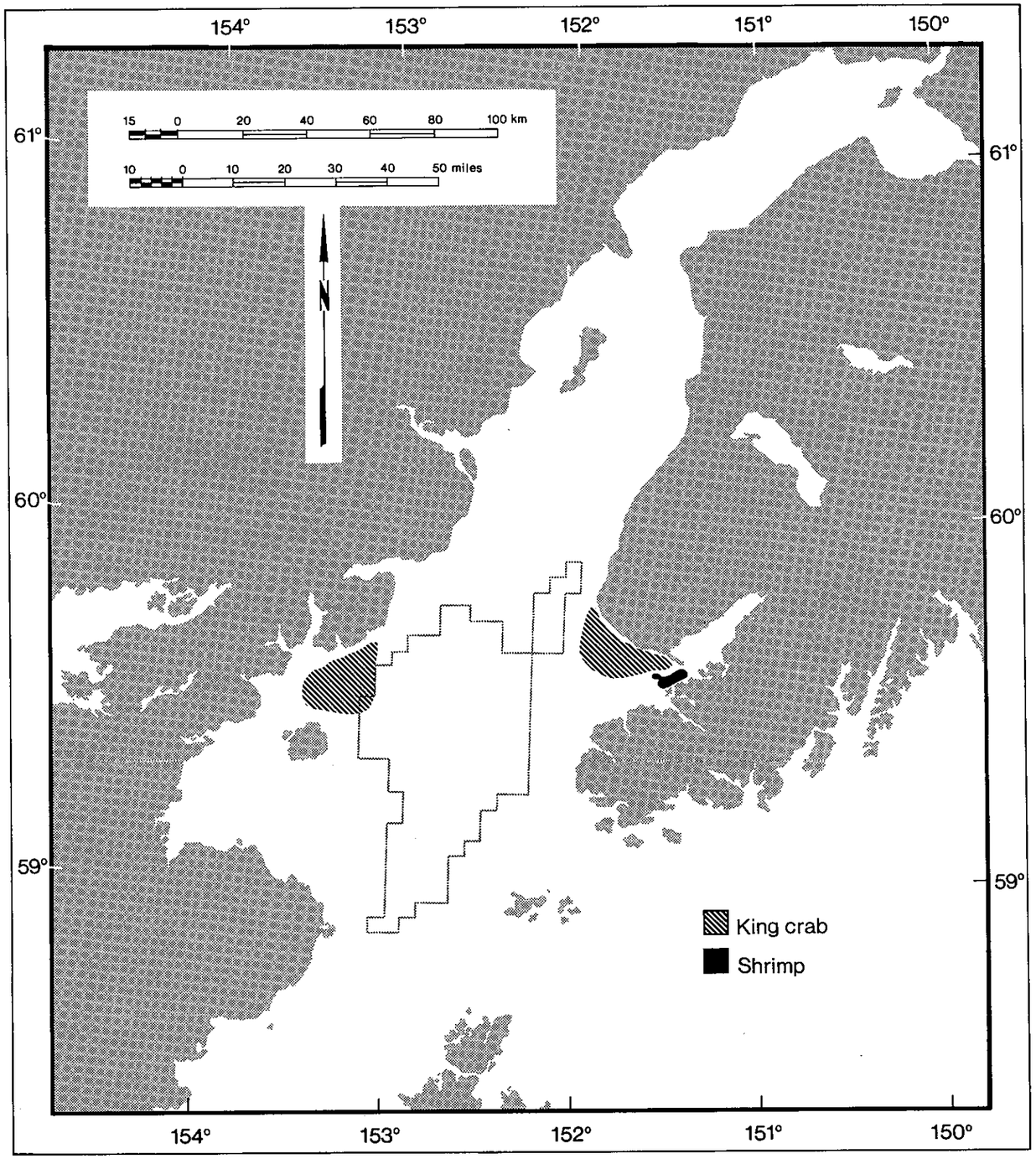


Figure E.7.3c Distribution of king crab and shrimp spawning areas in Lower Cook Inlet (ADF&G, 1976a).

Growth of king crabs, as measured by frequency of molt and increase in size, is affected primarily by abundance of food (Bright, 1967) and temperature (Kurata, 1960). They molt up to 11 times during their first year and in the next two years grow to about 60 mm carapace width (CW). After three years, both sexes usually molt annually. Males show an increase of about 16 mm in carapace width per annum, females less. Growth is rapid up to 80 mm carapace width. As maximum size is approached (200 mm CW for males, and 160 mm CW for females), molting occurs only once every two or three years (Weber, 1967). McCaughran and Powell (1977) present a growth model for Alaskan king crabs. It is estimated that king crabs may live about 20 years (Pereyra et al., 1976).

Tanner Crab

There is little information on migration of Cook Inlet Tanner crab (ADF&G, 1976a). They appear to migrate seasonally, moving into deeper water in the fall and winter and into shallower water for molt and spawning in the spring and summer. Bright (1967) found that the species migrates into the Cook Inlet area to spawn from March through September, with the peak of spawning occurring from May to August. In Kachemak Bay spawning peaks in mid-April and in Kamishak Bay in mid-May (ADF&G, 1976a).

Sexual maturity occurs at seven years (Eldridge, 1972b; Pereyra et al., 1976), corresponding to a size of 100-115 mm carapace width in males and about 85 mm carapace width in females (NPFMC, 1978). Females mature with their pubertal molt, and mating commences shortly thereafter while they are still softshelled. Males are hardshelled. Successful mating between two hardshelled adults also occurs for this species but is rare (NPFMC, 1978). Mature male Tanner crabs, like other decapods, are probably attracted to females by chemical odors released by the females (Kittredge and Takahashi, 1972).

Following egg extrusion and fertilization, females carry their eggs for about eleven months. Gravid females carry on the average 30,000-80,000 eggs, though egg masses of 150,000 ova have been recorded (Eldridge, 1972b; ADF&G, 1975). Females may control hatching times, as larval release appears to coincide with plankton blooms (ADF&G, 1975). Tanner crab larval phase varies from 12 to 90 days, depending on temperature (Pereyra et al., 1976). Larvae molt through about a dozen instars before finally metamorphosing into juveniles.

Juvenile Tanner crabs, resembling adults in general appearance, are bottom-dwellers (ADF&G, 1975). In juveniles, frequency of molting and growth is inversely proportional to age. A growth model for the species is presented in the Tanner Crab Fisheries Management Plan (NPFMC, 1978). Males and females have similar growth rates until maturity. Females do not molt after their pubertal molt, while males continue to molt annually. Old males molt only once every two or three years (Pereyra et al., 1976). Males may attain a maximum size of 185 mm CW (carapace width), females 125 mm. Estimates of longevity are 12-17 years (Pereyra et al., 1976).

Information on natural mortality is summarized in Pereyra et al., (1976). Disease, parasites, and predation are the main causes of death. Recently, population parameters and fishing pressure have been examined, and a Fisheries Management Plan for Tanner crabs in Alaskan waters has been written (NPFMC, 1978).

Dungeness Crab

Although the data are not conclusive, migrations of Dungeness crab in Kachemak Bay appear to be limited. Summer tagging operations showed that most crabs were recaptured at release points, indicating no movement. A few crabs released northeast of Homer Spit moved up the bay, and crabs released southwest of the spit (Barbara Point, Seldovia Bay) moved toward the southwest. Bluff Point crabs moved northward into the shallow waters off Bluff Point in spring and summer for molting and mating. The crabs move southward into deeper waters in the fall and winter.

Isolated bay stocks of Dungeness crab apparently do not migrate out of the bays. Usually these bays contain both a shallow shelf along the shoreline and a deep basin. The entire seasonal migration appears to occur within the bays between the deep and shallow areas. In areas without deep basins the crabs probably burrow into the mud and overwinter there (ADF&G, 1976a). The spawning time of Kachemak Bay Dungeness crab appears to occur from May to October with a peak in September.

The Dungeness crab life cycle has been summarized by Mayer (1972), Hoopes (1973) and ADF&G (1975). Females produce as many as 1.5 million eggs and carry them for 7 to 10 months. Planktonic larvae are then released. In three to four months, following five molts, larvae metamorphose into a planktonic megalops stage, and then into juveniles, which resemble adults in form. Dungeness crabs mature in about three years. Male crabs are approximately 140 mm CW at maturity and females 100 mm CW. Growth is more rapid than in king and Tanner crabs. Male Dungeness crabs may reach 200 mm CW in eight years; females grow to 150 mm CW.

Although data on natural mortality are lacking, these crabs presumably face natural hazards similar to those of king and Tanner crabs.

Several aspects of crab life histories make them particularly vulnerable to the presence of oil, gas, waste effluent, and heavy metal contamination. During the spawning season, males are attracted to mature females by chemical substances released by the females. The extreme sensitivity of male decapods to the character and concentration of these pheromones is well documented (McLeese, 1970; Kittredge et al., 1971; Atema and Gagsian, 1973; Eales, 1974). If a contaminant interferes with the production of the signal or its reception, the reproductive behavior, and hence species viability, may be drastically affected. Minute quantities of crude oil have been shown to affect feeding behavior in American lobsters. These animals are attracted to and consume food contaminated with oil derivatives (Atema and Stein, 1974).

Pandalid Shrimp

Pandalid shrimp undergo onshore-offshore, coastwise and vertical migrations. Migrations associated with age are also known. Newly-hatched larvae are found near the adults, but after the third stage of development the larvae segregate themselves into waters 10 to 70 m deep, where the first summer is spent. The juveniles join the adults in the deeper waters during the shrimps' first winter. The migration patterns of the adult populations are less well known.

In Kachemak Bay, the shrimp leave the bottom during late afternoon or evening and return to or near the bottom about dawn. These diel migrations are probably related to feeding behavior.

The shrimp spawn in Kachemak Bay from late September through mid-October (Fig. E.7.3c). The females produce 900 to 3000 eggs, which they carry for 5 to 6 months, after which the eggs hatch in late March and April. The larvae are planktonic for about sixty days while they pass through six stages. The juvenile stage begins the benthic existence of the adults.

The adults usually mature first as males and then later change into females. Once transformed, an individual remains female until death. Most shrimp mature as males at about 1½-2½ years and remain male for two years (Fox, 1972; ADF&G, 1975; Pereyra et al., 1976).

Mortality is high among pandalid shrimp because of high predation on both larval and adult stages. Virtually any large fish is a potential predator on the shrimp.

Weathervane Scallops

Life history information for weathervane scallops (Patinopecten caurinus) in Cook Inlet is not available (ADF&G 1976a). From data collected in the Kodiak and Yakutat areas, they appear to spawn once a year during June and early July. They do not move to special areas for breeding.

They spawn by releasing gametes into the water column. Fertilization is dependent on local water movements. After a brief egg and planktonic larval stage, juvenile scallops settle, preferably on mud, clay, sand or gravel substrates, and become filter-feeders (Eldridge, 1972c). Scallops mature in three years, when they measure 80 to 125 mm from umbo to outer shell margin. Additional rings are added to the shell at a rate of one per annum (Hennick, 1970). Scallops may live over 15 years (Hennick, 1970). Large specimens may reach 225 mm or more.

Razor Clams

Razor clams spawn in Cook Inlet from mid-July through mid-September, when water temperatures are about 13°C. Fertilization takes place in the open water, where surf action mixes the eggs and sperm. Eggs hatch into larvae a few hours to a few days after fertilization. The larvae exist as free-swimming veligers for the next 5-16 weeks, after which they develop a shell (average shell length 13 mm) and settle to the bottom. Mortality is high during the larval period due to heavy predation by plankton feeders. Juveniles settle into the top few centimeters of wind-swept beaches and are thus subjected to frequent heavy surf conditions (Kaiser and Konigsberg, RU #24, Final Report, 1977). Razor clams are active burrowers as juveniles, and inshore-offshore as well as coastwise movements are common. By their third year they are more stationary and remain so for the rest of their lives. Maturity is at 4.5-5.5 years, when the average shell length is 115 mm. They may live over 15 years (Nosho, 1972).

Butter Clams

Butter clams (Saxidomus gigantens) spawn in the spring and summer when water temperatures reach about 20°C (ADF&G, 1976a). Spawning takes place over several weeks with fertilization occurring in the open water. The larvae are free-swimming veligers for 20-30 days before they develop a shell and settle to the bottom into the top layer of substrate. Predation is high in the larval clams both from plankton feeders and adult butter clams.

The juvenile clams grow very slowly and are preyed upon by crabs, starfish and various demersal fishes. It may take 15 to 20 years for a clam to reach sexual maturity (average shell width 55 mm).

The adults live in the intertidal sediments with only their siphons protruding above the surface. They are primarily filter-feeders on detritus and plankton. Crabs (particularly Dungeness crabs), starfish, octopus, and demersal fishes are the principal predators.

Feder and Jewett (RU #281/5/303, Annual Report, 1978) has provided growth data for six clam species in Lower Cook Inlet (Fig. E.7.3d). These data show that while clams in the Inlet may live a long time, almost all of the clams in this area are relatively young individuals.

Figure E.7.3d Growth data for six species of clam in Lower Cook Inlet (Feder and Jewett, RU #281/5/303, Annual Report, 1978).

Species	Annual Shell Increase (mm)	Dominant Major Year Classes	Oldest (yrs)	Largest (mm)
Nuculana fossa	1-3	0-6	7	19.5
Glycymeris subobsoleta	1-3	0-4	11	27
Spisula polynyma	5-9	1-4	16	128
Macoma calcarea	1.3-2.7	0-5	14	31.4
Tellina nuculoides	0.5-2.0	5-10	13	16.4
Nucula tenuis	0.6-1.0	0-4	7	9.7

E.7.4 TROPHIC RELATIONSHIPS

Predator-prey relationships are identified and food webs are constructed by stomach content analyses and, when possible, by direct observations of feeding activities. Marine food webs show the major dependencies among infauna, epifauna, pelagic fish and invertebrates, birds, and mammals. They give a rough approximation of the path of energy flow through the ecosystem, broaden our awareness of community structure and function, and highlight critical pathways for contaminants. Several biases in interpreting the trophic structure of communities based on gut content analyses are discussed in the data evaluation section.

Predator-prey relationships of key benthic species occurring in Kodiak (Feder and Jewett, RU #517, Final Report, 1977), Lower Cook Inlet, Northeast Gulf of Alaska and the Bering Sea (Feder et al., RU #5/303, Annual Report, 1976; Feder, RU #281/5/303, Annual Report, 1977; Feder and Jewett, RU #281/5/303, Annual Report, 1978) have been examined. Feeding relationships of key benthic species are examined below. The results are based on stomach content analyses of specimens taken in the western Gulf of Alaska and occasionally in the adjacent waters of the Bering Sea.

King crab larvae eat mostly diatoms, barnacle nauplii, and hydroids. Juveniles consume mainly diatoms; Bright (1967) found them in 40 percent of the stomachs he examined. Juvenile king crabs also ingest ostracods, algae, echinoids, small molluscs and gastropods, and sponges. In Cook Inlet adults feed mainly on molluscs and polychaetes (Fig. E.7.4a; Feder, RU #5/281/303, Annual Report, 1977). King crabs have few predators as adults; walleye pollock,

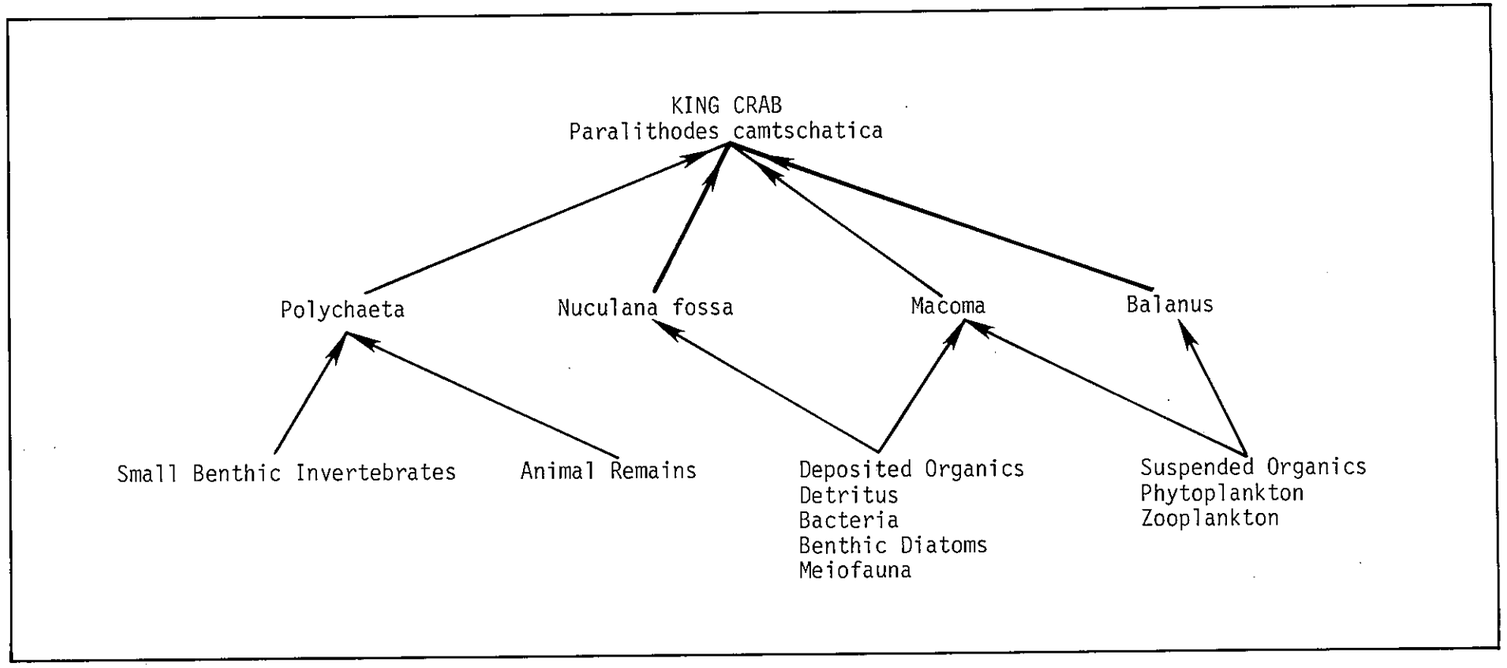


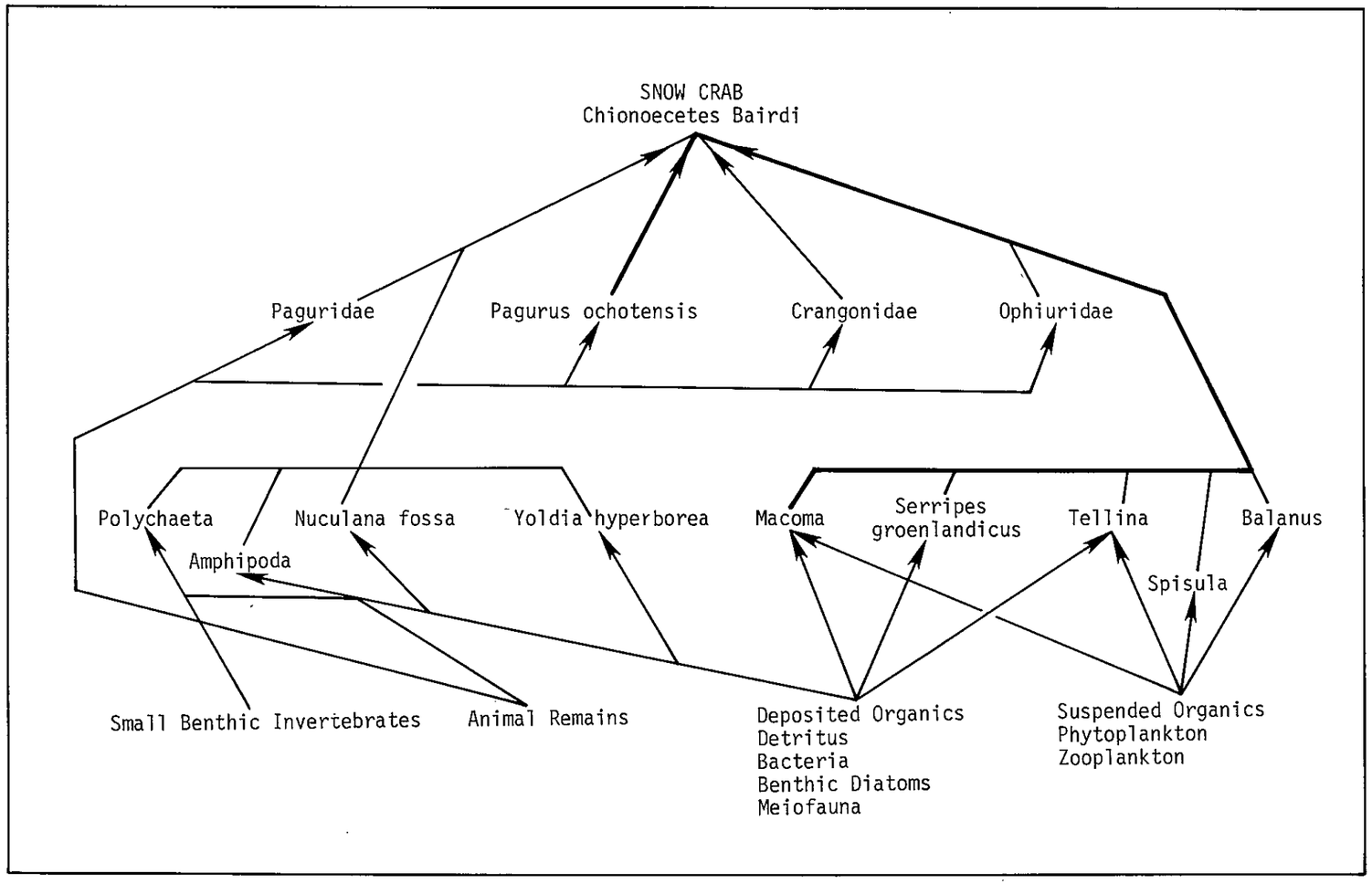
Figure E.7.4a Food web of king crab. Bold lines indicate major food sources based on frequency of occurrence (Feder, RU #281/5/303, Annual Report, 1977).

Pacific cod, and Pacific halibut are known predators (AEIDC, 1974; Pereyra et al., 1976), and other gadids, scorpaenids, and elasmobranchs are suspected. Adult crabs are most susceptible to predation after molting, when their shells are soft.

Tanner crab larvae prey on other plankters. Juveniles eat diatoms, algae and hydroids (Bright, 1967) and detritus (ADF&G, 1975). Feder and Jewett (RU #5/281/303, Annual Report, 1978) has done extensive work on the feeding preferences of the Tanner crab. Of 715 Tanner crabs examined, 428 (60 percent) had food items which included four phyla and seventeen genera. The dominant food organisms were clams, hermit crabs, and barnacles. Occurring most frequently were the small clams, particularly Macoma spp., which rarely exceeded 25 mm in length. Hermit crabs were next, followed by gray shrimps and barnacles (Balanus spp.). Juvenile Tanner crabs were found in the stomachs of five adults with polychaetes, amphipods, and ophiuroids occurring occasionally. A food web for this crab in Lower Cook Inlet is shown in Fig. E.7.4b.

Amphipods prey on Tanner crab eggs, a variety of fish eat juveniles, and octopi, gadids, and liparids and the yellowfin sole (Limanda aspera) take adult crabs (Pereyra et al., 1976; Feder and Jewett, RU #517, Final Report, 1977; Jewett, 1978).

Dungeness crabs feed on shrimp, crabs, barnacles, bivalve molluscs, and polychaetes (Hoopes, 1973). Mayer (1972) reports a predominance of clams in the Dungeness crab stomachs sampled in the NEGOA region. Predators of crab larvae include Pacific herring (Clupea harengus pallasi), salmon (Onchorhynchus spp.) and smelts. Adult crabs are eaten by Pacific halibut, gadids, sculpin, and rockfishes (Mayer, 1972).



Larvae of Pandalid shrimp feed on zooplankton, preferring brachyuran crab larvae (AEIDC, 1974; Pereyra et al., 1976). Juveniles shrimp are opportunistic scavengers. Adults are carnivorous, feeding mainly on benthic polychaetes and crustaceans (AEIDC, 1974). Shrimp predators are numerous; they include many other marine invertebrates, birds and mammals.

Figure E.7.4b Food web of Tanner crab. Bold lines indicate major food sources based on frequency of occurrence (Feder and Jewett, RU #281/5/303, Annual Report, 1978).

Clams are filter-feeders, utilizing phytoplankton and detritus as primary food sources; thus they serve as an important link between benthic microfauna and macrofauna populations. They store heavy metals in their tissues (Malins, 1977), and since they are long-lived, they may be good indicators of man's impact on arctic and subarctic ecosystems.

DATA EVALUATION

Distributional and life history data for commercially important species of shell fish are based mainly on catch statistics. Few life history studies have been conducted in Lower Cook Inlet; most life history information has been compiled from studies of the organisms in other areas. Areas of major abundance can be expected to change in the future because of the effects of exploitation as well as natural factors. It is important to remember that the Inlet continues to support an important commercial shell fishery.

Distributional data on non-commercial species come from limited sampling within the Inlet using a variety of equipment and techniques (van Veen grab, pipe dredge, try-net, clam dredge, Agassiz trawl, Eastern otter trawl, bottom skimmer, anchor dredge, underwater television, and color still photography). The variety of sampling techniques makes comparison of different areas difficult. Each method has its own sampling efficiency, which varies with the substrate type. The utility of bottom samplers is limited in rocky areas, and as a result this substrate type was not sampled in Kachemak Bay. Thus, selection of the areas to be sampled in Cook Inlet was biased. The present information does give a general idea of invertebrate populations in the Inlet.

SUBTASK E.8 General Description of the Littoral and Shallow Sublittoral Habitat and Biota

E.8.1 LITTORAL HABITAT

In a survey of the coastline of Lower Cook Inlet, Lees (RU #417, Final Report, 1978) distinguished six geological substrate types: pavement or bedrock beach or reef, boulder field, gravel/cobble beach, brown or gray sand beach, sand/gravel flats, and mudflats (Fig. E.8.1a). The first three habitats were observed in both protected and exposed locations while the fourth was found only in exposed locations and the last two habitats were found in protected areas.

The intertidal zone of the eastern shore from above Clam Gulch to north of Anchor Point is characterized by unconsolidated beaches with gravel upper slopes and sandy lower slopes. From Anchor Point to the base of Homer Spit the upper slopes are gravelly, but the lower slopes are rocky with sand patches. The shorelines of the south side of Kachemak Bay and Kennedy Entrance are irregular and are dominated by rocky intertidal zones with gravel beaches. Mudflats are found at the head of most embayments.

In contrast, the west side of the Inlet is characterized by sand beaches along exposed coastline and by extensive mudflats in embayments. These areas are often interspersed with gravelly upper slopes and flat sandstone beaches, especially in southern Kamishak Bay.

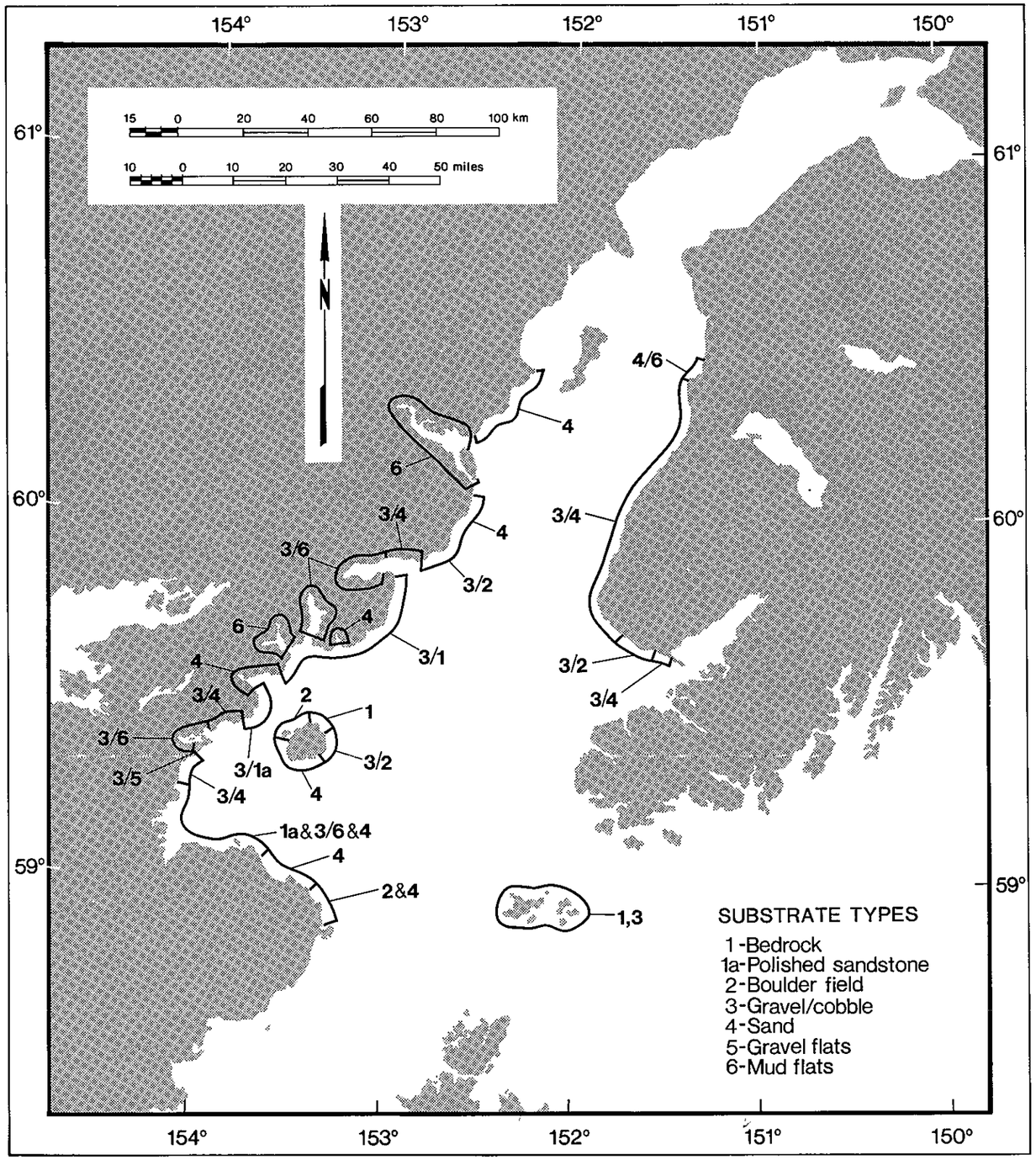


Figure E.8.1a Distribution of geological substrate types (aerial reconnaissance, May 1976) (Lees, RU #417, Final Report, 1978).

Except in Kachemak Bay, there is little diversity of habitat along the eastern side of the Inlet. A decrease in biotic diversity northward along the east coast has been attributed to the greater stress encountered by organisms there. Silt loading and ice conditions are more severe in the upper Inlet. Habitat diversity is greater on the western shore because of a greater variety of combinations of substrate types, turbidity, salinity conditions, and wave exposure levels.

Nord, Sugarloaf, Ushagat, Sud, East and West Amatuli of the Barrens group, Shaw, Augustine, Gull and Chisik Islands were surveyed. Shorelines of these islands differed according to proximity to the mainland or to the mouth of the Inlet, and to the side of the island examined.

The Barren Islands, more exposed than the other islands examined, are characterized by almost vertical rocky coastlines. Islands with less exposure (Augustine, Gull, etc.) have rocky shorelines interspersed with mudflats, sand or gravel beaches, and boulder fields.

Hayes et al. (1977) classified the coast of Lower Cook Inlet into erosional, neutral and depositional zones. About 45 percent of the 1,216 km of shoreline surveyed was described as undergoing active erosion (wave-cut scarps, erosional scarps, etc.) 38 percent as neutral shoreline (embayed areas, where no obvious advance or retreat of the shore has occurred recently), and 17 percent as depositional areas (spits, deltas) (Fig. E.8.1b).

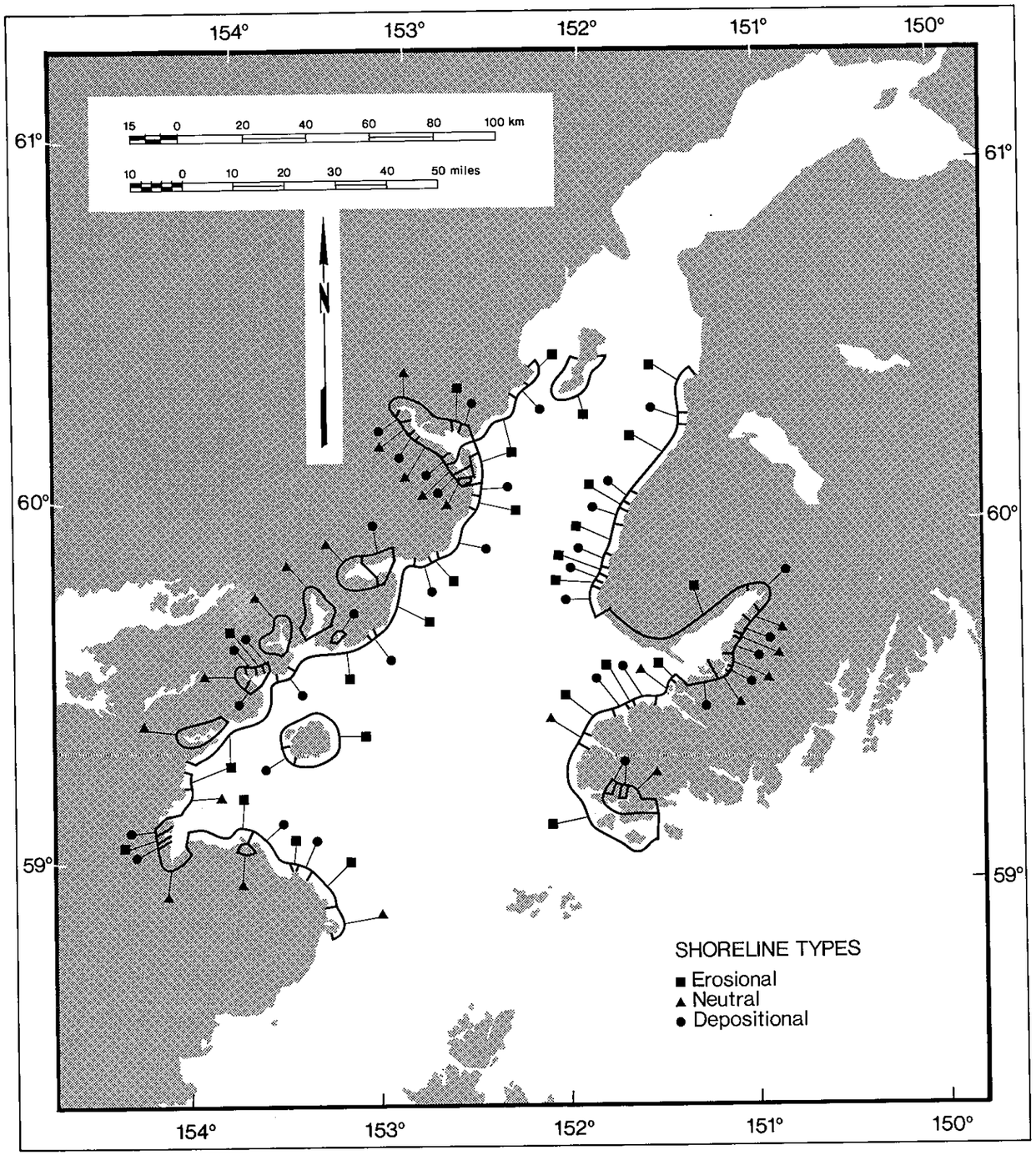


Figure E.8.1b Distribution of geomorphological units (Hayes et al., 1977).

The vulnerability of the various Lower Cook Inlet coastal environments to oil spill damage (Fig. E.8.1c) has been estimated by Hayes et al. (1977). They devised a vulnerability index based on the predicted longevity of spilled oil in each environment. According to this index the six habitats defined by Lees (RU #417, Final Report, 1978) are increasingly vulnerable to oil spill damage in the order: bedrock beach or reef, sand beach, mudflats, sand/gravel, gravel/cobble beach, and boulder field.

E.8.2 DISTRIBUTION OF LITTORAL BIOTA

The littoral biota of Lower Cook Inlet is distributed according to substrate (rocky, sand, mud, mixed) and depth (upper intertidal, above mean sea level (MSL); middle intertidal, between MSL and mean lower low water (MLLW); the lower intertidal, area between MLLW and extreme low water (ELW); and the shallow subtidal zone) (Lees, RU #417, Final Report, 1978). The characteristic biota of each substrate type and vertical division are given in Fig. E.8.2a.

Of the four substrates, the rocky type was the most diverse. Some 66 species and genera (Fig. E.8.2a) have been identified from this habitat throughout Lower Cook.

The lichens Verrucaria and Caloplaca dominate the upper intertidal biota. Dominant animals are a barnacle (B. glandula), limpets (N. persona and N. scutum), and a periwinkle (L. sitkana). While these species also range into the middle intertidal, that zone is dominated by macrophytes (F. distichus, S. lomentaria and Spongomorpha). Barnacles and mussels

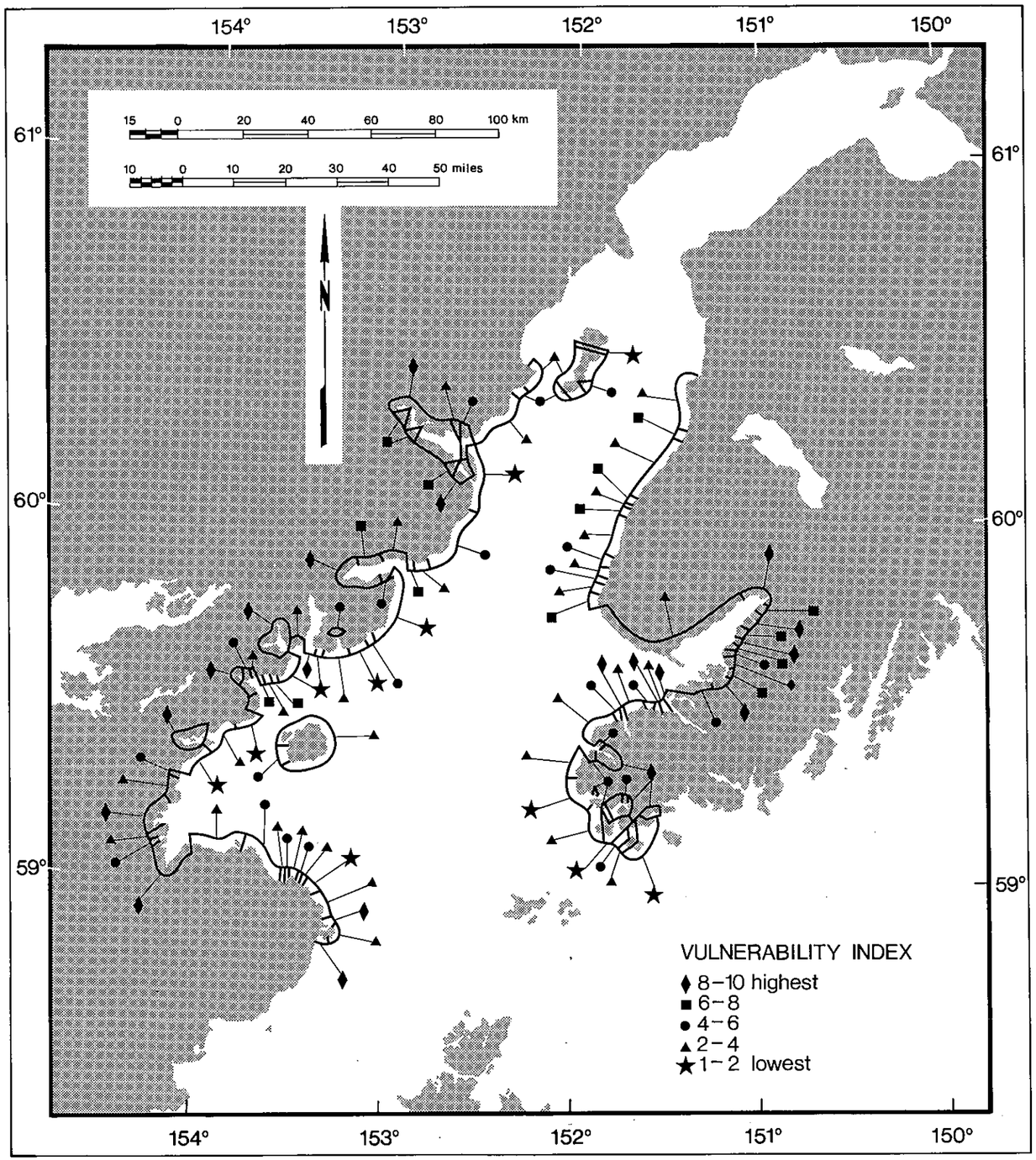


Figure E.8.1c Vulnerability of coastal environments to oil spill damage (Hayes et al., 1977).

Figure E.8.2a Characteristic biota by substrate type in the littoral and shallow sublittoral zone of Lower Cook Inlet (Lees, RU #417, Final Report, 1978).

Zone Designation	Rocky	Sand	Mud
Upper Intertidal	Verrucaria sp. Caloplaca sp. B. glandula N. persona N. scutum L. sitkana	Diptera sp. Orchestia sp.	M. balthica A. pacifica
Mid-Intertidal	F. distichus S. lomentaria Spongomorpha sp.	Nephtys sp. gammarid amphipods	N. caeca E. echiurus alaskanus nemerteans Paranemertes Cerebratulus
Lower Intertidal	Abietinaria sp. Serpulidae Sabellidae M. truncata H. arctica Haliclona sp. Halichondria sp. B. rostratus B. nubilus Alcyonidium sp. Aplidium sp. Distaplia sp. R. palmata sp. Iridaea sp.	Spio sp. S. polynyma C. bairdi	Clinocardium sp. Mya sp.
Shallow Subtidal	B. rostratus alaskanus H. panicea (?) Potamilla sp. N. lyrata E. oregonensis A. fistulosa L. groenlandica A. cribrosum N. luetkeana	T. nuculoides E. parma O. baetica	S. giganteus T. capax Macoma sp. C. nuttallii E. troschellii A. amurensis Z. marina L. saccharina L. groenlandica

dominate the middle intertidal fauna. The lower intertidal is characterized by a hydroid (Abietinaria), the polychaete familes Serpulidae and Sabellidae, bivalves (M. truncata and H. arctica), sponges (Haliclona and Halichondria), barnacles (B. rostratus and B. nubilus), the bryozoan (Alyconidium), and the tunicates (Aplidium and Distaplia. Most of these are encrusting filter feeders. Algae such as red algae (R. palmata and Iridaea), coralline algae, and large browns (Alaria and Laminaria) dominate a few areas. Dominant flora of the rocky subtidal to three meters below MLLW includes the brown algae (A. fistulosa, L. groenlandica, A. cribrosum and N. luetkeana). Predominant invertebrate species include a barnacle (B. rostratus alaskanus), a sponge (H. panicea), a polychaete (Potamilla), and gastropods (N. lyrata and E. oregonensis).

The sandy upper intertidal area is largely devoid of macroorganisms, although a fly (Diptera) and a beach hopper (Orchestia) are abundant in tide-carried algae. A deposit-feeding polychaete (Nephtys) and gammarid amphipods, representatives of the middle intertidal, are joined by polychaetes (Spio and Scolelepis), bivalves (T. lutea, Macoma, Siliqua and S. polynyma), and the Tanner crab (C. bairdi) in the lower intertidal. No data were collected from the sandy subtidal in Lower Cook but Lees (RU #417, Final Report, 1978) reports that a bivalve (T. nuculoides), an echinoid (E. parma), and a gastropod (O. baetica) are representative of this zone in Koyuktolik Bay.

In protected locations with muddy substrate above the MSL, a clam (M. balthica) and a lugworm (A. pacifica) are abundant. These species reach their greatest densities in the middle intertidal where they are joined by a polychaete (N. caeca), a spoon worm (E. echiurus alaskanus), and nemerteans (Paranemertes and Cerebratulus). The middle intertidal species commonly extend into the lower intertidal zone, but a cockle (Clinocardium) and a bivalve (Mya) are the dominant organisms in the latter zone.

Several shallow, subtidal, muddy, estuarine habitats were examined. No typical biota was discerned, but the flora was dominated by the eelgrass (Z. marina) or by brown algae (L. saccharina and L. groenlandica). The fauna was dominated by starfish and clams including S. giganteus, I. capax, Macoma, C. nuttallii, E. troschellii, and A. amurensis.

The mixed habitat was a designation for those substrate types that were transitions between two or more of the above three categories. Two clams of economic importance, S. giganteus and P. staminea, were often found in substrates of mud and silty gravel.

DATA EVALUATION

Descriptions of habitat type (Lees, RU #417, Final Report, 1978) determined by aerial reconnaissance appear to be reliable for western Lower Cook Inlet. The descriptive data for the eastern shore are assumed to have been extrapolated from studies at specific sites visited during the survey. Because of limited information on the effects of oil spills, environmental susceptibility to spills has been based on conclusions from two spills (Uraviola and Metula) (Hayes et al. 1977).

The characteristics of the intertidal and shallow subtidal communities described here are generalized from qualitative descriptions of biota from several locations. Specific locations probably do not completely correspond with these generalized descriptions.

Many organisms were not identified to the species level because of the lack of time and up-to-date taxonomic studies. Sites were chosen by aerial reconnaissance on the basis of substrate type, vulnerability to environmental stress, and accessibility; they probably adequately represent mainland littoral habitats. No sites were examined at island locations, such as Augustine and the Barren Islands, however.

Subtidal areas were studied were studied in less detail than the intertidal zone.

SUBTASK E.9 Ecosystem Dynamics for Littoral Biota of the Principal Shore Types

E.9.1 DISTRIBUTIONAL VARIATION OF LITTORAL BIOTA

(Lees, RU #417, Final Report, 1978) found barnacles, mussels and a gastropod, Nucella, to be characteristic of the rocky intertidal zone. In isolated areas laminarian seaweeds were also found. The communities on the western shoreline of Lower Cook Inlet tended to have low diversity; most rocky habitats were dominated by dense populations of pioneer species such as barnacles and green algae.

Rocky subtidal communities below a depth of three meters were different on the two sides of the Inlet. On the eastern shore two distinct zones were identified: the upper, 3 to 12 meters deep, was dominated by the macrophytes Alaria fistulosa, Nereocystis luetkeana, Laminaria groenlandica, and Agarum cribrosum; the lower, 12 to 20 meters deep, was dominated by the latter two species (Lees, RU #417, Final Report, 1978; Fig. E.9.1a). The fauna dominated by barnacles, encrusting bryozoans, and sponges became more dense with increased depth. The western shore subtidal also had two distinct zones: the upper, 0 to 3 meters deep, was dominated by the kelps L. groenlandica and A. marginata(?); the lower, 3 to 6 meters deep, dominated by coralline algae. Unlike conditions on the eastern shore, faunal diversity on the western shore was low, consisting of a poorly developed encrusting community (barnacles, sponges, and bryozoans).

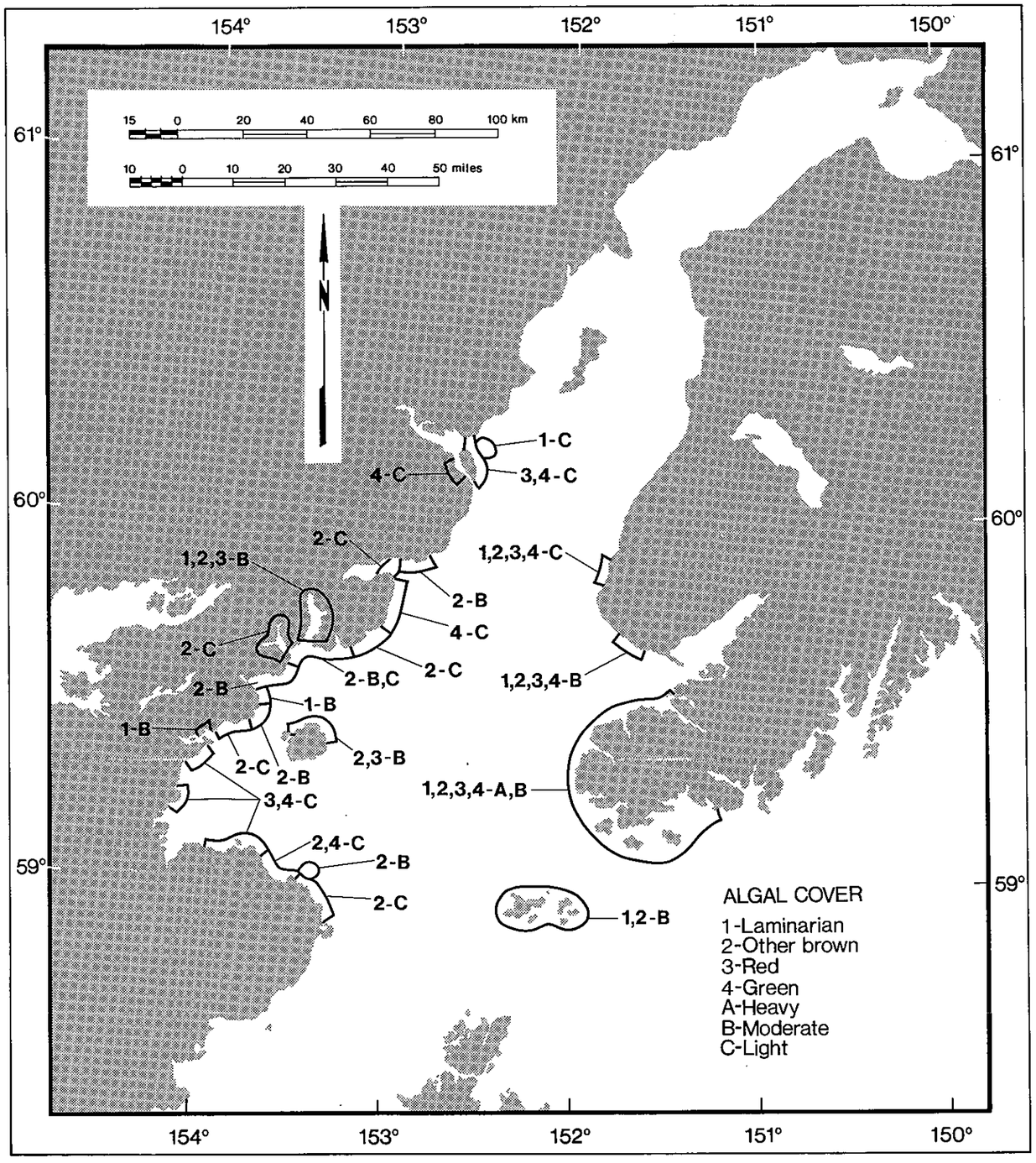


Figure E.9.1a Distribution of type and density of algal cover (aerial reconnaisance, May 1976) (Lees, RU #417, Final Report, 1978).

The lower diversity of the rocky intertidal and subtidal biota of the western shoreline is probably the result of the high turbidity and sedimentation rate, low air temperature, and ice abrasion prevalent on that side.

Figure E.9.1b Relative cover of algal species in Lower Cook Inlet, June through August 1976 (Lees and Rosenthal #27, Final Report, 1977; Lees, RU #417, Final Report, 1978).

	WEST SHORE						EAST SHORE
	INISKIN BAY				CHINITNA BAY		KOYUKTOLIK BAY
	Iniskin Rock	Rocky Point	Keystone Creek	Blackie Cove	Clam Cove Creek	Spring Point	
Upper Intertidal							
Laminaria groenlandica	-	-	-	+++	-	-	-
Fucus distichus	-	+++*	-	-	-	-	-
Lower Intertidal							
Alaria marginata	-	-	-	+++	-	-	-
Laminaria groenlandica	-	-	-	-	-	+++	-
Ralfsia pacifica	-	-	-	-	-	+	-
Callophyllis sp.	-	+++	-	++	-	++	-
Fucus distichus	-	-	-	++	-	++	-
Laminaria saccharina	-	-	+++	++	-	-	-
Monostroma sp.	-	++	+	++	-	++	-
Rhodymenia palmata	-	+++	+++	+++	-	++	-
Porphyra sp.	-	++	+	-	-	-	-
Pterosiphonia sp.	-	-	++	-	-	-	-
Constantinea subulifera	-	-	-	-	-	++	-
Corallina raneouveriensis	-	-	-	-	-	++	-
Enteromorpha intestinalis	-	-	-	-	-	++	-
Spongomorpha sp.	-	+++	-	-	-	-	-
Halosaccion glandiforme	-	-	-	-	-	-	+++
Encrustine coralline algae	-	-	-	-	-	+++	-
Subtidal							
Alaria marginata	++	-	-	-	+++	-	-
Laminaria groenlandica	+++	-	-	-	+++	-	++
Odonthalia Ramschatica	++	-	-	-	++	++	-
Ralfsia pacifica	+	-	-	-	++	-	-
Callophyllis sp.	-	-	-	-	-	++	-
Desmarestia ligulata	-	-	-	-	-	++	-
Hildenbrandia sp.	-	-	-	-	-	++	-
Opuntiella sp.	-	-	-	-	-	++	-
Phycodrys sp.	+	-	-	-	-	++	-
Monostroma sp.	+	-	-	-	-	-	-
Rhodymenia palmata	+	-	-	-	-	-	-
Purphyra sp.	++	-	-	-	-	-	-
Pterosiphonia sp.	++	-	-	-	-	-	-
Constantinea subulifera	+++	-	-	-	-	-	-
Halosaccion glandiforme	++	-	-	-	-	-	-
Encrusting coralline algae	+++	-	-	-	+++	+++	-
Rhodophyta, fleshy	-	-	-	-	-	+	-

* + = 0.1 to 1.0 percent cover
++ = 1.1 to 10.1 percent cover
+++ = 10.1 to 100.0 percent cover

Distribution and Density - Flora

The intertidal and shallow subtidal rocky shore of Lower Cook Inlet supported a diverse assemblage of algae. The east coast of Cook Inlet was more diverse and productive than that of the west coast. Algal production declined sharply on both coasts from south to north.

While large kelps, such as N. luetkeana and A. fistulosa, were restricted to the more exposed areas such as Kennedy Entrance, the smaller kelps Laminaria and Agarum occurred more commonly in protected areas on both sides of the inner Inlet.

Algae distribution and density, as estimated from aerial reconnaissance surveys, are mapped in Fig. E.9.1a (Lees, RU #417, Final Report, 1978). Relative cover of algal species at specific field sites and position in the intertidal zone is shown in Fig. E.9.1b.

The eelgrass Zostera marina was widely distributed throughout the Inlet, being found in Koyuktolik Bay (Lees, RU #27, Final Report, 1977) and Seldovia, Jakolof, Kasitsna, Mud, Iniskin, and Bruin Bays (Lees, RU #417, Final Report, 1978). The largest beds observed (estimated at 1,500,000m^2 and 750,000m^2) were at Koyuktolik and Bruin Bays, respectively (Lees, RU #417, Final Report, 1978).

Distribution and Density - Macrofauna

Molluscs were the most common macroinvertebrates in the intertidal and subtidal zones at three study sites (Lees, RU #417, Final Report, 1978; Fig. 9.1c).

Figure E.9.1c Relative densities of major infaunal taxa from sandy beaches in Lower Cook Inlet, May through July 1976 (Lees, RU #417, Final Report, 1978).

	EAST SHORE										WEST SHORE						
Location	Base of Homer Spit		Seafair Beach		Whiskey Gulch			Deep Creek		Clam Gulch		Amakdedori			Chinitna Clam Beach		Polly Creek	
Approx. Elevation (m)	0 to -0.3	-1.2	0 to -0.3	-1.2	0	0 to -0.3	-0.3 -0.6	+0.6 and -0.6	-0.9	-0.6	-1.2	+0.3	-0.6	-0.9	-0.9	-1.2	-0.3	-0.9
ANNELIDA-Polychaeta																		
Eteone nr. longa	**	-	**	-	-	-	-	-	**	+	-	-	**	-	-	+	+	**	-
Magelona sacculata		-		++	-	-	-	-		-	-	-		-	-	-	-		-
Scoloplos armiger		+*		-	-	-	-	-		+	-	-		-	-	-	-		-
Scolelepis sp.		-		-	-	-	++	-		-	-	-		-	-	-	-		-
Spionidae #1 C		-		-	-	-	-	-		-	-	-	++	-	-	-	-		-
Spio filicornis		-		-	-	-	-	-		+	-	+	+	+++	-	-	-		-
Spiophanes bombyx		+		+	-	-	-	-		-	-	-	-	-	-	-	-		-
Paraonidae. unid.		-		-	-	-	-	-		+	-	++	-	-	-	-	-		-
ARTHROPODA-Crustacea																			
Anisogammarus pugettensis		-		-	-	-	-	-		-	-	-	-	+	-	-	-		-
Anonyx sp. A		-		-	-	-	-	-		-	-	-	-	-	-	-	-		++
Archaeomysis grebnitzkii	-		-	-	-	-	-	-		-	-	-	-	-	-	-	-		-
Cumacea, unid.		++		-	-	-	-	-		++++	++++	++++	-	-	++	++	-		++
Eohaustorius spp.		+		+	+++	+	-	+++		-	-	-	-	-	-	-	-		-
Hippomedon sp. A		++		+++	-	-	-	-		-	-	-	-	-	-	-	-		-
Paraphoxus obtusidens		+		+	-	-	-	-		+	-	-	-	-	+	-	-		-
P. o. major		-		+	+++	+	-	++		-	-	-	-	-	+	-	-		-
?Neomysis sp.		-		-	-	-	-	-		-	-	-							
MOLLUSCA-Pelecypoda																			
Siliqua patula (juvenile)		-		-	-	-	-	-		-	-	-	+	++	-	-	-		-

* + = 0.10-0.49 animals/44 cm^2; ++ = 0.50-0.99 animals/44 cm^2; +++ = 1.00-1.99 animals/44 cm^2; ++++ = > 1.99 animals/44 cm^2
** Sampled, but no animals obtained.

At Iniskin Bay the most numerous species in the shallow intertidal were Modiolus modiolus (17 individuals/m^2) and Tonicella lineata (6 individuals/m^2). At Chinitna Bay, the most numerous species (in the lower intertidal) was Nuella emarginata (45 individuals/m^2), in the shallow subtidal, only T. insignis (48 individuals/m^2) was reported. At Koyuktolik Bay, a mussel bed (Mytilus edulis: 13,600 individuals/m^2) covered the upper intertidal, while only N. emarginata (96 individuals/m^2) was reported for the lower intertidal.

Distribution and Density - Infauna

The infauna of mud and sand substrates was dominated by polychaetes, crustaceans, and bivalves. The dominant taxa from eight sampling sites are given in Fig. E.9.1c. Species diversity and density appear to increase with increasing depth.

E.9.2 SEASONAL VARIATION OF BIOTA

Seasonal Density Comparisons - Flora

Preliminary data for Kachemak Bay show large annual differences in cover, composition, and biomass of brown seaweeds. Seaweeds were dominated by F. distichus in the mid-intertidal and by Alaria sp., H. sessile, L. groenlandica, and A. cribrosum to depths of 22 to 25 m, with a band between 8 and 12 m dominated by A. fistulosa and N. luetkeana. Biomass was lowest in winter and peaked during the mid-summer (Lees, RU #417, Quarterly Report, Oct-Dec, 1977; Fig. E.9.2a).

There is no information on the seasonal changes of Zostera beds in Lower Cook Inlet. This plant is a perennial and seeds each summer. Growth rates are highest during the summer and fall. Exposure to low temperatures and ice strips the leaves from the stems.

Seasonal Density Comparisons - Macrofauna

No data concerning macrofauna were available.

Seasonal Density Comparisons - Infauna

Two east coast sandy beaches (Homer Spit and Deep Creek) were examined quantitatively at three periods over a six-month period. The polychaetes Scolelepis and P. platybranchia were the dominant infaunal taxa at Homer Spit, while at Deep Creek gammarid amphipods were dominant. Faunal differences between the sites may be due to differences in intensity of tidal currents and storm wave frequency. Infaunal densities at the two sites were similar and increased about 60 percent from February to July (Lees, personal communication, February, 1978; Fig. E.9.2b).

Fluctuations in densities of organisms inhabiting mudflats were common. Comparison of size and density data of the bivalve M. balthica showed that winter stress conditions and predation pressure were the most important factors in affecting populations (Lees, personal communication, February, 1978).

Figure E.9.2a Seasonal biomass estimates of brown seaweeds in Kachemak Bay (Lees, RU #417, Quarterly Report, Oct-Dec, 1977).

Season	Zone	
	Intertidal	Subtidal
Winter	400-850 g/m^2	230-720 g/m^2
Spring	600-2200 g/m^2	425-1150 g/m^2
Midsummer	2400-5600 g/m^2	250-6500 g/m^2
Late Summer	950-2000 g/m^2	350-2020 g/m^2

DATA EVALUATION

Data are adequate for estimating the relative densities of infauna in substrates in eastern Lower Cook Inlet but are few for the western coast. Macrofaunal density data come mainly from the west coast at the Chinitna and Iniskin Bay study sites. Caution is needed in interpreting aerial reconnaissance data on type, distribution, and density of algal assemblages because of a lack of on-site verification (Lees, RU #417, Final Report, 1978). Seasonal density data are preliminary and incomplete; data could not be gathered during the winter because of weather conditions in the Inlet.

Figure E.9.2b Seasonal density comparisons of common infauna of sandy substrate at Homer Spit and Deep Creek, 1977 (Lees, pers. comm.).

	Density (no/m^2)					
	Homer Spit			Deep Creek		
	February	March	July	February	April	July
Annelida:						
Capitella			25.5			
Capitella capitata (?)				9.6		9.6
Etoone (?)	6.4		3.2	44.6	9.6	9.6
Nagelona pitelkai	12.8	3.2				
Nephtys caeca			3.2			9.6
N. ciliata (?)	6.4	9.5			9.6	
N. cornuta (?)			19.1			
Paraonella platybranchia	146.4	38.2	213.3	15.9	9.6	12.7
Scolelepis sp.	273.7	385.2	547.5	15.9	15.0	92.3
Scoloplos armiger		6.4		6.4	6.4	
Spiophanes bombyx			3.2			
Arthropoda:						
Eohaustorius eous	19.1	12.7	28.7	404.2	461.5	648.4
Paraphoxus sp.	44.6	50.9	19.1	9.6	28.6	19.1
Anisogammarus sp.				6.4	6.4	
Mollusca:						
Spisula sp.	12.7	3.2	6.4			
Chordata:						
Ammodytes hexapterus	12.7	6.4	3.2			
TOTALS	534.8	515.7	872.4	512.6	566.7	801.3

SUBTASK E.10 Seasonal Density Distribution of Principal Species of Plankton

E.10.1 DISTRIBUTION OF PRINCIPAL SPECIES OF ZOOPLANKTON

Five cruises between April 6 and August 31, 1976 collected information on resident zooplankton populations (Damkaer, RU #425a, Annual Report, 1977; Fig. E.10.1a) in Lower Cook Inlet and the nearby Gulf of Alaska.

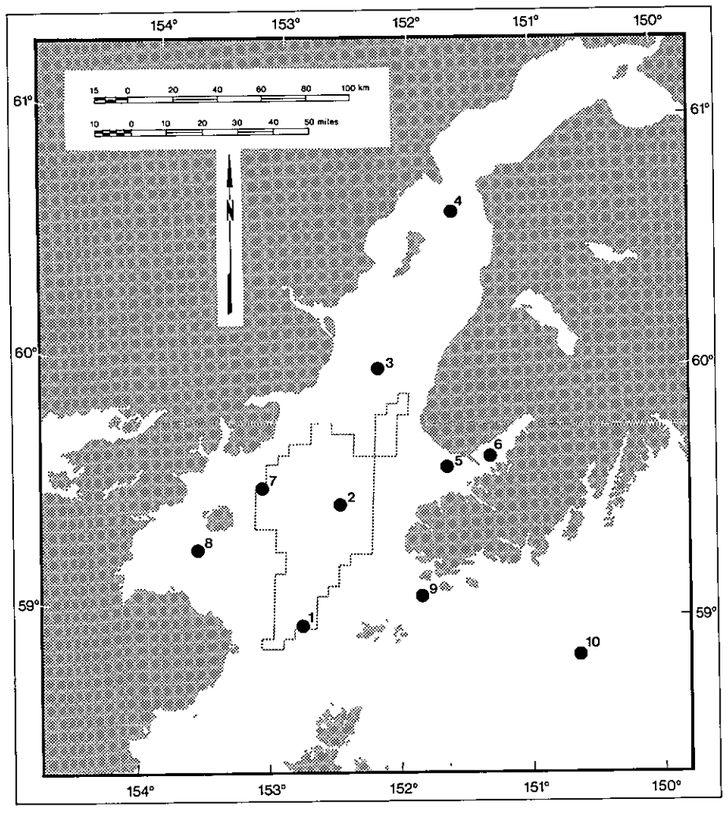


Figure E.10.1a Plankton sampling stations, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977).

A peak in zooplankton densities (in the main part of Lower Cook Inlet) was observed in early July, whereas in Kachemak Bay a peak was observed in early May. These patterns closely parallel those observed for the phytoplankton during the same period (see Subtask E.11). The pattern of seasonal abundance of zooplankton observed in Cook Inlet is similar to that observed in the more open waters of station 11 in the Gulf of Alaska (Fig. E.10.1b). The different pattern observed in Kachemak Bay is probably indicative of water conditions found there.

The zooplankton identified in Kachemak Bay are listed in Fig. E.10.1c. The abundance of zooplankton increased from April through August (Fig. E.10.1d). The copepods Pseudocalanus sp., Acartia longiremis, and Oithona similis, and barnacle nauplii were the most abundant taxa. The barnacle nauplii were abundant in the April, July, and August samples but were absent from samples taken in May. Barnacle cyprids (the second larval stage) were taken in May, July, and August.

Deep water locations usually had a more diverse fauna (35 species) than shallow-water or bay locations (18 species). Estimates of abundance were affected by time of sampling. Diel activity was detected in zooplankton in both Kachemak Bay and the more exposed stations in the Inlet (Fig. E.10.1e).

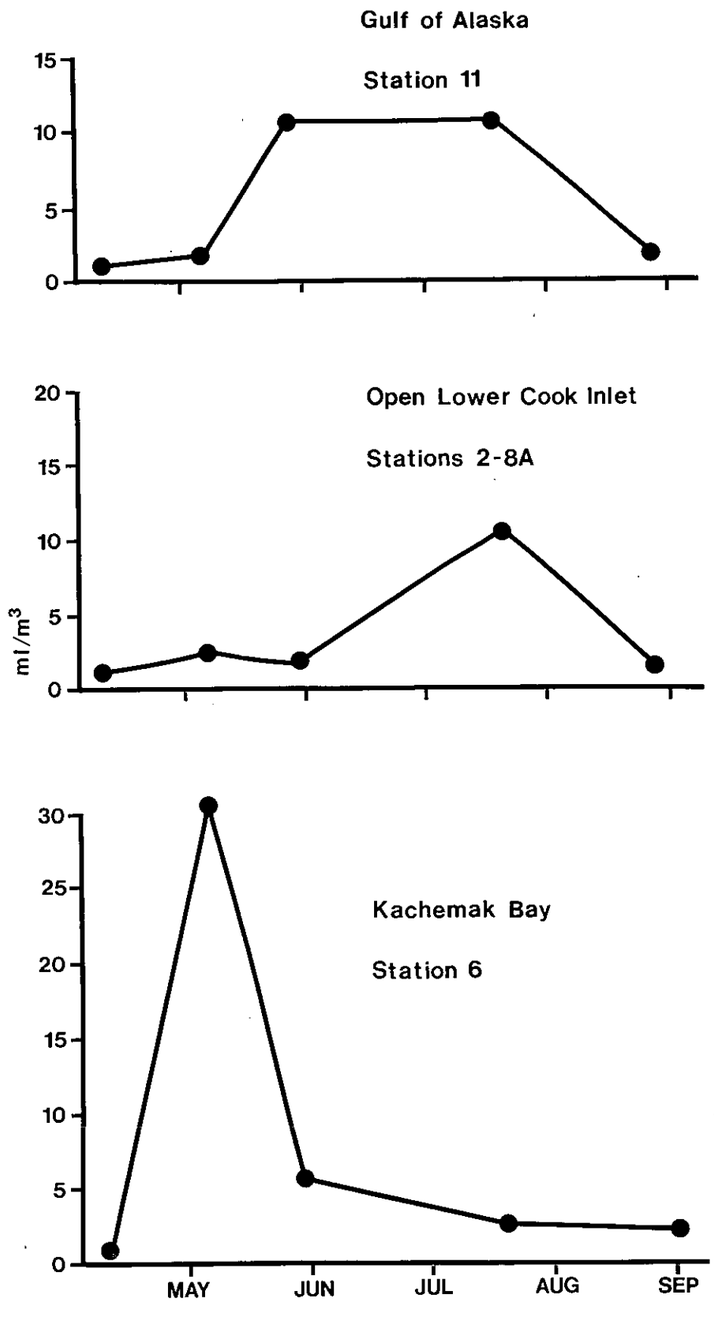


Figure E.10.1b Settled volumes of zooplankton, mean of all samples, upper 25 m, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977).

Figure E.10.1c Zooplankton species and major groups, Kachemak Bay, Alaska, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977).

COPEPODA CALANOIDA

- Calanidae
  - *Calanus cristatus*
  - *C. glacialis*
  - *C. marshallae*
- Eucalanidae
  - *Eucalanus* juveniles
- Pseudocalanidae
  - *Microcalanus* sp.
  - *Pseudocalanus* sp.
- Aetideidae
  - *Aetideus* sp.
- Metridiidae
  - *Metridia lucens*
- Centropagidae
  - *Centropages abdominalis*
- Acartiidae
  - *Acartia clausii*
  - *A. longiremis*
  - *A. tumida*
- Tortanidae
  - *Tortanus discaudatus*

COPEPODA CYCLOPOIDA

- Oithonidae
  - *Oithona similis*
- Cyclopinidae
  - *Cyclopina* sp.
- Oncaeidae
  - *Oncaea borealis*

COPEPODA HARPACTICOIDA

- Tegastidae
  - *Tegastes* sp.
- Tisbidae
  - *Tisbe gracilis*

COPEPODA MONSTRILLOIDA

CHAETOGNATHA

- *Sagitta elegans*

ECHINODERMATA

POLYCHAETA

MEDUSAE

GASTROPODA

CLADOCERA

- Polyphemidae
  - *Podon leuckarti*

EUPHAUSIACEA

- Thysanopodidae
  - *Thysanoessa longipes*
  - *T. raschii*

DECAPODA

LARVACEA

- Oikopleuridae
  - *Oikopleura* sp.

Larval fish and fish eggs

CIRRIPEDIA

ANOMURA

BRACHYURA

ISOPODA

AMPHIPODA

MYSIDACEA

CUMACEA

Figure E.10.1d Densities of zooplankton, Kachemak Bay, Alaska, April through August 1976 (Damkaer, RU #425a, Annual Report, 1977).

	Density (no/m^3)				
	I	II	III	IV	V
	6-13 Apr	5-9 May	24-30 May	8-15 July	24-31 Aug
COPEPODA					
Pseudocalanus spp.	55.2	61.1	113.3	435.3	386.2
Arcartia longiremis	38.2	109.4	13.4	374.0	731.7
Oithona similis	27.4	48.1	54.3	194.9	508.1
CHAETOGNATHA					
Sagitta elegans	3.7	2.8	3.3	47.2	101.6
CIRRIPEDIA					
Nauplii	372.6	0	0	118.8	650.4
Cyprids	0	2.8	0	9.8	20.3
Crab Larvae (Zoeae)	0.1	2.6	3.3	2.4	0
AMPHIPODA	0	0.1	0.02	0.1	0
EUPHAUSIACEA	1.7	1.9	4.0	25.4	0.6
Larval Fish	0	0.5	0.04	0.02	0.8
Fish Eggs	0	0.7	0	0.03	0

Figure E.10.1e Comparison of day and night estimates of zooplankton abundance from the upper 25 m of the water column in Kachemak Bay (Station 6) and other Lower Cook Inlet stations (Stations 2 through 8A) (Damkaer, RU#425a, Annual Report, 1977).

Sample	Settled Volume (ml/m^3)			
	Open Lower Cook Inlet		Kachemak Bay	
Cruise I (early April)	Day	0.6	Day	0.1
	Night	0.4	Night	0.4
Cruise II (early May)	Day	0.3	Day	31.0
	Night	4.7	Night	-
Cruise III (late May)	Day	0.6	Day	3.6
	Night	3.1	Night	7.6
Cruise IV (early July)	Day	5.5	Day	1.5
	Night	15.3	Night	3.6
Cruise V (late August)	Day	1.5	Day	1.3
	Night	1.1	Night	2.6

E.10.2 MEROPLANKTON

Fairly extensive surveys of meroplankton populations have been made in Lower Cook Inlet by sampling the same stations as were sampled for zooplankton. The early larval stages of commercially important invertebrates were most abundant from February to July, while the later stages were most abundant from July through August (English, RU #424, Annual Report, 1978). The periods of abundance varied with species (Fig. E.10.2a). Older larval stages were usually found in the same area as younger stages (Fig. E.10.2b). Of the larval shrimp, the humpback was the most abundant followed by northern pink and Pandalopsis montagui tridene. Of the non-commercial crabs, Anomura spp. and Brachyura spp. were present in large numbers, and the small hairy cancer crab, Cancer oregonensis, was the most abundant species. Red king crab was the most abundant commercial crab, followed by Tanner crab. These species were abundant in Kachemak and Kamishak Bays. Fewest specimens were collected in the most northern sampling locations, in the center of Lower Cook Inlet on a line between Kachemak and Kamishak Bays, and near the mouth of the Inlet.

Within Kachemak Bay, Tanner crab larvae were most abundant from late May through mid-June (ADF&G, 1976a). The greatest number of this species was found in an area extending due east to Homer Spit from a point due south of Anchor Point. The inner portion of the bay does not appear to be a major nursery area.

During 1972, in Kachemak Bay, the temporal and spatial distributions of king crab, pandalid shrimp and brachyuran zoeae were similar (Haynes and Wing, 1977). In outer Kachemak Bay these species were abundant during the first sampling period in April and became more abundant into mid- or late summer. During the latter half of June, king crab and pandalid shrimp zoeae were most abundant in the northwestern quarter of the outer bay. Populations were relatively low in inner Kachemak Bay, Sadie Cove, and Tutka Bay. Brachyuran zoeae at this time were uniformly distributed in the outer bay, with peak concentrations found at about 20 m (Fig. E.10.2c).

During 1976, data were collected on the distributions of larval king crab, pink shrimp, and humpy shrimp in Kachemak Bay (Haynes, 1977). The temporal and spatial distributions of these species were similar. Early in the season, larval abundance was greatest in the central and southern portions of the bay. Later they became more common in the southwest near Point Pogibshi; king crab larvae became more common near Anchor Point.

Figure E.10.2a Larval stages of commercially important invertebrates and periods when they are present in Cook Inlet (English, RU #424, Annual Report, 1978).

SPECIES	MONTH LARVAE PRESENT	LIFE STAGES PRESENT	PERIOD OF GREATEST ABUNDANCE
Pandalopsis dispar sidestripe shrimp	Apr, May, Jul, Aug, Feb,	I,II,III,IV	Feb(I), May(II) Jul(III), Aug(IV)
Pandalus borealis northern pink shrimp	Apr-Aug	I,II,III,IV,V, juveniles	May(I-III), Jul(IV,V), Aug(juveniles)
Pandalus danae	Jul, Aug	II, V	Jul
Pandalus goniurus humpback shrimp	Apr-Jul	I,II,III,IV, juveniles	May(I-IV), Jul(juvenile)
Pandalus hypsinotus coonstripe shrimp	May	I	May
Pandalus platyceros	Feb	II	Feb
Pandalus stenolepis	May-Aug	I,II,III,IV,V,VI	May(I), Jul(II-VI)
Pandalus montagui tridens	Apr-Jul	I,II,III	May
Anomuran crabs	Apr-Oct, Feb	zoea, megalopa	May-Aug
Brachyura crabs	May-Aug, Feb	zoea, megalopa	May-Jul
Cancer magister Dungeness crab	Jul-Oct	I,II,V, megalopa	Jul
Cancer oregonensis hairy cancer crab	Apr, Jul, Aug Oct, Feb	I,II,III,IV,V, megalopa	Jul(I-III) Aug(IV,V, megalopa)
Cancer productus rock crab	May	I	May
Chionoecetes bairdi Tanner crab	May, Jul	I,II	May(I), Jul(II)
Chionoecetes sp.	Apr, May, Aug	megalopa	Aug
Paralithodes camtschatica, red king crab	Apr, May, Feb	I,II,III	May
Paralithodes platypus blue king crab	Jul	megalopa	Jul

Figure E.10.2b Stations of greatest abundance for larval invertebrate stages in Lower Cook Inlet.

Species	Life Stage	Sampling Dates: 6-13 Apr	6-9 May	22-30 May	8-15 Jul	24-31 Aug	17-29 Oct	21-26 Feb
P. borealis	I		7,5,6,1,9	5				
	II		5,6,1,9	5,6,1				
	III			5,1,10	10			
	IV			5	3,7,9,10			
	V							
	VI							
	VII							
	Juv				1			
P. goniurus	I		5,6,7,8,9	3,7,5,6				
	II		5,8	5,6,7,8				
	III			5,6,7				
	IV			7				
	V							
	VI							
	VII							
	Juv			6				
P. stenolepis	I		1,9	1	9			
	II				1			
	III				1			
	IV				1			
	V							
	VI							
	Juv							
P. montagui t.	I		1,9	9,10				
	II			9,10				
	III			9				
	IV							
	Juv							
C. oregonensis	I				1,2,3,5, 6,7,9	2,5		6
	II				1,2,3,5, 6,8,9,10	2,3,4,5		
	III				1,2,3,9,10	1,2,3,4,5, 6,7,8,9		
	IV				1	1,2,3,4,5, 6,7,8,9		
	V					1,2,3,4,5, 6,7,8,9,10		
	I					1,2,5,6,9	2,5	
C. bairdi	I		5	1,2,3,5, 6,7,8,10	1			
	II				1,10			
C. sp.	Meg		2	1,10		1,2,9		
Brachyura	Zoea		1,2,3,5, 6,7,8,9	1,2,3,4,5, 6,7,8,10	1,2,3,5,6, 7,8,9,10	1,2,3,4,5, 6,7,8,9		6
	Meg				1,2,3,5, 7,9,10	1,2,3,5,8		
Anomura	Zoea	6,8	1,2,5,6. 7,8,9	1,2,3,5, 6,7,8,10	1,2,3,5, 6,7,8,9	1,2,5, 6,8,9	2,5	3,6
	Meg				2,6,9	1,2,4,7,8	5	

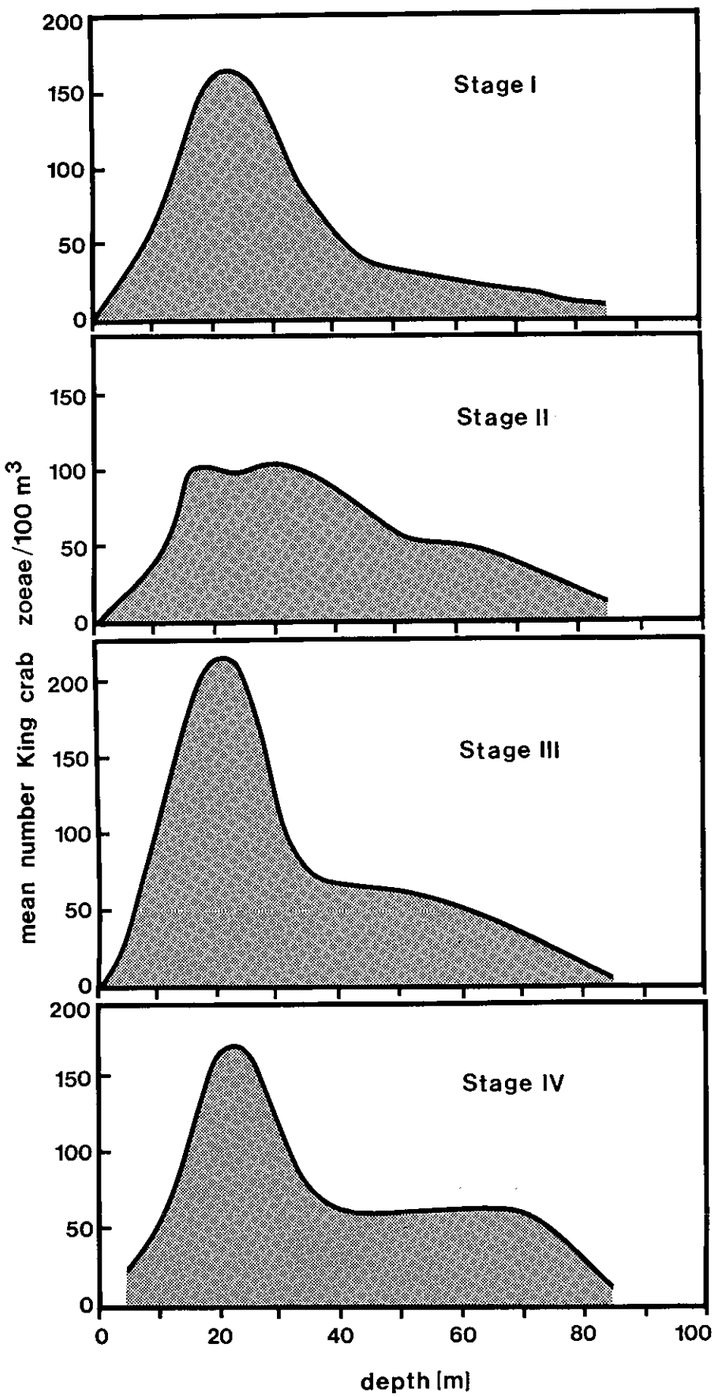


Figure E.10.2c Average depth distribution of king crab zoeae, Kachemak Bay, April through June 1972 (Haynes and Wing, 1977).

King crab larvae settled over wider areas of the central and northern sectors of outer Kachemak Bay than did pink shrimp or humpy shrimp larvae. King crab glaucothoe were distributed in the mouth of Kachemak Bay from Anchor Point to Point Pogibshi and southwestward into Lower Cook Inlet waters. Late stage pink and humpy shrimp larvae were found only in the southern portion of Kachemak Bay. The king crab glaucothoe and juveniles in the area between Anchor Point and Bluff Point indicate its importance as a settling area for king crab.

Major nursery areas for post-larval king crab were located along the shallow (<27 m) rocky perimeter of Kachemak Bay (Sundberg and Clausen, 1977). Post-larval crabs were usually not found on fine substrates. The area from Diamond Gulch to Mutnaia Gulch had high populations of these crabs (Fig. E.10.2d). Post-larval crab distributions appeared to depend on the type and density of epifaunal cover, which provides food and shelter. Areas that had a heavy epifaunal cover of the bryozoans Flustrella and Dendrobeania sp. seemed to have the greatest number of crabs.

DATA EVALUATION

Current evidence documents well the importance of Kachemak Bay to the overall productivity of Lower Cook Inlet. An extensive literature exists for the commercially important invertebrates in Kachemak Bay but not for other areas of Lower Cook Inlet. Additional data are necessary to identify spawning seasons and areas more clearly as well as to identify the factors which control them.

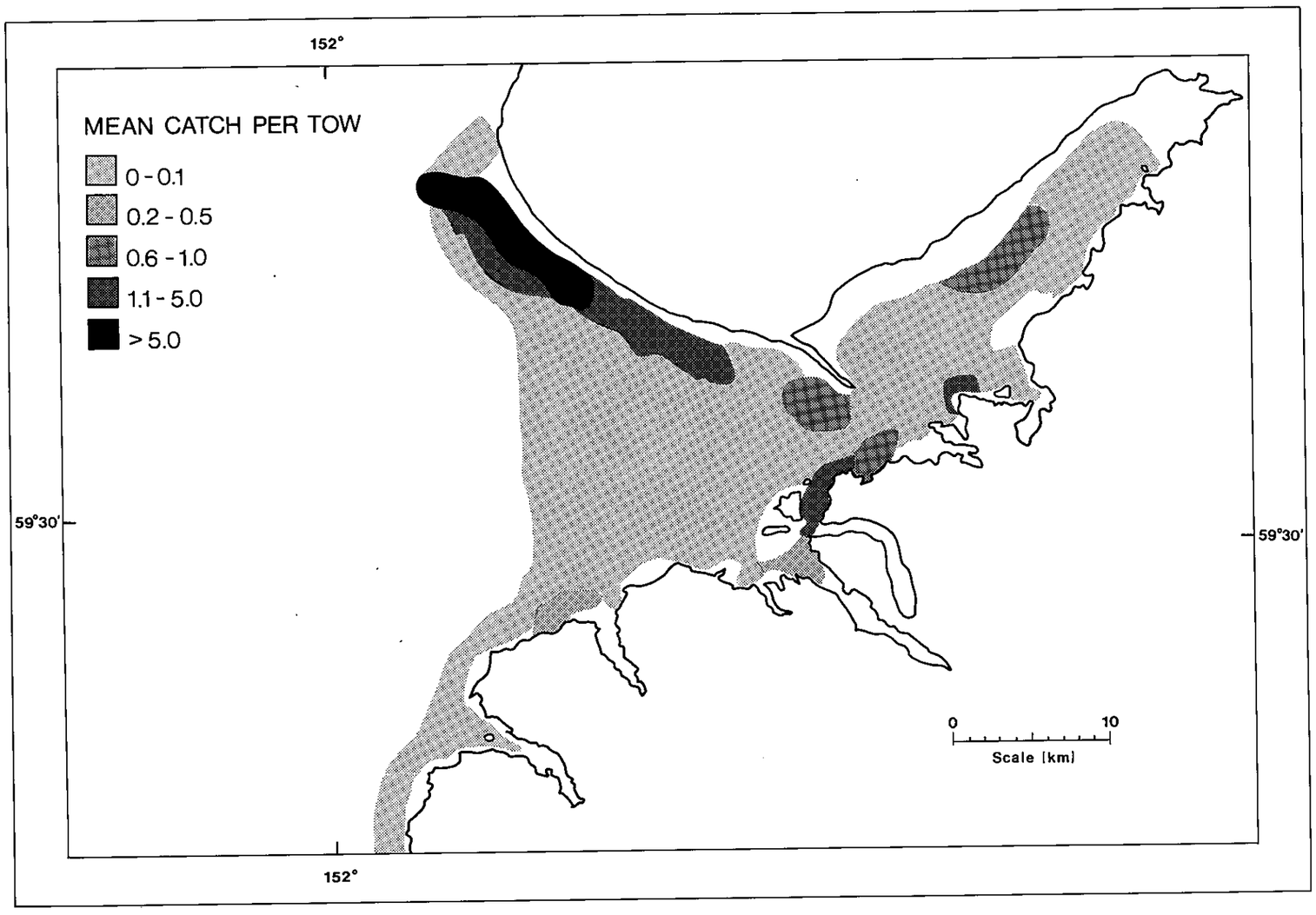


Figure E.10.2d Mean catch of postlarval king crab per tow from bottom skimmer samples (Sundberg and Clausen, 1977).

SUBTASK E.11 Seasonal Indices of Phytoplankton Production

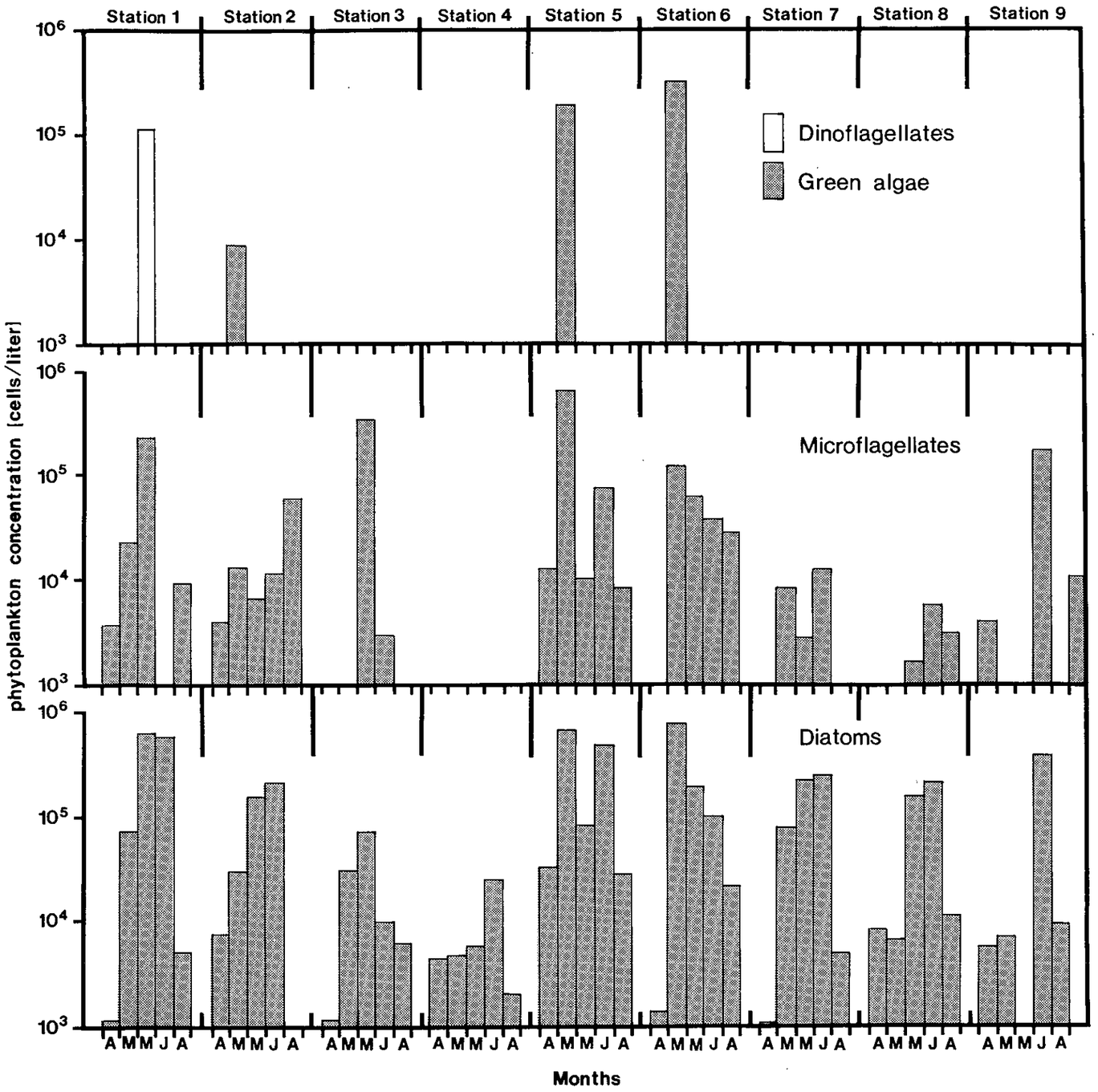
E.11.1 PHYTOPLANKTON PRODUCTION INDICES

The stations sampled for phytoplankton during spring and summer 1976 are shown in Fig. E.10.1a (Larrance et al., RU #425b, Final Report, 1977). Microflagellates and diatoms dominated the phytoplankton populations; green algae and dinoflagellates were present for only short periods (Fig. E.11.1a). Microflagellates were usually found in the southernmost parts of the Inlet, and a small centric diatom, Melosira sulcata, was usually found in the upper parts of Lower Cook Inlet. Chaetoceros spp. and Thalassiosira spp. were the dominant phytoplankton in the central portions of the Inlet and in Kachemak and Kamishak Bays.

The phytoplankton distributions are highly correlated with the hydrographic and chemical characteristics of the Inlet. Thomas and Simmons (1960) showed in the Mississippi delta area that Melosira sp. is characteristic of coastal waters of low salinity and high turbidity. Chaetoceros sp. and Thalassiosira sp. usually are found in the mixing zone between river and marine offshore waters.

Chlorophyll a and primary production were typical correlated with the levels of nitrates and incident radiation (Fig. E.11.1b). As chlorophyll a and primary production increased in the spring (peaking in late May), nutrient levels decreased. As chlorophyll a and production values reached a minimum in late August, nutrient levels began to increase again.

The highest primary production was measured in Kachemak Bay, with a peak of 4.9 g C/m^2/day in May. This value was two orders of magnitude greater than at other stations in Lower Cook Inlet. The periods of



phytoplankton blooms and nitrate depletion were different for Kachemak Bay, mid-channel Lower Cook Inlet, and Kamishak Bay. These differences probably resulted from variations in stratification, circulation, and turbidity.

During the winter there is insufficient light to support much phytoplankton growth. By early April, when light levels increase, the area becomes ice-free and nutrient concentrations are high; conditions are then conducive to phytoplankton blooms. Larrance et al. (RU #425b, Final Report, 1977) found that the onset of blooms in the bays of Lower Cook Inlet usually coincided with the formation of a thermocline or pycnocline caused either by freshwater runoff or by heating of the surface.

In mid-channel, nitrate reduction during mid-May phytoplankton blooms is not as dramatic as it is in Kachemak Bay (Larrance et al., RU #425b, Final Report, 1977). The nitrate levels are apparently sustained by the continuous flow of oceanic waters into the Inlet. In contrast, nitrate levels fall during phytoplankton blooms in Kachemak Bay, indicating that water in the Bay stays there longer than it does in mid-channel.

DATA EVALUATION

Current data came from only one spring and summer's field work. The pattern of nutrient reduction during phytoplankton blooms is typical of that found in most locations where such measurements have been made. No information is available on annual fluctuations of nutrient availability nor on phytoplankton production.

Figure E.11.1a Abundance of major groups of phyto - plankton for nine stations, 1976 (Larrance et al., RU #425b, Final Report, 1977).

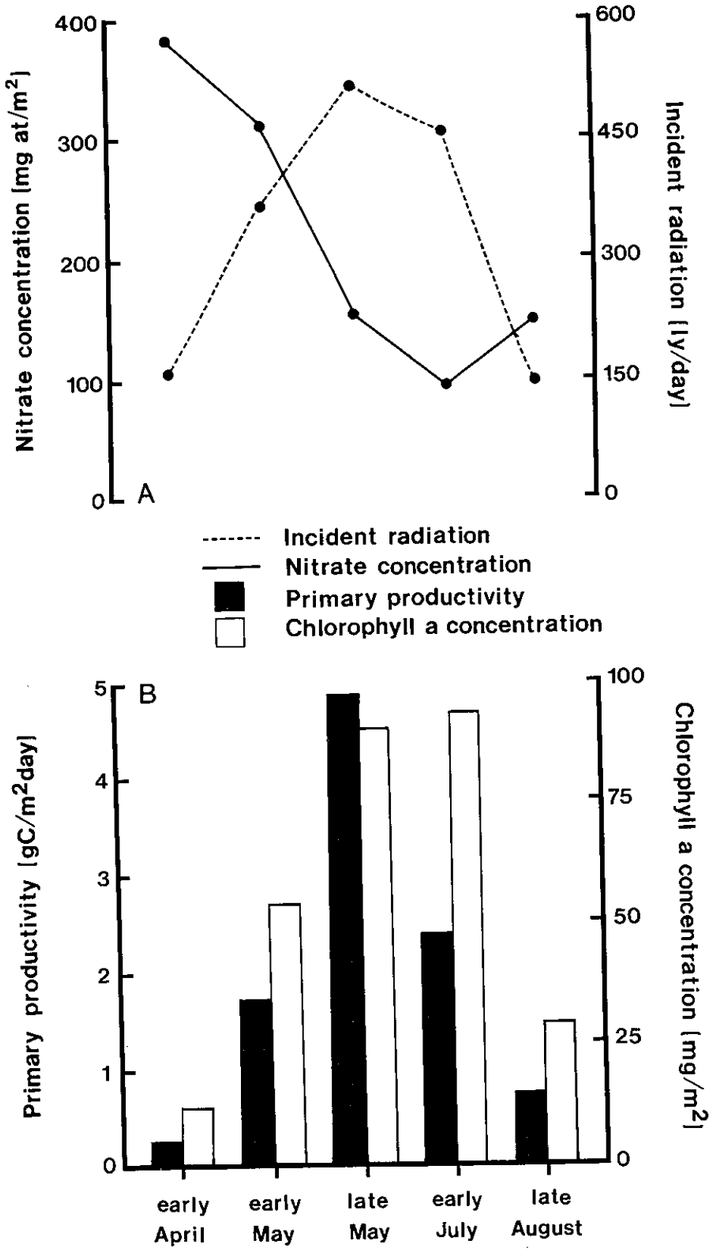


Figure E.11.1b Comparison of nitrate and incident radiation levels (A) with Chlorophyll a concentrations and primary productivity (B) in Lower Cook Inlet. Values are averages for nine stations (Larrance et al., RU #425b, Final Report, 1977).

SUBTASK E.12 Non-population Dependent Physiological and Population Parameters of Plankton Communities

No data for subtask E.12 are available for Lower Cook Inlet.

SUBTASK E.13 Identification and Seasonal Nature of Critical Habitats for Egg and Larval Stages of Fish and Shellfish

E.13.1 CRITICAL HABITATS FOR FISH EGGS

English (RU #156/424, Annual Report, 1977) sampled fish eggs on seven cruises from April 1976 to February 1977, at 10 stations in Cook Inlet and the Gulf of Alaska (Fig. E.5.3b). Eggs were most abundant from May to July (Fig. 13.1a).

Eggs of all sizes were most abundant in or near Kachemak and Kamishak Bays. They were fewest in Northern Cook Inlet and an area in the middle of the Inlet. The diameter of the chorion tentatively suggests that the eggs were those of demersal species, mostly flounders and soles (Fig. E.13.1b).

English (RU #156/424, Annual Report, 1977) suggested that these distributions result from the distribution of spawning areas and currents in the Inlet. Thus, eggs are concentrated in bays where most of the spawning takes place, and also where currents are weakest.

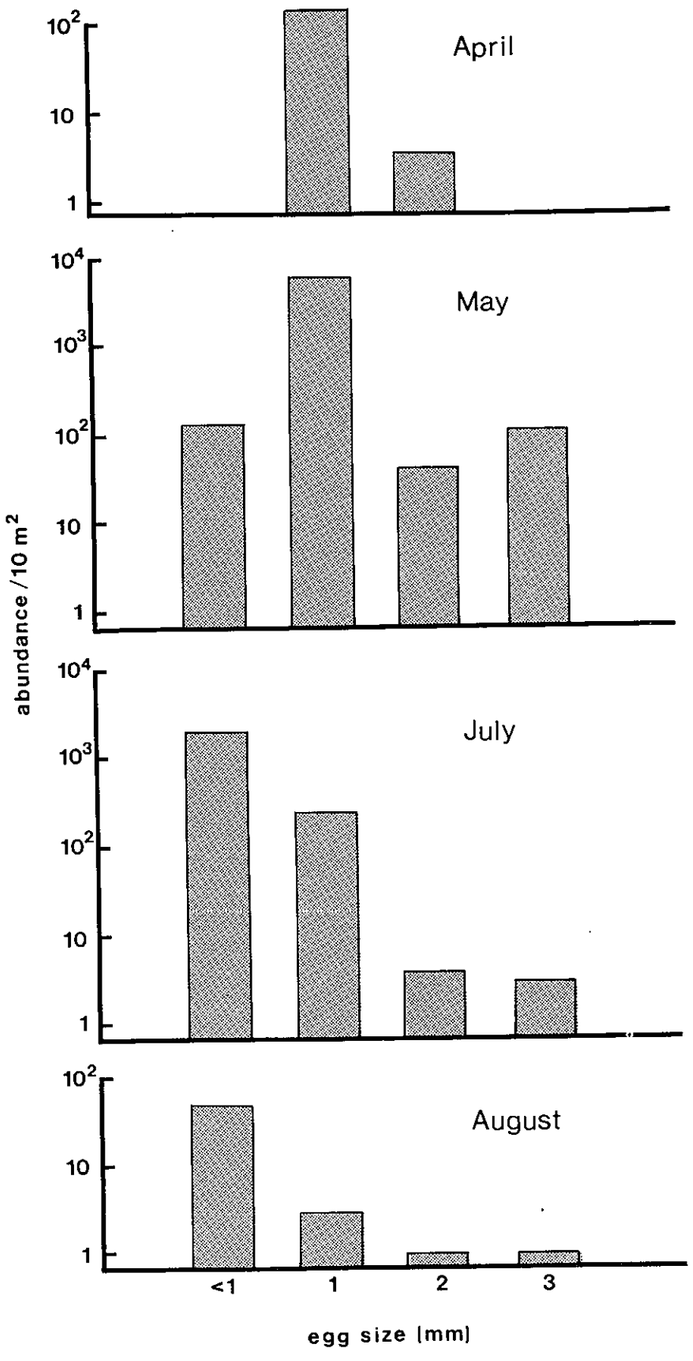


Figure E.13.1a Total monthly accumulations of fish eggs collected in Lower Cook Inlet. No data were collected during January, March, June, September, November, and December (English, RU #156/424, Quarterly Report, Apr - Jun, 1977).

Figure E.13.1b Tentative egg identifications by size in Lower Cook Inlet (English, RU #156/424, Annual Report, 1977).

Chorion Diameter	Species	Months of Peak Occurrence	Area of Peak Occurrence
<1mm (0.74 - 0.88)	Limanda aspera yellowfin sole	May - Aug	Kamishak & Kachemak Bays
<1mm (0.90 - 1.28mm)	Isopsetta isolepis butter sole Parophrys vetulus English sole Platichthys stellatus starry flounder Psettichthys melanostictus sand sole	Apr - Aug	Kamishak & Kachemak Bays
<2mm (1.3 - 2.54mm)	Theragra chalcogramma walleye pollock Atheresthes stomias arrowtooth flounder Glyptocephalus zachirus rex sole Lyopsetta exilis slender sole	Apr - Aug	various locations
<3mm (<2.56mm)	Hippoglossoides sp.	May - Aug	various locations

DATA EVALUATION

The number of sampling stations within the Inlet was small (10), but samples were taken at least once a season. Data on distribution and abundance of fish eggs are limited to those species with planktonic eggs. Additional information is required on life histories as well as on abiotic influences on egg and larval survival.

Subtask E.14 Alaskan Ichthyoplankton Key

A dichotomous key developed to identify ichthyoplankton from Alaskan waters has been prepared by English (RU #349, Annual Report, 1976).

SUBTASK E.15 Characterize Marine Microbiological Communities (Heterotrophs, Chemotrophs, and Pathogens)

E.15.1 HETEROTROPHS

Atlas (RU #30, Annual Report, 1977) reports that during October 1976 microbial populations were highest in the waters above Kalgin Island, intermediate in Kennedy Entrance and lowest in the central portions of Lower Cook Inlet. The number of organisms in offshore waters ranged from 0.5×10^5 to 11.6×10^5 cells/ml and averaged 1.85×10^5 cells/ml (Morita and Griffiths, RU #190E, Annual Report, 1977). The offshore distribution was relatively uniform, except for the high abundance (11.6×10^5 cells/ml) near the Forelands. Nearshore, however, the numerical abundance averaged 7.12×10^5 cells/ml and the spatial variability of heterotrophs was much greater. Samples collected from the nearshore waters adjacent to the Barren Islands contained a mean of 0.7×10^5 cells/ml; counts averaged 10.4×10^5 cells/ml in the Kamishak area and 2.9×10^5 cells/ml nearshore in Kachemak Bay.

Heterotroph numbers in sediment samples averaged 4.1×10^9 cells/g dry sediment and ranged from 0.4×10^9 to 13.0×10^9 cells/g dry sediment.

Atlas (RU #29, Annual Report, 1978) summarized the data collected in Lower Cook Inlet during October 1976 and April and November 1977. In both water and sediment samples, the direct microbial counts were highest in October and lowest in April. Patterns were less clear in those populations enumerated by agar plating methods. Viable bacteria enumerated in the water at $4^{\circ}C$ had the greatest numbers in October and the lowest in April. In the sediments, the greatest number was found in November and the least in October.

At 20°C, the highest numbers were measured in October in the water and April in the sediments. The lowest numbers were observed in November in both water and sediments.

Morita and Griffiths (RU #190E, Annual Report, 1977) found distinct geographical trends in the relative microbial activity levels in Cook Inlet (Fig. E.15.1a). Similar trends were observed whether glucose or glutamic acid was used as the labeled substrate. The highest activity was in the northern part of the Inlet with the lowest levels in the southern part near Kennedy Entrance. Intermediate levels were found in and near Kamishak and Kachemak Bays with the exception of increased activity near Homer. The high activity levels in the northern parts of the inlet, as well as near Homer, correlate with areas of possible petroleum contamination (see A.1.1-A.1.2). Seasonal trends were observed with the highest activity in April and reduced activities during October and November.

Few samples of microbial activity in the sediments were analyzed. The highest activity was found in the semi-enclosed bays of the Inlet with significantly lower levels in the offshore region.

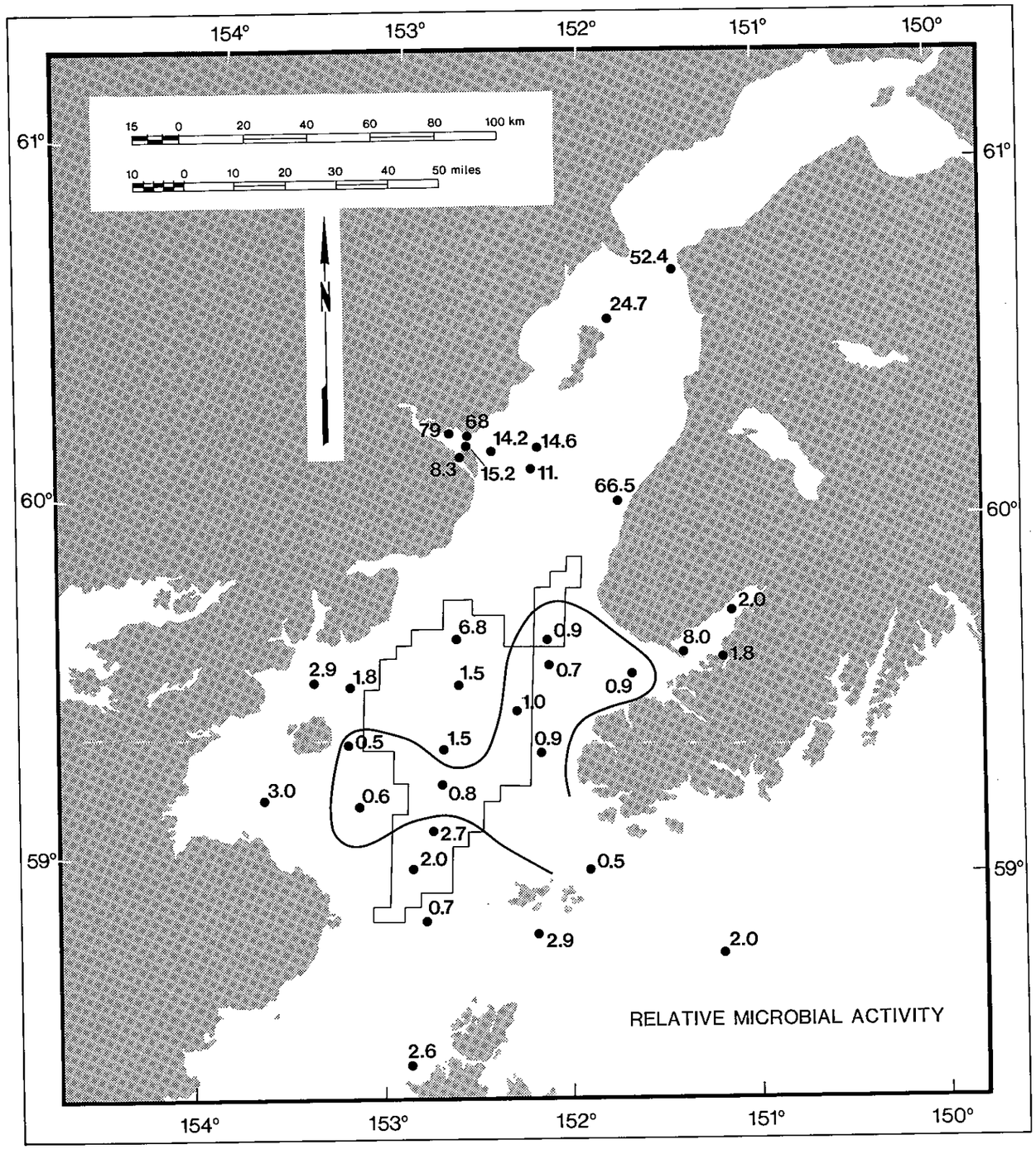


Figure E.15.1a Relative microbial activity in water samples as measured using glutamic acid during the April cruise. The units are ng/liter/h (Morita and Griffiths, RU #190/E, Annual Report, 1977).

Percent respiration of the microbial communities was determined using both glucose and glutamic acid substrates. During the months of April, October and November, the highest percent respiration was measured in the lower part of the Inlet near Kennedy Entrance (Fig. E.15.1b). The lowest values were observed in the northern part of the Inlet. Contours of increasing values run in lines extending diagonally from the northeast to the southwest.

The lower percent respiration in the upper part of the Inlet is a function of the large amounts of organic material in these waters. A higher percent respiration indicates that the micro-organisms are utilizing more of the organic substrate for energy requirements than for biosynthesis that increases cell mass. This is a pattern typical of an unbalanced growth condition that can be brought about by placing bacteria in a stress environment or in a medium with an inadequate supply of required growth factors. Morita and Griffiths (RU #190E, Annual Report, 1977) thought that the percent respiration observed reflected an absence of an adequately balanced nutritional source in the waters entering Kennedy Entrance and being transported along the eastern side of the inlet.

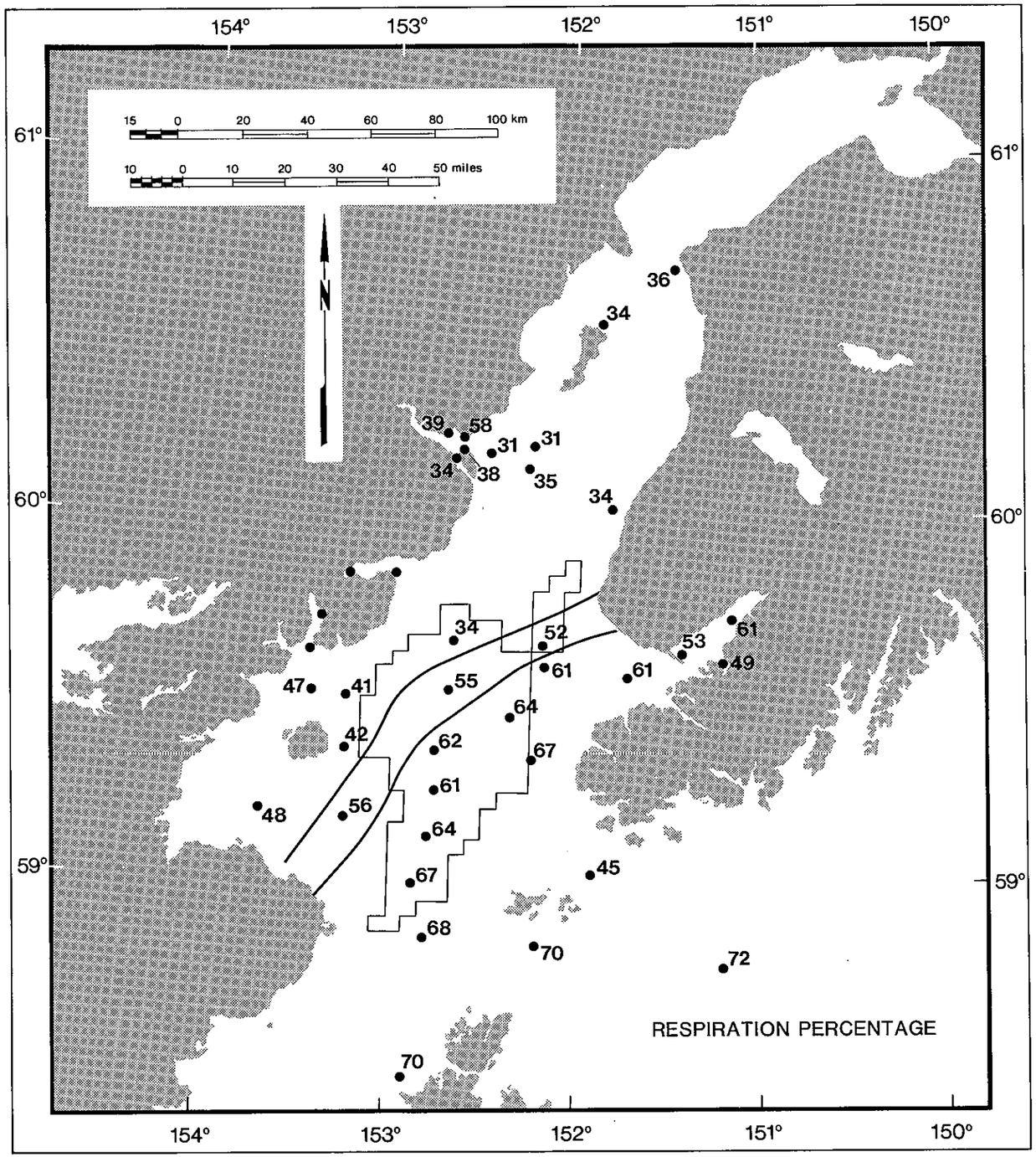


Figure E.15.1b Respiration percentage in water samples as measured using glutamic acid during the April cruise (Morita and Griffiths, RU #190/E, Annual Report, 1977).

The percent respiration measured in the sediments was typically lower than that observed in the water. In the water samples, the percent respiration was higher in the winter than in summer; whereas in the sediments, the percent respiration was relatively constant regardless of season.

The distribution patterns of the relative microbial activity and respiration appear to coincide with the distributions of water masses in the Inlet. Waters moving up through Kennedy Entrance along the eastern side of the Inlet probably contain low levels of available organic nutrients (Griffiths and Morita, RU #190, Annual Report, 1978). As a result, microbial activity is low and respiration percent high. The high levels of relative microbial activity and low respiration rates in the northern waters indicate that these waters contain nutrients qualitatively and/or quantitatively different from those found in the southern waters. The central Inlet, where these two water masses meet, has intermediate values of microbial activity and respiration. These intermediate values may be produced by two possible causes. As the northern waters move south along the western edge of the Inlet, the nutrients are being consumed by the microbes. At the same time, the low nutrient southern waters are further diluting the nutrients in the northern waters where these two water masses meet in the central inlet.

The relative levels of microbial activity also appear to coincide with the distributions of suspended sediments in the surface waters. In studies of Griffiths and Morita, 70-80 percent of the bacteria present in water samples were associated with the particulate matter. During November and April cruises in Cook Inlet, relatively high rates of microbial activity were seen in the sediments of Tuxedni Bay, Kachemak Bay and the southern portion of Kamishak Bay. The high rates of activity in Kachemak Bay probably resulted from the trapping of nutrients in the Bay by a restricted water flow as well as from a potential organic input at the Homer boat basin. The high rates in Tuxedni Bay were assumed to be due to the sedimentation of the microbiologically active suspended matter in the water column in this area. If this assumption is true, then it is likely that a similar process is occurring in Kamishak Bay and the Shelikof Straits as the northern water mass is carried out of the Inlet into the strait.

Detritus particles are an important nutrient source in the trophic structure of Cook Inlet. In order for the detritus to become available as a food source for animals from the level of protozoa on up the food chain, the detrital material must become colonized by bacteria. The bacteria then oxidize the organic detritus and convert it into products necessary for growth in the higher organisms. Fixed nitrogen is necessary for the bacteria to grow.

Fixed nitrogen rates have been too low in the water samples to be measured (Griffiths and Morita, RU #190, Annual Report, 1978). However, rates measured in the sediments have shown that the highest values were obtained in Kachemak Bay (Fig. E.15.1c). Levels here have been about 1 ng nitrogen fixed/g dry wt/hr. This level of nitrogen fixation could account for a yearly bacterial biomass production of 400 tons in Kachemak Bay.

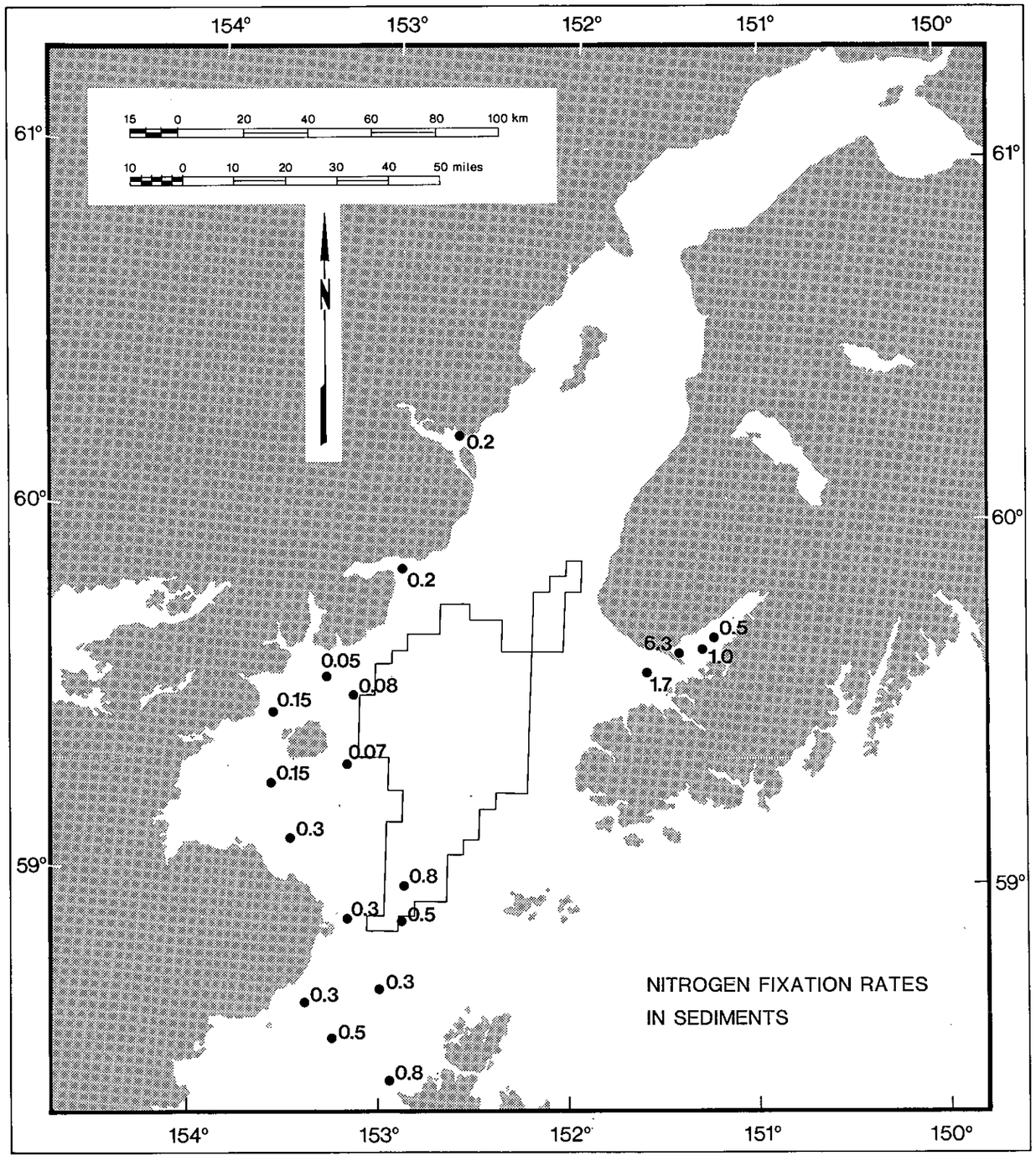


Figure E.15.1c Nitrogen fixation rates in sediment samples collected during the November cruise. The unit of measurement is ng nitrogen fixed/g dry wt./h (Griffiths and Morita, RU #190, Annual Report, 1978).

E.15.2 HYDROCARBON DEGRADERS

Atlas (RU #29, Annual Report, 1978) has calculated the number of viable hydrocarbon degrading microbes in the water and sediments of Cook Inlet (Fig. E.15.2a). Hydrocarbon utilizing bacteria are lower in the Inlet than in other Alaskan waters and are more typical of mid-ocean, non-continental shelf areas. In the Inlet there are no significant differences in the numbers of hydrocarbon utilizing microbes in the summer-fall and winter-spring samples. However, numbers are significantly higher in the sediments than in the water column. High numbers of hydrocarbon utilizers were observed near Kalgin Island and outside the entrance to the Inlet. Numbers also increase in the eastern part of the Inlet towards Kachemak Bay. The distributions of the hydrocarbon utilizers were consistent with hydrocarbon distributions in the sediments (see A.1).

No correlation was recognized between the number of hydrocarbon degraders and degradation rates. The natural hydrocarbon biodegration potentials were higher in April than in November for water samples but sediment samples from the two months gave similar results. Non-nutrient limited samples gave much higher potentials in April than November for all substrates. The highest biodegradation potentials were observed in Kachemak Bay and near Upper Cook Inlet, in agreement with the distribution of the hydrocarbon degraders.

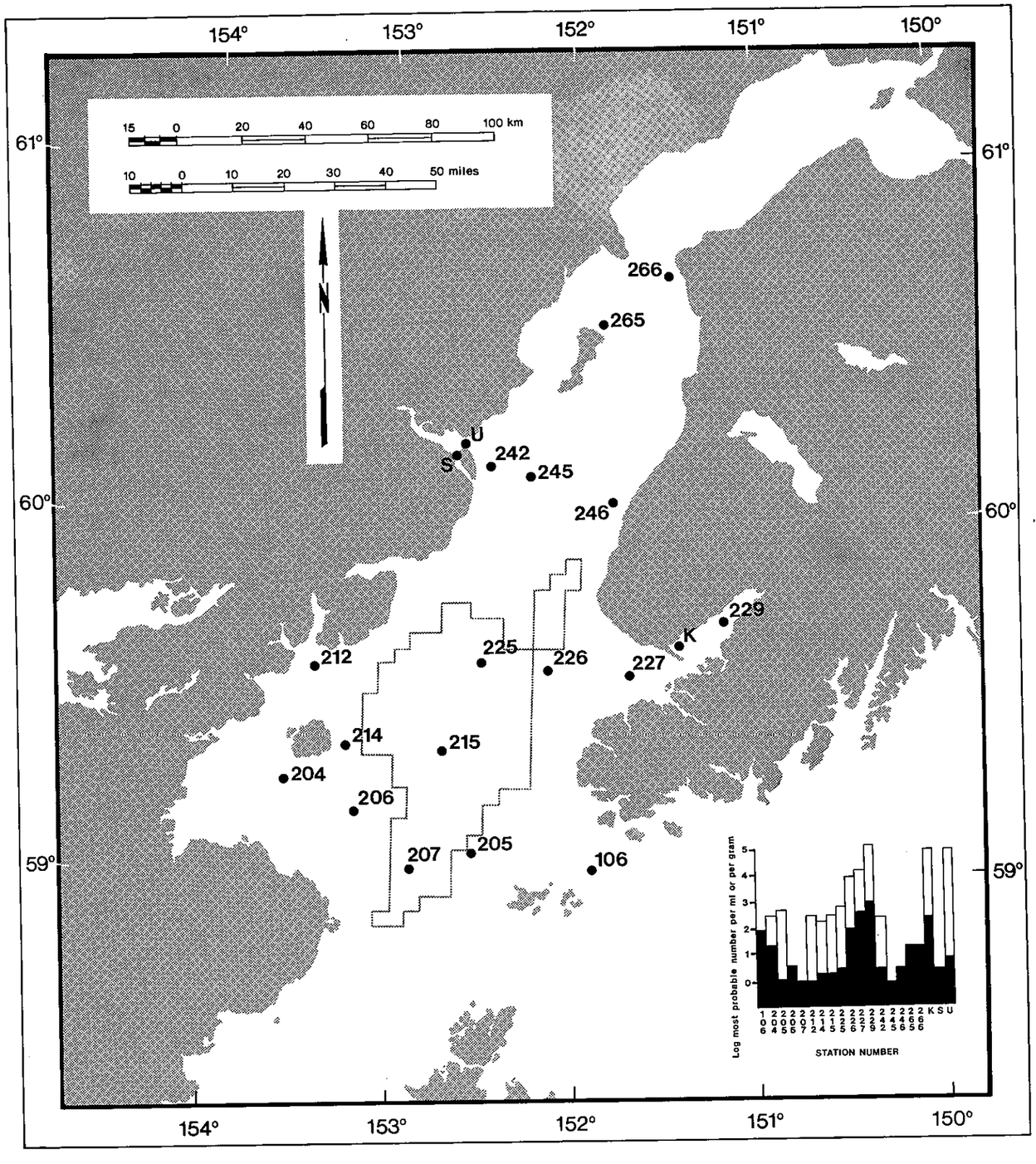


Figure E.15.2a Most probable numbers of hydrocarbon utilizers in Cook Inlet, April 1977 samples. Solid bars = water, open bars = sediment (Atlas, RU #29, Annual Report, 1978).

The natural hydrocarbon biodegradation potentials (no nutrients added) followed the order: naphthalene ≥ hexadecane > pristane ≥ benzanthracene in both water and sediment samples. The non-nutrient limited biodegradation potentials followed the order: hexadecane > naphthalene >>> pristane > benzanthracene. The compounds are representative of the four major classes of hydrocarbons found in petroleum: straight chain paraffins, branched paraffins, simple aromatics and polynuclear aromatics. Branching and multiple condensed aromatic rings appeared to reduce biodegradability. The removal of nutrient limitations resulted in higher biodegradation potentials for hexadecane and naphthalene but not for pristane and benzanthracene. This may mean that these latter compounds are resistant to mineralization by the available enzymatic systems. The higher biodegradation potentials in April may indicate that some additional growth factor was needed that was missing in November. This suggests that the fate of spilled oil in the Inlet will be highly dependent on the time of year at which the spill occurs.

The biodegradation rates that would occur in the Inlet probably lie somewhere between the natural and non-nutrient limited biodegradation potentials. In areas of Cook Inlet where there is a high mixing energy, the real degradation rates should approach the non-nutrient limited biodegradation potential rates.

Button et al. (1970) reported hydrocarbon oxidizing organisms to be on the order of 10^3/l throughout the upper Inlet. This number represented about 10% of the total population. Numbers were somewhat less in Lower Cook Inlet. These organisms were found to be present during both winter and summer suggesting a continuing process of hydrocarbon biodegradation. Laboratory simulations of oil slicks suggested that microbial biodegradation may be more important in removing hydrocarbon contaminants than physical flushing of the Inlet (Kinney et al., 1970). They found that biodegradation proceeds first in the microenvironments of the water in oil emulsion, later in the oil drops, and is probably complete within one to two months. Mixing proved to be an extensive aid to this process but the presence of suspended sediments had little effect.

Griffiths and Morita (RU #190, Annual Report, 1978) conducted biodegradation potential studies for Cook Inlet sediments. Results obtained in April 1977 showed the highest rates of degradation in samples collected in Tuxedni and Kachemak Bays (Fig. E.15.2b). Highest rates observed in November 1977 were near Homer and on the western side of the Inlet just north and south of Kamishak Bay. The biodegradation potential was higher in the November samples.

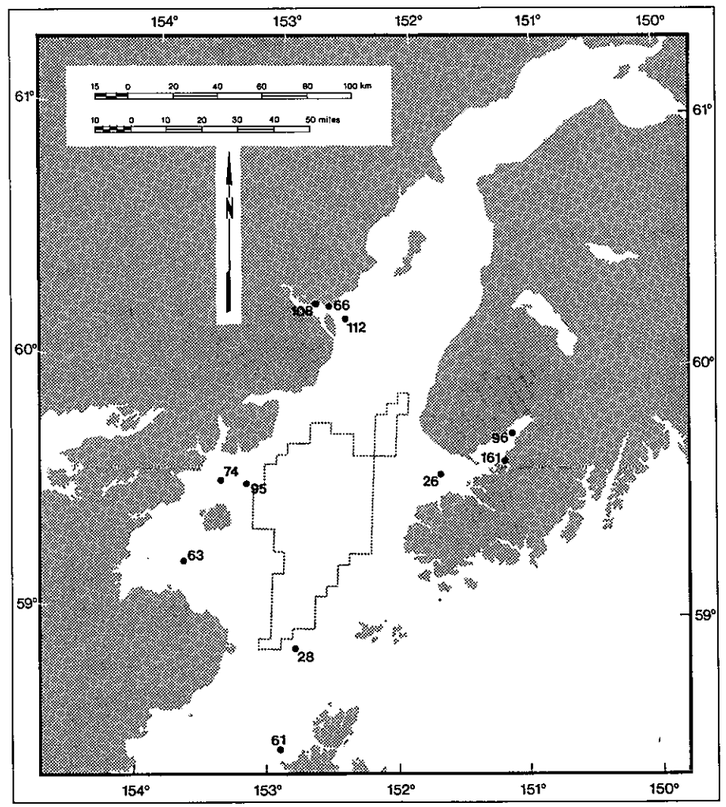


Figure E.15.2b Crude oil degradation potential measurements in sediments collected during the April cruise. Units are DMP/g dry wt. (Griffiths and Morita, RU #190, Annual Report, 1978).

E.15.3 PATHOGENS

Measurements for the presence of Desulfovibrio sp. bacteria in the sediments of Cook Inlet were made during April 1977 (Griffiths and Monita, RU #190, Annual Report, 1978). These organisms are important because they can greatly accelerate metal corrosion of proposed drilling platforms. The highest levels were observed in Kachemak Bay near Homer and in Tuxedni Bay (Fig. E.15.3a). Numbers were relatively low throughout the rest of the Inlet.

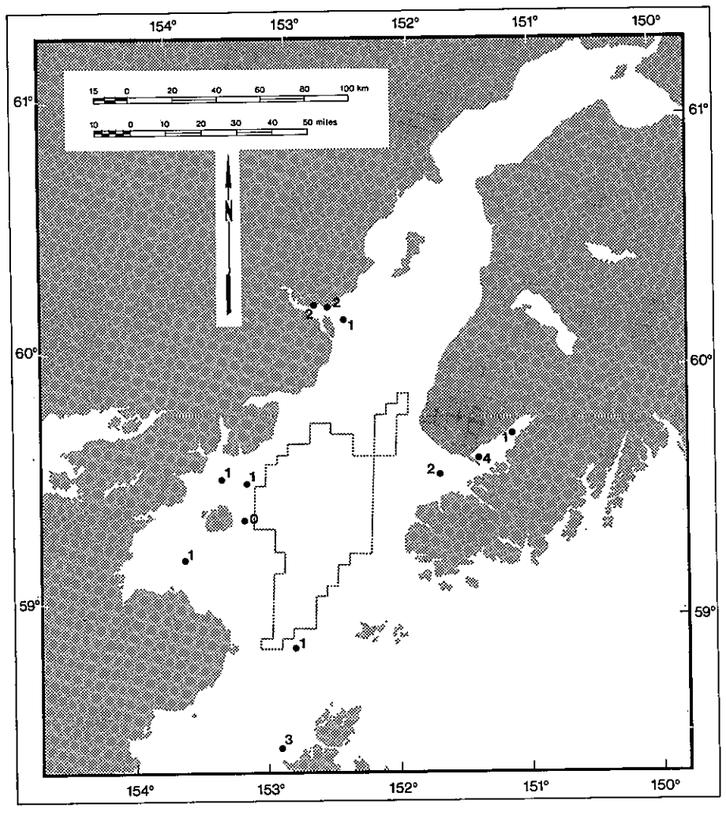


Figure E.15.3a Relative concentrations of Desulfovibrio sp. in sediments analyzed during April (Griffiths and Morita, RU #190, Annual Report, 1978).

DATA EVALUATION

The distributions of the heterotrophic and hydrocarbon degrading bacteria have been fairly well characterized within the open waters of Cook Inlet. However, seasonal data are restricted to spring and late fall sampling and data in the nearshore and intertidal regions, where the greatest effects of a spill would probably be observed, is lacking. The distributions of the pathogenic bacteria have been less closely studied. Additional sampling may be required to further characterize nitrogen fixation rates within the Inlet.

SUBTASK E.16 Behavior and Response to Stress of Heterotrophic Microorganisms, Pathogens, and Chemotrophs

E.16.1 RESPONSE TO STRESS

Bacterial isolates from water and sediment samples collected north of Augustine Island were tested for physiological tolerance to variations in temperature, NaCl concentration, and pH (Atlas, RU #30, Annual Report, 1977). Compared to water populations, sediment populations had a lower maximum upper temperature for growth, a narrower salt tolerance range, and a similar pH tolerance range (Fig. E.16.1a).

No significant differences (Mann-Whitney U-test) were found in the microbial species diversity between November and April in the water or sediments (Fig. E.16.1b; Atlas, RU #29, Annual Report, 1978). The overall high diversities indices were interpreted by Atlas to indicate that the area is not now under severe natural or man-made stress. The lowest diversities in the surface waters, at least during April, were observed outside the entrances of Cook Inlet and in the center portions of the Inlet. The center area is an area of low current exchange.

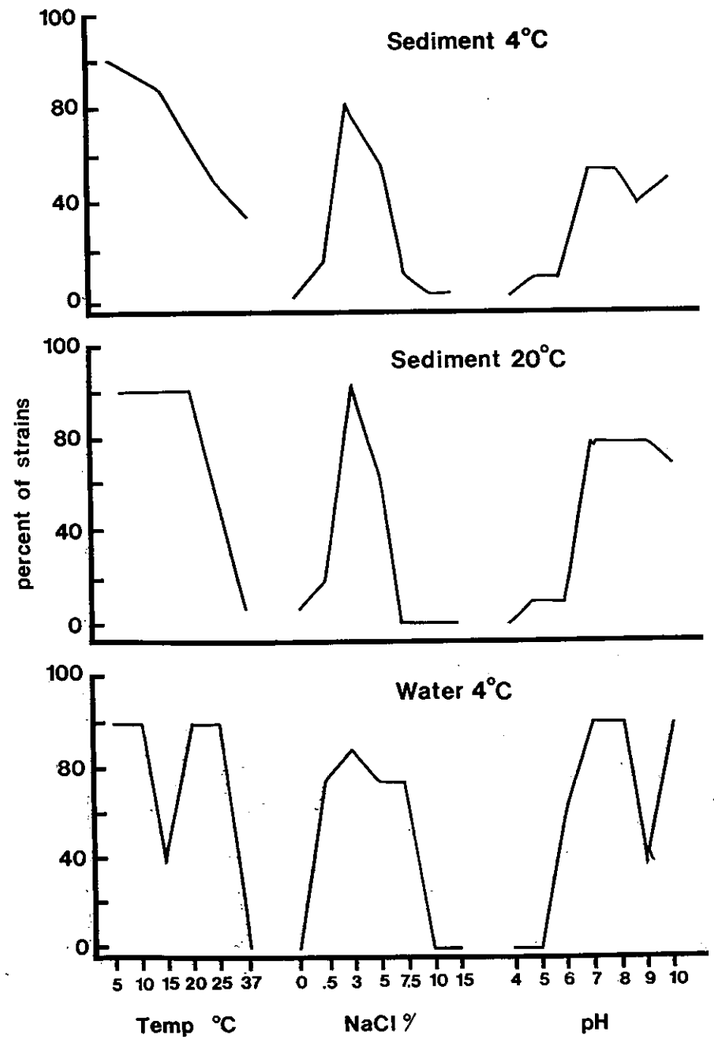


Figure E.16.1a Physiological tolerance ranges for water and sediment isolates, summer 1975 (Atlas, RU #30, Annual Report, 1978).

Figure E.16.1b Diversity indices ($\bar{H}$) for heterotrophic bacterial populations isolated at 4°C from Cook Inlet (Atlas, RU #30, Annual Report, 1978).

Station No.	November	April
	Water	
105	4.22	2.26
204	2.74	4.02
205	-	3.17
212	-	4.22
215	3.31	2.75
225	0.72	2.92
226	-	3.56
229	1.39	3.78
245	2.94	3.62
265	4.01	3.89
266	4.08	3.24
395	-	2.50
K	0.30	-
L	2.78	-
M	2.56	-
U	-	3.49
Average	2.64	3.34
	Sediment	
105	2.85	-
204	3.72	-
205	-	3.69
212	-	3.32
215	3.72	3.92
225	3.78	3.38
226	-	3.49
229	3.40	3.34
L	1.39	-
M	3.88	-
U	-	4.12
Average	3.25	3.61

Organisms closely similar in their ability to utilize hydrocarbons were isolated in the Gulf of Alaska, Cook Inlet, and the Beaufort Sea. The majority of the bacterial strains isolated were able to grow on media with petroleum hydrocarbons added (Fig. E.16.1c). Additionally a greater percentage of the strains were better able to utilize mixtures of rather than pure hydrocarbons, e.g., a crude oil.

Griffiths and Morita (RU #190, Annual Report, 1978) measured the responses to oil exposure of Cook Inlet sediment bacteria, collected in November 1977. An average 33 percent reduction in the number of colonies was observed on agar plates treated with crude oil. Studies of the effect of crude oil on the nitrogen fixation rates of bacteria from sediment samples were inconclusive.

The rate of glucose uptake and oxidation of sediment bacteria exposed to crude oil was reduced by an average of 41 percent. Griffiths and Morita (RU #190, Annual Report, 1978) and Atlas et al. (1976) collected data in the Beaufort Sea which show that the inhibitory effect of oil on bacteria decreases with long exposures. These observations suggest that initial exposure to oil depresses or kills oil-resistive bacterial populations, while long-term exposure promotes the growth of populations able to use hydrocarbons.

DATA EVALUATION

Data on Cook Inlet population are few and some of the conclusions are based on data gathered in the Beaufort Sea. The effects of oil on these populations require further study.

Figure E.16.1c Percent of strains in clusters scored positive for ability to utilize any hydrocarbon or hydrocarbon mixture.

From Enumeration Plates		From MPN Enrichments	
*Cluster No.	Percent Positive for hydrocarbon utilization	*Cluster No.	Percent Positive for hydrocarbon utilization
1	23	2	14
6	7	4	100
9	20	6	100
20	78	8	80
31	70	9	90
32	17	10	100
34	85	12	100
36	100	20	100
38	20	22	100
39	68	24	100
43	100		
49	100		
58	100		
59	100		

*Cluster No. refers to dendrogram (see Atlas, RU #30, Annual Report, 1978 for details of cluster membership).

A SYNTHESIS OF ENVIRONMENTAL INFORMATION CONCERNING POTENTIAL OCS OIL AND GAS DEVELOPMENT IN LOWER COOK INLET

Paul R. Becker, OCSEAP

INTRODUCTION

This section of the Interim Synthesis Report summarizes the information from previous chapters on potential effects of OCS oil and gas exploration. The major topics covered are OCS dev elopment in Cook Inlet, present levels of oil contaminants, major hazards to OCS development, important species and habitats in Lower Cook Inlet and the probable effect on these habitats and species from OCS development.

OCS DEVELOPMENT

Offshore oil and gas exploration and development in Cook Inlet began in 1959 with a sale of state land in Upper Cook Inlet. Oil and gas have been produced in Upper Cook Inlet for about ten years. There are now 14 offshore platforms, marine and onshore pipeline networks, and onshore production treatment facilities above the Forelands. Below the Forelands are marine terminals at Nikiski and Drift River and onshore pipelines.

In the October 1977 lease sale (Sale #CI) leases for approximately 500,000 acres of federal lands in Lower Cook Inlet were sold. Exploratory drilling of two tracts began in the summer of 1978. Exploratory drilling on seven blocks is expected to continue through 1980, and exploratory drilling is expected to be completed by 1985.

A second federal lease sale scheduled for March 1981 (Sale #60) will include all offshore federal lands below Kalgin Island that were not leased in Sale #CI and all of Shelikof Strait down to Cape Ikolik, Kodiak Island.

If oil and gas are discovered in this lease area (See Chapter 3), BLM has projected that certain areas of Cook Inlet could be developed. The area which appears most suitable for pipeline landfalls and onshore development is the eastern shore of the Inlet. Existing facilities at Drift River and Nikiski would probably be used and expanded. Discovery of oil and gas in the southern part of the lease area might necessitate pipeline landfalls and onshore storage facilities and terminals south of Nikiski and on the Kenai Peninsula.

PRESENT LEVELS OF PETROLEUM CONTAMINANTS

Potential sources of thermogenic hydrocarbons in Cook Inlet include natural oil seeps and coal outcrops, discharges from tankers and other vessels, waste discharges from urban areas, and offshore oil and gas operations. The concentration of thermogenic hydrocarbons in Lower Cook Inlet is naturally very low and is similar to concentrations measured in other Alaskan waters. Ratios of ethane to ethene and propane to propene fall below 1.0 and indicate that most of the hydrocarbons in Lower Cook Inlet are probably biogenic.

However, thermogenic hydrocarbons have been found near Cape Douglas and in Outer Kachemak Bay. Waters near Cape Douglas have yielded ethane/ethene ratios greater than 1.0 which indicates a possible natural oil seep in the area; actual concentrations of ethane are low (about 1.0 nl/l). Macoma balthica and Mytilus edulis collected near Cape Douglas showed no evidence of petroleum hydrocarbon accumulations, and sediment samples contained no thermogenic hydrocarbons.

Propane/propene ratios in outer Kachemak Bay indicate that thermogenic hydrocarbons may be found here, although the concentrations are low. Further evidence is supplied by the discovery of relatively high numbers of hydrocarbon utilizing microbes here.

Tissue analysis of Macoma balthica and Mytilus edulis from Mud Bay, inside Homer Spit, indicated possible low levels of thermogenic hydrocarbons. Thermogenic hydrocarbon contamination in Kachemak Bay probably comes from cities, vessels, and naturally occurring coal outcrops. Their relative importance would be hard to determine because of present low hydrocarbon levels.

In Upper Cook Inlet, where oil and gas development has been occurring for about a decade, elevated levels of thermogenic hydrocarbons have been found. Measurements of hydrocarbons of low molecular weight above the Forelands (Cline and Feeley, 1978) indicated relatively high ethane (2 to 8 nl/l) and relatively low ethene (0.2 to 0.6 nl/l) concentrations in Trading Bay. Propane concentrations were also relatively high (1 to 4 nl/l). Large numbers of hydrocarbon utilizing microorganisms and high hydrocarbon degradation rates further suggested the presence of thermogenic hydrocarbons.

The highest concentrations of thermogenic hydrocarbons were found near the West Foreland. The source could be a capped well, platform, or pipeline, or it could be a natural seep of oil or gas or a coal outcrop. Further study of these hydrocarbons is in progress.

GEOHAZARDS

Lower Cook Inlet is an active seismic region. Four active volcanoes are present: Mounts Redoubt, Iliamna, Augustine, and Douglas. These geohazards, and the possibility of unstable bedforms and highly dynamic sedimentation patterns, pose the greatest potential threat to the development of platforms, pipelines, and onshore facilities in Lower Cook Inlet.

Hazards to Platforms and Drilling Activities

Lower Cook Inlet is included in the seismic monitoring network of the Gulf of Alaska. Particularly important from placement and design of drilling platforms is the magnitude of ground shaking and ground rupture. Mobile exploratory rigs, such as the semisubmersible, are less vulnerable than permanent production platforms, but even these can be damaged if the ground ruptures.

Platform placement and drilling activities on tracts on the west side of Lower Cook Inlet are in danger from an eruption by Mount Augustine (Fig. 8.1). Recently this has been the most active volcano in the Inlet. Dangers to platform operations include falling debris, pyroclastic flows, corrosive rains, and clouds of noxious gases. Pyroclastic flows have extended 5 km off shore but not into the area of lease tracts; it is not known how far nuées ardentes, which are usually associated with pyroclastic flows, may travel off shore from Augustine Island. Large falls of debris 10 km off shore have been found, indicating that the nearest lease tracts might be hit by falling debris if Augustine erupted.

The monitoring of seismic activity is a promising technique for predicting eruptions. Shallow seismic events of low magnitude have been found to be random and associated with volcanic activity of Mounts Douglas, Augustine, and Iliamna. They may signal the probability of a volcanic event as much as four months before activity begins.

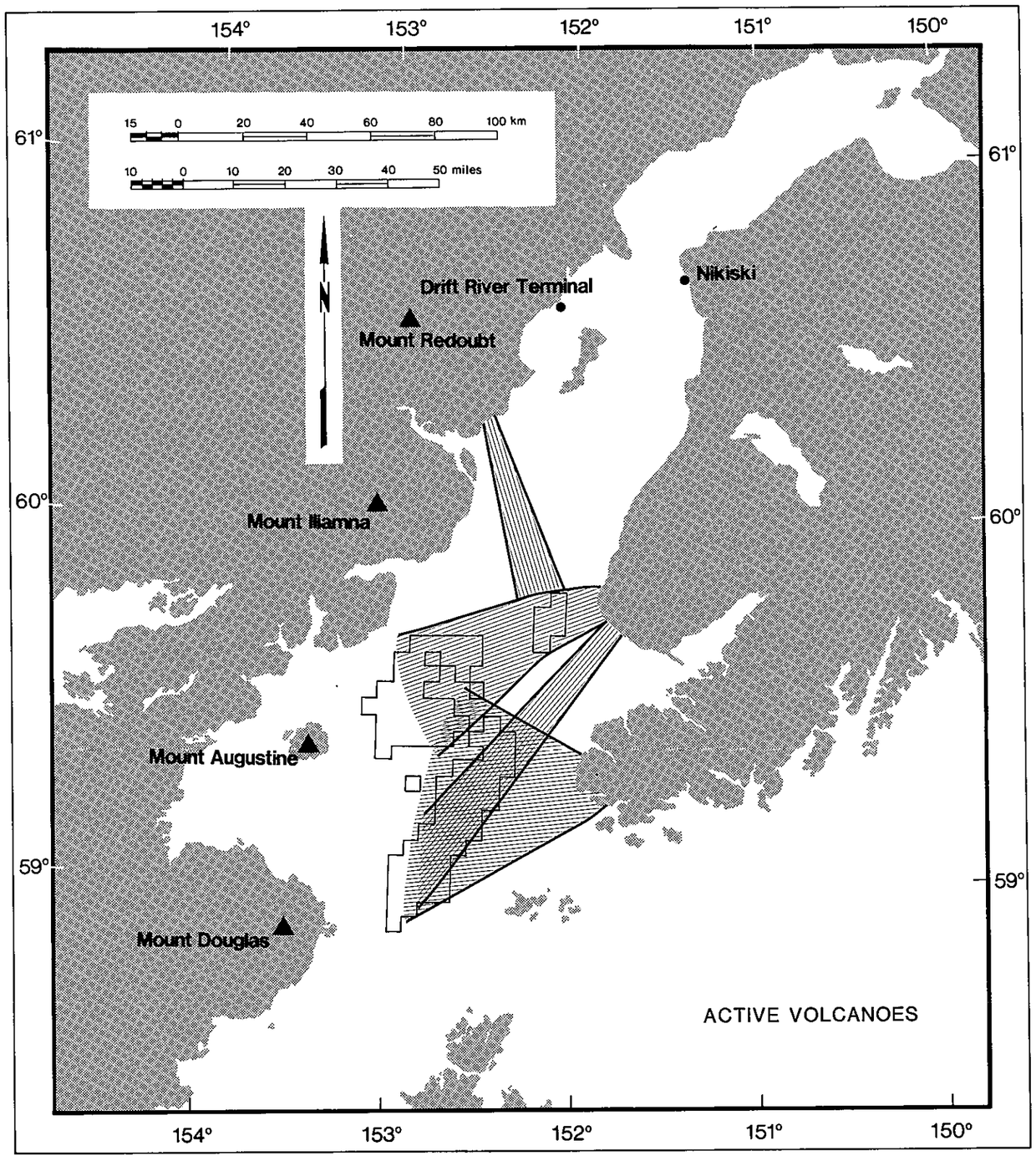


Figure 8.1 Locations of active volcanoes in relationship to lease tracts, onshore facilities, and projected pipeline corridors.

In the central part of Lower Cook Inlet, where many of the lease tracts lie, large sandwaves up to 12 m high are found over muds (Fig. 8.2). These sandwaves probably are not moving rapidly enough to have much effect on piling installations. Landslides, slumps, and unstable slopes do not appear to be major problems in Lower Cook Inlet.

Hazards to Submarine Pipelines

There appear to be surface faults in Lower Cook Inlet, possibly obscured by moving seafloor sediments. Minor faults are found south and west of Augustine Island and between the Kenai Peninsula and Shuyak Island.

Moving sandwaves might expose buried pipes, causing them to "flutter" and break as a reuslt of the strong currents in the central Inlet.

Sediment movements may also cause erosion and exposure, after a pipeline is laid on the seafloor. The seafloor erosion around pipelines and its resulting problems are well documented for existing pipelines in Upper Cook Inlet (see Chapter 3).

Hazards to Onshore Facilities

Most of the geohazard to OCS onshore facilities derives from either volcanism or earthquakes. Mt. Augustine does not lie near any present or projected area of onshore development; however, tsunamis produced during an eruption could threaten the shoreline of any part of Lower Cook Inlet. The 1884 eruption of Augustine generated a tsunami of about 8 m at Port Graham.

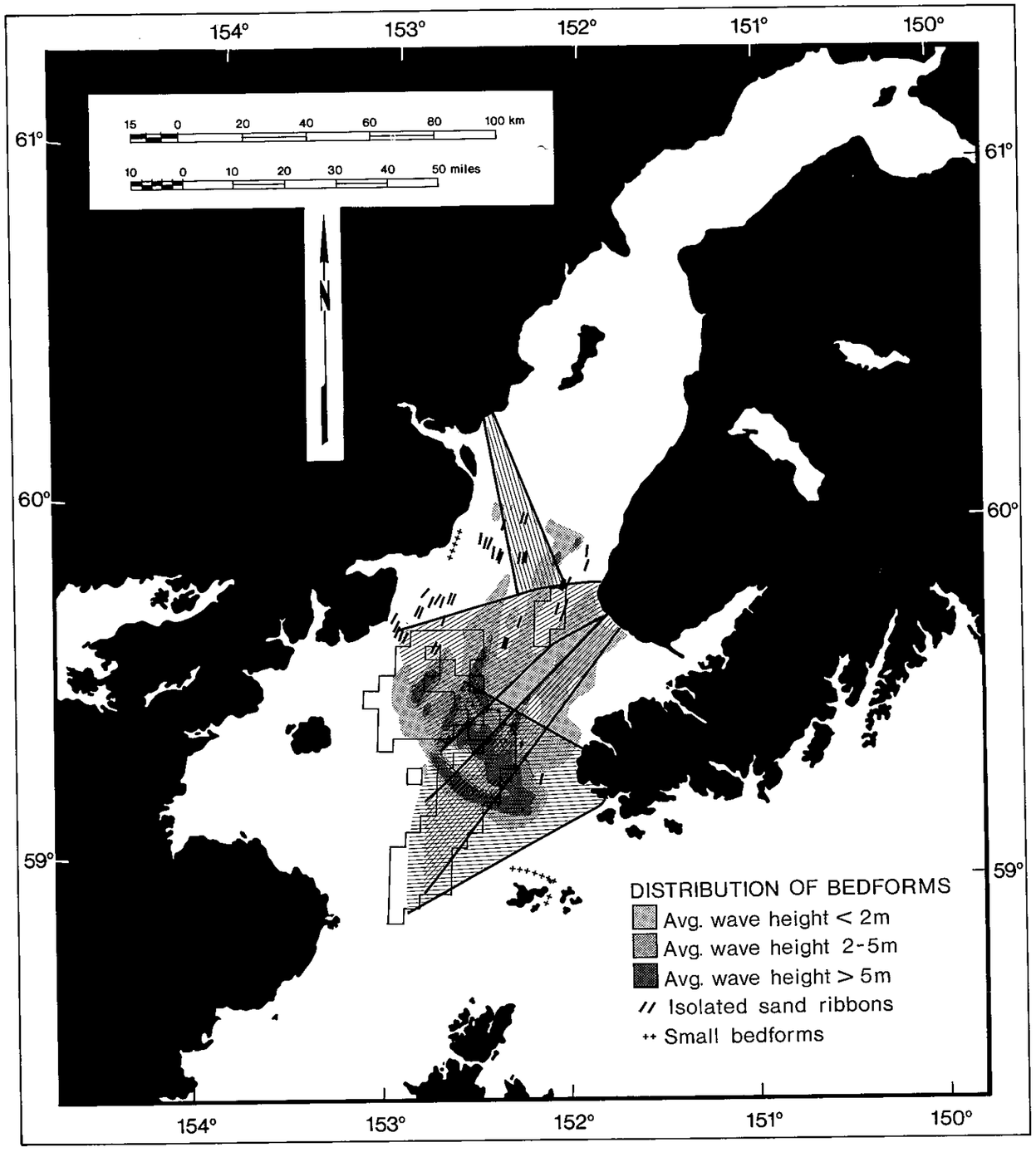


Figure 8.2 Distribution of sandwaves in Lower Cook Inlet in relation to lease tracts and projected pipeline corridors.

Volcanic activity at Mount Redoubt could cause flash flooding on the Drift River, which might damage the tanker terminal at Drift River (Fig. 8.1).

A rapid advance of the "North Glacier" of Mt. Redoubt across the river valley could cause damming of the river and result in further floods on the Drift River.

Seismic hazards to onshore development are tsunamis and the physical instability of the coastal shoreline. An onshore facility would have to be built above the line where tsunamis have been recorded in the past.

Tsunamis may also be generated locally if an unstable section of a shoreline slumps and slides into a bay. This is an additional factor to consider in designing onshore facilities.

THE FIVE NATURAL REGIONS OF LOWER COOK INLET

Introduction

Five natural regions have been identified in Lower Cook Inlet (Fig. 8.3): Kachemak Bay, Kennedy Entrance, Kamishak Bay, the Lower Central Region, and the Kalgin Island Region. These regions are distinguished by differences in physical conditions and biota. Details on biota and habitats are given in Chapter 6.

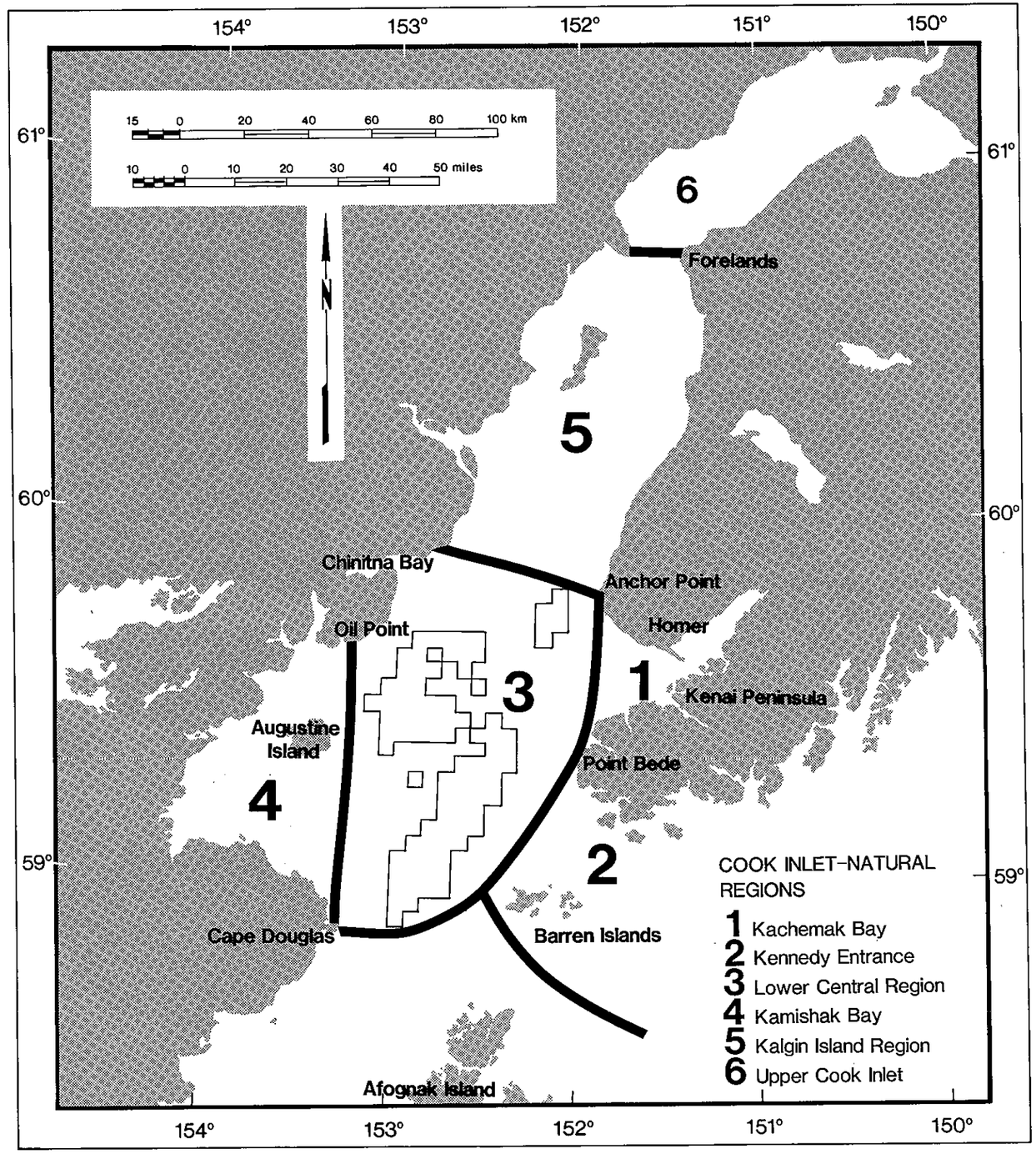


Figure 8.3 Natural regions of Cook Inlet.

General description

Kachemak Bay contains important habitat for probably the greatest assortment of biological resources in Lower Cook Inlet. Because of its importance to commercial fisheries and its utilization by breeding seabirds and migrating waterfowl and shorebirds, it has been designated as a "critical habitat" under Title 16 of Alaska State Law. Kachemak Bay is managed by the Alaska Department of Fish and Game to insure the compatibility of commercial activities with its biological resources.

Homer Spit separates Kachemak Bay into an inner bay and an outer bay (Fig. 8.4). The floor of the Bay is flat except for a trench 55 to 73 m deep along the south-central side. It averages 46 m in depth, with a 176-m depression at the entrance to the inner bay.

In the outer bay water from the Gulf of Alaska moves from Kennedy Entrance along the south shore, and flows out into the Lower Central Region along the north shore. There is a net movement of surface water from the inner bay to the outer bay. The salinity of the surface water varies with seasonal freshwater runoff but usually averages 30 to 32 °/oo.

The high productivity and density of Kachemack bay result from a combination of factors. The Gulf of Alaska water entering Kachemak Bay is nutrient-rich from the upwelling northwest of the Chugach Islands (Burbank, 1977). These clear waters (<2 mg/l suspended particles) allow for deeper light penetration and higher primary productivity in the water column than in

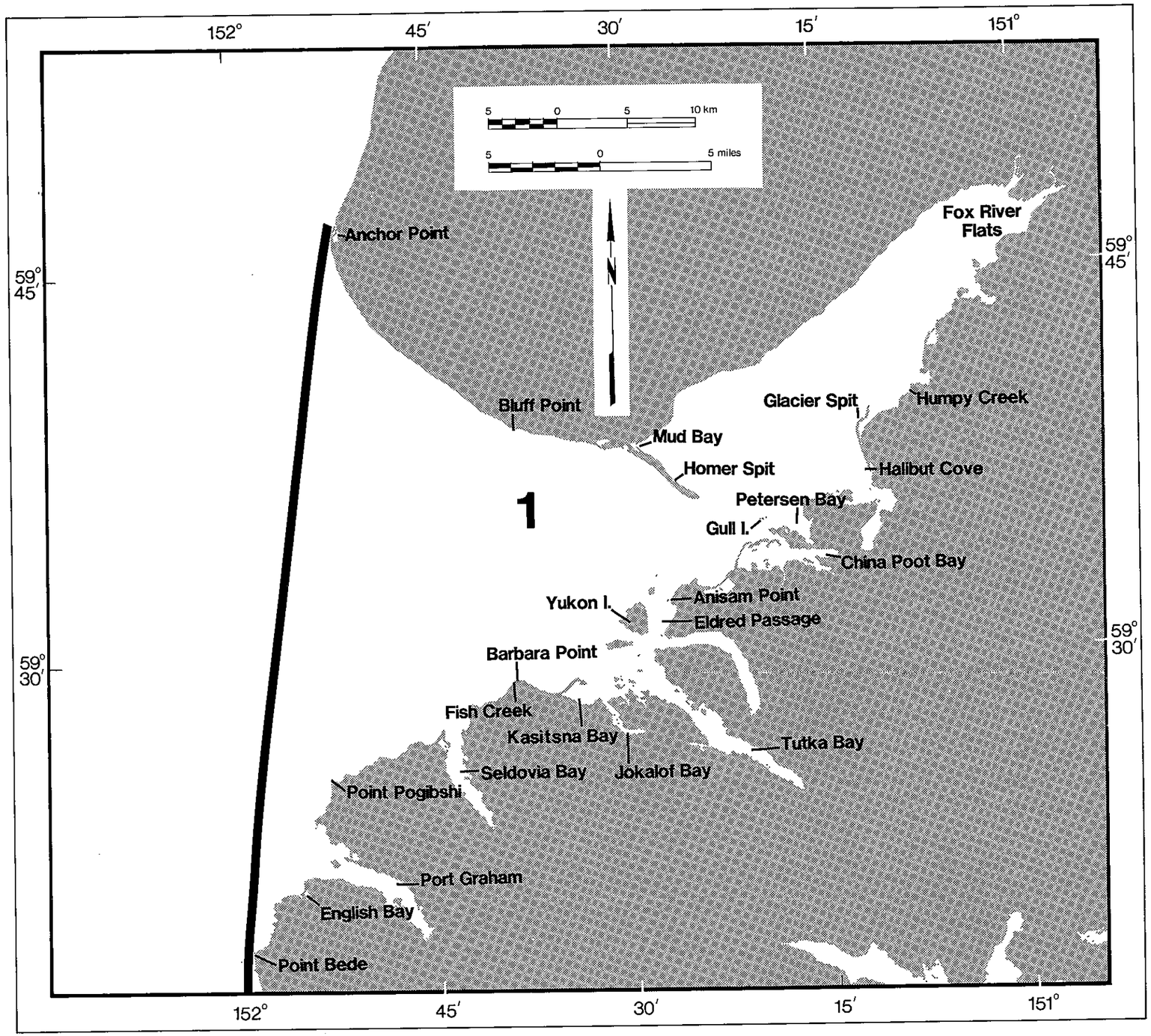


Figure 8.4 Kachemak Bay.

other regions of Lower Cook Inlet, twice as high as in Kamishak Bay and ten times as high as the area near Kalgin Island (Larrance, 1977).

Phytoplankton blooms occur between April and August, peaking in late May. The water column stratifies in late May and remains stratified through July. A simultaneous depletion in nitrate levels in spite of high nitrate concentrations in the entering ocean water indicates water column stability and relatively long water residence times in Kachemak Bay (Larrance, 1977). Gyre systems described for outer Kachemak Bay by Burbank (1977) are another indicator of long residence times.

Such stability in outer Kachemak Bay also suggests that if spilled oil should enter the system, it might be retained long enough to be deposited on the bottom sediments of the bay.

The clear nutrient-rich water from the Gulf of Alaska not only causes high productivity in the water column but also promotes the growth of kelps and other seaweeds at greater depths in Kachemak Bay in the Kennedy Entrance Region than in other regions of Lower Cook Inlet.

The heaviest growth of seaweeds in Lower Cook Inlet occurs along the coast of the Kenai Peninsula. This growth, together with the extensive coastal marshes (Fox River Delta, China Poot Bay, and Halibut Cove), not only provides additional direct plant food source and detritus for the growth of consumer organisms, but also increases the diversity of habitats. This habitat diversity is a second important factor in maintaining the high biological productivity and diversity in Kachemak Bay.

Kachemak Bay has many different kinds of habitats. The shoreline and intertidal zone are characterized by gravel and cobble beaches, sand and mudflats, and marshes. This diversity is also reflected in the subtidal benthic region of the Bay. The inner Bay sediments are fine-grained while those of the outer Bay are coarser. Driskell (1977) mapped five different substrate types, each with its characteristic assemblage of benthic organisms. Clay/silt/sand mixtures are found in the eastern, deeper portion of the bay with deposit-feeders predominating, while shell debris with suspension feeders predominating are characteristic of the northern and southern shorelines.

A third factor in maintaining the high biological productivity in Kachemak Bay is the relatively mild winter climate compared with other regions in Lower Cook Inlet. Sea conditions are less severe than in other parts of Lower Cook Inlet due to the Bay's protected geographical locations and the inner bay's protection by Homer Spit. Kachemak Bay remains relatively ice free during the winter, although shore ice has extended for up to three miles off the northern shore of the Inner Bay during severe winters and floe ice from the head of the bay can accumulate behind Homer Spit (Trasky et al., 1977). The lack of severe icing is probably due to warming by inflowing Gulf of Alaska water, the protected location of Kachemak bay, and a circulation pattern that prevents floe ice originating from the upper part of the Inlet from accumulating in the Bay.

Although the biomass of certain kelps is reduced during the winter, such species as Laminaria groenlandica and Agarum cribrosum grow year-round. In addition, Kachemak Bay is an important wintering area for marine birds and waterfowl. The major biological resources and habitats in Kachemak Bay are shown in Fig. 8.5.

Figure 8.5 Major biological resources and habitats in Kachemak Bay.

I. Major biological resources
  A. Commercial fisheries
    1. Shellfish: king, Tanner, and Dungeness crab; pink, humpy, sidestripe, and coonstripe shrimp
    2. Finfish: Sockeye, pink, and chum salmon; herring; halibut
  B. Birds: waterfowl, marine birds, and shorebirds
II. Major habitats
  A. Open water habitat
    1. Most diverse commercial fishery in Cook Inlet: Tanner, king and Dungeness crab; pink, humpy, coonstripe, and side-stripe shrimp; pink, chum, and sockeye salmon; halibut; herring. The king crab is the most valuable commercial species
    2. Spawning area for halibut, other demersal fish, commercial crab species, and shrimp
    3. Important overwintering area for white-winged scoters and oldsquaws, common murres and marbled murrelets, cormorants, guillemots, mew and glaucous-winged gulls
    4. Highest density of feeding seabirds in Lower Cook Inlet during spring and summer: black-legged kittiwakes, glaucous-winged gulls, common murres, scoters, fulmars, guillemots, shearwaters, fork-tailed storm petrels, and several species of migratory ducks
    5. Anchor Point to Bluff Point from shoreline out to about the 30-meter depth contour
      a. Nursery area for king and Dungeness crab
      b. Concentration and feeding area for overwintering oldsquaw and white-winged scoter
      c. Possible feeding area for migrant adult salmon in spring and summer
    6. Southern shoreline out to about the 30-meter depth contour
      a. Probable nursery area for king and Dungeness crab
      b. Commercial fishing area for sockeye, pink, and chum salmon
      c. Major spawning area for herring
  B. Coastal habitat
    1. Rocky southern shoreline of Kachemak Bay
      a. Colonies of tufted puffins, black-legged kittiwakes, common murres, red-faced cormorants, pelagic cormorants, and glaucous-winged gulls at Point Bede, Eldred Passage, and Gull Island
      b. Sheltered embayments -- Port Graham, English Bay, Seldovia Bay, Tutka Bay, China Poot Bay, and Humpy Creek
        (1) Major pink and chum salmon spawning streams and intertidal/shallow subtidal spawning areas
        (2) Feeding areas for juvenile salmonids
        (3) Herring spawning areas
    2. Marshlands
      a. China Poot Bay
        (1) Foraging area for waterfowl and shorebirds
        (2) Probable feeding area for pink and chum salmon, shrimp, and king and Dungeness crabs
      *b. Fox River Flats
        (1) Foraging area for waterfowl and shorebirds
        (2) Probable feeding area for pink and chum salmon, shrimp, and king and Dungeness crabs
        (3) Major staging area for migrating waterfowl and shorebirds
        (4) Breeding area for about 800 geese and dabbling ducks

* Designated as "Critical Habitat" under Title 16 of Alaska State Law

Kennedy Entrance

General description

Kennedy Entrance lies between the Kenai Peninsula and the Barren Islands (Fig. 8.6). It extends southward from Point Bede and includes the Barren Islands. It is narrow and deep, dropping rapidly to water depths greater than 100 m a short distance from shore. The central part, between the Chugach Islands and the Barren Islands, contains a narrow depression (about 300 m deep), which is probably scoured by the tides. Much of the bottom is bedrock with scattered boulders and gravel, reflecting the strong tidal currents in the area.

The depth of the Entrance decreases rapidly toward the north end of the region, and upwelling occurs northwest of the Chugach Islands. This has an important bearing on the primary productivity of Kachemak Bay.

The water is clear (2 mg/l suspended particles). Productivity in the water column during the spring and summer is probably high but not as high as in Kachemak Bay, as the water residence time is not as great as in Kachemak Bay. Scarce information on the productivity of this area shows an estimated 1 $gC/m^2/day$ (Larrance, 1977).

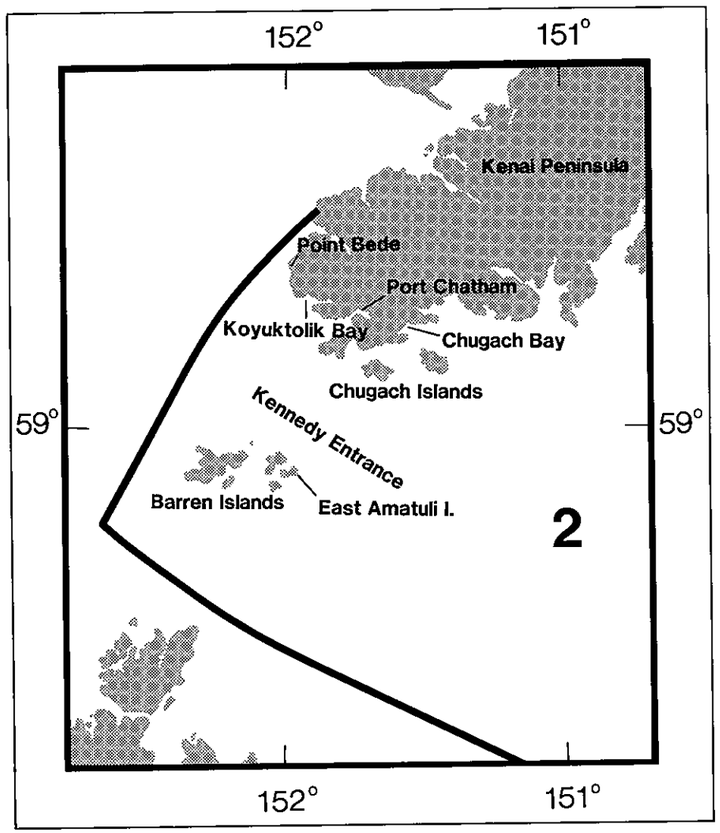


Figure 8.6 Kennedy Entrance.

The nutrient-rich, Gulf of Alaska water flowing past the rocky shoreline promotes an extensive nearshore growth of seaweed similar to that of the south shore of Kachemak Bay. Several species are perennial. Macrophytes are important in providing a diversity of habitat near shore as well as a direct and detrital food source to primary consumers.

Besides its contribution to the productivity of Kachemak Bay, the Kennedy Entrance Region is the major pathway for movement of salmon between Cook Inlet and the Gulf of Alaska. It also contains habitat for the largest concentration of colonial marine birds, sea lions, harbor seals, and sea otters in Lower Cook Inlet. The major biological regions and habitats of the Kennedy Entrance Region are summarized in Fig. 8.7.

Figure 8.7 Major biological resources and habitats in Kennedy Entrance.

I. Major biological resources
   - A. Marine bird colonies
   - B. Marine mammals (Northern sea lions, harbor seals, and sea otters)

II. Major habitats
   - A. Open water habitat
     1. Principal pathway and probable feeding area for salmon between Cook Inlet and Gulf of Alaska
     2. Important foraging area for Northern sea lions, harbor seals, and marine birds from colonies on the Barren and Chugach Islands and the mainland of the Kenai Peninsula
   - B. Coastal habitat
     1. Barren Islands
        - a. Principal breeding and pupping area for Northern sea lions and harbor seals
        - b. Major concentration area for sea otters
        - c. Largest marine bird colonies in Cook Inlet: about 500,000 birds, mostly alcids
     2. Chugach Islands
        - a. Major concentrations of Northern sea lions, harbor seals, and sea otters
        - b. Important marine bird colonies
     3. Rocky shoreline, Kenai Peninsula
        - a. Major concentrations of Northern sea lions, harbor seals, and sea otters
     4. Koyuktolik Bay
        - a. Commercial fisheries of pink and chum salmon, Dungeness crab, and herring
        - b. Largest eelgrass beds in Cook Inlet
        - c. Pink and chum salmon spawning areas
        - d. Probable nursery area for Dungeness crab, king crab, pink, and chum salmon
        - e. Probable spawning habitat for herring
        - f. Overwintering habitat for shorebirds and waterfowl
     5. Port Chatham
        - a. Commercial fisheries of Dungeness and king crab, pink and chum salmon
        - b. Pink and chum salmon spawning areas
        - c. Probable nursery area for Dungeness and king crab, pink and chum salmon
        - d. Probable spawning habitat for herring
        - e. Overwintering habitat for shorebirds and waterfowl

Lower Central Region

The Lower Central Region (Fig. 8.8) has a relatively flat bottom with sediments of poorly sorted sands. The central part contains fields of sand waves, ridges, and ribbons described in the section on geohazards.

This region exhibits highly variable current speeds and direction, concentration of suspended particles, and water column primary productivity. This variability results from mixing of the water from the Gulf of Alaska with highly turbid brackish water from Upper Cook Inlet which flows down the west side of Cook Inlet and enters the Lower Central Region from the northwest. Where the waters converge, frontal zones or rips are detected by accumulations of floating debris which may remain for weeks or months. While the rips are more common in the Kalgin Island Region, a mid-channel rip may extend into the Lower Central Zone and Kamishak Bay.

Tides are the major influence on the circulation of the Lower Central Region. Regional tidal energy is dissipated by bottom friction, turbulence occurs, and the water column does not undergo periodic vertical stratification as it does in Kachemak Bay.

The convergence of waters from Upper Cook Inlet and Kennedy Entrance results in horizontal gradients in salinity and suspended particles but weak vertical gradients. In spring and summer the salinity increases from northwest to southeast (28^{o}/oo to 32^{o}/oo while the concentration of suspended particles decreases (21 mg/l to <2 mg/l). Values in the Region probably vary according to seasonal variability of river discharge into the upper portion of the Inlet.

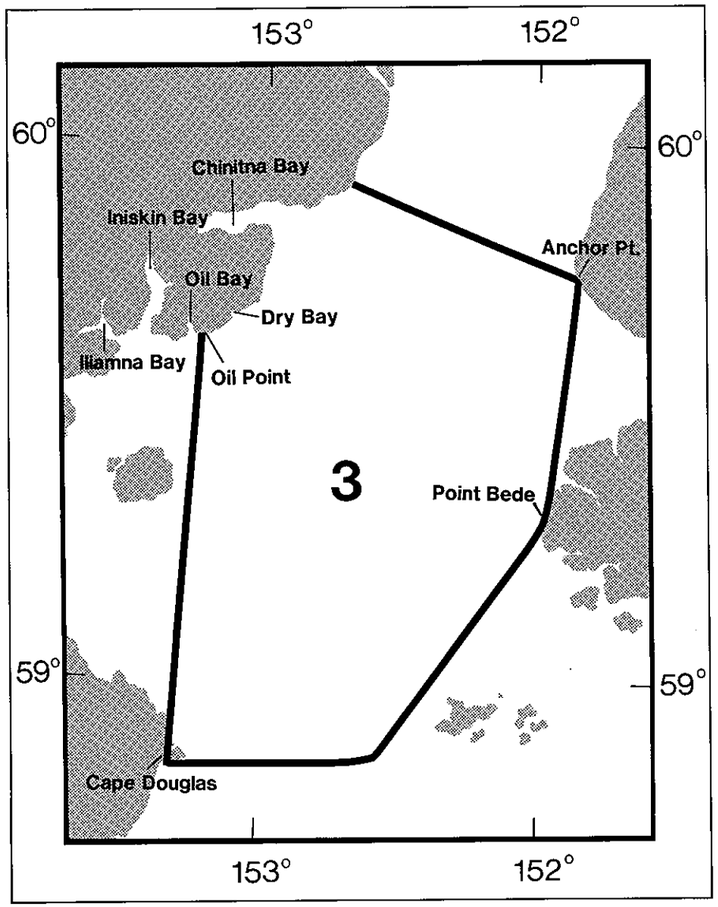


Figure 8.8 Lower Central Region, Lower Cook Inlet.

About 10 g/m^2/day of suspended particles are deposited in the Lower Central Region in spring and summer (Feeley et al., 1978). However, as resuspension probably also occurs, the rate of deposition could be higher.

Short-term variations in the concentration of suspended particles appear to be strongly influenced by tidal currents. Maxima appear to occur shortly after the ebb current reaches maximum velocity (Gatto, 1976; Feeley et al., 1978).

The net circulation and physical characteristics of the water column suggest that the Lower Central Region is an environmental transition area between Kachemak and Kamishak Bays. In addition, herring, demersal fish, king crab, and Tanner crab, which feed and spawn in both bays from spring through fall, move into the Lower Central Region for overwintering. The major biological resources and habitats of the Lower Central Region are summarized in Fig. 8.9.

The Lower Central Region includes all of the tracts leased in OCS Sale #CI. It also includes the major Tanner and king crab fishery of Lower Cook. It is a major concentration area for demersal fish, several species of which could be exploited commercially in the future. Conflicts between commercial fishing operations and oil and gas activities at the lease tracts need to be considered in planning for OCS development in Cook Inlet.

Figure 8.9 Major biological resources and habitats in the Lower Central Region, Lower Cook Inlet.

I. Major biological resources
   - A. Commercial Fisheries
     1. Tanner and king crabs
     2. Potential fisheries of yellowfin sole, rock sole, butter sole, Dover sole, flathead sole, arrowtooth flounder, Pacific cod, and walleye pollock

II. Major habitats
   - A. Open water habitat
     1. The major Tanner and king crab commercial harvest area in Cook Inlet
     2. Concentration area for demersal fish; several species may be commercially exploitable
     3. Nearshore between Iliamna and Dry Bays: settling and nursery areas for king crab
     4. Cape Douglas nearshore area: settling and nursery areas for Tanner crab
   - B. Coastal habitat
     1. Chinitna Bay
        - a. Razor clam beds along north shore appear to be large and have commercial potential
        - b. Mudflats and marshland provide feeding habitat for shorebirds and oldsquaws, scoters, and scaups

Kamishak Bay

Kamishak Bay lies west of a line extending from Oil Point, just east of Oil Bay, to Cape Douglas (Fig. 8.10). It is shallow (averaging about 30 m) and flat-bottomed. Sediments are finer than in the Lower Central Region. Current velocities are much lower than in the Lower Central Region (usually less than half a knot), and circulation is tidally dominated.

Overall biological productivity and diversity are much lower in Kamishak than in Kachemak Bay because of the turbidity of the water and the severe winter conditions that usually occur here. Turbid, brackish water from upper Cook Inlet converges with clear ocean water from Kennedy Entrance in the Kalgin Island and Lower Central Regions and flows into the bay. This turbid water is characteristic of the outer part of Kamishak Bay; however, tidal and wind-driven currents may carry the suspended particles into the inner part. Concentrations of suspended particles are usually similar to those for the west side of the Lower Central Region (about 20 mg/l during spring through fall).

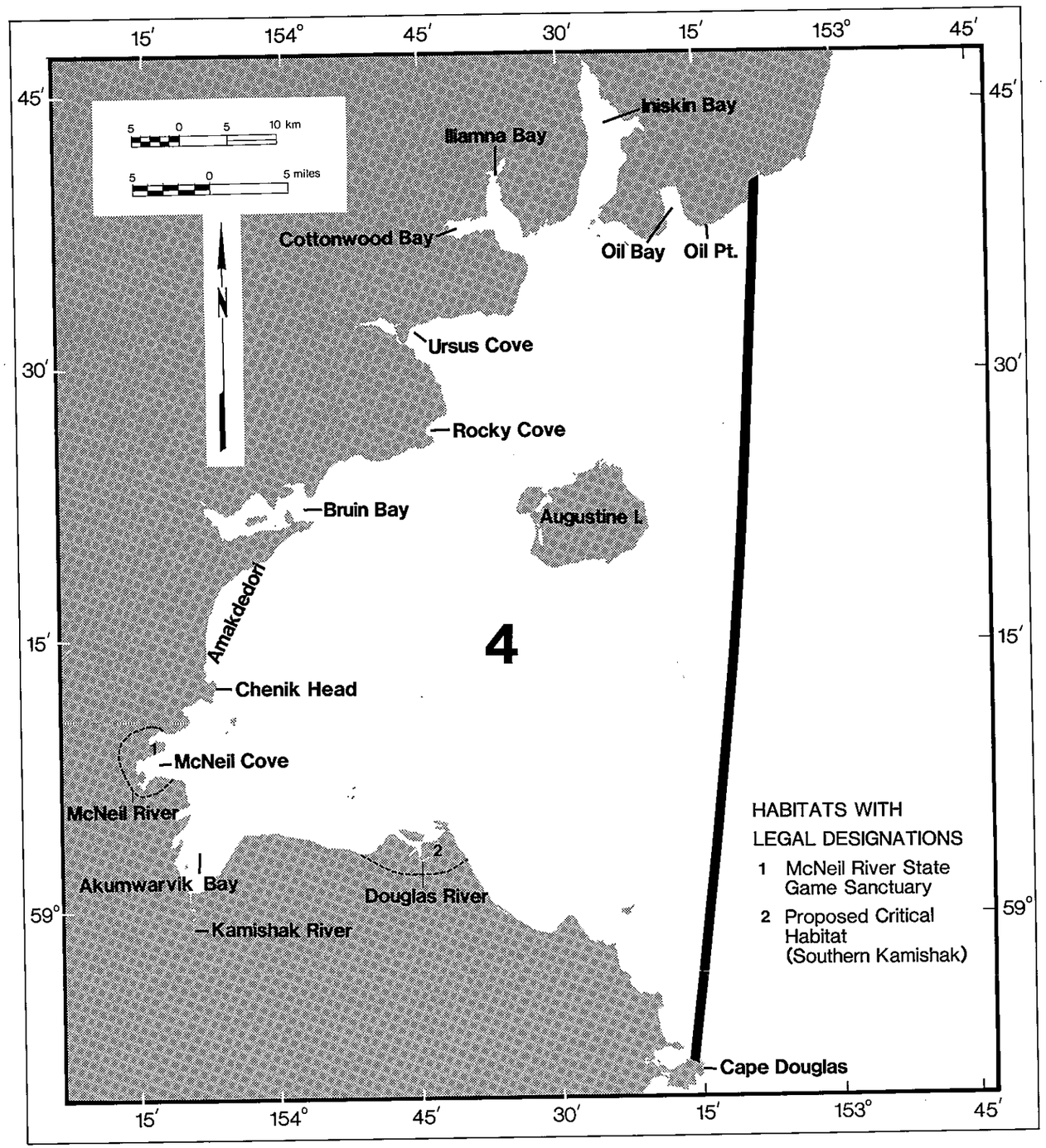


Figure 8.10 Kamishak Bay.

The turbidity limits the penetration of light and, hence, primary productivity. Water column primary productivity is usually about one-half that in Kachemak Bay. The spring increase in productivity begins about a month later (late May) in Kamishak Bay than in Kachemak Bay (Larrance, 1977). The fall decrease begins in August, about the same time as in Kachemak Bay.

The average rate of settlement of suspended particles has been 25 g/m^2/day in Kamishak Bay compared to 1 g/m^2/day for the Lower Central Region (Feeley et al., 1978). Larrance (1978) measured a high of 72 g/m^2/day in Kamishak Bay in May when concentrations of suspended particles are usually high. The rate of resuspension is not known; however, because of the slow currents in Kamishak Bay there probably is net accumulation.

Much of the shoreline of Kamishak Bay is exposed to wind and waves from winter storms, and icing is usually severe. Ice accumulation from both landfast shore ice and floe ice may completely cover Kamishak Bay during severe winters and during most winters, extends out to Augustine Island. Ice is usually at a maximum in February.

In spring floe ice in Kamishak Bay together with additional floe ice moving from Upper Cook Inlet melt releasing sediments on the mud flats in Upper Cook Inlet.

Landfast and floe ice in Kamishak Bay reduce its importance as an over-wintering area for resident marine birds, shorebirds, and waterfowl. It also restricts macrophyte growth to spring throug fall and generally limits fauna , pioneer and cryptic species.

Although biological productivity and diversity are generally not as high as in Kachemak Bay, Kamishak Bay is important as a spawning and nursery area for several species of commercial fish and shellfish. The small embayments also provide staging and stopover areas for waterfowl and shorebird during the spring migration. The major biological resources and habitats are summarized in Fig. 8.11.

Figure 8.11 Major biological resources and habitats in Kaligin Island Region.

I. Major biological resources
  A. Principal commercial fisheries
    1. Shellfish: king and Tanner crab
    2. Finfish: pink and chum salmon (minor catches of coho and halibut), herring (most important harvest area in Lower Cook Inlet).
  B. Migratory waterfowl and shorebirds
  C. Harbor seals and sea otters
II. Major habitats
  A. Open water habitat
    1. Extension of the Tanner and king crab fishery of the Lower Central Region into the east side of Kamishak Bay as far as Augustine Island.
    2. Major spawning area for king and Tanner crab, halibut, and other demersal fish species.
    3. Nearshore between Iliamna and Dry Bay
      a. Apparent settling and nursery area for king crab
      b. Major commercial fishing area for herring
    4. Nearshore from Ursus Cove to Iliamna Bay - Major commercial fishing area for herring
    5. Cape Douglas nearshore area - apparent settling and nursery area for Tanner crab
  B. Coastal habitat
    1. Bays
      a. Bruin Bay
        (1) Important commercial salmon fishing area
        (2) Second largest eelgrass bed in Cook Inlet (750,000 m^2)
        (3) Marshes and mudflats provide staging and feeding areas for migrating waterfowl and shorebirds
        (4) Pink and chum salmon intertidal/shallow subtidal spawning habitat
        (5) Feeding area for juvenile salmon
        (6) Important herring spawning habitat
      b. Iniskin Bay
        (1) Important commercial salmon fishing area
        (2) Marshes and mudflats provide staging and feeding area for migrating waterfowl and shorebirds
        (3) Eelgrass beds provide suitable spawning habitat for herring
        (4) Chum salmon spawning stream and intertidal/shallow subtidal spawning habitat
        (5) Feeding area for juvenile salmon
      c. Iliamna - Cottonwood Bay
        (1) Important commercial salmon fishing area
        (2) Marshes and mudflats provide staging and feeding area for migratory waterfowl and shorebirds
        (3) Chum salmon intertidal/shallow subtidal spawning habitat
        (4) Feeding area for juvenile salmon
      d. Akumwarvik Bay
        (1) Important commercial salmon fishing area
        (2) Marshes and mudflats provide staging and feeding area for migratory waterfowl and shorebirds
        (3) Major pink salmon spawning habitat in Kamishak River and in intertidal/shallow subtidal areas
        (4) Feeding area for juvenile salmon
      e. McNeil Cove (part of McNeil River State Game Sanctuary)
        (1) Major salmon spawning habitat in McNeil River and in intertidal/shallow subtidal areas
        (2) Major chum salmon spawning habitat in Paint River and in interdial/shallow subtidal areas
        (3) Marshes and mudflats provide important staging and feeding area for migrating waterfowl and shorebirds
      f. Ursus Cove
        (1) Important commercial salmon fishing area
        (2) Marshes and mudflats provide staging and feeding area for migrating waterfowl and shorebirds
        (3) Important herring spawning habitat
        (4) Pink and chum salmon intertidal/shallow subtidal spawning habitat
        (5) Feeding area for juvenile salmon
    2. Other coastal habitat
      **a. Douglas River Flats
        (1) Marshlands, mudflats, and eelgrass beds provide staging and feeding areas for migrating whistling swan, black brant, lesser snow goose, plover, sandpiper, and ruddy turnstone
        (2) Principal commercial salmon fishing area
      b. Augustine Island
        (1) Important herring spawning habitat
        (2) Largest concentration of sea otter in Kamishak Bay
        (3) Major haulout and breeding area for harbor seals

**Proposed as Critical Habitat under Title 16

Kalgin Island Region

The Kalgin Island Region extends south from the Forelands to the northern edge of the Lower Central Region (Fig. 8.12). The rips (mentioned previously) develop most frequently east of Kalgin Island and extend from the Forelands to the southern part of the Region. During high runoff in spring and summer the rips may reach as far as Kamishak Bay. In winter reduced runoff and river flow into Upper Cook Inlet probably allow ocean water to intrude farther north into this region. Northerly winter winds are thought to produce onshore flows of surface water and debris to the south and into Kamishak Bay (Burbank, 1977).

Tidal currents reach 3 knots. The bottom, scoured by the tides, is predominantly rock outcrops covered with boulders, gravels, and sands.

Horizontal gradients in salinity and suspended particles run from east to west and from the Forelands to the Lower Central Region. The highest concentration of suspended particles and lowest salinity occur to the northwest around Kalgin Island. Concentrations of suspended particles during spring through fall are > 50 mg/l at the Forelands and between 1 to 5 mg/l in the southeastern corner near Anchor Point. The area around Kalgin Island has a shallow euphotic zone (<1m), which limits water column primary productivity. Primary production in this area in spring and summer was less than one-tenth that of Kachemak Bay during the same period (Larrance, 1977).

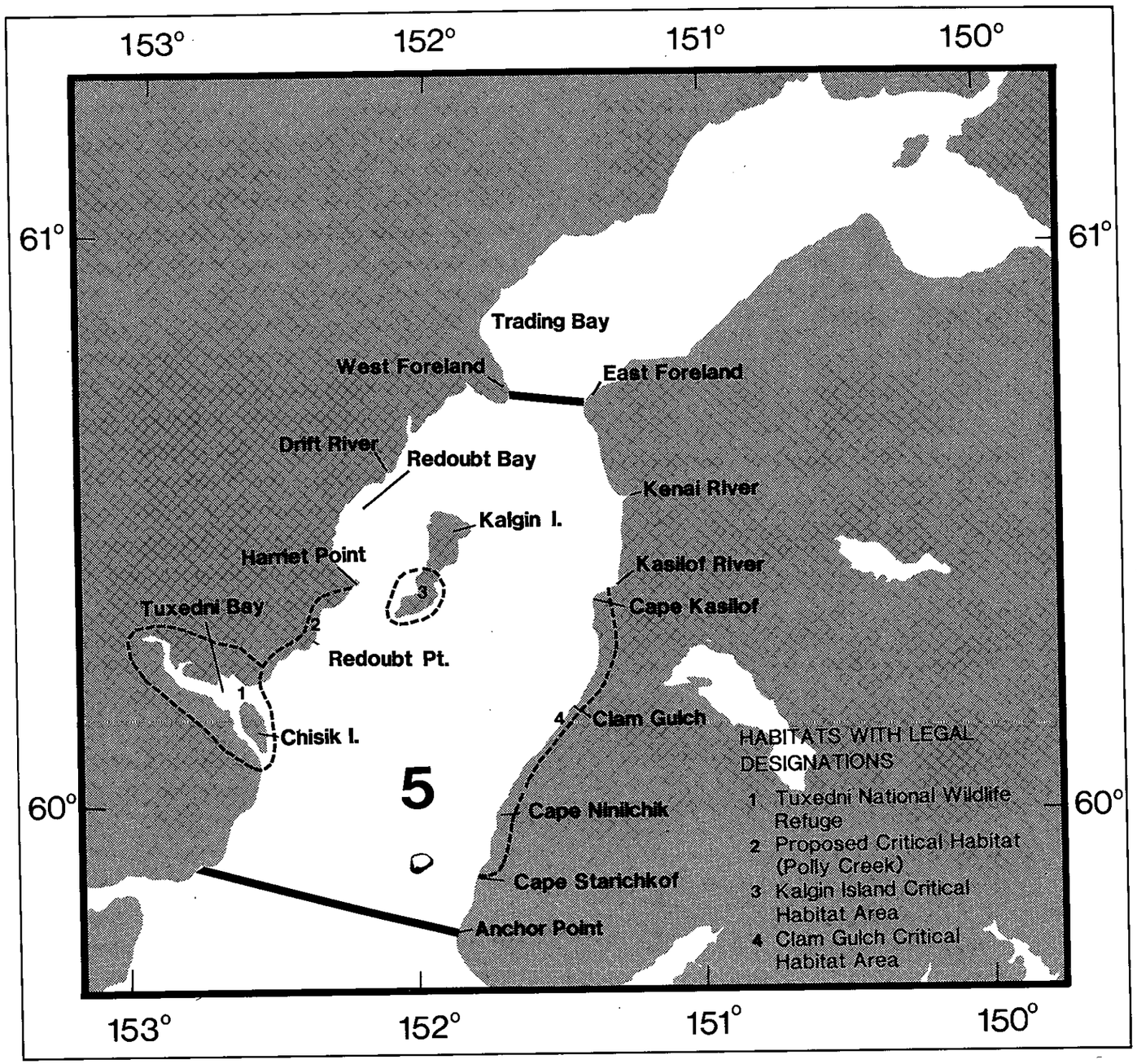


Figure 8.12 Kalgin Island Region.

The turbidity in the Kalgin Island Region, together with ice scouring along the shoreline, and the lack of suitable substrate results in a paucity of littoral algae and other macrophytes compared to the lower regions of Cook Inlet. During the winter, floe ice is carried from Upper Cook Inlet into the Kalgin Island Region. During extreme winters this floe ice may reach as far as Anchor Point. In addition to floe ice, landfast ice usually forms. The principal biological resources and habitats of the Kalgin Island Region are summarized in Fig. 8.13.

Figure 8.13 Major biological resources and habitats in the Kalgin Island Region.

I. Major biological resources
  A. Commercial fisheries
    1. Finfish: sockeye, pink, chum, coho, and king salmon
    2. Shellfish: razor clams
  B. Birds: marine birds, waterfowl, and shorebirds

II. Major habitats
  A. Open water habitats
    1. Central portion of the Region from the Forelands to Anchor Point: gillnet fishery for sockeye, pink, chum, coho, and king salmon, the most important commercial salmon fishing area in Lower Cook Inlet
    2. Adjacent to Tuxedni Bay: important foraging area for bird colonies in Tuxedni Bay
  B. Coastal habitats
    1. Tuxedni Bay
      a. Minor staging area for migratory dabbler ducks
      b. Overwintering habitat for marine birds, waterfowl, and shorebirds
      c. Largest marine bird colonies (Chisik Island) in Lower Cook Inlet outside of the Barren Islands (mainly black-legged kittiwakes and common murres)
      d. Included in the Tuxedni National Wildlife Refuge
    **2. Polly Creek (Tuxedni Bay to Harriet Point)
      a. Sand beaches with dense concentrations of razor clams, which support a small commercial fishery
    3. Redoubt Bay
      a. Extensive wetlands
      b. Important staging and feeding area for migratory waterfowl and shorebirds
      c. Largest concentration of breeding waterfowl in Lower Cook Inlet (30,000 birds)
    *4. Southern shore of Kalgin Island
      a. Important staging area for migratory waterfowl
    *5. Sandy beaches from Cape Starichkof to Cape Kasilof (Clam Gulch)
      a. Largest concentration of razor clams in Lower Cook Inlet, with heavy recreational and subsistence use
    6. Kasilof and Kenai Rivers
      a. The principal producers in Lower Cook Inlet of sockeye, pink, coho, and king salmon
      b. Probable intertidal spawning of pink salmon at river mouths
      c. Marshlands at river mouths provide staging and feeding areas for migratory geese, dabbling ducks, and shorebirds

*Designated as "Critical Habitat" under Title 16 of Alaska State Law
**Proposed as "Critical Habitat"

RISK OF IMPORTANT HABITATS TO EFFECTS OF OCS OIL AND GAS ACTIVITIES

Drilling Platforms

The most likely hazard from platforms would be large-volume spills from platform fires or blowouts. The effects of such oil spills would depend on the type of oil, amount spilled and rate of spillage, transport patterns, season, clean-up methods employed, and sensitivity of affected populations.

Identification of habitats at risk requires adequate information on transport mechanisms to calculate trajectories from potential oil spill sites. Trajectories for the Lower Cook lease area were computed as the sum of the tidal and net surface currents and wind induced motion under four different tidal cycles and eight different seasonal wind patterns (Putnin, 1956; Dames & Moore, 1976; 1979). Results were presented as trajectory paths, days to landfall, and probability of shoreline exposure to trajectory based on windfield probabilities. Principal landfall areas (those areas with at least a 10-20% probability and three days or less to landfall) and trajectory origins are presented in Fig. 8.14.

The results of the trajectory analysis must be viewed with caution. Circulation in Cook Inlet is highly variable as are wind patterns. In addition, the analysis does not consider weathering, spreading, dispersion, and "smearing" (spreading along the shoreline). The roles of winter ice floes, rips in the Kalgin Island Region, and adsorption and transport by suspended particles are also not considered.

The trajectory analysis generally confirms the existing knowledge of circulation and transport in Lower Cook Inlet, however. Kamishak Bay as a landfall area for trajectories originating from the lease tracts is generally confirmed by Burbank's 1976 and 1978 drift card and drift bottle studies (ADF&G, 1978a).

Within Kamishak Bay Dames and Moore found the principal landfall areas to be Ursus Cove and northward, while Burbank found them to be from Ursus Cove southward to McNeil Cove. The heaviest accumulations of debris on the shore of Kamishak Bay occur from Rocky Cove (just south of Ursus Cove) through Amakdedori Beach to Chenik Head. The difference between the two studies is probably the result of local wind patterns not considered in the trajectory analysis together with nearshore net circulation toward the south. The studies should be considered as complementary. Principal landfall areas for Kamishak Bay should include the coastal area between Chinitna Bay and McNeil Cove.

Areas at Risk

Kamishak Bay

A major oil spill in any part of the lease area could move into the Kamishak Bay Region. The ultimate effect depends on the volume of spilled oil, rate of spillage, and behavior of the oil: spreading and dispersion, evaporation of short-chain volatile fractions, photochemical oxidation and microbial degradation, formation of emulsions, adsorption to particulate matter, flocculation, and settling (IMCO et al., 1977).

Spilled oil begins spreading immediately. The more toxic fractions (aromatics) are also more volatile and more soluble and, therefore, readily available to organisms in the water column. As molecular size increases, toxicity increases, but solubility decreases. Thus, most of the acute deleterious effects are due to crude oil components that are balanced between water solubility and toxicity.

Evaporation of the short-chain volatiles takes a few hours to a few days. This process is slower at cold temperatures, suggesting that the substances could persist during the winter.

Formation of emulsions, particulate adsorption, and flocculation occur continuously following a spill. Flocculants in various sizes may be distributed throughout the water column and deposited on the bottom. Flocculation is stimulated by surface turbulence produced by high winds and waves. This may minimize the chance of heavy concentrations of oil reaching the shoreline but may increase the impact on organisms in the water column and the benthos.

Fine suspended particles tend to agglutinate and attach themselves to the surface slick rather than to flocculate as discrete particles, and ultimately they form the nuclei of tar balls.

Photochemical oxidation and microbial degradation begin immediately following a spill and continue for about a week. Microbial degradation rates would be higher in the spring and summer than in the fall and winter.

The most sensitive organisms of the water column include the larvae and pelagic eggs of finfish and the planktonic larvae of crustaceans. Kamishak Bay is a major spawning area for king crab, Tanner crab, and demersal fish. The effects of oil spills on them depends on the season, size of the spill, and area affected, and the population stability, natural mortality rates, and long-term production potential of the species affected.

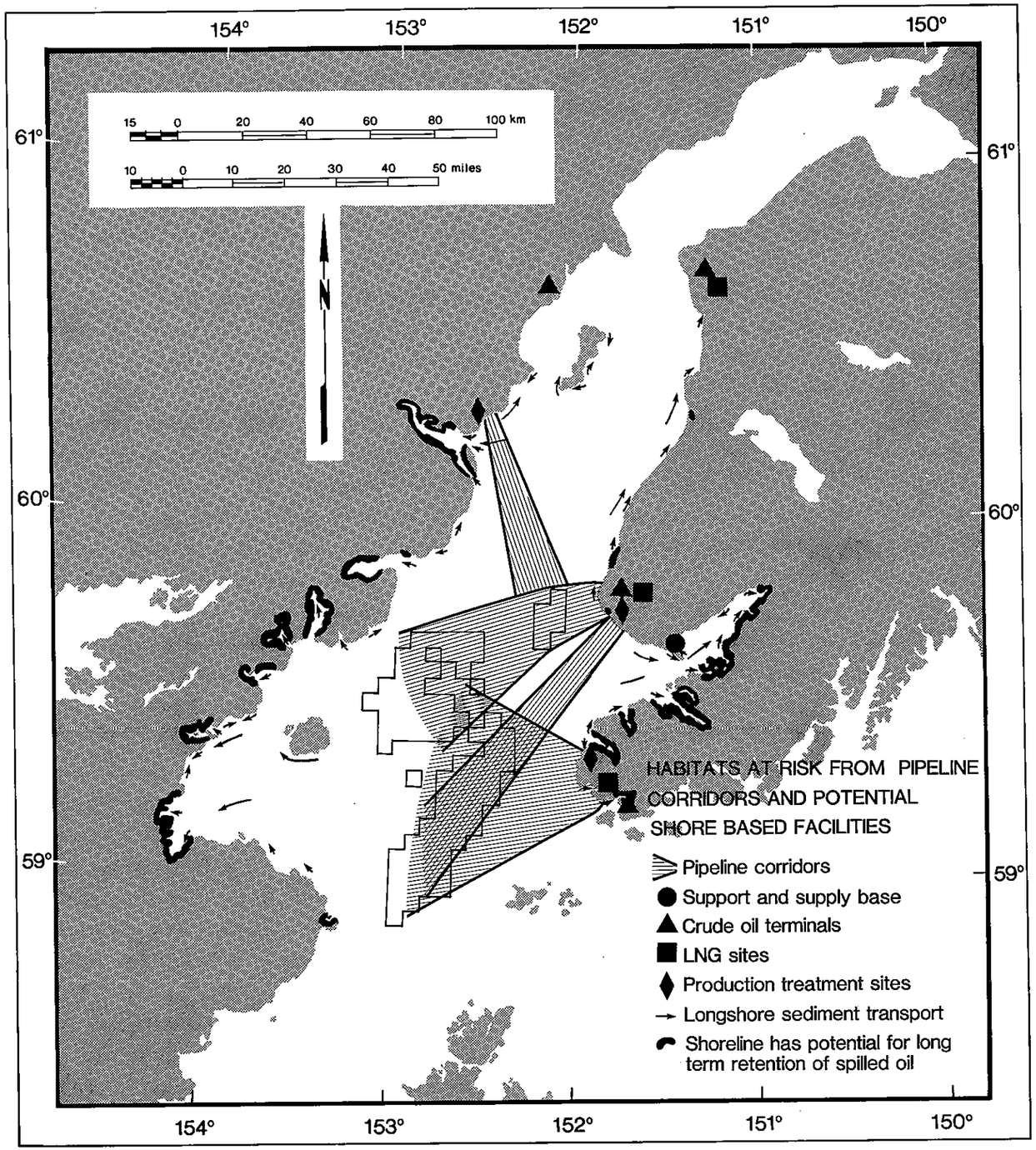


Figure 8.14 Habitats at risk from pipeline cooridors and potential shore based facilities.

The effect on bottom communities depends on the rates of adsorption of oil fractions to suspended particles and deposition, as well as sensitivity of the various populations. Cook Inlet oil could be adsorbed by suspended matter in Cook Inlet, and deposition of suspended sediments could also occur in Kamishak Bay (Feeley et al., 1978; Cline and Feeley, 1978).

Compared to effects on the shoreline and planktonic larvae, the benthos would probably be much less affected. However, special consideration should be given to important nursery areas of shellfish, such as the king crab settling and nursery area near shore between Iliamna and Dry Bay and that for Tanner crab near Cape Douglas (Fig. 8.4).

The major coastal habitats of Kamishak Bay (Fig. 8.4) at greatest risk from major oil spills in the lease area are in McNeil Cove, Bruin Bay, Ursus Cove, Iliamna/Cottonwood Bay, and Iniskin Bay (Fig. 8.14). Spilled oil reaching the shoreline might eventually enter the bays if incorporated in the nearshore sediment. Floating oil might also be transported into the bays by tidal currents and winds. The flushing rates of these coves or bays are unknown; however, sections of the intertidal zones, particularly the marshes and mudflats at the bay heads, are known to retain spilled oil for long periods.

Habitats at risk include the marshes and mudflats (foraging areas for waterfowl, shorebirds, juvenile pink and chum salmon), intertidal and shallow subtidal (spawning areas for pink salmon, chum salmon, and herring), and major nursery areas for juvenile king crab. A single oil spill that resulted in long-term retention of oil in the intertidal sediments could cause chronic harmful effects on associated biological populations. Vulnerable organisms would include the clams, polychaetes, and small crustaceans that provide food for shorebirds, waterfowl, juvenile salmon, and other fish. However, the most sensitive components would probably be the emergent salmon fry at the intertidal spawning areas and the herring spawn.

The eastern shore of Augustine Island is also at risk. Although the rocky shore would not retain spilled oil, acute effects on resident sea otters and harbor seals might be expected if a spill is large and particularly if it occurs during the spring and summer, when the animals are most numerous.

Kachemak Bay

A major oil spill within the easternmost leased tracts might result in the transport of oil into Kachemak Bay (Fig. 8.14). Drift bottle studies (ADF&G, 1978) do not support this hypothesis, but data were gathered in summer. Winter winds, or no wind, could cause oil to be transported into Kachemak Bay.

The dispersion of spilled oil reaching Kachemak Bay could be enhanced by oscillatory tidal excursions (Burbank, 1977) and, combined with net circulation, could cause wide dispersal in the Outer Bay.

Although the period of greatest biological activity and therefore sensitivity in Kachemak Bay is spring and summer, spilled oil from the lease area is most likely to reach the Bay in winter. During the spring and summer, prevailing wind patterns and net circulation would tend to keep oil out of the Outer Bay. In addition, surface water outflow past Homer Spit, which is maximum in spring, would limit transport into the Inner Bay.

Deposition of suspended material (at least during the spring and summer) occurs in the central part of Outer Kachemak Bay (Feeley et al., 1978), particularly in the Outer Bay gyre system which lies near the organically enriched clay and fine sand bottom described by Driskell (1977). If sediment (with ?) adsorbed oil is deposited in this area, it could affect bottom-dwelling organisms such as deposit-feeding clams and polychaetes, demersal fish, shrimp, king and Tanner crab.

Principal landfall areas indicated by the trajectory analysis include Anchor Point, Port Chatham, and the eastern part of the Outer Bay (including Homer Spit). The wetlands at the mouth of the Anchor River and sections of the shoreline at Port Chatham could retain spilled oil for a long time. Port Chatham contains major intertidal/shallow subtidal spawning habitat for pink salmon, herring spawning areas, and nursery areas for juvenile salmonids (Fig. 8.1).

In addition, longshore sediment transport and northwesterly winds could transport oil contaminants along the north shore toward Bluff Point, placing major feeding areas for overwintering sea ducks and nursery areas for king and Dungeness crabs in danger (Fig. 8.1).

Most of the southern shoreline of the Inner Bay could retain spilled oil for a long time. However, since it is nearest the Outer Bay and provides important foraging areas for waterfowl and shorebirds and feeding areas for chum and pink salmon juveniles, shrimp, and Dungeness crab, the China Poot Bay wetlands would be at greatest risk.

Kennedy Entrance

Because of the net circulation away from Kennedy Entrance toward the lease area, the presence of spilled oil in the Entrance will depend on the frequency of northerly and northwesterly winds and on tidal transport. These winds are most frequent in winter. Little suspended material is deposited here. This, combined

with northward-moving bottom currents, would probably minimize harm to offshore bottom communities. The landfall areas would be of more concern.

The principal areas at risk are the Koyuktolik Bay-Port Chatham area, Elizabeth Island, and the Barren Islands (Dames and Moore, 1978). Principal sources would probably be the eastern tracts of the lease area (Fig. 8.6).

The major concern is for Koyuktolik Bay and Port Chatham, Although the rocky outer shoreline would not retain spilled oil, sections of the shoreline inside these protected bays could retain it for long periods. Both contain intertidal/shallow subtidal pink and chum salmon spawning areas, spawning habitat for herring, overwintering habitat for shorebirds and waterfowl, and probably also nursery areas for Dungeness crab, king crab, and pink and chum salmon (Fig. 8.6).

As longshore sediment transport appears to be into these two bays, oil adsorbed onto sediment could be transported into the system. Whether oil is trapped in these bays depends to a large extent on flushing rates, which are presently unknown.

The sea otter, harbor seal and Steller sea lion populations at Elizabeth Island, the outer Kenai Peninsula coast, and the Barren Islands are at risk. The most sensitive period for both the sea lions and harbor seals is during the pupping and molting season (summer). This is also the most sensitive period for the large sea bird colonies on the Barren Islands. However, spilled oil is less likely to enter the area in summer than in winter.

Lower Central Region

Strong currents in the offshore region and little deposition of suspended material are evidence that spilled oil would probably pose little threat to the benthos of this region, but it would be a major threat to Kamishak Bay and the shoreline from Oil Point to Chinitna Bay.

Principal landfalls would be the north shore of Chinitna Bay and the shoreline between Oil Point and Chinitna Point.

Two major habitats are at risk (Fig. 8.8). Although the shoreline between Oil Point and Chinitna Point would not retain oil for a long time, the nearshore area between Oil Point and Dry Bay is a settling and nursery area for juvenile king crab and would be seriously harmed by spilled oil.

The north shore of Chinitna Bay is a large razor clam beach. Heavy concentrations of spilled oil could destroy these populations. The mudflats and marshland within the bay provide feeding areas for shorebirds and waterfowl and could retain oil for long periods. The flushing rates of this bay are unknown, but longshore sediment transport is into the bay along the north shore. Oil adsorbed onto sediment could enter the bay by this means. Southerly winds could transport oil along the shore and into the bay if the landfall was near the mouth.

Kalgin Island Region

Principal landfall areas, according to trajectory analysis, are the Redoubt Point area and Kalgin Island. Source points would be the northernmost tracts of the lease area.

The rips, which are not considered in the analysis, retain floating debris for long periods and they would probably have considerable effect on the trajectories.

Specific major habitats at risk are the waterfowl staging areas on the south side of Kalgin Island, the razor clam beaches at Polly Creek, and the Tuxedni Bay Area. In the last, the area surrounding Chisik Island is an important foraging area for seabird colonies on the island. Feeding seabirds could be harmed by spilled oil in this area during the spring and summer. Much of the shoreline of Tuxedni Bay, which supports foraging waterfowl and shorebirds, could retain spilled oil for long periods.

Oil adsorbed on sediment could be transported into the bay. In addition, spilled oil could be carried into the bay during flood tide. The flushing rate of Tuxedni Bay is presently unknown but would affect the capacity of the bay to trap oil.

Shorebased Facilities

The regions where the development of shorebased facilities (production treatment facilities, tanker terminals, LNG plants) are most likely Kachemak Bay, the Kennedy Entrance Region, and the Kalgin Island Region (Fig. 8.15). The principal environmental considerations are the prevention of permanent destruction of important habitats during construction, and accumulations of contaminants in important habitats. Although the release of contaminants would probably be small compared to those from platforms and pipelines (Task B), concentrations of pollutants in small bays and inlets could become a problem if flushing rates were low.

Kennedy Entrance Region

Two bay systems contain important biological habitats and are likely areas for the development of onshore facilities: Koyuktolik Bay and Port Chatham (Fig. 8.6). Although it is in the Kachemak Bay Region, the English Bay-Port Graham area is also considered here (Fig. 8.4), since it is part of the shore-based system

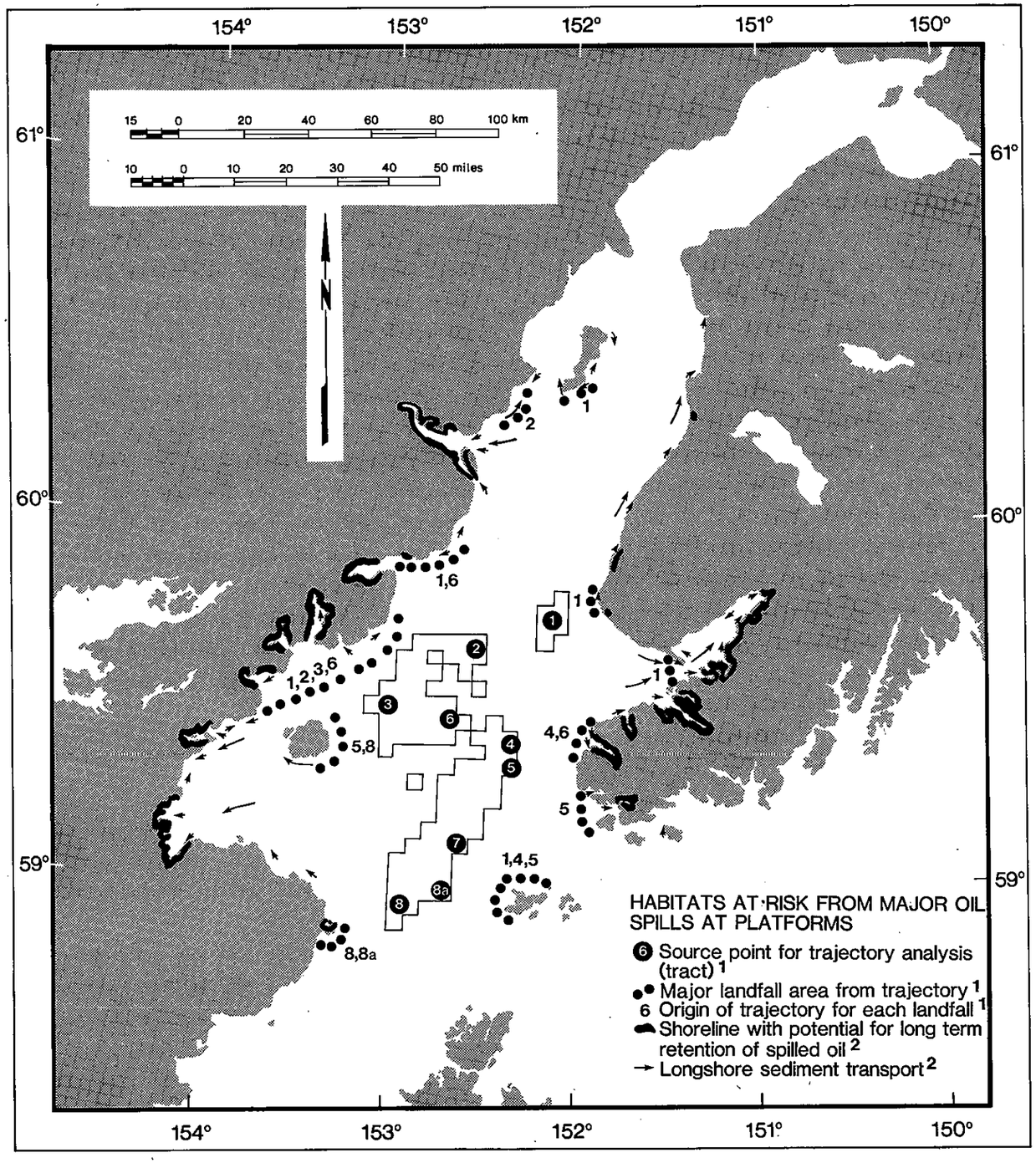


Figure 8.15 Habitats at risk from pipeline corridors and potential shore based facilities.

projected in the BLM Development Scenario. The habitats found in all four bays are similar and can, therefore, be discussed together.

Destruction of habitats during construction of facilities can be minimized by judicious siting, e.g., selecting an area that would require minimum dredging and little maintenance dredging (in the case of tanker terminals). Site selection is complicated and requires information not presently available on flushing rates and sediment transport patterns alongshore and in the bays.

If sites are selected inside the bays, and if flushing rates are slow, contaminants may accumulate. If sites are selected outside the bays, inflow currents and sediment transport may bring contaminants into the bays from surrounding areas.

Major habitats considered to be sensitive and to be protected are intertidal and shallow subtidal commercial fish spawning areas (pink slamon, chum salmon, herring), and nursery areas for juvenile salmon, Dungeness crab and king crab.

Kachemak Bay

Besides the English Bay-Port Chatham area discussed above, the other area in Kachemak Bay where onshore facilities are likely is Anchor Point. The major habitat at risk here is the nearshore area from Anchor Point to Bluff Point. This area, with its diverse benthic communities of macrophytes, epifauna, and infauna, supports juvenile king and Dungeness crab concentrations, overwintering sea ducks and is a potential feeding area for migrating salmon (Fig. 8.4). Although net circulation is toward Anchor Point and away from the area, winter winds are from the north and northwest and could drive spilled oil along the shore. In addition, longshore sediment transport is toward Bluff Point. If oil is incorporated in the sediment, it could be transported into this area from Anchor Point.

As was pointed out by Nyquist (LCSM, 1978), the area off Anchor Point is shallow and dredging would probably be required if a tanker terminal were built there. Maintenance dredging would also be necessary, but it would have to be done during periods that would avoid the nearshore migrations. Most suitable periods would be the late fall and winter.

Kalgin Island Region

The onshore facilities projected for the Kalgin Island Region include expansion of existing facilities at Nikiski and the pipeline landfall and associated production treatment facilities between Tuxedni Bay and Redoubt Point. The major habitat at risk in the case of the latter is the Polly Creek razor clam beaches (Fig. 8.12). The principal problems are discussed in the following section on pipeline corridors.

Pipeline corridors

The most important environmental consideration in selecting pipeline routes in Cook Inlet, with the exception of geohazards, is the avoidance of unique and biologically important areas. The most important effects would be chronic leaks and pipeline breaks. In most cases effects would be localized and probably greatest in sensitive nearshore areas with slow circulation and little capacity for dispersal.

The major regions at risk from installation of pipeline corridors are the Lower Central Region, Kennedy Entrance, Kachemak Bay, and the Kalgin Island Region (Fig. 8.15).

Lower Central Region

Since no landfall areas are projected for this region, major habitats of concern are the deep-water benthic communities. The benthic epifaunal and infaunal communities support Tanner and king crab and several species of demersal fish. This is the major Tanner and king crab harvest area in Cook Inlet (Fig. 8.8). This region has strong bottom currents, and it is quite probable that for most of the area the capacity for dispersal of contaminant releases may be quite high. Deposition of suspended particulates is low here, and accumulations in the sediments from leaks may not be detectable. Consideration of geohazards in siting, design, and laying of the pipeline will minimize pipeline breaks which could release large amounts of oil.

Kachemak Bay

The major habitats to be concerned with in Kachemak Bay are the important biological communities near shore between Anchor Point and Bluff Point (Fig. 8.4). The benthic communities here, which support juvenile Dungeness and king crab, overwintering sea ducks, and probably migrating salmon, could be at risk from pipeline leaks near shore. A possible transport mechanism to consider is the adsorption of oil onto nearshore suspended sediments and bottom sediments and transport of such sediments into this area.

A major pipeline rupture in winter could cause an oil slick that would be driven by northwesterly winds along the shore, endangering overwintering seaducks and possibly the benthic communities. Careful siting, design, and laying operations to avoid geohazards can prevent a rupture.

Kennedy Entrance

Corridors projected for the Kennedy Entrance are associated with shore-based facilities projected for the Kenai Peninsula. Major considerations for the offshore segments are the same as those described for the Lower Central Region: avoidance of geohazards, such as the steep ramps and short surface faults existing off the Kenai Peninsula, that could result in major oil spills from pipeline ruptures.

A major pipeline rupture near shore could pose a hazard for Koyuktolik Bay, Port Chatham, English Bay, and Port Graham. If it occurred during the spring, summer, or fall when southerly winds are more dominant or when winds are moderate (0-10 kts) and net circulation becomes the dominant transport mechanism, movement into the southern coastline of Kachemak Bay could occur.

Habitats at risk from chronic releases in nearshore areas are Koyuktolik Bay, Port Chatham, English Bay, and Port Graham. The outer coastline of the Kenai Peninsula provides a major pathway, and probably an important feeding area, for migrating salmon. Strong currents in the Kennedy Entrance will probably disperse releases from chronic leaks rapidly. The levels of hydrocarbons that affect migrating behavior are not known.

Kalgin Island Region

The pipeline corridor projected for the Kalgin Island Region is associated with the projected production treatment facility between Tuxedni Bay and Redoubt Point. The bathymetry between Tuxedni Bay and Kalgin Island is complex (Becker, Appendix) and geohazards must be avoided. This is particularly important near shore since two major habitats could be at risk from an oil spill in this area: the marine bird colonies in Tuxedni Bay and the razor clam beaches at Polly Creek (Fig. 8.12). Although circulation in this area is not well known, nor is the flushing rate of Tuxedni Bay, oil adsorbed onto sediment could be transported alongshore into the bay from the mouth of Polly Creek. Northerly winter winds and tidal currents could also transport spilled oil into the bay, though there is no evidence for this at present. Sections of the shoreline, including the west shore of Chisik Island, which could retain spilled oil for a long time, provide overwintering habitat for waterfowl and shorebirds.

Tanker, Support Boat, and Aircraft Traffic

The basic environmental problems that may be expected from increased marine traffic associated with OCS oil and gas exploration or development are: fuel leaks, major oil spills from tankers, interference with commercial fishing activities, and disturbance of normal activities of cliff-nesting colonial birds and breeding marine mammals. At present, the major potential problems in Lower Cook Inlet are large-volume tanker spills and the interference of tanker traffic with commercial fishing activities.

Tanker routes are projected in the Kennedy Entrance Region, Kachemak Bay, the Kalgin Island Region, and the extreme eastern part of the Lower Central Region (Fig. 8.16). An oil spill could occur anywhere along a projected tanker route, and the results of trajectory analysis (Dames and Moore, 1976; 1979) and drifter studies (ADF&G, 1978) suggest that almost any area of Lower Cook Inlet could be at risk. Much depends on seasonal winds, tidal currents, and net circulation.

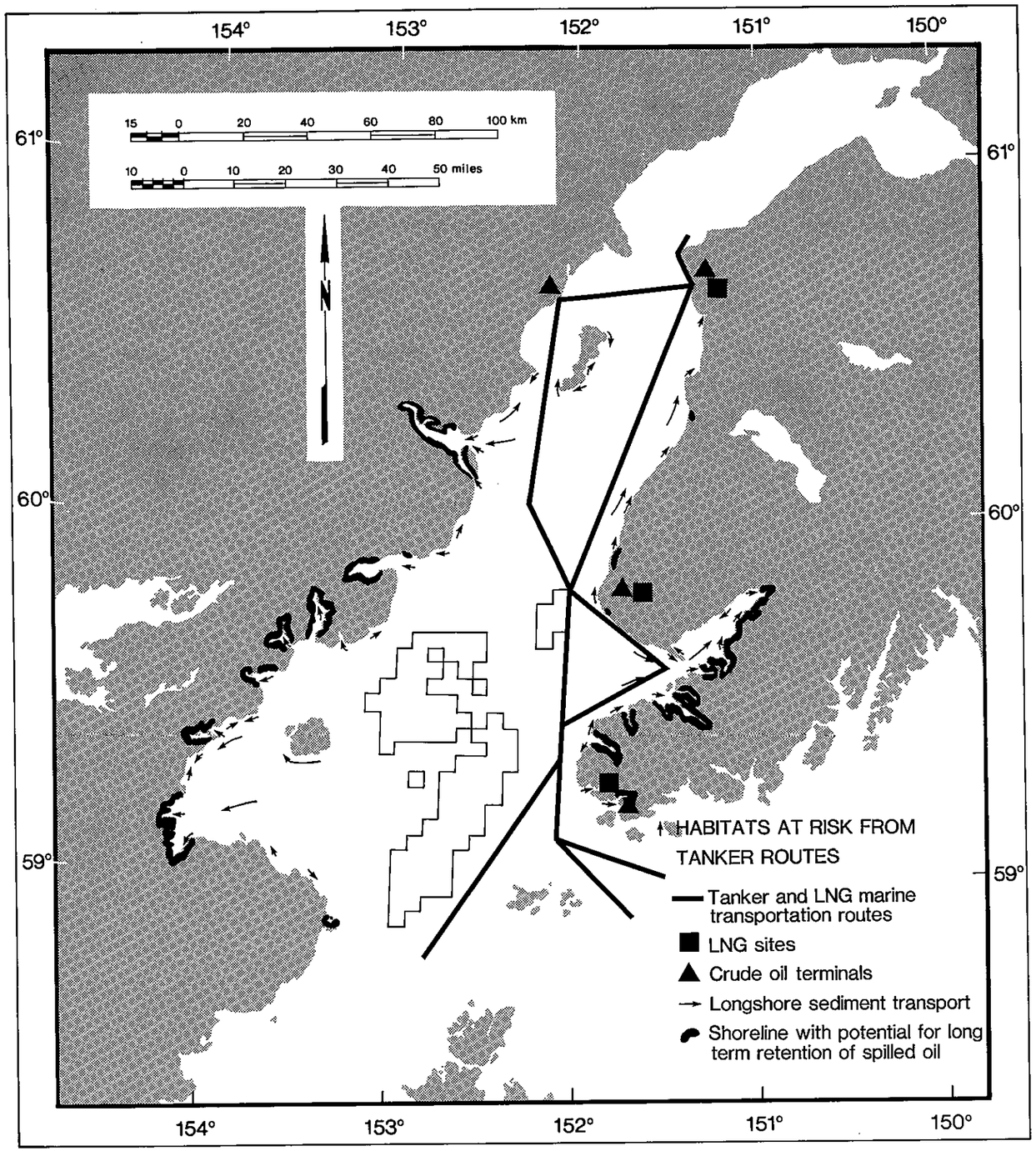


Figure 8.16 Habitats at risk from tanker routes.

The rate of spillage from tanker operation and the potential for a large spill depend upon the size of the offshore production. Large-volume spills usually occur near shore. If the greatest risk of spillage is near projected tanker routes and particularly on those routes which run near shore, the regions in Lower Cook Inlet at greatest risk are Kennedy Entrance, Kachemak Bay, and the Kalgin Island Region.

Kennedy Entrance

The greatest danger from spilled oil here is from tankers. Oil transport from a tanker spill to an important habitat could occur during any season, including the biologically active period of spring and summer. Much would depend on whether the spill occurred outside the Entrance, within the Entrance, or northward toward Point Bede. The tanker routes place the source of a potential spill much closer than platforms to important habitats in this region.

An oil spill just outside of Kennedy Entrance during the spring and summer could endanger important foraging areas of sea lions and harbor seals, as well as sea otters (Fig. 8.6). This is because the net circulation and southerly winds would transport spilled oil into the Entrance, possible reaching the Chugach and Barren Islands. These marine mammals would be most vulnerable then, since the largest concentrations occur at this time, which is the pupping and molting season.

An oil spill just outside Kennedy Entrance or within the Entrance itself during the spring and summer could also result in transport of oil into Koyuktolik Bay and Port Chatham, both of which contain important habitats and both of which have sections of shoreline which could retain oil for long periods.

Kachemak Bay

The tanker routes projected for Kachemak Bay place all the important habitats in this system in danger from tanker spills (Fig. 8.5). The greatest risk is for those habitats in Outer Kachemak Bay, but the Inner Bay could be endangered under appropriate wind and tide conditions.

Another problem in Kachemak Bay is the conflict of tanker traffic with the important commercial crab pot fisheries (Tanner and king crab).

Where specific shipping lanes are designated, crab pots can be placed out of the way of moving vessels. In important fishing grounds, such as Kachemak Bay, there are no designated shipping lanes and, therefore, crab pot losses from large ships can be substantial. The projected tanker routes in Fig. 8.16 are commonly used routes only and are not designated shipping lanes. Crab pot losses from ships commonly occur in Kachemak Bay and will probably increase with future increased tanker traffic.

Kalgin Island Region

Increased tanker traffic to the Nikiski facilities and Drift River Terminal would increase the possibility of a tanker spill in this region. The projected tanker route to Nikiski runs near the eastern shore. Important habitats along this shore include the Clam Gulch razor clam beaches and the mouths of the Kasilof and Kenai Rivers. The river mouths are important habitats (Fig. 8.12), and the two streams are the major salmon producers in Lower Cook Inlet. Drift card studies show these habitats to be at risk from spills along the east shore (Burbank, 1977; ADF&G, 1978).

Ice and tide hazards related to shipping and the potential for increasing the possibility of a major oil spill in this region during the winter need to be considered in expanding the Nikiski terminal.

A second projected tanker route runs along the west shore of the Kalgin Island Region to the Drift River Terminal. Although little information on local transport patterns is available, the important habitats in the following areas are probably at risk: the foraging area for marine birds off shore adjacent to Tuxedni Bay, Tuxedni Bay itself, Polly Creek, Redoubt Bay, and the staging area for migratory waterfowl on the southern shore of Kalgin Island (Fig. 8.12).

GLOSSARY

ACCRETION: a process of continental growth resulting from convergence of two lithospheric plates; as the subducted (or underthrust) plate descends, material originally between the plates or on the surface of the descending plate is compressed and added (accreted) to the upper stationary plate.

ALCID: any member of the avian family Alcidae, a group of marine diving birds. The family is confined to the northern hemisphere and its members breed in colonies on cliff ledges and in burrows. Includes auks, murres, guillemots, murrelets, auklets and puffins.

ADF&G: Alaska Department of Fish and Game, a state regulatory agency which conducts research on sport, commercial, and other wildlife species.

ADVECTION: in oceanography, the horizontal or vertical flow of seawater as a current without mixing with the surrounding water.

AFTERSHOCKS: smaller earthquakes which follow the largest earthquake of a series; all shocks occur in a restricted crustal volume and are related to the same strain release event.

ALEUTIAN ARC: prominent geographical feature which includes the Aleutian Island chain and extends into the Alaskan mainland; it is expressed topographically by volcanic peaks and ranges, and by the Aleutian Trench; the arc is a product of subduction of the Pacific Plate under the North American Plate. (See also PLATE TECTONICS.)

ANADROMOUS: pertaining to the life history of such fish as salmon and shad, in which young hatch in fresh water and migrate to marine waters where most of the adult stage is spent. Adults migrate back to natal fresh water to spawn.

ANDESITIC: pertaining to a rock type commonly associated with volcanism on the perimeter of the Pacific Ocean (the "ring of fire" which surrounds the Pacific lithospheric plate).

ANNELID: any member of the phylum Annelida, including the polychaete and oligochaete worms and the Hirudinea (leeches). They are found in marine, fresh water and terrestrial environments. The major distinguishing characteristic is the division of the body into similar rings or segments.

ANNULUS: the space around a pipe suspended in a wellbore; its outer wall may be either the wall of the borehole or the casing.

ANTICLINE: a fold in a geologic formation which is convex upward, generally forming ridge or hill topography. The oldest strata are in the core of the fold.

AROMATICS: a group of organic compounds containing at least one six carbon ring (benzene ring): abundant in crude oil and derived petroleum products.

ATOMIC ABSORPTION: a spectrographic method for detecting elements based on their characteristic absorption of specific wavelengths of radiation.

AVIFAUNA: species of birds in a specific region.

BAROCLINIC CURRENT: A current that is driven exclusively by the internal distribution of density within a water mass.

BAROTROPIC CURRENT: A current that is driven by the slope of the sea surface.

BASALT: in general, any fine-grained, dark colored, extrusive volcanic rock. The principal component of the crustal rock of the ocean floor.

BATHYMETRY: the topography of the ocean bottom or a display of ocean depths.

BCF: Bureau of Commercial Fisheries - Currently: National Marine Fisheries Service. An agency within NOAA for the research, development and maintenance of U.S. fishery resources.

BENIOFF ZONE: planar zone (within the earth) of intense earthquake activity dipping in the direction of a descending (subducting) lithospheric plate.

BENTHIC: refers to organisms (the benthos) living in, on, or occasionally associated with aquatic sediments. These organisms include bacteria, plants, and animals.

BIOGENIC HYDROCARBONS: organic compounds containing only carbon and hydrogen, formed by the physiological activities of organisms.

Biogenic hydrocarbons include saturated and unsaturated aliphatic hydrocarbons, as well as branched-chain hydrocarbons, especially the isoprenoids. Naphthenic and aromatic hydrocarbons occur at very low levels in marine organisms.

BIVALVE MOLLUSC: any member of the class Pelecypoda, phylum Mollusca. Distinguishing characteristics include two laterally compressed hinged shells and a large, muscular wedge-shaped foot for locomotion and burrowing. Most are sedentary and are filter-feeders involving gills. They range from 1 mm to 1 m in length. Examples are clams, scallops, mussels.

BLOWOUT PREVENTER: equipment installed at the wellhead to control pressures in the annular space between the casing and drill pipe, or in an open hole during drilling and completion operations.

BOTTOMFISH: bottom-living or demersal fish. They usually enter the benthos as larval forms. They prey on all size groups of bottom dwelling organisms. Most demersal fish species remain at or just above the bottom as epifauna but some browse or bury themselves in the sediment surface. Example: flounder, sole.

BRYOZOA (POLYZOA): sea-mats, corallines. Phylum of small, aquatic, usually fixed and colonial animals, superficially resembling hydroid coelenterates but considerably more complex. Have ciliated tentacles with which they feed; anus; coelom; some have horny or calcareous skeletons. Contains two classes, Ectoprocta and Endoprocta, which are sometimes regarded as distinct phyla.

CALANOID: any member of the order Calanoida, subclass Copepoda, class Crustacea. Most species are marine, freeliving, and planktonic, with global distribution. The body is divided into differentiated segments with varied appendages for swimming and feeding. An important source of food for many other marine organisms. Size ranges from 0.1 to 1.0 mm.

CARNIVORE: an animal that feeds principally or entirely on other animal tissues, either living or dead.

CASH BONUS TRACT: a tract on which the bidder offers a front end cash value on a dollars-per-acre basis; a minimum of 16.6% of oil/gas profits pass to the federal government.

CEPHALOPOD: Any member of the class Cephalopoda, phylum Mollusca. Characterized by a crown of tentacles surrounding the head and often a reduced shell; highly mobile swimming animals. Examples: squid, octopus.

CETACEAN: any member of the mammalian orders Mysticeti and Odontoceti, all members of which are adapted for a completely aquatic existence. The Mysticeti consist of the baleen whales, which feed by straining small organisms from the water through baleen plates (or "whale bone"). The Odontoceti include the toothed whales such as sperm whales and killer whales, porpoises and dolphins.

CHEMOTROPHS: microbial organisms (bacteria) which synthesize organic compounds from energy derived through chemical reactions rather than from the sun.

CIRQUE: erosional morphologic feature remaining after a mountain glacier has melted away; characterized by a smooth, curved slope at the head of the valley which the glacier occupied; similar in shape to a Roman armchair.

COHORT: a group of individuals having a statistical factor, such as age or class membership, in common in a demographic (population) study.

COMMUNITY: an association of interacting populations occupying a specific locality.

COMPACTION: decrease in volume of sediments due to compression, usually resulting from continued deposition above them, but also from drying and other causes.

COPEPOD: Any member of the subclass Copepoda, class Crustacea. Exist in a variety of aquatic habitats, have elongated segmented bodies, forked tails. May be herbivorous or carnivorous. Often dominate planktonic communities and are important food items for fish and baleen whales. Size range is on the order of mm.

CORIOLIS FORCE: apparent force due to the earth's rotation, causing a moving particle to be deflected to the right of motion in the northern hemisphere, and to the left in the southern hemisphere; it is proportional to the speed and latitude of the moving particle and cannot change the speed (only the direction) of the particle.

CPUE: catch per unit effort, i.e., the number of fish or shellfish caught by a particular method over a specified period of time.

CRITICAL HABITAT: (a) a limited area composed of special physical qualities (i.e., temperature, substrate type, food availability) used by a species as a necessary site for some biological function, (e.g., spawning, denning, breeding). As a consequence of an area's functional use, it may be a location of high productivity (e.g., rookery, fishing grounds). Impairment of the space may jeopardize the viability of one or more species. (b) A critical habitat may also be a "fragile" area, vulnerable to physical perturbations, easily altered in character such as an area supporting high species diversity, or an area that requires a long recovery period following damage (i.e., tundra, coral reefs, estuarine marshes). High-latitude ecosystems are particularly susceptible because temperature and climatic regimes preclude rapid growth of many of the life forms. (c) An area may also be considered as critical from an economic or cultural aspect. Included are areas of economic resources such as commercial fisheries and areas of archaelogical and scenic value. (d) Any air, land, or water area, including any elements thereof, that the Secretary of the Interior, through the Director, U.S. Fish and Wildlife Service, or National Marine Fishery Service, has determined is essential to the survival of wild populations of a listed species or to its recovery to a point at which the measures provided pursuant to the Endangered Species Act of 1973 are no longer necessary. Such determinations are published in the Federal Register.

CRYPTIC SPECIES: a species adapted by color, size, texture or morphology to appear as inconspicuous as possible in its surroundings.

DEMERSAL SPECIES: organisms which spend most of their life history at or near the ocean bottom, including remaining at or just above the bottom or burrowing or browsing in the sediment surface.

DEPOSIT-FEEDING: consuming of edible material from sediment or detritus, either by ingesting material unselectively and excreting the unusable portion, or selectively by ingesting discrete particles.

DETRITUS: non-living particulate debris in the sea, including inorganic and organic materials and particulates originating from dead organisms. An important source of food for many organisms.

DEVIATION WELL: a well drilled at an angle from the vertical.

DOWNWELLING: the downward motion of water caused by the convergence of two or more water masses.

DYNAMIC TOPOGRAPHY: the height of the ocean surface above some reference level, usually a level of constant pressure. Differences in height are caused by differences in the density of water between the surface and the reference level.

ECHINODERM: any member of the invertebrate phylum Echinodermata. They are characterized by radial symmetry, no segmentation or well-defined head region. All are marine, most are nearshore bottom-dwellers. Examples: sea stars, sea cucumbers, sand dollars, sea lilies, sea urchins.

EDDY: circular movement of water, usually formed where currents pass obstructions, between two adjacent currents flowing counter to one another, or along the edge of a current such as the Gulf Stream.

EDIS: Environmental Data and Information Service (formerly EDS). Department within National Oceanic and Atmospheric Administration composed of five data collection and dissemination facilities on various aspects of environmental sciences, including oceanography, weather, marine geology, and geophysics.

EKMAN LAYER: that part of a water column influenced by frictional forces. Wind blowing over the ocean surface causes a surface Ekman layer and the friction of currents flowing across the bottom causes a bottom Ekman layer.

ELASMOBRANCHS: Fish which are members of the class Elasmobranchii. Characterized by cartilaginous skeletons, well-developed sense organs and swimming musculature; includes sharks, rays and skates.

EPIBENTHOS: organisms that live at or just above the sediment surface. Includes animals (epifauna) and plants (epiflora) such as king crab and algae respectively.

EPICENTER: point on the surface of the earth directly above the focus (or hypocenter) of an earthquake.

EPIFAUNA: See EPIBENTHOS

EULERIAN MEASUREMENTS: Eulerian current measurements taken at a fixed point, such as a current meter attached to a buoy. They differ from Lagrangian

measurements which are made by following a device that drifts with the currents.

EUPHAUSIIDS: members of the order Euphausiacea, class Crustacea. These are shrimplike animals differing from true shrimps in not having the first three pairs of thoracic limbs modified as mouthparts; entirely marine, often occurring in dense populations. They constitute the main food of baleen whales. Also known as krill.

FAULT: a fracture or zone of fractures in rock along which there has been relative displacement of the adjacent sides; amount of displacement varies from centimeters to kilometers and direction may be vertical or horizontal.

FAULT SCARP: the cliff formed by vertical movement along a fault.

FECUNDITY: rate at which a female individual produces offspring.

FINES: the fine fraction of a sediment; finer than 0.074 mm in particle diameter.

FLUX: in oceanography, the rate of transport of fluid properties such as momentum, mass, heat, or suspended matter by advection or turbulent motion.

FOOD CHAIN: an abstract representation of the transfer of energy from its primary source (the sun) to plants and the various animals in a community. Example: algae - insects - small fish -larger fish - fish-eating birds or mammals.

FORMATION WATERS: water naturally occurring in sedimentary strata.

FUMAROLE: hole or vent associated with volcanism, through which fumes or vapors issue.

GADIDS: fish belonging to the family Gadidae; include the cod fishes, hakes and haddocks.

GAMMARID AMPHIPOD: any member of the suborder Gammaridea of the order Amphipoda, class Crustacea. Like other amphipods, these marine invertebrates are laterally compressed. The gammarids comprise a large and important group and are often associated with the bottom of freshwater and marine systems. An example is the sand hopper. Size range in mm.

GAS CHROMATOGRAPHY: a method for identifying molecules based on their characteristic retention times on liquid or solid substrates.

GASTROPOD: any member of the class Gastropoda, phylum Mollusca. Aquatic and terrestrial, most possess a shell which may be whorled. Locomotion is by means of large muscular foot. Examples: snails, limpets, slugs.

GEOSTROPHIC CURRENTS: ocean currents resulting from the balance of the pressure gradient force and the force associated with the acceleration due to the rotation of the earth (the Coriolis force). The distribution of geostrophic currents can be inferred from charts of dynamic topography

GEOTECHNICAL PROPERTIES: the physical properties of sediments and rocks that are especially important for engineering purposes; these properties include porosity, permeability, and shear strength.

GRAVIMETRIC ANALYSIS: laboratory analytical procedure made in terms of weight or mass units.

GYRE: a closed or nearly closed circulation pattern in the horizontal plane.

HABITAT: The environment of animal or plant species, characterized by the physical and biological components that are necessary for the survival of the species.

HEAVY METALS: transition elements on the periodic table. Generally present in sea water in trace amounts, i.e., quantities less than µg/l. Examples: zinc, nickel, lead.

HERBIVORE: an organism that feeds principally or entirely on living plants or plant products.

HARPACTICOID: any member of the order Harpacticoida, subclass Copepoda, class Crustacea. Marine and freshwater invertebrates usually living on or in the bottom sediments. See COPEPOD. Size range in mm.

HETEROTROPH: an organism incapable of synthesizing its own food; it depends on other organisms, such as green plants, as its source of food. Includes all animals, fungi, parasites.

HEXAGRAMMID: fish belonging to the family Hexagrammidae. Examples: greenlings, lingcod.

HOLOZOOPLANKTON: animals which spend their entire lives floating in open water. Example: copepods.

HYPOCENTER: point within the earth where rupture first occurs during an earthquake; also referred to as focus or source.

INFAUNA: animals which live within the sediment, utilizing either the interstitial space between sediment particles, or burrows or tubes. Example: razor clam.

INPFC: International North Pacific Fisheries Commission. Member countries include the United States, Canada, and Japan. Its purpose is primarily to determine the oceanic distribution, abundance and migration of salmon.

INTENSITY: a subjective measure of earthquake size based on felt effects and damage to structures; the Mercalli scale contains the commonly used criteria for various levels of intensity (described with Roman numerals).

IPHC: International Pacific Halibut Commission, Member countries include the United States and Canada. Its purpose is to regulate catches of Pacific halibut in order that the population remain healthy and that maximum catches be sustained.

ISOPYCNAL: In oceanography, a line connecting all points of equal water density on a map; an isopleth of density.

ISOSEISMAL: lines or contours on a map connecting observations of equal intensity of felt effects or structural damage due to an earthquake.

KELP: any large brown seaweed of the family Laminariaceae.

KEY SPECIES: a species that plays an important ecological role in determining the overall structure and dynamic relationships within a biotic community. A component species of a biotic community whose presence is essential to the integrity and stability of a particular ecosystem. Key species may be unimportant as energy transformers in a biotic community (i.e., they may be neither very abundant nor consume large portions of the biotic productivity of a community). However, slight variations in their abundance results in large changes in the abundance of other species and/or in biotic-community relationships and structure (Example: sea otter).

LAGRANGIAN (DRIFTER) MEASUREMENTS: current measurements made by tracking a device such as a drogue, which drifts with the ocean currents. The trajectory of the drifter is assumed to represent the trajectory of the surrounding water.

LC_{50}: (lethal concentration$_{50}$) the concentration of a toxic substance necessary to kill 50% of a test population. (Usually defined for a specific time period.)

LIQUEFACTION: process during which soil and sand behave as a dense fluid rather than as a wet solid; may occur spontaneously in marine sediments during an earthquake and result in severely reduced bearing strength of the sediment.

LITHOSPHERE: the solid outer shell of the earth; the earth's crust; contains the relatively rigid plates, both oceanic and continental, which are in motion and produce the near surface physiography of the earth. (See PLATE TECTONICS) Primarily granite in continental areas, basalt in oceanic areas.

LITTORAL: pertaining to intertidal and shallow subtidal waters. Sunlight is able to penetrate and large seaweeds can grow.

MACROPHYTE: a macroscopic plant. In aquatic communities, these include seaweeds and emergent vascular plants (sea grasses).

MAGMA: naturally occurring mobile rock material generated within the earth at high temperature and pressure; may contain both solid and liquid phases; the source of volcanic rocks extruded on the earth's surface.

MAGNITUDE: a rough measure of earthquake size based on the ground motion recorded by a seismograph. It is calculated by taking the common logarithm of the largest motion (revealed by a deflection on the seismograph) recorded during the arrival of a seismic wave. A correction for distance between the seismograph station and the epicenter is applied. A unit increase in magnitude indicates a tenfold increase in earthquake size. Ground motion is represented by three seismic wave types, any of which may be used to determine magnitude: two are body waves (P and S), which travel through the earth, and the third is a surface wave, which travels near the surface of the earth. Magnitudes are identified by the wave type used during the

calculation: body wave magnitude (m_b) and surface wave magnitude (M_s). "Richter" magnitude (M_L) is based on the largest seismograph deflection only and does not specify wave type.

MARINE RISER: a telescopic pipe running from a floating drilling rig to the ocean floor which is used to direct the drill stem and carry mud.

MARMAP: Marine Monitoring, Assessment, and Prediction, a program of the National Marine Fisheries Service to evaluate the fisheries resources of the United States.

MEIOFAUNA: animals between 0.5 and 5 μm long usually living in the interstitial areas of the upper layer of sediments in aquatic environments.

MERCALLI SCALE: See INTENSITY.

MESOPHILIC: microbial organisms which grow well at temperatures from 20° to 45°C but which will not grow well at temperatures outside this range.

MESOPLANKTON: phytoplankton, zooplankton or larvae between 0.5 amd 1 mm in size.

MESOSCALE: a size scale of 10 to 100 km for measuring oceanographic features.

MICROFLAGELLATE: microscopic plant or animal species having one or more flagella, long whiplike structures used for locomotion.

MOHO: Mohorovicic discontinuity; boundary between crust and mantle as indicated by a rapid increase in seismic wave velocity; occurs at a depth of 5 km under the oceans and 30 to 45 km under continents.

MYSID: any member of the higher crustacean order Mycidacea. Shrimplike animals which are characterized by having eight or nine thoracic appendages. The females possess a brood pouch, are planktonic in lifestyle. Size range on the order of mm. Also called opossum shrimp.

NEARSHORE: a term that is loosely defined and whose meaning is dependent on the discipline of the user: 1) that area of an aquatic environment between the high water mark and the point offshore where the wind influences currents in the entire water column; 2) the area between the high water mark and the point where the depth of the water column becomes shallow enough to cause waves to break; 3) oceanic waters of depths shallower than 200 m (neritic).

NEMERTEAN: any member of the invertebrate phylum Nemertina or ribbon worms. Elongated, flattened body with distinctive proboscis (an anterior feeding appendage). They live in shallow marine habitat under stones, or in sand, or mud. All are carnivores. Range in size from an inch to several feet.

NERITIC: referring to oceanic waters of depths shallower than 200 m.

NGSTDC: (or NGSDC) National Geophysical Solar-Terrestrial Data Center, part of the Environmental Data and Information Service within the National Oceanic and Atmospheric Administration. One of the five major facilities of the EDIS, its purpose is to acquire and disseminate data in the fields of seismology, marine geology and geophysics, geomagnetism, and related fields.

NMFS: National Marine Fisheries Service, a branch of the National Oceanic and Atmospheric Administration, whose purpose is to research the development and maintenance of fish resources. (Formerly Bureau of Commercial Fisheries)

NODC: National Oceanographic Data Center, part of the Environmental Data and Information Service within the National Oceanic and Atmospheric Administration. One of the five major facilities of the EDIS, its purpose is to acquire and disseminate oceanographic data.

NONSAPONIFIABLE: organic compounds which are not soluble in an alkali solution.

NORTH AMERICAN PLATE: lithospheric plate which includes most of the North American continent. See PLATE TECTONICS.

NPDES: National Pollution Discharge Elimination System: a program in which the EPA regulates permissible discharges from drilling platforms through monitoring, establishment of standards, and issuance of permits.

NUEE ARDENTE: extremely hot gaseous cloud of volcanic ash ejected during an explosive eruption; may flow downslope like an avalanche at high speeds; associated with pyroclastic ash flows.

OFFSHORE: 1) those deeper waters beyond the nearshore zone seaward to the edge of the continental shelf. See NEARSHORE. 2) All area of an aquatic environment seaward of the high water mark, as opposed to the onshore environment.

OLEFINIC HYDROCARBON: an unsaturated, (i.e., containing at least one carbon-to-carbon double bond) straight or branched hydrocarbon in which the carbon atoms are arranged in an open chain.

ONSHORE: landward from the point of highest tidal influence.

OSMERID: fish belonging to the family Osmeridae; mainly small marine fish which spawn in fresh water. Examples: smelts, eulachon, and capelin.

PACIFIC PLATE: lithospheric plate underlying most of the Pacific Ocean. See also PLATE TECTONICS.

PELAGIC: relating to, or living or occurring in the open sea; oceanic.

PELECYPOD: See BIVALVE MOLLUSC.

PHENOLOGY: The study of the periodically recurring natural phenomena and their relation to climate and changes in season.

PHYTOPLANKTON: algae which live in the open water, passively drifting with the currents. Size ranges from microns to a few centimeters.

PINNIPED: Any member of the mammalian suborder Pinnipedia, a group of carnivores adapted to marine life, but which breed on land; for example, sea lions.

PLANKTON: organisms inhabiting aquatic environments which are weak swimmers or passive drifters. Includes phytoplankton (algae) and zooplankton (invertebrates and larval fish).

PLATE TECTONICS: contemporary hypothesis which explains the continuing evolution of the earth's crust; proposes that the surface of the earth is composed of approximately 12 rigid, relatively thin (100 to 500 km), lithospheric plates which are in continuous motion relative to each other; earthquakes, volcanism, and mountain building are concentrated at plate margins as a result of plate motions; mechanism explaining Continental Drift.

PLEURONECTIDS: fishes which are members of the family Pleuronectidae. These are the right-eyed flounders (the eyes of the flatfish migrate to the right side of the head at metamorphosis). Examples: halibut and flounder.

PLUG DOME: a steep-sided protrusion of viscous lava forming a dome-shaped or bulbous mass over a volcanic vent.

POLYCHAETE: any member of the class Polychaeta of the phylum Annelida. Segmented worms that are chiefly marine, including sedentary (living in self-secreted tubes or burrows) and free-moving forms. Distinguishing characteristics include lateral appendages (parapodia) on each segment for food gathering and locomotion. The majority are 5-10 cm in length.

PSYCROPHILIC: type of microbial organism which grows fairly rapidly in temperatures of 10° to -8°C; these organisms may also grow well in the mesophilic range (20° to 45°C).

PYROCLASTIC MATERIAL: hot, often incandescent, ash and other debris ejected during an explosive volcanic eruption.

RICHTER MAGNITUDE: See MAGNITUDE.

RISER: a pipe through which liquid travels upward.

ROYALTY TRACT: tract lease for which the bidder offers a minimal cash payment but instead proposes to pay the federal government a significant royalty on any oil/gas profits. Royalties in excess of 60% have been proposed.

SALMONID: fish which are members of the family Salmonidae. Examples: salmon, trout, char, whitefish.

SATURATED HYDROCARBON: a hydrocarbon in which all the carbon-to-carbon bonds in the molecule are single bonds.

SEISMIC GAP: geographical area within a larger seismic trend which displays a relative scarcity of seismic activity; may also be used in a temporal sense to indicate an inactive time period during a longer period trend of seismic activity.

SEISMIC REFLECTION SURVEY: technique to measure the depth to various geologic horizons, such as the bottom of unconsolidated sediment deposits and

various rock formations. An energy pulse is projected into the earth and the travel time for the pulse to penetrate and reflect back to the surface is measured; this travel time is converted to distance (i.e. depth, thickness, etc.) by knowing the velocity at which the energy pulse travels through the geologic formation.)

SEISMICITY: physical disturbances in the earth caused by earthquakes or explosions; the occurrence of earthquakes in space and time.

SEISMOGRAPH: an instrument which detects and records ground motions due to the passage of seismic energy waves through the earth.

SHALE SHAKER: a vibrating sleeve that removes cuttings from the circulating fluid stream in rotary drilling operations.

SHELF BREAK: the transition seaward from continental shelf to continental slope, marked by an abrupt change in the bottom slope.

SIGMA-T (σ_T): abbreviated value of the density of a seawater sample after the effect of pressure on density has been removed. To find the equivalent value of density expressed in gm/cm^3, divide σ_T by 1000 and add 1.0.

SLIDE: mass of unconsolidated material moving downslope, with little coherency.

SLUMP: mass of material moving downslope, primarily as a unit and along a single surface; often occurs with a backward rotation on an axis parallel to the strike (plane of inclination) of the slope.

SPARKER: a type of seismic reflection equipment for marine surveys which uses an electrical spark to generate an energy pulse.

SPUD: to commence actual drilling operations.

STD MEASUREMENTS: STD stands for salinity, temperature and depth. Measurements of the salinity and temperature at various depths allow dynamic topographies to be constructed. (See also DYNAMIC TOPOGRAPHY).

SUBDUCTION ZONE: lithospheric plate margin where one crustal plate (generally oceanic) is thrust under another (generally continental) as the result of the convergence of two plates; a deep trench may be formed, such as the Aleutian Trench or Peru-Chile Trench. See PLATE TECTONICS.

SUBLITTORAL: pertaining to the area of an aquatic environment below the littoral zone where sunlight is able to penetrate.

SUSPENSION-FEEDING: filtering or trapping edible particles that are suspended in the water; a feeding mode typical of many zooplankters and other marine organisms of limited mobility.

SVERDRUP: in oceanography, a unit of mass transport of water equal to 10^6 m^3/sec.

SYNCLINE: fold in a geologic formation in which the strata dip inward from both sides toward the axis, generally forming valley topography, i.e., the oldest rock strata are on the outside of the feature.

TECTONIC SUBSIDENCE (or UPLIFT): a lowering (or raising) of sections of the earth's crust resulting from adjustment to stresses within the earth; "tectonic" generally refers to physical deformation in the lithosphere.

TEMPLATE PLATFORM: an offshore platform whose supporting legs fit into a frame previously constructed and anchored to the sea floor. The platform, constructed on shore, is taken to location and set into the frame using a crane-barge.

TERRIGENOUS: land based or originating from a land source.

TEXTURE: (in reference to sediments) geometrical aspects of the component grains, including size, shape, and arrangement.

THERMOCLINE: in some layer of a water body, a vertical negative temperature gradient (temperature decreasing with increasing depth) appreciably greater than the gradients above and below it; a layer in which such a gradient occurs. Principal thermoclines in the ocean are either seasonal, due to heating of the surface water in summer, or permanent.

THERMOGENIC HYDROCARBONS: hydrocarbon compounds produced through alteration of organic materials by temperature and pressure. Examples: crude oils

and products of industrial combustion.

TRAMMEL NET: a three layered net with the center layer finely meshed and slack so that fish passing through carry some of the center layer through the coarser opposite layer and are thus entangled.

TRY NET: a small trawl net towed behind a boat to capture organisms within the net's path.

TSUNAMI: "seismic sea wave"; great wave generated by submarine crustal displacement or landslides; associated with major earthquakes and volcanic eruptions. They travel at high speed and low wave height in deep water, but slow in speed and build to tremendous heights upon reaching shorelines.

TUNICATE: marine chordate animals of the subphylum Tunicata. Most are sessile as adults after passing through a planktonic larval stage. Widely distributed in all seas from nearshore to great depth. They vary in size from microscopic forms to several inches in length and have internal organs surrounded by a non-living "tunic". Common name is sea squirt.

UNIBOOM: type of seismic reflection equipment.

UNIVALVE MOLLUSC: animal of the phylum Mollusca possessing a shell that is attached to the body at one point. Examples: snails, limpets, abalone.

UNSATURATED HYDROCARBON: hydrocarbons in which at least one of the carbon-to-carbon bonds is a double or triple bond.

UPWELLING (COASTAL): the upward motion of water caused by forcing of surface waters away from a coastline. The importance of upwelling is that it can bring nutrient-rich waters into the surface layers where they can be used by phytoplankton.

USGS: United States Geological Survey, Department of the Interior. Primary responsibility is research and development in seismology, geology, and geophysics.

VAN VEEN GRAB SAMPLER: bottom sediment sampler having two hinged jaws and a clamshell-like operation.

VELOCITY SHEAR: in oceanography, rate of change of velocity with horizontal or vertical distance.

ZOOPLANKTON: animals occupying aquatic environments but considered weak swimmers or passive drifters. Maximum size of organisms falling in this category is a few cm and includes small jelly fish, larval fish, and larval and adult forms of many invertebrates.

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Chapter 3 includes the major results of this meeting. The authors cited in the text and the titles of their presentations are:

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