Environmental Assessment of the Alaskan Continental Shelf

Northeast Gulf of Alaska

Annual Reports Summary for the Year Ending March 1975

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF INTERIOR
Bureau of Land Management

Annual Reports Summary

March

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) coordinates all marine environmental assessment activities relating to energy development for the National Oceanic and Atmospheric Administration (NOAA). The Alaskan program is managed by NOAA on behalf of the Bureau of Land Management (BLM), which provides most of the program funding. The Boulder office provides overall planning, contracting, reporting, analysis, syntheses of results, quality control, management, and coordination with BLM and other agencies. Field project offices have been established in Juneau and Fairbanks, Alaska. These maintain project quality, direct the flow of data and reports, coordinate logistics for field operations, and negotiate revised work statements. The Juneau office directs projects for the Bering Sea and Gulf of Alaska, serves as the center for all data management functions, and provides liaison with the State of Alaska. The Fairbanks office is under contract to the University of Alaska and provides an operational center for the Arctic projects on the Beaufort and Chukchi Seas.

The OCSEAP considers that part of its mission is to disseminate quickly and accurately all data received from principal investigators in the field, to synthesize and integrate the material supplied, and to provide this knowledge as a comprehensive and useful data source for impact statements and decision-making.

The enclosed report is the first Annual Report Summary under the OCSEA Program. It has been delayed in publications, but should be of value in that it contains numerous data antedating later reports and important for baseline information. The first year's work was done in the Northeast Gulf of Alaska; hence this report is limited to data for that area.

OUTER
CONTINENTAL
SHELF
ENVIRONMENTAL
ASSESSMENT
PROGRAM

ANNUAL REPORTS SUMMARY - 1975

NORTHEAST GULF OF ALASKA

Report to the Bureau of Land Management
based on studies through March 1976

MAY 1977

ENVIRONMENTAL RESEARCH LABORATORIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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ENVIRONMENTAL ASSESSMENT OF THE ALASKAN CONTINENTAL SHELF

NORTHEAST GULF OF ALASKA

1975 SUMMARY

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PREFACE

In July 1974 the National Oceanic and Atmospheric Administration, at the request of the Bureau of Land Management, initiated a program of environmental assessment in the Northeastern Gulf of Alaska (NEGOA). The scope and nature of these studies were outlined in the document "Environmental Assessment of the Northeastern Gulf of Alaska, First Year Program," issued by U.S. Department of Commerce in May 1974. This first annual report summarizes progress through July 1975 involving the efforts of 10 principal investigators representing NOAA, U.S. Geological Survey, U.S. Fish and Wildlife Service, National Bureau of Standards, State of Alaska, and University of Alaska. However, Chapter 8, on Demersal Fish and Shellfish, includes data for the period May-August 1975.

Since the commencement of NEGOA studies, the scope of research on environmental assessment in the Gulf of Alaska has changed considerably. The NEGOA Project has been absorbed by a larger Alaskan Outer Continental Shelf Environmental Assessment Program, and NEGOA now represents a first-year effort of a multi-year program.

In developing this report, which will be followed by updated and evaluated editions in future years, we have tried to anticipate the needs of those who will be the primary users of the information. First consideration has been given to the immediate requirements of BLM for material to be used in the development of the Final Environmental Impact Statement related to petroleum development in the NEGOA region. Accomplishments are summarized, but abbreviated technical and scientific details are included to provide a meaningful information base for management decision. Technical reports resulting from this project will be published later in various scientific and technical journals.

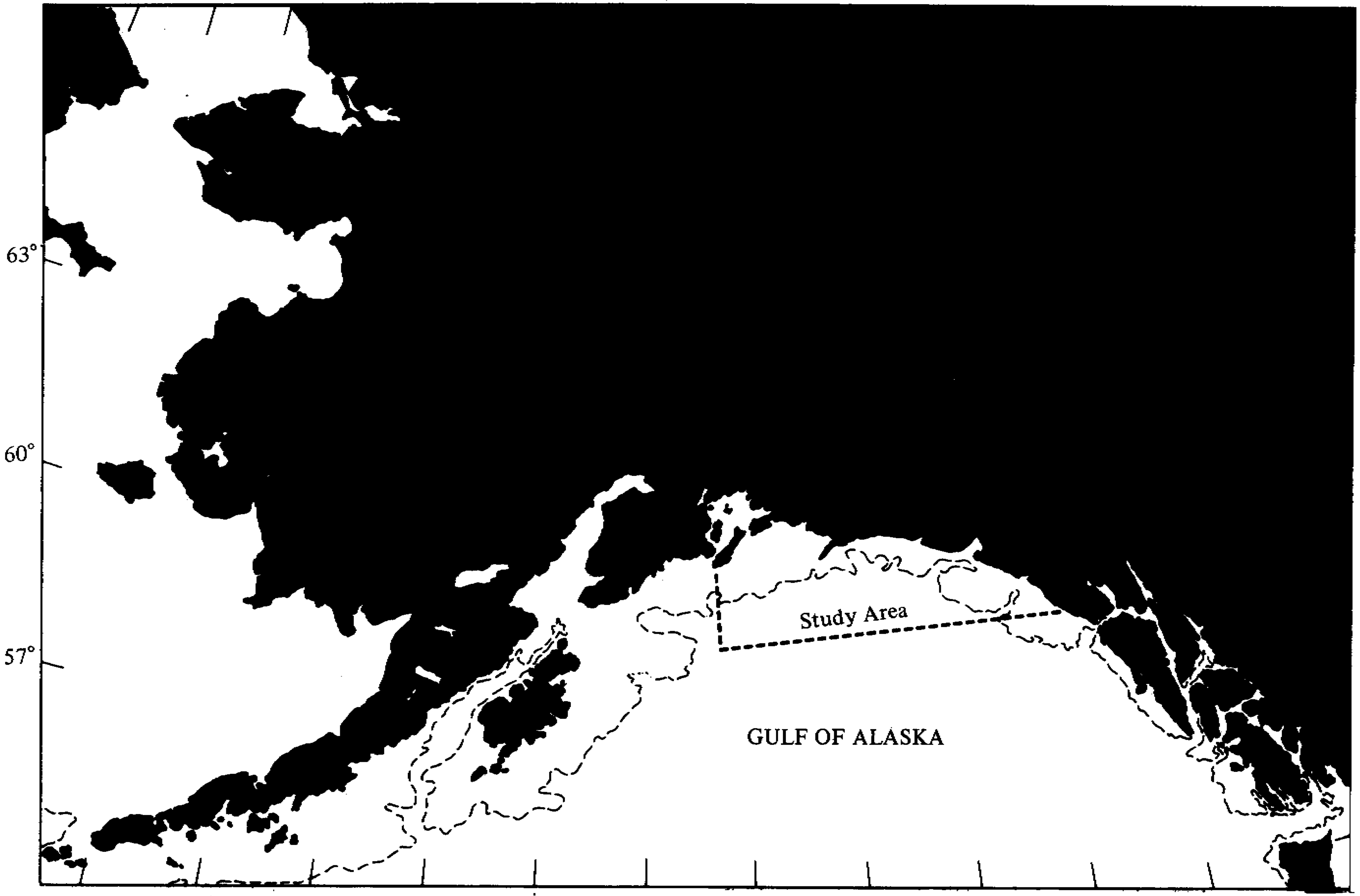

Fig. 1. Northeast Gulf of Alaska Study Area

1. SUMMARY

This report summarizes the first year's progress of an interdisciplinary environmental assessment program, centered in the Northeast Gulf of Alaska (see figure 1). The program has two interrelated major objectives:

A. To establish an environmental baseline in the region, against which development-related impacts might be detected and assessed, and

B. To provide a basis for evaluating the primary impact of the petroleum development on the marine environment of the region.

Accomplishment of these objectives will require (1) assessment of the physical and biological components of environment, (2) determination of the transport processes that influence the distribution of biological resources and potential contaminants from OCS development, (3) elucidation of the physiological and ecological effects of contaminant exposure, and (4) assessment of impact potential through the synthesis of data on environmental characterization, transport phenomena, and physiological effects.

For the first year of the NEGOA program, emphasis was placed on the first two of these research categories. Research on contaminant effects was incorporated in the second year, following a period of preparation extending over several months. Due to limitations in the scope and completeness of first year's findings, a synthesis of research results to date is not attempted in this report.

SUMMARY OF RESEARCH RESULTS

In subsequent sections of this report, the results of first year studies are outlined in some detail. Progress over the past year in each of the various research areas is briefly discussed below and further summarized in table 1.

Physical Oceanography

The objectives of the physical oceanographic program are to describe the general circulation in the study area, determine the variability and spatial coherence of currents, obtain a preliminary understanding of mixing and dilution processes, and describe characteristic waves and weather.

Table 1. Analysis of Accomplishments
Northeastern Gulf of Alaska

Activities	Target Stations	Accomplished Stations*	Accomplished but not Programmed
Current meter array stations	5	5	
Tide gauge station			1
Wave follower buoy station	1	0	
Meteorological buoy station			1
Salinity, temperature, depth (STD) measurements	520	504	
Surface temperature and salinity			114
Expendable bathythermograph (XBT)			60
Radiosondes (hours)			22
Acoustic echosounder profiling, atmospheric (hours)			72
Nephelometer measurements	260	56	
Secchi disc measurements			57
Water samples for nutrients, dissolved oxygen, T, S	95	140	
Water samples for hydrocarbon analysis	96	43	
Water samples for trace metal analysis	40	43	
Sediment samples for faunal analysis (benthos)	140	186	
Sediment samples for hydrocarbon analysis	96	49	
Sediment samples for trace metal analysis	20	34	
Sediment samples for lithological analysis	60	357	
Suspended sediment analysis	50	42	
Floating tar samples for hydrocarbon analysis	36	24	
Seismic reflection profiling, high resolution (n.mi.)	1177	6645	
Seismic reflection profiling, medium penetration (n.mi.)	769	769	
Seismic refraction experiment (n.mi.)	769	769	
Magnetic survey (n.mi.)	1500	1572	
Gravity survey (n.mi.)	1500	3955	
Bathymetry (n.mi.)			3995
Side-scan sonar survey (n.mi.)			8
Demersal fish survey, Otter trawl (**plus 21 station trawl hung-up; 66 stations untrawlable)	214	136*	
Zooplankton and micronekton samples	120	117	
Biota for hydrocarbon analysis (plus demersal fish and benthic invertebrates)			20
Biota for trace metal analysis			9
Intertidal biota for faunal analysis ($^{+}$plus 7 sites in NWGOA)	10	9^{+}	
Conduct marine bird observations and aerial surveys	3	2	
Conduct marine mammal observations and surveys (aerial)	3		
Sample coastal oil seeps for hydrocarbon analysis (sites)	--	3	

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* Total number of times stations were occupied successfully and samples/measurements obtained. At many stations, replicate samples/measurements were obtained. These are not indicated in the above tabulation. Many stations were occupied several times during the year, e.g., the STD grid contained 60 stations that were occupied repeatedly.

Cross sections and vertical profiles of temperature, salinity, and density were obtained throughout the year except for intervals in late fall and mid-winter. Analysis of density-field data indicated the sampling scheme was adequate to resolve major hydrographic features in most regions, an exception being the shelf area west of Cape St. Elias where smaller scale features tend to dominate the distributions.

Weather observations from radiosondes, oceanographic vessels, environmental data buoys (EB-03 and EB-33), and nearby stations such as Middleton Island have been used to estimate geostrophic and surface winds, wind stress and curl. The coastal upwelling parameter from Bakun (1972) has been calculated at 60°N., 149°W. for the past year study period and compared with previous years. Comparison of meteorological data from the sources above showed mixed agreement in the pressure-field. As expected from observations made during Cruise 805, outflow or katabatic winds resulted in a highly variable onshore-offshore windfield.

Current meter data were successfully obtained from five locations, one of which was a dual station with two meters located 300 meters apart. The seasonal and spatial coverage, however, was limited during the first year by availability of current meters. With one exception, all moorings were recovered intact.

Good agreement was found between the general circulation in the Northeast Gulf of Alaska as inferred from density-field measurements and as generated by the diagnostic model. The direct observations of the currents also agreed well with the diagnostic model, particularly for the flow direction. The further refinement of the "working-model" to include baroclinic constraints is expected to result in current speeds more representative of those measured.

In preliminary findings, the hydrographic data revealed the persistence of the warm layer, which is associated with the Alaska Stream, moving along the bottom at the 150 m level. This clearly offers a relatively warm region for benthic animals around the Outer Continental Shelf. In addition, the warmest season for this domain is in the winter when temperatures are higher than 6.5°C. The biological implications of this warm band may be of significance to development activities.

The hydrographic data and general understanding of the wind patterns suggest a relatively strong onshore motion of surface waters during the fall and winter. Contrasted to this, the summer has weak offshore motion, thus leaving the dominant flow along bathymetric contours. This suggests that the report of oil spill trajectories for the Gulf of Alaska by Stewart et al. (1974) may have been in error when it predicted higher probabilities of oil going onshore in the summer than in the winter. In reviewing that report, it appears likely that the authors used wind data from a coastal station that was perhaps strongly influenced by fiord topography (e.g., Seward). In addition, the wind drift term in their model did not include any considerations of Ekman dynamics. This would tend to cause their trajectories to go left of a more realistic drift (Tayfun et al., 1973). The surface transport calculations of Bakun (1973) probably represent a more realistic basis for trajectory modeling.

GEOLOGY

Surface Sediment Distribution

Four major sedimentary units, which are characterized by their seismic signatures, occur on the seafloor of the Continental Shelf in the study area. Holocene sediment, predominantly clayey silt, blankets (1) the entire nearshore area between Hinchinbrook Island and the south end of Kayak Island, (2) most of the nearshore area east of Kayak Island, (3) the surface fill in the Hinchinbrook Sea Valley and Bering Trough, and (4) the area south of Tarr Bank and north of Middleton Island, and occurs in a series of isolated pods near the edge of the shelf. The maximum thickness is > 300 m near the mouth of the copper river.

Holocene end moraines are found at the mouth of Icy Bay, south of the Bering Glacier, and possibly at the mouth of Yakutat Bay, and south of the Malaspina Glacier.

Quaternary glacial marine sediments, generally a pebbly or sandy mud, occur in a narrow arc along the north and west sides of Tarr Bank and in a large arc 20 or more kilometers offshore between Kayak Island and Yakutat Bay. They are believed to underlie most of the Holocene sediment as well.

Stratified sedimentary rocks, often folded, faulted, or truncated, crop out on Tarr Bank, offshore of Montague Island, in several localities southwest and southeast of Cape Yakataga, on Seal Rocks, and on Wessels Reef.

These outcrops apparantly are offshore extensions of onshore formations such as the Orca, Katalla, Poul Creek, and Yakataga.

Holocene Sediment Thickness

The term Holocene is applied to recent sediment accumulations and to end moraines formed in historic times. The Copper River prodelta reaches a maximum thickness of 350 m fine sand to clayey silt, just southeast of the main channel. Other thick accumulations are (1) seaward of Icy Bay near the Malaspina Glacier (260 m), (2) south of the Bering Glacier (200 m), (2) south of the Bering Glacier (200 m), (3) between Hinchinbrook and Montague Islands (250 m), and (4) at the southwest end of Kayak Trough (155 m).

The areas that are largely devoid of Holocene sediments are an irregularly shaped topographic high that includes Tarr Bank and Middleton Island platform, east of Montague Island and southwest of Hinchinbrook Island, along the Continental Slope from south of Kayak Island to the easternmost seismic profile line off the Malaspina Glacier, the Kayak Island platform, and two structural highs near Cape Yakataga.

The three main sources of sediment are the Copper River and the Bering and Malaspina Glaciers. The suspended sediment, whether supplied by river, glacial runoff, or wind, generally moves westerly in the counter-clockwise current. For example, some of the Copper River suspended sediment is being carried into Prince William Sound through channels north and south of Hinchinbrook Island.

Clay Mineralogy of NEGOA Sediment Samples

Nineteen sediment samples were processed and analyzed for the quantity and type of clay minerals. Chlorite was predominant, averaging 52.6 percent; Illite averaged 37.8 percent, Kaolinite, 9.2 percent, and Montmorillonite, the least abundant, averaged 0.6 percent. No other clays were detected.

Structure of the Tertiary Province

Preliminary interpretation of the data indicates that the offshore Gulf of Alaska Tertiary Province (GATP) is structurally complex and consists of several areas of markedly differing structural styles. Complexity in the near surface section appears to increase from east to west.

Between Icy Bay and Kayak Island the shelf is underlain by two types of structures. The first is a series of asymmetric linear folds that trend obliquely across the shelf, roughly between northeast-southwest and east-west. The second is a large shelf-edge arc east of Kayak Island trending subparallel to the coast with a very gentle surface dip.

The shelf between Kayak and Middleton Islands includes a broad zone of complex structures trending between east-west and northeast-southwest, subparallel to major onshore structures and to the eastern Aleutian Trench. Structural highs tend to be asymmetric and bounded by thrust faults on their south or southeast limbs. Uplift, deformation, and faulting are greater than on the Icy Bay structural features, and the crests of many of the highs appear to have undergone extensive erosional truncation apparently exposing complexly deformed Tertiary rocks at or near the seafloor. Northwest of Middleton Island are two large northwest-southeast trending high areas separated by a deep basin.

Submarine Slides and Near Surface Faults

The near surface faults so far detected occur in four main parts of the OCS area: (1) south of Cape Yakataga, (2) on or adjacent to the Kayak Island Platform, (3) on Tarr Bank, and (4) near Middleton Island. In most cases, the faults cut strata that are Tertiary and Pleistocene in age. A few appear to cut Holocene sediments.

Seismic profiles from two parts of the area show disrupted bedding and irregular topographic expression commonly associated with submarine slides or slumps. The slumped section south of Icy Bay and southwest of the Malaspina Glacier (about 1770 square kilometers) has a gradual slope of less than 1/2° but is in an area of thick Holocene sediment (> 150 m).

Similarly, in the second area where slump structures were seen in the seismic records (about 1730 square kilometers along the Copper River prodelta) the slope is gentle ($\sim 1/2°$), but a thick wedge of Holocene sediment (> 200 m) has accumulated rapidly.

Acoustic profiles show a massive submarine slide at the east edge of the Copper River. This slide, 17 km long and containing 5.9×10^{11} m^3, moved down a slope of about 1 degree to the bottom of Kayak Trough.

Several areas are indicated as potential slump or slide zones based on thickness (> 25 m) of unconsolidated sediment and relative steepness of slope (from 1 to 8 degrees).

BIOLOGY

Most biological projects were still in the data gathering stage during the summer, and therefore definitive reports are not yet available. In general, biological field work progressed well, although in some instances investigations were thwarted by severe weather and associated logistics problems. Brief commentaries on progress in the biological disciplines follow.

Birds

Substantial data on the distribution and abundance of birds in NEGOA were collected despite the unfortunate loss of an airplane with all aboard while conducting a survey. Data now available give a preliminary picture of how marine birds use the Gulf of Alaska during the important spring period. Censuses of birds conducted in the Gulf of Alaska from oceanographic vessels indicated a standing stock of about 1.5 million birds in the NEGOA region during winter, and as many as 48 million during the spring migration. The number of birds actually dependent of the region may be substantially larger because population estimates do not take into account turnover of individuals within the population. Sooty shearwaters, which nest in the Southern Hemisphere, were overwhelmingly the most abundant species during spring and summer. Murres, kittiwakes, and tufted puffins, fulmars, glaucous-winged gulls (in winter), and herring gulls (in summer) were the most prominent resident species. During winter, a large part of the population was sighted over the outer edge of the Continental Shelf (100 to 500 fathoms), but in summer, major concentrations were found nearer to shore. The need now is to fill in certain geographical and seasonal gaps and focus on information that will allow conversion of the data on standing stock to the more important fluctuating parameters of migration and production. No work was scheduled on species population dynamics or physiology of birds during the first year, and these gaps remain to be filled.

Marine Mammals

Research on mammals has been fruitful over the past year and has filled major gaps relating principally to areas of haul-out and concentration of pinnipeds (seals and sea lions) in the Gulf of Alaska. Data on pelagic occurrence of these species will be gathered in future years. Few new data have been collected on whale and porpoise use of either the pelagic zone or the inshore zone. The sea otter is a prime example of a highly vulnerable species and some baseline-quality data on vulnerable habitats were developed during this first year. Baseline data on all other species remain to be gathered. Similarly, information gaps on food dependencies, population dynamics, physiological vulnerability to oil, and mediation of petroleum impacts by behavior remain.

Demersal Fish and Shellfish

Considerable information has been obtained for demersal fish and shellfish in the NEGOA region. This report includes the results of an otter trawl survey (April to July 1975) of demersal fish and invertebrate resources within a coastal area of the northeastern Gulf of Alaska between Cape Cleare and Yakutat Bay. The survey area included depths from nearshore to 400 m, and encompassed an area of 39,000 km^2 of ocean bottom. A total of 131 trawl stations was sampled and at each station species composition and weight were determined. Sex, length, weight, sexual maturity, and age data were collected on designated species.

The total standing stock in the survey area, as estimated from the otter trawl catches, was 297,486 mt. Of this tonnage, 40% were flatfish, 26% were roundfish, 5% were elasmobranchs, 4% were rockfish, 15% were commercially important invertebrates, and 10% were miscellaneous invertebrates. Walleye pollock, arrowtooth flounder, and Tanner crab collectively made up approximately 48.5% of the total estimated standing stock.

Catch per unit effort (CPUE) indexes in kg/std tow for the principal species groups within the survey area were: elasmobranchs - 29.5, flatfish - 220.6, roundfish - 144.6, rockfish - 19.7, all fish - 414.4; commercially important invertebrates - 81.5, miscellaneous invertebrates - 59.0, all vertebrates - 140.5; and all species - 554.9. For the three most prominent species, the CPUE indexes were: walleye pollock - 101.2, arrowtooth flounder - 98.0, and Tanner crab - 69.4.

The survey area was partitioned into three areas and three depth zones to form nine area-depth intervals, each of which was examined with respect to community composition. The bulk of the estimated standing stock of each area-depth community is composed of elements from the four classes based on species abundance and distribution:

Class (1) Species found within all depth zones and generally throughout the survey area: Arrowtooth flounder (*Atheresthes stomais*), longnose and big skates (*Raja* spp.), rex sole (*Glyptocephalus zachirus*), flathead sole (*Hippoglossoides elassodon*), Tanner crab (*Chionoecetes bairdi*), and black skate (*Raja kincaidi*).

Class (2) Species found mostly in shallower waters throughout the survey area: Walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and Pacific halibut (*Hippoglossus stenolepis*).

Class (3) Species found mostly in deeper waters throughout the survey area: Pacific ocean perch (*Sebastes alutus*), shortspine thornyhead (*Sebastolobus alascanus*), Dover sole (*Microstomus pacificus*), sablefish (*Anoplopoma fimbria*), and rougheye rockfish (*Sebastes aleutianus*).

Class (4) Species important only within one area-depth intervals of the survey area:

- a: Shallower waters: searcher (*Bathymaster signatus*), butter sole (*Isopsetta isolepis*), rock sole (*Lepidopsetta bilineata*), pink shrimp (*Pandalus borealis*), and starry flounder (*Platichthys stellatus*).
- b: Deeper waters: bigmouth sculpin (*Hemitripterus bolini*), golden king crab (*Lithodes aequispina*), sidestripe shrimp (*Pandalopsis dispar*), and spiny dogfish (*Squalus acanthias*).

The distribution of these classes is far from even. If all but two of the area-depth intervals (i.e., Eastern and Central inner shelf areas) class (1) species made up 40 to 64% of the estimated standing stock. On the eastern-inner shelf, class (1) species accounted for only 17% of the estimated abundance and nearly half (47.6%) of the standing stock was contributed by two class (4a) species, starry flounder and butter sole. These were not found in any significant numbers elsewhere in the survey area. The central-inner shelf region was different from that considered above. Class (1) species made up 26.5% of the estimated standing stock, while class (2) species, walleye pollock, Pacific cod, and Pacific halibut made up 60%. These species were not unique to this area-depth interval as they also comprised 46% of the estimated standing stock on the western-outer shelf.

Littoral Biology

Littoral surveys in NEGOA during FY 75 concentrated only on the rocky habitat at what proved to be a satisfactory intensity of study. Nine of 10 intertidal sites were sampled during the fall of 1974 following a reconnaissance of the NEGOA area. All 10 sites were sampled during the spring of 1975. Sorting of samples is presently incomplete, but data on distribution and species present at some sites are presented. Methodology has been tested and data manipulation and archival systems are ready. The literature survey is basically complete. Future studies will emphasize mud, silt, sand and gravel beaches, in various settings (e.g., open vs. protected coast, isolated sand in a rocky area vs. continuous sandy beach, etc.). The reconnaissance data on littoral biota will be examined for suitability of extrapolation to areas of major habitat types where sampling data are not available, and the sampling program will then be correspondingly adjusted. The coastline will also be surveyed for the occurrence and distribution of major beach types and principal subdivisions made of these types so that general impacts on the biota may be predicted for any region. Future littoral surveys will include shallow subtidal data in coordination with benthic studies. Realistic field studies on the potential effects of petroleum products will also be undertaken.

Benthos

Sampling for benthos in the NEGOA region was accomplished principally during July 1974 and February and May 1975. With the analysis of the May samples complete, the geographic distribution of the principal benthic organisms can be tentatively described. Initial assessment of the data indicates that (1) sufficient station uniqueness exists to permit development of a monitoring program based on species composition at selected stations, and (2) adequate numbers of unique, abundant and/or large species are available to permit future nomination of likely monitoring candidates. Stations will be re-sampled periodically throughout the entire area to establish whether the community types have been adequately correlated with benthic habitats (e.g., by depth and bottom type) to allow reasonable extrapolation to regions where the habitats are known but the benthos have not been sampled. This capability will be developed particularly for species of commercial or ecosystem importance. Similar data will be developed for the inshore region, particularly the shallow zone for which virtually no quantitative data are available. In order to determine the biases of trawl and grab sampling, the relationship must be established (photographically or otherwise) between data sampled by grabs or trawls and those actually present. Physiological and bioassay studies were initiated on potential indicator species of benthos in the FY 76 program.

Zooplankton

Inshore-offshore variation in occurrence of selected zooplankton species in the NEGOA region has been described, principally for July 1974 and February and May 1975. Seasonal and spatial differences in standing stocks were detected for 17 numerically dominant species or taxonomic composites. The variance of this data set was described as to interpretation of trends in the abundance of these organisms with season and location in coastal, shelf, and offshore waters. Although continuity is evident in the overall plankton and micronekton assemblages found over the shelf and in the open ocean, this first year's effort obviously missed many important seasonal events. Geographic coverage will be expanded in the coming months to include the western sector of the Gulf of Alaska, and seasonal coverage will be increased to document short-term changes over the entire region, particularly over the spring and fall peaks of abundance. Zooplankton species of particular importance to ecosystem functioning are to be identified and their roles defined. Population dynamics of the principal zooplankton species will be described, including important relationships with both phytoplankton and higher levels. Research on effects of petroleum on selected planktonic forms has been incorporated into the FY 76 program.

CHEMISTRY

Chemical studies in FY 75 focused on determining the concentration and distribution patterns of hydrocarbons and trace metals in selected components of the environment. Hydrocarbon analyses were undertaken by the University of Alaska and the National Bureau of Standards on benthic sediments and surface water. Biological samples were collected and frozen for future hydrocarbon analysis. Samples from known natural oil seeps were collected and analyzed for hydrocarbon, and limited sampling was accomplished for floating tar.

The fixed limiting factor in the hydrocarbon studies was the time required to analyze a given number of samples after they were received by the analyst. Also adverse weather essentially aborted two early cruises in the fall and winter on which hydrocarbon samples were to be collected.

No spatial or seasonal trends were detected in the concentration and distribution of hydrocarbons. However, it must be recognized that the number of samples collected and analyzed was insufficient to provide a full statistical characterization of hydrocarbon distribution. Future efforts obviously need to focus on providing statistical validity to the results.

The primary objectives of the first year trace metal studies were to determine the baseline distribution of a selected suite of trace metals within the Gulf of Alaska environment (i.e., the present heavy metal content of sediments, coastal biota, and surface water). The first year accomplishments toward this objective were good; however, the number of samples collected and analyzed are as yet inadequate for reliable statistical characterization of trace metal concentration and distribution patterns. Particularly in this area, historical data are unavailable that might make better interpretation of reported data possible.

PROGRAM MANAGEMENT SUMMARY

Management of the Alaskan Environmental Assessment Program is assigned to NOAA's Environmental Research Laboratories. The program is directed from a headquarters office in Boulder, Colorado with field activities conducted under the purview of project offices in Juneau and Fairbanks.

History

The NEGOA Program was formally established early in 1974 by interagency agreement between BLM and NOAA. Field studies, which began in July of that year, were initially limited to the eastern Gulf of Alaska, but in October were extended to include all of the Alaskan Outer Continental Shelf (OCS). Field work is underway in the Gulf of Alaska, the Southeastern Bering Sea, and the Beaufort Sea, and studies are scheduled to begin in the Northern Bering and Chukchi Seas on April 1, 1975. A brief chronology of significant events in this process follows.

February 1974: Initial information contacts were made between representatives of BLM in Anchorage and NOAA in Juneau, relating to the environmental baseline studies in the Gulf of Alaska. Meetings were held at National Marine Fisheries Service, Auke Bay Fisheries Laboratory, Juneau, Alaska, and at the BLM Alaskan OCS Office in Anchorage.

April 18-19, 1974: A conference was held by BLM and NOAA in Juneau to discuss the environmental studies program. Principal topics were BLM views on the scope and general content of the prospective program, time constraints, funding, and other support that might be available.

April 18, 19, 1974: Conference at Environmental Research Laboratories Headquarters in Boulder, Colorado, set up the general administrative structure of the program and established general research objectives.

May 20, 1974: Final integrated program proposal for NEGOA was submitted by NOAA to BLM.

July 1, 1974: R/V *Acona*, operated by the Institute of Marine Sciences, University of Alaska, departed Seward, Alaska, on first cruise of the BLM-sponsored environmental assessment program.

August 1974: Detailed work statements for ongoing NEGOA program were submitted by NOAA to BLM in volumes entitled, "Work Statements for Environmental Assessment of the Northeastern Gulf of Alaska - First Year Program."

October 1974: BLM requested that the NOAA assume research management responsibilities for all OCS areas in Alaska, including three areas in the Gulf of Alaska, two in the Bering Sea, and one each in the Beaufort and Chukchi Seas.

December 1974: The formal interagency basic agreement between BLM and NOAA was signed.

January 6-10, 1975: Workshop to identify needed elements of the OCS study program in Alaska was held in Seattle, Washington. Approximately 150 scientists and administrators attended. The recommendations were subsequently consolidated by ERL and BLM representatives in Boulder, Colorado. The volume was entitled, "An Environmental Assessment of the Gulf of Alaska, Eastern Bering and Beaufort Seas," and was circulated for public review and comment.

January 16-18, 1975: Mid-year review of NEGOA Program was held in Seattle, Washington.

February 18-22, 1975: Public workshop was held on draft plan, "An Environmental Assessment of the Gulf of Alaska, Eastern Bering and Beaufort Seas," at Anchorage, Alaska. The workshop was conducted by the University of Alaska Sea Grant Office under contract to BLM. The workshop recommended principally that the plan give stronger attention to dynamic processes, the nearshore and littoral zones, and socio-economic studies.

February 28, 1975: "Letter" proposals for OCS research were received from government and state agencies and universities. These proposals were based on tasks identified in the revised study plan, discussed above.

March 3-8, 1975: Source Evaluation Board and associated technical evaluation panels convened to review approximately 400 research proposals. Panels were composed of representatives from several Alaskan state agencies and Federal agencies concerned with OCS development. Approximately 160 proposals were accepted subject to revision and negotiations.

April 17, 1975: Draft environmental studies program was formally presented to BLM Research Advisory Board.

July 8-10, 1975: First year review for NEGOA project was held in Juneau, Alaska.

Vessel Summary

Several oceanographic research vessels were used in the first year of the NEGOA program. A brief description of these vessel operations follows; the details of research activities performed on individual cruises are presented in Table 2. Table 3 is a summary of other field operations.

The R/V *Acona*, Institute of Marine Science, University of Alaska, performed four physical oceanographic cruises in the Northeastern Gulf of Alaska (NEGOA) between July 1974 and June 1975 with some biological, chemical, and sediment sampling. The November cruise was severely hampered by weather and only partially completed. *Acona* is a 78-foot side trawler vessel based in Seward and operates in the Continental Shelf and estuarine areas.

One physical oceanographic cruise was completed in August 1974 by the NOAA Ship *MacArthur*, a 175-foot hydrographic vessel that normally operates in Continental Shelf and estuarine areas.

The United States Coast Guard vessel *Planetree* deployed the NOMAD meteorological data buoy, EB-33 in September 1974. The *Planetree* is a medium-endurance buoy tender based in Juneau.

The State of Alaska owned limit seiner *Montague* based in Cordova, sailed in September 1974, providing marine mammal observations in Prince William Sound as far as Kayak Island.

In September and October of 1974, the University of Washington R/V *Thomas G. Thompson*, under charter by the United States Geological Survey, completed 1,757 nautical miles of geophysical trackline. The *Thompson* is a 280-foot vessel of the AGOR class.

The 303-foot NOAA Ocean Survey Ship *Oceanographer* completed two multipurpose cruises in February 1975. The standard hydrographic grid was occupied twice for basic STD coverage; the work of the second leg was partially deleted because of bad weather. Other operations included meteorological observations as well as biological, chemical, and sediment sampling.

The Class II (231-foot) NOAA Ship *Rainer* completed two cruises in April, deployed two current meter arrays (but recovered only one) and completed a general CTD survey.

The NOAA Ship *Townsend Cromwell*, a side trawler of 163 feet, completed two cruises in May and June, the first a biological-chemical sampling program for the University of Alaska, and the second a sediment sampling program for the United States Geological Survey.

The 292-foot NOAA Ship *Surveyor* completed five legs of a cruise from April to June, accomplishing two legs of intertidal biology sampling involving shipboard helicopter operations, and the final leg a CTD survey occupying the 59-station standard grid and recovering and redeploying one current meter array.

Table 2 is a detailed list of the FY 1975 cruises; Table 3 is a summary of other field operations.

Data Management

Data management is concerned with the orderly processing, flow, storage, and retrieval of data collected in field programs. To ensure that the schedule commitments of the program are met and that the data are available in a readily usable form, the following guidelines were defined.

1. Principal Investigators are required by contract to document their individual data management plans including: schedules, formats, quality control procedures, and data processing procedures. All information necessary for successful retrieving and interpretation of the data must accompany data submission.
2. Data should be on magnetic tape available for archiving within 120 days after they are in digital or numerical form.
3. All data are public property and may be examined by the public wherever the data exist.
4. All data will be placed in a data base, which is a keyed magnetic tape file operated by the Environmental Data Service, NODC. Access to the data base is open to all.
5. Standard medium for data archival is magnetic tape in a format specified in part by the Project Office. Exceptions to magnetic tape storage include photos or analog records, such as bathymetric records.

Table 2. Cruise Summary - FY 75
Northeastern Gulf of Alaska

Date	Ship (Institution)	Type of Sample or Data	Type of Analysis	Number of Stations	Miles of Survey Trackline
Jul 74	*Acona* (IMS)	STD	S,T, σ_t	59	
		Water samples (Niskin)	T,S,DO,N	19	
		Bottom sediment (Van Veen)	HC	15	
		Bottom sediment (Van Veen)	Benthos, density & distribution	15	
		Zooplankton	Density and distribution	16	
		Micronekton (mid-water trawl)	Density and distribution	10	
		Demersal fish trawl	HC	3	
		Demersal fish trawl	Density and distribution	9	
		Deploy current meter array, Station 60	Current speed and direction	1	
Aug 74	*McArthur* (NOAA)	STD	S,T,σ_t	54	
		Nephelometer	Suspended particulate matter	56	
		Deploy current meter arrays, Stations 61, 62	Current speed and direction	2	
Sep 74	*Planetree* (USCG)	Deploy meteorological buoy, NOMAD EB-33	Wind speed, direction, air temperature, sea surface temperature	1	
Sep 74	*Montague* (NMFS Charter)	Marine mammal observations	Density and distribution	53	
Sep-Oct 74	*Thompson* (USGS charter)	Seismic reflection	Sub-bottom geological structure		1757
		Sesimic refraction	Sound velocity in sediments, rocks		5 traverses
		Marine bird & mammal observations	Density and distribution		All seen
8-14 Oct 74	*Acona* (IMS)	STD	S,T,σ_t	15	
		Water samples	T,S	15	
		Water samples	HC, TM	3	
		Zooplankton	Density and distribution	5	
		Bottom sediment	Benthos, density and distribution	4	
		Floating tar (neuston tow)	HC	3	
		Recover current meter array, Station 60		1	
18-21 Nov 74	*Acona* (IMS)	STD	S,T,σ_t	2	
		Bottom sediment	Benthos, density and distribution	2	
		Water samples	HC,TM	2	
		Floating tar	HC	2	
		Recover current meter array, Station 61		1	

Table 2. Cruise Summary - FY75
Northeastern Gulf of Alaska. (Continued)

Date	Ship (Institution)	Type of Sample or Data	Type of Analysis	Number of Stations	Miles of Survey Trackline
27 Jan - 5 Mar 75	*Oceanographer* (NOAA)	STD	S,T,σ_t	104	
		Water samples	T,S,DO,N	72	
		Water samples	HC,TM	18	
		XBT	T	35	
		Zooplankton	Density and distribution	15	
		Micronekton	Density and distribution	4	
		Bottom sediment	HC,TM	18	
		Bottom sediment	Benthos, density, and distribution	22	
		Floating tar	HC	5	
		Recover current meter array, Station 62		1	
		Deploy current meter arrays, Stations 62B, 63, 63-1/2 (tide gauge)		3	
		Acoustic echosounder profiles, atmospheric	Air movements, turbulence levels	72 hrs	
		Radiosondes profiles	Air temperature and humidity	22 hrs	
		Zooplankton	HC	10	
		Marine mammal observations	Density and distribution	159 hrs	
		Marine bird observations	Density and distribution	153 hrs	
5-18 Apr 75	*Surveyor* (NOAA)	Seismic reflection	Sub-bottom geological structure		2606
		Gravity	Sub-bottom geological structure		2002
		Magnetics	Sub-bottom geological structure		990
		Bathymetry	Sea-floor morphology		2002
		Marine mammal observations	Density and distribution		
20 Apr - 2 May 75	*Surveyor* (NOAA)	Intertidal biota	Density and distribution	7 (NWGOA)	
		Marine mammal observations	Density and distribution		
27 May - 9 Jun 75	*Cromwell* (NOAA)	Sediment samples: a. Van Veen - 202 b. Shipek - 200 c. Box core - 31 d. Dart core - 42	Lithology	357	
		Secchi disc	Light absorption	57	
		Seismic reflection	Sub-bottom geological structure		26
		Marine mammal observations	Density and distribution		

Table 2. Cruise Summary - FY75
Northeastern Gulf of Alaska. (Continued)

Date	Ship (Institution)	Type of Sample or Data	Type of Analysis	Number of Stations	Miles of Survey Trackline
2-13 Jun 75	*Surveyor* (NOAA)	STD	S,T,σ_t	59	
		Recover current meter array, Station 62C		1	
		Deploy current meter array, Station 62D		1	
3-14 Jun 75	*Acona* (IMS)	STD	S,T,σ_t	60	
		Water samples	T,S,DO,N	16	
		Recover current meter array, Station 64		1	

List of Symbols Used:
S - Salinity
T - Temperature
σ_t - Water density
DO - Dissolved oxygen
HC - Hydrocarbons
TM - Trace metals
N - Nutrients

Table 3. Summary of Non-Vessel Field Operations
FY-75 Northeastern Gulf of Alaska

Date	Type of Operation	Type of Sample	Type of Analysis	Stations	Trackline
Sep - Oct 74	Intertidal biology, sampling transects	Littoral biota	Density and distribution	9	
		Littoral biota	HC	7	
		Littoral biota	TM	8	
Mar 75	Marine bird observations, aerial survey	Counts, photographs	Density and distribution		1050
Jun 75	Marine bird observations, aerial survey	Counts, photographs	Density and distribution		1650
Jul 74	Hydrocarbon chemistry, sampling at oil seeps	Oil-water mixture	HC	4 (no seep found at Middleton)	

The multi-disciplinary nature of the program, with scientists requiring data from several disciplines to analyze the overall nature of the problem, pointed out the need for standardized data formats and codes. To this end, a general magnetic tape format has been defined that covers all types of data; specific formats have been defined for certain specialized types of data. The need for specific data formats for all types of data has been recognized, and efforts to establish such formats are continuing. In addition, the need has been identified for a species code to provide a unique code number for each biological species. Such a code has been found to be necessary in the automated processing, storing, and retrieving of biological data. A 10-digit code system using the taxonomic hierarchy from phylum to species has been devised by the Virginia Institute of Marine Science and has been accepted for use in all OCS areas.

An information retrieval system called IRS, developed by the Environmental Data Service, is used for the storage and retrieval of the NEGOA data base. This system allows a user to request correlation between two sets of data as well as a simple listing ordered by time or location. Use of this system for all data in the NEGOA project will provide easy retrieval of data for further scientific analysis.

2. MARINE MAMMALS

INTRODUCTION[1]

The marine mammals of the Gulf of Alaska may be classified into a land-based group--including seals, sea lions, and sea otters--and a pelagic group that includes whales, porpoises and, for all practical purposes, fur seals, which are pelagic in the Gulf of Alaska. These two groups generally represent quite different ecological niches. The land-based group feeds principally on demersal fishes in the inshore zone and most species breed and rest ashore. In contrast, most of the pelagic species feed offshore on pelagic fish and invertebrates, and are not dependent upon land for breeding or resting. However, several species of whales and porpoises do routinely occur in bays, fiords, and estuaries. The sea lion occurs well offshore but the sea otter rarely comes ashore. Like birds, mammals function as top predators in the ecosystem and serve the important functions of recycling nutrients and maintaining health and balance in prey populations.

Petrochemical related developments in NEGOA will inevitably result in the contamination of the marine ecosystem. Degradation of marine habitats, whether resulting from chronic low-level contamination or large spills, may impact marine mammal populations by lowering biological productivity as well as through direct contact with the animals. Baseline abundance data are needed to detect and evaluate changes that might occur. Seasonal distribution data are essential to make sound recommendations on development in the area, since contingency plans must be based on a knowledge of areas important to marine mammal populations.

Marine mammals likely to be found in the Gulf of Alaska are shown in Table 4. An attempt is made to include all marine mammals found in the area, although this report is directed primarily toward the sea otter *Enhydra lutris*, the Steller (Northern) sea lion *Eumetopias jubatus*, and the harbor seal *Phoca vitulina richardi*.

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[1] Extracted from: Fiscus, Clifford H. (1975): Northeast Gulf of Alaska Marine Mammal Subtask, First year Final Report to the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Division of Marine Fish and Shellfish, Northwest Fisheries Center, National Marine Fisheries Center, Seattle, Washington, 6 pp.; and Calkins, Donald G., Kenneth W. Pitcher, and Karl Schneider (1975): Distribution and Abundance of Marine Mammals in the Gulf of Alaska, Alaska Department of Fish and Game, Division of Game, Fairbanks, Alaska, 189 pp.

Table 4. List of marine mammal species found in NEGOA waters.

Species	Occurrence	
	Coastal and Inside Waters	Offshore
Sea Otter (*Enhydra lutris*)	X	
Northern sea lion (*Eumetopias jubatus*)	X	
Northern fur seal (*Callorhinus ursinus*)		X
Harbor seal (*Phoca vitulina*)	X	
Black right whale (*Balaena glacialis*)		X
Gray whale (*Eschrichtius robustus*)		X
Minke whale (*Balaenoptera acutorostrata*)	X	X
Sei whale (*Balaenoptera borealis*)	X	X
Fin whale (*Balaenoptera physalus*)		X
Blue whale (*Balaenoptera musculus*)		X
Humpback whale (*Megaptera novaeangliae*)	X	X
North Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)		X
Killer whale (*Orcinus orca*)	X	X
Harbor porpoise (*Phocoena phocoena*)	X	
Dall porpoise (*Phocoenoides dalli*)	X	X
Sperm whale (*Physeter catodon*)		X
Bering Sea beaked whale (*Mesoplodon stejnegeri*)		X
Goosebeaked whale (*Ziphius cavirostris*)		X
Northern right whale dolphin (*Lissodelphis borealis*)		X
Short-finned pilot whale (*Globiciphala macrorhyncha*)	X	X
Belukha (*Delphinapterus leucas*)	X	
Pacific giant bottlenose whale (*Berardius bairdi*)		X

The general purpose of this report is to delineate our present knowledge of the status of the marine mammal populations in the Gulf of Alaska. Should large-scale oil spills or other environmental contamination occur, the detailed information on marine mammal distribution and habitats will indicate priorities for contaminant cleanup operations. Major changes in use patterns or population numbers of sea lions, harbor seals and sea otters should be detectable by repetition of all or parts of the survey and comparison of the results obtained with the baseline data provided in this report. These data on relative abundance and distribution of marine mammals will be useful in pinpointing (1) areas of potential impact in the event of oil spills, and (2) areas where leasing activities should be withheld or restricted.

METHODS

Much of the data included in this report was available in the records and files of the Marine Mammal Division of the NMFS Northwest Fisheries Center and the Alaska Department of Fish and Game. This report consolidates in one volume, for ready reference, these reports and sighting records. New records were obtained by aerial surveys of certain localities and surface surveys from four NOAA vessels operating in the NEGOA (Table 5).

Additional information was obtained from interviews with individuals who have observed marine mammals along the Gulf Coast and on the high seas, and from scientific publications on Gulf of Alaska marine mammals.

STUDY AREA

The area covered by this report extends from Cape Spencer on the north side of Cross Sound in southeastern Alaska to Scotch Cape on Unimak Island. The study area extended from the coast to at least the 1,000 fathom depth curve.

Information is summarized below for the three principal species of marine mammals in the Gulf of Alaska. The original report from the Alaska Department of Fish and Game lists and identifies each of the major rookery or haul-out locations, with numbers of animals sighted in each area. Most of the offshore sightings of marine mammals were made by Mathisen and Lopp (1963) and Alaska Department of Fish and Game. The offshore sightings were made by National Marine Fisheries Service personnel during their pelagic fur seal investigations.

Table 5. *Marine mammals data collected and status.*

Data Name	Information	Cruise	Quantity	Status
ADF&G Final report	Species, population estimates, distribution Cape Spencer to Unimak Pass	NA	Contract report	Completed - will be forwarded to project office when received. Delayed pending printing - distribution maps - tables.
NOAA Ships				
Oceanographer	Species, sighting locations	Jan 28 to Mar 5, 1975	All seen	Incorporated in report. Individual sightings to be placed in data bank FY 76.
Surveyor	Species, sighting locations	April 4 to June 8, 1975	All seen	Marine mammal logs received to be placed in FY 76 report data bank.
Discoverer	Species, sighting locations	May 9 to June 23, 1975	All seen	Marine mammal logs received to be placed in FY 76 report and data bank.
Townsend Cromwell	Species, sighting locations	April 28 to June 10, 1975	All seen 35 pg. log	Marine mammal logs received to be placed in FY 76 report and data bank.

Sea Lion

The Northern sea lion *Eumatopias jubatus* is found throughout the Gulf of Alaska and is considered one of the more important marine mammal species. The sea lion's single most pronounced characteristic, distinguishing it from other marine mammals of the Gulf of Alaska, is its affinity for specific, well-defined locations used as breeding and pupping rookeries and haul-out areas along the coast of the Gulf of Alaska.

Adult sea lions gather on the breeding rookeries in late May. The large dominant bulls gather harems of cows and defend territories. Pupping generally takes place within these defended territories and is closely following by mating. As the breeding season progresses, harem bulls become more tolerant of other male intruders; early in July they begin to desert their territories. "Not all sea lions go to rookery areas during the breeding season. Large numbers of mature bulls occupy male hauling grounds, generally located next to rookeries. Also, males and females without pups may gather on hauling grounds where males also defend territories and engage in breeding activities" (Alaska Department of Fish and Game, 1973).

Although pups can swim within hours of birth, they rarely enter the water before they are one month old (Sandegren 1970; Alaska Department of Fish and Game, 1973). As many as 25 percent of adult females may fail to produce a pup each year, and more than half of the new pups die in their first year. Drowning, abandonment, malnutrition, and predators are the major causes of death (Alaska Department of Fish and Game, 1973).

During the winter, many sea lions leave the breeding and pupping rookeries in favor of more protected waters and have been known to follow predictable feeding patterns, such as concentrating on herring spawning schools in the spring (Alaska Department of Fish and Game, 1973). Sea lions eat a wide variety of fishes and crustaceans, although they are generally considered to be primarily piscivorous (Fiscus and Baines, 1966; Mathisen et al., 1962; Brooks, 1957).

Fishermen have long considered sea lions from the Gulf of Alaska and other areas as enemies because of their dietary preference for fish (Mathisen et al., 1962; Brooks, 1957, 1963; Fiscus and Baines, 1966), but few actual quantitative data are available regarding the extent of predation on commercial fishes.

Throughout history, populations of sea lions have been exploited by man. The earliest records of harvest of sea lions in the Gulf of Alaska comes from middens near native village sites and show that sea lions were used extensively. In fact, hunting of sea lions substantially reduced their populations before the early 1900's.

Commercial interest in sea lions brought about harvests of pups for their pelts and some experimental harvest of adults for meat. A total of 45,808 sea lion pups were recorded harvested from Alaskan rookeries from 1959 through 1972.

Previous surveys by Alaska Department of Fish and Game, information from other marine mammal biologists, and our survey located 91 different rookeries and hauling areas in the northest Gulf of Alaska. Sea lion rookeries and haul-out areas are found on a variety of different substrates ranging from sand beaches to beaches with boulders up to 10 m in diameter to bedrock and are often found on exposed points or isolated small islands. These rookeries and hauling areas are precisely defined on maps of the original report.

Of these 91 different rookeries and hauling areas, the following eight sites are considered to be the most important for breeding and pup production: (1) Pinnacle Rock on the south end of Kayak Island, (2) Seal Rocks near Cape Hinchinbrook in Prince William Sound, (3) Fish Island, the outermost of the wooded islands on the south end of Montague Island in Prince William Sound, (4) Chiswell Island on the west approach to Resurrection Bay on the Kenai Peninsula, (5) Outer Island, the smallest and outermost of the Pye Islands on the Kenai Peninsula, (6) Sugarloaf, near East Amatuli Island in the Barren Islands, (7) Marmot Island, which parallels the eastern side of Afognak Island, and (8) Chowiet Island, the larger southern island of the Semidi Islands. These eight areas, with approximately 43,000 animals, account for slightly less than one-half of the sea lions found in the Gulf of Alaska. Our estimate of the total sea lion population in the Gulf of Alaska is about 90,000.

Sea Otter

Although hunted to near extinction by the early 1900's, the sea otter (*Enhydra lutris*) is abundant in much of the Gulf of Alaska, which is considered a location of primary importance to the continued recovery of this species. Their numbers are slowly increasing in many parts of the Gulf of Alaska and are expanding and reoccupying former habitats.

The best information, based on all records held by NWFC, indicates a total population of sea otters of over 12,000 in the Gulf of Alaska. Sea otters are gregarious animals and are found in groups of up to 1,000 animals, although single animals are also common. Sea otter habitat is generally inside the 50 fathom curve; they prefer areas with reefs and rocky shoals. Their diet consists of bottom dwelling invertebrates and fishes, such as crabs, clams, sea urchins, abalone, sea cucumbers, octopus, and squid. Fishes known to be eaten by sea otters are the globe fish (*Cycloperichthys glaber*), the red Irish lord (*Hemilepidotus hemilepidotus*), Atka mackerel (*Pleurogrammus monopterygius*), and the Sablefish (*Anoplopoma fimbria*) (Kenyon, 1969).

Pupping and breeding can occur throughout the year, but probably reach their peaks in the spring. Delayed implantation is known to occur. Pups remain with the females for about 1 year, during which time they grow rapidly.

In the Aleutian Islands, sexual segregation is pronounced, and probably occurs in some form in most areas. Territoriality during breeding has been observed and appears to be in response to specific environmental conditions (Calkins and Tent, 1975).

Sea otter censusing techniques have been discussed by Schneider (unpublished Alaska Department of Fish and Game report) who concluded that the best survey techniques are (in order) : the shore count, the skiff count, the helicopter count, and the fixed-wing aircraft count. The majority of our information on sea otter populations (Table 6) is based upon aerial counts, both fixed-wing and helicopter.

Table 6. Summary of Sea Otter Surveys[1]

Location	1951	1957	1962	1969	1970
		ALASKA PENINSULA			
C. Kuliak-C. Igvak		0	1		7
C. Igvak-C. Kunmik		19	22		139
Aniakchak Bay & Amber Bay	8	6	47		197
Sutwick Area[2]	355	581	109		14
Kujulik Bay & C. Kumlik[3]	12	103	684		1,253
C. Kumliun					101
Univakshak Island	13	180	86		62
Nakchamik Island			Not Surveyed		5
Chignik Bay		0			118
Castle Bay & Cape					16
TOTAL	388	889	949		1,912
		SHUMAGIN (Few reports before 1940)			
Mainland Shore Kupreanof Pen. to Pavlof Bay		1			23
Unga Island		2	4		184
Popof Island		2			52
Korovin Island					46
Karpa Island					4
Andronica & the Haystacks		1		75	
Nagai		149	338	232	
Spectacle				8	
Bendel		268	105	27	
Turner				6	
Twins		7			
Near		3	14	150	
Peninsula		0	3	15	
Big Koniuji		220	222	296	
Little Koniuji & Atkins		430	255	290	
Simeonof[4] (1953)	633	455	294	329	
Bird		160	38	76	
Chernabura		132	79	6	
TOTAL	633	1,830	1,352	1,510	309

Table 6. Summary of Sea Otter Surveys (Continued)

Location	1951	1957	1962	1969	1970
		SANAK-SANDMAN			
Mainland Shore Pavlof Bay to Unimak Bay					141
Pavlof Islands					
Wosnesenski Island		2			4
Ukolnoi Island					2
Poperechnoi Island					29
Dolgoi Island					67
Goloi Island					2
Outer Iliasik Island					16
Inner Iliasik Island					2
Sandman Reefs					
Cherni Island[5]		271	259		
Clubbing Rocks[6]	97	33	2		12
Goose Island		76	82		7
Deer Island & Other Reefs		123	295		(Inc.)
Sanak Island[7]	62	251	548		239
TOTAL	159	756	1,186		521

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[1] (Compiled by population from Lensink (1962), Kenyon (1962, 1965, and 1969), and Alaska Department of Fish and Game).

[2] Miscellaneous reports.

[3] Since 1936.

[4] 500 estimate (1947).

[5] In 1948, 27 sighted.

[6] No sightings before 1942.

[7] Sightings since 1922.

Harbor Seal

The land breeding harbor seal (*Phoca vitulina richardi*) is the most abundant pinniped of coastal Alaska from Dixon Entrance to the Bering Sea (Alaska Department of Fish and Game, 1973). Harbor seals are common residents of coastal waters throughout the area and are found at times in rivers and lakes some distance from salt water. Harbor seals usually live close to the coast, although sightings of animals a mile or two offshore are not unusual. Spalding (1964) did not consider the harbor seal a pelagic species, and states that they are seldom found more than 5 miles from shore. Bigg (1969) supports this viewpoint. The National Marine Fisheries Service has sighted a number of single animals up to 50 miles offshore. Spalding (1964) reported harbor seals 30-40 miles offshore of the Portlock Banks near Kodiak.

Coastal waters are considered harbor seal habitat in the Gulf of Alaska, but some areas support much greater concentrations than others. A few of these high density areas are Icy Bay, the Copper River Delta, Prince William Sound, Aialik Bay, Harris Bay, Nuka Bay, the Chugach Islands, the Barren Islands and the entire Kodiak group, particularly the Trinity Islands.

Haul-out areas include offshore rocks, sandbars, and beaches of remote islands. Floating ice pans carved from glaciers are used for hauling out when available. During winter, ice shelves that form at the heads of bays are frequently used as hauling platforms. The versatility of the harbor seal is further illustrated by its successful inhabitation of areas with varying bottom types, water clarity, and salinity.

Sexual maturity is attained by female harbor seals at 3 to 5 years and by males at 5 to 6 (Bigg, 1969; Bishop, 1967). Some live 30 years. Large males in some areas may exceed 400 pounds, but the average adult weighs about 200 pounds. Pupping takes place from late May to mid-July, most occurring during the first 3 weeks in June. Pups average 28 pounds at birth and nearly double their weight by weaning, 3 to 4 weeks later. Ovulation and breeding of the females happen shortly after weaning. Delayed implantation occurs and embryonic development is retarded for about two months. The period of active fetal development is about 8.5 months. No significant amount of twinning is known to occur.

Harbor seals are mainly fish eaters and feed on a wide variety of species including herring, gadids, flounder, smelt, rockfish, sculpin, salmon, and greenling. Octopus, squid, and shrimp have been found in large quantities in harbor seal stomachs (Imler and Sarber, 1947; Spalding, 1964).

Reliable techniques for counting harbor seal populations have not been developed. Aerial surveys are commonly used to determine distribution and relative abundance (Mathisen and Lopp, 1963; Richardson, 1973). However, these surveys are inadequate for estimating population size and are only marginally suited for determining distribution (Pitcher, in prep.). When under water, seals can be seen only under the most favorable conditions, i.e clear, shallow, calm water with good lighting. Even when on the surface, seals are difficult to see and many are missed. Seals are most easily seen and counted when hauled out. However, even when large numbers of seals are seen hauled out, there is no method of determining what proportion of the total population this group represents. Aerial surveys are a valuable tool as long as their limitations are realized and the resulting data interpreted accordingly.

In the early and mid-1960's, Alaskan phocid seal skins were introduced and became popular in the European fur market. High prices were paid for harbor seal skins which stimulated intensive hunting in many areas of Alaska. High harvests of seals occurred in the southeastern part along the Gulf Coast, along the Kenai Peninsula, in the Kodiak area, and in several locations on the Alaska Peninsula. Through a combination of bounty records, fur export permits, interviews with fur buyers, and field observations, the Department of Fish and Game calculated the size of harvest. It was not unusual for an area to produce many more seals than were thought to occur in the area and still have a population that was apparently not greatly reduced. Then by using basic information on the reproductive potential of harbor seals, the size of populations required to support these harvests was estimated. This information, while admittedly imprecise, provides the best estimate of population size. Bigg (1969), in a study of harbor seals in British Columbia, found that 53 percent of the population older than pups consisted of females, of which 55 percent were sexually mature. He found that 88 percent of the mature females produced offspring each year. Using these data, the annual production of a harbor seal population amounted to about 20 percent of the post-whelping population. Boulva (1971), working on Sable Island in Nova Scotia, found that pups represented about 18 percent of the population after whelping. Current investigations indicate that reproductive rates vary in different populations, possibly related to habitat productivity and population density. The only basis for population estimates in areas of little hunting are observations of relative abundance and knowledge of available habitat.

Cetaceans

Miscellaneous observations on cetaceans are included in this section only to indicate the presence and possible relative abundance of the species. In most cases, there is no more information than a collection of sightings, no population estimates can be made nor, as a rule, can distribution be defined.

Pacific Right Whale or Black Right Whale, *Balaena glacialis*

This large whale species was hunted to near extinction in the North Pacific and was most frequently found in the Gulf of Alaska in the summer. Little is known about its present distributuion and abundance except it is considered rare (Leatherwood et al. 1972). No sightings are recorded in files for the present studies.

Gray Whale, *Eschrichtius robustus*

Gray whales are known to migrate through the Gulf of Alaska in the spring to feed in the waters of the Bering and Chukchi Seas from May through November. In December and January, they return south to breed in shallow waters of California and Mexico (Leatherwood et al. 1972). The National Marine Fisheries Service reports sightings of gray whales between the Fairweather Grounds and Yakutat Bay in April 1958.

Minke Whale, *Balaenoptera acutorostrata*

Minke whales are relatively common throughout the Gulf of Alaska and are known to concentrate in areas of abundant food such as Kodiak Island and Prince William Sound. They are migratory, moving into the Gulf of Alaska in spring and returning south in the fall. The minke is the most common small whale in the Gulf of Alaska; 43 minkes were reported sighted at 33 locations.

Sei Whale, *Balaenoptera borealis*

The range of the Sei whale extends into Gulf of Alaska water, although their specific distribution is poorly known (Leatherwood et al. 1972). Sei whales have been sighted, but they are uncommon.

Blue Whale, *Balaenoptera musculus*

Blue whales are found in te Gulf of Alaska from May through September (Leatherwood et al. 1972). Seven blue whales were sighted from 1958 through 1968. Blue whales are considered an endangered species, near extinction.

Humpback Whale, *Megaptera novacangliae*

Humpback whales are the most common of the large whales with dorsal fins in the Gulf of Alaska, and according to Leatherwood et al. (1972) in the summer they can be seen in virtually any part of their range, which includes all of the Gulf of Alaska. Investigators have sighted 132 humpbacks on 64 different occasions in the Gulf of Alaska.

North Pacific White Sided Dolphin, *Lagenorhynchus obliquidens*

North Pacific White Sided Dolphins, or Lags, are found from Alaska to Baja California according to Leatherwood et al. (1972), but sightings are not common in the Gulf of Alaska. One sighting of 2,000+ Lags was recorded during a cruise of the NOAA Ship *Oceanographer*. These Lags were recorded as being near the 1,000 fathom curve off Yakutat Bay.

Killer Whale, *Orcinus orca*

Killer whales are found throughout the Gulf of Alaska during the summer and may shift to the south in the winter (Leatherwood et al. 1972). On nine different occasions in the Gulf of Alaska, 36 Killer whales were sighted. National Marine Fisheries Service special agent Jim Branson reported seeing 500+ Killer whales near Middleton Island on April 24, 1973.

Harbor Porpoise, *Phocoena phocoena*

The Harbor Porpoise is the smallest cetacean in the Gulf of Alaska and, according to Leatherwood et al. (1972), can often be seen in bays and harbors throughout the Gulf. Between 1958 and 1968, 176 animals were sighted at 17 locations.

Dall Porpoise, *Phocoena dalli*

The Dall Porpoise is probably the most common cetacean seen in Gulf of Alaska waters; sightings are common both nearshore and offshore. Between 1958 and 1968, 1,912 Dalls were sighted on 289 occasions.

Sperm Whale, *Physeter catodon*

Leatherwood et al. (1972) considers the sperm whale migratory, being found in the Gulf of Alaska in the summer only. Nineteen sperm whales were sighted on nine occasions.

Pelagic catches of whales in the Gulf of Alaska by Japan and Russia are shown in Table 7. This reflects the total catch of whales by these two nations in all Gulf of Alaska waters, including areas south of Cape Spencer.

Table 7. Pelagic Catches of Wheales in the Gulf of Alaska by the USSR and Japan 1965-1974.

Year	Blue	Humpback	Fin	Sei	Sperm
1965	68	106	1118	816	1344
1966	0[1]	0[1]	833	1174	1009
1967			101	145	1137
1968			35	239	356
1969			11	49	538
1970			115	119	180
1971			59	100	138
1972			4	15	311
1973			4	8	171
1974			88	10	307

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[1] Completely protected from 1966 on.

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3. MARINE BIRDS

INTRODUCTION

This study was initiated to obtain information on populations and distribution of marine birds in the Northeastern Gulf of Alaska (NEGOA). The immediate objectives of the study were to:

1. Delineate the seasonal distribution of birds within the region.
2. Identify numbers and species composition of birds in nesting colonies adjacent to NEGOA.
3. Assess the possible impact of proposed oil lease sales on avian populations.

This study addresses direct impacts of development and does not measure potential indirect impacts that could result from changing the food chains or from peripheral disturbance of nesting areas. A few effects, however, may be predicted or assumed and are discussed briefly under the species summaries.

Of the birds that may be affected by proposed development programs, only those species typically dependent on pelagic food sources are considered in this study. This category of birds was given priority in current studies since their primary food source is obtained from the sea, thus rendering them vulnerable to an oil spill. Numerous shorebirds and waterfowl using tidal mudflats and marshlands of the Copper River and Bering River deltas are not discussed. However, all avian colonies that are subject to disturbances, as well as spilled oil, are being identified and categorized and will be addressed in future studies. Substantial information on these faunal groups is available from on-going U.S. Fish and Wildlife Service (USFWS) programs. A listing of other USFWS bird programs is in preparation by that agency and will be available in the near future.

The NEGOA region covered in this report includes all waters from shore to 58° N. latitude and between 138° and 147°W. longitude. Supplemental information is provided for the Northwest Gulf of Alaska (NWGOA), Lower Cook Inlet (LCI), the Kodiak Basin (KB), and the Alaska Peninsula (AKP) from the Shumagin Islands to Unimak Pass; all are considered a part of the Gulf of Alaska, as well as the shipping route from NEGOA to Seattle.

Previously information on pelagic distribution of birds within this region has been based for the most part on extrapolation of data from a larger region, from other regions (Shuntov 1964; Sanger 1972; King 1974), or from observations and evaluation of breeding colonies adjacent to the NEGOA. None of these sources provided adequate statistical data on size, distribution, or composition of the population by season. Waters off the coast of Alaska, including particularly the Gulf of Alaska, the Bering Sea, and the Aleutian chain, have long been considered of unique importance to marine birds (Gabrielson, 1959; Shuntov, 1964). This study supports that conclusion; the NEGOA region alone had more than 48 million birds during the spring migration.

METHODS

Censuses were conducted from the NOAA ship *Oceanographer* from January 28 to March 4, 1975, and the NOAA ship *Surveyor* from April 21 to June 14, 1975. Supplemental information was obtained for adjacent areas by observers on the NOAA ship *Discoverer* operating in the Western Gulf of Alaska and Bering Sea between May 9 and June 30, 1975.

Two types of counts were obtained. Most important were the transect counts, which were obtained while ships were underway and used procedures adapted from those described by King (1974). Initial counts, obtained from the *Discoverer* during February, were made on a strip 1/4 mile (402 m) wide from the most favorable side of the ship for viewing, but to increase accuracy this width was reduced to 300 m on later voyages. Observations within the 300 m wide transect were recorded by 100 m increments (i.e., 0 to 100 m, 101 to 200 m, and 201 to 300 m) to permit evaluating the biases that resulted from deflection or attraction of birds from the ship and the visibility of certain species at various ranges. Counts were made during a 15-minute interval in each daylight hour. Additional counts were considered separately to avoid bias on non-random counts in high density areas. Because the transect length varied with the ship's speed, the transect area also varied, ranging from 0.6 to 3.0 km^2.

The second type of data were counts while the ship was on station. These proved generally ineffective for population analysis, but were valuable for interpreting other data and frequently provided the major source of records for uncommon species. For example, 43 blackfooted albatrosses were observed on one station, but only 16 were observed on all transects censused in NEGOA.

RESULTS

Birds were counted on 631 transects between January 28 and June 14. Of these, 295 were within the NEGOA region, while the remainder were located on shipping lanes between NEGOA and Seattle and throughout other parts of the Gulf of Alaska region as far west as Unimak Pass.

Within NEGOA 58,863 birds were tallied on the 295 transects (Table 8); these represented a 0.12 percent coverage of the NEGOA region in March, 0.03 percent in April, 0.10 percent in May, and 0.13 percent in June. Sampling during February appeared to be adequately distributed except near shorelines. However, from April to June sampling was inadequate for the oceanic area beyond the margin of the Continental Shelf and for the immediate nearshore area. Coverage in other geographic areas was much less than in NEGOA. Biases that may result from the sample distribution will be evaluated in later reports. It is anticipated that such an evaluation will change some population estimates but it will not substantially change major conclusions of this report.

Birds were encountered on all transects during both winter and summer. During March, the glaucous-winged gull was the most widely distributed species, being encountered on 96.6 percent of transects in NEGOA. Its distribution and abundance were generally similar to the black-legged kittiwake, which was seen on 89.8 percent of transects. Other species appeared to be less widely distributed; murres were encountered on only 47.5 percent of transects, fulmars on 45.8 percent, and tufted puffins on 32.2 percent. These differences are partly related to the relative size of populations rather than to differences in distribution patterns. No other species was present on more than 20 percent of transects.

Censuses in April (25 transects in NEGOA) were inadequate to reflect clearly all changes in numbers or distribution that occurred; nevertheless, they revealed dramatic changes in population size, composition, and distribution ("dramatic" changes in population size, composition and distribution are here defined as changes of approximately 50% or greater.) Most spectacular was the influx of large flocks of sooty shearwaters, which made up 96 percent of all birds observed, although other species had also become more abundant. The number of shearwaters is probably overestimated during April; maximum numbers may have occurred in May when they were encountered on 83.7 percent of transects. Pelagic populations of other species were also highest in May when average density (excluding shearwaters) reached 29 birds per km^2.

Table 8. *Populations of Pelagic Birds in the NEGOA Region (North of 58°N. between 138° & 147°W.).*

Species[1]	No. of Birds Observed on Transects				Percent of Transects on which Observed				Estimated Pelagic Popu. (thousands[2])			
	Feb.	Apr.	May	June	Feb.	Apr.	May	June	Feb.	Apr.	May	June
Arctic Loon	0	0	74	6	0	0	11.1	6.5	0	0	74	4
Common Loon	0	0	95	7	0	0	14.1	6.5	0	0	96	4
Black-footed Albatross	0	1	7	8	0	4.0	4.4	7.9	0	3	8	7
Northern Fulmar	396	0	546	305	45.8	0	31.9	67.1	333	0	548	231
Fork-tailed Petrel	8	0	34	252	6.8	0	14.8	50.0	7	0	34	190
Leaches Petrel	0	0	0	40	0	0	0	15.8	0	0	0	31
Sooty Shearwater	0	16,261	32,611	2,426	0	28.0	83.7	67.1	0	46,604	32,700	1,837
Pelagic Cormorant	1	25	16	6	1.7	12.0	5.2	5.3	1	72	17	3
Double-crested Cormorant	0	0	4	2	0	0	1.5	2.6	0	0	4	1
Oldsquaw Duck	0	0	70	3	0	0	4.4	2.6	0	0	70	2
Surf Scoter	1	2	0	10	1.7	4.0	0	2.6	1	6	0	8
Northern Phalauope	0	0	641	0	0	0	21.5	0	0	0	642	0
Peresitic Jaeger	0	4	4	6	0	16	2.2	7.9	0	11	4	4
Pomourine Jaeger	0	0	3	2	0	0	1.5	2.6	0	0	3	1
Long-tailed Jaeger	0	0	2	6	0	0	1.5	3.9	0	0	2	4
Gull (unidentified)	0	3	9	10	0	12.0	1.5	6.6	0	9	6	8
Glaucous Gull	2	9	0	0	3.4	8.0	0	0	2	25	0	0
Glaucous-winged Gull	435	65	207	29	96.6	56.0	41.5	11.8	366	186	208	21
Herring Gull	4	8	354	60	6.8	8.0	67.4	34.2	3	23	355	45
Mew Gull	13	7	4	0	13.6	20.0	3.0	0	11	20	4	0
Black-legged Kittiwake	424	13	397	665	89.8	16.0	67.4	78.9	356	37	398	504
Sabine's Gull	0	0	1	71	0	0	0	5.2	0	0	1	54
Arctic Tern	0	20	191	163	0	12.0	35.6	59.2	0	57	191	123
Murre (unidentified)	348	413	147	74	47.5	88.0	24.4	25.0	293	1,183	147	56
Tufted Puffin	34	35	103	37	32.2	44.0	23.0	21.1	29	100	103	28
Cassins Auklet	0	0	0	7	0	0	0	2.6	0	0	0	6
Marbled Murret	15	5	9	9	10.2	4.0	1.5	3.9	12	14	9	8
Kittlitz's Murrelet	0	0	4	2	0	0	1.5	1.3	0	0	4	1
Ancient Murrelet	0	0	24	16	0	0	.7	3.9	0	0	24	13
Small Alcid (unidentified)	22	47	239	199	15.3	40.0	38.5	38.2	19	134	239	150
Other[3]	0	0	6	2	0	0	2.2	2.6	0	0	6	1
Total	1703	16,920	35,802	4428	100.0	100.0	100.0	100.0	1,431	48,468	35,900	3,352
Total without Shearwaters	1703	651	3,194	2002	100.0	100.0	100.0	100.0	1,431	1,864	3,199	1,516
Total Transects	59	25	135	76		----	----	----				
Total area of transects	130.8	38.4	109.7	145.3		----	----	----				

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1. Unidentified loons (118), petrels (31), cormorants (15), scoters (7), and jaegers (6) were prorated or assigned to most likely species.
2. Calculations are based on a NEGOA area of 110,000 km^2.
3. Other species included widgeon (2), black brant (1), pigeon guillemot (1), dunlan (3), and rhinocerous auklet (1).

Estimates of the average number of birds at sea (i.e., standing stock) within NEGOA ranged from 1.4 million in February to 48.5 million in April; declining to 3.4 million in June. These populations, however, do not represent the total number of birds using, or dependent on, the region. Many birds present in April and May were a part of a much larger population migrating through the area. Similarly, during June a large number of birds (more than half the population) were at breeding colonies and spent only a small part of each day at sea; thus, only the average number at sea is included in transect counts. The censuses further underestimate this population by inadequately sampling either nearshore waters, or water seaward of the boundary of the survey area where many of the colonial birds forage. These must also be considered in evaluating the impacts of development programs, but at present neither the daily or seasonal turnover rate, nor the total populations involved can be estimated with any accuracy.

Sampling in the regions adjacent to NEGOA was not as extensive as in NEGOA, and populations were not estimated. The large counts in the NEGOA area as compared with other regions resulted almost entirely from the large flocks of shearwaters encountered there during April and June, and the general offshore location of transects in other regions. Excluding shearwaters, the surveys suggest that populations of pelagic birds are generally larger in other parts of the Gulf of Alaska where nesting colonies are larger and more numerous. An even greater difference may have been detected if sampling in other regions had included nearshore waters.

The following sections consider examples of individual species that have been selected for their rarity, abundance, or interest. Their status and probable vulnerability to petroleum development activities are discussed.

Diomedeidae (Albatrosses)

A total of 16 black-footed albatrosses, *Diomedia nigripes*, were observed on transects in the NEGOA region from late April to the end of the study period in June. They ranged well offshore and were never recorded closer to land than 34 km. Most were beyond the edge of the Continental Shelf except for one observed near Middleton Island; all records were from Cape Yakataga south to Vancouver Island. The majority of sightings were of "ship followers," and although few albatross were seen on transects, they collected at the ship when it was on station. The maximum number at a station was 43 at Station 35 (58°59'N., 142°12'W.).

Because albatross generally range far from land, are at the northern periphery of their range in NEGOA, and are surface foragers, it does not appear that their population would be appreciably affected by the proposed development program.

Procellariidae (Tubenoses)

Northern Fulmar, *Fulmarus glacialis*

Northern fulmars, present in the NEGOA region throughout the year, were the third most numerous species recorded in February, second in May, and third again in June. They were also numerous in other offshore waters of the Gulf of Alaska. None were observed in April; but this lack resulted from the sampling distribution not covering offshore waters most used by fulmars. During March, Isleib encountered them most abundantly at the edge of the Continental Shelf (100 to 500 fathoms), only rarely shoreward, but commonly on transects and stations seaward to the limit of the survey area (about 58°N.). Hatch and Timson also found fulmars to the limit of the survey area in May and June and confirmed their continued abundance at the edge of the Continental Shelf, although they found somewhat higher densities shoreward than occurred in March. Highest densities were only 6 to 18 km offshore near Port Dick (NWGOA), and near Sitkalidak Island (KB)--both locations being near nesting colonies.

The offshore dispersal of shearwaters, the lack of major colonies within the NEGOA area, and the surface foraging behavior indicate that neither the local nor the overall population is likely to be substantially affected by a single oil spill in the Northeast Gulf of Alaska.

Sooty Shearwater, *Puffinus grieseus*

Sooty shearwaters spend the winter at nesting areas on the coasts of Chile, New Zealand, and southern Australia, but by the time our censuses began on April 21, large flocks of shearwaters dwarfed populations of all other species. An estimated 46 million shearwaters occupied the NEGOA region at this time. Although this estimate is suspect because of biases in sampling, the continued occurrence of shearwaters in May, when they were observed on 83.7 percent of transects, indicated their great abundance. Although still the most abundant species in June, the population was less than one-twentieth of that indicated by earlier transects.

Shearwaters were rarely observed within 5 km of land, but they appeared to be most numerous between 5 and 10 km and to decrease seaward. However, evaluation of distribution patterns and estimates of population are extremely tenuous with the data presently available.

Due to their large population, many shearwaters could be affected if an oil spill occurred during spring or summer. Although they are facile in flight and may avoid polluted areas, their underwater foraging as well as their frequent concentration in dense flocks would contribute to their vulnerability. However, because of the general abundance and wide distribution of shearwaters throughout the Gulf of Alaska, it seems unlikely that any one incident or even several could threaten the existence of the species. Persistent pollution of surface waters or food chain organisms could eventually reduce the populations or productivity of shearwaters. Such effects, either direct or indirect, could have substantial long-term impact.

Short-tailed Shearwater, *Puffinus tenuirostris*

The status of this species is uncertain. None were observed on the censuses, but this Australian shearwater has an annual 20,000 mile circular migration around the Pacific basin, migrating north to the Bering Sea through the western Pacific and returning to Australia via the North American coast from Alaska to Baja California and then crossing the South Pacific to their nesting areas (Dementov and Gladkove, 1951). Short-tailed shearwaters are similar to the sooty; hence they may be abundant in NEGOA during late summer and fall. Confirmation of this report is still required, although Isleib and Kessel (1973) recorded numerous short-tailed shearwaters in the region.

Phalacroacidae (Cormorants)

Pelagic Cormorant, *Phalacrocorax pelagicus*

More than 90 percent of the cormorants identified were of this species, which nests commonly on rocky coasts throughout the Gulf of Alaska. Most appear to remain close to nesting or roosting areas on land and were not often encountered on offshore transects.

The species is widely distributed along the Alaskan coast including the Aleutian Islands and Bering Sea. OCS development would generally have minor impact in offshore areas, but could cause a loss of local populations if spills drifted to the nearshore zone during the nesting season.

Double-crested Cormorant, *Phalacrocorax auritus*

This species is much less abundant than the pelagic cormorant; however, their distribution and behavior are similar and impacts from OCS development would be identical.

Anatidae (Ducks)

Numerous species of waterfowl use the shoreline zone, but few were observed on transects. Most important of these are: greater scaup, *Aythya marila*; common goldeneye, *Bucephala clangula*; Barrow's goldeneye, *Bucephala islandica*; harlequin, *Histrionicus histrionicus*; white-winged scoter, *Melanitta deglandi*; and black (common) scoter, *M. rigra*. Collectively these species number more than 1000,000 birds. Most are found within bays and estuaries of Prince William Sound, the Northwestern Gulf of Alaska, Kodiak, and the Alaska Peninsula; OCS development is likely to have an important effect on the populations only if these nearshore habitats should be extensively polluted.

Surf Scoter, *Melanitta perspecillata*

In nearshore waters, surf scoters are the most abundant duck at all seasons. Peak populations probably exceed 100,000 (Isleib and Kessel, 1973), but few were observed on transects that did not adequately sample the shoreline area. The species would be vulnerable to oil pollution, and losses could be substantial if such pollution reached the shoreline. However, dispersal of scoters through the numerous fiords and estuaries of Prince William Sound suggests that the impact of OCS development on this species will be of minor importance to the total population.

Laridae (Gulls and Terns)

Seven species of gulls and terns were observed in NEGOA and, collectively, the members of this family were observed more frequently than those of any other family of birds resident in Alaskan waters. All gulls are surface feeders, facile flyers, and avoid water polluted by oil; so they are less vulnerable to development activities than species that dive for food. Additionally, the glaucous-winged, herring, and mew gulls may benefit by scavenging human debris that may result as a by-product of development. Such behavior in winter can already be observed in Anchorage. Increases in herring gulls

(*Larus argentatus*) on the east coast of North America have proved harmful to the welfare of other species, causing measurable losses in populations of common puffins (*Fratercula arctica*) (Nettleship, 1972). In areas of persistent or heavy contamination by oil, productivity of gulls could be affected by contamination of eggs or changes in availability of food.

Herring Gull, *Larus argentatus*

Herring gulls were rare in winter, but beginning in early May they rapidly replaced glaucous-winged gulls and became the most common of large gulls present in NEGOA. Their numbers increased only slightly in the Northwest Gulf and remained rare in the regions of Kodiak and the Alaska Peninsula. Herring gulls are found on the Copper River Delta and elsewhere in the NEGOA region, but those nesting within NEGOA probably account for only a part of the pelagic population. The extensive use of the shoreline zone including river mouths and beachline for foraging also suggests that pelagic counts provide lower estimates of populations than actually occur as compared with more completely pelagic foragers such as the kittiwake. The herring, glaucous, and glaucous-winged gulls are the three gull species most likely to benefit by development activities in Alaska, since they also feed on refuse in harbors, at canneries, and in garbage dumps.

Black-legged Kittiwake, *Rissa tridactyla*

Kittiwakes were commonly observed during all months of the survey and were the most abundant larid in May and June. In winter highest densities were found at the outer edge of the Continental Shelf and over the continental slope. In summer adult kittiwakes generally occurred as scattered individuals over the shelf and in flocks only when close to land. Immature kittiwakes, however, were frequently in flocks of 10 to 50 individuals and were present in 21 of 25 transects seaward of the Continental Slope.

The continuous association of kittiwakes with the pelagic environment and their nesting colonies with the immediate shore indicates that they are the most likely of the larid species to be adversely affected by OCS development. Although not nearly as vulnerable to direct mortality as diving species such as the alcids, losses of adult kittiwakes or reduced reproduction are likely to occur with any substantial oil pollution near breeding colonies.

Alcidae (Auks, Murres, and Puffins)

The species *Alcidae* are the most vulnerable of all species to pollution of the ocean environment. Several species nest in dense local colonies--the typical "seabird cities" of marine cliffs. All dive for food and are confined year-round to marine waters. Compared with larids and procelarids, they are reluctant flyers, generally have low productivity, and are frequently subject to mass mortality from undocumented causes, which are probably related to food shortages or storm conditions in winter. These characteristics cumulatively contribute to their extreme vulnerability.

Murres, *Uria aalge and U. lomvia*

Two species of murres, the common, *U. lomvia*, live in the NEGOA region. They are distinguished with difficulty when at a distance and were not counted separately on transects. Both nest in colonies from a few dozen pairs to many thousands of pairs throughout the Gulf of Alaska, Bering Sea, and Chukchi Sea regions.

Murres are abundant at all seasons. In February, they were seen on 48 percent of transects and had an average density of 2.7 per km^2. Major concentrations (exceeding 100 per km^2) were found at Hinchinbrook Entrance and within Prince William Sound, about 10 km off the Copper River Delta, on the Continental Slope 55 km south of Yakataga, and on the high seas about 110 km south of Middleton Island. Scattered individuals were found throughout the region. The persistence of these winter concentrations is unaccountable.

Murres became more abundant during April when they were present on 88 percent of transects and reached an estimated population of 1.2 million birds. This high level probably coincided with the return of birds wintering farther offshore or to the south. The murre population observed on transects declined rapidly in May and reached their lowest numbers in June when nesting colonies were occupied.

The murres using waters of the NEGOA region are more numerous than those living in local colonies; the population includes birds from Prince William Sound, the Northwestern Gulf, Kodiak, and perhaps the Alaska Peninsula where many large colonies live.

Pigeon Guillemot, *Cepphus columba*

Only one guillemot was seen on transects within NEGOA, but this species was observed regularly--usually less than 5 km from shore--in protected waters from Hinchinbrook Island to the Shumagin Islands. Since this species is associated with waters of the immediate shoreline and is not likely to be encountered at sea, our transects do not provide a reliable estimate of population size. Isleib and Kessel (1973) estimate that the population on the North Gulf Coast and Prince William Sound numbers several tens of thousands. The species may be particularly vulnerable to oil that washes ashore; many adults could be lost and oil contaminating low rocky beaches could ruin their nesting habitat. Local populations are likely to be destroyed.

Tufted Puffin, *Lunda cirrhata*

Tufted puffins are far more abundant in NEGOA than the horned puffin (*Fratercula corniculata*) and were encountered regularly in all months of the survey. No concentrations were noted except near breeding colonies. Elsewhere they were recorded as scattered individuals. In winter, many were seen over the continental slope, and they were encountered on 60 percent of transects seaward of the 100-fathom (200 m) contour.

Horned Puffin, *Fratercula corniculata*

No horned puffins were observed within NEGOA or Prince William Sound, and only three were observed in the NWGOA. Westward, in the Kodiak Basin and along the Alaska Peninsula, they were fairly common, although they were not as abundant as tufted puffins, which occurred on all transects in the Kodiak Basin and 94 percent of transects along the Peninsula. Both species would be severely affected by oil, both at sea and at nesting colonies. Local populations could be destroyed by oil that drifted nearshore in summer.

Small Alcids

Rhinoceros Auklet, *Cerorhinca monocerata*
Cassin's Auklet, *Ptychoramphus aleutica*
Marbled Murrelet, *Brachyramphus marmoratum*
Kittlitz's Murrelet, *Brachyramphus breviostre*
Ancient Murrelet, *Synthliboramphus antiquum*

A total of 92 individuals of the five species of small alcids listed above were identified on transects. In addition, 507 individuals were recorded as unidentified small alcid, demonstrating the difficulty of censusing this group. Two additional species are known to live in the North Gulf Coast region: the parakeet auklet, *Cyclorrhynchus psittacula,* an uncommon local nester, and the crested auklet, *Aerthia cristatella,* occurring only as a rare visitor.

Populations of small alcids within NEGOA vary from about 31,000 in February to 130,000 in April and 400,000 in May and then decline slightly to 340,000 in June. Much additional censusing is necessary for adequate evaluation of populations for this group, since their size, nondescript appearance, and behavior all suggest that a substantial number of birds that were present were not observed.

Marbled murrelets were found in all months, Kittlitz's and ancient murrelets were not observed until May, and Cassin's and rhinoceros auklets not until June. Observers considered the marble murrelet to be much more abundant than other species, and Isleib and Kessel (1973) state that it "composes the greatest avian biomass in Prince William Sound." Earlier estimates by the U.S. Fish and Wildlife Service suggest populations of 250,000 marbled murrelets in Prince William Sound alone, which are not included in NEGOA estimates.

The vulnerability of small alcids would be similar to that of murres and puffins. However, since in this area some use protected bays and estuaries extensively some of the population would be isolated from potential oil spills. Marbled and Kittlitz's murrelets nest as isolated individuals far from water; thus, breeding birds do not have the same high vulnerability at colony sites as would murres or puffins. Although losses could be severe for extensive pollution or spills, the populations may not be jeopardized.

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4. DEMERSAL FISH AND SHELLFISH

INTRODUCTION[1]

During 1975 the Northwest Fisheries Center (NWFC) conducted a comprehensive survey of demersal fish and commercially important invertebrate resources of the continental shelf and upper slope of the northeastern Gulf of Alaska (NEGOA). This survey was part of a major effort by the United States Government to assess the environmental risks involved with developing potential offshore petroleum reserves in Alaska.

The 1975 study was designed to estimate demersal fish and shellfish population parameters and community characteristics that would be subject to change due to man-made causes or environmental stress. Specific objectives of the study were to: (1) describe the density distribution of the principal demersal fish and commercially important invertebrates in the study area; (2) estimate the standing stock and size composition of the principal species; (3) define the composition of the demersal fish communities by area and depth; and (4) for demersal fish species, collect data on individual lengths as related to weight, age, and maturity for later analysis.

PRIOR RESEARCH AND THE COMMERCIAL FISHERIES

Since the 1950's the Bureau of Commercial Fisheries (BCF), now the National Marine Fisheries Service, (NMFS), has been conducting fish and shellfish exploratory surveys in the Gulf of Alaska region. The northeast gulf area was first investigated in 1954. Various types of commercial fishing gear (otter trawl, shrimp trawl, crab pots, and beam trawls) were used to assess the potential of demersal fish and shellfish resources in Prince William Sound and in adjacent offshore waters (Schaefers, Smith, and Greenwood, 1955).

In 1961 and 1962 the northeast Gulf of Alaska was included in a survey by the International Pacific Halibut Commission (IPHC) to determine the

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[1] Extracted for OCSEAP by E.G. Wolf, of Science Applications Incorporated, Boulder, Colorado, from Ronholt, L.L, Shippen, H.H., and Brown, E.S. (1976). An Assessment of the Demersal Fish and Invertebrate Resources of the Northeastern Gulf of Alaska, Yakutat Bay to Cape Cleare, May-August 1975. NEGOA Annual Report to the National Oceanic and Atmospheric Administration/ Outer Continental Shelf Environmental Assessment Program.

availability to trawl gear of halibut and other bottomfish. The BCF conducted cooperative surveys with the IPHC (Hitz and Rathjen, 1965). The systematic sampling scheme designed by the IPHC consisted of one-hour drags on the continental shelf at every 6' of latitude and 15' of longitude. The IPHC repeated the study of the northeast gulf area in the summer of 1962 (Hughes, 1974; IPHC, 1964). IPHC attempted to resurvey the study area in the following fall and winter, but severe weather limited the number of stations sampled. From 1962 to 1970 the BCF conducted several exploratory fishing surveys in portions of the northeast gulf. These surveys were primarily designed to locate commercially exploitable concentrations of demersal fish and shellfish (Anon., 1962; Anon., 1963). During 1968 a cooperative BCF-Alaska Department of Fish and Game (ADF&G) scallop survey was conducted throughout the survey area, and during 1970 shrimp explorations were conducted in selected areas of Prince William Sound (Anon., 1968; Anon., 1970).

Since 1963 intensive commercial fishing for demersal fish and shellfish have been conducted in the eastern Gulf of Alaska by Japanese and Soviet nationals, harvesting substantial amounts of rockfish, primarily Pacific ocean perch and flounder, with trawl gear. The Japanese have also had an intensive longline fishery for sablefish. In recent years, South Korea entered the fishery for groundfish in this region. In addition to the trawl and longline fisheries by Asian nationals, there has been a traditional longline fishery for halibut by U.S. and Canadian nationals since the early part of the century. U.S. nationals also fish for scallops and Dungeness and Tanner crabs. From 1967 to 1974 the total harvest by all nations in the eastern Gulf of Alaska, of which the NEGOA study area is a major part, ranged from 101,000 metric tons (mt) in 1968 to 58,000 mt in 1970 (Table 9). Rockfish, mainly Pacific ocean perch, have been the principal species harvested and have accounted for 42 to 72% of the total catch, averaging 55%. Sable fish have constituted from 4 to 31% of the total harvest and averaged 21%, while the halibut catch has ranged from 6 to 16% and averaged 10%. Flounder and pollock were not target species during these years, except that in 1973 flounder made up 22% of the total harvest. The annual catch of halibut by North American nationals has ranged from about 5,300 to 9,900 mt since 1967.

*Table 9. Estimated groundfish catches (1,000 mt) by species group in the Gulf of Alaska east of 147°W. longitude and north of 54°30'N. latitude. Nations included are the U.S.A., Canada, Japan, U.S.S.R., and Rep. of Korea.**

Species group	1967	1968	1969	1970	1971	1972	1973	1974
Halibut	8.7	5.8	9.9	9.0	6.7	6.0	5.8	5.3
Flounders	1.4	2.4	1.7	2.8	0.9	5.5	18.4	4.2
Rockfishes	44.9	68.6	36.4	28.1	36.8	33.6	35.8	25.7
Pollock	1.4	3.7	2.6	0.6	0.7	1.5	2.5	2.7
Sablefish	2.7	12.9	13.9	16.2	16.6	21.7	14.8	17.4
Others	2.9	7.7	1.5	1.0	0.9	1.8	5.7	6.5
Total	62.0	101.1	66.0	57.7	62.6	70.1	83.0	61.8

* Table compiled by H.A. Larkins of the Northwest Fisheries Center from various sources, some unofficial and uncitable. In some instances, amounts have been estimated.

Prior to 1975, data available on demersal fish and shellfish resources in the NEGOA survey area were insufficient in several respects. Density distribution data collected during the IPHC surveys of 1961-1962 is outdated since these studies were conducted prior to the intensive foreign trawl fisheries in that region. There is also some evidence indicating that pollock abundance has increased since the 1960's. In addition, biological stock parameters such as age-length-weight relationships, growth, and stock compositions by size were unknown for the NEGOA survey area, except for Pacific ocean perch.

STUDY AREA

The study area includes the continental shelf (0-200 m) and upper slope (201-400 m) from Yakutat Bay (140°00'W. longitude) to Cape Cleare (148°00'W. longitude). This portion of the Gulf of Alaska has a relatively wide continental shelf, up to 100 km in width. Two prominent gullies intersect the shelf in the survey area, the Yakutat Gully extending from the mouth of Yakutat Bay southwest to the edge of the continental shelf and the Prince William Sound Gully extending south from Hinchinbrook Entrance. Just south of Cape Suckling, the Bering Trough cuts southward through the continental shelf. Wessels Reef is located between Hinchinbrook and Middleton Islands. Bottom sediments include soft mud, firm mud, mud with boulder, gravel, and rock.

METHODOLOGY

Presently no adequate alternative methods to direct sampling are available to measure density distribution, standing stock, or biological stock parameters of demersal fish populations.

As most sampling devices are known to be selective to certain species and fish size, there are recognized problems in precise quantitative extrapolation of the catches or catch per unit effort (CPUE) to population standing stocks. The otter trawl was selected to maintain comparability of results of this survey to previous surveys in the study area. Other sampling devices would severely minimize areal coverage, and it was considered the best gear for sampling a wide range of demersal species.

The systematic bottom trawl station pattern employed in the NEGOA survey was comparable to that used by the IPHC and BCF from 1961 to 1963. Trawl stations were located from nearshore to a depth of 400 m, along north-south transect lines at every 15' of longitude (∿ 14 km). Along each of these lines, stations were located every 6' of latitude (∿ 11 km) apart to a depth of 183 m. At greater depths, one station was plotted between 183 and 318 m and another between 318 and 400 m. On alternative longitudinal lines, stations were shifted by 3' of latitude from adjacent lines. The station block was designated as the area surrounding each station, usually a rectangle 11x14 km. If bottom conditions prevented trawling at the pre-designated station location, then a catch made from anywhere within the block was considered representative.

Survey operations were conducted from the F/V North Pacific, a chartered commercial fishing vessel. The North Pacific is a 26 m overall length, combination-type west coast fishing vessel powered by a 565 hp V-8 Caterpillar engine. Split trawl winches, each capable of holding 1,170 m of 2 cm wire cable, were mounted immediately behind the deck house. The hydraulic powered net reel was situated between the trawl winches. Electronic equipment included dual lorans, dual radars, single side band radio, two-way radio telephone, radio direction finder, dual sounders, single sonar, and surface seawater temperature indicator.

Demersal sampling was conducted with a 400-mesh eastern otter trawl of the type employed in the west coast groundfish trawl fishery. Trawls were rigged with 15 deepsea trawl floats (20 cm) spaced along the headrope, a 3.2 cm stretched-mesh nylon liner placed in the cod end, and 10.2 cm mesh chafing gear constructed of 0.6 cm polypropylene. Trawls were spread with 1.5 x 2.1 m V-type otter boards, weighing approximately 386 kg each. Dandylines were 36.6 m long and constructed of 1.3 and 1.6 cm wire rope for the top and bottom legs, respectively. A 54.8 m snag cable of 0.95 cm wire rope was attached to the doors to reduce damage to the trawl.

Trawl configuration measurements and bottom-trending observations were made prior to the start of the cruise by NWFC diving personnel. The 400-mesh eastern otter trawl was found to open approximately 12.2 m horizontally and 1.8 m vertically, and the foot rope was in contact with the substratum along its entire length except at the very lead end of the wings.

Prior to trawling, a sounding transect was made along a preselected depth contour to pass approximately through the center coordinates of the grid. If the recording showed the bottom was relatively level, soft, and free of obstructions, the trawl was set. If the soundings indicated an unsuitable bottom contour or texture, 30 minutes additional time was allotted to conduct transects nearer to the borders of the station block. If the bottom was not trawlable, the station block was designated as untrawlable and the vessel deployed to the next station.

When a trawlable location was found the vessel would reverse its course, return to that location, set its trawl in a standard manner, tow for one hour, and then retrieve the trawl. An echo trace of the bottom was recorded during fishing. Time of fishing was measured from the setting of the trawl winch brakes until the trawl winch started retrieval. The amount of trawl warp let out to reach the desired depth was approximately three units of cable for each unit of depth. For each station a record of the date, time, and position at start and finish of the tow, vessel speed, and distance fished was logged.

Each catch was processed to obtain species composition and biological information on selected species. Catches of approximately 1,000 kg or less were entirely processed, but larger catches were subsampled.

If one or more species were excessively abundant, specimens were sorted from the catch into three baskets simultaneously, by species, until all three baskets were filled. This process (May and Hodder, 1966) was continued until the catch was completely sorted. Then, one basket from each set of three was selected at random to provide a subsample for analysis of length and sex composition. When sorting was complete, the catch components were weighed and counted. Counts recorded were the actual number caught, estimates from the average weight of specimens in a subsample, or estimates on the basis of a previously determined average weight per specimen.

Certain species of commercial value were selected for biological examination. Biological data collected included sex and length composition for demersal fish and crab species, length-weight relationship, stage of sexual development as related to time and place of spawning, materials for age determination, and food studies for demersal fish species.

The sex of a fish was determined by cutting the abdomen and exposing the gonads for examination. Crabs were sexed by examination of external features.

The method described by Davenport and Laring (1965) was used to determine fish length; i.e., length is recorded to the nearest centimeter on a plastic strip. Care was exercised to see that the specimen's back was straight and jaws were closed when measured.

Weight, sexual development, and age data were collected from a stratified subsample of fish (except halibut). To insure that these observations were spread throughout the survey area, a maximum of five specimens from each species, sex, and centimeter length class was examined in each of the nine area-depth intervals.

DATA ANALYSIS

For data analyses, the NEGOA survey area was divided into nine area-depth intervals based upon the species density distribution found during the 1961 IPHC survey (Fig. 2; Table 10). Area-depth intervals were combined to form three areas -- Eastern, Central, and Western -- and three depth zones -- inner shelf, outer shelf, and upper slope -- for better definition of the density distribution trends within the survey area.

The species catches by stations were converted from the English to the metric system and standardized to an equal trawling distance of 6 km. Standardized CPUE's were calculated:

$$\mathrm{CPUE}_{ijk} = \frac{C_{ijk}(0.45359)\ (6\ \mathrm{km})}{D_{ij}(1.852)}$$

where CPUE_{ijk} equals the standardized catch in kg/std tow for species k for the j^{th} station in the i^{th} area-depth interval, C_{ijk} equals the catch in pounds, and D_{ijk} equals the distance fished in nautical miles. An area-depth interval mean CPUE by species was computed:

$$\overline{\mathrm{CPUE}}_{ik} = \sum_{j=1}^{n_i} \frac{\mathrm{CPUE}_{ijk}}{n_i}$$

where n_i equals the number of stations in the i^{th} area-depth interval.

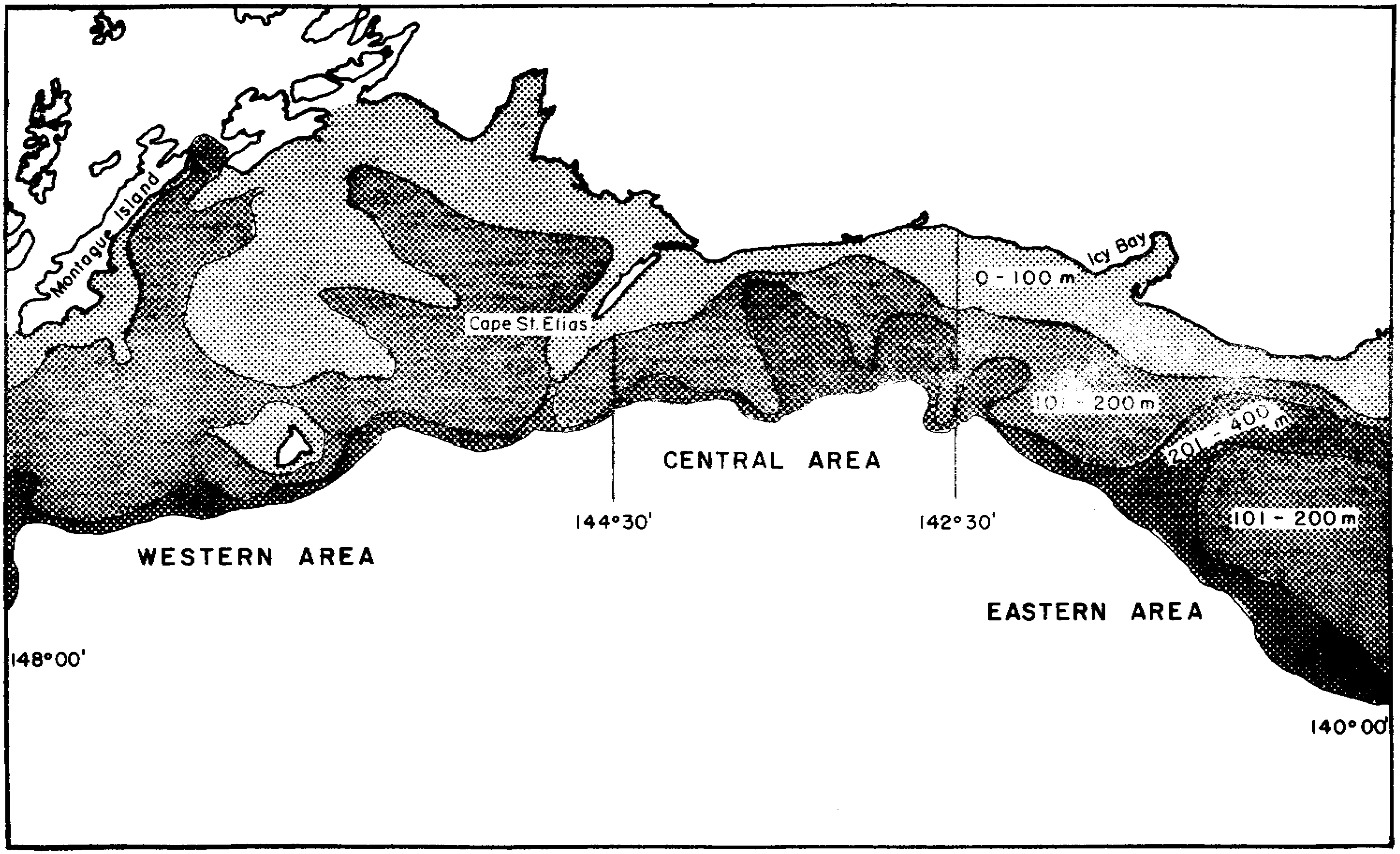

Figure 2. The NEGOA survey area and the 9 area-depth interval subdivisions.

Table 10. Boundaries for areas, depth zones, and area-depth intervals within the NEGOA survey area.

Area	Coordinates	Depth zones	Depth (meters)	Area-depth intervals
Eastern	140°00'W-142°30'W	inner shelf	1-100	Eastern area - inner shelf
		outer shelf	101-200	Eastern area - outer shelf
		upper slope	201-400	Eastern area - upper slope
Central	142°30'W-144°30'W	inner shelf	1-100	Central area - inner shelf
		outer shelf	101-200	Central area - outer shelf
		upper slope	201-400	Central area - upper slope
Western	144°30'W-148°00'W	inner shelf	1-100	Western area - inner shelf
		outer shelf	101-200	Western area - outer shelf
		upper slope	201-400	Western area - upper slope

Calculations of the estimated standing stock by area-depth intervals followed the methods described by Alverson and Pereyra (1969):

$$\overline{P}_{ik} = \sum_{j=1}^{n_i} CPUE_{ijk}/q_k n_i$$

Where $\overline{P}_{ik}$ equals the estimated standing stock in weight or numbers of the k^{th} species in the i^{th} area-depth interval and q_k is the coefficient of catchability, obtained from $q_k = C_k(\overline{a}/A_i)$. The coefficient of vulnerability (C_k) is not known for the species in the survey area but has been assumed to be constant and equal to 1.0. The average area covered by the trawl when towed 6 km is equal to $\overline{a}$, and A_i is the total area within the i^{th} area-depth interval. Therefore, the estimated standing stock in an area-depth i is:

$$\overline{P}_{ik} = \overline{CPUE}_{ik} \quad (A_i \;/\; c_k\overline{a})$$

The estimated standing stock for combined area-depth intervals was the sum of the estimates of the individual area-depth interval combined.

Size composition of the standing stock for each species was computed by area-depth intervals. Size composition data for individual stations within an area-depth interval were converted to proportions of the total length frequency, sexes combined, using the formula:

$$Prop_{ijklm} = \frac{N_{ijklm}}{\sum_{m=1}^{2} \sum_{l=1}^{L} N_{ijklm}}$$

where N_{ijklm} equals the number of individuals of size category l and sex m and L equals the total number of length categories. Proportional length frequencies were weighted by the ratio of the total catch in numbers of species k at station j to the total number of species k at all stations in area-depth intervals i where length frequencies were taken.

$$\mathrm{Prop}_{iklm}(\mathrm{NUM}) = \Sigma\, \mathrm{Prop}_{ijklm} \frac{\mathrm{CPUE}_{ijk}}{\sum_{j=1}^{n_i} \mathrm{CPUE}_{ijk}}$$

The proportion [Prop_{iklm}(NUM)] multiplied by the estimated standing stock, in numbers, for area-depth interval i provides the total number of individuals in each size-sex category.

$$\mathrm{SS}_{iklm} = \mathrm{Prop}_{iklm}(\mathrm{NUM})\ \overline{P}_{ik}$$

where SS_{iklm} equals the estimated standing stock in numbers. Standing stock size compositions by combined area-depth intervals were obtained by summing the number of individuals in each species size-sex category for the area-depth interval.

The names of fish assigned by the American Fisheries Society (1970), Quast and Hall (1972), and Hart (1973) are used in this report. The importance of the species or group within the community has been measured by frequency of occurrence and percentage contribution.

DEFINITIONS

Species Group Definitions

The animal species found in the survey area were divided into six groups:

1. Elasmobranchs: sharks and skates (rays). No Chimaeridae (ratfish) were encountered.

2. Flatfishes: members of order Pleuronectiformes. All the species encountered were from the family Pleuronectidae; no Bothidae were taken.

3. Roundfishes: all orders of the class Osteichthyes (bony fishes) except family Scorpaenidae (rockfishes) and Pleuronectidae (flatfishes).

4. Rockfishes: members of the family Scorpaenidae including the genera *Sebastes* and *Sebastolobus*.

5. Commercially important invertebrates, including the following species: *Pandalus borealis*, pink shrimp; *P. jordani*, ocean pink shrimp; *P. hypsinotus*, coonstripe shrimp; *P. platyceros*, spot shrimp; *P. montagui*

tridens, Montagui shrimp; *P. danae*, dock shrimp; *Pandalopsis dispar*, sidestripe shrimp; *Chionoecetes bairdi*, snow crab; *Lithodes aequispina*, golden king crab; *Cancer magister*, Dungeness crab; and *Patinopecten caurinus*, weathervane scallop.

6. Miscellaneous invertebrates: all other invertebrates except the commercially important group. The miscellaneous invertebrates are treated casually here since they are the subject of a separate report by the University of Alaska, Institute of Marine Science.

Definition of Terms

Standing stock. The total population, in terms of weight or numbers of individuals, of the species vulnerable to the trawl in the defined area.

Standard tow. The area swept (0.73152 km^2) by the 400-mesh eastern otter trawl when towed over a distance of 6 km.

Catch per unit of effort (CPUE). An index of density expressed as the catch in weight or numbers per standard tow.

Percent of group catch. The percentage by weight that the species represents of the total catch of its species group.

Frequency of occurrence. The percent of the total stations sampled in the area under discussion at which the species occurred.

Assumptions

1. The CPUE is a function of stock density in the area being surveyed, and changes in the CPUE are directly proportional to changes in density.

2. The catchability coefficient for the trawl is 1.0; i.e., the trawl captures all fish and invertebrates in its path.

3. No immigrations or emigrations caused significant changes in the distribution and density of the population during the survey period.

4. The configuration of the trawl and its bottom-tending characteristics remained constant throughout the survey.

Data Limitations

1. The community of demersal fish and invertebrates observed during faunal surveys, and the relative importance of species or species groups within the community, are largely functions of the sampling tools employed. Trawls are selective, as is most gear employed to sample the marine biota.

Sizes, and even species, of fish captured are influenced by mesh size used, particularly in the cod end. Even species within the size range, which theoretically would be retained if engulfed in the trawl, may differ in their ability to escape through the mouth of the net. The selective features of trawl alter the composition, sizes, and quantities of species captured from that which occur in its path. The degree to which the "apparent" distribution and relative abundance differs from the actual is unknown. Thus, it is important to note that subsequent discussions of distribution and relative abundance of demersal species and communities reflect the results obtained with the sampling gear employed (Alverson, Pruter, and Ronholt, 1964).

2. The estimates of standing stock are representative only for those species that are vulnerable to the trawl and only to sizes retained by the trawl.

RESULTS

Number of Stations Sampled and Data Collected

Density distribution data, species weights and numbers, and pertinent station and fishing parameters were collected at 131 stations in the NEGOA survey area (Fig. 3). Biological data were collected for selected dominant species. Length measurements by sex were taken of 43,503 specimens; aging structures, scales, or otoliths of 5,017 specimens; and length-weight measurements of 4,516 specimens.

Flatfish

Flatfish (Pleuronectidae) were the most abundant of all fish caught in the survey area, accounting for 53% of the estimated standing stock. Twelve species of pleuronectids were collected in the NEGOA lease area (Table 11).

The CPUE for the flatfish by area and depth ranged from 83.5 to 667.3 kg/std tow and averaged 220.6 kg/std tow for the entire area surveyed (Table 12). The average CPUE decreased from 327.6 in the Eastern Area to 139.5 kg/std tow in the Western Area. Within the three depth zones, the lowest average CPUE, 180 kg/std tow, was on the outer continental shelf, increasing to 242.3 kg/std tow on the inner shelf and 289.4 kg/std tow on the upper slope.

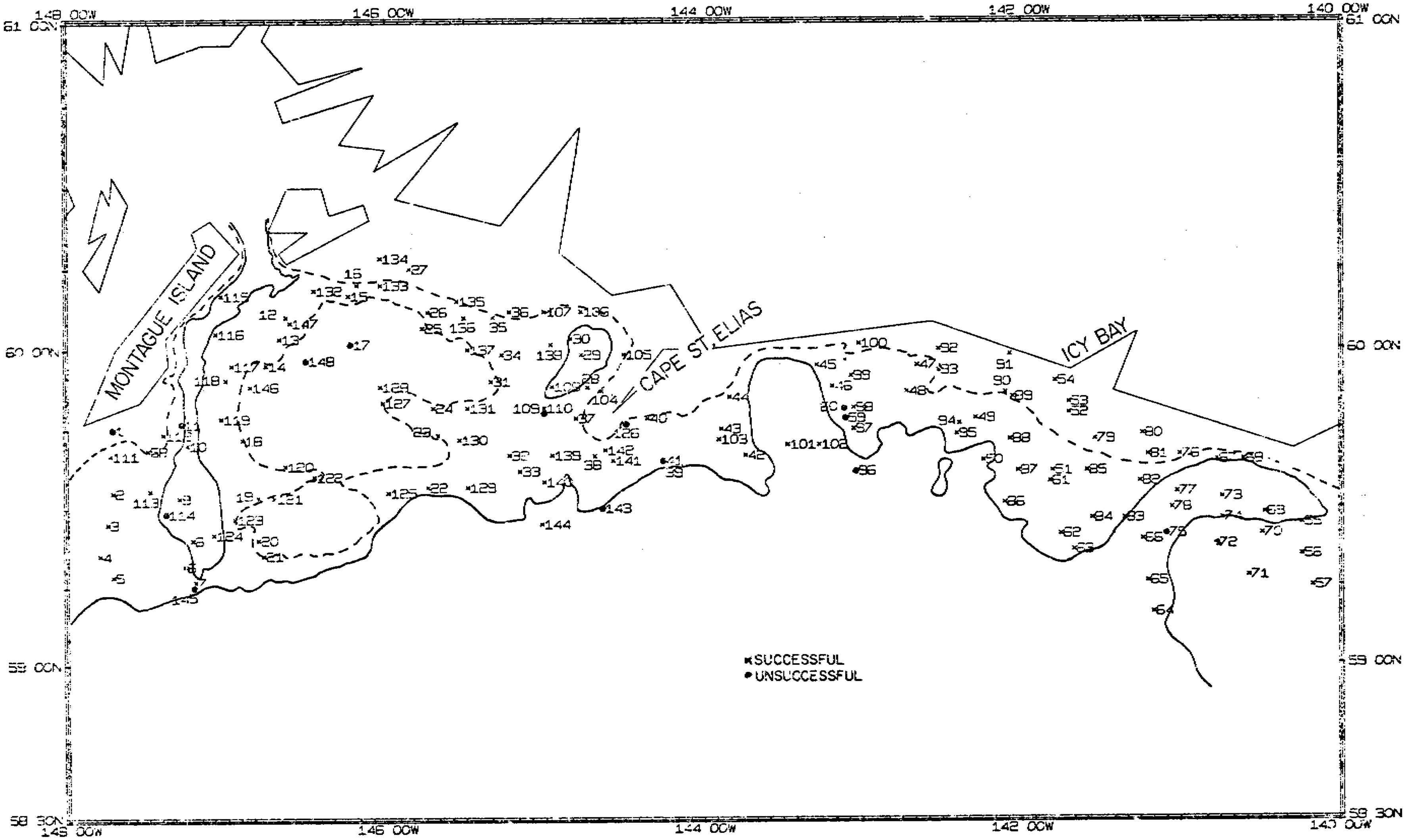

Figure 3. Sampling distribution Gulf of Alaska Resource Assessment Survey 1975.

Table 11. Flatfish species caught in the NEGOA survey area.

Scientific Name	Common Name
Pleuronectidae	Righteyed Flounders
Atheresthes stomias	Arrowtooth flounder or turbot
Eopsetta jordani	Petrale sole
Glyptocephalus zachirus	Rex sole
Hippoglossoides elassodon	Flathead sole
Hippoglossus stenolepis	Pacific halibut
Isopsetta isolepis	Butter sole
Lepidopsetta bilineata	Rock sole
Lyopsetta exilis	Slender sole
Microstomus pacificus	Dover sole
Parophrys vetulus	English sole
Platichthys stellatus	Starry flounder
Reinhardtius hippoglossoides	Greenland halibut

Table 12. Average CPUE in kilograms of flatfish species within the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Arrowtooth flounder	64.6	161.9	168.8	144.5	34.2	135.4	129.7	103.7	57.9	75.5	31.1	62.4	56.2	118.7	112.9	98.0
Starry flounder	442.5	0	0	86.3	0	0	0	0	0.7	0	0	0.3	100.0	0	0	31.4
Flathead sole	29.0	27.2	0.4	21.3	17.1	65.6	2.5	33.4	30.1	32.5	58.5	35.0	28.1	34.3	21.0	29.8
Dover sole	1.9	2.6	111.3	28.0	0.6	3.0	138.8	40.6	1.8	10.3	30.9	9.6	1.7	6.2	89.1	20.6
Rex sole	17.8	6.4	64.1	22.2	17.3	8.3	117.3	41.7	5.5	12.9	36.8	13.1	9.8	9.6	65.7	20.4
Pacific halibut	49.6	5.4	0.2	12.8	6.1	17.0	0	9.0	25.6	14.9	0	17.2	28.4	11.2	0.1	14.5
Butter sole	57.8	0	0	11.3	0	0	0	0	0.6	*	0	0.2	13.4	*	0	4.2
Rock sole	1.7	0	0	0.3	8.2	0	0	2.4	2.2	0.1	0	0.9	2.9	0.1	0	1.0
English sole	2.4	0	0.1	0.5	0	0	0	0	1.9	*	0	0.8	1.8	*	*	0.6
Slender sole	0	0.1	1.4	0.4	0	0	0	0	0	0	0	0	0	*	0.6	0.1
Petrale sole	*	0	0	*	0	0	0	0	0	0	0	0	*	0	0	*
Greenland sole	0	0	0	0	0	0	0	0	0	*	0	*	0	*	0	*
Total	667.3	203.6	346.3	327.6	83.5	229.3	388.3	230.8	126.3	146.2	157.3	139.5	242.3	180.1	289.4	220.6

* - Less than 0.1 kilogram per six kilometers.

The number of species of flatfish collected varied throughout the survey area (Table 13). Eleven species were found in the Eastern Area, ten in the Western Area and six in the Central Area. Ten species occurred on the inner and outer continental shelves, while only seven species were found on the upper slope. Within area-depth intervals, the number of flatfish species ranged from four on the Central and Western-upper slope areas to ten on the Eastern Area-inner shelf.

Flatfish species, which had the highest average CPUE, were generally the most widely distributed and frequently occurring species in the study area, except starry flounder (Tables 12 and 14). Starry flounder was the second most abundant with an average CPUE of 31 kg/std tow, but was caught at only 5% of the stations sampled.

Although the rank order of species dominance of flatfish varied, arrowtooth flounder was always one of the three most abundant species in all area-depth intervals sampled (Table 15). Flathead sole, rex sole, Pacific halibut, and Dover sole also occurred frequently in all area-depth zones. Flathead sole and Pacific halibut were collected primarily in the outer continental shelf area-depth interval, and rex sole and Dover sole in the upper slope area-depth intervals. Starry flounder and butter sole made significant contributions on the Eastern Area-inner shelf. In all area-depth intervals, the three dominant species made up over 80% of the total flatfish catch (Table 15).

Additional data for species specific are discussed in the following sections.

Atheresthes stomias (Arrowtooth flounder)

Arrowtooth flounder were the most abundant and widely distributed flatfish species in the NEGOA survey area (Tables 12 and 14). This species occurred at all stations sampled and accounted for 24% of the total finfish and 44% of the flatfish catches.

Standing stock estimates. The standing stock for arrowtooth flounder in the survey area was estimated at 560 metric tons (mt) (144 million fish) (Tables 16 and 17): 28,058 mt (53%) in the Eastern Area; 16,643 mt (32%) in the Western Area; and 7,869 mt (15%) in the Central Area. Within the three depth zones, the outer continental shelf contained 31,524 mt (60%) of the standing stock, the upper slope 11,567 (22%), and the inner shelf 9,469 mt (18%).

Table 13. Number of flatfish species collected in the NEGOA survey area.

Depth Zones (m)	Areas			Total
	Eastern	Central	Western	
1-100	10	6	9	10
101-200	6	5	9	10
201-400	7	4	4	7
Total	11	6	10	12

Table 14. Percent occurrence of flatfish species in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Arrowtooth flounder	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Starry flounder	41.7	0	0	13.2	0	0	0	0	11.8	0	0	2.8	21.2	0	0	5.3
Flathead sole	66.7	50.0	50.0	55.3	100	86.7	100	90.5	88.2	100	60.0	94.4	81.8	87.7	58.8	82.4
Dover sole	58.3	51.3	90.0	76.3	50.0	86.7	100	81.0	70.6	62.0	80.0	65.3	63.6	70.4	88.2	71.0
Rex sole	83.3	93.8	100	92.1	100	100	100	100	82.0	100	100	95.8	84.8	98.8	100	95.4
Pacific halibut	91.7	56.3	10.0	55.3	75.0	53.3	0	52.4	88.2	68.0	0	68.1	87.9	63.0	5.9	61.8
Butter sole	50.0	0	0	15.8	0	0	0	0	17.6	2.0	0	5.6	27.3	1.2	0	7.6
Rock sole	50.0	0	0	15.8	75.0	0	0	14.3	41.2	28.0	0	29.2	48.5	17.3	0	22.9
English sole	33.3	0	10.0	13.2	0	0	0	0	29.4	8.0	0	12.5	27.3	4.9	5.9	10.7
Slender sole	0	25.0	30.0	18.4	0	0	0	0	0	0	0	0	0	4.9	17.6	5.3
Petrale sole	8.3	0	0	2.6	0	0	0	0	0	0	0	0	3.0	0	0	0.8
Greenland sole	0	0	0	0	0	0	0	0	0	2.0	0	1.4	0	1.2	0	0.8

Table 15. Most abundant species of flatfish and the percentage each contributed to the flatfish catch within the NEGOA survey area.

	AREAS							
Depth Zones (m)	EASTERN	%	CENTRAL	%	WESTERN	%	TOTAL	%
1-100	Starry flounder	66.3	Arrowtooth flounder	41.0	Arrowtooth flounder	45.8	Starry flounder	41.3
	Arrowtooth flounder	9.7	Rex sole	20.7	Flathead sole	23.8	Arrowtooth flounder	23.2
	Butter sole	8.7	Flathead sole	20.5	Pacific halibut	20.3	Pacific halibut	11.8
101-200	Arrowtooth flounder	79.5	Arrowtooth flounder	59.1	Arrowtooth flounder	51.7	Arrowtooth flounder	65.9
	Flathead sole	13.4	Flathead sole	28.6	Flathead sole	22.3	Flathead sole	19.0
	Rex sole	3.1	Pacific halibut	7.4	Pacific halibut	10.2	Pacific halibut	6.2
201-400	Arrowtooth flounder	48.7	Dover sole	35.8	Flathead sole	37.2	Arrowtooth flounder	39.0
	Dover sole	32.1	Arrowtooth flounder	33.4	Rex sole	23.4	Dover sole	30.8
	Rex sole	18.5	Rex sole	30.2	Arrowtooth flounder	19.8	Rex sole	22.7
Total	Arrowtooth flounder	44.1	Arrowtooth flounder	44.9	Arrowtooth flounder	44.7	Arrowtooth flounder	44.4
	Starry flounder	26.3	Rex sole	18.1	Flathead sole	25.1	Starry flounder	14.2
	Dover sole	8.5	Dover sole	17.6	Pacific halibut	12.3	Flathead sole	13.5

Table 16. *Estimated standing stock in metric tons for flatfish species by area-depth intervals in the NEGOA survey area.*

Species	Areas/Depth Zones (m) Eastern 1-100	 101-200	 201-400	 All Depths	 Central 1-100	 101-200	 201-400	 All Depths	 Western 1-100	 101-200	 201-400	 All Depths	 Total 1-100	 101-200	 201-400	 All Depths
Arrowtooth flounder	2,445	17,915	7,688	28,048	773	4,323	2,773	7,869	6,251	9,286	1,106	16,643	9,469	31,524	11,567	52,560
Starry flounder	16,744	0	0	16,744	0	0	0	0	79	0	0	79	16,823	0	0	16,823
Flathead sole	1,098	3,017	21	4,136	386	2,096	54	2,536	3,254	4,005	2,079	9,338	4,738	9,118	2,154	16,010
Dover sole	72	295	5,071	5,438	14	98	2,968	3,080	198	1,273	1,101	2,572	284	1,666	9,140	11,090
Rex sole	677	712	2,919	4,308	391	266	2,508	3,165	597	1,589	1,310	3,496	1,665	2,567	6,737	10,969
Pacific halibut	1,378	603	11	2,492	139	544	0	683	2,765	1,837	0	4,602	4,782	2,984	11	7,777
Butter sole	2,189	0	0	2,189	0	0	0	0	67	1	0	68	2,256	1	0	2,257
Rock sole	67	0	0	67	185	0	0	185	245	14	0	259	497	14	0	511
English sole	91	0	6	97	0	0	0	0	209	5	0	214	300	5	6	311
Slender sole	0	14	62	76	0	0	0	0	0	0	0	0	0	14	62	76

Table 17.

Estimated standing stock in numbers (1,000's) for flatfish species by area-depth intervals in the NEGOA survey area.

Species	Areas/Depth Zones (m) Eastern 1-100	 101-200	 201-400	 All Depths	 Central 1-100	 101-200	 201-400	 All Depths	 Western 1-100	 101-200	 201-400	 All Depths	 Total 1-100	 101-200	 201-400	 All Depths
Arrowtooth flounder	8,389	41,927	6,180	56,496	2,372	13,661	2,042	18,075	40,847	26,909	1,474	69,230	51,608	82,497	9,696	143,801
Starry flounder	13,465	0	0	13,465	0	0	0	0	149	0	0	149	13,614	0	0	13,614
Flathead sole	5,725	7,409	87	13,221	1,336	5,265	95	6,696	19,229	13,781	3,327	36,337	26,290	26,455	3,509	56,254
Dover sole	210	565	7,657	8,432	98	341	4,526	4,965	905	2,906	2,697	6,508	1,213	3,812	14,880	19,905
Rex sole	4,092	3,077	12,619	19,788	2,556	1,650	12,790	16,996	12,244	11,560	9,290	33,094	18,892	16,287	34,699	69,878
Pacific halibut	709	72	4	785	82	113	0	195	1,960	482	0	2,442	2,751	667	4	3,422
Butter sole	17,447	0	0	17,447	0	0	0	0	685	5	0	690	18,132	5	0	18,137
Rock sole	212	0	0	212	521	0	0	521	994	52	0	1,046	1,727	52	0	1,779
English sole	208	0	9	217	0	0	0	0	681	22	0	703	889	22	9	920
Slender sole	0	313	641	954	0	0	0	0	0	0	0	0	0	313	641	954

Standing stock estimates by area-depth intervals ranged from 773 mt (1.5%) on the Central Area inner shelf to 17,915 mt (34%) on the Eastern Area outer shelf.

Size composition. Arrowtooth flounder in the NEGOA survey averaged 31.7 cm in length. Male flounder accounted for 44.3% of the population and ranged from 7 to 61 cm in length, averaging 29.2 cm. Females made up 55.7% of the population and ranged from 11 to 78 cm in length with an average length of 33.6 cm (Figs. 4 and 5). The mean length of male flounder by area-depth interval ranged from 25.3 to 40.6 cm and generally increased from east to west and with water depth (Table 18). A similar area-depth interval pattern was noted for female flounders; however, the average size by area-depth interval was 26.9 to 54.1 cm, 0.9 to 14.7 cm larger than the males.

Spawning observations. None of the arrowtooth flounders examined exhibited ripe eggs or running sperm. Most mature ovaries appeared flaccid as if spawning had occurred prior to the survey.

Platichthys stellatus (Starry flounder)

Starry flounder was the second most abundant flatfish in the survey area, contributing 8% of the total finfish and 14% of the flatfish catches (Tables 12 and 14). However, this species was not widely distributed, occurring at only 5% of the stations sampled.

Standing stock estimates. The standing stock of starry flounder was estimated at 16,823 mt (13.6 million fish), over 99% (16,744 mt) of which occurred on the Eastern region-inner shelf (Tables 16 and 17). The remaining 79 mt (< 1%) were located on the Western-inner shelf area.

Size composition. Percent composition and length frequencies by sex are not available for this species. However, a combined sex length frequency of randomly selected flounder from two stations on the Eastern Area-inner shelf is presented in Fig. 6. Specimens sampled ranged from 27 to 62 cm and averaged 44.7 cm in length.

Spawning observations. No starry flounder collected were in spawning condition.

Hippoglossoides elassodon (Flathead sole)

Flathead sole contributed 7% of the total finfish and 14% of the flatfish catches and occurred at 82% of the stations sampled (Tables 12 and 14).

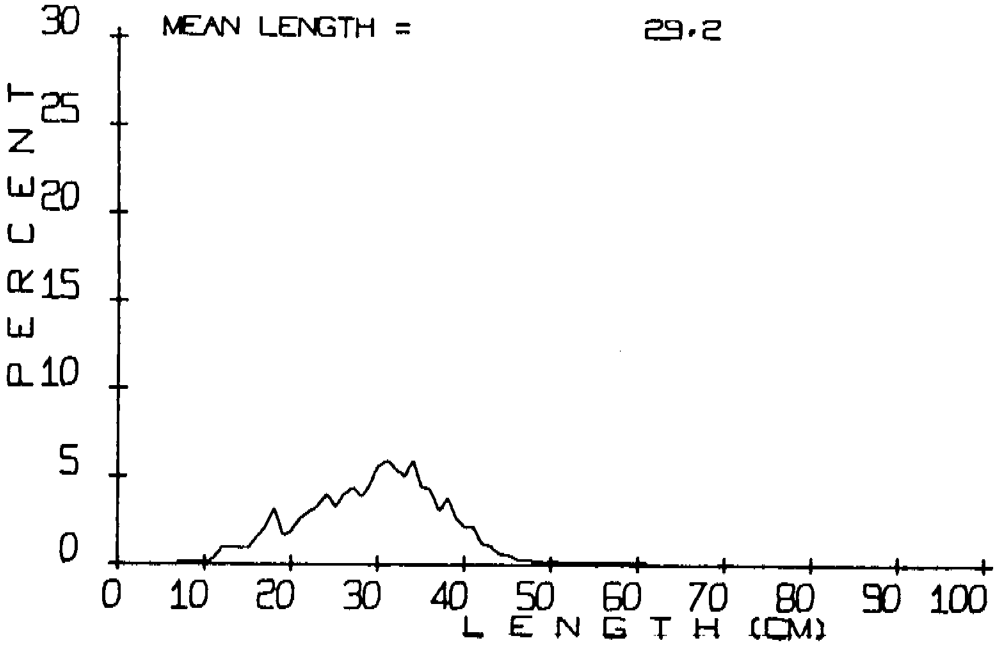

Figure 4. The percent size composition of the estimated standing stock (in numbers) of male Atheresthes stomias *(Arrowtooth flounder) in the NEGOA study area.*

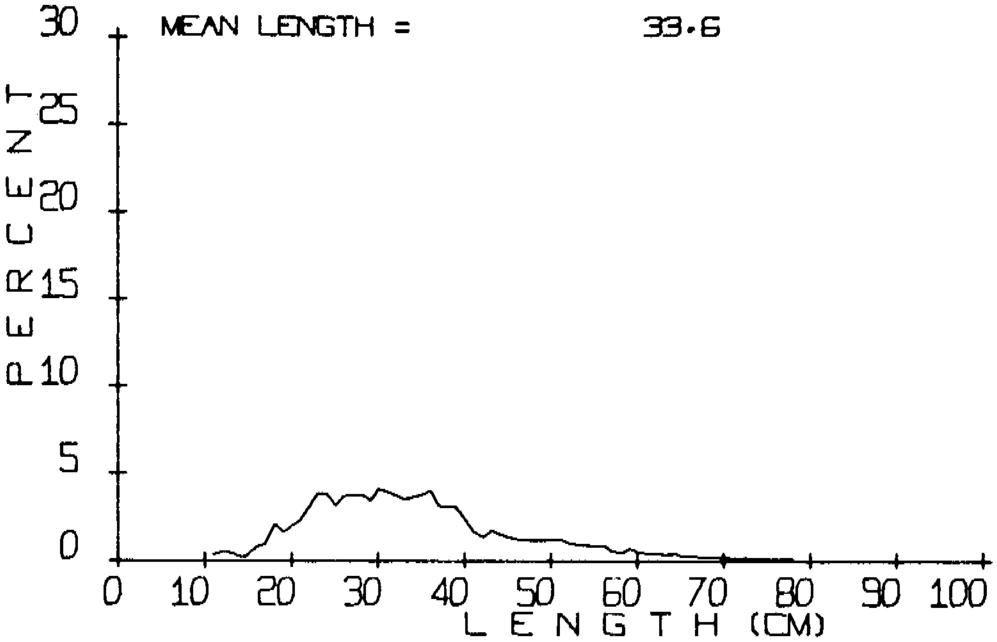

Figure 5. The percent size composition of the estimated standing stock (in numbers) of female Atheresthes stomias *(Arrowtooth flounder) in the NEGOA study area.*

Table 18. Average length of Atheresthes stomias *(Arrowtooth flounder) by area-depth intervals.*

Depth Zones (m)	AREAS Eastern		Central		Western	
	Male	Female	Male	Female	Male	Female
	cm		cm		cm	
1-100	25.9	34.6	28.8	32.0	25.3	26.9
101-200	32.6	35.1	31.0	31.9	29.2	32.2
201-400	40.6	54.1	38.0	52.7	32.0	44.5

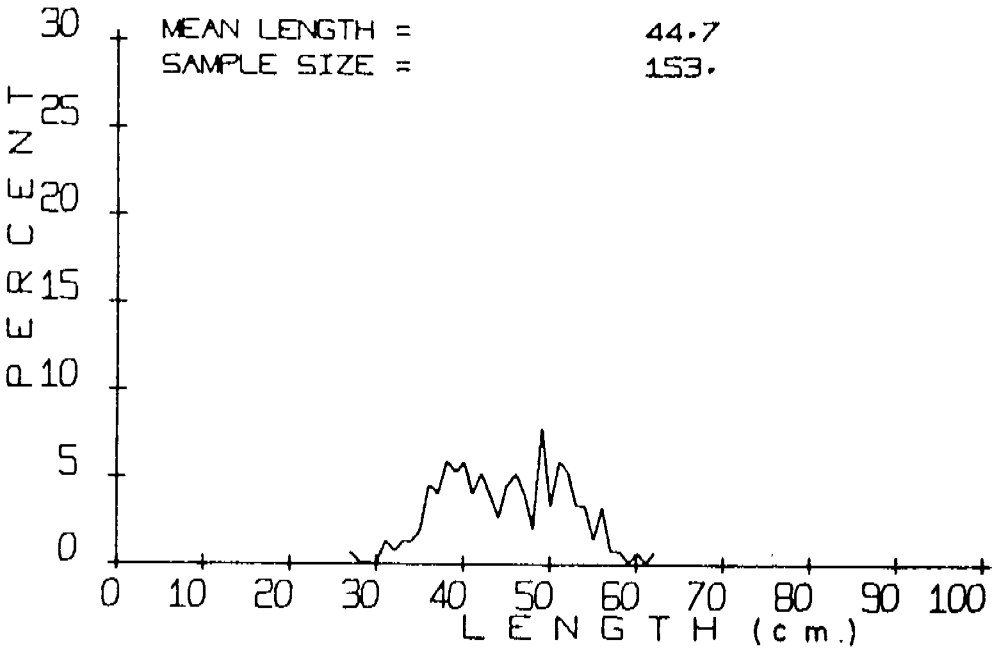

Figure 6. The percent size composition of Platichthys stellatus *(Starry flounder), sexes combined, based on random samples from the Eastern Area-inner shelf.*

Standing stock estimate. The standing stock of flathead sole in the survey area was estimated at 16,010 mt (56 million fish) (Tables 16 and 17): 58% (9,338 mt) occurred in the Western Area; 26% (4,136 mt) in the Eastern Area; and 16% (2,536 mt) in the Central Area. By weight, the major concentration of flathead sole occurred on the outer shelf (101-200 m); however, similar numbers (47%) were estimated for the inner (1-100 m) and outer shelves. The standing stock decreased measurably on the upper slope. Standing stock estimates by area-depth interval ranged from 21 mt (< 1%) on the Eastern Area-upper slope to 4,005 mt (25%) on the Western Area-outer shelf.

Size composition. Flathead sole in the NEGOA survey area averaged 29.4 cm in length and consisted of 46.6% males and 53.4% females. The size of males ranged from 6 to 44 cm in length and averaged 27.2 cm, while females ranged from 7 to 58 cm in length and averaged 31.3 cm (Figs. 7 and 8). The average size of male and female flathead sole increased with the water depth, and females averaged 2.9 to 7.5 cm larger than males (Table 19).

Spawning observations. Only a few male and female flathead sole were found in spawning condition.

Microstomus pacificus (Dover sole)

Dover sole made up 5% of the total finfish and 9% of the flatfish catches and occurred at 71% of the stations sampled (Tables 12 and 14).

Standing stock estimates. The estimated standing stock for Dover sole was 11,090 mt (19.9 million fish) (Tables 16 and 17). The major concentration of this species was in the Eastern Area, 5,438 mt (49%), followed by the Central Area, 3,080 mt (38%), and the Western Area, 2,572 mt (23%). Eighty-two percent (9,140 mt) of the Dover sole standing stock was located on the upper slope, 15% (1,666 mt) on the outer shelf, and 3% (284 mt) on the inner shelf. Estimated standing stocks by area-depth intervals ranged from 14 mt on the Central Area-inner shelf to 5,071 mt (45%) on the Eastern Area-upper slope.

Size composition. Dover sole in the NEGOA survey area averaged 37.3 cm in length and the population consisted of 35.3% males and 64.7% females. Males ranged from 20 to 51 cm and averaged 34.1 cm in length; females ranged from 14 to 66 cm, averaging 39.0 cm in length (Figs. 9 and 10). The average size of both males and females increased with increasing water depth. However,

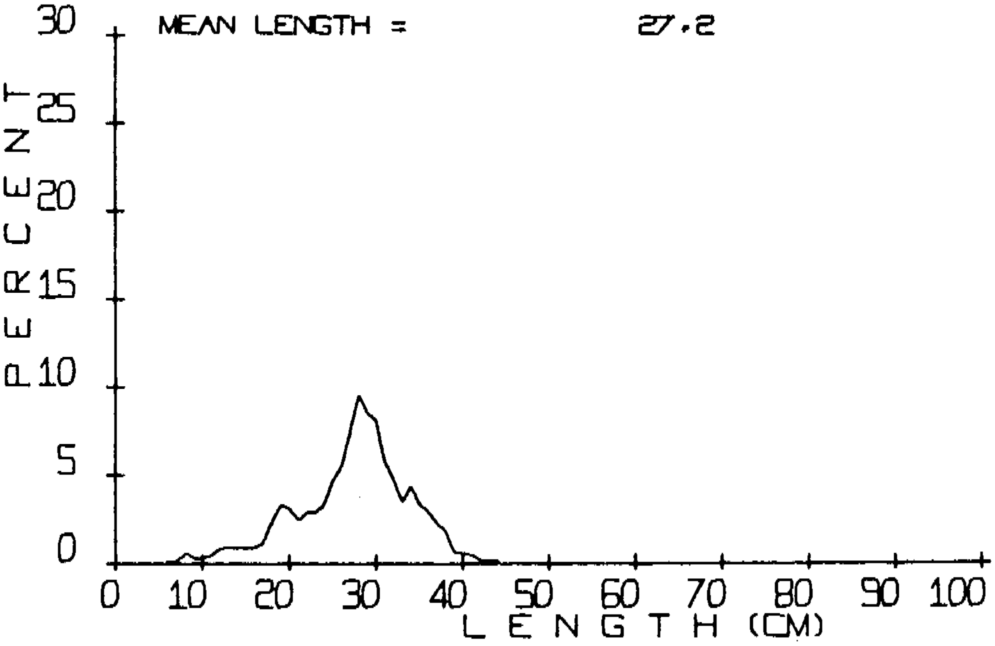

Figure 7. The percent size composition of the estimated standing stock (in numbers) of male Hippoglossoides elassodon *(Flathead sole) in the NEGOA survey area.*

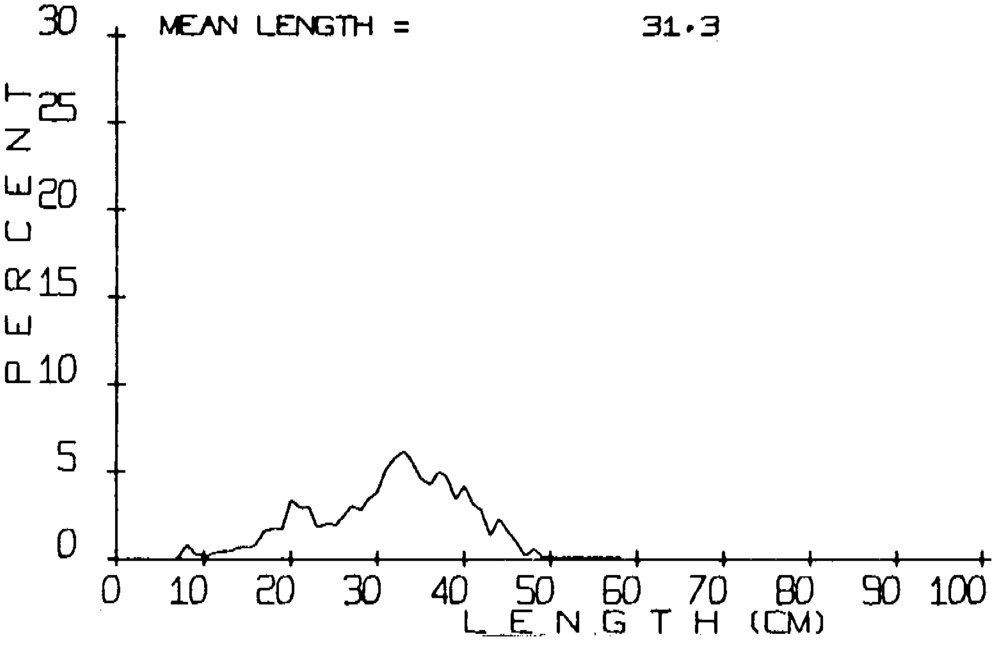

Figure 8. The percent size composition of the estimated standing stock (in numbers) of female Hippoglossoides elassodon *(Flathead sole) in the NEGOA survey area.*

Table 19. Average lengths of Hippoglossoides elassodon *(Flathead sole) by area-depth intervals.*

Depth Zones (m)	AREAS					
	Eastern		Central		Western	
	Male	Female	Male	Female	Male	Female
	cm		cm		cm	
1-100	24.0	26.9	28.2	31.2	23.5	28.8
101-200	31.3	35.4	31.6	35.0	27.4	31.2
201-400	--	--	--	--	32.5	40.0

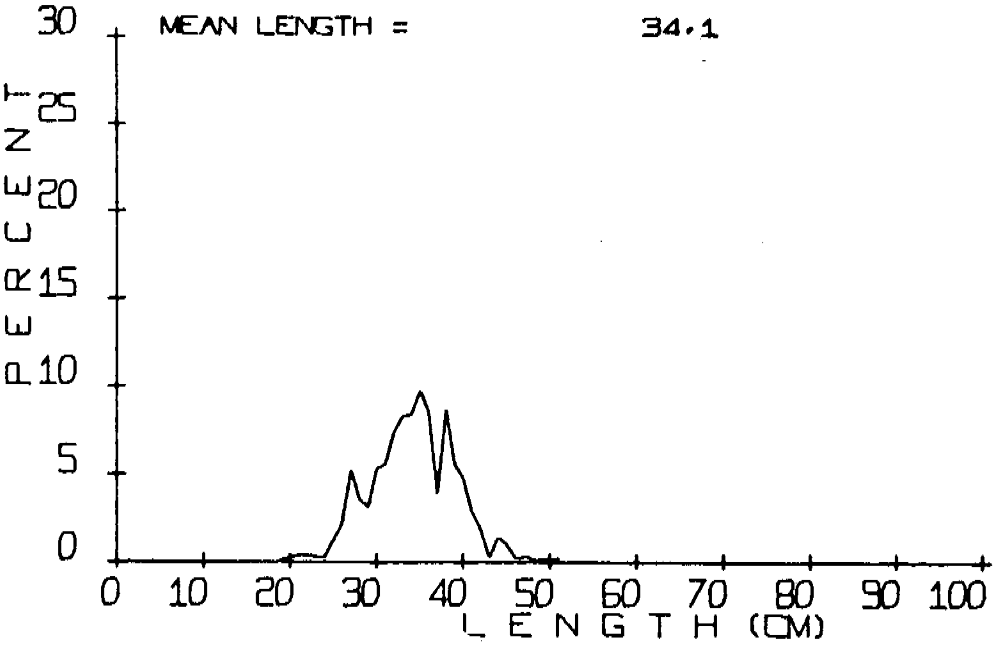

Figure 9. The percent size composition of the estimated standing stock (in numbers) of male Microstomus pacificus *(Dover sole) in the NEGOA survey area.*

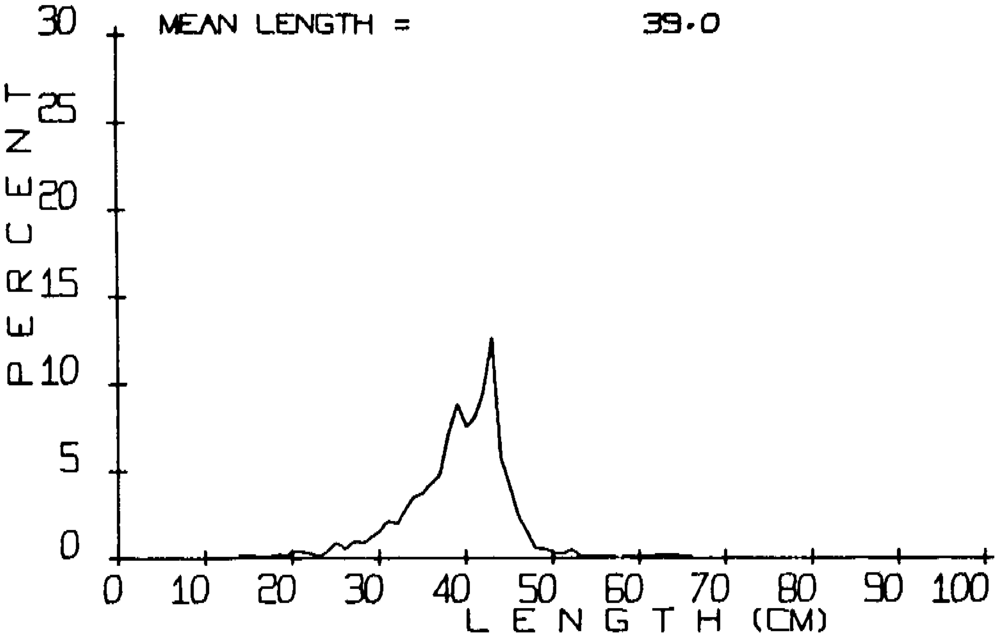

Figure 10. The percent size composition of the estimated standing stock (in numbers) of female Microstomus pacificus *(Dover sole) in the NEGOA survey area.*

females averaged 1.6 to 5.7 cm larger than the males, except on the Western Area-inner shelf where males averaged 0.1 cm larger (Table 20).

Spawning observations. No specimens of Dover sole collected were in spawning condition.

Glyptocephalus zachirus (Rex sole)

In the NEGOA survey area, rex sole made up 5% of the total finfish and 9% of the flatfish catches and was caught at 95% of the stations sampled (Tables 12 and 14).

Standing stock estimates. The estimated standing stock for rex sole in the NEGOA survey area was 10,969 mt (69.9 million fish) (Tables 16 and 17). By area, the estimated standing stock was fairly evenly divided: the Eastern Area contained 39% (4,308 mt), the Western Area 32% (3,496 mt), and the Central Area 29% (3,165 mt). An analysis of the standing stock by depth zone also showed the concentrating of rex sole in deeper waters. The upper slope held 61% (6,737 mt) of the estimated standing stock, while the outer shelf had 23% (2,567 mt) and the inner shelf 15% (1,665 mt). The estimated standing stock ranged from 266 mt (2%) on the Central Area-outer shelf to 2,919 mt (27%) on the Eastern Area-upper slope.

Size composition. The rex sole population in the NEGOA survey area averaged 27.7 cm in length and consisted of 54.2% males and 45.8% females. The size of males ranged from 8 to 42 cm, averaging 27.2 cm; females ranged from 11 to 49 cm with a mean length of 28.2 cm (Figs. 11 and 12). The mean length of both male and female rex sole generally decreased from east to west and increased with water depth (Table 21). The size of females averaged 1.1 to 4.8 cm larger than males, except on the Western Area-inner shelf where females were 1.1 cm smaller.

Spawning observations. Occasionally male and female rex sole in spawning condition were collected during the survey.

Hippoglossus stenolepis (Pacific halibut)

Pacific halibut made up 3% of the total finfish and 7% of the flatfish catches and occurred at 62% of the stations sampled (Tables 12 and 14).

Standing stock estimates. The estimated stock for the NEGOA survey area was 7,777 mt (3.4 million individuals) (Tables 16 and 17). Over half (59% or 4,602 mt) of the estimated standing stock was in the Western Area,

Table 20. Average lengths of Microstomus pacificus *(Dover sole) by area-depth intervals.*

Depth Zones (m)	AREAS					
	Eastern		Central		Western	
	Male	Female	Male	Female	Male	Female
	cm		cm		cm	
1-100	--	--	--	--	30.6	30.5
101-200	34.0	39.3	28.4	32.5	32.8	34.4
201-400	35.3	41.0	37.1	40.9	31.5	36.8

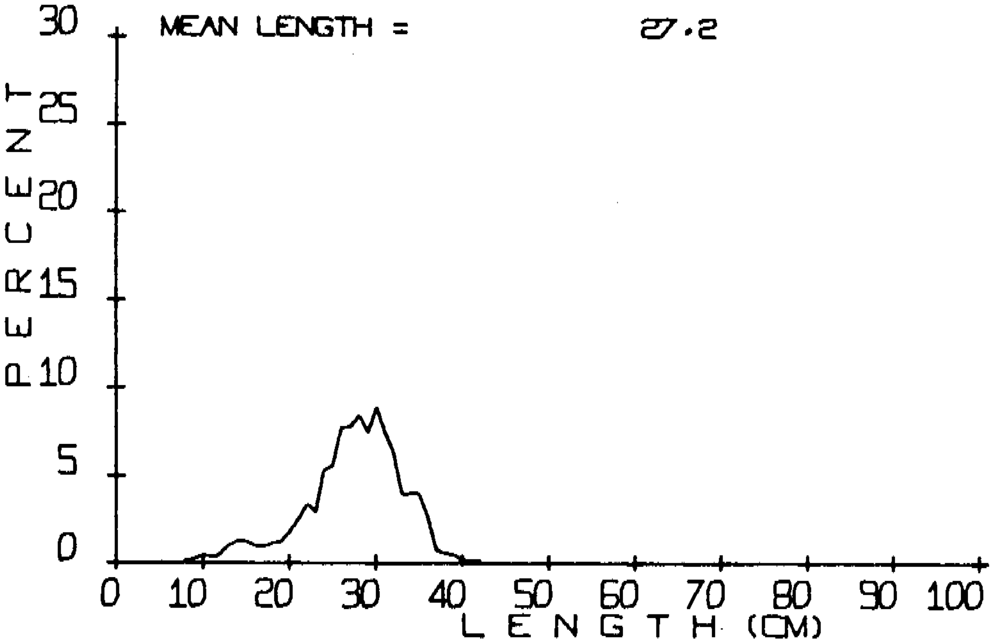

Figure 11. The percent size composition of the estimated standing stock (in numbers) of male Glyptocephalus zachirus *(Rex sole) in the NEGOA survey area.*

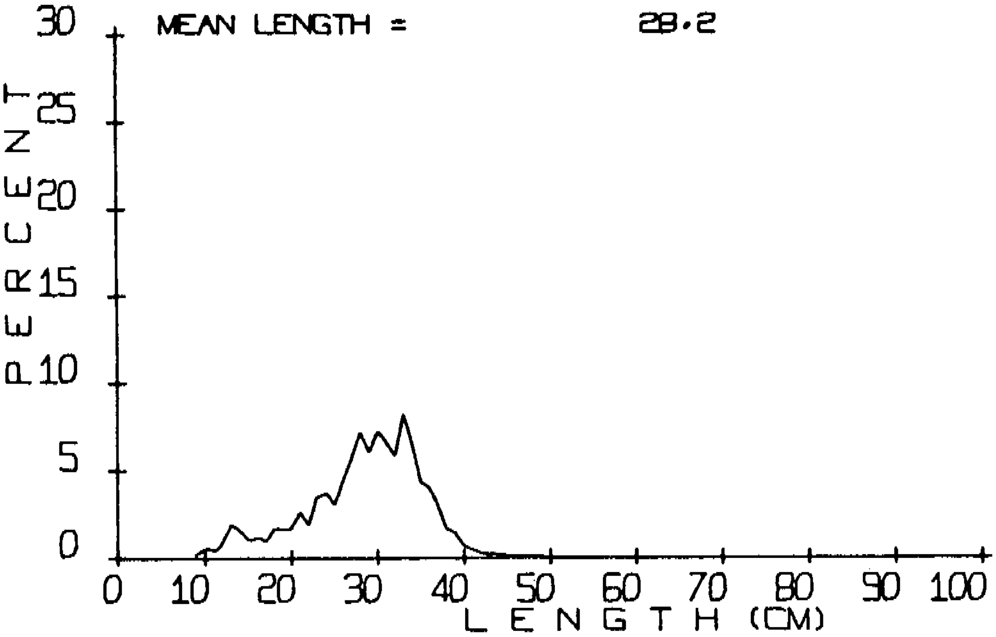

Figure 12. The percent size composition of the estimated standing stock (in numbers) of female Glyptocephalus zachirus *(Rex sole) in the NEGOA survey area.*

Table 21. Average lengths of Glyptocephalus zachirus *(Rex sole) by area-depth intervals.*

Depth Zones (m)	AREAS					
	Eastern		Central		Western	
	Male	Female	Male	Female	Male	Female
	cm		cm		cm	
1-100	26.4	29.7	25.1	29.9	22.3	21.2
101-200	25.9	29.6	26.9	29.6	25.0	27.0
201-400	31.1	32.9	30.4	31.5	26.4	28.8

32% (2,492 mt) in the Eastern Area, and 9% (683 mt) in the Central Area. By depth zone analysis, 61% (4,782 mt) of the halibut were on the inner shelf, 38% (2,984 mt) on the outer shelf, and less than 1% (11 mt) on the upper slope. Estimated standing stock by area-depth interval ranged from 0 mt on the Central and Western Area-upper slopes to 2,765 mt (36%) on the Western Area-inner shelf.

Size composition. Percent composition and length frequencies by sex are not available for this species. Halibut in the NEGOA survey area ranged from 28 to 140 cm in length and averaged 52.0 cm (Fig. 13). The mean size of halibut decreased from east to west, but increased with water depth (Table 22).

Spawning observations Observations on gonadal development did not indicate any halibut in spawning condition.

Isopsetta isolepis (Butter sole)

Butter sole made up 1% of the total finfish and 2% of the flatfish catches and occurred at 8% of the stations sampled (Tables 12 and 14).

Standing stock estimates. Of the total butter sole estimated standing stock (2,257 mt or 18 million fish), 97% occurred on the Eastern Area-inner shelf (Tables 16 and 17).

Size composition. Percent composition and length frequencies by sex are not available for this species. Length measurements of butter sole, selected randomly, at two stations on the Eastern Area-inner shelf ranged from 13 to 37 cm and averaged 22.8 cm (Fig. 14).

Spawning observations. Although the number of maturity observations for this species was limited, no specimens examined were in spawning condition.

Lepidopsetta bilineata (Rock sole)

Rock sole accounted for 0.2% of the total finfish and 0.4% of the flatfish catches and occurred at 23% of the stations sampled (Tables 12 and 14).

Standing stock estimates. The estimated standing stock for rock sole in the survey area was 511 mt (1.8 million fish) (Tables 16 and 17). It was estimated that 97% of the total standing stock was located on the inner shelf. The estimated abundance also increased from east to west.

Size composition and spawning observation data were not collected for this species.

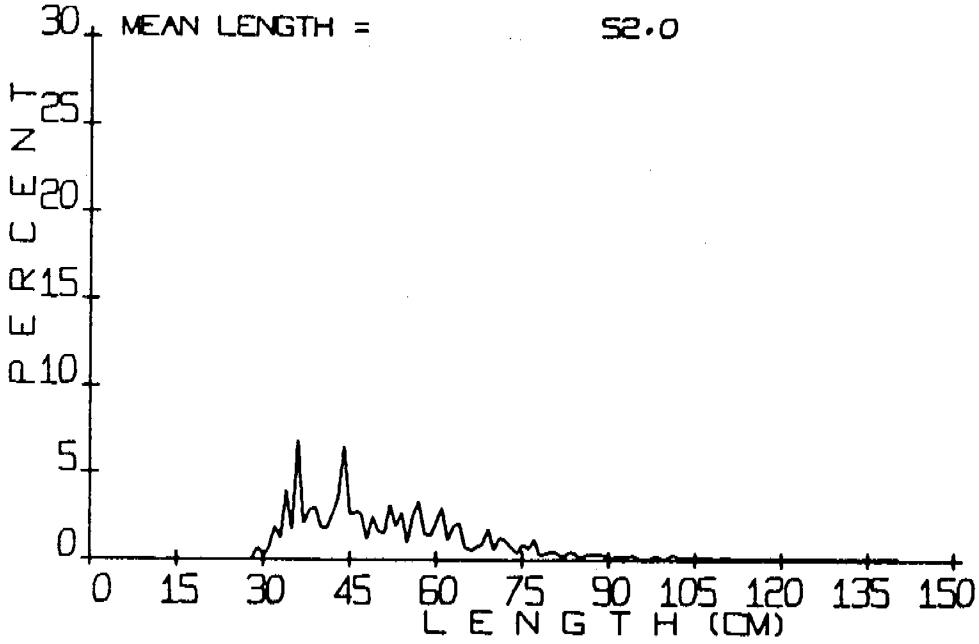

Figure 13. The percent size composition of the estimated standing stock (in numbers) of Hippoglossus stenolepis *(Pacific halibut), sexes combined, in the NEGOA survey area.*

Table 22. Average lengths of Hippoglossus stenolepis *(Pacific halibut) by area-depth intervals, sexes combined.*

Depth Zones (m)	AREAS Eastern	 Central	 Western
	cm	cm	cm
1-100	54.8	53.1	47.0
101-200	76.0	73.3	59.3
201-400	--	--	--

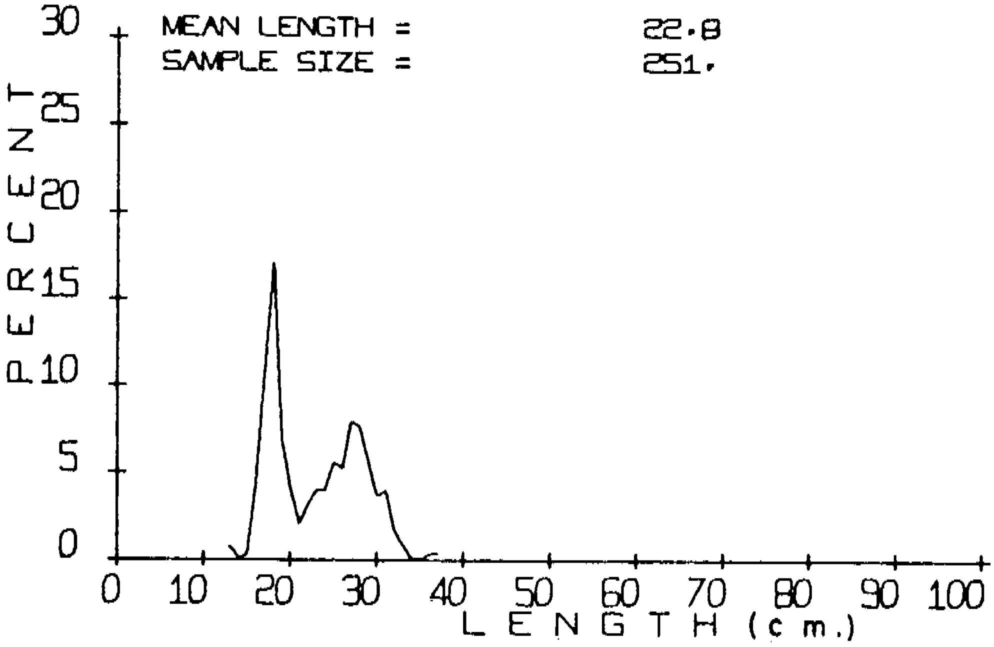

Figure 14. The percent size composition of Isopsetta isolepis *(Butter sole), sexes combined, based on random samples from the Eastern Area-inner shelf.*

Parophrys vetulus (English sole)

English sole occurred at 11% of the stations sampled and contributed 0.1% of the total finfish and 0.3% of the flatfish catches (Tables 12 and 14).

Standing stock estimates. The English sole estimated standing stock for the survey area was 11 mt (0.9 million individuals) (Tables 16 and 17); 98% occurred on the inner shelf and 67% on the Western Area-inner shelf.

Size composition and spawning observation data were not collected for this species.

Lyopsetta exilis (Slender sole)

Slender sole accounted for less than 0.1% of the total finfish and 0.1% of the flatfish catches (Tables 12 and 14). This species occurred at 5% of the stations sampled.

Standing stock estimate. The estimated abundance of slender sole in the survey area was 76 mt (0.9 million individuals) (Tables 16 and 17). This species was only found in the Eastern Area and 82% of the estimated standing stock occurred on the upper slope.

Size composition and spawning observation data were not collected for this species.

Other Flatfish

Petrale sole and Greenland halibut were also caught in the NEGOA survey area. One petrale sole was collected on the Eastern Area-inner shelf, and a Greenland halibut was taken on the Western Area-outer shelf.

Roundfish

Forty species of demersal and eight pelagic roundfish species were collected during this survey, representing ten families (Table 23). Of the 40 demersal species, 34 were identified to species, 1 to genus, and 5 to family.

Roundfish were found throughout the survey area. The estimated standing stock of the roundfish in the survey area was 77,774 mt, 35% of the estimated standing stock for all finfish. The average CPUE for this group in the NEGOA survey area was 144.6 kg/std tow.

Table 23. Roundfish families and demersal species collected in the NEGOA survey area.

Scientific Name	Common Name
Agonidae	Poachers
Agonus acipenserinus	Sturgeon poacher
Hypsagonus quadricornis	Fourhorn poacher
Unidentified	
Anoplopomatidae	Sablefishes
Anoplopoma fimbria	Sablefish
Bathymasteridae	Ronquils
Bathymaster signatus	Searcher
Cottidae	Sculpins
Dasycottus setiger	Spinyhead sculpin
Hemilepidotus jordani	Yellow Irish lord
Hemitripterus bolini	Bigmouth sculpin
Icelinus borealis	Northern sculpin
I. oculatus	Frogmouth sculpin
Icelus spiniger	Thorny sculpin
Leptocottus armatus	Pacific staghorn sculpin
Malacocottus kincaidi	Blackfin sculpin
Myoxocephalus polyacanthocephalus	Great sculpin
Psychrolutes paradoxus	Tadpole sculpin
Rhamphocottus richardsoni	Grunt sculpin
Triglops macellus	Roughspine sculpin
T. pingeli	Ribbed sculpin
Triglops sp.	
Unidentified	
Cryptacanthodidae	Wrymouths
Deloplepis gigantea	Giant wrymouth
Lyconectes aleutensis	Dwarf wrymouth

Table 23. Roundfish families and demersal species collected in the NEGOA survey area (continued).

Scientific Name	Common Name
Cyclopteridae	Lumpfishes and Snailfishes
Eumicrotremus orbis	Pacific spiny lumpsucker
Unidentified	
Gadidae	Codfishes
Gadus macrocephalus	Pacific cod
Microgadus proximus	Pacific tomcod
Theragra chalcogramma	Walleye pollock
Hexagrammidae	Greenlings
Ophiodon elongatus	Lingcod
Stichaeidae	Pricklebacks
Lumpenella longirostris	Longsnout prickleback
Lumpenus maculatus	Daubed shanny
L. sagitta	Snake prickleback
Poroclinus rothrocki	Whitebarred prickleback
Unidentified	
Zoarcidae	Eelpouts
Bothrocara molle	Soft eelpout
Lycodapus fierasfer	Blackmouth eelpout
Lycodes brevipes	Shortfin eelpout
L. diapterus	Black eelpout
L. palearis	Wattled eelpout
Lycodopsis pacifica	Blackbelly eelpout
Unidentified	

The CPUE of roundfish varied with area and depth (Table 24). Density was greatest (189.2 kg/std tow) in the Western Area, declining to 87.8 kg/std tow in the Eastern Area. Average catch rates declined with increasing water depth from 178.6 kg/std tow on the inner shelf to 77.9 kg/std tow on the Eastern Area-outer shelf to 273.8 kg/std tow on the Central Area-inner shelf.

The number of roundfish species caught also varied with area and depth (Table 25). Forty-two species were collected in the Western Area; however, only 21 and 25 species were caught in the Central and Eastern Areas, respectively. Roundfish species abundance was greatest on the inner shelf (35) and declined with depth to 26 species on the outer shelf and 22 species on the upper slope. The number of species declined with increasing depth in the Eastern and Western Areas, but in the Central Area most species were found on the outer shelf. This pattern may reflect the emphasis of sampling on the Central Area-outer shelf (15 stations), as compared to four stations on the Central Area-inner shelf and two stations on the Central Area-upper slope.

The catch rates of the more abundant roundfish species (those with an overall average density of at least 0.1 kg/std tow) are listed in Table 24. Walleye pollock, Pacific cod, and sablefish were the most abundant species collected and usually the more abundant species in each sub-division.

The most abundant species in each sub-division of the survey area and the percentage contributed to the standing stock total are listed in Table 26. Walleye pollock and Pacific cod dominated all survey areas and two of the depth zones; sablefish dominated the upper slope.

The percent occurrence of roundfish species among the stations sampled is listed in Table 27. Sablefish and shortfin eelpout were caught in all area-depth intervals, and Pacific cod, bigmouth sculpin, and walleye pollock were collected in eight of the nine area-depth intervals. Species that appeared infrequently were of little consequence in terms of abundance, except Pacific tomcod occurred in a single area-depth interval, but ranked prominently in overall abundance.

Detailed and summary information on the more abundant roundfish collected in the survey area follows.

Table 24. *Average CPUE in kilograms of roundfish species within the NEGOA survey area.*

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Walleye pollock	159.7	17.9	1.1	41.6	216.9	43.1	0	82.6	95.6	226.9	49.0	150.0	126.3	117.7	17.5	101.2
Pacific cod	79.0	19.9	1.0	27.0	55.0	14.1	0	22.3	13.5	27.0	12.6	19.6	33.8	22.5	4.8	22.7
Sablefish	0.9	1.5	49.3	12.6	0.4	1.4	82.2	23.9	1.5	2.5	12.0	3.4	1.2	2.0	43.2	9.6
Searcher	0.3	0.4	0	0.3	0.4	1.2	0	0.6	9.8	*	0	4.0	6.4	0.3	0	2.2
Bigmouth sculpin	0.1	1.1	4.2	1.6	0	1.9	1.0	1.1	0.1	1.3	8.7	1.8	0.1	1.3	5.1	1.6
Shortfin eelpout	0.3	0.3	*	0.2	0.1	0.3	0.3	0.2	2.5	1.8	1.4	2.0	1.7	1.0	0.6	1.1
Yellow Irish lord	0.1	0	0	*	0.1	*	0	*	2.7	1.5	*	1.8	1.8	0.7	*	0.9
Pacific tomcod	8.3	0	0	1.6	0	0	0	0	0	0	0	0	1.9	0	0	0.6
Blackbelly eelpout	0.3	0.3	*	0.2	0	0.4	0	0.2	0.8	0.5	1.0	0.7	0.6	0.4	0.4	0.5
Wattled eelpout	0	0	0	0	0	*	0	*	*	1.1	0.2	0.5	*	0.5	0.1	0.3
Spinyhead sculpin	0	*	*	*	0	*	0	*	0.9	0.3	*	0.5	0.6	0.1	*	0.3
Other roundfish	2.2	0.1	*	0.5	0.7	0.4	2.8	1.2	2.4	0.3	0.2	1.2	2.2	0.2	0.7	0.9
TOTAL	251.8	44.9	56.1	87.8	273.8	63.8	86.3	132.6	132.6	264.2	100.3	189.2	178.6	148.7	77.9	144.6

* - Less than 0.1 kilogram per six kilometers.

Table 25. Number of roundfish species occurring in the NEGOA survey area.

Depth Zones	Areas			
	Eastern	Central	Western	Total
1-100	20	9	31	35
101-200	12	19	25	26
201-400	11	5	17	22
Total	25	21	42	48

Table 26. Most abundant species of roundfish and the percentage each contributed to the roundfish catch within the NEGOA survey area.

Depth Zones (m)	AREAS							
	EASTERN	%	CENTRAL	%	WESTERN	%	TOTAL	%
1-100	Walleye pollock Pacific cod Pacific tomcod	63.0 31.0 3.3	Walleye pollock Pacific cod Blackmouth eelpout	79.0 20.0 0.2	Walleye pollock Pacific cod Searcher	72.0 10.0 7.4	Walleye pollock Pacific cod Searcher	71.0 19.0 3.6
101-200	Pacific cod Walleye pollock Sablefish	44.0 40.0 3.3	Walleye pollock Pacific cod Bigmouth sculpin	67.0 2.2 3.0	Walleye pollock Pacific cod Sablefish	86.0 10.0 1.0	Walleye pollock Pacific cod Sablefish	79.0 15.0 1.3
201-400	Sablefish Bigmouth sculpin Walleye pollock	87.0 8.0 2.0	Sablefish Bigmouth sculpin Shortfin eelpout	95.0 1.2 0.4	Walleye pollock Pacific cod Sablefish	49.0 13.0 12.0	Sablefish Walleye pollock Bigmouth sculpin	55.0 22.0 6.5
Total	Walleye pollock Pacific cod Sablefish	47.0 31.0 14.0	Walleye pollock Sablefish Pacific cod	62.0 13.0 17.0	Walleye pollock Pacific cod Searcher	79.0 10.0 2.1	Walleye pollock Pacific cod Sablefish	70.0 16.0 6.7

Table 27. Percent occurrence of roundfish species in the NEGOA survey area.

Species	Eastern				Central				Western				Total			
	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Sturgeon poacher	50.0	0	0	15.8	0	0	0	0	17.6	2.0	0	5.6	27.2	1.2	0	6.0
Sablefish	41.7	50.0	90.0	57.9	50.0	46.7	100	52.4	58.8	54.0	100	58.3	51.5	51.9	94.1	57.3
Searcher	25.0	25.0	0	18.4	50.0	40.0	0	38.1	35.3	14.0	0	18.1	33.3	21.0	0.	21.4
Soft eelpout	0	0	0	0	0	0	0	0	0	0	20.0	1.4	0	0	5.9	0.8
Spinyhead sculpin	0	6.3	20.0	7.9	0	13.3	0	9.5	58.8	76.0	40.0	69.4	30.3	50.6	23.5	42.0
Giant wrymouth	0	0	0	0	0	6.7	0	4.8	5.9	8.0	0	6.9	3.0	6.2	0	4.6
Pacific spiny lumpsucker	0	0	0	0	0	0	0	0	11.8	0	0	2.8	6.1	0	0	1.5
Pacific cod	100	75.0	30.0	71.1	100	73.3	0	71.4	58.8	90.0	60.0	80.6	78.8	84.0	35.3	76.3
Yellow Irish lord	16.7	0	0	5.3	50.0	13.3	0	19.0	52.9	42.0	0	41.7	39.4	28.4	0	27.5
Bigmouth sculpin	16.7	37.5	50.0	34.2	0	66.7	50.0	71.4	23.5	44.0	60.0	40.3	30.3	46.9	52.9	43.5
Fourhorn poacher	0	0	0	0	0	0	0	0	11.8	0	0	2.8	6.1	0	0	1.5
Northern sculpin	0	0	0	0	0	0	0	0	5.9	0	0	1.4	3.0	0	0	0.8
Frogmouth sculpin	0	0	0	0	0	0	0	0	5.9	0	0	1.4	3.0	0	0	0.8
Thorny sculpin	0	0	0	0	0	6.7	0	4.8	11.8	0	0	2.8	6.1	1.2	0	2.3
Pacific staghorn sculpi	0	0	0	0	0	0	0	0	5.9	0	20.0	2.8	3.0	0	5.9	1.5

Areas/Depth Zones (m)

Table 27. *Percent occurrence of roundfish species in the NEGOA survey area (continued).*

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Longsnout prickleback	0	0	0	0	0	0	0	0	0	2.0	0	1.4	0	1.2	0	0.8
Daubed shanny	8.3	0	0	2.6	25.0	0	0	4.8	0	0	0	0	6.0	0	0	1.5
Snake prickleback	16.7	0	0	5.3	0	0	0	0	11.8	0	0	2.8	12.2	0	0	3.1
Blackmouth eelpout	0	0	0	0	25.0	0	0	4.8	0	0	0	0	3.0	0	0	0.8
Shortfin eelpout	41.7	56.3	30.0	44.7	50.0	73.3	50.0	66.7	82.4	92.0	60.0	87.5	63.6	81.5	41.2	71.8
Black eelpout	0	0	0	0	0	0	0	0	0	0	20.0	1.4	0	0	5.9	0.8
Wattled eelpout	0	0	0	0	0	6.7	0	4.8	11.8	42.0	40.0	74.7	6.1	27.2	11.8	19.9
Blackbelly eelpout	41.7	62.5	20.0	44.7	0	53.3	0	38.1	35.3	36.0	40.0	36.1	33.3	44.4	23.5	38.9
Dwarf wrymouth	0	0	0	0	0	0	0	0	0	0	20.0	1.4	0	0	5.9	0.8
Blackfin sculpin	0	0	0	0	0	0	0	0	0	2.0	20.0	2.8	0	1.2	5.9	1.5
Pacific tomcod	16.7	0	0	5.3	0	0	0	0	0	0	0	0	6.1	0	0	1.5
Great sculpin	0	0	0	0	0	0	0	0	5.9	6.0	0	5.6	3.0	3.7	0	3.1
Lingcod	8.3	0	0	2.6	0	0	0	0	5.9	0	0	1.4	6.1	0	0	1.5
Whitebarred prickleback	8.3	12.5	0	7.9	0	13.3	0	9.5	0	0	0	0	3.0	4.4	0	2.3
Tadpole sculpin	0	0	0	0	0	0	0	0	5.9	0	0	1.4	3.0	0	0	0.8
Grunt sculpin	0	0	0	0	0	0	0	0	5.9	0	0	1.4	3.0	0	0	0.8
Walleye pollock	91.7	81.3	40.0	71.1	100	93.3	0	85.7	94.1	98.0	80.0	95.8	93.9	92.6	47.1	87.0
Roughspine sculpin	0	0	0	0	0	0	0	0	11.8	0	0	2.8	6.1	0	0	1.5
Ribbed sculpin	0	0	0	0	0	0	0	0	5.9	0	0	1.4	3.0	0	0	0.8

Theragra chalcogramma (Walleye pollock)

Pollock made up 70% of the estimated standing stock of roundfish in the survey area and occurred at 87% of the 131 stations sampled (Tables 24 and 26).

Standing stock estimates. The standing stock of pollock in the survey area was estimated at 54,292 mt (264 million individuals) (Tables 28 and 29). Of this tonnage, 39,945 mt (73.6%) was estimated for the Western Area, 8,078 mt (14.9%) for the Eastern Area, and 6,269 mt (11.5%) for the Central Area. The outer shelf accounted for 31,249 (57.6%) of the standing stock, the inner shelf for 21,249 mt (39.1%), and the upper slope for 1,794 mt (3.3%).

Size composition. The percentage length frequency distribution for male and female pollock over the entire survey area is shown in Figs. 15 and 16. The length range for males was from 10 to 62 cm with a mean of 22.9 cm; females ranged in size from 10 to 76 cm and averaged 29.5 cm. The mean length of pollock by sex within each area-depth interval is shown in Table 30. The smallest fish were collected on the Eastern Area inner shelf. The average size of male and female pollock generally increased with increasing water depth in the Eastern and Western Areas. Females averaged from 0.4 to 6.1 cm larger than males. The pollock population consisted of 59% males and 41% females.

Spawning condition. No specimens of pollock in or near spawning condition were caught during the survey.

Gadus macrocephalus (Pacific cod)

Pacific cod made up 16% of the roundfish estimated standing stock and was second to pollock in roundfish abundance. This species was caught at 76% of the stations sampled during the survey.

Standing stock estimates. The standing stock for Pacific cod in the survey area was estimated at 12,178 mt and consisted of 8.6 million fish (Tables 28 and 29). Of the total estimated tonnage, 5,246 mt (43%) was in the Eastern Area, 5,236 mt (43%) in the Western Area, and 1,695 (14%) in the Central Area. Most of the estimated standing stock was located on the continental shelf, with 5,991 mt (49%) on the outer shelf and 5,688 (47%) on the inner shelf. Only 498 mt (4%) was estimated for the upper slope.

Table 28. Estimated standing stock in metric tons for roundfish species by area-depth intervals in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Walleye pollock	6,045	1,981	52	8,078	4,893	1,376	0	6,269	10,311	27,892	1,742	39,945	21,249	31,249	1,794	54,292
Pacific cod	2,990	2,209	47	5,246	1,242	453	0	1,695	1,456	3,329	451	5,236	5,688	5,991	498	12,178
Sablefish	35	175	2.247	2,457	10	46	1,757	1,813	172	313	428	913	217	534	4,432	5,183
Searcher	12	50	0	62	9	41	0	50	1,066	7	0	1,073	1,087	98	0	1,185
Bigmouth sculpin	4	125	193	322	0	60	21	81	19	162	310	491	23	347	524	894
Shortfin eelpout	14	41	3	58	3	10	8	21	279	222	52	553	296	273	63	632
Yellow Irish lord	5	0	0	5	2	0	0	2	292	187	0	479	299	187	0	486
Blackbelly eelpout	14	38	3	55	0	14	0	14	95	72	36	203	109	124	39	272
Wattled eelpout	0	0	0	0	0	0	0	0	10	143	9	162	10	143	9	162
Spinyhead sculpin	0	0	2	2	0	0	0	0	97	39	2	138	97	39	4	140

Table 29. Estimated standing stock in numbers (1,000's) for roundfish species by area-depth intervals in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Walleye pollock	111,518	5,879	106	114,503	10,759	3,632	0	14,391	47,640	80,756	4,169	132,565	169,917	90,267	4,275	264,459
Pacific cod	2,122	2,351	18	4,491	946	241	0	1,187	1,085	1,668	173	2,926	4,153	4,260	191	8,604
Sablefish	82	160	1,121	1,363	31	45	800	876	447	383	322	1,152	560	588	2,243	3,391

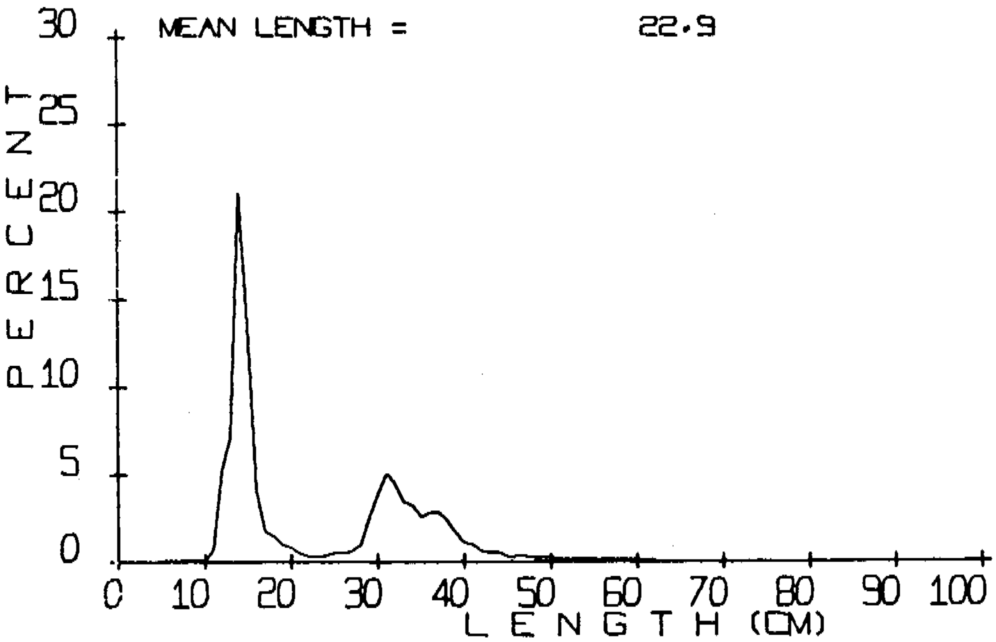

Figure 15. The percent size composition of the estimated standing stock (in numbers) of male Theragra chalcogramma *(Walleye pollock) in the NEGOA survey area.*

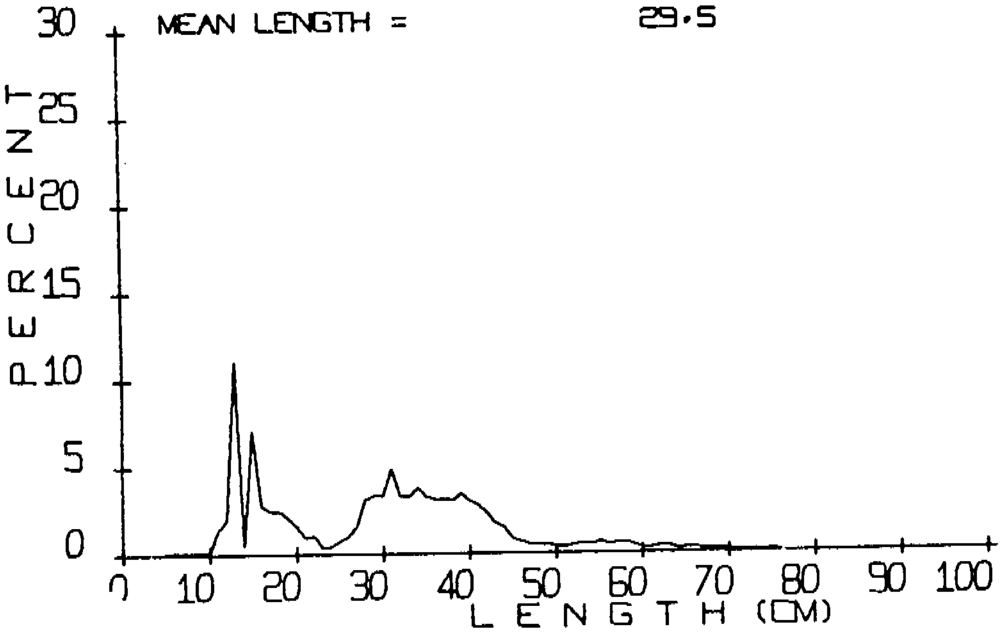

Figure 16. The percent size composition of the estimated standing stock (in numbers) of female Theragra chalcogramma *(Walleye pollock) in the NEGOA survey area.*

Table 30. Average lengths of Theragra chalcogramma *(Walleye pollock) by area-depth intervals.*

Depth Zones (m)	AREAS Eastern		Central		Western	
	Male	Female	Male	Female	Male	Female
	cm		cm		cm	
1-100	14.8	18.3	35.8	38.0	30.6	33.0
101-200	29.1	35.2	33.7	36.6	32.4	32.8
201-400	--	--	--	--	35.7	36.4

Size composition. Pacific cod in the NEGOA survey area averaged 48.6 cm in length and consisted of 44.5% males and 55.5% females. Male cod ranged from 32 to 79 cm in length and averaged 47.6 cm; females ranged from 28 to 98 cm, averaging 49.4 cm (Figs. 17 and 18). The mean lengths of Pacific cod by sex within each area-depth interval are listed in Table 31. In the Central and Western Areas the average size of male and female cod increased with water depth; however, in the Eastern Area the largest fish of both sexes occurred on the inner shelf. Females averaged 0.4 to 3.6 cm larger than males.

Spawning condition. No specimens of Pacific cod in spawning or near to spawning condition were caught in the survey area.

Anoplopoma fimbria (Sablefish)

Sablefish contributed 6.7% of the estimated standing stock of roundfish and were present at 57% of the stations sampled in the survey area (Tables 24 and 26).

Standing stock estimates. The estimated standing stock of sablefish in the survey area consisted of 5,187 mt or 3.4 million individuals (Tables 28 and 29). Sablefish estimated standing stock decreased from 2,457 mt (47%) in the Eastern Area to 913 mt (18%) in the Western Area. Thirty-six percent or 1,813 mt of the estimated standing stock was located in the Central Area. The depth distribution data indicate that 85% (4,432 mt) of the total estimated standing stock occurred on the upper slope, 10% (534 mt) on the outer shelf, and 4% (217 mt) on the inner shelf.

Size composition. Sablefish in the NEGOA survey area averaged 51.1 cm in length and consisted of 59.2% males and 40.8% females. Male sablefish ranged from 25 to 75 cm in length with a mean of 54.6 cm; females were 25 to 85 cm in length with an average size of 56.2 cm (Figs. 19 and 20). Limited data on mean lengths of this species by sex within each area-depth interval are listed in Table 32.

Spawning condition. No sablefish in spawning or near spawning condition were collected in the NEGOA survey area.

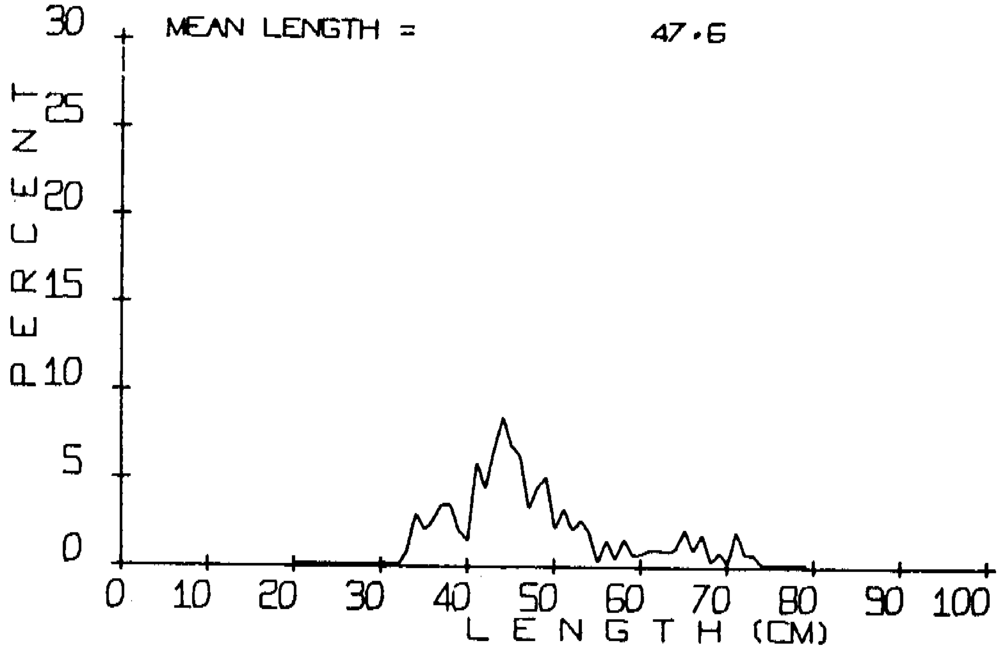

Figure 17. The percent size composition of the estimated standing stock (in numbers) of male Gadus macrocephalus *(Pacific cod) in the NEGOA survey area.*

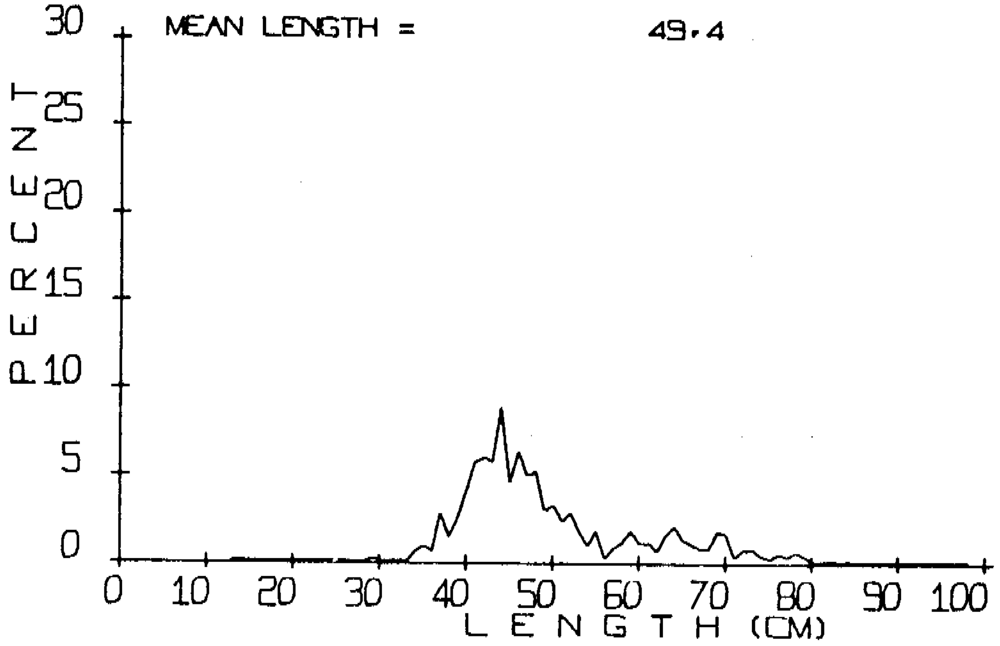

Figure 18. The percent size composition of the estimated standing stock (in numbers) of female Gadus macrocephalus *(Pacific cod) in the NEGOA survey area.*

Table 31. Average lengths of Gadus macrocephalus *(Pacific cod) by area-depth intervals.*

Depth Zones (m)	AREAS Eastern		Central		Western	
	Male (cm)	Female	Male (cm)	Female	Male (cm)	Female
1-100	48.3	51.9	43.4	47.8	47.1	49.3
101-200	43.7	44.0	48.3	55.7	52.8	53.9
201-400	--	--	--	--	59.9	61.2

Table 32. Average lengths of Anoplopoma fimbria *(Sablefish) by area-depth intervals.*

Depth Zones (m)	AREAS Eastern		Central		Western	
	Male (cm)	Female	Male (cm)	Female	Male (cm)	Female
1-100	--	--	--	--	--	--
101-200	--	--	--	--	44.0	43.4
201-400	58.5	57.5	59.7	59.7	58.1	62.7

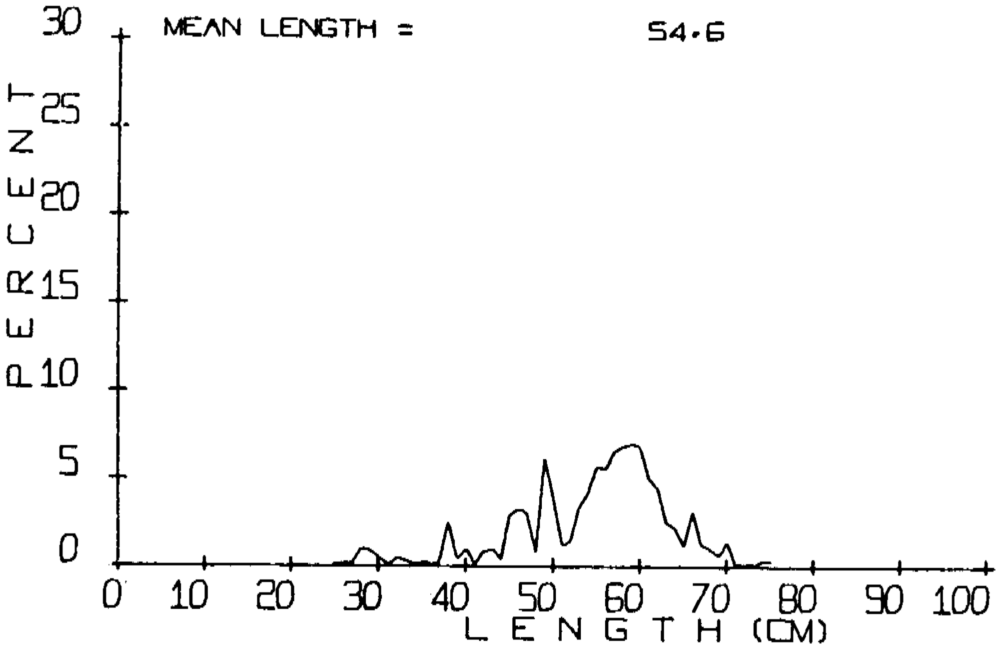

Figure 19. The percent size composition of the estimated standing stock (in numbers) of male Anoplopoma fimbria *(Sablefish) in the NEGOA survey area.*

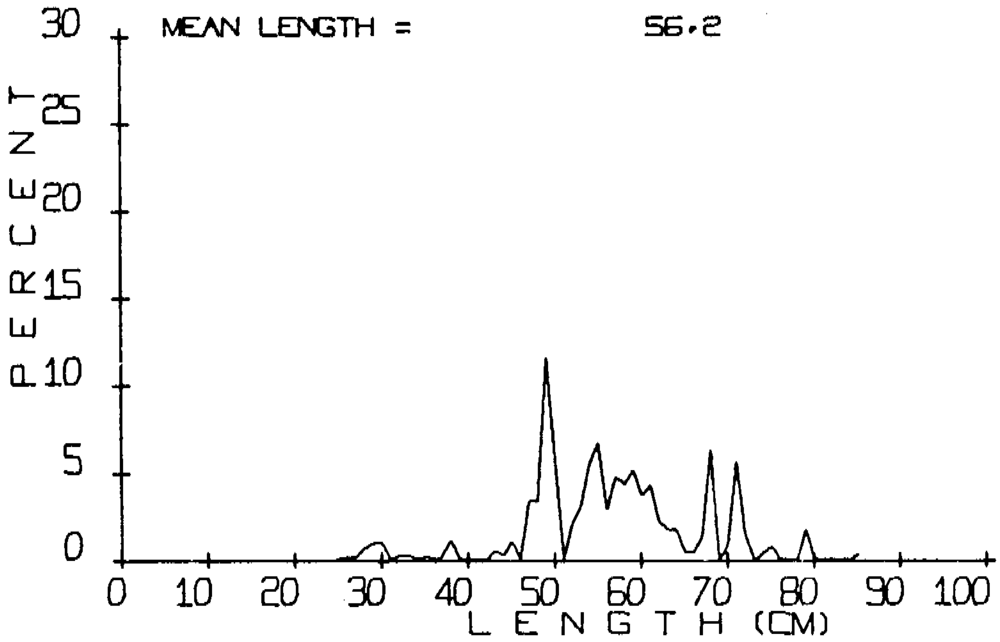

Figure 20. The percent size composition of the estimated standing stock (in numbers) of female Anoplopoma fimbria *(Sablefish) in the NEGOA survey area.*

Bathymaster signatus (Searcher)

Searcher made up 1.5% of the roundfish estimated standing stock and was present at 21% of the stations sampled in the NEGOA survey area (Tables 24 and 26).

Standing stock estimates. The standing stock of searcher was estimated at 1,185 mt, of which 90% was located in the Western Area (Table 28). The remaining 10% was distributed equally between the Eastern and Central Areas. The inner shelf depth zone accounted for 92% of the tonnage with the remainder occurring on the outer shelf. This species was not caught on the upper slope.

Size composition, sex frequency, and spawning data were not collected for this species.

Hemitripterus bolini (Bigmouth sculpin)

Bigmouth sculpin comprised 1.2% of the roundfish estimated standing stock and occurred at 43.5% of the stations sampled (Tables 24 and 26).

Standing stock estimates. Fifty-five percent (491 mt) of the total estimated standing stock (894 mt) of bigmouth sculpin occurred in the Western Area, 36% (322 mt) in the Eastern Area, and only 3% (81 mt) in the Central Area (Table 28). The major part (58% or 524 mt) of the total estimated standing stock of this species occurred on the upper slope, while 39% (347 mt) occupied the outer shelf and 3% (23 mt) the inner shelf.

No size composition, sex frequency, or spawning observations were collected on this species.

Lycodes brevipes (Shortfin eelpout)

Shortfin eelpout accounted for 0.8% of the estimated standing stock of roundfish and were caught at 72% of the stations sampled (Tables 24 and 26).

Standing stock estimates. The estimated standing stock of shortfin eelpout was 632 mt, of which 87% (553 mt) was in the Western Area, 9% (58 mt) in the Eastern Area, and 3% (21 mt) in the Central Area (Table 28). The estimated standing stock decreased with increasing water depth; i.e., 47% (296 mt) on the inner shelf, 43% (273 mt) on the outer shelf, and 10% (63 mt) on the upper slope.

No size composition, sex frequency, or spawning data were collected for this species.

Hemilepidotus jordani (Yellow Irish lord)

Yellow Irish lord contributed 0.6% of the roundfish estimated standing stock and occurred at 27.5% of the stations sampled in the survey area (Tables 24 and 26).

Standing stock estimates. Ninety-eight percent (479 mt) of the total estimated standing stock (486 mt) of yellow Irish lords was from the Western Area; the remaining 2% (7 mt) was located in the Eastern and Central Areas (Table 28). Depth distribution data indicate that 61% (299 mt) of the estimated standing stock for this species occurred on the inner shelf and 39% (187 mt) on the outer shelf. A few specimens were collected over the upper slope.

No size, sex frequency, or spawning data were collected for this species.

Microgadus proximus (Pacific tomcod)

Only 0.4% of the roundfish estimated standing stock in the survey area were Pacific tomcod, occurring at 1.5% of the stations sampled (Tables 24 and 26).

Standing stock estimates. Tomcod were caught only on the Western Area-inner shelf. The estimated standing stock was 314 mt.

No size composition, sex frequency, or spawning observations were made for this species.

Lycodopsis pacifica (Blackbelly eelpout)

Blackbelly eelpout contributed 0.4% of the total roundfish estimated standing stock; however, this species was collected at 39% of the stations sampled in the survey area (Tables 24 and 26).

Standing stock estimates. The estimated standing stock for this species was 272 mt, 74% (203 mt) occurring in the Western Area, 21% (55 mt) in the Eastern Area, and only 5% (14 mt) in the Central Area (Table 28). It is estimated that the outer shelf has 45% (124 mt) of the estimated standing stock and the inner shelf has 40% (109 mt). The remaining 15% (39 mt) was on the upper slope.

Size, sex frequency, or spawning data were not collected for this species in the survey area.

Dasycottus setiger (Spinyhead sculpin)

Spinyhead sculpin were found primarily in the area west of Cape St. Elias. It contributed 0.1% of the total roundfish estimated standing stock and was caught at 42% of the stations sampled (Tables 24 and 26).

Standing stock estimates. Ninety-seven percent (138 mt) of the 144 mt of sculpin estimated to be in the study area was located in the Western Area (Table 28). This species occurred in trace quantities in the Central and Eastern Areas. Sixty-eight percent (97 mt) of the estimated standing stock was found on the inner shelf, 28% on the outer shelf, and only 4% on the upper slope.

No size, sex frequency, or spawning data were collected for this species.

Other Roundfish

The remainder of the roundfish accounted for 0.6% of the total roundfish standing stock in the survey area.

Standing stock estimates. The estimated standing stock of other roundfish (494 mt) was distributed throughout all areas and depth zones. The Western Area accounted for 312 mt (63%), the Central Area for 89 mt (18%), and the Eastern Area for 93 mt (19%). The inner shelf contributed 363 mt (73%), the outer shelf 61 mt (12%), and the upper slope 70 mt (14%).

Elasmobranchs

Elasmobranchs were the third most abundant species group in the NEGOA survey area with an average catch of 29.5 kg/std tow and contributed 7% to the total finfish catch (Table 33). Mean catch rates were highest in the Eastern Area (36.8 kg/std tow) and lowest in the Central (25.1 kg/std tow) and Western (25.3 kg/std tow) Areas. The highest mean catch rate (40.1 kg/std tow) occurred over the inner shelf; whereas, the upper slope and outer shelf had mean catch rates of 31 and 22 kg/std tow, respectively. The highest mean CPUE's of the nine area-depth intervals occurred over the Eastern-inner shelf (52.0 kg/std tow) and Eastern-upper slope (46.0 kg/std tow) regions, while the lowest catch rates were on the Western-upper slope (14.9 kg/std tow) and Western-outer shelf (17.3 kg/std tow).

Four species of elasmobranchs (Table 34) were caught in the NEGOA survey area; however, the taxonomic characteristics of *Raja rhina* (Longnose skate) and *R. binoculata* (Big skate) overlapped to the extent that it was difficult

Table 33. *Average CPUE of elasmobranch species in kilograms within the NEGOA survey area.*

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Black skate	11.3	8.3	21.5	12.0	7.5	7.3	4.5	6.6	0.4	3.5	9.3	3.0	3.8	6.3	13.7	6.8
<u>Raja</u> spp.	37.9	18.0	22.9	23.0	19.9	13.1	21.2	17.4	37.3	13.3	5.1	21.9	35.1	15.2	16.4	21.7
Spiny dogfish	2.8	1.6	1.6	1.8	2.6	0.9	0	1.1	0.3	0.5	0.5	0.4	1.2	1.0	0.9	1.0
Total	52.0	27.9	46.0	36.8	30.0	21.3	25.7	25.1	38.0	17.3	14.9	25.3	40.1	22.5	31.0	29.5

Table 34. *Elasmobranch families and species collected in the NEGOA survey area.*

Scientific Name	Common Name
Squalidae	Dogfish sharks
Squalus acanthias	Spiny dogfish
Rajidae	Skates
Raja binoculata	Big skate
R. rhina	Longnose skate
R. Kincaidi	Black skate

Table 35. *Percent occurrence of elasmobranch species in the NEGOA survey area.*

	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Black skate	91.7	93.8	90.0	92.1	75.0	93.3	50.0	85.7	23.5	60.0	80.0	52.8	54.6	72.8	82.4	69.5
<u>Raja</u> spp.	66.7	100.0	100.0	89.5	50.0	86.7	100.0	81.0	64.7	66.0	80.0	66.7	63.6	76.5	94.1	75.6
Spiny dogfish	50.0	18.8	40.0	34.2	25.0	40.0	0	33.3	5.9	10.0	20.0	9.7	24.2	17.3	29.4	20.6

to distinguish between them. Catch data for these two species have been combined and listed in the table and text as *Raja* spp. Elasmobranchs exhibited a wide geographic and bathymetric distribution, appearing in all nine area-depth intervals; spiny dogfish did not occur in the Central Area-upper slope.

Raja spp. (Big skate and Longnose skate)

Raja spp. accounted for 73% of the elasmobranch and 5% of the total finfish catches, and occurred at 76% of the stations sampled (Tables 33 and 35).

Standing stock estimates. The estimated standing stock of *Raja* spp. over the entire study area was 11,742 mt (2.6 million fish) (Tables 36 and 37), of which 50% (939 mt) was in the Western Area. The Eastern and Central Areas had 38% (4,481 mt) and 11% (1,322 mt), respectively. The estimated standing stock decreased from shallow to deeper waters with 5,909 mt (51%) occurring on the inner shelf. The outer shelf and upper slope had considerably lower estimates, 4,100 (35%) and 1,700 mt (14%), respectively. Estimates for area-depth intervals ranged from 279 mt on the Western Area-upper slope to 4,025 mt on the Western Area-inner shelf.

Size composition. Size, sex frequency, and maturity observations were not taken for *Raja* spp.

Raja kincaidi (Black skate)

The black skate occurred at 70% of the stations trawled and contributed 23% of the elasmobranch and nearly 2% of the total finfish catches (Tables 33 and 35).

Standing stock estimates. The estimated standing stock for black skate in the survey area was 3,653 mt (3.6 million fish) (Tables 36 and 37). The greatest density (2,336 mt or 64%) occurred in the Eastern Area; estimates in the Western and Central Areas declined sharply to 816 mt (22%) and 501 mt (14%), respectively. Depth distribution analyses indicate similar densities on the outer shelf (1,603 mt or 44%) and upper slope (1,407 mt or 39%). Only 600 mt (18%) was estimated to occur on the inner shelf. Fifty-two percent of the estimated abundance occurred in two area-depth intervals, the Eastern Area-upper slope (27%) and Eastern Area-outer shelf (25%).

Size composition. Size composition, sex frequency, and spawning data were not collected for this species.

Table 36. Estimated standing stock in metric tons for elasmobranch species by area-depth intervals in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Raja sp.	1,436	1,999	1,046	4,481	448	419	455	1,322	4,025	1,635	279	5,939	5,909	4,053	1,780	11,742
Black skate	430	927	979	2,336	169	235	97	501	44	441	331	816	643	1,603	1,407	3,653
Spiny dogfish	106	177	76	359	59	29	0	88	38	69	20	127	203	275	96	574

Table 37. Estimated standing stock in numbers (1,000's) for elasmobranch species by area-depth intervals in the NEGOA survey area.

	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Raja sp.	389	803	285	1,477	35	92	71	198	568	298	56	922	992	1,193	412	2,597
Black skate	417	1,286	796	2,499	120	266	23	409	93	417	196	706	630	1,969	1,015	3,614
Spiny dogfish	58	88	42	188	26	15	0	41	12	33	14	59	96	136	56	288

Squalus acanthias (Spiny dogfish)

Spiny dogfish were caught at 21% of the stations sampled and constituted 4% of the elasmobranch and 0.3% of the total finfish catches (Tables 33 and 35).

Standing stock estimates. The total estimated standing stock of this species was 574 mt (0.3 million fish), of which 62% (359 mt) occurred in the Eastern Area, 127 mt (22%) in the Western Area, and 88 mt (16%) in the Central Area (Tables 36 and 37). The estimated abundance on the outer shelf was 275 mt (48%), 204 mt (35%) on the inner shelf, and 97 mt (17%) on the upper slope. Standing stock estimates in the survey area ranged from 0 mt on the Central Area-upper slope to 177 mt on the Eastern Area-outer shelf.

Size composition. Length, sex frequency, and maturity data were not taken for this species.

Rockfish

Rockfish had the lowest average catch rate of the four finfish groups in the NEGOA survey area, contributing only 5% of the total finfish catch.

The mean CPUE for rockfish over the entire study area was 19.7 kg/std tow (Table 38). The highest average CPUE (29.6 kg/std tow) occurred in the Eastern Area. Values of 15.2 and 13.6 kg/std tow were recorded in the Central and Western Areas, respectively. Mean catch rates increased with water depth; i.e., 47.6 kg/std tow on the upper slope, decreasing to 20.1 kg/std tow on the outer shelf and 1.9 kg/std tow on the inner shelf. The highest average CPUE (66.2 kg/std tow) for this group occurred on the Eastern Area-upper slope. Mean catch rates declined from east to west but were relatively high on the Central and Western-upper slopes. The lowest catches occurred at water depths less than 100 m and ranged from less than 0.1 kg/std tow on the Eastern Area-inner shelf to 3.0 kg/std tow on the Western Area-inner shelf.

Fourteen species of rockfish were collected in the NEGOA survey area (Table 39). The number of species declined from east to west (Table 40). The highest number of species (13) were collected on the outer shelf, declining to five species on the upper slope and four species on the inner shelf. The number of species collected ranged from one on the Eastern Area-inner shelf to nine on the Eastern and Center outer shelves.

Sebastolobus alascanus (Shortspine thornyhead), *Sebastes alutus* (Pacific ocean perch), and *S. aleutianus* (Rougheye rockfish) accounted for almost 93% of the total rockfish standing stock.

Table 38. *Average CPUE of rockfish species in kilograms within the NEGOA survey area.*

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Shortspine thornyhead	0	7.3	54.6	17.0	<0.1	0.1	27.8	7.9	3.0	5.5	29.9	7.7	1.9	5.6	40.4	11.1
Pacific ocean perch	0	4.5	7.0	4.2	0.2	4.9	4.0	3.2	0	11.0	1.5	5.3	<0.1	7.6	4.5	4.6
Rougheye rockfish	<0.1	8.3	4.1	5.7	0	4.6	1.0	2.2	<0.1	0.9	1.4	0.6	<0.1	4.4	2.5	2.7
Other rockfish	0	4.6	0.5	2.7	0	4.6	0	1.9	<0.1	0.1	0	<0.1	<0.1	2.5	0.2	1.3
Total	<0.1	24.7	66.2	29.6	0.2	14.2	32.8	15.2	3.0	17.5	32.8	13.6	1.9	20.1	47.6	19.7

Table 39. *Rockfish families and species caught in the NEGOA survey area.*

Scientific Name	Common Name
Scorpaenidae	Scorpionfishes
Sebastes aleutianus	Rougheye rockfish
S. alutus	Pacific ocean perch
S. babcocki	Redbanded rockfish
S. brevispinis	Silvergray rockfish
S. ciliatus	Dusky rockfish
S. crameri	Darkblotched rockfish
S. entomelas	Widow rockfish
S. flavidus	Yellowtail rockfish
S. melanops	Black rockfish
S. mystinus	Blue rockfish
S. ruberrimus	Yelloweye rockfish
S. variegatus	Harlequin rockfish
Sebastolobus alascanus	Shortspine thornyhead
S. altivelis	Longspine thornyhead

Table 40. *Number of rockfish species collected in the NEGOA survey area.*

Depth Zones (m)	AREAS[a]			
	Eastern	Central	Western	Total
1-100	1	2	3	4
101-200	9	9	7	13
201-400	5	3	3	5
Total	11	8	6	14

Sebastolobus alascanus (Shortspine thornyhead)

Shortspine thornyheads were the most abundant rockfish species in the survey area and occurred at 34% of the stations trawled (Table 41) and accounted for 56% of the rockfish and 3% of the total finfish catches.

Standing stock estimates. The estimated standing stock for this rockfish was 5,980 mt (20.9 million fish) (Tables 42 and 43). The highest estimated abundance occurred in the Eastern Area (3,298 mt), representing 55% of the total estimated standing stock of this species. The remaining stock was divided between the Western (35%) and Central Areas (10%). Depth distribution analysis showed that 69% of the standing stock was located on the upper slope, 25% on the outer shelf, and 6% of the inner shelf. Approximately 60% of the estimated standing stock of this species came from the Eastern (42%) and Western upper slope (18%) Areas.

Size composition. Percentage length frequencies for combined sexes from fish collected on the Eastern-upper slope and Western-outer shelf Areas are illustrated in Fig. 21. The 215 specimens measured ranged from 12 to 48 cm in length and averaged 30.1 cm.

Spawning condition. No specimens collected were in spawning condition.

Sebastes alutus (Pacific ocean perch)

Ocean perch were caught at 33% of the stations sampled and represented 23% of the rockfish and 1% of the total finfish catches (Table 41).

Standing stock estimates. The estimated standing stock of Pacific ocean perch in the survey area was 2,490 mt (7.2 million fish) (Tables 42 and 43). The highest standing stock estimated was 1,415 mt in the Western Area, representing 57% of the total for this species. Thirty-three percent (826 mt) occurred in the Eastern Area and the Central Area had 249 mt (10%). Large differences in estimated standing stock occurred between depth zones. It was estimated that 81% (2,023 mt) of the standing stock occurred on the outer shelf. The highest standing stock estimated for this species was 1,415 mt, occurring on the Western Area-outer shelf and representing almost 55% of the estimated stock. Estimates for the eight remaining area-depth intervals were well below 600 mt.

Size composition. In the NEGOA survey area, Pacific ocean perch averaged 29.1 cm in length and consisted of 53.4% males and 46.6% females. The size of male perch ranged from 17 to 41 cm and averaged 29.8 cm, while females ranged from 18 to 43 cm and averaged 28.3 cm (Figs. 22 and 23).

Table 41. Percent occurrence of rockfish species in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Rougheye rockfish	8.3	81.3	60.0	52.6	0	66.7	50.0	52.4	17.6	62.0	60.0	51.4	12.1	66.7	58.8	51.9
Pacific ocean perch	0	62.5	70.0	44.7	25.0	73.3	100	66.7	0	20.0	40.0	16.7	3.0	38.3	64.7	32.8
Redbanded rockfish	0	6.3	0	2.6	0	6.7	0	4.8	0	0	0	0	0	2.5	0	1.5
Silvergray rockfish	0	12.5	0	5.3	0	6.7	0	4.8	0	0	0	0	0	3.7	0	2.3
Dusky rockfish	0	12.5	0	5.3	0	0	0	0	5.9	2.0	0	2.8	3.0	3.7	0	3.1
Darkblotched rockfish	0	0	10.0	2.6	0	0	0	0	0	0	0	0	0	0	5.9	0.8
Widow rockfish	0	12.5	0	5.3	0	13.3	9	9.5	0	0	0	0	0	4.9	0	3.1
Yellowtail rockfish	0	0	0	0	0	6.7	0	4.8	0	2.0	0	1.4	0	2.5	0	1.5
Black rockfish	0	0	0	0	0	6.7	0	4.8	0	0	0	0	0	1.2	0	0.8
Blue rockfish	0	6.3	0	2.6	0	0	0	0	0	4.0	0	2.8	0	3.7	0	2.3
Yelloweye rockfish	0	0	10.0	2.6	0	13.3	0	9.5	0	0	0	0	0	2.5	5.9	2.3
Harlequin rockfish	0	12.5	0	5.3	0	0	0	0	0	0	0	0	0	2.5	0	1.5
Shortspine thornyhead	0	56.3	100	50.0	25.0	20.0	100	28.6	11.8	28.0	60.0	26.4	9.1	32.1	88.2	33.6
Longspine thornyhead	0	0	0	0	0	0	0	0	0	2.0	0	1.4	0	1.2	0	0.8

Table 42. Estimated standing stock in metric tons for rockfish species by area-depth intervals in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Shortspine thornyhead	0	809	2,489	3,298	1	6	595	602	328	688	1,064	2,080	329	1,503	4,148	5,980
Pacific ocean perch	0	504	322	826	5	158	85	249	0	1,361	54	1,415	5	2,023	462	2,490
Rougheye rockfish	0	923	188	1,111	0	148	21	169	7	115	51	173	7	1,186	260	1,453

Table 43. Estimated standing stock in numbers (1,000's) for rockfish species by area-depth intervals in the NEGOA survey area.

	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Shortspine thornyhead	0	3,283	8,838	12,121	11	18	1,719	1,748	1,673	1,619	3,702	6,994	1,684	4,920	14,259	20,863
Pacific ocean perch	0	874	481	1,355	13	254	215	482	0	5,220	92	5,312	13	6,348	788	7,149
Rougheye rockfish	3	2,783	332	3,118	0	460	47	507	51	415	92	558	54	3,658	471	4,183

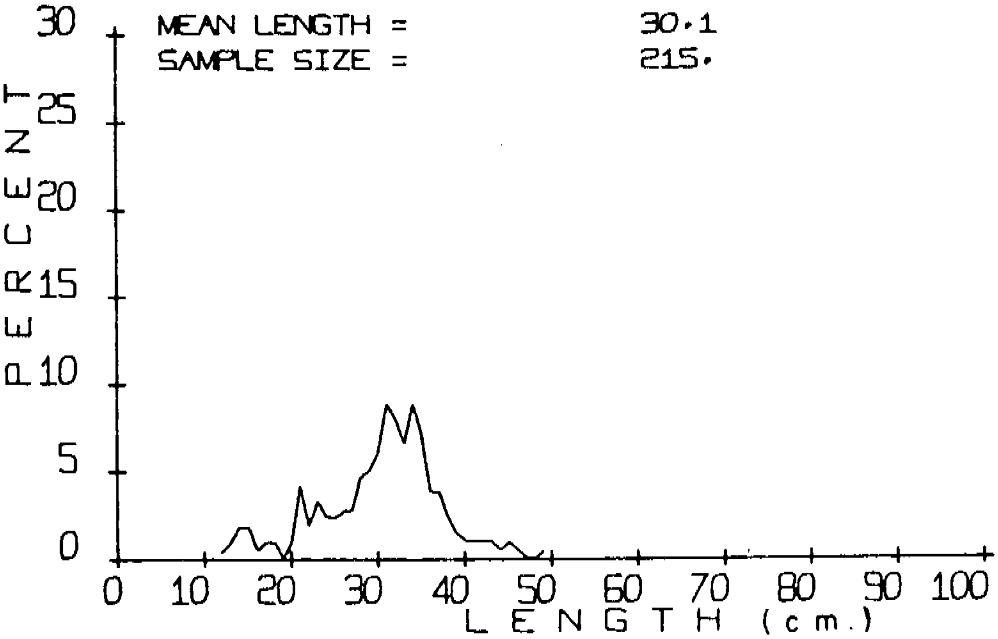

Figure 21. The percent size composition of Sebastolobus alascanus *(Shortspined thornyhead) based on random samples from the Eastern-upper slope and Western-outer shelf Areas.*

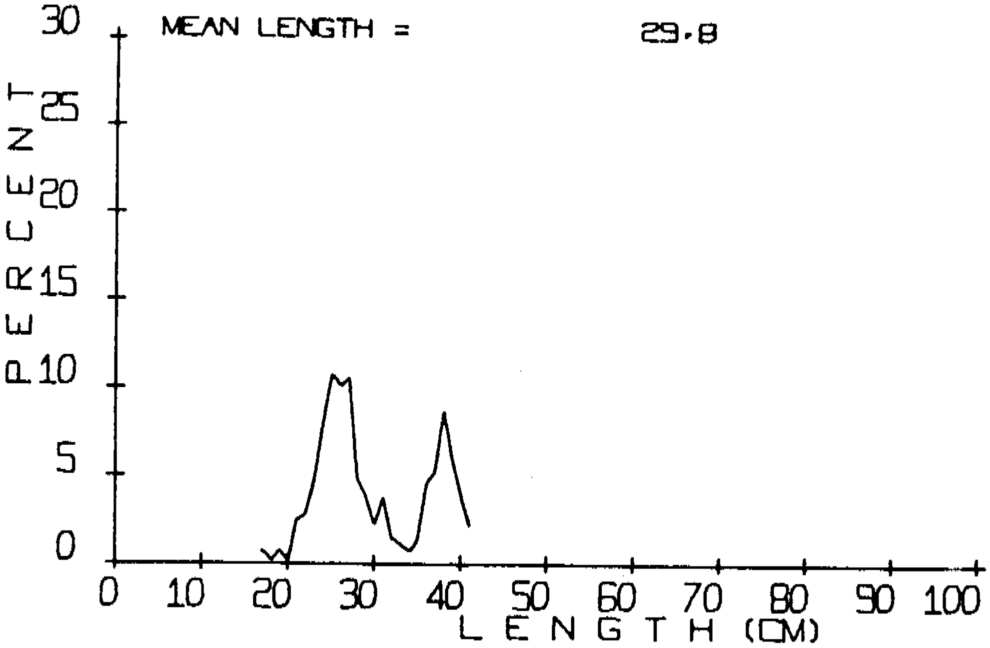

Figure 22. *The percent size composition of the estimated standing stock (in numbers) of male* Sebastes alutus *(Pacific ocean perch) in the NEGOA survey area.*

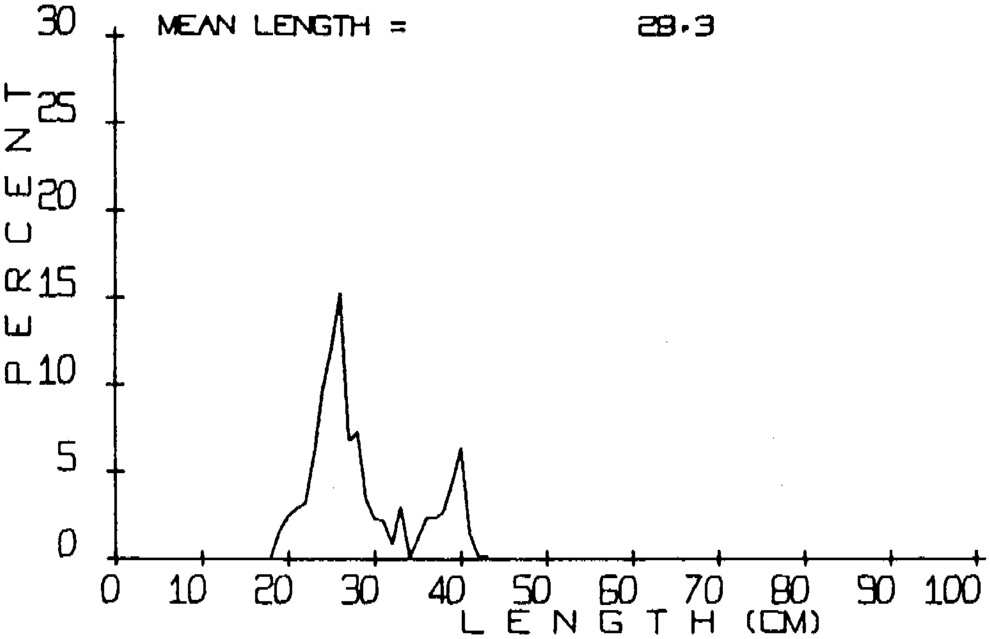

Figure 23. *The percent size composition of the estimated standing stock (in numbers) of female* Sebastes alutus *(Pacific ocean perch) in the NEGOA survey area.*

Spawning condition. A limited number of Pacific ocean perch were observed for spawning condition. There was no evidence of running sperm in the males or developing embryos in the females.

Sebastes aleutianus (Rougheye rockfish)

This species was caught at 52% of the stations sampled, contributing 14% of the rockfish and 0.7% of the total finfish catches (Table 41).

Standing stock estimates. The total standing stock of rougheye rockfish has been estimated at 1,453 mt (4.1 million fish) (Tables 42 and 45). By geographic region, the highest density (76% or 1,111 mt) was estimated in the Eastern Area; the Western and Central Areas both contributed 12% (∿ 170 mt). The highest estimated standing stock (1,186 mt or 82%) occurred over the outer shelf, decreasing to 260 mt (18%) on the upper slope, and less than 10 mt on the inner shelf. Sixty-three percent of the total estimated standing stock came from the Eastern-outer shelf.

Size composition and spawning condition. Spawning condition and size composition data are not available for this species.

Other Rockfish

As a combined group, the 11 remaining species of rockfish had a total standing stock of 692 mt which represented 7% of the rockfish and 0.3% of the total finfish catches.

Ninety-six percent of the widow rockfish, *Sebastes entomelas*, were caught on the Eastern Area-outer shelf and the remaining 4% were collected on the Central Area-outer shelf.

Most (70%) of the silvergray rockfish, *S. brevispinis*, caught in the survey area came from the Central Area-outer shelf. The other 30% were collected on the Eastern Area-outer shelf.

The total catch of yellowtail rockfish, *S. flavidus*, came from the Central and Western-outer shelf Areas where the contribution of the total species catch was 93 and 7%, respectively.

The harlequin rockfish, *S. variegatus*, came solely from the Eastern-outer shelf.

The remaining seven species of rockfish had individual mean catch rates of less than 0.1 kg/std tow.

Commercially Important Invertebrates

Commercially important invertebrates in the survey area consisted of 11 species representing five families and constituted 60% of the total invertebrate catch (Table 44).

The CPUE for this group averaged 81.5 kg/std tow for the survey area. The catch rate was highest in the Western Area (149.8 kg/std tow) decreasing to 22.9 kg/std tow in the Central Area and 10.6 kg/std tow in the Eastern Area (Table 45). The average CPUE on the inner shelf was 119.0 kg/std tow, decreasing to 80.7 kg/std tow on the upper slope and 58.0 kg/std tow on the outer shelf. Within the nine area-depth intervals, the mean CPUE ranged from 2.5 kg/std tow on the Eastern Area-upper slope to 220.4 kg/std tow on the Western Area-upper slope.

Eleven species were found in the Eastern Area; the number decreased to ten in the Western Area and nine in the Central Area (Table 46). Across the shelf and slope, the largest number of species (9) occurred on the inner shelf, decreasing to eight on the outer shelf and six on the upper slope. Within the study area, the number of species identified ranged from three on the Central Area inner shelf to nine on the Western Area inner shelf.

The three principal species and the percentage each contributed to the total group catch is summarized in Table 47. In the eight area-depth intervals where Tanner crab occurred, this species made up 50 to 90% of the catch of commercially important invertebrates. In all area-depth intervals, generally three species constituted over 85% of the commercially important invertebrate catch.

Chinoecetes bairdi (Tanner crab)

Tanner crab was the most abundant shellfish in the study area, making up 83% of the commercially important shellfish and occurred at 89% of the stations sampled (Table 48). This species also represented 50% of the total invertebrate catch.

Standing stock estimates. The standing stock of Tanner crab was estimated at 37,237 mt (199.5 million crabs) (Table 49). Ninety-four percent (35,050 mt) of the estimated stock occurred in the Western Area, followed by 3% (1,318 mt) in the Eastern Area, and 2% (869 mt) in the Central Area. On a depth basis, 41% (15,276 mt) of the estimated Tanner crab abundance occurred on the inner shelf, 38% (14,123 mt) on the outer shelf, and 21% (7,838 mt) on the upper

Table 44. Commercially important invertebrate families and species encountered in the NEGOA survey area.

Scientific Name	Common Name
Inachidae	
Chionoecetes bairdi	Tanner crab
Cancridae	
Cancer magister	Dungeness crab
Lithodidae	
Lithodes aequispina	Golden king crab
Pandalidae	
Pandalus borealis	Pink shrimp
P. danae	Dock shrimp
P. hypsinotus	Coonstripe shrimp
P. jordani	Ocean pink shrimp
P. montagui tridens	
P. platyceros	Spot shrimp
Pandalopsis dispar	Sidestripe shrimp
Pectinidae	
Patinopecten caurinus	Weathervane scallop

Table 45. Average CPUE of commercially important invertebrate species in kilograms within the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Tanner crab	24.8	2.7	1.5	6.7	26.7	8.2	0.1	11.4	127.3	110.3	218.4	131.6	90.8	53.2	76.5	69.4
Pink shrimp	*	0.5	0	0.3	0	2.5	*	1.1	26.0	6.4	1.3	13.7	16.7	3.5	0.5	7.1
Sidestripe shrimp	0	*	0.6	0.1	0	*	7.4	2.1	4.3	0.7	0.5	2.1	2.8	0.3	2.0	1.4
Ocean pink shrimp	*	0.4	*	0.2	0	0.1	0	*	0.4	*	0	0.2	0.3	0.2	*	0.2
Weathervane scallop	14.8	0	0	2.9	12.5	5.7	0.1	6.1	2.4	0.3	0.2	1.1	6.5	0.8	0.1	2.5
Other invertebrates	0.9	0.1	0.4	0.4	*	*	7.6	2.2	2.8	*	*	1.1	1.9	*	1.6	0.9
TOTAL	40.5	3.7	2.5	10.6	39.2	16.5	15.2	22.9	163.2	117.7	220.4	149.8	119.0	58.0	80.7	81.5

* - Less than 0.1 kilogram per six kilometers.

Table 46. Number of commercially important invertebrate species occurring in the NEGOA survey area.

Depth Zones (m)	AREAS			
	Eastern	Central	Western	Total
1-100	7	3	9	9
101-200	7	7	8	8
201-400	4	5	4	6
Total	11	9	10	11

Table 47. The three principal species of commercially important invertebrates and the percentage each contributed to the commercially important invertebrate group catch within the NEGOA survey area.

	AREAS							
Depth Zones (m)	EASTERN	%	CENTRAL	%	WESTERN	%	TOTAL	%
1-100	Tanner crab	61.2	Tanner crab	68.0	Tanner crab	78.0	Tanner crab	76.3
	Weathervane scallop	36.5	Weathervane scallop	31.9	Pink shrimp	15.9	Pink shrimp	14.0
	Dungeness crab	2.2			Sidestripe shrimp	2.6	Weathervane scallop	5.5
101-200	Tanner crab	73.0	Tanner crab	49.7	Tanner crab	93.7	Tanner crab	91.7
	Pink shrimp	13.5	Weathervane scallop	34.6	Pink shrimp	5.4	Pink shrimp	6.0
	Ocean pink shrimp	24.0	Pink shrimp	15.1	Sidestripe shrimp	0.6	Weathervane scallop	1.4
201-400	Tanner crab	60.0	Golden king crab	50.0	Tanner crab	99.0	Tanner crab	94.8
	Sidestripe shrimp	24.0	Sidestripe shrimp	48.7	Pink shrimp	0.5	Sidestripe shirmp	2.5
	Golden king crab	16.0			Sidestripe shrimp	0.2	Golden king crab	2.0
Total	Tanner crab	63.2	Tanner crab	49.8	Tanner crab	87.9	Tanner crab	85.2
	Weathervane scallop	27.4	Weathervane scallop	26.6	Pink shrimp	9.2	Pink shrimp	8.7
	Pink shrimp	2.8	Sidestripe shrimp	9.2	Sidestripe shrimp	1.4	Weathervane scallop	3.1

Table 48. Percent occurrence of commercially important invertebrate species in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Dungeness crab	33.3	0	0	10.5	0	0	0	0	23.5	0	0	5.6	24.2	0	0	6.1
Tanner crab	100	87.5	60.0	84.2	50.0	93.3	50.0	81.0	88.2	94.0	100	93.1	87.9	92.6	70.6	88.6
Golden king crab	0	0	10.0	2.6	0	0	100	9.5	0	0	0	0	0	0	17.6	2.3
Sidestripe shrimp	0	25.0	90.0	34.2	0	26.7	100	28.6	5.9	54.0	80.0	44.4	3.0	43.2	88.2	38.9
Pink shrimp	8.3	43.8	0	21.1	0	73.3	50.0	57.1	64.7	90.0	80.0	83.3	36.3	77.8	29.4	60.3
Coonstripe shrimp	8.3	0	0	2.6	0	0	0	0	23.5	4.0	0	8.3	15.1	2.5	0	5.3
Ocean pink shrimp	8.3	43.8	20.0	26.3	0	33.3	0	23.8	5.9	2.0	0	2.8	6.1	16.1	11.8	13.0
Pandalid shrimp	0	12.5	0	5.3	0	20.0	0	14.3	17.6	12.0	0	12.5	9.1	13.6	0	10.7
Spot shrimp	0	6.3	0	2.7	0	13.3	0	9.5	0	10.0	0	6.9	0	9.9	0	6.1
Weathervane scallop	58.3	12.5	0	23.7	75.0	33.3	50.0	42.9	64.7	28.0	60.0	38.9	63.6	25.9	23.5	35.1

Table 49. *Estimated standing stock in metric tons for commercially important invertebrate species within the NEGOA survey area.*

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Tanner crab	941	305	72	1,318	604	263	2	869	13,731	13,555	7,764	35,050	15,276	14,123	7,838	37,237
Pink shrimp	0	62	0	62	0	82	0	82	2,807	788	46	3,641	2,807	932	46	3,785
Sidestripe shrimp	0	5	30	35	0	0	160	160	472	93	18	583	472	98	208	778
Ocean pink shrimp	0	51	2	53	0	5	0	5	50	0	0	50	50	56	2	108
Weathervane scallop	560	5	0	565	282	182	2	466	263	40	9	312	1,105	227	11	1,343

slope. Within the study area, estimated standing stocks ranged from 2 mt (< 0.1%) on the Central Area-upper slope to 13,731 (36%) on the Western-inner shelf.

Size composition. Tanner crab in the NEGOA survey area averaged 82.6 mm (carapace width) and consisted of 52.6% males and 47.4% females. The size of males ranged from 16 to 183 mm in carapace width and averaged 85.0 mm, while females ranged from 24 to 115 mm and averaged 79.9 mm (Figs. 24 and 25).

Other Crab Species

Dungeness and golden king crab were captured at isolated stations. The total catch for Dungeness crab was 42 kg, of which 77% occurred on the Western Area-inner shelf. The remaining 33% was caught over the Eastern-inner shelf. The golden king crab catch for the survey area was 18 kg, 77% occurring on the Central Area-upper slope and 33% on the Eastern Area-upper slope.

Pandalus borealis (Pink shrimp)

Pink shrimp was the most abundant shrimp species collected, making up 5% of the total invertebrate catch. This species also comprised 8% of the commercially important shellfish catch and occurred at 60% of the stations sampled (Table 48).

Standing stock estimates. It was estimated that 3,785 mt of pink shrimp occurred in the NEGOA area, 96% (3,041 mt) of which is attributed to the Western Area (Table 49). The inner shelf held 74% (2,807 mt) of the estimated standing stock, the outer shelf 25% (932 mt), and the upper slope 1% (46 mt). Catchability coefficients for the 400-mesh eastern otter trawl are undoubtedly lower than 1.0 for Pandalid species, hence the standing stock estimates should be considered minimal.

No biological data were collected for this species.

Pandalopsis dispar (Sidestripe shrimp)

Sidestripe shrimp accounted for 1% of the total invertebrate and 2% of the commercially important shellfish catches. This species occurred at 39% of the stations trawled (Table 48).

Standing stock estimates. The estimated standing stock of sidestripe shrimp was 778 mt; 583 mt (75%) occurred in the Western Area, 160 mt (21%) in the Central Area, and 35 mt (5%) in the Eastern Area (Table 49). The

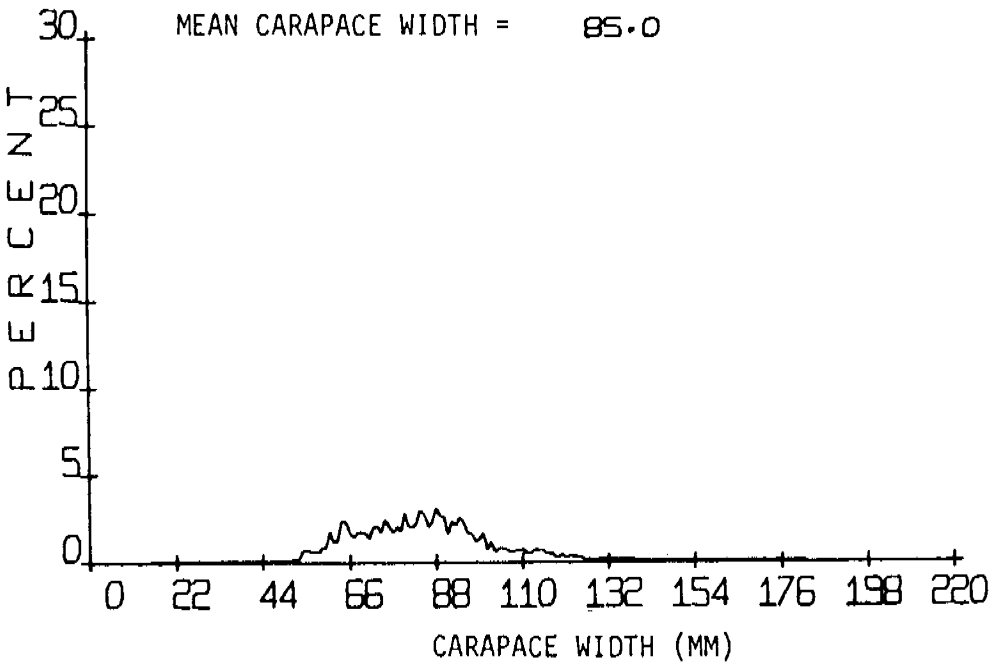

Figure 24. The percent size composition of the estimated standing stock (in numbers) of male Chionoecetes bairdi *(Tanner crab) in the NEGOA survey area.*

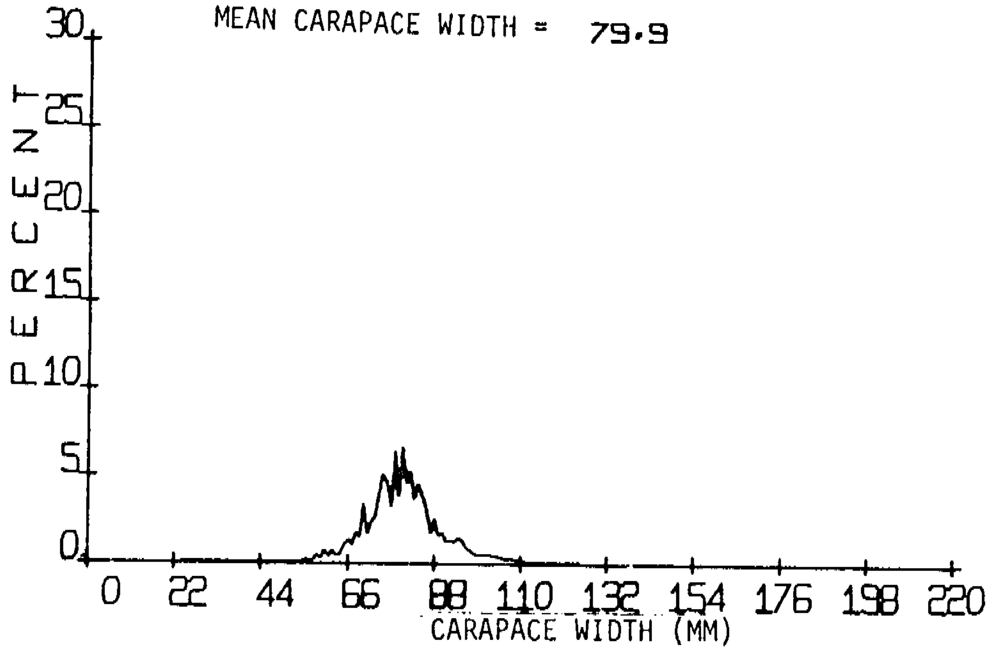

Figure 25. The percent size composition of the estimated standing stock (in numbers) of female Chionoecetes bairdi *(Tanner crab) in the NEGOA survey area.*

estimated standing stock on the inner shelf was 472 mt (60%), on the outer shelf 98 mt (13%), and on the upper slope 208 mt (27%). In the survey area where sidestripe shrimp occurred, the estimated standing stocks ranged from 0.6 mt (< 1%) on the Central Area-outer shelf to 472 mt (60%) on the Western Area-inner shelf.

No biological data were collected for this species.

Pandalus jordani (Ocean pink shrimp)

Even though this species was the third most abundant Pandalid shrimp collected, it contributed less than 0.2% of the total invertebrate catch, and occurred at 13% of the stations sampled (Table 48).

Standing stock estimates. The standing stock of this species was estimated at 108 mt, 47% occurring on the Eastern Area-outer shelf and 46% on the Western Area-inner shelf (Table 49).

No biological data were collected for this species.

Other Shrimp Species

Four other species of Pandalid shrimp were caught in the survey area: *P. montagui tridens*, *P. platyceros*, *P. hypsinotus*, and *P. danae* (Table 44).

The total catch of *P. montagui tridens* was 5.4 kg, most of which was collected on the outer shelf (87%) in the Eastern and Western Areas.

The *P. platyceros* (Spot shrimp) catch totalled 5.2 kg, 94% occurring in the Western Area, 2% in the Central Area, and 4% in the Eastern Area. This species was only caught on the outer shelf.

Of the 4.7 kg of *P. hypsinotus* (Coonstripe shrimp) collected in the survey area, 99% of the catch came from the Western Area. The remaining fraction was caught in the Eastern Area. The inner shelf region produced 79% of the total catch; 21% was taken from the outer shelf.

P. danae (Dock shrimp) occurred infrequently and totalled only 0.3 kg. One-third of the catch occurred in each of the survey areas and all the catch was on the inner shelf.

Patinopecten caurinus (Weathervane scallop)

Weathervane scallops comprised 2% of the total invertebrate catch, 3% of the commercially important invertebrate catch, and occurred at 35% of the stations sampled (Table 48).

Standing stock estimates. The standing stock of weathervane scallops was estimated at 1,343 mt (Table 49). Of the total abundance, 466 mt (35%) occurred in the Central Area, 42% (565 mt) in the Eastern Area, and 23% (312 mt) in the Western Area. Eighty-two percent (1,105 mt) of the estimated abundance was on the inner shelf, while 17% (227 mt) was estimated on the outer shelf and less than 1% (11 mt) on the upper slope. The estimated standing stock ranged from 0 mt on the Eastern Area-upper slope to 560 mt on the Eastern Area-inner shelf.

No biological data were collected for this species.

DEMERSAL FISH AND SHELLFISH COMMUNITIES

This section examines the diversity of the demersal fauna and the relative importance of species groups and individual species in the survey area. The miscellaneous invertebrates will be considered only as a group.

Number of Species

The number of species collected in the survey area and by sub regions and depth zones is given in Table 50. A total of 79 fish and 11 commercially important invertebrates, including eight pelagic fish species, was present. The most species (79) occurred in the Western Area, while 49 species were collected in the Central Area and 63 species in the Eastern Area. A similar number of species, 66 and 64, were caught on the inner and outer shelf, respectively; however, only 39 were found on the upper slope. Among the three areas, only the Eastern and Western exhibited similar patterns of species abundance. However, the largest number of species occurred on the outer shelf in the Central Area. The number of species found in each of the nine area-depth intervals ranged from 19 to 56.

Composition of Demersal Fauna

Species Groups

Survey Area

The estimated standing stock for each species group and the percent of the total standing stock that it represents is presented in Tables 51 and 52.

The total estimated standing stock (297,486 mt) within the survey area was 75% fish and 25% invertebrates. In decreasing order of abundance, flatfish represented 40%, roundfish 26%, elasmobranchs 5%, and rockfish 4% of the total.

Table 50. *Number of species of indicated groups collected within the NEGOA survey area.*

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Elasmobranchs	4	4	4	4	4	3	2	4	4	4	3	4	4	4	4	4
Flatfish	10	6	7	11	6	5	4	6	9	9	4	10	10	10	7	12
Roundfish	20	12	11	25	9	19	5	21	31	25	17	42	39	28	17	48
Rockfish	1	10	5	12	2	9	3	9	3	7	3	7	4	14	5	15
All fish	35	32	27	52	21	36	14	40	47	47	27	63	57	56	33	79
Commercially important invertebrates	7	7	4	11	3	7	5	9	9	8	4	10	9	8	6	11
Total species	42	39	31	63	24	43	19	49	56	53	31	73	66	64	39	90

Table 51. Estimated standing stock in metric tons for species groups by area-depth intervals in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Flatfish	25,264	22,560	15,784	63,608	1,890	7,329	8,304	17,523	13,669	18,012	5,598	37,279	40,823	47,901	29,686	118,410
Roundfish	9,546	5,018	2,579	17,143	6,182	2,053	1,848	10,083	14,394	32,563	3,588	50,545	30,122	39,634	8,015	77,771
Elasmobranchs	1,972	3,104	2,102	7,178	677	684	552	1,913	4,108	2,147	535	6,790	6,757	5,935	3,189	15,881
Rockfish	0	2,740	3,025	5,765	7	458	704	1,169	339	2,177	1,170	3,686	346	5,375	4,399	10,620
All Fish	36,782	33,422	23,490	93,694	8,756	10,524	11,408	30,688	32,510	54,899	10,891	98,300	78,048	98,845	45,789	222,682
Commercially Important Invertebrates	1,536	447	123	2,106	886	536	342	1,764	17,613	14,492	7,839	39,944	20,035	15,475	8,304	43,814
Misc. Invertebrates	1,474	5,522	7,936	14,932	861	774	348	1,983	9,319	2,658	2,072	14,049	11,654	8,954	10,356	30,964
All Invertebrates	3,010	5,969	8,059	17,038	1,747	1,310	690	3,747	26,932	17,150	9,911	53,993	31,689	24,429	18,660	74,778
TOTAL	39,792	39,391	31,549	110,732	10,503	11,834	12,098	34,435	59,442	72,049	20,802	152,293	109,737	123,274	64,449	297,460

Table 52. Percent contribution by species group to the estimated standing stock by area-depth intervals in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Flatfish	63.5	57.3	50.0	57.4	18.0	61.9	68.6	50.9	23.0	25.0	26.9	24.5	37.2	38.8	46.1	39.8
Roundfish	24.0	12.7	8.2	15.5	58.8	17.3	15.3	29.3	24.2	45.2	17.2	33.2	27.4	32.2	12.4	26.2
Elasmobranchs	5.0	7.9	6.7	6.5	6.5	5.8	4.6	5.5	6.9	3.0	2.6	4.5	6.2	4.8	4.9	5.3
Rockfish	0.0	7.0	9.6	5.2	0.1	3.9	5.8	3.4	0.6	3.0	5.6	2.4	0.3	4.4	7.6	3.6
All Fish	92.4	84.9	74.5	84.6	83.4	88.9	94.3	89.1	54.7	76.2	52.3	64.6	71.1	80.2	71.0	74.9
Commercially Important Invertebrates	3.9	1.1	0.4	1.9	8.4	4.5	2.8	5.1	29.6	20.1	37.7	26.2	18.3	12.5	12.9	14.7
Misc. Invertebrates	3.6	14.0	25.1	13.5	8.2	6.6	2.9	5.8	15.7	3.7	10.0	9.2	10.6	7.3	16.1	10.4
All Invertebrates	7.6	15.1	25.5	15.4	16.6	11.1	5.7	10.9	45.3	23.8	47.7	35.4	28.9	19.8	29.0	25.1
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 53. Average CPUE in kilograms by area-depth intervals for species groups in the NEGOA survey area.

	Areas/Depth Zones (m)															
	Eastern				Central				Western				Total			
Species	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths	1-100	101-200	201-400	All Depths
Flatfish	667.3	203.6	346.3	327.6	83.5	229.3	388.3	230.8	126.3	146.2	157.3	139.5	242.3	180.1	289.4	220.6
Roundfish	251.8	44.9	56.1	87.6	273.8	63.8	86.3	132.6	132.6	264.2	100.3	189.2	178.6	148.7	77.9	144.6
Elasmobranchs	52.0	27.9	46.0	36.8	30.0	21.3	25.7	25.1	38.0	17.3	14.9	25.3	40.1	22.2	31.0	29.5
Rockfish	*	24.7	66.2	29.6	0.2	14.2	32.8	15.2	3.0	17.4	32.8	13.6	1.9	20.1	47.6	19.7
All Fish	971.1	301.1	514.6	481.8	387.5	328.6	533.1	403.7	299.9	445.1	305.3	367.6	462.9	371.1	445.9	414.4
Commercially Important Invertebrates	40.5	3.7	2.5	10.6	39.3	16.5	15.2	22.9	163.2	117.7	220.4	149.8	119.0	58.0	80.7	81.5
Misc. Invertebrates	39.1	50.2	174.5	78.3	38.2	24.6	17.1	27.4	86.7	21.9	58.5	54.7	70.7	35.3	102.6	59.0
All Invertebrates	79.6	53.9	177.0	88.9	77.5	41.1	32.3	50.3	249.9	139.6	278.9	204.5	189.7	93.3	183.3	140.5
TOTAL	1,050.7	355.0	691.6	570.7	465.0	369.7	565.4	454.0	549.8	584.7	584.2	572.1	652.6	464.4	629.2	554.9

Of the invertebrates, the commercially important species comprised 15% of the estimates standing stock and the miscellaneous group 10%.

The CPUE in the survey area was 414.4 kg/std tow for fish and 140.5 kg/std tow for invertebrates, totaling 554.9 kg/std tow (Table 53).

Areas and Depth Zones

Fish were the major contributor to the total estimated standing stock in each area and depth zone. Their estimated abundance varied from 65 to 89% of the total, while the fraction contributed by the invertebrates ranged from 11 to 35% (Table 52).

Flatfish were the most abundant fish in all areas and depth zones, except in the Western Area roundfish were the primary group (Table 53). The abundance of elasmobranchs and rockfish was minor in comparison to the flatfish and roundfish in all areas and depth zones.

The combined CPUE for fish and invertebrates was nearly the same in the Eastern (570.7 kg/std tow) and Western (572.1 kg/std tow) Areas, but somewhat less, 454.0 kg/std tow, in the Central Area. The highest CPUE in any depth zone was the 652.6 kg/std tow on the inner shelf. The catch rate declined to 464.4 kg/std tow on the outer shelf, but increased to 629.2 kg/std tow on the upper slope (Table 53).

Area-Depth Intervals

The estimated standing stock and percent contribution of each species group to the total within each area-depth interval is shown in Tables 51 and 52. The fish fauna, by weight, dominated the total demersal catch in all area-depth intervals. Fish abundance ranged from 52.3 to 94.3% of the estimated standing stock, while the invertebrates ranged from 5.7 to 47.7%.

Among the fish, the flatfish group, ranging from 18.0 to 68.6% of the standing stock, was dominant in six of the nine area-depth intervals and made up 18.0 to 68.6% of the total estimated standing stock. Roundfish were dominant in three area-depth intervals, ranging from 8.2 to 58.5%.

Elasmobranchs and rockfish were always represented less in any catch than either flatfish or roundfish.

The average CPUE for each species group in each area-depth interval is shown in Table 53. Catch rates in the survey area ranged from 355.0 to

1,050.7 kg/std tow. The catch rate for fish as a group exceeded that for invertebrates in every area-depth interval.

Principal Species

Survey Area

The more prominent species of fish and commercially important invertebrates in the NEGOA survey area are listed in Table 54 along with their contribution to the estimated standing stock and average CPUE. Walleye pollock (*Theragra chalcogramma*), Arrowtooth flounder (*Atheresthes stomias*), and Tanner crab (*Chionoectes bairdi*) comprised 48.5% of the total estimated standing stock.

Areas and Depth Zones

The percent contribution to standing stock and the catch rates of the five most abundant species of fish and commercially important invertebrates for each of the three areas and depth zones are listed in Table 55. The five species listed accounted for 57 to 75% of the total estimated standing stock in each of the divisions.

Area-Depth Intervals

The bulk of the estimated standing stock of each area-depth community is composed of elements from the four classes based on species abundance and distribution:

Class (1) Species found within all depth zones and generally throughout the survey area: Arrowtooth flounder (*Atheresthes stomais*), longnose and big skates (*Raja* spp.), rex sole (*Glyptocephalus zachirus*), flathead sole (*Hippoglossoides elassodon*), Tanner crab (*Chionoecetes bairdi*), and black skate (*Raja kincaidi*).

Class (2) Species found mostly in shallower waters throughout the survey area: Walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and Pacific halibut (*Hippoglossus stenolepis*).

Class (3) Species found mostly in deeper waters throughout the survey area: Pacific ocean perch (*Sebastes alutus*), shortspine thornyhead (*Sebastolobus alascanus*), Dover sole (*Microstomus pacificus*), sablefish (*Anoplopoma fimbria*), and rougheye rockfish (*Sebastes aleutianus*).

Table 54. Prominent fish and commercially important invertebrate species in the NEGOA survey area.

Species	Standing Stock mt	%	CPUE kg/std tow
Walleye pollock	54,294	18.3	101.2
Arrowtooth flounder	52,564	17.7	98.0
Tanner crab	37,240	12.5	69.4
Starry flounder	16,823	5.7	31.4
Flathead sole	16,014	5.4	29.8
Pacific cod	12,181	4.1	22.7
Longnose and Big skates	11,649	3.9	21.7
Dover sole	11,094	3.7	20.6
Rex sole	10,971	3.7	20.4
Pacific halibut	7,782	2.6	14.5
Shortspine thornyhead	5,982	2.0	11.1
Sablefish	5,185	1.7	9.6
Pink shrimp	3,788	1.3	7.1
Black skate	3,657	1.2	6.8
Pacific ocean perch	2,494	0.8	4.6
Butter sole	2,257	0.8	4.2
Rougheye rockfish	1,456	0.5	2.7
Weathervane scallop	1,347	0.5	2.5
Searcher	1,187	0.4	2.2
Sub-total	257,965	86.8	480.5
Other fish and commercially important invertebrates	8,542	2.9	15.4
Sub-total	266,507	89.7	495.4
Miscellaneous invertebrates	30,969	10.4	59.0
Total estimated standing stock	297,476	100.1	554.9

Table 55. The five most abundant species in each area and depth zone of the NEGOA survey area.

AREAS

Eastern			Central			Western		
SS: 110,740	%	CPUE kg/std tow	SS: 34,444	%	CPUE kg/std tow	SS: 152,301		CPUE kg/std tow
Atheresthes stomais	25	144	*Atheresthes stomais*	23	104	*Theragra chalcogramma*	26	150
Platichthys stellatus	15	86	*Theragra chalcogramma*	18	83	*Chionoecetes bairdi*	23	132
Theragra chalcogramma	7	42	*Glyptocephalus zachirus*	9	42	*Atheresthes stomais*	11	62
Microstomus pacificus	5	28	*Microstomus pacificus*	9	41	*Hippoglossoides elassodon*	6	35
Gadus macrocephalus	5	28	*Hippoglossoides elassodon*	7	33	*Raja* spp.	4	22

DEPTH ZONES

Inner Shelf			Outer Shelf			Upper Slope		
SS: 109,748	%	CPUE kg/std tow	SS: 123,232	%	CPUE kg/std tow	SS: 64,455	%	CPUE kg/std tow
Theragra chalcogramma	19	126	*Atheresthes stomais*	26	119	*Atheresthes stomais*	18	113
Platichthys stellatus	15	100	*Theragra chalcogramma*	25	118	*Microstomus pacificus*	14	89
Chionoecetes bairdi	14	91	*Chionoecetes bairdi*	12	53	*Chionoecetes bairdi*	12	76
Atheresthes stomais	9	56	*Hippoglossoides elassodon*	7	34	*Glyptocephalus zachirus*	11	66
Raja spp.	5	35	*Gadus macrocephalus*	5	22	*Anoplopoma fimbria*	7	43

SS: Estimated standing stock of fish and invertebrates in metric tons.

%: Percent of total estimated standing stock.

Class (4) Species important only within one area-depth intervals of the survey area:

a: Shallower waters: searcher (*Bathymaster signatus*), butter sole (*Isopsetta isolepis*), rock sole (*Lepidopsetta bilineata*), pink shrimp (*Pandalus borealis*), and starry flounder (*Platichthys stellatus*).

b: Deeper waters: bigmouth sculpin (*Hemitripterus bolini*), golden king crab (*Lithodes aequispina*), sidestripe shrimp (*Pandalopsis dispar*), and spiny dogfish (*Squalus acanthias*).

The distribution of these classes is far from even. In all but two of the area-depth intervals, Eastern and Central inner shelf Areas, the Class (1) species made up 40 to 64% of the estimated standing stock.

On the Eastern inner shelf, Class (1) species accounted for only 17% of the estimated abundance; however, nearly half (47.6%) of the standing stock was contributed by two Class (4a) species, starry flounder and butter sole. These were not found in any significant numbers elsewhere in the survey area. Thus, a large element of the fauna in this area-depth interval appeared to be composed of species that are unique to that area.

The Central inner shelf region was different from that considered above. Class (1) species made up 26.5% of the estimated standing stock, while Class (2) species, walleye pollock, Pacific cod, and Pacific halibut made up 60%. These species were not unique to this area-depth interval as they also comprised 46% of the estimated standing stock on the Western outer shelf.

SUMMARY

This report includes the results of an otter trawl survey from April to July 1975 of demersal fish and invertebrate resources within a coastal area of the Northeastern Gulf of Alaska between Cape Cleare (148°W. long.) and Yakutat Bay (140°W. long.). The survey area included depths from nearshore to 400 m, and encompassed an area of 39,000 km^2 of ocean bottom.

A total of 131 trawl stations was sampled, and at each station the species composition and weight determined. Sex, length, weight, sexual maturity, and age data were collected on designated species.

The total standing stock in the survey area, as estimated from the otter trawl catches, was 297,486 mt. Of this tonnage, 40% were flatfish, 26% were roundfish, 5% were elasmobranchs, 4% were rockfish, 15% were commercially important invertebrates, and 10% were miscellaneous invertebrates. Walleye pollock, arrowtooth flounder, and Tanner crab collectively made up approximately 48.5% of the total estimated standing stock.

For the survey area, the CPUE indices in kg/std tow for the principal groups were: elasmobranchs - 29.5, flatfish - 220.6, roundfish - 144.6, rockfish - 19.7, all fish - 414.4; commercially important invertebrates - 81.5, miscellaneous invertebrates - 59.0, all vertebrates - 140.5; and all species - 554.9. For the three most prominent species, the CPUE indices were: walleye pollock 101.2, arrowtooth flounder 98.0, and Tanner crab 69.4 kg/std tow.

The survey area was partitioned into three areas and three depth zones to form nine area-depth intervals, each of which was examined in respect to community composition. Walleye pollock, arrowtooth flounder, Tanner crab, the skates, rex sole, flathead sole, cod, and halibut were widely represented in a majority of the area-depth intervals. In one area-depth interval, however, nearly half of the estimated standing stock was starry flounder and butter sole, which were not caught in significant numbers in any other locale.

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5. LITTORAL BIOLOGY

INTRODUCTION

Only a few Gulf of Alaska intertidal studies have previously been completed and published, and most of these were lacking in quantitative measures. Thus, the littoral zone, an area of maximum impact from Outer Continental Shelf (OCS) oil development, is almost completely unstudied.

In oil pollution incidents, the littoral zone may be the first point of contact of large quantities of oil with the marine substrate. Also, as oil comes ashore tidal movements repeatedly expose the intertidal and subtidal zone to oil-contaminated water.

The effects of petroleum development on intertidal biota are very difficult to predict. Some recent studies (Mitchell et al., 1970; Smith, 1968) indicate that certain crude oil spills may have very little effect on the dominant intertidal biota. Although some species, such as the vascular plant *Phyllospadix*, may be severely impacted, the dominant algal and invertebrate species seem to survive all but the heaviest spills. Algae are apparently able to secrete a mucous covering that protects them from toxic and suffocating effects (Clark et al., 1975). Many of the invertebrate species are able to withdraw into shells or topographic features that provide them some protection from the oil.

The opinion that crude oil spills have little effect is not, however, universally accepted, and data from other crude spills show that they may have a severely detrimental effect (Wilson and Hunt, 1975). Whichever the case, it is a well accepted fact that refined petroleum products, or the detergents used to desperse oil, almost always have a devastating effect on intertidal biota (Wilson and Hunt, 1975; Smith, 1968; Chia, 1971; Mitchell et al., 1970). When these compounds float ashore, mortality effects can be extreme. Repopulation of an impacted area may take from only a few weeks for certain diatom and algae species (Chan, 1975; Castenholz, 1967) to as much as 5 years to re-establish mussel beds (North, 1967). Total recovery may take several years (Michael et al., 1975) or may never occur for all species.

The problem is compounded not only by the varying effects of different petroleum types on different species, but also by the frequency of impact on any area. Areas receiving chronic contamination, as from permanent off-shore oil rigs or tanker transfer systems, may show different rates and types of recovery than areas that receive a one-time spill.

The effect of long-term buildup of oil levels in the waters along a coastal area are unpredictable. The effects of constant, low levels of oil on critical larval states could possibly change recruitment and settling patterns among dominant species. This in turn could cause changes in the feeding and behavior of marine birds, fish, and mammals that inhabit the area.

Studies to delineate such effects and their potential for occurring in the Gulf of Alaska need to be carried out. While oil spill areas may recover in a few years, areas receiving chronic oil fluxes may show permanent changes in community patterns.

OBJECTIVES

The major purpose of this subject for study is to document the distribution, biological composition, and abundance of habitat types along the coast to provide (a) an estimate of potential impact of OCS development at base sites upstream and (b) to provide an estimate (broad picture) of the status of things prior to OCS development.

The general goals of the project for the first year were to determine the abundance and distributions of littoral zone organisms at a variety of sites likely to be affected by oil pollution and to survey the literature concerning life histories of dominant organisms so the potential effects of oil pollution could be evaluated relative to specific organisms.

STUDY AREA

Sites in the Gulf of Alaska that have so far been sampled are shown in Fig. 26 and Table 56. In addition, seven sites in the western Gulf were sampled during May 1975. This work is an extension of the NEGOA program and will be covered in later reports.

METHODS

The scope and methodology of this project have been evolving continually. The original intention was to sample the three major substrate habitat types: rocky, muddy, and sandy. Emphasis has been on the rocky sites consisting of boulders and the solid rock faces of cliffs. For these habitat types, exact locations can be sampled repetitively and the dominant communities at these sites are most suited to accomplishment of program objectives. For these rocky intertidal areas specific square meter locations are enumerated by photographic documentation. Sucn an approach in sand or mud would require destructive sampling.

Table 56. Littoral sampling sites for NEGOA.

Fall 1974	*Location*		*Spring 1975*
	(N)	*(W)*	
(September)			*(April)*
Anchor Cove-Day Harbor	59°59',	149°05'	Anchor Cove-Day Harbor
Squirrel Bay-Evans I.	60°01',	148°08'	
	59°55',	148°05'	LaTouche Point*
MacLeod Harbor	59°53',	147°47'	MacLeod Harbor
Zaikof Bay	60°17',	147°00'	Zaikof Bay
	60°21',	146°39'	Port Etches
Boswell Bay	60°24',	146°06'	Boswell Bay
Katalla	60°16',	144°31'	Katalla
(October)			
Middleton Island	59°28',	146°19'	Middleton Island
			(June)
Cape Yakataga	60°05',	142°27'	Cape Yakataga
Yakutat-Ocean Cape	59°33',	139°44'	Yakutat-Ocean Cape

* In spring sampling, LaTouche Point replaced Squirrel Bay-Evans Island, which was inaccessible.

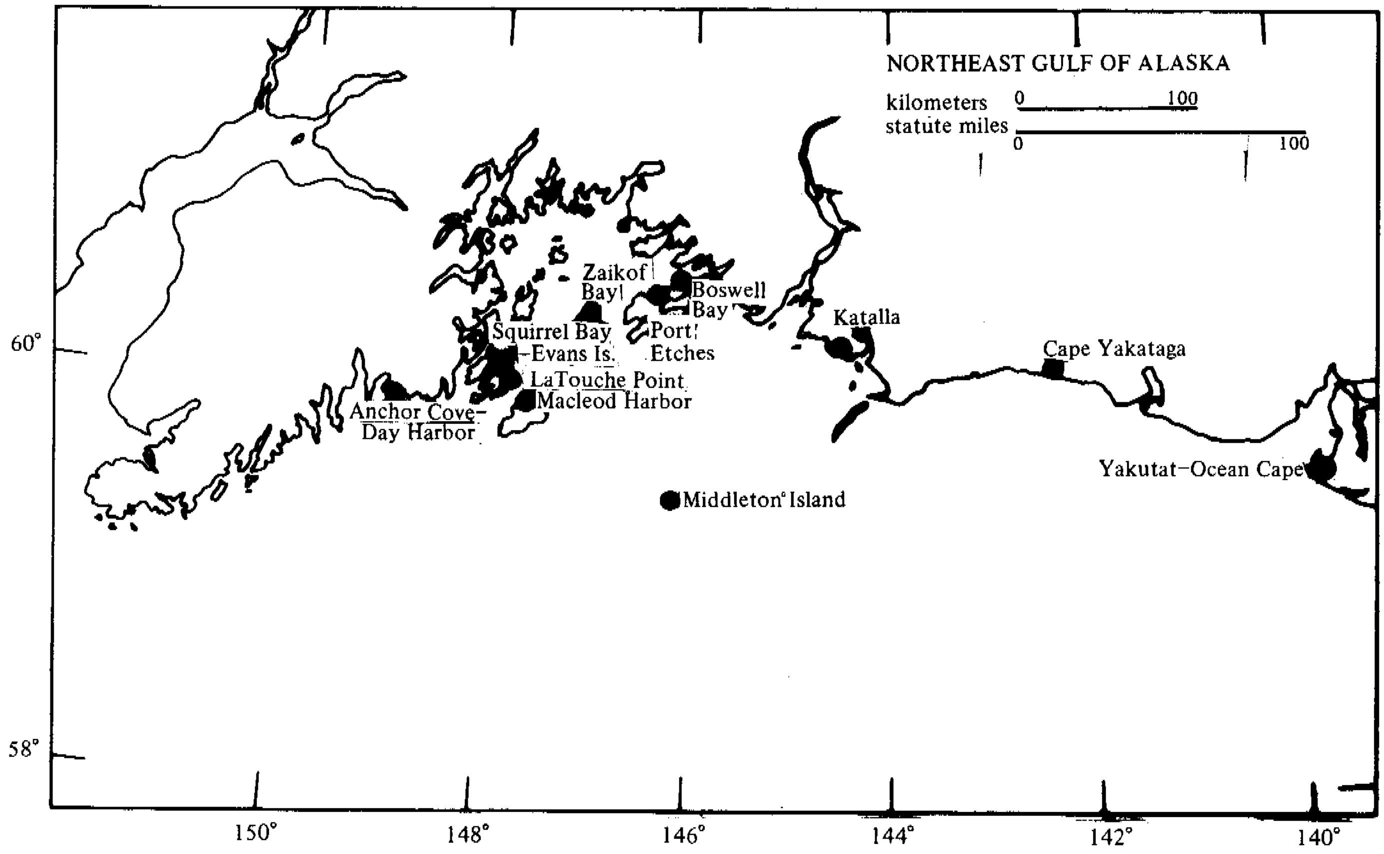

Figure 26. Intertidal sampling sites in the Gulf of Alaska 1974 - 1975.

Some attention will be given to muddy and sandy habitats in close coordination with studies by the U.S. Fish and Wildlife Service (USFWS) and Alaska Department of Fish and Game (ADF&G). OCSEAP studies of rocky sites are closely coordinated with these studies by the other agencies.

Since this project began most of the available literature concerned with Gulf of Alaska intertidal studies, eastern Pacific oil spills, and toxicity of oil to Alaskan intertidal forms has been collected and reviewed. Information on other areas (for instance oil spills in the Atlantic) has been reviewed where appropriate. Discussions have been held with all other known investigators currently carrying out littoral research in Alaska.

Biotic samples collected at our 10 study sites were processed by the University of Alaska Marine Sorting Center (MSC). In collaboration with the MSC, a data format was developed for archive retrieval and manipulation of data.

At each rocky site, transect lines were extended across the beach from the area of highest tidal influence to the water's edge at low tide. The number of transect lines at each site was determined by the slope of the beach; on a low gradient beach only one line was sampled, while on a steep beach as many as three lines were sampled. Sampling frames (1/16 m^2) were laid at regular intervals along the line. The area inside the frames was photographed and the biota within each frame scraped from the rocks, preserved in 10 percent formalin, and packaged for shipment to the University of Alaska Sorting Center. The level of each sample was determined with a transit and stadia rod, using standard engineering procedures. Leveling was done with respect to predicted low-tide levels, and heights of permanent benchmarks were established for each beach.

A second sampling method was developed to study hilly topography or areas that contain large boulders. This method involved sketching a facsimile of the area to be sampled and its biotic zones on a sheet of Mylar plastic. Numbered homogeneously arrayed dots were then placed on the sketch. A random number table was used to choose the dots (locations) to be sampled, then hardboard, numbered arrows were placed at corresponding locations on the rock face. Photographing and tidal leveling followed in the same manner as for the transects. Destructive quantitative collections (1/16 m^2) were also made next to but not on the random arrow sites to preserve the site as an undisturbed area for further study.

In addition to providing a better method for studying vertical faces, this technique is quite effective for studying the distribution of biota within zones. Such areas as a *Fucus* zone or a *Rhodymenia* zone can be sampled individually by randomly placing arrows within the desired zone.

A third sampling method was also occasionally used on rocky beaches: a "nested quadrat sampler." This frame consisted of 16 squares, each 1/64 m^2. Each 1/64 m^2 area was collected, preserved, identified, and sorted. The resulting data were then studied and combined to determine the adequacy of different sample sizes.

At muddy sites, transect lines were also used, but the soft sediment was sampled using a rectangular mud corer. It measures approximately 10 cm on a side, and collects approximately 1ℓ of sediment. Two replicate samples were collected from each location along the transect line. Sampling of muddy substrates was done at Middleton Island and Boswell Bay. It began with two biologists' reconnaissance by air of several intertidal areas along the coast of the eastern Gulf of Alaska in August 1974. Choice of areas was based on proximity to potential OCS impact areas, richness of biota, and accessibilty.

RESULTS

Nine of 10 scheduled sites were sampled during the fall of 1974 following a reconnaissance of the NEGOA area. Results included 218 quantitative samples, approximately 650 photographic samples, 20 trace metal collections, and several species collections. New methods were field tested and their adequacy has been assessed. Fig. 27 shows that a 1/16 m^2 frame is adequate for sampling most of the species in an intertidal zone.

Sample sorting has proceeded more slowly than anticipated. Contractual difficulties delayed the start 3 months. Consequently, by July 1, 1975, the data from only part of the samples had been returned. Within this data set, only two stations, MacLeod Harbor and Boswell Bay were relatively complete.

On July 7th the data from 100 additional stations were received in rough form. None of the data so far received contain the assigned code numbers for each species for computer analyses. MSC has the responsibility for coding all species, and until the code numbers are assigned, the data cannot be processed using pertinent programs and data archival system.

The species lists are also being compiled. These are presently complete for Boswell Bay and MacLeod Harbor and partially complete for Anchor Cove, Squirrel Bay, and Zaikof Bay.

Ten of ten sites in the NEGOA area were sampled during the spring of 1975. This work resulted in 238 quantitative samples, approximately 350 photographic

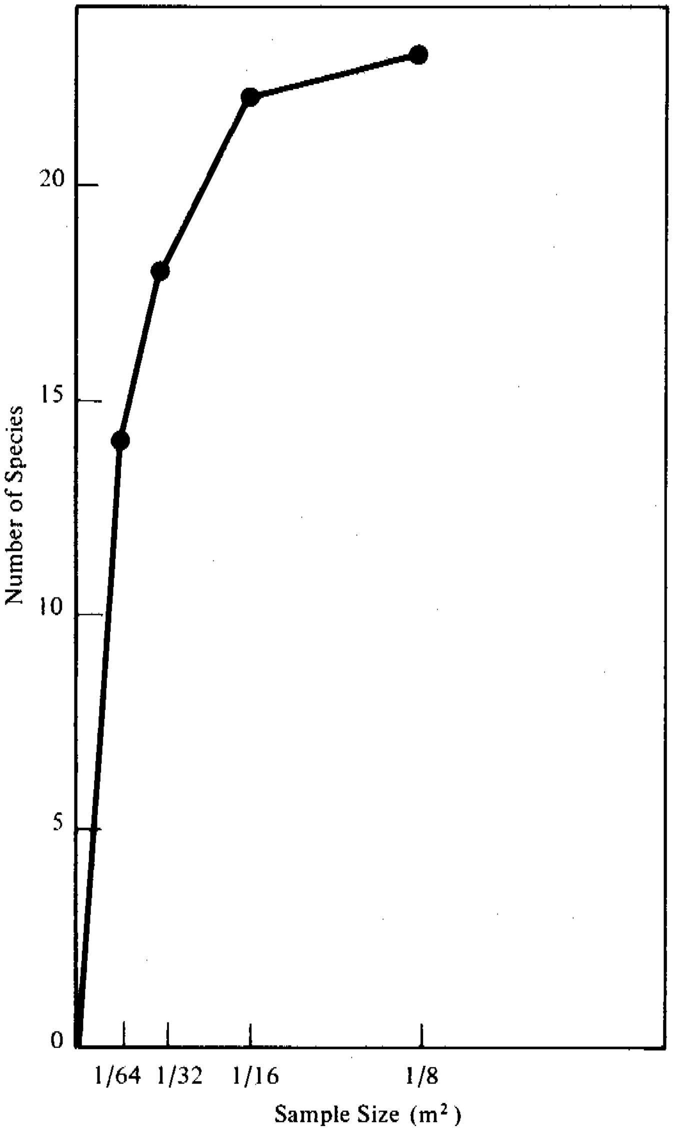

Figure 27. Number of species collected in Odonthalia *zone at Anchor Cove by different sized sampling frames.*

samples, 12 trace metal collections, and several species collections. No sorting has begun on these samples.

DISCUSSION

The data produced thus far are very preliminary. Fig. 28 is a prototype diagram relating tidal height to the number and biomass of dominant species. Eventually, a standard method of displaying data will be developed; this will show the location and biomass of the same 20 dominant algal and invertebrate species over a tidal range of +5 m to -1 m. These diagrams will be produced by computer and will provide a quick and consistent visual method for comparing different areas. After more data are received, it will be possible to use computer-developed methods to study such problems as species richness, community associations, dominance, and seasonal patterns at a variety of sites.

FUTURE STUDY

In anticipation of the need for information going beyond a data baseline in the Eastern Gulf of Alaska, several new studies are being started. The western area has already been sampled at several sites to provide better coverage of the entire Gulf. Subtidal sampling and observations by biologist-divers have begun. Studies of the drift zone areas at the upper limit of storm tides, where the mortality effects of pollution are often most evident, will begin shortly.

To provide a synoptic coverage and a better understanding of the major habitats in the intertidal zone aerial surveys and mapping of the entire coastline are underway. Cooperative ventures to study sand and muddy areas have been initiated with other agencies, e.g., FWS and ADF&G. Intensive monitoring of selected sites to provide detailed information on recruitment and seasonal changes will begin in the spring of 1975. Associated physiological studies will be carried out by the Physiology Section of the Auke Bay Laboratory.

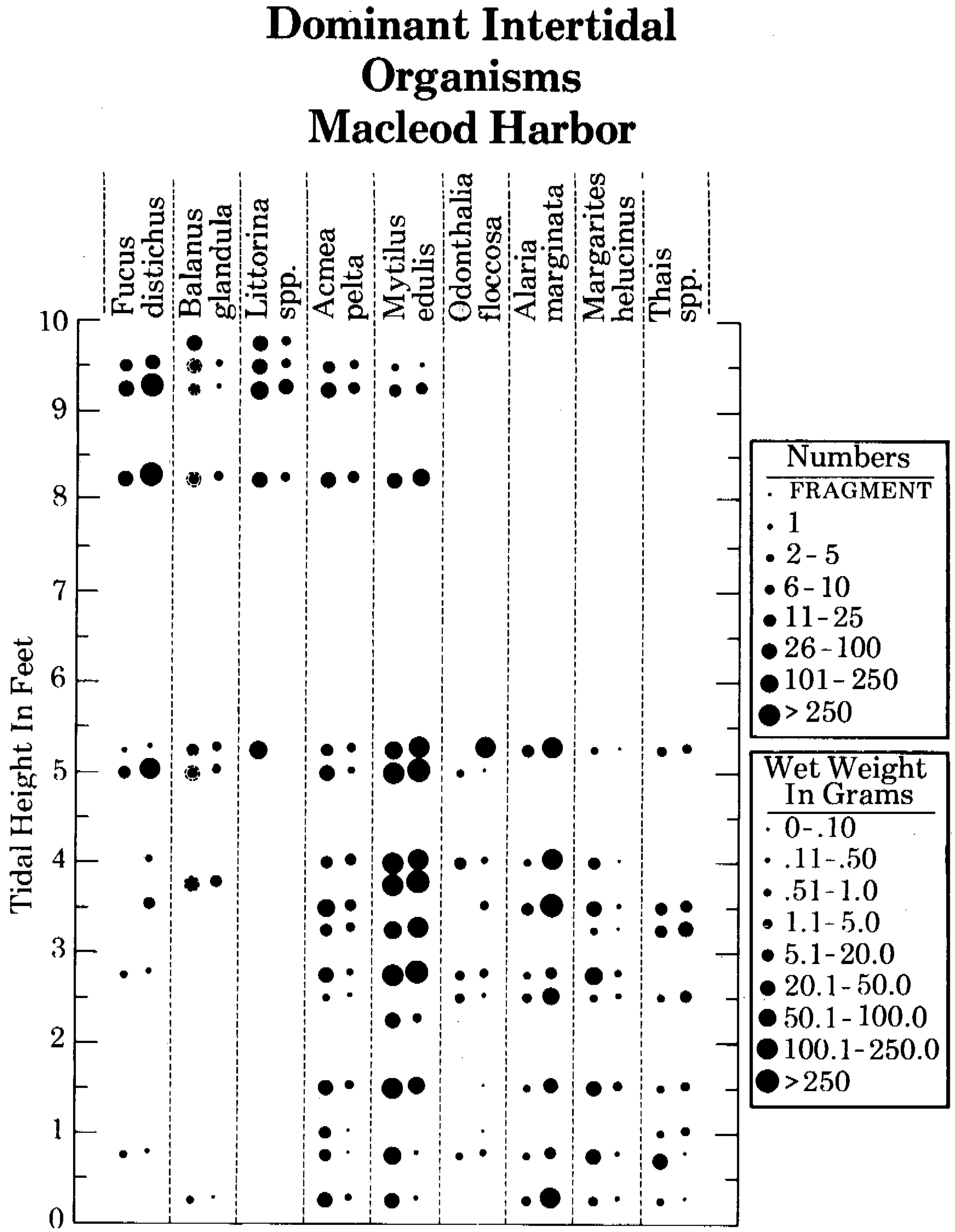

Figure 28. Prototype diagram for representing location of dominant intertidal organisms with respect to tidal height. Size of black circle represents number of organisms, size of gray circle represents wet weight of organisms.

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6. BENTHIC BIOLOGY[1]

INTRODUCTION

Benthic organisms (primarily the infauna and sessile and slow-moving epifauna) are particularly useful indicator species of a disturbed area because they tend to remain in place, to react to long-range environmental changes, and to reflect the nature of the substratum. Consequently, the organisms of the infaunal benthos have frequently been chosen to monitor long-term pollution effects and are believed to reflect accurately the biological health of a marine area (see Pearson, 1971, 1972, and Rosenberg, 1973, for discussions on long-term usage of benthic organisms for monitoring pollution).

The presence of large numbers of benthic epifaunal species of actual or potential commercial importance (crabs, shrimps, scallops, snails, fin fishes) in the Gulf of Alaska further dictates the necessity of understanding benthic communities, since many commercial species feed on infaunal and small epifaunal residents of the benthos (see Zenkevitch, 1963, for a discussion of the interaction of commercial species and the benthos). Any drastic changes in density of the food benthos could affect the health and numbers of these fisheries organisms.

Experience in pollution-prone areas of England (Smith, 1968), Scotland (Pearson, 1972), and California (Straughan, 1971) suggests that at the completion of an initial exploratory study, selected stations should be examined regularly on a long-term basis to determine any changes in species content, diversity, abundance, and biomass. Such long-term data acquisition could make it possible to differentiate between normal ecosystem variation and pollutant-induced biological alteration. An intensive investigation of the benthos of the Gulf is also essential to an understanding of the trophic interactions involved there and the potential changes that may take place once oil-related activities begin. The ongoing benthic biological program will continue to emphasize the development of a qualitative and quantitative inventory of prominent species of the benthos as part of the overall examination of the portions of the Gulf of Alaska shelf slated for oil exploration and drilling activity.

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[1] Extracted from: Feder, Howard M., and Mueller, George (1975): Environmental Assessment of the Northeastern Gulf of Alaska: Benthic Biology, First Year Final Report to the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Contract No. 03-5-022-34, Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 200 pp.

OBJECTIVES

Specific objectives during the first year were:

a. Qualitative and quantitative inventory and census of dominant species.

b. A description of spatial and seasonal distribution patterns of selected species.

c. Preliminary observations of biological interrelationships between selected segments of the benthic marine communities.

STUDY AREAS

A series of stations were occupied with a van Veen grab on a grid established in conjunction with the physical, chemical, hydrocarbon, and trace metal programs (Fig. 29). Thirty-six dispersed stations were sampled over seven transects extending from Resurrection Bay to Yakutat Bay, and typically extended from inshore (43 m) to a maximum depth of approximately 200 m. A few deep stations were occupied, generally by use of the Shipek Grab (Tables 57 and 58).

A large number of stations were occupied in conjunction with the resource assessment trawl survey that sampled a grid extending from the western tip of Montague Island to Yakutat Bay. This survey sampled to maximum depths of approximately 500 m (250 fathoms).

METHODS AND SOURCES OF DATA

Benthic infauna were collected on three cruises of the R/V *Acona* (July, October, and November 1974), one cruise of the NOAA Ship *Oceanographer* (February 1975), and one cruise on the NOAA Ship *Townsend Cromwell* (May 1975). To satisfy the objectives of the project, stations were selected over the entire study area; these stations were occupied whenever a vessel was available.

Samples were taken with a 0.1m^2 van Veen grab. A minimum number of samples, three replicates, were taken in July, October, and February cruises to increase the possibility of complete station coverage in the study area; the number of replicates was increased to 4-to-5 in the May cruise of the NOAA Ship *Townsend Cromwell*. Material from each grab was washed on a 1.0 mm stainless steel screen, preserved in 10 percent formalin buffered with hexamine, and stored in plastic bags.

This sample processing procedure precludes the study of benthic microorganisms less than 1.0 mm which may be important as indicator species. Future sampling will therefore include sub-sampling and grab samples for microorganisms prior to screening for macro-organisms.

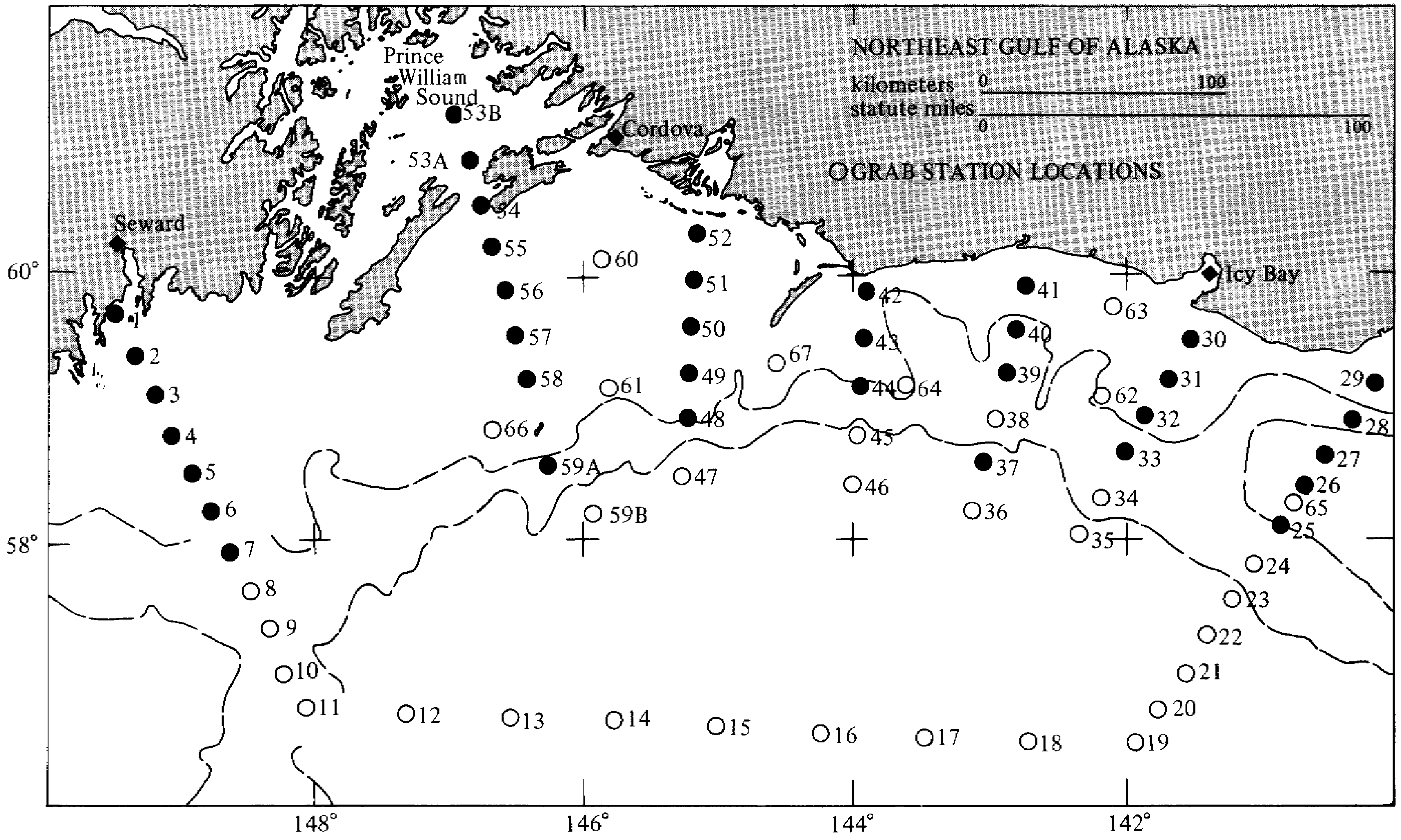

Figure 29. Station grid established for oceanographic investigations in the study area. Dark circles are stations occupied by a grab sampler, either van Veen or Shipek grab.

Table 57. Stations sampled during four cruises in the Gulf of Alaska 1974 - 1975.

GASS Station	Latitude (N)	Longitude (W)	Depth (m)	July	Oct.	Nov.	Feb*	May
				1974			1975	
1	59°50.2'	149°30.5'	263			X		
2	59°41.5'	149°22.0'	219					0
3	59°33.0'	149°13.2'	220	X				
4	59°24.5'	149°04.9'	200					0
5	59°16.0'	148°56.0'	174					0
6	59°07.2'	148°47.5'	151	X				
7	58°58.7'	148°38.7'	220					0
25	59°02.5'	140°49.8'	179					0
26	59°10.8'	140°38.9'	148	X				
27	59°18.6'	140°27.9'	129					0
28	59°26.5'	140°16.9'	239					0
29	59°34.6'	140°06.0'	68	X				
30	59°44.1'	141°27.9'	43	X				
31	59°35.2'	141°36.8'	117				X	
32	59°26.3'	141°45.0'	179	X				
33	59°17.5'	141°54.8'	219				X	
37	59°16.2'	142°59.2'	2,620				X	
39	59°35.7'	142°49.5'	549	X			X	
40	59°45.5'	142°44.5'	195				X	
41	59°55.1'	142°39.5'	119	X			X	
42	59°55.1'	143°51.2'	93	X			X	
43	59°45.0'	143°52.8'	117				X	
44	59°35.0'	143°54.2'	181	X			X	
48	59°27.5'	145°11.5'	117	X				
49	59°37.5'	145°10.0'	186				X	0
50	59°47.7'	145°09.0'	164	X	X			0
51	59°57.6'	145°07.8'	135				X	
52	60°07.6'	145°06.5'	53	X	X		X	
53b	----	----	384				X	0
53a	60°23.0'	146°54.0'	279				X	
54	60°13.9'	146°48.6'	204				X	
55	60°04.5'	146°42.6'	117	X			X	
56	59°55.2'	146°36.8'	64				X	
57	59°45.6'	146°31.0'	69		X		X	
58	59°36.2'	146°25.5'	97		X			
59	59°17.1'	146°14.0'	334	X				

X = sample analyzed
0 = sample collected but not analyzed
* All February samples have been analyzed, but not all were available for inclusion in this report.

Table 58. Gulf of Alaska stations sampled in 1974 - 1975 with a van Veen grab sampler.

			Number of replicates				
Transect (No.)	Station (No.)	Depth (m)	July	Oct.	Nov.	Feb.-Mar.	May
1	1	263			3?		
	2	219					5
	3	220	3				
	4	200					4
	5	174					4
	6	151	3				
	7	220					1
2	53b	279		3		2	
	53a	—				1*	1*
	54	204				3	
	55	117	3			4	
	56	64				4	
	57	69		3		3	
	58	97				4	
	59	334	1				
3	52	53	3	3		4	
	51	135				4	
	50	164	2	3		4	
	49	186				4	1*
	48	117	2				
4	42	93	3			2	
	43	117				3	
	44	181	3			1	
5	41	119	3			4	
	40	195				4	
	39	549	1			1*	
	37	2620				1*	
6	30	43	1			6	
	31	117				4	
	32	179	3			4	
	33	219				1	
7	29a	68	3				
	28	239				4	
	27	129				4	
	26	148	3			4	
	25	179				3	

*Shipek sampler

In the laboratory (Marine Sorting Center, University of Alaska, Fairbanks) all samples were rinsed to remove the last traces of sediment, spread on a gridded tray, covered with water, and rough-sorted by hand. The material was then transferred to fresh preservative (buffered 10 percent formalin) and identified. All organisms were counted and wet-weighed after excess moisture was removed with an absorbent towel.

Trawl material was collected with commercial gear on board the *M/V North Pacific*. All invertebrates of non-commercial importance were sorted out on shipboard, given tentative identifications, counted, weighed when time permitted, and aliquot samples of individual species preserved and labeled for final identification at the Marine Sorting Center. Counts and weights of commercially important invetebrate species were recorded by the National Marine Fisheries Service (NMFS) biologists, and the data were made available to the benthic invertebrate program. A selected series of fish species was collected or their stomachs removed and preserved; this material was given to Ronald Smith for further intensive analysis.

Criteria developed by Feder et al. (1973) to recognize Biologically Important Taxa (BIT) were applied to the data collected in the Gulf of Alaska. Each species was considered independently (items 1 and 2 below) as well as in combination with other benthic species (items 3 and 4 adopted from Ellis, 1969). Each taxon classified as BIT in this study met at least one of the four conditions.

1. It was distributed in 50 percent or more of the total stations sampled.
2. It was over 10 percent of either the composite population density or the biomass collected at any one station.
3. Its population density was significant at any given station. The significance was determined by the following procedure:
   a. A percentage was calculated for each taxon with the sum of the population density of all taxa equal to 100 percent.
   b. These percentages were than ranked in descending order.
   c. The percentages of the taxa were summed in descending order until a cut-off point of 50 percent was reached. The BIT were those taxa whose percentages were used to reach the 50 percent cut-off point. When the cut-off point of 50 percent was exceeded by the percentage of the last taxon added, this taxon was also included.
4. Its biomass was significant at any given station. This significance was determined by the following procedure:

a. A percentage was calculated for each taxon with the sum of all taxa equalling 100 percent.

b. These percentages were then ranked in descending order.

c. The percentages of the taxa were summed in descending order until a cut-off point of 50 percent was reached. The BIT were those taxa whose percentages were used to reach the 50 percent cut-off point. When the cut-off point of 50 percent was exceeded by the percentage of the last taxon added, this taxon was also included.

Species Diversity was examined by two Indexes of Diversity, as defined below, where

n_i = importance value for each species (number of individuals, biomass, production, etc.)
N = total of importance values
$p_i = n_i/N$ = importance probability for each species.

1. Shannon Index of General Diversity ($\overline{H}$):

$$\overline{H} = -\sum p_i \ln p_i$$

2. Simpson Index (C):

$$C = \sum \frac{n_i\left(n_i - 1\right)}{N(N - 1)}$$

These indexes were calculated for all stations sampled.

The Simpson index is an index of dominance, since the maximum value, 1, is obtained when there is a single species (complete dominance), and values approaching zero are obtained when there are numerous species, each a very small fraction of the total (no dominance). The Shannon index is an index of diversity, the higher the value, the greater the diversity and the less the community is dominated by one or a few kinds of species (see Odum, 1975, for further discussion and additional references).

All species taken by grab were coded according to the 10 digit VIMS system used for fauna collected in a benthic study in Chesapeake Bay (Swartz et al. 1972); coding was suitably modified to conform to species collected in the Gulf of Alaska.

RESULTS

Benthos Infaunal Grab Program

The basic plan of operation suggested in the initial proposal was completed with little alteration. Seven transects were occupied in conjunction with other programs (physical and chemical oceanography, trace metal, hydrocarbon, zooplankton), and 36 permanent stations were established and occupied for benthic work (Fig. 29; Tables 57 and 58). These 36 stations will represent the basic grid to be occupied for the balance of the study. A total of 57 stations (inclusive of repeated occupation of stations on the basic grid) was occupied on five separate cruiese (July-15 stations; October-4 stations; November-1 stations; February-21 stations; May-12 stations) using R/V *Acona* July, October, November 1974), NOAA Ships *Oceanographer* February 1975) and *Townsend Cromwell* (May 1975) (Tables 57 and 58). Although vessel time and weather constraints did not permit complete sampling of all stations on a seasonal basis, it was possible to accumulate data in two time blocks--July through November and February through May. Some overlap of stations occurred during these time blocks (Tables 57 and 58).

All of the station data from the July, October, and November cruises have been processed. Eight stations were available from the February cruise. The balance of the February stations and all of the May stations will be completely processed by the end of the next quarter.

Two hundred and nine species were isolated from the grab samples examined to date. Members of 12 marine phyla were collected, polychaetous annelids being the most important group with 90 species. Molluscs were next in importance with 51 species, and arthropod crustaceans next with 39 species. Echinoderms were fourth in significance with 13 species. Other groups were less important (Tables 59 and 60).

The two indexes, Simpson and Shannon, calculated for all species and summarized in Table 61, are included in the computer printout for all grab station data. In the Simpson Index, values approaching 0.2 are a reflection of the dominance in numbers of individuals of a few species (Stations 39 and 30); at both stations, the Shannon Index is relatively low, also reflecting the dominance by a few species. Shannon Index values up to 5 are found at stations with many species and no particular dominance of any one species (Stations 6 and 48).

Use of the criteria for Biologically Important Taxa has delineated 82 species for further consideration. The data used to determine the BIT were pooled from the cruises in July, October, November, and February. Twenty-

Table 59. *The invertebrate phyla collected by van Veen grab in the Gulf of Alaska July, October, November 1974, and February 1975.*

Phylum	Number of species	% of species
Annelida	90	43.1
Mollusca	51	24.4
Arthropoda (Crustacea)	39	18.7
Echinodermata	13	6.2
Priapulida	1	0.4
Sipunculida	2	0.9
Porifera	1+	0.4
Cnidaria	2+	0.9
Nemertea	1+	0.9
Bryozoa	3+	1.4
Brachiopoda	4	1.9
Chordata (Tunicata)	1	0.4
Unidentified	1+	0.4
Total	209+species	100.0%

+ indicates that species have not been determined, and the value shown is minimum.

Table 60. *Species of subgroups of mullusca, echinodermata, and crustacea collected by van Veen grab in the Gulf of Alaska.*

Phylum	Subgroup	Number of species	% of species
Mollusca	Pelecypoda (clams, scallops, cockles)	30	58.8
	Gastropoda (snails)	18	35.2
	Polyplacophora	1	2.0
	Scaphopoda (tooth shells)	1	2.0
	Aplacophora	1	2.0
	Total	51	100.0%
Arthropoda (Crustacea)	Amphipoda	17	43.6
	Cumacea	14	35.8
	Harpacticoida	1+	2.6
	Ostracoda	1+	2.6
	Thoracica (barnacle)	1	2.6
	Decapoda	2	5.1
	Isopoda	3	7.7
	Total	39	100.0%
Echinodermata	Ophiuroidea (brittle star)	8	61.5
	Asteroidea	1	7.7
	Holothuroidea	2	15.4
	Echinoidea	1	7.7
	Crinoidea	1	7.7
	Total	13	100.0%

+ indicates that species have not been determined, and the value shown is minimum.

Table 61. Simpson and Shannon Diversity Indexes for Benthic Stations in the Gulf of Alaska.

Station	Sample Date	Simpson	Shannon
1	July	0.105	3.108
3	July	0.061	3.978
6	July	0.031	5.46
26	July	0.039	4.93
29	July	0.238	3.127
30	July	0.208	2.895
32	July	0.033	4.797
37	July	0.044	2.921
39	July	0.197	2.646
39	Feb.	0.044	2.921
41	July	0.127	3.621
42	July	0.136	3.611
42	Feb.	0.122	3.608
43	Feb.	0.092	3.621
44	July	0.07	5.113
44	Feb.	0.076	3.221
48	July	0.033	5.275
49	Feb.	0.065	4.566
50	July	0.040	4.423
50	Oct.	0.058	4.406
51	Feb.	0.071	3.971
52	July	0.126	3.758
52	Oct.	0.085	4.245
53	Oct.	0.105	4.028
55	July	0.091	4.165
55	Feb.	0.057	4.252
57	Oct.	0.047	5.178
59	July	0.166	2.681

seven of the BIT were identifiable as important by way of biomass at one or more stations. Some of the latter species were well distributed throughout the study area: the clams *Axinopside serricata, Nucula tenuis, Nuculana pernula;* the polychaete *Sternaspis scutata;* the echinoderms *Ctenodiscus crispatus, Ophiura sarsi,* and *Molpadia* sp. These species may be ones with great influence on the trophic interactions in their particular localities and will be followed carefully in succeeding years.

Trawl Program

Forty-three species of fishes and 79 species of invertebrates have been tentatively identified from the trawl samples. Members of eight phyla were collected with Arthropoda (Crustacea) representing the most important group with 25 species. Echinoderms were next with 24 species. Mollusca were next with 19 species. Of the crustaceans, the Decapoda were the most common (24 species). In the Echinodermata, the Asteriodea was the dominant group collected (11 species). The Gastropoda represented the major group of Mollusca collected (10 species) (Tables 62 and 63).

Although decapods were a considerable proportion of the biomass of many of the trawl samples (e.g., *Chionoecetes bairdi and Lopholithodes foraminatus*--the box crab), echinoderms also consistently made up an important segment of the invertebrates of many of the trawls (e.g., the sea stars *Ctenodiscus crispatus*--up to 36 kg, *Pycnopodia helianthoides*--22 kg; *Gorgonocephalus,* the basket star--up to 6.8 kg; *Brisaster,* the heart urchin--up to 6.8 kg per trawl).

DISCUSSION AND SYNTHESIS

Station Coverage

The intensive grab-sampling program now in progress over the shelf from Yakutat Bay to Resurrection Bay is the most comprehensive one carried out by an American research group to date. Results of a somewhat parallel study by the Soviet Union, extending from the southern end of the Kenai Peninsula to Cape Spencer, are available from an earlier period for comparison (Semenov, 1965). Although the Soviet study is broad, the bases for Seminov's calculations (i.e., the station data--number of replicate samples per station, the species taken per replicate, the number of individuals of each species per replicate) are lacking. Thus, precise quantitative comparisons are not possible. Analysis of Semenov's study (1965) and other published work from the Gulf of Alaska will be available at the end of the next study year (Feder, 1975).

Table 62. *The Invertebrate Phyla of each Phylum Collected by Commercial Trawl in the Gulf of Alaska (May-August 1975).*[1]

Phylum	Number of species	% of species
Arthropoda (Crustacea)	25	31.6
Echinodermata	24	30.4
Mollusca	19	24.0
Coelenterta	4	5.1
Annelida	2	2.5
Brachiopoda	3	3.8
Bryozoa	1	1.3
Porifera	1	1.3
Total	79	100.0%

[1] All identifications are tentative.

Table 63. *Species of Subgroups of Arthropoda (Crustacea), Echinodermata, and Mollusca Collected by Commercial Trawl in the Gulf of Alaska (May-August 1975).*[1]

Phylum	Subgroup	Number of species	% of species
Arthropoda	Decapoda (crabs, shrimps)	24	96.0
	Isopoda	1	4.0
	Total	25	100.0%
Echinodermata	Asteroidea (sea stars)	11	47.8
	Echinoidia (sea urchins)	4	17.4
	Ophiuroidea (brittle star)	4	17.4
	Holothuroidea (sea cucumber)	3	13.0
	Crinoidea (feather stars)	1	4.4
	Total	23	100.0%
Mollusca	Gastropoda	10	52.6
	Pelecypoda	8	42.1
	Cephalopoda	1	5.3
	Total	19	100.0%

[1] All identifications are tentative.

The trawl program permitted further coverage of the lease area and made it possible to collect the more motile, as well as the larger, epifaunal species. Thus, the integrated trawl program (demersal fish, benthos invertebrates, fish stomach analysis, meristic analysis of fish species, trace metal and hydrocarbon studies) represented a significant supplement to the data collected in the first year.

Species Composition of the Stations

The general distribution of benthic species in the projected lease area is now well documented (present investigation and Semenov, 1965), and members of the major marine phyla were collected in both investigations. Polychaetous annelids were the most important infaunal group collected (Table 59); similar results are also reported for Port Valdez on Prince William Sound, an embayment of the Gulf of Alaska with similar fine sediments in its fiords and bays (Feder et al. 1973). The crustaceans and echinoderms were the major epifaunal invertebrate groups taken by trawl in this investigation. A variety of infaunal groups contribute to the biomass at stations sampled by grab. Sizable biomasses of echinoderms, especially sea stars, were typical of most of the trawl station samples, and many of the species were abundant enough to present suitable organisms for in-depth biological investigations. Availability of sufficient numbers of the latter types of organisms is a preliminary requirement for development of satisfactory monitoring schemes and acquisition of suitable predictive capabilities for stressed benthic systems.

Qualitative examination of the species composition at various grab stations suggests distinct regional differences in species and biomass. However, widely dispersed or ubiquitous species are also apparent. Perhaps one of the obvious features of most stations is the patchiness of the infauna. Examination of infaunal species composition at stations occupied in separate sampling dated (e.g., Stations 42, 44, 50, 52, 55) indicates species common to each series of grabs, but also demonstrates omissions or additions of certain species on the two dates. Some of this patchiness of station variance will be damped out with more intensive sampling at each station. In addition, presence of species aggregates is essential to clarify station differences; such an approach will be pursued in the comming year (Feder et al. 1973, for use of a cluster analysis technique to delineate groups of benthic species in Port Valdez).

Feeding Methods

Initial information presented for the feeding methods used by the majority of the infaunal species collected comes basically from a literature compilation, but some unpublished data are included as well (Table 64). Most of the food data are based on extrapolations from literature for related species, or the same species from other areas, emphasizing the paucity of data on the feeding biology of Gulf fauna. This lack of basic data also dictates the urgency of immediate support for experimental work on selected species from the benthos and elsewhere in the waters of the Gulf.

Some further insights into feeding biology will also be gleaned from food analyses to be performed on collected and presently archived material. Particular attention will be paid to brittle stars and sea stars, two taxa occurring in great density in some areas.

CONCLUSIONS

Thirty-six widely dispersed stations have been established in conjunction with the physical, chemical, heavy metals, and hydrocarbon programs. These stations represent a nucleus around which a monitoring program could be developed.

General patchiness of many components of the fauna suggests that at least five replicates should be taken per station. Quantitative field testing for the optimum number of replicates per station is indicated for the coming year.

There is now satisfactory information on a station basis for invertebrate species present (infauna and epifauna) and general species distribution on the shelf in the least area. Two-hundred and nine species have been identified to date. It is probable that all species with numerical biomass importance have been collected over the past sampling year and that only rare species will be added to the list in the coming years of sampling.

The joint National Marine Fisheries Service trawl charter for investigation of demersal fishes and epifauna benthos was effective and maximum spatial coverage was achieved. Integration of this information with the infaunal benthic data will enhance the understanding of the shelf ecosystem. Information on invertebrate and demersal fish food habits, by way of stomach analysis of material collected on the trawl charter, will represent the first basic data available for understanding benthic trophic interactions in the Gulf.

Table 64. *Feeding Methods Used by Selected Invertebrate Species Collected from the Benthic Stations in the Gulf of Alaska 1974-75.*

Taxon	Species Code	DF	SF	S	P	E
Cnidaria	3303					
Leioptilus guerneyi	33030101		X			
Acanthoptilium ptile	3303		X			
Annelida	--					
Polychaeta	4801					
Sabellidae	480168					
Megalomma splendida	4801680401		X			
Maldanidae	480191					
Asychis similis	4801610102	X				
Ampharetidae	480165					
Melinna cristata	4801650501	X				
Lubrineridae	480130					
Lumbrineris similabris	4801300105	X				
Onuphidae	480128					
Onuphis geophiliformis	4801280102	X				
Eunicidae	480129					
Eunice kobiensis	4801290102	X				
Capitellidae	480158					
Heteromastus filiformis	4801580201	X				
Sternaspidae	480157					
Sternaspis scutata	4801570102	X				
Sipunculida	5901					
Golfingia margaritacea	5901010101	X				
Mollusca	---					
Pelecypoda	4904					
Axinopsida serricata	4904150201		X			
Thyasira flexuosa	4904150301		X			
Nuculana pernula	4904030201	X	X			
Nuculana minuta	4904030202	X	X			
Nucula tenuis	4904020201	X	X			
Macoma calcarea	4904240101	X	X			
Psephidia lordi	4904210501		X			
Crenella dessucata	4904070201		X			
Yoldia sp.	49040305	X	X			
Portlandia arctica	4904030511	X	X			
Yoldia scissurata	4904030504	X	X			
Cyclopecten randolphi	4904080201		X			
Cardiomya pectenata	4904370101		X			
Cyclocardia ventricosa	4904120101		X			
Musculus discors	4904070402		X			
Astarte montagui	4904110103		X			
Astarte polaris	4904110104		X			
Siliqua media	4904270104		X			

Table 64. *Feeding methods used by selected invertebrate species collected from the benthic stations in the Gulf of Alaska 1974-75. (Continued)*

Taxon	Species Code	DF	SF	S	P	E
Gastropoda	4905					
Lepeta caeca	4905050201			X?		
Aplacophora						
Chaetoderma robusta	490103101	X			X	
Scaphopoda	4906					
Dentalium sp.	49060101	X			X	
Arthropoda	---					
Crustacea	53					
Amphipoda	5331					
Harpiniopsis sandpedroensis	5331420201			X		
Byblis crassicornis	5331020301			X		
Ericthonius hunteri	5331150101			X		
Cumacea	5328					
Eudorella emarginata	5328040201	X				
Eudorellopsis integra	5328040301	X				
Isopoda	5330					
Gnathia sp.	533001					X
Decapoda	5333					
Paguridae	533303					
Pagurus hirsutiusculus	5333030213			X		
Majiidae	533309					
Chionoecetes bairdi	5333090302			X	X	
Bryozoa	66					
Microporina borealis	660207		X			
Clavopora occidentalis	660301		X			
Brachiopoda	67					
Terebratulina unguicula	6702030101		X			
Terebratulina spindent	6702030104		X			
Echinodermata	68					
Asteroidea	6801					
Ctenodiscus crispatus	6801060101	X				
Ophiuroidea	6803					
Ophiura sarsi	6803090611				X	
Unioplus macraspis	6803020301	X				
Ophiopenia disacantha	6803090501	X				
Echinoidea	6802					
Brisaster townsendi	6802030101	X				
Holothuroidea	6804					
Molpadia sp.	68040701	X				

DF=Deposit Feeder. SF=Suspension Feeder. S=Scavenger. P=Predator. E=Ectoparasite.
Data Sources are Feder *et al.* (1973) and unpublished observations.

Criteria established for Biologically Important Taxa (BIT) have delineated 82 species. These species will be ranked, and most of those of high rank will be subjected to detailed analysis in an attempt to comprehend station species aggregations or communities.

Initial qualitative assessment of data printouts indicated that (1) sufficient station uniqueness exists to permit development of an adequate monitoring program based on species composition at selected stations, and (2) adequate numbers of unique, abundant and/or large species are available to permit ultimate nomination of likely monitoring candidates.

IMPLICATIONS RELATED TO ENVIRONMENTAL ASSESSMENT OF OCS PETROLEUM DEVELOPMENT ACTIVITIES

The effects of oil pollution on subtidal benthic organisms have been seriously neglected, although a few studies, conducted after serious oil spills, have been published (see Boesch *et al.* 1974, for review of these papers). Thus, lack of a broad data base elsewhere makes it difficult at present to predict the effects of oil-related activity on the subtidal benthos of the Gulf of Alaska. However, the rapid expansion of research activities on the Gulf should eventually enable us to point with some confidence at certain species or areas that might bear closer scrutiny once industrial activity becomes a reality. It must be emphasized that a considerably large time frame is needed to understand long-term fluctuations in density of marine benthic species, and it cannot be expected that a short-term research program will result in total predictive capabilities. Assessment of the environment must be conducted on a continuing long-term basis.

As indicated previously, infaunal benthic organisms tend to remain in place and consequently have been useful as an indicator species for disturbed areas. Thus, close examination of stations in the Gulf with substantial complements of infaunal species is warranted. Changes in the environment at these and other stations with relatively large numbers of species might be reflected in a decrease in diversity of species with increased dominance of a few (see Nelson-Smith, 1973, for further discussion of oil-related changes in diversity.) Similarly, stations with substantial numbers of epifaunal species should be assessed on a continuing basis. The potential effects of loss of species to the overall trophic structure in the Gulf cannot be assessed at this time, but the problem can probably at least be addressed in the coming year once benthic food studies are initiated.

Data indicating the effects of oils on most subtidal benthic invertebrates are fragmentary, but echinoderms are "notoriously sensitive to any reduction in water quality" (Nelson-Smith, 1973). Echinoderms (ophiuroids, asteroids, and holothuroids) are conspicuous members of the benthos of the Gulf and could be affected by oil activities there. Asteroids (sea stars) and ophiuroids (brittle stars) are often important components of the diet of demersal fishes and large crabs (for example, king crab feed on sea stars). The tanner or snow crab (*Chionoecetes bairdi*) is a conspicuous member of the shallow shelf of the Gulf and its quantity supports a commercial fishery of considerable importance there. Laboratory experiments with this species have shown that postmolt individuals lose most of their legs after exposure to Prudhoe Bay crude oil. Obviously this aspect of the biology of the snow crab must be considered in the continuing assessment of this benthos species in the Gulf (J. Karinen and S. Rice, in press: cited in Evans and Rice, 1974). Little other direct data based on laboratory experiments are available for subtidal benthic species (see Nelson-Smith, 1973). Experimentation on toxic effects of oil on other common members of the subtidal benthos is strongly recommended for the near future in the overall OCS program.

Rhoads (1974) demonstrated direct relationship between trophic structure (feeding type) and bottom stability from a diesel fuel-oil spill that resulted in absorption of oil on sediment particles with resultant mortality of many deposit feeders living on sublittoral muds. Bottom stability was altered with the death of these organisms, and a new complex of species became established in the altered substratum. The most common members of the infauna of the Gulf of Alaska are deposit feeders; thus, oil-related mortality of these species could result in a changed near-bottom sedimentary regime with alteration of species.

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7. ZOOPLANKTON

INTRODUCTION

The primary goal of this study is to develop a quantitative and predictive understanding of the stability, productivity, and ecological importance of zooplankton and micronekton in the northern Gulf of Alaska. Seasonal density distribution and environmental requirements of principal species will be determined along with the identification and characterization of critical regions and habitats required by eggs and larvae of fish and shellfish. Field investigations will be keyed to critical periods of blooms and spawning while simultaneously obtaining data on circulation patterns. Existing and unpublished data on transfer of synthesized organic matter to zooplankton, micronekton, and ichthyoplankton will be summarized.

Status of Knowledge

Cooney (1972) reviewed the biological oceanography of the northern Gulf of Alaska and summarized the information describing zooplankton and micronekton. Almost no observations were available for the region of the shelf now scheduled for petroleum development. This area is notoriously weather restricted, and aside from one halibut investigation the area has received little routine survey attention. Through 1956 to 1964, the Pacific Oceanographic Group, Nanaimo, B.C., collected over 5,000 vertical tow samples from the upper 150 m north of 45°N. latitude and east of 160°W. longitude. The results of this effort were published as a zooplankton biomass atlas (LeBrasseur, 1959a).

During the same period, animal plankton were also collected routinely from the Canadian weatherships occupying station *Papa* in the southern Gulf of Alaska. LeBrasseur (1956b) and McAllister 1961) described this material in detail, providing seasonal and vertical distributions for many of the dominant pelagic organisms. However, station *Papa* is located well offshore (50°N, 145°W), approximately 600 nautical miles (nmi) south of the proposed lease area.

OBJECTIVES

Before an accurate description of the occurrence and abundance of animal plankton populations is possible, the major sources of variation must be

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[1] Extracted from: Cooney, R. Ted (1975): Environmental Assessment of the Northeastern Gulf of Alaska: Zooplankton and Micronekton, First Year Final Report to the Natl. Oceanic and Atmospheric Admin., U.S. Dept. of Commerce, Contract No. 03-5-022-36, Inst. of Marine Sci. Univ. of Alaska, Fairbanks, Ak. 159 pp.

identified. In most temperate oceans, there is a strong seasonal component of variability that is usually associated with differences between the biologically active and inactive times of the year. Also, in the pelagic community, both horizontal and vertical patchiness is pronounced on a variety of spatial scales; large-scale distributions and temporal fluctuations often reflect local physical advective processes. The resulting non-random patterns of abundance and seasonal fluctuations hinder attempts to describe these populations in time and space; only in a strictly statistical sense can patterns be objectively interpreted.

Research conducted the first year of this study addressed the problem of identifying some of the important sources of variability influencing zooplankton and micronekton populations in the northern Gulf shelf area. The objectives were:

1. To inventory and census the numerically dominant or otherwise obvious species;
2. To describe spatial and seasonal distributions;
3. To examine relationships to hydrographic and biochemical parameters.

METHODS AND SOURCES OF DATA

Samples were gathered at selected locations on the grid of stations occupied for physical oceanographic measurements (Fig. 30). Since there was initial concern regarding the possible success of collecting efforts, particularly during the late fall, winter, and early spring, attention was focused on the problem of assessing spatial heterogeniety between subareas ranging from nearshore to deep water. Because several cruises were scheduled through the year, seasonality was also examined in a general rather than specific way.

Accordingly, the study area was divided into four regimes: 1) the nearshore (stations at the landward terminus of cross-shelf transects); 2) the shelf (stations along transects extending to the shelf break at 200 m depth); 3) the slope (stations located over depths between 200 m and 2000 m); and 4) the open ocean (stations on the outermost traverse of the area or depths over 2000 m).

The sampling strategy called for at least five observations in each of these regimes on individual cruises. In reality, weather restrictions and/or cruise modifications caused the number of samples to vary and the design quickly became unbalanced (i.e., only one open ocean location was occupied between September 1974 and March 1975).

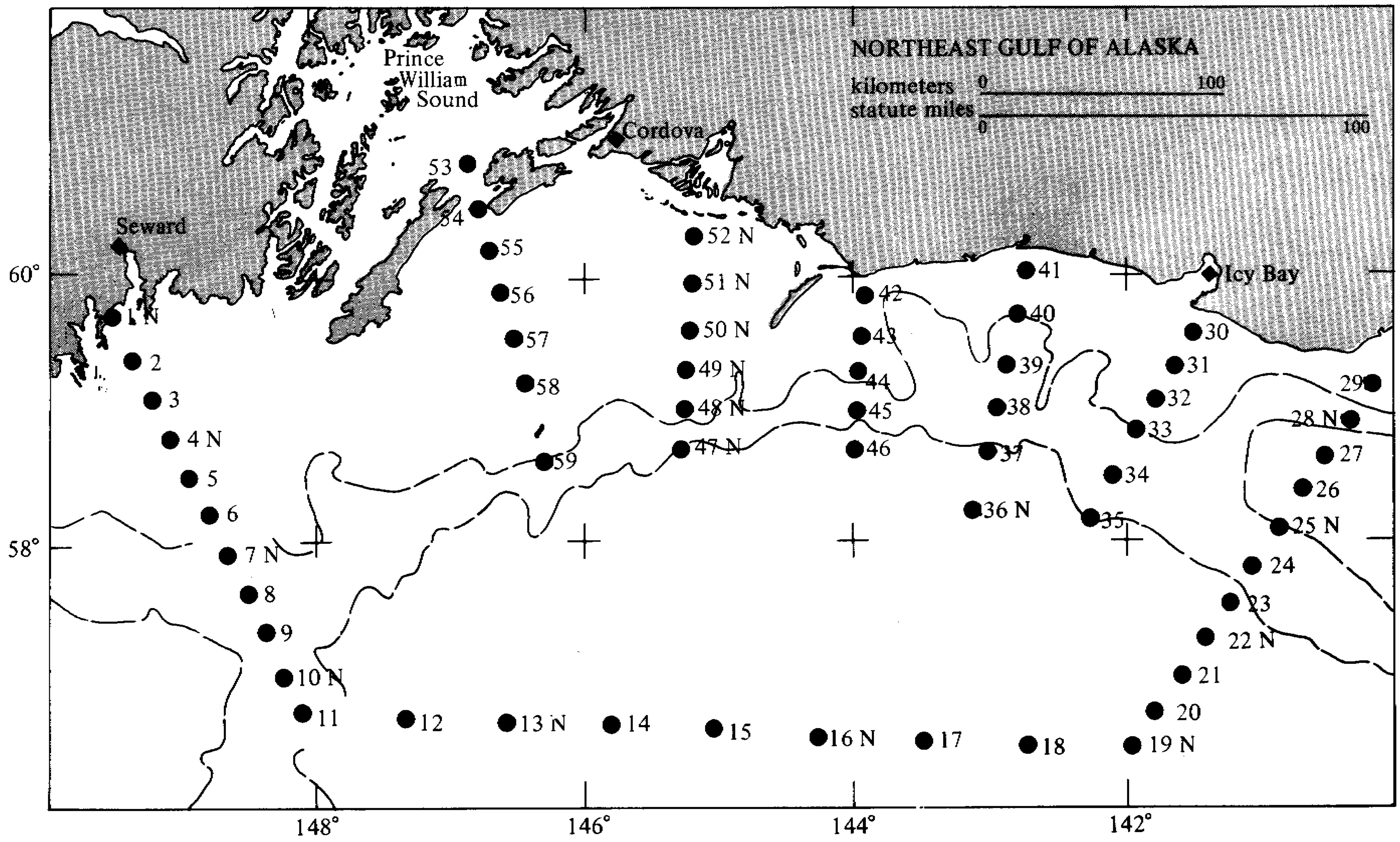

Figure 30. The locations of hydrographic stations defining the northern Gulf of Alaska study area.

Zooplankton was sampled with 1 m nets (0.333 mm Nitex) fished vertically between the seabed and the surface over the shelf, and in the upper 500 m in the slope and open ocean regimes.

The equipment and mode of operation were chosen to enhance the probability of success in gathering samples from several different vessels and sea conditions, and also to compare the results with previous studies. Since the large Canadian investigations employed vertically towed ring nets (NORPAC design; Motoda _et al._ 1957) it seemed reasonable to adopt this procedure.

The vertical tow is an accepted and documented method for quantitatively sampling zooplankton. Its advantages are simplicity of field sampling and accuracy of collecting populations through an entire water column. A one meter diameter zooplankton net lowered to depth and raised vertically at slow speed will capture all zooplankton except highly mobile forms capable of net-avoidance. If the net can be raised vertically between the seabed and the surface (as it was over the shelf) then regardless of where the animals are in the water column, they can be captured. Time of day (daylight or darkness) was not considered important in this initial study, although it was recognized that diel avoidance behavior might change the observed variability when both day and night observations were grouped in regimes.

The disadvantages of the vertical tow are associated with the question of how representatively it samples the population in terms of the quantity or organisms collected at any depth. A 1-m net raised from 100 m to the surface filters, at most, about 80 m^3 of water. This means that organisms scarcer than 1 per 80 m^3 will generally not be present in samples (i.e., a zero score for abundance translates fairly to "undetectable" at the volume filtered). Since most of the plankters often occur as hundreds per m^3, this objection seems minor. A vertical tow is seldom absolutely vertical, particularly if the vessel is drifting; this causes different and unknown volumes to be filtered, unless a flow-meter is employed. Finally, a vertical haul properly executed integrates very little horizontal patchiness, often resulting in quite high variability between replicate observations taken only a few minutes apart at the same location. Zooplankton populations differ by orders of magnitude, vertically and horizontally, at any given time. A plankton tow may or may not pass through a "patch" of plankton; so to adequately demonstrate changes in population size a number of short time-space replicate tows or a long integrated tow is required.

The larger more active animals (euphausiids, pelagic shrimp, and small fishes) were collected at night with a modified 2-m Tucker trawl (3.0 mm-knotless nylon) fished obliquely or horizontally at about 2 m/sec in the upper 100 m (a few tows were deeper). A time-depth recorder checked the maximum depth fished, and a flow-meter measured the volume filtered for the May 1975 cruise. In a 20 to 30 minute tow, several hundred cubic meters of water are sampled with this trawl. The nighttime trawling took advantage of the nightly concentration of midwater animals that migrate up into the nearsurface waters from depth each day.

To be interpreted objectively, field collections must be analyzed statistically for variability. Sampling error was measured by replicating observations at some of the locations. This describes how precisely any location can be censused with the method being employed. The variability within spatial regimes was similarly evaluated by analysis of variance techniques, which were also used to test the significance of differences observed between regimes and times of the year (cruises).

Samples were sorted, identified, and counted in the Marine Sorting Center, University of Alaska, Fairbanks. Most collections contained thousands of animals and thus were subsampled. The large and obvious organisms were counted first, and then smaller portions were used to count the more common plankters. Copepods and similar sized animals were counted in subsamples obtained with a volumetric pipette from a known volume of total sample; 150 and 200 organisms were usually counted. Large collections from the Tucker trawl were subsampled using a mechanical splitter described by Cooney (1971). This device performs a binary (i.e., one-half to one-fourth, one-fourth to one-eighth, etc.) division of samples with high precision. Again, at least 100 animals were counted in subsamples.

Subsampling introduces additional variability to a data set, while also reducing the probability of finding the less abundant organisms. However, in terms of error, the problem of subsampling catches is minor compared with that of sampling the ocean. The inability to census the rarer animals adequately is offset by the gain in precision afforded by processing more samples for the dominant members of the community.

RESULTS

A total of 74 stations were occupied for animal plankton sampling on cruises conducted in July, October, and November 1974; and February, March, and May 1975. In addition, the Tucker midwater trawl was fished on 33 stations in July and October 1974, and February and May 1975.

The Zooplankton and Micronekton Community

In all, 181 taxonomic groups were sorted from the 1-m net samples, and 99 from the Tucker trawl collections. This inventory is similar to that reported for the open Gulf of Alaska (LeBrasseur, 1959a; Brodskii, 1967), and for Alaska inshore waters (Cooney et al. 1973; Wing and Reid, 1972). The net-plankton (0.333 mm) was dominated by copepods (53 categories, 31 general), while fishes (20 categories, 17 general) were the most diverse group in the 2-m trawl samples.

Statistical Studies

The variance structure for spatial and temporal phenomena was examined for 21 categories, arbitrarily selected from the 1-m net samples; the group included most of the numerically dominant organisms, as well as those known to be indicators of water mass properties.

Analyses of variance techniques were used to evaluate spatial differences observed on the three most successful cruises, July 1974, and February and May 1975. A logarithmic transformation was applied to sample counts expressed as numbers of organisms under a unit area of sea surface. This transformation is appropriate for data of this kind using the analysis of variance (English, 1961). A regime effect was found to be significant ($P<0.05$) for 14 of the 21 groups. The effect of cruise (season) was discernible in 12 cases, and an interaction of these main effects is apparent for three of the organisms (Table 65). Distribution patterns by regime and month were plotted for 17 zooplankters to show abundance trends. Examples for one species of arrow-worm and two species of copepods are given in Figs. 31 to 33.

As with any censusing scheme, the ability to detect differences between sample sets depends upon the magnitude of the variability between measurements within the sets and the number of observations obtained in each. The sampling precision of the various regimes was determined by calculating confidence limits ($P=0.05$) for the geometric mean abundance of specific organisms taken within these sub-areas on these three cruises (Table 66). For an average of four observations per regime, these statistical limits range from 21.8 to 2.5. This information indicates that for *Metridia okhotensis*,

Table 65. *Analysis of Variance for Cruises and Spatial Regimes in the Northern Gulf of Alaska*

			Source of Variation			
Taxonomic Category	Cruise		Regime		Interaction	
	F[1]	df	F	df	F	df
Phylum Cnidaria						
Aglantha digitale	NS	2,3	**	3,6	NS	6,38
Phylum Chaetognatha						
Eukrohnia hamata	**	2,3	**	3,6	NS	6,38
Sagitta elegans	NS	2,3	*	3,6	NS	6,38
Phylum Arthropoda						
Acartia longiremis	**	2,3	**	3,6	NS	6,38
Calanus cristatus	**	2,3	**	3,6	NS	6,38
C. pacificus	NS	2,3	**	3,6	NS	6,38
C. plumchrus	**	2,3	**	3,6	*	6,38
Eucalonus b. bungii	**	2,3	**	3,6	NS	6,38
Metridia lucens	**	2,3	NS	3,6	NS	6,38
M. okhotensis	NS	2,3	NS	3,6	NS	6,38
Oithona similis	**	2,3	*	2,6	NS	6,38
O. spinirostris	*	2,3	NS	3,6	NS	6,38
Pseudocalanus spp.	**	2,3	**	3,6	**	6,38
Cyphocaris challengeri	NS	2,3	NS	3,6	NS	6,38
Parathemisto libellula	NS	2,3	NS	3,6	NS	6,38
P. pacifica	NS	2,3	**	3,6	NS	6,38
Euphausia pacifica	*	2,3	**	2,6	NS	6,38
Thysanoessa longipes	NS	2,3	**	3,6	NS	6,38
Euphausiid larvae	**	2,3	NS	3,6	*	6,38
Oregoniinae larvae	**	2,3	**	3,6	NS	6,38
Phylum Chordata						
Oikopleura spp.	NS	2,3	NS	3,6	NS	6,38

1. NS = $P \geq 0.05$
* = $P \leq 0.05$;
** = $P \leq 0.01$;
NS = not significant.

Table 66. *Sampling Precision Using 95-Percent Criteria for 1-m Net Observations in Regimes; Computed for n=1 through n=10*

Taxonomic Category	Observations per Regime									
	1	2	3	4*	5	6	7	8	9	10
Phylum Cnidaria										
Aglantha digitale	8.2	4.4	3.4	2.9	2.6	2.4	2.2	2.1	2.0	1.9
Phylum Chaetognatha										
Eukrohnia hamata	29.8	11.0	7.1	5.5	4.5	4.0	3.6	3.3	3.1	2.9
Sagitta elegans	8.4	4.5	3.4	2.9	2.6	2.4	2.2	2.1	2.0	2.0
Phylum Arthropoda										
Acartia longiremis	50.3	15.9	9.6	7.1	5.8	4.9	4.4	4.0	3.7	3.5
Calanus cristatus	16.2	7.2	5.0	4.0	3.5	3.1	2.9	2.7	2.5	2.4
C. pacificus	109.3	27.6	15.0	10.5	8.2	6.8	5.9	5.3	4.8	4.4
C. plumchrus	58.0	17.7	10.4	7.6	6.1	5.2	4.6	4.2	3.9	3.6
Eucalanus b. bungii	66.5	19.5	11.3	8.2	6.5	5.5	4.9	4.4	4.1	3.8
Metridia lucens	9.1	4.8	3.6	3.0	2.7	2.5	2.3	2.2	2.1	2.0
M. okhotensis	475.1	78.2	35.1	21.8	15.7	12.4	10.3	8.8	7.8	7.0
Oithona similis	145.6	33.8	17.7	12.1	9.3	7.6	6.6	5.8	5.2	4.8
O. spinirostris	120.6	29.6	15.9	10.9	8.5	7.1	6.1	5.4	4.9	4.6
Pseudocalanus spp.	7.2	4.0	3.1	2.7	2.4	2.2	2.1	2.0	1.9	1.9
Cyphocaris challengeri	11.3	5.6	4.1	3.4	2.9	2.7	2.5	2.4	2.2	2.2
Parathemisto libellala	14.8	6.7	4.7	3.8	3.3	3.0	2.8	2.6	2.5	2.3
P. pacifica	24.0	9.5	6.3	4.9	4.1	3.7	3.3	3.1	2.9	2.7
Euphausia pacifica	6.0	3.6	2.8	2.5	2.2	2.1	2.0	1.9	1.8	1.8
Thysanoessa longipes	12.4	5.9	4.3	3.5	3.1	2.8	2.6	2.4	2.3	2.2
Euphausiid larvae	157.5	35.8	18.6	12.6	9.6	7.9	6.8	6.0	5.4	5.0
Oregoniinae larvae	10.8	5.4	4.0	3.3	2.9	2.7	2.5	2.3	2.2	2.1
Phylum Chordata										
Oikopleura spp.	29.9	11.1	7.1	5.5	4.6	4.0	3.6	3.3	3.1	2.9

* Average number of observations for all cruises and regimes; range, 1 to 9

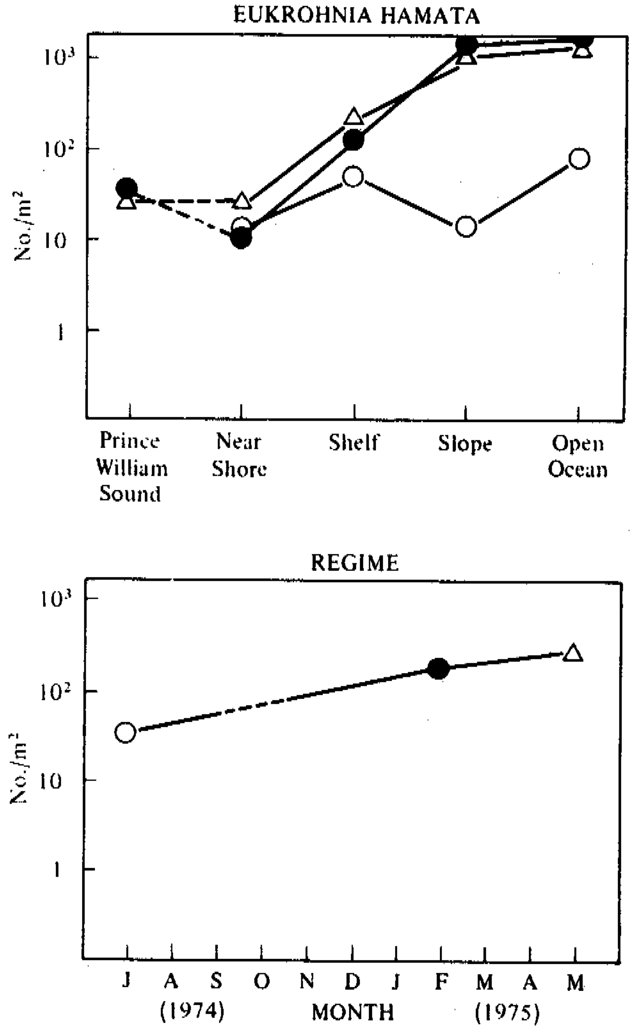

Figure 31. The average abundance of the arrow worm Eukrohnia hamata. *Open circles are the July 1974 observations; darkened circles, the February 1975 information; and triangles the May 1975 data. Counts from single samples are plotted for one station (53) inside Prince William Sound.*

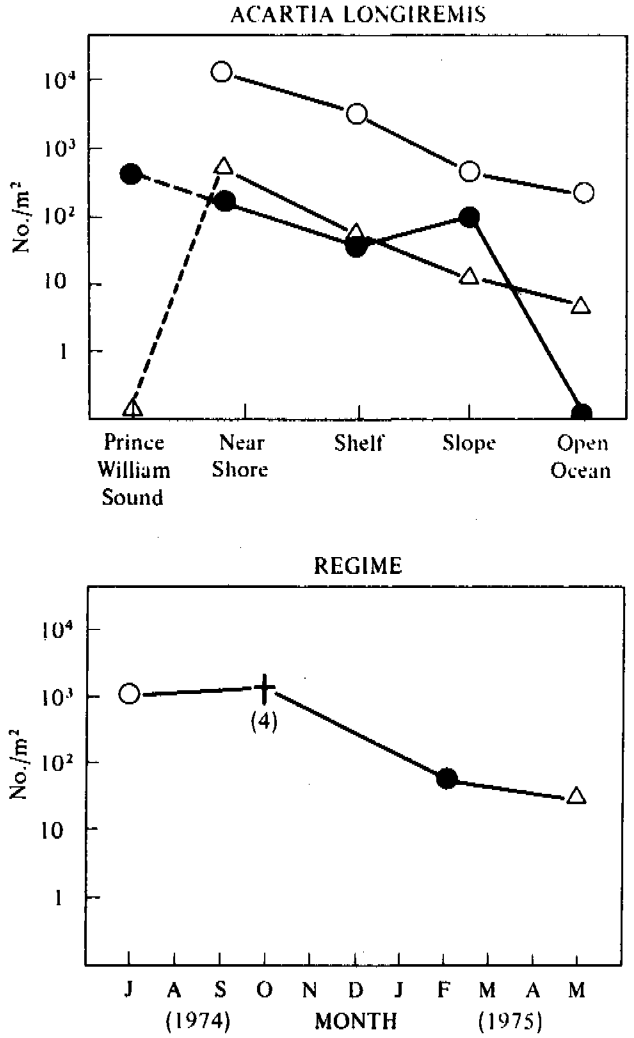

Figure 32. *The average abundance of the copepod Acartia longiremis. Open circles, are the July 1974 observations; darkened circles, the February 1975 information; and triangles the May 1975 data. Counts from single samples are plotted for one station (53) inside Prince William Sound. The cross indicates standing stock calculated from four samples available in October 1974.*

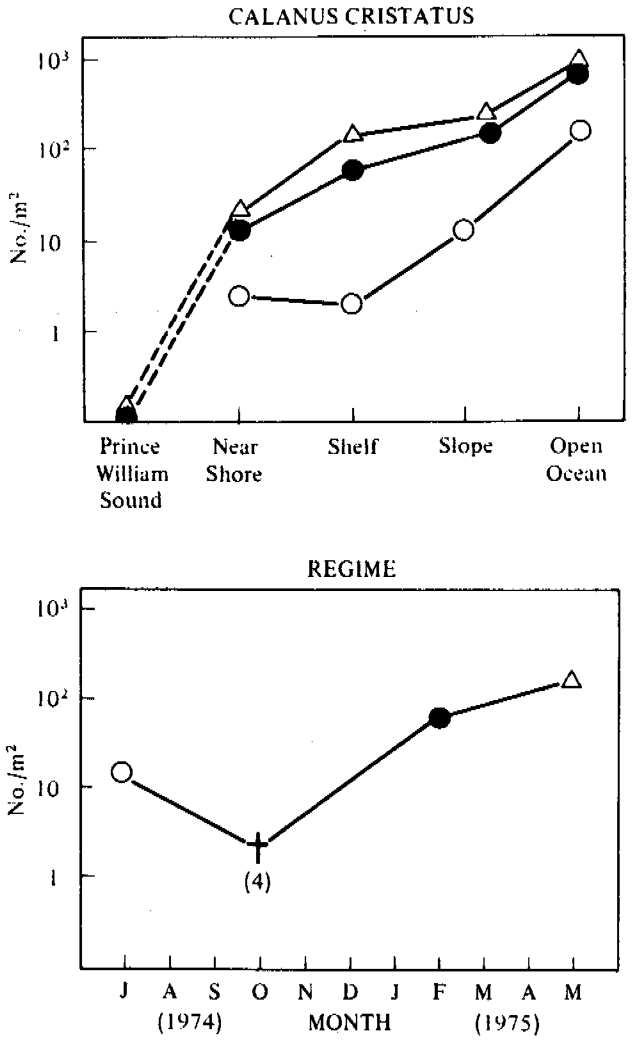

Figure 33. *The average abundance of the copepod Calanus cristatus. Open circles are the July 1974 observations; darkened circles, the February 1975 information; and triangles the May 1975 data. Counts from single samples are plotted for one station (53) inside Prince William Sound. The cross indicates standing stock calculated from four samples available in October 1974.*

differences between sub-areas and cruises of less than a factor of about 22 are not discernible at $P=0.05$; whereas, differences of only 2.5 are significant for *Euphausia pacifica*.

The sampling precision of any particular station was similarly determined using a small set of duplicate tows obtained on February and May cruises. The within-station variability was used to compute confidence limits ($P=0.05$) for single and multiple observations at any given location (Table 67). For comparison; these limits are listed with those associated with sampling a regime. Except for *Calanus plumchrus* (at low and spotty abundance during the winter), for the same numbers of observations individual locations can be sampled with much less variability than can regimes.

Table 67. *Sampling Precision for 1-m Net Observations Measured by Replication at Locations in Regimes, and Between Locations in Regimes, $\underline{P}=0.05$*

Taxonomic Category	Number of Observations					
	Locations			Regimes		
	1	5	10	1	5	10
Phylum Chaetognatha						
Eukronia hamata	2.5	1.5	1.3	29.8	4.5	2.9
Sagitta elegans	2.4	1.5	1.3	8.4	2.6	2.0
Phylum Arthropoda						
Acartia longiremis	8.4	2.6	2.0	50.3	5.8	3.5
Calanus cristatus	6.8	2.4	1.8	16.2	3.5	2.4
C. plumchrus	92.1	7.6	4.2	58.0	6.1	3.6
Eucalanus b. bungii	2.4	1.5	1.3	66.5	6.5	3.8
Metridia lucens	2.9	1.6	1.4	9.1	2.7	2.0
Oithona similis	6.8	2.4	1.8	145.6	9.3	4.8
O. spinirostris	5.4	2.1	1.7	120.6	8.5	4.6
Pseudocalanus spp.	3.0	1.6	1.4	7.2	2.4	1.9
Parathemisto pacifica	5.7	2.2	1.7	24.0	4.1	2.7

Measures of variance within a regime can also be used to predict the number of samples required to achieve any desired level of field precision. Table 68 presents the predicted effort by taxonomic category necessary to detect differences ranging from 2 orders of magnitude (100.0) to a factor of only 1.5. For most of the organisms selected for this analysis, the effort required to detect real differences by a factor of 10.0 to 5.0 at any time ranged between 1 and 15 observations per regime. However, to monitor routinely population differences by a factor of only 1.5 would require a greatly increased effort--between 20 and 231 samples per regime. Although these estimates are based on a relatively small number of observations, they may be considered as guidelines for future studies.

Table 68. Numbers of Samples per Regime Reguired to Achieve Six Levels of Precision; Based on the Within-Regime Variance for each Category of Organism Obtained with the 1-m net

Taxonomic	Observations per Regime					
	Desired Level of Precision					
Category	100.0	50.0	10.0	5.0	2.5	1.5
Phylum Cnidaria						
Aglantha digitale	1	1	1	2	6	27
Phylum Chaetognatha						
Eukrohnia hamata	1	1	2	5	14	70
Sagitta elegans	1	1	1	2	6	28
Phylum Arthropoda						
Acartia longiremis	1	1	3	6	18	93
Calanus cristatus	1	1	2	3	10	48
C. pacificus	1	2	4	9	27	134
C. plumchrus	1	2	3	7	20	100
Eucalanus b. bungii	1	2	4	7	21	107
Metridia lucens	1	1	1	2	6	30
M. okhotensis	2	3	7	15	46	231
Oithona similis	2	3	5	10	30	151
O. spinirostris	2	2	5	9	38	140
Pseudocalanus spp.	1	1	1	2	5	24
Cyphocaris challengeri	1	1	1	3	7	36
Parathemisto libellula	1	1	2	3	9	44
P. pacifica	1	1	2	4	12	62
Euphausia pacifica	1	1	1	2	4	20
Thysanoessa longipes	1	1	2	3	8	39
Euphausiid larvae	2	2	5	10	31	156
Oregoniinae larvae	1	1	1	2	7	35
Phylum Chordata						
Oikopleura spp.	1	1	3	6	19	96

Although the fishes were the most diverse group sampled with the mid-water trawl, four species of euphausiids were consistently more numerous. *Euphausia pacifica* tended more toward an oceanic distribution with minimum abundance (<10 per haul) measured in February and maximum abundance (<100 per haul) found in May. *Thysanoessa inermis* and *T. spinifera* seemed to prefer both the shelf and slope regions, while *T. longipes* definitely selected the slope waters. The statistical significance of observed spatial differences was not evaluated.

These data are limited for strictly quantitative evaluation because the operation of the 2-m Tucker trawl was difficult to standardize in the field, and the flow-meter was used only on the May cruise. However, since the measured volumes varied by no more than a factor of 3 (except for one very deep tow), some selected distributions were examined as mean number of animals per haul within the matrix of regimes and cruises already described (there were no trawl samples taken at nearshore stations).

DISCUSSION AND SYNTHESIS

The organisms found are representative of the diverse animal plankton and micronekton community in the open ocean and shelf waters of the Northern Gulf of Alaska. However, the inventory is not complete or exhaustive. Had a smaller-mesh net been used, or the samples themselves been examined more fully, additional species would have undoubtedly been added.

LeBrasseur (1965a) described the seasonal abundance of 28 dominant zooplankters occurring in the upper 150 m of the open ocean at station *Papa*; 13 of these organisms were also quantitatively examined in this study. If the northern shelf is in fact 600-800 nmi "downstream" from station *Papa*, the large-scale seasonal fluctuation reported there might be very similar to those observed in this study, at least for species exhibiting distributional preference for the slope or the open ocean.

Of the 21 categories examined quantitatively from 1-m net collections, three species, *Metridia okhotensis*, *Parathemisto libellula*, and *Cyphocaris challengeri* occurred in so few samples that no distribution pattern was statistically apparent, although the first two organisms were clearly restricted to the nearshore and shelf; *P. libellula* never occurred in samples from the slope or open ocean. *Cyphocaris* seemed to prefer the shelf and slope environment. The remaining 18 taxa can be classified according to apparent environmental preference as follows:

1. Neritic - *Arcartia longiremis*, *Pseudocalanus* spp., euphausiid larvae, and oregoniiae larvae (mostly *Chionoecetes* spp.);
2. Oceanic - *Aglantha digitale*, *Eukrohnia hamata*, *Calanus cristatus*, *C. pacificus*, *Eucalanus b. bungii*, and *Euphausia pacifica*;
3. Shelf and Slope - *Parathemisto pacifica* and *Thysanoessa longipes*;
4. No obvious preference - *Sagitta elegans*, *Calanus plumchrus*, *Metridia lucens*, *Oithona similis*, *O. spinirostris*, and *Oikopleura* spp.

Only *Acartia*, oregoniiae larvae, and *Oithona spinirostris* were not obvious members of the southern Gulf net-plankton community at station *Papa*. *Arcartia longiremis* is known to be neritic; the appearance of oregoniia larvae in the coastal waters is also expected in view of the large fishery for this species (the snow or tanner crab) located close to shore. It is possible that *Oithona spinirostris* was not separated from *O. similis* in sample counts from station *Papa*, or that it just did not occur as frequently as observed near and over the shelf.

Some of the remaining 16 organisms do exhibit temporal patterns (as crudely discerned in the present design) remarkably similar to those described by LeBrasseur (1965b) for the open ocean community in the upper 150 m:

1. *Aglantha digitale*, *Sigitta elegans*, and *Thysanoessa longipes* - little or no obvious seasonality;
2. *Oithona similis* and *O. spinirostris* - most abundant during the fall, winter, and early spring;
3. *Eucalanus b. bungii* and *Calanus plumchrus* most abundant during spring and summer.

The strong seasonality measured for the arrow worm *Eukrohnia hamata* at station *Papa* was not apparent in these observations, however, nor were temporal patterns as obvious for *Metridia lucens*, *Calanus cristatus*, and *C. pacificus*. Except for *Eukrohnia*, these animals exhibited at station *Papa* a seasonality that seemingly eluded detection within the cruise-time framework of the present study.

Much emphasis was placed on vertical biomass distributions at station *Papa* as they reflect interactions with well-defined hydrographic features. McAllister (1961) reported the virtual absence of animals within the permanent halocline at depths between 100 and 200 m in all seasons. At present there is no indication of whether this relationship occurs throughout the northeast Pacific, and what the implication might be for a pelagic shelf community interacting with this physical feature. Marlowe (1974) indicates that although the collective biomass under a unit area of sea surface may show bimodal distribution around the halocline, several species extend their depth ranges through this feature without apparent difficulty.

A variety of physical oceanographic measurements was obtained within the overall framework of the present northern Gulf of Alaska environmental study (see Royer and Galt, end of year report; Physical Oceanography). These observations and those continuing are expected to be most useful in subsequent years in interpreting the results of plankton censusing. Also, obvious physical features must be considered in planning future field work. Many species that are found well offshore occur also on the shelf. Some of these organisms (the "no preference" group) demonstrate a high tolerance for salinity differences, while the "oceanic" group clearly reflects diminished survival in the more neritic shelf and nearshore waters.

The statistical studies have obvious implications for the continuing investigation of plankton in continental waters. The ability to detect differences in standing stocks between broadly defined hydrographic areas and specific locations can now be approached for any arbitrary level of precision with at least some indication of the effort necessary to acquire the data base. Population differences of a factor of 5 or 10 can be monitored for many dominant species with fewer than about 20 observations per area and time. On the other hand, demonstrating significant "minor" fluctuations requires an enormous sampling effort. This problem (not unknown to those who census animal plankton populations) will undoubtedly modify the conception of what is and what is not reasonable in long-term plankton monitoring.

CONCLUSIONS

The conclusions drawn from this first year's research are in most cases only tentative. Certain generalities are apparent, however.

1. The animal plankton and micronekton assemblages observed in collections from the northern Gulf of Alaska are similar to those reported from elsewhere in the northeast Pacific and Alaska coastal waters. The shelf community is a mixture of open ocean animals and those requiring a more nearshore neritic habitat.
2. Large-scale seasonal variations for dominant species match, to some extent, those observed over a long time (1956-64) well offshore in the southern Gulf of Alaska (implying both biological and physical continuity in this system).
3. Seasonal and spatial differences (in the standing stocks of dominant net zooplankters) exceeding about one-half an order of magnitude can be routinely measured with "reasonable" sampling effort.

The major contribution of the preliminary investigation is that more than 100 samples have been collected and processed from a region that has never before been studied so rigorously. This on-site collection permits a description of the actual rather than surmised constituency and provides some indication of seasonal and spatial distributions. It is the "holes" in this beginning data base which focuses attention on continuing studies of the unobtrusive fauna.

The effects of introduced hydrocarbons on natural populations of zooplankton and micronekton have never been adequately evaluated. The extremely difficult field sampling problem reduces the resolution of most surveys far below that necessary to detect significant changes in abundance, biomass, or even species composition. Only recently have advances in gas and liquid chromatographic techniques provided a sufficiently sensitive means of describing and monitoring levels of synthesized and introduced hydrocarbons in living organisms. Using these techniques, in conjunction with an adequate field sampling design, the question of food-web incorporation and the transfer and possible accumulation of fossil fuels and their derivatives in portions of natural systems can be considered. Without some indication of the relative sensitivity of the various organisms present in the water column at any time to fossil fuels or other contaminants associated with offshore development no objective predictions of potential impact can be made.

The implications of this work, related to development over the outer continental shelf, would seem to be the demonstration that the shelf waters contain a diverse and abundant fauna at all times of the year. In addition to members of the oceanic net plankton and micronekton communities advected through the area, the eggs and larval stages of fishes and many local benthic invertebrates (some of great commercial importance) are present seasonally, presumably dependent upon the shelf pelagial for survival. There can be little question that these organisms will be the first to be affected by pollutants entering the water column.

Continuing studies of net plankton and micronekton in the northern Gulf of Alaska will emphasize biological and ecological interrelationships in addition to refining views of spatial and seasonal distributions. This information will be required to understand the effects under theoretical and/or actual impact circumstances. Physiological studies, funded within the overall program, should select organisms for experimental work from the list of species and other taxonomic categories presented here.

FUTURE STUDIES

An understanding of the several levels of sampling variability described in this report for dominant species should be considered a basis for structuring the continuing field effort within an expanding format of program objectives. It is obvious that many of the more important seasonal events were missed because of the crude temporal resolution of this investigation. During the next year's field effort, zooplankton will be sampled seasonally over at least one annual cycle in areas covered by lease tracts. This minimum sampling program will identify the distribution and abundance of populations to at least an order of magnitude, provide some measure of species diversity, and identify some non-population-dependent statistical parameters. It should be noted that data on zooplankton from the 1 m net and Tucker trawl collections are still preliminary.

A most critical feature of the environment, and one not addressed in the past year's survey, is that of the vertical distributions of zooplankton and micronekton and their relationships with other biological and environmental parameters in the water column. Before the problem of introduced contaminants can be reasonably evaluated, some knowledge of where the various organisms are, relative to the ocean surface, must be available. As the result of a zooplankton sampling workshop (Univ. of Washington; July 1975), the coming year's effort in the Gulf of Alaska will emphasize the vertical and seasonal aspects of distributions in much more detail than was possible this first year. Several cross-shelf transects are planned, with the water column being stratified in discrete layers. Day-night variations related to diel migration will also be examined.

As the spatial and seasonal relationships between the various components become more apparent, the interactions between populations (pre-predator-competitor) will receive increased attention; these dependencies must be known in formulating a predictive understanding of the system.

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8. CHEMISTRY

HYDROCARBONS (I)

INTRODUCTION[1]

Several reviews of petroleum in the marine environment have recently appeared (Wilson and Hunt, 1975; Goldberg, 1972; Junghans, 1974; SCEP, 1970). These reviews assess the current state of knowledge and introduce the primary literature of the field.

This report presents the results of a 12 month effort to determine hydrocarbon levels in the water and sediments of the Gulf of Alaska. This is the first attempt to obtain such data in this area, but in relation to the amount of information needed for well-informed management decisions, the information in hand is inadequate. The knowledge gaps are so numerous and so large that any interpretations drawn from the present data must be considered highly tentative and subject to revision as additional data are obtained.

STUDY AREA

The area studied is that portion of the Continental Shelf between Resurrection Bay and Yakutat Bay, Alaska. Limited studies have also been conducted in Prince William Sound and at onshore oil seeps near Katalla and Cape Yakataga. Offshore samples were collected at stations selected from a network being used for several projects in this program. Stations in Prince William Sound were chosen from stations previously occupied in that area by various projects of the Institute of Marine Science, University of Alaska. The locations of these stations are given in Table 69. This use of common stations makes maximum intercomparison of data with other projects possible.

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[1] Extracted from Shaw, David G. (1975): Environmental Assessment of the Northeastern Gulf of Alaska: Chemical Oceanography (Hydrocarbons). First Year Report to the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Contract No. 03-5-022-36, Institute of Marine Science University of Alaska, Fairbanks, Alaska, 198 pp.

Table 69. Sample Locations

Station	N. Latitude	W. Longitude	Station	N. Latitude	W. Longitude
GASS 1	59°50.2'	149°30.5'	GASS 33	59°17.5'	141°54.8'
GASS 2	59°41.5'	149°22.0'	GASS 34	59°08.5'	142°03.8'
GASS 3	59°33.0'	149°13.2'	GASS 35	58°59.5'	142°13.0'
GASS 4	59°24.5'	149°04.9'			
GASS 5	59°16.0'	148°56.0'	GASS 36	59°06.5'	143°04.0'
			GASS 37	59°16.2'	142°59.2'
GASS 6	59°07.2'	148°47.5'	GASS 38	59°25.9'	142°54.2'
GASS 7	58°58.7'	148°38.7'	GASS 39	59°35.7'	142°49.5'
GASS 8	58°49.7'	148°30.0'	GASS 40	59°45.5'	142°44.5'
GASS 9	58°41.1'	148°21.6'			
GASS 10	58°32.3'	148°13.2'	GASS 41	59°55.1'	142°39.5'
			GASS 42	59°55.1'	143°51.2'
GASS 11	58°23.2'	148°04.8'	GASS 43	59°45.0'	143°52.8'
GASS 12	58°22.1'	147°18.8'	GASS 44	59°35.0'	143°54.2'
GASS 13	58°20.7'	146°32.5'	GASS 45	59°24.9'	143°55.8'
GASS 14	58°19.6'	145°46.5'			
GASS 15	58°18.1'	145°00.5'	GASS 46	59°14.6'	143°56.9'
			GASS 47	59°17.5'	145°13.0'
GASS 16	58°16.9'	144°14.8'	GASS 48	59°27.5'	145°11.5'
GASS 17	58°15.4'	143°28.5'	GASS 49	59°37.5'	145°10.0'
GASS 18	58°14.1'	142°42.1'	GASS 50	59°47.7'	145°09.0'
GASS 19	58°13.0'	141°55.0'			
GASS 20	58°21.2'	141°44.0'	GASS 51	59°57.6'	145°07.8'
			GASS 52	60°07.6'	145°06.5'
GASS 21	58°29.5'	141°33.0'	GASS 53	60°23.0'	146°54.0'
GASS 22	58°38.0'	141°22.2'	GASS 54	60°13.9'	146°48.6'
GASS 23	58°46.1'	141°11.3'	GASS 55	60°04.5'	146°42.6'
GASS 24	58°54.3'	141°06.5'			
GASS 25	59°02.5'	140°49.8'	GASS 56	60°55.2'	146°36.8'
			GASS 57	59°45.6'	146°31.0'
GASS 26	59°10.8'	140°38.9'	GASS 58	59°36.2'	146°25.5'
GASS 27	59°18.6'	140°27.9'	GASS 59A	59°17.1'	146°14.0'
GASS 28	59°26.5'	140°16.9'	GASS 75	59°40.6'	147°41.3'
GASS 29	59°34.6'	140°06.0'			
GASS 30	59°44.1'	141°27.9'			
			PWS 12	60°27.0'	146°54.0'
GASS 31	59°35.2'	141°36.8'	PWS 16	60°42.0'	147°00.0'
GASS 32	59°26.3'	141°46.0'	PWS 107	61°00.3'	146°45.9'

METHODS

Sampling

While strict conformity has not yet been achieved throughout the NOAA-BLM programs, the sampling and analytical procedures reported here are compatible with those being recommended as the basis for BLM studies elsewhere. Intercomparison will be conducted with NBS, UCLA, IMA, NMFS-NWFC and Battelle-Columbus.

Benthic Sediments

Forty-three collections of benthic sediment were made at 36 stations usually in less than 400 m of water (Table 70). Each collection was in duplicate; i.e., two jars each containing approximately 200 grams of sediment constitute one collection. The tool for obtaining 34 collections was the van Veen grab, which produces a slightly disturbed sample of surficial benthic sediment with minimal risk of contamination (the grab is all metal and requires no lubrication). A Shipek grab was used on four occasions to collect sediment in 400-2000 m of water. The Shipek grab is more reliable than the van Veen but has a greater risk of contamination. Five collections were made in water deeper than 2000 m using boomerang corers. Sediment was taken from the sampler using a stainless steel spoon that had been heated to incandescence. Samples were frozen until time of analysis in glass jars with screw caps lined with aluminum foil. Jars and their cap liners had previously been washed and baked at 500°C for 24 hours, then sealed until used.

Surface Water

Sixty-five samples of surface water were collected during three cruises (November 1974, February 1975, and May 1975). Water was collected in 1 gallon amber glass bottles fitted with cleaned teflon cap liners. The glass jugs were cleaned by rinsing three or four times with tap water, twice each with tap distilled water, laboratory distilled water, acetone, and hexane. The bottles were extracted with 25 mℓ of hexane, concentrated to 0.6 mℓ to 1.0 mℓ. Five μℓ of the concentrate was injected into the gas chromatograph (GC) set at maximum sensitivity. A bottle showing any contaminated trace was re-extracted with 25 mℓ of hexane and checked again. (Only one bottle cleaned by this method had to be extracted twice.)

Table 70. Sediment Sample Collection Stations.

CRUISE	STATIONS		CRUISE	STATIONS	
	GASS	PWS		GASS	PWS
R/V ACONA Cruise 193	03		NOAA Ship OCEANOGRAPHER	31	12
(July 1974)	06		(February 1975)	32	
	26			37	
	32			39	
	39			40	
	41			41	
	42			43	
	44			44	
	48			51	
	50			54	
	52			55	
	59			56	
				57	
R/V ACONA Cruise 200	48			58	
(October 1974)	57				
	75		NOAA Ship TOWNSEND CROMWELL	09	12
			(May 1975)	13	107
R/V ACONA Cruise 202	01			16	
(November 1974)				19	
				22	
				25	
				27	
				28	

Bottles were lowered to just below the water surface either by hand or with a winch. To minimize contamination from the ship, the samples were collected as far forward on the ship as possible and as soon as the ship came on station. Water samples were processed immediately after collection.

Floating Tar

The sampler used to collect flotsam has been described by Sameoto and Jaroszynski (1969). The sampler towed from the side of the ship fishes in undisturbed water ahead of the ship's bow wake. The net is towed for approximately 1 nmi at 4 knots either with or against the prevailing swell; this minimizes the tendency of the net to "porpoise" as the ship rolls. A simple calculation based on the width of the sampler opening and the distance towed indicated that 740 m^2 were sampled on each tow. The effective sampling area was probably less, since the sampler had its own small bow wake that pushed water around rather than through it, and since the mouth of the sampler was occasionally completely out of or under water. The net of the sampler had 363 μm openings. At the end of each tow, the material collected was rinsed into a PVC cup at the cod end, transferred to a precleaned glass bottle, and frozen until analysis.

Coastal Oil Seeps

Coastal oil seeps were sampled in the Katalla and Cape Yakataga areas during July 1974. Mr. Donald Blasko of the Bureau of Mines, U.S. Department of the Interior, provided invaluable help in making these collections. One sample of oil was collected from a seep in an abandoned oil field approximately 3.25 miles southeast of the town of Katalla. The surface drainage from the seep area entered the Gulf of Alaska through the Katalla River. Two samples of oil were collected on the east fork of Munday Creek approximately 17 miles southeast of Cape Yakataga. Munday Creek flows directly into the Gulf of Alaska. Samples were collected by dipping a precleaned glass jar into the water where the oil floated. The samples obtained each contained two phases: oil and water.

Analysis

Benthic Sediments

The procedure for analysis of benthic sediments was similar to that described by Farrington et al. (1972). All solvents were distilled in glass at least once before use. The volume of distilled solvent used in the extraction procedure was concentrated to 1.0 mℓ on a rotary evaporator. Five μℓ of the concentrate were examined by gas chromatography (GC). Batches of solvent showing little or no impurity were used for analysis; others were redistilled. Sodium chloride, sodium sulfate and glass wool were purified by treatment in a muffle furnace at 500°C for 24 hours. The rotary evaporator used was a "Buchi Rotavapor-R."

A complete Soxhlet apparatus including double thickness Whatman cellulose thimbles was extracted 24 hours with 300 mℓ methanol:benzene (1:1). The solvent was replaced and the thimbles were extracted for another 24 hours. The solvent from the second extraction was concentrated to approximately 1.0 mℓ on a rotary evaporator and checked by GC. Extractions were routinely run in sets of six: five samples and a blank. Blanks were subjected to every step of the analytical procedure. The sediment was thawed and approximately 100 gram weighed into the thimble. This sample was extracted for 48 hours with 300 mℓ methanol:benzene (1:1). After 24 hours the sample was stirred to prevent channeling. Periodically, an additional 24 hour extraction with fresh solvent was run to check completeness of the extraction.

The Soxhlet extract was allowed to cool and then extracted three times with one-third volume of hexane. The combined hexane phases were washed with one-third volume of saturated NaCl and then dried over anhydrous Na_2SO_4 overnight. This hexane extract was concentrated to approximately 1.0 mℓ on a rotary evaporator. Copper prepared according to Blumer (1957) was added to the concentrate to precipitate elemental sulfur.

A column of 35 mm Al_2O_3 packed over 35 mm SiO_2 was prepared in a Pasteur pipet, using glass wool as a plug. The sample was added to the column; a 1.0 mℓ void volume and two 3 mℓ hexane elutions were collected. The liquid column eluate was collected in a tared vial and concentrated under a stream of N_2 to approximately 1.0 mℓ. The eluate was then weighed and the volume calculated from the density of hexane (0.66). A 100 μℓ aliquot was taken, air dried, and weighed on an electrobalance. The total weight of hydrocarbon extracted was then calculated.

Gas-liquid chromatographic analysis of the concentrated eluates was done on a Hewlett-Packard model 5711 gas chromatograph with flame ionization detectors, using 6 foot by 1/8 inch columns of 1.5 percent OV101 on Chromosorb W100-120 HP. The temperature program was 80°C for 2 minutes, 80 to 280°C at 16°C per minute, then isothermal at 280 C.

Surface Water

1. Tenax Procedure. Solvents were distilled in glass and quality checked for each one gallon batch. For hexane, methanol, and benzene, 400 ml were concentrated to 1 ml in a rotary evaporator. Water was distilled with $KMnO_4$ and checked by one of two methods. One was to run 1 ℓ of water through the Tenax procedure described below; the other was a hexane extraction of 400 mℓ of water. The water was extracted three times with 100 mℓ hexane, the extracts pooled, dried with Na_2SO_4, and concentrated on a rotary evaporator to 0.5 to 1.0 mℓ for GC analysis.

All glassware, teflon, and metal fittings associated with the Tenax procedure were cleaned by successive rinsing with the above distilled water, acetone or methanol, benzene and hexane.

The columns of Tenax-GC[2] were stainless steel tubing 1/4 inch OD (∿ 5 mm ID) and 6 cm long, fitted with stainless steel swagelok fittings on each end. The columns were cleaned by rinsing with acetone and then hexane. Thin glass wool plugs were used at each end of the column and the Tenax was compacted by vibration.

After the columns were packed they were cleaned by heating the columns to 350°C for 40 minutes with carrier gas flowing through them at about 30 mℓ per minute. The columns were then cooled with gas flow and sealed with swagelok caps. Columns were checked for contamination by running them through the same GC program used for samples.

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[2] Registered trade mark of Enka N.V., The Netherlands.

Two different approaches were used to extract the organics via Tenax-GC from the water sample. One of these employed an all glass and metal system, whereas the other used teflon and metal. Both of these systems were sealed while the extraction was taking place to prevent contamination from the ship's atmosphere.

Before a sample was placed in the system, a clean glass wool filter bed and a clean 7 μm filter were inserted. The 7 μm filter holders and brass glass wool filter holders were rinsed with methanol before each use. Filters were used only once during each cruise. Part of the sample was then used to rinse the reservoir two to three times before the addition of the sample to be extracted.

With the glass wool filter in place the glass reservoir was filled by pouring about 1500 mℓ of the sample into the reservoir from the sample bottle. It was then sealed with a ground glass stopper and connected to the rest of the system.

Once the sample was in the reservoir and the system completely assembled, the metering pump was turned on and air purged from the system by applying a slight vacuum with a syringe. Once the air was purged, the sample was pumped through the system at 460 mℓ per minute.

After 1 ℓ of sample was extracted, the Tenax column was taken out of the system, sealed at each end with swagelok caps, and frozen. The samples were kept frozen until just before analysis in the laboratory. They were then thawed for about 1 hour and dried with a stream of ultra high purity nitrogen. For 5 hours, 60 ℓ of N_2 was run through each column. After a sample was dried it was either run on the GC within 24 hours or returned to the freezer until it could be analyzed.

To analyze the samples by GC, a Tenax column was placed in front of the analytical column in the GC and, with carrier gas flowing at the normal rate, the column was heated while the analytical column was cooled. This thermally focused the organics on the analytical column. The heat and cooling bath were then removed and the GC run through the program.

The first analyses were made on a Varian model 1520 GC. The analytical columns were stainless steel 6 feet x 1/8 inch packed with 3 percent Apiezon L on 70-80 Anakrom Q. The program used was 60°C for 2 minutes, 60°C to 270°C at 15°C a minute, and isothermal at 270°C, making use of a Hewlett

Packard model 5711A GC. The analytical columns were the same, but packed with 1.5 percent OV-101 on 100-120 Chromosorb W.H.P. The program was 80°C for 2 minutes, 80°C - 280°C at 16°C a minute, and 280°C for 8 minutes.

The Tenax was heated by placing around it an aluminum block containing a 200 W resistance heater controlled by a variac. The block was heated in about 2.5 minutes to 325°C and maintained there for 20 minutes. The analytical column was cooled by placing an isopropyl alcohol-dry ice bath on the second 4 cm of the analytical column.

2. CCl_4 Procedure. The CCl_4 used either has been distilled in the laboratory or was GC-spectrophotometric quality. In either case, the quality was checked by concentrating 100 mℓ of CCl_4 with a rotary evaporator to 0.5 mℓ and injecting 10 μℓ of this concentrate into the GC under the same conditions as the samples were run.

The sample was weighed before the extraction began. It was then liquid-liquid extracted once by the 25 mℓ CCl_4 added during collection and once more with 25 mℓ CCl_4. The sample was extracted the first time in the sample bottle and the second time in another bottle that had been through the same cleaning procedure. The extracts were combined in a 250 mℓ separatory funnel; the CCl_4 extract was drained off, concentrated to about 2 mℓ with a rotary evaporator, and transferred to a sample vial. In the sample vial it was evaporated to 0.5 mℓ with a stream of ultra high purity N_2.

The CCl_4 extract was analyzed by gas chromatography under the same conditions described for the Tenax procedure. Total organic content was determined by measuring the peak areas via planimetry.

Selected CCl_4 extracts were analyzed further to determine the fraction of hydrocarbons in the total organic extract. A 50 mℓ sample of CCl_4, which had been taken on a cruise, was concentrated to about 0.5 mℓ on a rotary evaporator and used as a blank in the first of these analyses. The blank and three of the samples (Stations 26, 41, and PWS 107) were taken up in hexane and then concentrated to about 0.5 mℓ. Then the 0.5 mℓ sample was chromatographed through a 7 cm column of 6 percent deactivated alumina over 5 percent deactivated silica (1:1). The samples were eluted with hexane and three 3 mℓ fractions were collected. Each fraction was concentrated to about 0.3 mℓ with a stream of nitrogen. The samples were analyzed by gas chromatography both before and after the column chromatography.

Two samples (Stations 06 and 22) were taken up in benzene instead of hexane and were then saponified by refluxing for 2 hours in 10 mℓ benzene, 5 mℓ water, and 10 mℓ 0.5N methanolic KOH. Each sample was then extracted with three 10 mℓ portions of hexane that were pooled, washed with 10 mℓ saturated NaCl solution, and dried overnight with Na_2SO_4. The extract was then concentrated, column chromatographed on an alumina-silica column, and analyzed by gas chromatography as above.

Floating Tar

In the laboratory, samples were thawed and then transferred to a large shallow pan for visual inspection. Any tar observed was transferred to a vial, placed in a desiccator to remove water and weighed. Selected samples were characterized by gas chromatography using the same conditions described for benthic sediments.

Coastal Oil Seeps

An aliquot of approximately 1.0 mℓ of the oil and water mixture was withdrawn from the samples by pipet. Care was taken to obtain as much as possible of the oil phase. The aliquot was placed in a separatory funnel to which some saturated aqueous sodium chloride had been added. The oil and water mixture was extracted four times with 10 mℓ of hexane. The combined hexane extracts were dried with anhydrous Na_2SO_4. Most of the hexane was removed with a rotary evaporator to give a dark viscous oil. This was rediluted with hexane for gas chromatography, carried out using the same conditions as for benthic sediments.

RESULTS AND DISCUSSION

Benthic Sediments

Values obtained for total weight of hydrocarbons range from 1.1 to 26.3 μg/g based on wet weight of sediments (Table 71). These are weights of all hydrocarbons isolated by the extraction and column chromatography procedures. The weights of hydrocarbons in the C_{14} to C_{30} range vary from 0.2 to 17.5. If we compare the data on a sample-by-sample basis, the total weight is consistently higher than the C_{14} to C_{30} weight. The one exception to this (Station 48) undoubtedly is the result of an analytical error at some point. The lower weight of the C_{14} to C_{30}

Table 71. Weights of Hydrocarbons in Sediments (μg hydrocarbon/g wet sediment).

STATION	Weight (C_{14}-C_{30})	Weight (Total)
GASS 01	2.1	4.5
03	5.2	16.2
06	2.0	13.7
09	0.6	2.4
13	3.3	10.9
16	1.4	5.3
19	0.3	1.4
22	0.2	1.2
26	1.0, 0.6*	3.7, 1.1*
30	1.5	3.1
32	3.2	13.0
37	2.4	5.0
39	2.6	7.2
41	8.2	17.2
42	9.7	12.5
44	6.4	11.1
48	6.3, 17.5*	16.0, 14.8*
50	10.1, 4.0*	21.1, 15.1*
52	4.4	14.4
53	5.4	15.9
55	7.8	7.8
GASS 57	13.3	26.3
59	10.5	18.4
75	6.0	16.7
PWS 12	1.3	3.0
NBS 919	0.5	8.3
923	1.0	2.9
931	< 0.1	11.0
928	0.6	67
948	0.5	6.2

* Analyzed in duplicate.

fraction is to be expected since the total may contain compounds outside the narrower range. However, for some samples, the C_{14} to C_{30} weight is a surprisingly small portion of the total weight. One possible explanation for this observation is that the sediments sampled contain a substantial portion of very large hydrocarbon materials that are extracted by the procedures used but which are too low in volatility to be detected by gas chromatographic procedure. Samples collected at three stations (26, 48, and 50) have been analyzed in duplicate. These show fair agreements at low values (Station 26) and good agreement at higher values for the totals and fair agreements for the C_{14} to C_{30} fraction. In each case, the duplicate chromatograms are quite similar. In two cases (Stations 41 and 48), the Soxhlet extraction procedure was continued for a second 48 hours using fresh solvent. Further workup of these second extracts indicated that the first extract removed approximately 80 percent of the extractable material.

The qualitative character of the chromatograms provides considerable insight, but no definite resolution of the question of whether the hydrocarbons in the benthic sediments of the Gulf of Alaska are of petroleum or biosynthetic origin. The most frequently cited criterion for distinguishing between petroleum and biosynthetic hydrocarbons is the odd-to-even ratio for *n*-alkanes. In petroleum this ratio is near unity; biosynthetic *n*-alkanes often show a preference for odd carbon numbers since alkanes are frequently the product of the decarboxylation of fatty acids. Fatty acids tend to contain even numbers of carbon atoms since they are built up of two carbon acetic acid units. However, some bacteria show no odd-to-even preference in *n*-alkanes.

No preference for odd chain lengths can be observed in the hydrocarbons of the benthic sediments. Although this suggests petroleum origin, several other bits of evidence indicate biogenic origin so that the latter origin appears more consistent with the present data.

The *n*-alkane peaks in the chromatogram of petroleum characteristically rise in intensity to a single maximum and then descend. This stair-step appearance is absent in the Gulf of Alaska sediments. The ratio of resolved peaks to unresolved envelope is too large for all but the least degraded petroleums. For fresh appearing petroleum to be present would require a high input rate. This is inconsistent with the low concentrations of hydrocarbons observed and with the lack of stair-stepping *n*-alkane peaks.

Phytane (2,6,10,14-tetramethylhexadecane) is an isoprenoid hydrocarbon that is common in petroleum but is not produced biosynthetically. It is the product of the reductive dehydroxylation of the phytol side chain of chlorophyll. Phytane is never a major peak in chromatograms of the Gulf of Alaska sediments. A few chromatograms (Stations 6, 39, 52, and 75) contain minor peaks at the retention time of phytane, but these peaks cannot be positively identified from the present data.

More detailed analysis will be required to resolve fully the petroleum or biogenic origin of these hydrocarbons. This work should include a more detailed search for phytane and an investigation of the aromatic content of the sediment hydrocarbons.

The data for hydrocarbon concentrations in benthic sediments that are most comparable with the present, both in origin of sediments and method of analysis, are those of Kinney (1973) who studied sediments from similar depths at Port Valdez, Alaska. His values for weights of C_{16} to C_{28} hydrocarbons ranged from 0.47 to 2.5 ppm by wet weight. These values and the qualitative appearance of his chromatograms are similar to those obtained in this research. Kinney's chromatograms show a substantial envelope and no odd preference in *n*-alkanes.

Inspection of the spatial distribution of the data reveals no obvious trends in hydrocarbon concentration or in the character of the chromatograms.

Surface Water

As described above, two methods have been used for the analysis of surface water: the CCl_4 method and the Tenax method. The Tenax method possesses inherent advantages: (1) it lowers the likelihood of sample contamination by minimizing the amount of sample handling required; (2) its use of a resin bed extractor is well suited to treatment of very large volumes of seawater. However, the Tenax method is new and unlike other extraction procedures. At the time this project began, the method had not been used at sea.

The strategy of carrying out water analyses by both methods resulted in allowing familiarity with the Tenax procedure without complete reliance on it for the acquisition of baseline data. After approximately 9 months of working with a Tenax procedure similar to that developed at the National Bureau of Standards, it was found that the procedure is not yet routine or trouble free. In fact, serious problems remain and the procedure continues under development. However, considerable progress has been made toward getting the Tenax procedure operational. The generous cooperation and advice of scientists at the National Bureau of Standards has helped substantially in this regard.

The Tenax procedure basically consists of two steps, the concentration of hydrophobic molecules (hydrocarbons and other non-polar organics) from the water sample onto the Tenax resin followed by the analysis of those concentrated materials, with no intermediate fractionation step in which hydrocarbons are physically separated from other classes of non-polar organic compounds. If the analysis step is performed using a computerized gas chromatograph-mass spectrometer system, hydrocarbons can be distinguished from non-hydrocarbons by data manipulation. This makes the fractionation of the sample unnecessary. If, as in present analyses, only gas chromatography is used for the analysis, no distinction between hydrocarbons and other non-polar organics can be made. In this mode of analysis, the Tenax procedure gives a concentration of total organics in the water analyzed. This concentration is then an upper bound for the hydrocarbon concentration in that water.

In the CCl_4 procedure, hydrophobic molecules are first concentrated from the water sample into CCl_4; then the analyst has the option of carrying out physical fractionation procedures on the extract. Finally the extract, either raw or fractionated, is analyzed by gas chromatography. If the raw extract is analyzed directly, the CCl_4 procedure is almost like the Tenax procedure. If a CCl_4 extract is analyzed both raw and fractionated, the percentage of hydrocarbons in the total organic extract can be obtained. This percentage has been found to be highly variable.

In November 1974, surface water samples were collected from the R/V *Acona*. Three analyses by the CCl_4 method showed total organic levels lower than 1 part per billion (ppb) at Stations 01, 53, and 55. One analysis at Station 01 by the Tenax method showed 3.3 ppb of total hydrocarbon (Table 72).

Table 72. Weights of Organics in Surface Water (μg organic/kg seawater).

	Station	CCl_4	Tenax
R/V ACONA 202	GASS 01	<1	3.3
(November 1974)	53	<1	
	55	<1	
OCEANOGRAPHER	GASS 32	<1	3.1
(February 1975)	33	<1	4.2
	37		3.1
	39	<1	2.5
	40	<1	4.2
	41		3.4
	42		2.6
	44		3.0
	47		7.7
	48		3.3
	52	54.2	Offscale
	53		3.9
	55		3.3
	57		2.5
	59		1.4
	PWS 12	<1	5.8
TOWNSEND CROMWELL	GASS 01		--
(May 1975)	03		--
	06	12.8	--
	09		--
	13		--
	16		--
	19		--
	22	10.0	--
	26	10.5	--
	32		--
	37	19.7	--
	39		--
	41	13.8	--
	42		--
	44		--
	48		--
	50		--
	52		--
	53		--
	55		--
	57		--
	59		--
	75	9.7	--
	PWS 107	22.1	--

-- Indicates data not yet available.

In February 1975, a somewhat more extensive surface water sampling program was done by the NOAA ship *Oceanographer*. Of nine analyses by the CCl_4 method, each showed total organic concentrations of less than 1 ppb. At Station 52 the CCl_4 method showed a total organic concentration of 54.2 ppb; since a high value was found also by the Tenax method, contamination during the collection process is suspected. The GC traces from Station 52 showed the characteristics of fuel oil. Fifteen other sample analyses by the Tenax method gave values of total organics ranging from 1.4 to 7.7 ppb with a mean of 3.6 ppb. The spatial distribution of these values showed no trends; the values appeared randomly distributed. Wilson and Hunt (1975 p. 56) reviewed values of hydrocarbons obtained in the water column from various parts of the world's oceans. While none of these data came from areas similar to the Gulf of Alaska, the values reported here (Table 72) appear consistent with those found in other low pollution areas.

A third suite of surface water samples was collected in May 1975 from the NOAA ship *Townsend Cromwell*. Six samples have so far been analyzed by the CCl_4 procedure (Table 72). The range of total organics in these samples was 9.7 to 19.7 ppb with a mean of 12.9 ppb. The rise from less than 1 ppb 3 months before might reflect greater biological activity in May than in February. Three CCl_4 extracts were fractionated to separate hydrocarbons from other organics. Samples from Stations 09 and 26 were first saponified and then subjected to column chromatography. Station 09, which contained 12.8 ppb of total organics, contained 9.2 ppb of hydrocarbons. Station 26 contained 10.0 ppb of total organics of which 4.7 were hydrocarbons. The extracts from Stations 26, 41, and PWS 107 were subjected to column chromatography only. For Station 26 the before and after values were 10.5 ppb and 3.7 ppb; for Station 41, 13.8 ppb and 1.1 ppb; for Station PWS 107, 22.1 ppb and 7.8 ppb.

In each case, fractionation removed most of the unresolved envelope and left undiminished resolved peaks in the range of C_{23} to C_{33}. These resolved peaks, however, present a puzzle in that the chromatograms have the appearance of neither petroleum nor biosynthetic hydrocarbons.

Floating Tar

Floating tar was obtained on six of 19 tows made in the Gulf of Alaska and Prince William Sound (Table 73). The mean value of tar collected on all tows was 0.01 mg of tar per m^2 of sea surface. This mean is strongly influenced by a single tow on which 127 mg of tar were collected. On the other five occasions when tar was found, the weights were 0.5, 7.4, 5.9, 8.7, and 3.2 mg. If the highest value is rejected, the mean for the remaining 19 tows is 2×10^3 mg/m^2. The highest value is real in the sense that the material collected is tar, but it may not be a representative sample. Many more tows are needed to assess the distribution of tar.

In any event, the mean tar concentration provides a rather poor description of the marine environment since tar lumps are discontinuous. Most of the sea surface has no tar at all. When a tar lump is present, its local concentration is far above the mean. Mean values are useful for comparing floating tar in various parts of the world's oceans, and a comprehensive source of comparative data has been provided for 10 areas of the world's oceans by Wilson and Hunt (1975 p. 53). These range from a high of 20 mg/m^2 in the Mediterranean to a low of < 0.01 in the southwest Pacific and include a value of 0.4 for the northeast Pacific. Thus preliminary data would indicate that the floating tar concentration in the Gulf of Alaska is among the lowest of all oceanic areas studied to date.

The gas chromatogram of the hexane extract of a portion of one tar lump shows a single broad envelope peaking at about the retention time of triacontane with only very small peaks rising above the envelope. The character of this chromatogram is distinctly unlike those of the benthic sediments or surface water and is much more like highly weathered crude oil or tanker ballast washings. Possible sources of this tar include local seeps, tankers transporting crude oil from Cook Inlet, and the Kuroshio Current system that might bring tar from as far away as Japan.

Table 73. Floating Tar.

Station	Date	Weight of Tar (mg)
GASS 01	5/75	0.5
19	5/75	--
26	5/75	7.4
30	2/75	3.2
30	5/75	5.9
37	2/75	--
37	5/75	--
40	2/75	--
42	5/75	--
48	10/75	--
48	2/75	127.1
53	5/75	--
57	10/74	8.7
75	5/75	--
PWS 12	2/75	--
16	5/75	--
107	5/75	--
107	5/75	--
107	5/75	--

-- Indicates no tar observed.

Coastal Seeps

If petroleum is found in the Gulf of Alaska OCS, that oil may or may not chemically resemble the oil presently issuing coastal seeps between Katalla and Icy Bay. Some of these seeps were described early in this century (Martin, 1906). The seeps have recently been re-examined and a report is being prepared (Blasko, personal communication). No estimates are available for the rate of flow from these seeps. An inspection of seep areas during this project detected no oil slicks in marine waters. However, residents of the area report occasional slicks.

Gas chromatograms of the seep oils indicate that, even near the seeps, these oils are highly weathered petroleum, quite unlike the hydrocarbons found in surface water and sediments.

CONCLUSIONS

The values obtained for concentrations of hydrocarbons in sediments and surface water and for standing stock of pelagic tar indicate that hydrocarbon levels in the Gulf of Alaska are as low as or lower than those found in other world's oceans areas that are free of obvious pollution.

No spatial trends in hydrocarbon distributions have been recognized within the study area. It may be that trends could be detected if these data and data from other projects were subjected to statistical procedures such as factor analysis.

This report provides information about the ambient concentrations of hydrocarbons in the Gulf of Alaska between July 1974 and May 1975. Direct knowledge of the dynamics, fate, and effects of petroleum added to this area is still lacking.

Although the Tenax procedure for the analysis of surface water continues to hold promise, it is not yet a completely satisfactory procedure. Further laboratory measurements will put greater emphasis on the CCl_4 method for data acquisition while developmental work with the Tenax method continues.

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HYDROCARBONS (II)

INTRODUCTION[3]

Since Prince William Sound and the Gulf of Alaska basically are presently pristine areas, hydrocarbons are expected to be present at the microgram per kilogram (part per billion) level and may well be non-petroleum in origin. The small amounts of hydrocarbons anticipated to be in the samples collected throughout the Sound necessitate the development of an analytical technique sensitive at the submicrogram per kilogram level. At this concentration the problems of analytical blanks and component recoveries become paramount. Futhermore, an analytical method is desired that would ultimately permit the identification of individual components among the hydrocarbons present in the samples.

To date several authors and groups have developed methods for the analysis of hydrocarbons in marine samples. These methods are of three basic types: a screening method for total extractable hydrocarbons (Brown et al., 1973); a headspace analysis method specifically for low molecular weight hydrocarbons (McAuliffe, 1971; Wasik and Brown, 1973); and a method involving digestion or extraction of the sample followed by clean-up and concentration procedures and gas chromatographic analysis of the hydrocarbon components from the sample (Clark and Finley, 1973; Warner, 1974; Farrington et al., 1973). Careful evaluation of each of these three basic methods revealed certain limitations when considered in terms of the goals of this study.

1. A screening technique for total extractable hydrocarbons is not specific enough for this study; it would not permit the identification of a single compound--an important goal in environmental studies.
2. Extraction/digestion methods are generally lengthy, involve considerable handling of the sample, and usually result in considerable losses of hydrocarbons having molecular weights of 200 and below. Hence these methods are not compatible with analyses for hydrocarbons present at the submicrogram per kilogram level.

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[3] Extracted from NBS Quarterly Reports of October 1974 and January, April, and July 1975, submitted to the NOAA/OCSEAP Program by the Chromatography Group, Bioorganic Standards Section, Analytical Chemistry Division, National Bureau of Standards, Washington, D.C. 20234.

3. Static headspace and extraction/digestion methods are optimum for molecular weight ranges and compound classes other than the ones of primary interest in this study.

The scheme developed for the analysis of hydrocarbons in marine samples involves dynamic headspace sampling using a stream of purified nitrogen as a sweep gas for trapping the volatile components on a Tenax-GC packed pre-column for subsequent gas chromatography. Headspace sampling has been applied to other analysis systems (Wasik and Brown, 1973; Melpolders et al., 1953; Grob, 1973; Zlatkis et al., 1973) and has a number of advantages over the classical techniques of solvent extraction and column chromatography.

1. Sample handling is minimal.
2. Separation of components from the matrix occurs in a closed system. This minimizes both the risk of loss of trace level volatile constituents and the possibility of contamination by laboratory vapors and particulates.
3. The method affords efficient separation and concentration of the components of interest from the matrix. In particular, the technique is most efficient for naphthalene and substituted naphthalenes, a class of compounds of special interest in this study.
4. Water is the only solvent needed for sample preparation and analysis. Use of hydrocarbon-free water further reduces opportunities for contamination of the sample by fossil hydrocarbons.
5. Even relatively non-volatile hydrocarbons, such as pyrene (molecular weight 202) and decosane (molecular weight 310), can be successfully headspace sampled.

OBJECTIVES

The original purpose of this study was to develop analytical methodology and determine baseline levels of hydrocarbons in the area of Prince William Sound in Alaska before the development of oil transfer facilities in Port Valdez.

When the NEGOA project was initiated, the original sampling stations in Prince William Sound were supplemented by several stations in other regions of the Northeast Gulf of Alaska. This expansion increased the total number of analyses available to the project and provided for quality assurance through mutual analysis with the University of Alaska of sample splits.

STUDY AREA

The locations sampled during the fall of 1974, under this expanded study are identified in Fig. 34.

METHODS

To analyze materials in amounts of sub-microgram per kilogram, significant contamination of the sample during collection, storage, and analysis must be avoided. Much effort was therefore expended to insure that such contamination did not occur. An extensive procedure has been developed for cleaning all bottles and tools in contact with the samples. Since it has been well established that fossil hydrocarbon contaminants are present in most organic solvents (Clark and Findley, 1973) and in distilled water, these chemicals were carefully purified and then frequently checked by sensitive analytical techniques to assure continued low contaminant levels. In addition, blanks were analyzed with each set of samples. Continuous monitoring of these blank values permitted problems in sample handling and reagent purity to be spotted quickly.

When attempting to analyze for hydrocarbons at the sub-microgram per kilogram level, any loss from the sample must be considered as a serious problem. Adsorption of sample components by glass and other surfaces in contact with the sample can lead to significant losses. A well-recognized technique for monitoring sample component losses is to add an internal standard to the sample. This technique has been employed by various workers in the area of oil pollution analysis (Clark and Findley, 1973; Warner, 1974). To be truly effective and accurately reflect the sample, the internal standard should be present in the sample from the time it is collected or at least from the first step of the analysis procedure. Thus, all water samples collected have an internal standard added at the site of collection or as soon as practical thereafter. All samples are frozen on dry ice after collection. Since it was not feasible to add the internal standard to sediment and tissue samples when they were collected, the internal standard was added when the samples were thawed and opened for analysis. The compound or compounds used as the internal standard must be representative of the components of interest in the sample. Only then may it be assumed that the internal standard will be subject to losses (through adsorption and other causes) equivalent to those of the components of interest. An internal

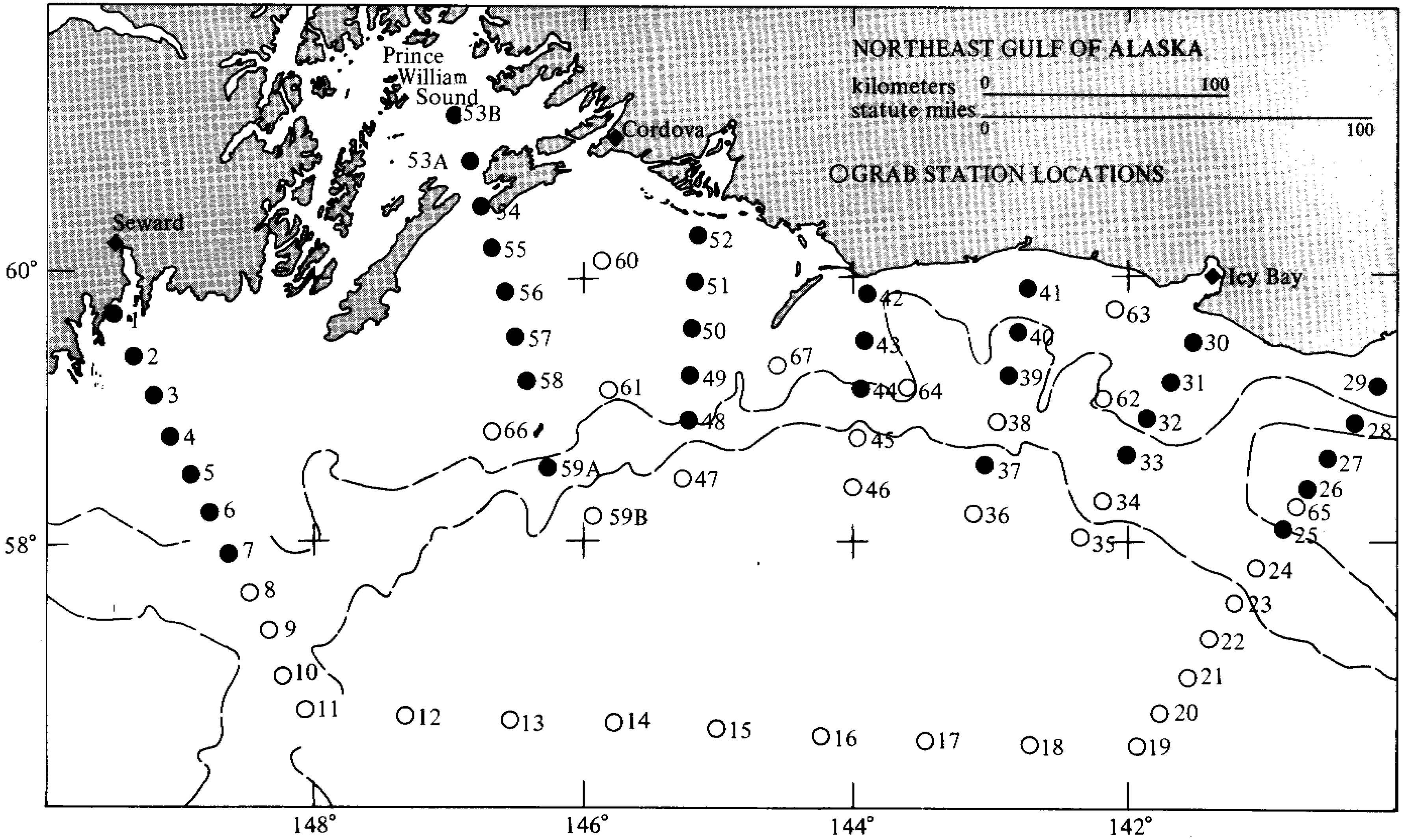

Figure 34. Locations Sampled During the Fall of 1974.

standard consisting of mesitylene, naphthalene, *n*-propylnaphthalene, and phenanthrene was selected as representative of the compounds and molecular weight range appropriate to this study.

RESULTS AND DISCUSSION

Analyses of sediment and water samples collected in the fall of 1974 have been completed. Sediment samples received as sample splits from the University of Alaska have also been analyzed using headspace sampling and gas chromatography. These results are presented and discussed below. In addition, progress has been made in method development for headspace sampling of marine tissue and for coupled-column liquid chromatographic analysis of polynuclear aromatic hydrocarbons.

SEDIMENT ANALYSIS

The sediment samples collected in the fall of 1974 have been analyzed using headspace sampling and GC/GC-MS. The results of the sediment analyses (Table 74) are presented as weight-averages by molecular weight region. Sediment was not collected from the site at Anchor Cove, since the beach consisted of fist-sized stones and larger. Note that by the addition of phenanthrene, the internal standard used in the current analyses differs from that used previously. This addition was believed to allow a more realistic evaluation of the recoveries of the compounds in the phenanthrene molecular-weight region. The addition of phenanthrene had little effect on the value for the total maximum hydrocarbon content. In several instances, a phenanthrene peak was not observed on the gas chromatogram (denoted by *** in the tables) and the organic compound peaks within the phenanthrene region were included in the trimethylnaphthalene region. This treatment can cause the weight-averages and percentages for these two molecular-weight regions to be incorrectly biased. A single weight-average and/or percentage value calculated using the combined results from these two regions is therefore presented as reflecting more accurately the correct weight-average and percentage.

The results of detailed study of the gas chromatographic analyses of sediments from Katalla River and Middleton Island demonstrate the large extent of sample inhomogeneity present in these sediments. The gas

Table 74. Hydrocarbon Content of Sediment Samples Collected in the Fall of 1974

Site/Bottle No.	Total Maximum Hydrocarbon Content (μg/kg wet weight) Obtained by Headspace Sampling	Total Hydrocarbons by Molecular Weight Region (μg/kg wet weight)				Number of Component Peaks >1 μg/kg wet weight
		Mesitylene	Naphthalene	Trimethyl-naphthalene	Phenanthrene	
Dayville Mud Flats 913, 915	167±45 (3)*	10.4±11.9	4.9±2.8	16.9±8.0	134.7±49.7	32 ±8
Old Valdez 917	167±12 (2)	19.8±11.4	25.6±13.1	77.9±51.8	91.1*** (single result)	74 ±32
				123.4 ±12.7 better value for combined regions		
Cape Yakataga 902	72±28 (3)	22.3±19.6	11.0±8.8	9.6 ±6.8	28.7 ±8.0	23 ±10
902**	367 (1)	137.2	67.3	28.2	134.6	76
Katalla River 903	566±248 (3)	142.5±24.2	179.7±91.5	188.8 ±174.8	81.8 ±79.3*** (two results)	118±9
				243.4 ±151.7 better value for combined regions		
Anchor Cove	NO SEDIMENT COLLECTED FROM BOULDER BEACH					
Hinchinbrook**** Island 935, 937	91±58	15.4±5.8	7.6±4.3	9.6 ±9.9	51.3±39.8	24 ±16
MacLeod Harbor**** 929, 933	124±109 (5)	24.6±20.2	32.0±38.4	47.3 ±46.5	20.0 ±14.5	44 ±26
Middleton Is.**** 939, 940	146±55 (4)	32.3±28.7	48.9±44.4	21.8 ±8.5	26.1 ±9.0	42 ±20
Siwash Bay**** 944, 946	61±10 (3)	31.8±4.8	11.7±3.2	7.7 ±3.0	13.9 ±5.0*** (two results)	19 ±1
				17.0±9.2 better value for combined region		
Squirrel Bay**** 942	956±90 (2)	106.4±36.7	38.9±29.5	700.9	890.8*** (single result)	70 ±14
				811.0 ±155.8 better value for combined region		

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* ( ) Denotes the number of samples analyzed.

** See discussion in test.

*** Phenanthrene spike not recovered in all analyses so component amounts included in trimethylnaphthalene molecular weight region.

**** Sample splits with the University of Alaska.

chromatograms obtained from both of these sediments indicated the presence of petroleum. The GC-MS analyses of the sediments from Katalla River and Middleton Island confirm that the major constituents are all hydrocarbons. Because of the large number of aromatic hydrocarbons, the presence of petroleum is indicated. This is expected for Katalla River, a site of oil seepage, but is a somewhat unexpected result for Middleton Island. Examination of the m/e 43 mass chromatogram reveals some even/odd preference for Middleton Island. Thus, some of the hydrocarbons at Middleton may be of recent biogenic origin.

Middleton Island sediments were all collected within an area of 600 cm^2 on a beach on the eastern tip of the island. The sediments analyzed were taken using the procedure outlined in the October 1974 protocol and brought back frozen in two separate bottles (Nos. 939 and 940). The contents of each bottle were well mixed before analysis and supplied enough sample to allow duplicate examinations. The chromatograms from these analyses dramatically pointed out the microscopic and macroscopic inhomogeneity of the samples collected and represent most of the samples from all sites collected to date. There was a gross, single-species, concentration difference between the No. 939 chromatograms and the No. 940 chromatograms, indicating that the samples contained in the two bottles were not identical. Chromatograms from samples of the same bottle, although more similar than those from samples of different bottles, still showed considerable single-species concentration differences. This demonstrated that the samples of the sediment from a single bottle were not homogeneous despite the fact that the bottle contents were thoroughly mixed before analysis. The chromatographic patterns, i.e., elution peak position as a function of time, is identical in all the Middleton Island chromatograms. This pattern is representative only of Middleton Island. Thus, the same compounds are present in all the sediment samples, but their concentrations differ widely.

The Middleton Island analyses illustrate the large standard deviations present in the sediment analyses. The sediments collected are inherently inhomogeneous in single-species concentrations, and this leads to the largest source of experimental error in the determination.

Another site that demonstrates the inhomogeneity of sediment samples is Cape Yakataga. As Table 74 shows, three of the results from sample bottle No. 902 showed a maximum hydrocarbon content of 72 ± 28 μg/kg (wet weight), while the fourth analysis from the same bottle indicated 367 μg/kg. Since the sediment was well mixed in a clean dish before analysis, it must be assumed that this inhomogeneity is microscopic, i.e., a contaminant was associated with a single (or very few) grains of sand in the sample. Inasmuch as the site of Cape Yakataga is near known oil seeps, hydrocarbon contamination of the sediment could occur in the form of discrete balls of tar or globules of weathered oil. It is worth noting that the percentages of total hydrocarbon found in each molecular weight region of the 367 μg/kg sample agree (within the standard deviations) with those of the other three Yakataga samples.

The site at Squirrel Bay shows a much higher maximum hydrocarbon content than do any of the other sites sampled. Squirrel Bay has not been sampled on any previous trip, so there are no previous data for comparisons. The recovery of the internal standard added to these samples was extremely low, presumably because of the highly adsorptive nature of this sediment. This, rather than hydrocarbon contamination, might be the cause of the high results presented in the table. The sampled site is at the far end of Squirrel Bay (away from the open water) and is within 30 m of a fresh water stream. These natural conditions differ from those at any of the other sites. Any definite conclusions must await resampling of the site.

UNIVERSITY OF ALASKA SEDIMENT SAMPLES

Sediment samples were collected by both the University of Alaska and NBS investigators. Some of these samples were "split" so that analyses could be performed by both laboratories for intercomparison of results. Splits of five sediment samples were received from the University of Alaska as part of this NBS quality assurance program. The samples were insufficiently packed with dry ice, thus they reached NBS thawed. Two of the bottles were cracked. Each cracked bottle was wrapped with aluminum foil and all were refrozen until analyzed. Table 75 presents the results of these sediment analyses in terms of total maximum hydrocarbon content and percentages by molecular weight region.

Table 75. Hydrocarbon Content of University of Alaska Sediment Samples.

U of A Sample No.	Headspace Sampling Total Max. Hydrocarbon Content (µg/kg wet weight)	Hydrocarbons by Molecular Weight Region			
		Mesitylene (%)	Naphthalene (%)	Trimethylnaphthalene (%)	Phenanthrene (%)
53-290M	200± 77(2)*	31± 2	22± 3	21±3	26± 9
44-190M**	727± 86(2)	21±11	14± 1	20±2	44±15
57-79M	382± 89(3)	48± 4	23± 1	15±3	14± 1
41-118M**	413±176(2)	39± 7	27± 5	21±4	13± 2
32-184M**	488±111(2)	60± 7	21±13	13±0.2	7± 6

* ( ) denotes the number of samples analyzed.

** Sample bottle cracked upon receipt; some contamination or losses possible.

WATER ANALYSIS

Water samples collected from the surface and from a depth of 10 m were analyzed by the NBS dynamic headspace sampling technique. The 10 m samples were collected with a sub-surface drop sampler developed at NBS for this program[4] (Gump *et al.*, 1975).

Total hydrocarbon content of the water samples ranged from 0.95 μg/km, except for one anomalously high replicate analysis from MacLeod Harbor (Table 76). In most cases where both surface and 10 m samples were analyzed, the values at depth were less than those from the surface water.

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[4] OCSEAP questions the usefulness of *all* water column measurements as well as other parametric measurements in the baseline-monitoring concept. Each of these parameters is being evaluated for its relevance and applicability to monitoring needs. Current water column measurement tests include hydrocarbons, metals, suspended sediments, etc. After general concentrations have been documented for broad characterization purposes, it will be determined whether any of them can be used for baseline-monitoring purposes.

Table 76. Water Analyses -- Fall 1974 Sampling.

		Total Hydrocarbons By Molecular Weight Region			
Location	Headspace Sampling Max. Hydrocarbon Content (μg/kg)	Mesitylene (%)	Naphthalene (%)	Propyl Naphthalene (%)	Phenanthrene (%)
Dayville Mud Flats					
Surface	2.7 ±1.9 (3)*	36±34	21± 5	44±33	**
10 m	1.6 ±0.3 (2)	38± 2	42± 2	20± 1	**
Old Valdez					
Surface	14.9 ± (1)	27	29	44	**
10 m	0.95±0.68(3)	20±10	37±13	44±16	**
Cape Yakataga					
Surface	11.3 ±1.6 (3)	21±18	32± 2	47±18	**
10 m	----				
Katalla River					
Surface	3.4 ±2.2 (3)	21±14	23± 6	5±19	**
10 m	----				
Anchor Cove					
Surface	8.0 ±0.2 (2)	21± 2	8± 4	8± 1	63± 5
10 m	3.6 ±0.6 (2)	55±22	10± 1	14± 5	20±16
Hinchinbrook Island					
Surface	5.3 ±1.8	46±33	19±18	27±32	11± 2
10 m	----				
MacLeod Harbor					
Surface	7.3 ±0.2 (2)	53± 5	8± 3	7± 3	31± 2
10 m	30.5 (1)	57	23	6	14
	3.9 ±2.0 (3)	76±10	10± 6	12± 9	**
Middleton Island					
Surface	5.4 (1)	26	16	22	36
10 m	----				
Siwash Bay					
Surface	3.0 (1)	41	45	13	**
10 m	1.9 ±0.2 (3)	40±17	7± 3	30±16	22±14
Squirrel Bay					
Surface	4.5 ±1.9 (3)	26±18	8± 7	42±32	23± 9
10 m	5.1 (1)	44	4	9	44

* ( ) denotes number of samples analyzed.

** Phenanthrene not included in internal standard.

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HEAVY METALS[5]

INTRODUCTION

Heavy Metals in the Marine Environment

Heavy metals exist in ultra-trace amounts in solution in seawater (in the range of fractions of parts per billion) and in orders of magnitude higher concentrations (but still only at the parts per million level) in the various coexisting solid phases: suspended and deposited sediment and the marine biota. Very basically, these metals are only "trace" because various physical and chemical processes remove them from solution to immobile "sinks," largely into the sediments. Marine organisms may naturally concentrate--often on a selective basis--very large amounts of a range of metals. Man, however, has a rather biased interest in the concentrations of metals in organisms that he consumes directly, or are major steps in the food web ending in species that are consumed.

Trace heavy metals are carried into the oceans, whether from natural or anthropogenic sources, largely via the rivers. On a geological time scale, open ocean soluble concentrations are steady-state; i.e., as much metal is removed as is added. As already noted, the sediments are the major repository for the fractions removed from solution and these processes are largely completed within the estuarine-coastal environment (see Burrell, 1975, for a more detailed account). For this reason most research to date on marine metal pollution has focused on the fresh-saline interface areas. It has been suggested, in fact, that because of the various efficient scavenging mechanisms that operate close to shore, open-ocean metal pollution is unlikely to be a major cause for concern. One important characteristic of OCS exploitation, however, is that it represents a source for heavy metals to be deposited directly on the Continental Shelf and thus by-pass the natural estuarine "screening" mechanisms.

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[5] Extracted from: Burrell, David C. (1975): Environmental Assessment of the Northeastern Gulf of Alaska: Chemical Oceanography (Trace Metals), First Year Final Report to the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Contract No. 03-5-022-36, Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 50 pp.

Trace Metals Associated With Crude Oil

Crude oil itself contains trace quantities of certain of the heavy metals. This has led to the erroneous supposition that it is this specific restricted suite of metals that is of sole concern in the various OCS impact programs. The actual metal content ranges are not well-known, again mainly because of the poor analytical techniques that have been applied to date. Table 77 reproduces two recent compilations that are believed to be among the best available. Vanadium, nickel, iron, and zinc appear to occur in fairly high concentrations in these crudes and the possibility of commercially extracting vanadium from this material has been seriously suggested in recent years. Both the vanadium and nickel porphyrin complexes have been studied for many years, but it would appear that additional significant quanitities of these two metals are associated also with the asphaltic fraction. This may be so also for the other listed trace elements, but this is mostly speculative, and some workers, (e.g., Filby, 1975), have suggested that the supposed contents are associated not with the oil *per se*, but with foreign particulate material contained within the oil.

Regardless of the actual contents of metals in the various crude fractions, this source (i.e., direct spillage of crude oil into the ocean) could only result in insignificant and probably undetectable perturbations in the water column because of diluting and mixing. The volume of foreign organic liquids likely to be added to the seawater must be even less than for the previously considered formation waters. This source appears to be of potential concern in one respect only; namely, that these particular metal fractions may be held in solution as stable organo-metallic complexes. Such an enhanced solubilization phenomenon related to petroleum in natural waters has been suggested by Bugel'skii and Tsimliyanskaya (cited by Davis, 1968).

The Importance of Trace Metals Associated With the Sediments

The major threat to the normal, "buffered," oceanic trace metal regime posed by offshore industrial activity lies in potential perturbation of the geochemical environment of the surface sediments.

The deposited sediments constitute a vast reservoir for trace metals; they are, under normal conditions, a sink for metals naturally removed from solution. The geochemical environment of the sediments differs from the

Table 77. Trace Metal Contents of Crude Oils.

	Alberta Crudes[a] Av. concs (ppm)	Calif. Crudes[b] Ranges (ppm)
Ag	---	---
As	0.10	0.06- 1.0
Cd	---	---
Cr	0.09	0.01- 0.02
Co	0.05	0.20- 10.00
Cu	---	0.24- 6.33
Fe	10.80	16.80- 85.50
Hg	0.05	0.08- 30.00
Mn	0.10	0.73- 2.54
Ni	9.38	140.00-265.00
Pb	---	---
Se	0.05	0.40- 1.40
V	13.60	---
Zn	0.46	7.40- 85.80

[a] Hitchon _et_ _al_. (1975).

[b] Shah _et_ _al_. (1970).

overlying sea water; i.e., there is disequilibrium between the water and sediment and between various zones within the sediment itself (e.g., Mannheim and Sayles, 1974). Considerable efforts are currently being devoted to determining the existence and magnitude of chemical gradients (both positive and negative) for the major constituents across the water-sediment interface. There are indications also in some environments (e.g., for copper in fiord estuaries; Heggie, unpublished data) for trace metal migration from the surface sediments into the overlying water.

Contamination of the surface sediment from OCS activity may exacerbate these natural interface reactions. Only small changes to the chemical environment--availability of organic complexing ligands or changes in the redox environment for example--could result in large fluxes of metals from the sediment into the water column. Lags may occur within this sequence; the often expressed fear (e.g., Meadows and Meadows, 1973) of harmful effects appearing long after the application of the pollutional stress is very real. The persistence of harmful reactions beyond the time when the cause has been suppressed is an obvious corollary. Such hysteresis is dangerous because remedial actions may not be taken in time to avert considerable damage to the environment.

Previous Work

A search of the relevant literature has uncovered no available data for the heavy metal contents of water, biota, or sediment in the Gulf of Alaska proper. A few numbers exist for one or two specific estuaries, and assays for mercury have apparently been made on a few seafood species (halibut, for example), although no hard data has been located. Data from a previously completed study on selected heavy metals in salmon that migrate through this area (currently unpublished) are included in this report. In most aspects the work reported here is both unique and timely.

OBJECTIVES

The primary objective of this first year's program has been to determine the baseline distribution of the present heavy metal contents of water, biota, and sediment within the Gulf of Alaska. Because these trace constituents are transported in solution and are available for uptake by the biota, analysis of the soluble contents has been a major initial objective.

Although it was originally proposed to delay work on sediments until the essential ancillary sedimentological information could be obtained by geologists working with splits of the same samples, the sediment analysis program was started during the third quarter of the contract without these descriptive parameters.

A literature search for data on metal distributions in the Gulf has been a minor yet essential objective, because of the lack of information on trace element distributions. Initial efforts were concentrated on obtaining an overall baseline inventory. The program has been designed, however, to emphasize the cycling (i.e., transport rates and routes) of the heavy metals in subsequent years.

This program also requires continuing research on analytical methodology.

THE STUDY AREA

Water column and bottom sediment samples for this program were collected on the standard hydrographic grid shown in Fig. 35. It was initially intended to take water samples only on those stations at which nutrients were to be analyzed. However, because of the poor station coverage obtained on most of the cruises, in practice, this scheme has not been closely adhered to.

Biota samples were to have been collected by the various biological co-investigators. By the deadline date, samples from the intertidal working group only had been received and analyzed. The localities for these latter specimens are also given in Fig. 36 and Table 78.

PROCEDURES

Metals Selected for Study

Nickel was selected because of its direct association with crude oil, but zinc, chosen primarily on other criteria, could well be similarly classified. The remaining metals selected for study--mercury, cadmium, copper, zinc, lead--are both important anthropogenic pollutants and (except mercury) exceedingly sensitive to available analytical techniques.

Both copper and zinc are essential constituents of organisms but may be toxic if excess amounts are present. More is known of the marine distribution and behavior of these two elements than of any other heavy metal,

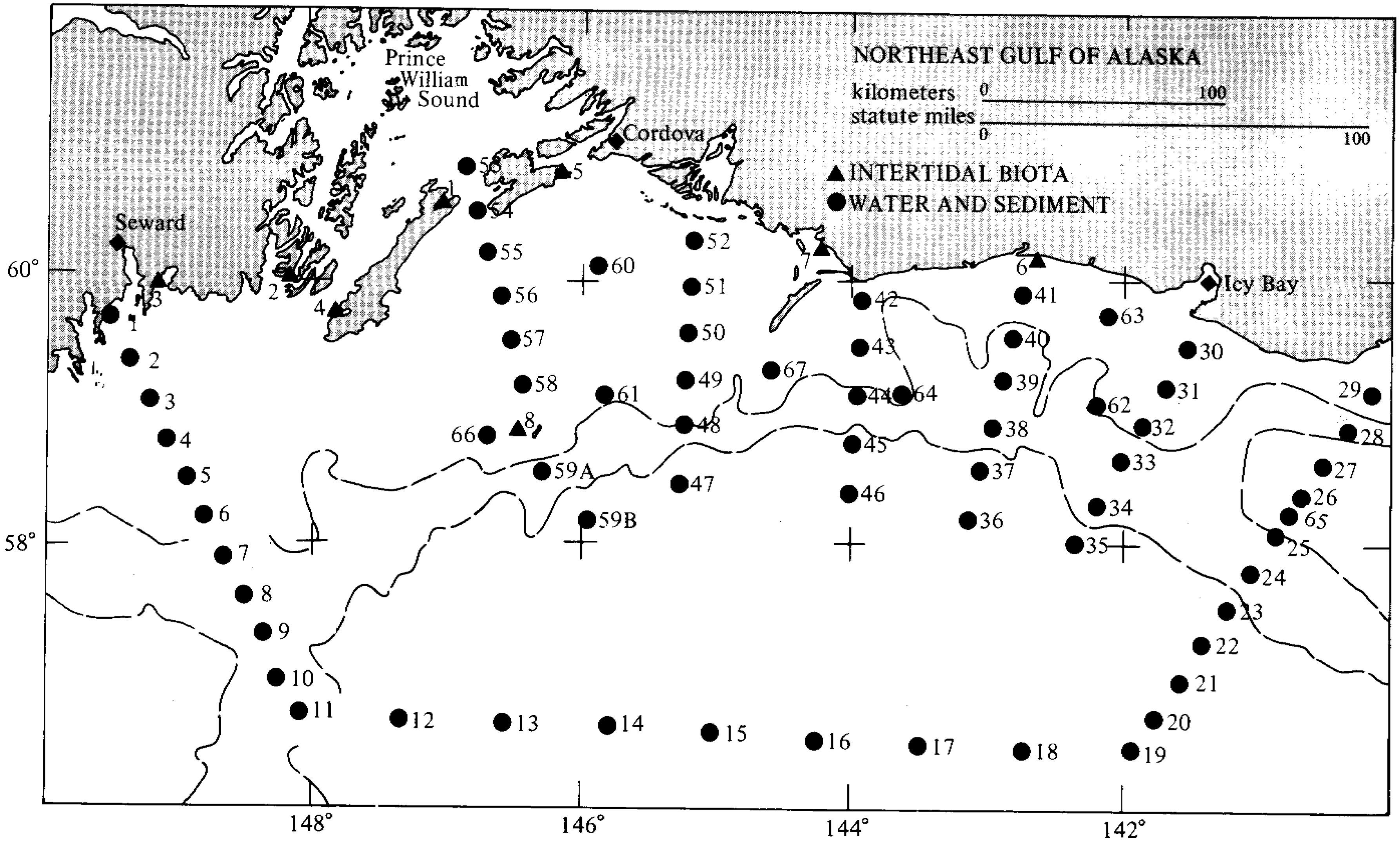
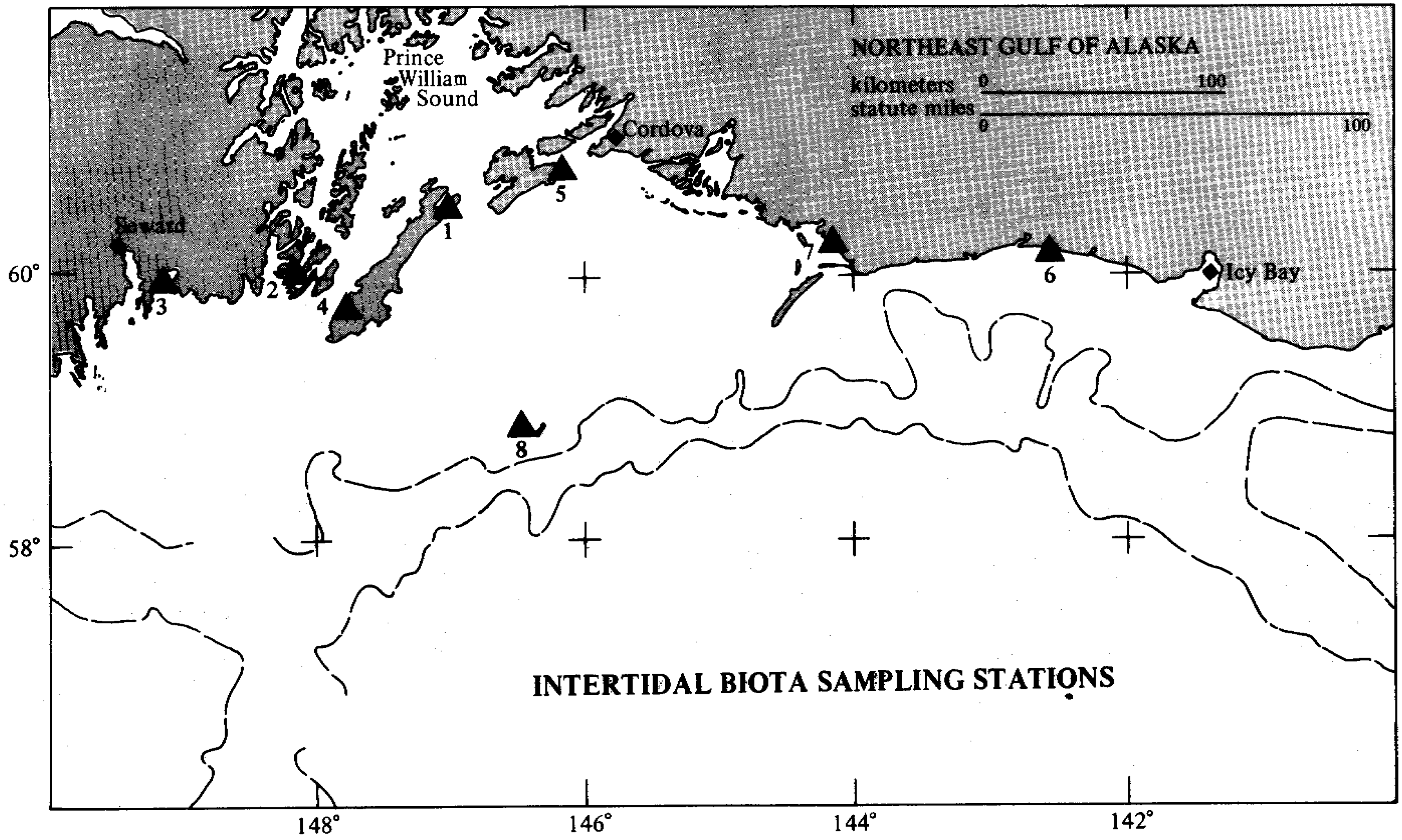


Figure 35. Water column and bottle sediment samples collected on the Standard Hydrographic grid.



INTERTIDAL BIOTA SAMPLING STATIONS

Table 78. Intertidal Biota Sampling Stations.

Sites are shown (▲) in Figure 34

Site No.	Locality	Lat. (N)	Long. (W)
1	Zaikof Bay	60° 17'	147° 00'
2	Squirrel Cove	60° 01'	148° 08'
3	Anchor Cove	59° 59'	149° 05'
4	MacLeod Harbor	59° 53'	147° 47'
5	Boswell Bay	60° 24'	146° 06'
6	Yakataga	60° 05'	142° 27'
7	Katalla	60° 14'	144° 31'
8	Middleton Island	59° 30'	146° 20'

so that there is a framework of knowledge that should eventually aid in interpreting the data. Cadmium and lead have no known biological function (the evidence for cadmium is equivocal, however.) Both lead and zinc are readily scavenged from solution onto solid surfaces (this causes acute analytical problems). Cadmium, which might be expected to behave similarly to zinc, appears to be less prone to scavenging, although the evidence is scanty and sometimes conflicting. Mercury is the metallic pollutant of greatest current concern. This element also represents that important group of metals (arsenic, antimony, etc.) that may be remobilized from passive inorganic reservoirs *via* volatile organic complexes.

Sample Collection

Water and sediment samples have been collected on every available and accessible oceanographic cruise into the study area. It was initially hoped to completely sample the standard hydrographic grid for sediment samples, and the designated nutrient stations for water. In practice, available station coverage has been spotty and both water and sediment have been collected at as many of the hydrographic localities as possible. Trace metal samples were collected on R/V *Acona* Cruise No. 200 in October (1974), NOAA Ship *Oceanographer* cruise in February (1975), R/V *Acona* Cruise No. 207 in March, and the more recent NOAA Ship *Townsend Cromwell* cruise (May, 1975), but these last samples were too late for analysis and inclusion in this report.

Water samples were collected in wire-hung trace metal-free Niskin bottles, at variable depths, but usually near to the surface and the bottom. Two 125 mℓ subsamples for electroanalysis--one filtered through a 0.4 μ Nucleopore membrane--were acidified and stored frozen. A larger sample (∿ 2ℓ) for nickel analysis, acidified but unfiltered, was stored frozen in 1 gallon cubetainers, and 10 mℓ samples (where taken) for subsequent atomic spectrometric analysis were treated and stored as described by Burrell (1974) and Lee and Burrell (1975). No other on-board processing of the water samples was attempted.

Sediment samples were taken on the standard hydrographic stations associated with the benthic biology program. All samples recorded in this report were extracted from van Veen grabs. Samples were taken from the center of the grab to avoid contamination from the body of the sampler.

Biota samples have been collected for us by biologists associated with the OCS program as described below.

Biota

Since it is clearly impossible to analyze a very large number of organisms in a program such as this, it has been necessary to identify a few "index species." There now exists considerable literature describing the uptake of metals into particular organisms that have been selected as useful indicator species of wide applicability. Such are various mollusks (Huggett et al., 1973) and seaweeds (Bryan and Hummerstone, 1973).

The expertise of the biological personnel associated with the program has been relied on almost entirely to aid in selecting and collecting a small number of suitable index species. Specimens of *Mytilus edulis* and *Fucus distichus* have been received from the intertidal zone and data for these are given below. Because of the importance of the sediments as the source of potentially remobilized metals, it was originally decided to look at various open ocean benthic species, with a bias toward those of commercial importance. Unfortunately, no such samples for analysis have been received from the trawl survey operations. One mixed sample of Gulf tanner crab has been purchased however, and values for this are included in this report. All biota samples were shipped frozen but otherwise unprocessed.

Analytical Techniques

Water Analysis

Table 79 gives preferred methods for determining precisely a range of soluble heavy metals in seawater. A thin film, anodic stripping voltammetry for cadmium, copper, lead (at pH 2.5), and zinc (at pH 8) were used. Initially a number of procedures were researched for nickel (especially pulsed polarography on a HMD electrode), but the method finally was conventional flame atomic absorption spectroscopy following chelation and extraction into MIBK (Brooks et al., 1967). This is not an ideal procedure but it has been used by many other people, so that these data should include the same systematic errors. Some values for cadmium have also

Table 79. Analytical Techniques Suitable for Determining Heavy Metals in Seawater.

Analytical	Heavy Metals																
Techniques	As	Ag	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	Sb	Se	V	Zn
AA - Flameless	x	x		o			x		x	x		x	x	?	?		x
AF		?		x					x								
AS - Thin film							o		?				o				x
Pulse Polarog.	?											x					
NAA - Instrum.					x			x						x			x
NAA - Prechem.	x	x	x		x	x			x	x					x		
Isot. D.I.			o	?			o						o				
GLC						?						?			?		
Color	x							?				x					
AE	x																

o = preferred method
x = suitable technique

been obtained using flameless atomic spectrometric techniques, since research on these has been proceeding in the laboratory concurrently with the OCS program (Lee and Burrell, 1975).

Biota Analysis

All biota samples were freeze-dried before weighing and dissolution, and all data were expressed on a dry weight basis. The dissolution technique applied to the freeze-dried organic material is simple modification of the nitric acid vapor oxidation of Thomas and Smythe (1975), with an additional hydrogen peroxide reaction (e.g., Tolg, 1970). This method was chosen not only for ease and rapidity, but also for minimizing potential contaminations from reagents. Subsequent mercury analysis has been by cold vapor atomic spectroscopy after reduction to the metal (Burrell, 1974), and analysis for copper, cadmium, nickel, and zinc was by conventional flame absorption spectroscopy.

Sediment Analysis

The sediment leaching technique advocated by Chester and Hughes (1967) was used to obtain the data cited in this report. This procedure--a combined acid-reducing treatment--removes both absorbed species and the ferromanganese minerals that are thought to be important scavengers. A weak acid treatment (e.g., acetic acid) is insufficient to remove the ferromanganese minerals, whereas hydrochloric acid, for example, attacks the lattice structure of some clays (Rays et al., 1957). Extracts from the sediments were analyzed using conventional flame absorption techniques.

RESULTS AND DISCUSSION

Biota

The broader question of correct statistical sampling of the biota has not been addressed. Both *Mytilus edulis* and *Fucus distichus* samples have been analyzed exactly as received from the intertidal biology program. The entire soft parts of *Mytilus* were separated and combined to produce each sample. Shell material was discarded, as were the crab carapaces. Unfortunately, individual parts and organs of the crabs were not subsambled. The organs were not sampled scientifically but were a mixed batch purchased from a commercial fisherman who collected them from the Gulf off Prince William Sound.

Each organism was analyzed in duplicate (Table 80). Table 81 shows results for combined *mytilus* samples from two different areas and for two NBS standards, the analytical precision in terms of a percent coefficient of variation on replicate analysis (between three and eight determinations). Overall analytical precision appears to be worse for copper but is well within the usually accepted range for all elements. In recent years, trace metal chemists have tended to cite the accuracy of their determinations of marine biota in terms of the only two widely available National Bureau of Standards (NBS) reference materials having comparable matrices: orchard leaves and bovine liver. A comparison of the data for these standards, together with the provisionally certified NBS values, is given in Table 82. The accuracy of heavy metal analyses of biota would appear to be excellent. No non-systematic errors have appeared and the dissolution technique developed for this program has proved to be very suitable.

The heavy metal contents of various functional parts of the organism have not been analyzed. This is unfortunate since whole-organism analysis does not give a fair picture of the concentration of metals, or consequent potential harm resulting from this. Heavy metals may be particularly concentrated, for example, in organs such as the liver or kidneys. Very frequently, the parts of the organism consumed by man contain considerably lower concentration of the pollutant metals than would be indicated from a total analysis, e.g., crab muscle versus the "brown" meat.

The two principal indicator species worked on in this study--*Mytilus* and *Fucus*--have both been excellent, sensitive indicators of environmental pollution in various parts of the world. Many authors have demonstrated marked differences between metal contents found in the same species in adjacent polluted and non-polluted waters, and even quite marked seasonal fluctuations. The metal contents from the Gulf of Alaska *Mytilus* samples are reasonably comparable with those from unpolluted waters of New Zealand (Brooks and Runsby, 1965). This organism should prove to be most useful as a monitor of future perturbations of the environment. The present areas showing somewhat higher concentration of copper and zinc, for example, are Squirrel Cove, Anchor Cove, and Yakataga. The reasons for this are unknown at this time. Mean heavy metal contents of *Fucus* samples for a relatively unpolluted site in Europe are: cadmium, 2.3 ppm; copper, 4 ppm; nickel,

Table 80. *Trace Elements in Biological Materials from the Gulf of Alaska. All values are means of replicate determinations and are expressed in mg/kg dry weight.*

Station	Cd	Cu	Hg	Ni	Zn
Mytilus					
Squirrel Cove	4.3	15.8	0.15	<10	146
Boswell Bay	3.2	9.5	0.33	"	64
Anchor Cove	5.8	10.4	0.20	"	126
Zaikof Bay	4.5	8.7	0.34	"	120
MacLeod Harbor	4.3	9.8	0.26	"	111
Yakataga	4.8	16.4	0.43	"	171
Fucus					
Squirrel Cove	1.3	3.5	0.25	<10	12
Boswell Bay	1.2	13.1	0.72	"	9
Anchor Cove	1.6	9.3	0.29	"	17
Zaikof Bay	1.3	2.5	0.44	"	5
Yakataga	2.2	37.3	0.09	"	25
Middleton Island	1.5	7.2	0.04	"	12

Table 81. *Precision Data (% coefficient of variation) for Metals in Mytilus Samples from two Localities and NBS Standards.*

Material	n	Cd	Cu	Zn
Mytilus No. 1	8	4.4	12.3	5.1
Mytilus No. 2	3	9.4	5.1	2.9
Orchard leaves	6	---	13.2	6.5
Bovine liver	6	---	2.5	3.3

Table 82. *Accuracy: Analysis Values (and standard deviation) for NBS Standards (µg/g dry weight).*

	This Study	NBS Certified Values
Orchard Leaves		
Cadmium	<0.50	0.11 ± 0.02
Copper	12.1 ± 1.6	12 ± 1
Mercury		0.155 ± 0.015
Zinc	21.6 ± 1.4	25 ± 3
Bovine Liver		
Cadmium		0.27 ± 0.04
Copper	185.8 ± 4.6	193 ± 10
Mercury		0.016 ± 0.002
Zinc	128.6 ± 4.2	130 ± 10

12.3 ppm; zinc, 75 ppm (Fuge and James, 1973). Again the data for the Gulf of Alaska are comparable or lower. It would be expected that these algae also prove useful pollution indicators as this program develops.

Values for the salmon specimens taken from the Gulkana River in 1972 illustrate the trend for heavy metals to accumulate in organs, such as the liver or kidneys, rather than in muscle tissue. Data for Tanner crab samples also appeared to show a trend of increasing copper content as a function of carapace size. Such an increase with age of the organism has been frequently observed for many species and in many areas.

Sediment

It has not been possible to test the accuracy of the sediment extract data (Table 83), because no suitable standards exist. No obvious anomalies are apparent. Meaningful discussion of the data is impossible until the complementary sedimentological work can be incorporated.

Water

A large number of uncertainties are associated with the analysis of soluble heavy metal fractions in seawater. Three separate instrumental analytical procedures have been used in this study. Two of these--filament atomic absorption spectroscopy, and anodic stripping voltammetry--are being actively developed in the laboratory, and tests for the precision of various sampling and analytical operations have been incorporated. Unfortunately, there is, at present, no way of evaluating the accuracy of an analysis for soluble contents, and there are too few published compilations available that would provide a confident "oceanic mean value" against which various program data could be tested. Much of the historical data for soluble seawater trace metals can probably be safely discarded, and there has been a general trend toward considerably lower (and narrower) concentration ranges for all the common heavy metals. The "mean" values recently compiled by Brewer (1975) have been selected from the *lowest* ranges cited in the most recent literature (Table 84); this is especially so for silver and lead. Trace metal analysis is plagued with potential sources of non-systematic error, and certainly contamination (addition) error is the commonest problem. It is not, however, entirely safe to assume that the lowest ranges are

Table 83. *Heavy Metal Contents of Sediment Extracts (µg/g dry weight)*

Station No.	Cd	Cu	Ni	Zn
30	*	7.6	4.5	9.9
31		29.7	2.5	6.1
32		19.3	2.9	12.1
34		20.7	3.5	14.6
41	*	22.5	6.9	16.9
40		23.4	6.0	17.1
37		9.3	7.3	16.4
42	*	18.9	5.5	15.7
43		24.1	5.6	17.3
44		16.6	6.4	15.5
52	*	31.4	12.3	24.5
51		19.7	8.9	16.4
49		25.8	6.2	17.6
48		14.1	6.9	15.9
53A	*	31.1	12.0	25.9
53		12.4	7.6	13.0
55		14.9	9.2	14.6
56		8.3	8.4	9.1
57		14.2	7.1	12.9
58		13.4	4.6	16.5

* All Cd data <0.3 µg/g.

Table 84. *Most Recent Published Compilation of Soluble Contents of Heavy Metals in Seawater.*

Element	Soluble seawater conc. (µg/ℓ)[a]
Ag	0.04
Cd	0.1
Cu	0.5
Ni	1.7
Pb	0.03
Zn	5

a - Brewer (1975).

Table 85. *Precision Data (% coefficient of variation) for Replicate (n=5-9) Determinations of Individual Samples by Anodic Stripping Voltammetry (Cd, Cu, and Pb at pH 2.5; Zn at pH 8).*

Sample No.	Depth (m)	n	Cd	Cu	Pb	Zn
04	0	5	20	13	8	----
50	0	6	----	----	----	14
51	0	8	15	19	11	----
51	40	9	----	----	----	18
52	0	6	----	----	----	28

necessarily more accurate. Absorption and other removal processes may be equally troublesome, and it has been previously demonstrated (Burrell, 1974) that the two elements cited above are prime culprits in this respect, especially silver.

The analytical method used for nickel is relatively routine, but time consuming, and we have not measured precision in any regular fashion. This procedure has appeared to give good results in other areas (e.g., Spenser et al., 1970). The data range reported here is somewhat lower than the 1.7 μg/ℓ value of Table 84. We have not yet been able to duplicate any of these nickel analyses using an independent technique.

Copper, cadmium, lead, and zinc have been determined by differential pulse anodic stripping voltammetry, zinc at pH 8, the remaining elements at pH 2.5. Analytical precision values (i.e., percent coefficient of variation for replicate determinations of the sample) for this technique are listed in Table 85.

Initial analyses were performed on samples filtered through a 0.45 μ membrane filter. This is the conventional cut-off for particulate soluble fractions. On each of the subsequent cruises, however, two parallel sets of samples were taken, one filtered, the other unfiltered. Both sets of filtered samples gave results that were higher than the unfiltered. The filtering operation has presumably caused additional contamination errors, and the values shown in Table 86 are for unfiltered water. It is felt that reference to these as soluble fractions is justified, since the suspended load is exceedingly low in the open Gulf at this time of year.

All four of the metals plus silver determined voltammetrically, have also been analyzed by carbon filament atomic spectroscopy. The precision of this method is indicated in Table 87. The close correspondence may be judged as indicative of the accuracy of both methods for analyzing this metal. Values determined for copper, lead, and zinc, however, were consistently higher by filament absorption spectroscopy than the voltammetric data. The reason for this is unknown, but different chemical species may be involved; electrochemical methods determine the "free" ion present at the analysis pH, whereas the absorption method of Lee and Burrell (1975) determines that fraction chelated by dithizone at seawater pH. The convention of citing the lower set of concentration values has been followed in this

Table 86. *Soluble Contents of Heavy Metals (µg/ℓ) NOAA Ship Oceanographer - February 1975.*

Station No.	Depth (m)	Cd	Cu	Ni	Pb	Zn
30	0	0.10	0.55	0.70	0.44	1.30
32	250	---	---	0.60	---	---
33	0	0.10	0.45	0.55	0.35	(10.00)
	250	0.06	0.45	---	0.14	1.70
	350	0.22	0.46	0.30	0.30	2.80
35	0	---	---	1.00	---	---
37	0	0.11	0.40	0.60	0.18	3.10
	200	---	---	0.90	---	---
	1000	0.10	0.27	0.95	0.17	1.20
46	0	0.11	0.45	0.70	0.27	2.90
	500	0.20	0.29	0.90	0.39	2.80
	1000	0.14	0.17	0.90	0.10	1.10
52	0	0.14	0.59	0.65	0.25	1.20
51	0	0.05	0.59	0.80	0.23	2.90
49	0	0.07	0.54	0.60	0.18	0.80
48	0	0.10	0.43	0.70	0.17	1.10
	250	---	0.39	0.55	---	1.30
47	0	0.10	0.56	0.70	0.66	1.30
	170	0.13	0.40	---	0.39	1.30
	400	0.20	0.32	---	0.23	1.00
53A	0	0.06	0.52	---	0.67	1,80
	250	0.10	0.50	---	0.30	0.85
53	0	0.10	0.42	---	0.70	2.20
	200	0.10	0.23	---	0.28	1.30

Table 87. *Precision Data (% coefficient of variation) for Filament Atomic Absorption Analysis of Chloroform Extracts from Seawater (after Burrell and Lee, 1975)*

Reservoir[a]	Cd	Cu	Pb	Zn
Tube		4.0	6.0	----
Cavity		5.7	----	5.5
Reservoir[b]	**Cd**	**Cu**	**Pb**	**Zn**
Tube	----	11.0	11.5	
Cavity	9.0	12.6	8.2	

a. Replicate (n=10) injections into two types of filament reservoir from single extract.

b. Single injections from multiple (n=10) extractions from sea water samples into the same atomization reservoir designs.

report, but it is not possible, given the present state of the art, to resolve these differences. There is least confidence in the lead data, since recent inter-laboratory evaluations (using isotope dilution techniques as the standard) have shown that both atomic absorption and electroanalytical methods tend to yield values that are too high.

The soluble heavy metal values for open Gulf of Alaska waters show no uniquivocal trends; none were expected. These "normal" seawater values may be taken to be the unpolluted baseline. No anomalies are apparent adjacent to the Copper River, but this is not unexpected since the "estuarine reaction zone" would be considerably shoreward of the closest station. Values for cadmium, copper, and zinc, did, however, appear to be higher at Station 53 at the entrance to Prince William Sound. Several of the surface samples, particularly for zinc, were much higher than for the same stations at depth. This is presumably caused by inevitable contamination at the surface near the sampling vessel. There is, however, an indication of a possibly "real" increase near to the bottom at many localities.

CONCLUSIONS

Baseline trace heavy metal levels have been established for a limited number of samples of water, sediment, and biota taken from the Gulf of Alaska. No areawide geographic trends are apparent from the soluble data. Slightly higher levels possibly occur adjacent to Prince William Sound. No seasonal trends were detected. The heavy metal contents of the biota analyzed--mussels, seaweed, crab, and salmon--fall within the ranges published for similar species from unpolluted regions of the world. For some metals, ranges are even lower than those generally cited from elsewhere. Certain localities show higher contents, but the number of samples is far too small for this to be statistically meaningful at this time. There is no backlog of data for this area which would supplement and allow better interpretation of the findings. Copper levels in crab appear to increase with carapace size, i.e., approximately with age. No conclusions regarding the levels determined for sediment extracts are possible at this time until some sedimentological description is available.

IMPLICATION OF CONCLUSIONS

The baseline levels of trace metals in the Gulf of Alaska are as low or lower than in those other unpolluted areas of the world studied to date. Perturbation of these existing distributions by industrial activity on the shelf or in coastal regions could be relatively more important here than in other regions.

FUTURE WORK

The following are some of the major points which will be emphasized in future studies:

1. Intercalibration of analytical methods for seawater analysis, especially using neutron activation analysis.
2. Emphasis on one or two detailed standard vertical water analysis stations and considerably more emphasis on the coastal/estuarine regions.
3. Continued use of mussels and seaweed as index species and evaluation of other species as selected by the biologists.
4. Differentiation of trace metal contents of various parts of organisms.
5. Evaluation of other extraction systems for sediments and of relationships between determined heavy metal fractions, sedimentological characteristics, and metal contents in coexisting benthic fauna.

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9. PHYSICAL OCEANOGRAPHY[1]

INTRODUCTION

Before the studies initiated by the OCS program in July 1974, approximately 360 hydrographic stations had been occupied in the area bounded by 58° to 61°N. latitude and 139° to 150°W. longitude. One of the earliest studies of the region was in 1927 and 1928 (McEwen *et al*. 1930). They occupied section lines normal to the coast near Yakutat and Montague Islands; 21 stations were in our study region. From 1954 through 1959, Dodimead *et al*. (1963) studied the Northeast Pacific Ocean and occupied 125 stations in the northern Gulf of Alaska OCS region. Unfortunately, the seasonal distribution was poor; over one-half of the stations were occupied in the third quarter of the year and none in the fourth. In the 1960's, 109 stations were sampled with a similar seasonal distribution. Hydrographic data gathered in the region by the Russians in 1961 and 1962 are generally not available but are discussed in some detail by Plakhotnik (1964) who also summarizes the other studies in the Gulf of Alaska.

The first STD study of the gulf was in 1967 (Roden, 1969). A station line out of Seward was begun in 1970 but has been occupied infrequently. Data from this line are approximately one-half of all hydrographic data available for the region from the National Oceanographic Data Center (NODC). The north-south line running out of Seward represents the only existing data on the seasonal variability of the waters in the study region (Royer, 1975).

Previous current studies for the Gulf of Alaska include the above investigations inasmuch as the baroclinic portion of the geostrophic current was calculated. Previous drift-bottle studies were limited by long trajectories and small recovery rates, but they did demonstrate a westward drift near the study region. An early current meter installation near Hinchinbrook Entrance gave evidence of westward flow. A drogue study near Middleton Island in 1972 yielded a 20 cm/sec westward drift.

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[1] Extracted from: Galt, J.A. (1975): Physical Oceanography, First Year Final Report to the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Pacific Marine Environmental Laboratories, Seattle, Washington, 72 pp.

OBJECTIVES

The purpose of the physical oceanography program is to examine advective and diffusive processes as they relate to potential pollution problems associated with OCS petroleum development. In pursuit of this goal, the following general objectives were defined:

1. Describe the general water circulation in the study area for each season, including indications of downstream flow for advective time scales of approximately a week;
2. Determine the variability of currents and obtain indications of spatial coherence;
3. Obtain a preliminary understanding of mixing and dilution processes;
4. Describe characteristic waves and weather;
5. Develop a numerical model to aid in the interpretation of results and explore simple dynamic processes.

STUDY AREA

The hydrographic survey used in this study covers approximately 925 nmi (nautical miles) of cruise track and occupies 59 standard stations (Fig. 37). The plan has an inner and outer array of stations; both were sampled six times during the year.

The outer array will be used to describe conditions downstream from the study area, offshore (representing oceanic flow) and along the expected inflow boundary. The downstream line running south-southeast out of Seward repeats the stations occupied by Royer and thus ties the survey with 3 years of seasonal historical data. Stations are spaced every 10 nmi, except along the offshore leg where they are 25 nmi apart.

The inner array consists of five station lines crossing the Continental Shelf and concentrating on the potential lease area. The easternmost three lines measure the flow over the complex bathymetric features found here on the Continental Shelf. The next line of stations extends out from the Copper River Delta and describes the river water mixing across the shelf. The stations from Prince William Sound out past Middleton Island should also help define the mixing of the Copper River effluent with the waters of the Gulf of Alaska, as well as gather data on conditions along the expected outflow boundary of the lease area.

Closely spaced STD stations were placed along lines normal to the coast to study small-scale ($\simeq$2 km) variations and to assess the magnitude of aliasing of the data obtained at stations spaced farther apart. In addition, to assess

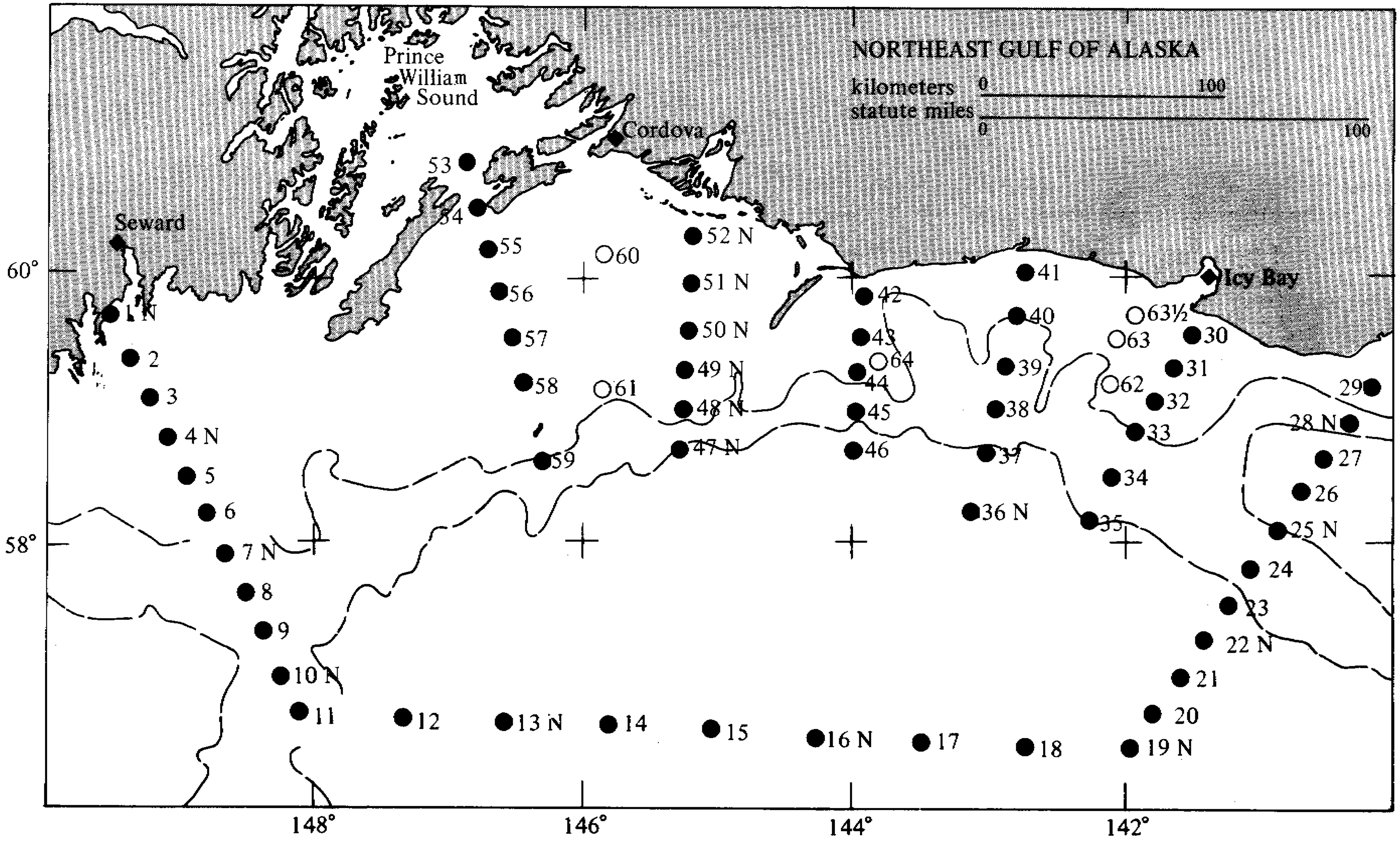

Figure 37. STD and current meter stations.

the temporal variations, a small number of stations were repeatedly sampled at 1-hour intervals.

METHODS AND SOURCES OF DATA

Hydrographic data were collected with the following equipment:

Plessey 9006 STD
Plessey 9060 STD
Plessey 9040 CTD
Plessey 9400 data logger
Nansen Bottles
Niskin Bottles

The methods of acquiring and processing STD data were similar to those described in Halpern _et al_. (1973) and Holbrook and Halpern (1974).

Current meter data were collected with Aanderaa RCM-4 current meters, and the ensuing magnetic tapes were processed by PMEL's Aanderaa tape system.

In addition to radiosondes, ship-board observations, and acoustic sounding equipment, meteorological data included satellite photos (from NOAA 2 and 3); data from environmental data buoys EB-03 (56°0'N., 147°9'W.) and EB-33 (58°5'N., 141°0'W.), installed and serviced by NOAA's Data Buoy Office (National Ocean Survey) National Weather Service, and Fleet Numerical Weather Service, Monterey, California.

The vibration for collecting wave data did not operate. The wave-rider aspect of this task lacked logistical support due to a delay in the Wave Propagation Laboratory program. However, construction of a large HF skywave radar facility on San Clemente Island (off San Diego, Calif.) was completed May 1, 1975. The facility is to be operated in a joint NOAA/Navy research program. The first phase of this program is to assess the radar's accuracy and capability for measuring sea state (i.e., significant wave height, dominant wave period, and mean wave direction) over about 5 million square kilometers of the North Pacific and Northeast Gulf of Alaska (Fig. 38).

The objective of the research phase just beginning is to gather sea-echo data for all times of the day and seasons of the year, process the signals, extract the sea-state data digitally, generate (in near-real time) computer maps of sea state over the North Pacific, and finally to assess the accuracy of these computerized techniques by comparing them with actual sea-state data from the area. Since completion of construction, over 30 hours of observations have already been gathered. These sea-echo Doppler spectra have thus far been measured: (1) over

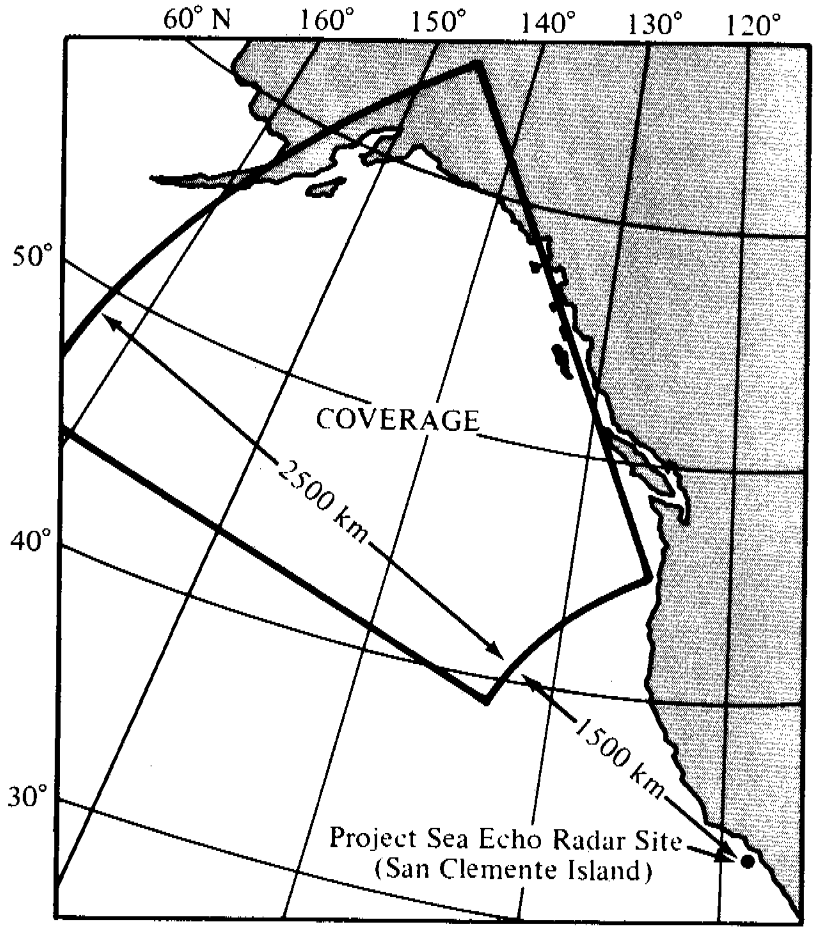

Figure 38. Measurement of Sea State for North Pacific and Northeast Gulf of Alaska.

a sector exceeding 5 million square km in the North Pacific for a 3-hour period, (2) at nighttime, and (3) to "one hop" ranges as great as 3750 km (reaching the southern coast of Alaska). Each of these three items is a "first" compared with past observations. The sea-echo signal spectra produced by the computer/ processor thus far generally exceed the quality of similar results taken sporadically over the past 10 years at similar radar facilities. These encouraging data appear to justify the investment in this facility, primarily for sea-state observations (rather than for defense applications).

The primary limitations on the technique are from unknown signal distortions imposed by the ionosphere during the radar-wave propagation. For this reason, the digital processing software that extracts sea-state data from the averaged sea-echo spectra is not yet working automatically to our satisfaction, hence no wave-height data or "sea-state" maps are yet available. Software modifications are proceeding in this area, and by October 31 the system should be able to produce automatically such sea-state data for comparison with ship and buoy data.

Near surface circulation studies used AMF vector-averaging current meters. EG&G current meters, and a wind recorder. Mooring configuration and data processing procedures are described by Halpern _et_ _al_. (1974).

RESULTS

Cross-sections and vertical profiles for time-series stations of temperature, salinity, density, and isotachs have been prepared. This information is being synthesized and incorporated into the overall analysis. Weather observations from radiosondes, oceanographic vessels, environmental data buoys (EB-03 and EB-33), and nearby stations such as Middleton Island have been used to estimate geostrophic and surface winds, wind stress and curl. The coastal upwelling parameter from Bakun (1972) has been calculated at 60°N., 149°W. for the past year's study and compared with previous years.

Analysis of density-field data indicated that the sampling scheme was adequate to resolve major hydrographic features in most regions, an exception being the shelf area west of Cape St. Elias where smaller scale features tend to dominate the distributions.

An Aanderaa tape processing system, including both software and hardware, was developed and refined. Using this system, Aanderaa current meter tapes can be reduced to the standard format agreed upon by PI's and Project Office personnel and present the results in 2 to 3 weeks. This system can also reduce the number of Aanderaa pressure gauge tapes, which will expedite data reduction for FY 76 sea-slope studies.

Comparison of meteorological data from EB-33, Fleet Numerical, NWS, and ship-board observations showed mixed agreement in the pressure-field. As expected from observations made during Cruise 805, outflow or katabatic winds resulted in a highly variable onshore-offshore windfield.

Good agreement was found between the general circulation of the Northeast Gulf of Alaska as inferred from density-field measurements and as generated by the diagnostic model. The direct observations of the currents also compare well with the diagnostic model, particularly for the flow direction. The further refinement of the "working-model" to include baroclinic constraints is expected to result in current speeds even more representative of those measured.

DISCUSSION

Hydrographic Properties

The analysis of temperature and salinity data is a useful way to gain some information about large- and intermediate-scale flow. Once water is away from the surface, the temperature and salinity of any particular parcel are conservative (i.e., they change only through mixing). This means that water from various sources can be identified and traced as it moves from one region to another. The STD or CTD cruises that were carried out in the Northeast Gulf of Alaska provided a number of useful data sets that can be analyzed in this way.

As a point of departure, consider the analog trace that would be obtained from a typical hydrographic station in deep water off Yakutat. Figure 39 is the record from Station 18 taken during the July 1974 cruise on the *R/V Acona.* The salinity increases monotonically with depth, but there are several distinctive features that can be identified in the temperature trace. Most apparent is the subsurface temperature minimum of 80m and the maximum at 130m. Both represent water that was not formed locally. This water took on its characteristics somewhere else and was carried into the region by the currents that are themselves part of the larger Gulf of Alaska circulation.

Concentrating first on the deeper temperature maximum, we can identify this as water formed near the surface, well south near the North Pacific drift (probably at the sub-arctic convergence) (Sverdrup et al. 1942). As the current turned north and formed the large-scale counterclockwise gyre in the Gulf of Alaska, this water was swept along with surface water that was more dilute and consequently lighter. This forced the warmer and more saline water below the surface where it continued at approximately the level of the $\sigma_t = 26.5$ surface layer.

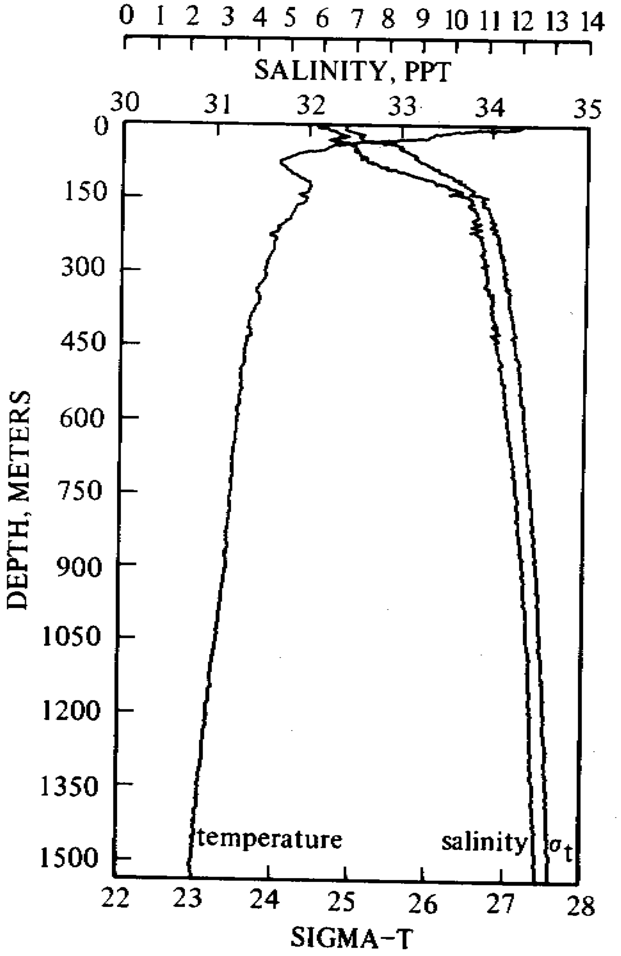

Figure 39. Temperature, salinity and σ_t distributions at Station 18, July 1974.

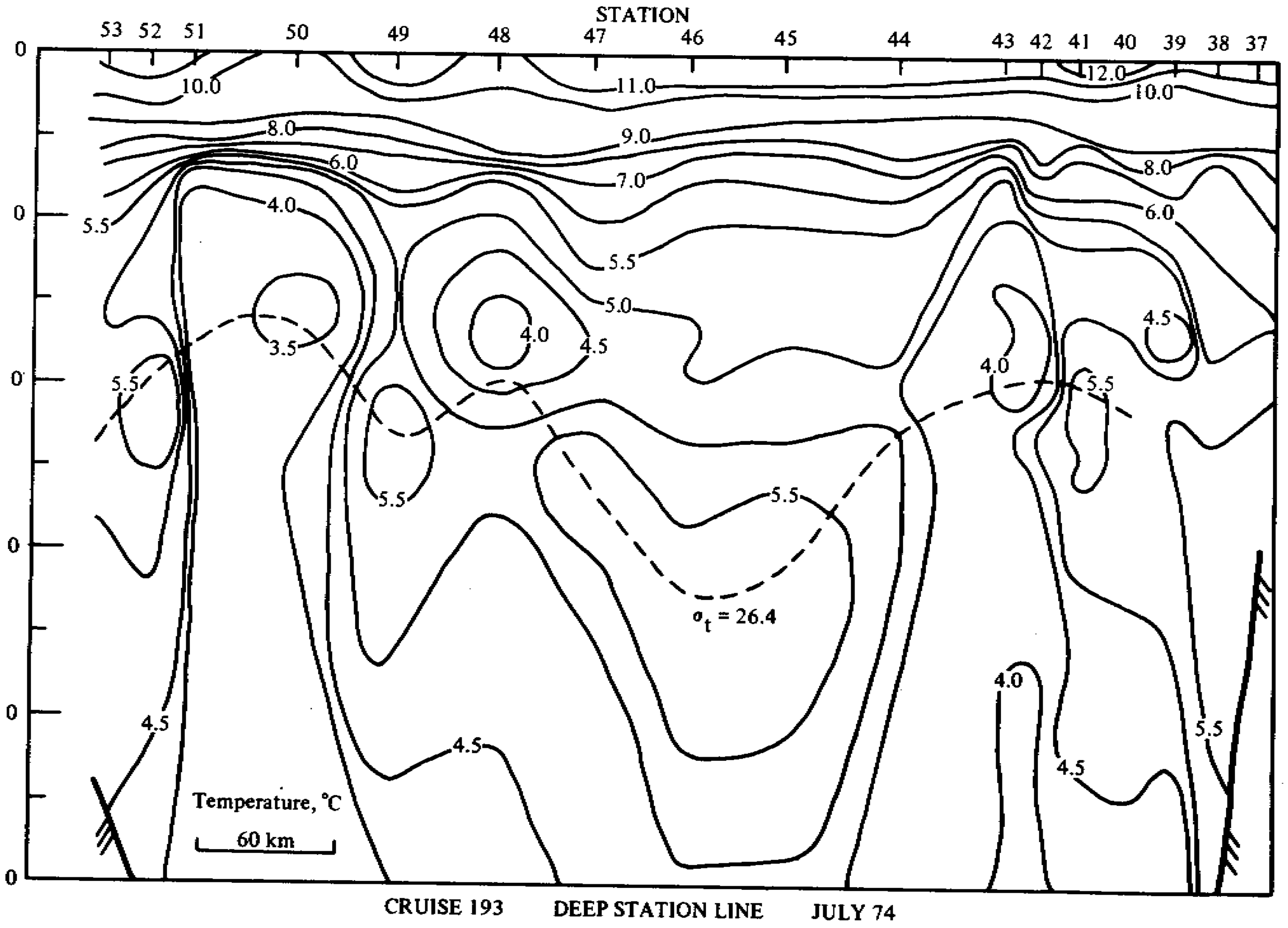

Figure 40. Vertical temperature distribution along the deep station line July 1974.

The distribution of this warm layer then indicates the path along which this water is carried.

Figure 40 gives the temperature distribution around the outside of the region of interest. (For reference, the viewer would be looking north at a vertical section with Seward off the page to the left and Yakutat off the page to the right.) These data were collected in July 1974 during the first few days of the study. The warm water was clearly not in a uniform layer, but in relatively narrow filaments. Thus the stronger flow from the south enters the region in a narrow stream at Station 21(>5.5°C at 130 m). The same water seems to leave the region, at least in part, between Stations 17 and 15, and then surprisingly, it re-enters at Station 13 and finally leaves at Station 10. The fact that this is the same water can be confirmed by plotting the depth of the σ_t = 26.4 surface. This has been done in Fig. 40 with a dotted line clearly linking the isolated filaments of warm water together. Between the places where the warm water enters and leaves the region, the cold water layer becomes more apparent (i.e., at Stations 20 to 19 and 12). The relatively complex distribution of the σ_t = 26.4 surface suggests a clockwise intermediate-scale gyre along the boundary of the region. From what little historical data are available, it is believed this may be an anomalous situation (personal communication Dr. F. Favorite, NMFS).

The next relatively complete set of STD data was collected from the NOAA Ship *Oceanographer* cruise in February 1975. Once again, these data were examined to determine the position of the warm subsurface layer, or filament. A plot of temperature on the σ_t = 26.4 surface is shown in Fig. 41. Here, a belt of temperature >5.5°C is found flowing east-to-west over the continental slope. The actual temperatures in this layer were well above those found during the summer with the maximum actually over 6.2°C. It takes this water roughly 6 months to travel from the surface around the gyre to this region of the Gulf of Alaska. Once again, these data suggest that the current splits in the eastern part of the region off Yakutat.

An additional complete set of STD data was collected from the NOAA Ship *Surveyor* in June 1975 as well as partial data from the NOAA Ship *MacArthur* in August 1974 and from the NOAA Ship *Rainier* in April 1975. Analyses of these data have been undertaken and a more complete discussion of the results is presented in the original report.

From the temperature and salinity data examined thus far, conjectures can be made regarding the large-scale currents of the region. A study of the large clockwise gyre just offshore (1974 data) shows that the June 1975 data are un-

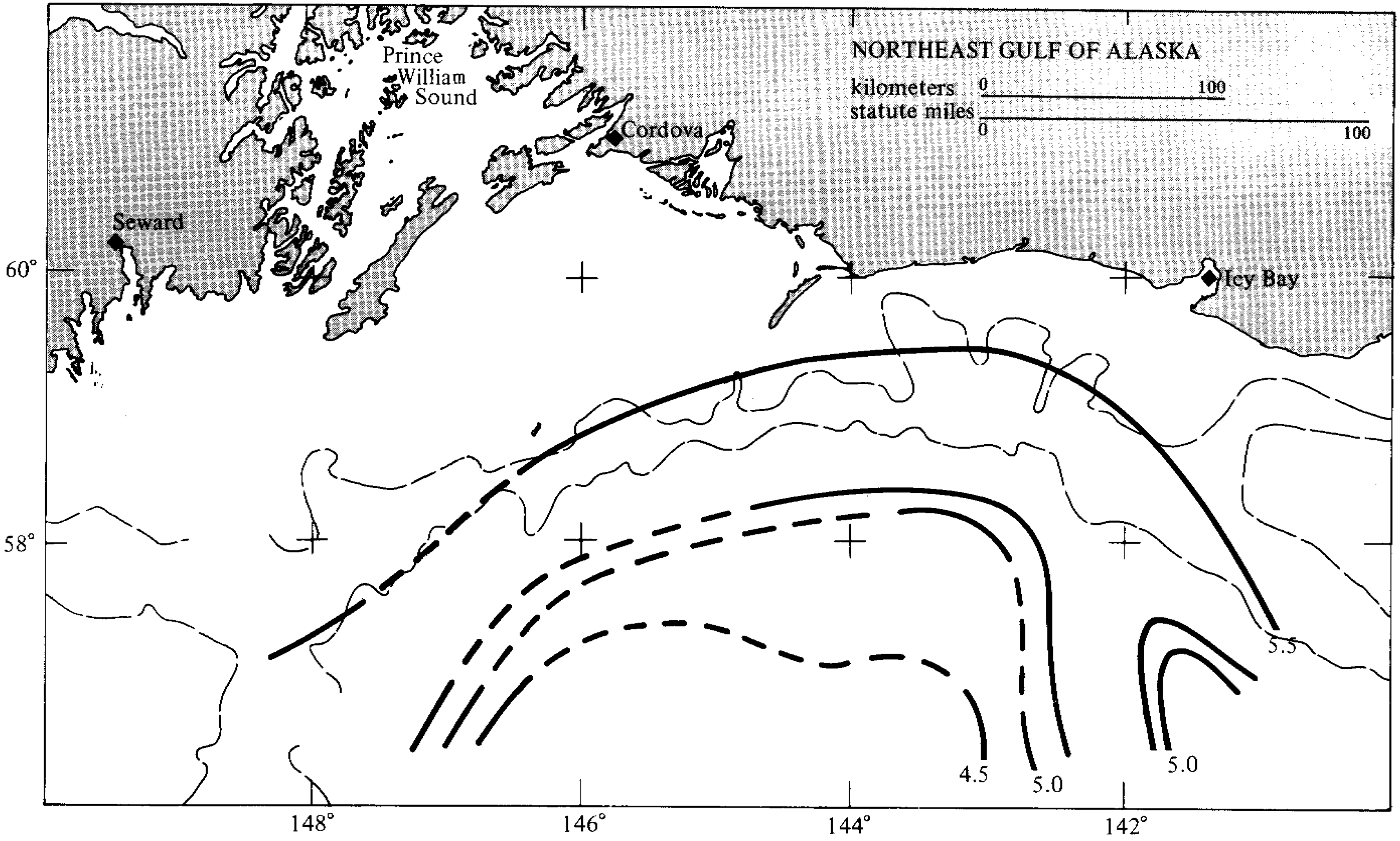

Figure 41. Plot of temperature on the $\sigma_t = 26.4$ surface.

like those of July 1974. There is no way to determine from the available data, how common this type of gyre is.

The currents in the eastern segment of the region (Yakutat to Cape St. Elias) are influenced year-round by part of the large-scale Gulf of Alaska circulation, flowing near the shelf break and following the 150 m isobath. In this region the Continental Shelf is narrow and the influence of the current will reach quite close to shore (a few tenths of kilometers). The tendency of the currents to follow the bathymetry indicates that the flow is approximately in the same direction from top to bottom, although vertical shear is likely. The first-order currents in this area are not locally driven. This means that large-scale perturbations in the flow, like the anti-cyclonic gyre, cannot be explained without more knowledge of the much larger system. In particular, the entire Gulf of Alaska, or Northeast Pacific, generates this current and would have to be examined to understand the detailed dynamics of the flow.

In the western segment of the region (Cape St. Elias to Seward), the warm layer current associated with the Alaska Stream moves offshore and the relatively wide shelf behind Middleton Island is largely free from the influence of winds, shelf topography, and discharges from the Copper River and Prince William Sound are much more pronounced.

The description thus far has concentrated on the largest scale feature that appears to represent somewhat mean or average conditions over the entire year. Superimposed on this flow is a complex series of time-dependent variations. The hydrographic data can once again be examined to provide some initial estimates of the transient behavior.

Station 53 (the innermost station on the Seward line) has been occupied irregularly since 1970. It provides an opportunity to ascertain the seasonal changes at a point on the shelf in the Gulf of Alaska. The salinity changes demonstrate a strong annual input of fresh water at the surface from late spring through late fall. Coincident with the decrease in surface salinity is an increase in near-bottom salinity. The source for this near-bottom water is near the shelf break. Its intrusion onto the shelf is probably the result of large-scale wind stress changes over the region since the monthly mean upwelling index (Royer, 1975) is well correlated with these changes in the near-bottom water. The index represents the onshore-offshore component of the Ekman wind drift transport. Upwelling indicates surface water moving offshore with near-bottom water moving onshore to replace it. The reverse occurs for downwelling. The strong downwelling during the winter appears to flush the shelf waters onshore-offshore annually.

This effect presumably occurs to some extent all along the shelf and acts as a first-order perturbation to the warm water current associated with the Alaska Stream. Seasonal changes in the density structure give a better insight into the possible spatial dependence of this wind-driven effect.

Vertical profiles of temperature and salinity (and density) were measured along a line normal to the coastline near Icy Bay in February and in May. In February, the spacing between stations was 18 km; in May the station spacing was 2 km. The depth of the isolines of σ_t varied considerably along the onshore-offshore direction during May Betwen 35 km and 40 km offshore, all the isolines slope downward toward the coast. During winter the shelf waters were more homogeneous (horizontally and vertically) than in summer. In winter the 25.0 to 27.75 σ_t band was nearly level and located between 100 and 160 m below the surface, and the surface baroclinic geostrophic current at 100 m deep was approximately 1 cm/sec at 20 km to 40 km offshore. In May the 25.50 to 25.75 σ_t band was at the surface 50 km from the coast and at the bottom 20 km from the coast. The inclination of the isolines of density produced horizontal gradient currents, and these data can be used to estimate the shear in the water column. The surface baroclinic geostrophic current referenced to 100 m deep at 25 km to 40 km offshore was about 12 cm/sec toward the northwest. The more intense baroclinic geostrophic flow observed in May could represent a summertime shoaling of the Alaskan Stream when light winds prevailed, or a relaxation of the winter downwelling condition.

During the summer this current shear effect is at its maximum; however, there is still no evidence that it is likely to set up a countercurrent. Thus in summer, the flow in the lower layer may be somewhat reduced or sluggish compared with the winter, but along the coast the direction appears to be uniformly westward.

On an even smaller scale, the flow will vary in time and space with the tides, individual storms, and a variety of different waves. These kinds of variations are inherently difficult to examine in the density data; however, some time series CTD measurements were collected at several locations and they provide some interesting examples. The mixed layer depth appears to be dominated by an oscillation at approximately semidiurnal tidal frequency. This suggests an internal tide with an amplitude of about 10 m. A similar series collected in February at Station 63 showed that along the bottom a layer of water about 10 m deep intruded suddenly in just a few hours.

In summary, the hydrographic data support the idea of a fairly stable mean circulation dominated by the Alaska Stream and modified by an onshelf-offshelf perturbation correlated with regional winds. Superimposed on this are significant smaller scale (in both time and space) variations related to storms or tieds (and probably otherthings as well). There appears to be a difference in the dominance of the Alaska Stream in the regions east and west of Cape St. Elias. On the east, global forcing seems more important and the stream's influence is close to shore. On the west, the stream is well offshore and local forcing appears to be more significant.

Direct Current Measurements

Current meters have particular value in circulation studies because they provide direct, not inferred, values; they provide continuous measurement with high frequency resolution; and they can operate untended. Major difficulties in using current meters include their high expense, lack of spatial coverage, and measurement at a point that does not give the trajectory of water flow (unless spatial coverage is very thorough). The initial results of this study can be considered in terms of scale.

First, consider the longer period or quasi-steady components to the flow. To obtain a rough estimate of these, simply average the currents for a week and present them as a mean progressive vector diagram for that week. In most cases this approach effectively removes most of the tidal signal.

The first data to be considered came from Station 2, located in the western segment well up on the shelf between the mouth of the Copper River and Middleton Island. The observations cover 8 weeks during July to August 1974. The upper layer, the flow was quite small, indicating a substantial baroclinic shear (about 14 cm/sec).

Current data from Station 1 extending from August to November 1974 were examined in the same way. This station is located near the edge of the shelf midway between Middleton Island and Cape St. Elias. In this case, the flow was agin generally to the west and surprisingly consistent in its direction, particularly in the upper meter. The seasonal build-up throughout October and November was pronounced, although the lower layer did not exhibit the same response. The general direction of the flow corresponds closely to the local bathymetric contours, and regardless of the season it appears that the steepness of the bottom slope dominates the flow direction along this segment of the shelf break.

The results from Station 62 cover 23 weeks from August 1974 to February 1975. Once again, an upper and lower meter were examined. The station is located near the shelf break offshore from Icy Bay. As before, the direction of the flow was remarkably consistent except for a short period late in December when it was weak and had a pronounced easterly drift. Most of the time, the flow was north-northwest at both levels, with weaker flow at depth. As in the results from Station 61, the flow shows a marked increase through the fall and tends to align itself along the local isobath. Both of these features are consistent with the barotropic pressure gradient that would be created with the build-up of seasonal downwelling in response to the winter wind regime.

Current meter data also provide a means for examining higher frequency response to storms. For example, at a site 25 km off Icy Bay, the vector-averaged mean value of near-surface currents for February 3-10 was about 12 cm/sec to the northeast. After a storm arrived on February 11, the current speed was about 44 cm/sec toward the west-northwest and was 25° to the right of the wind, which was 17 m/sec.

Currents recorded at 10 m above the bottom at Station 63 showed a similar response to the passage of the February 11 storm. Before the arrival of the storm, the vector-averaged mean current speed was 3 cm/sec. During the storm, the vector-averaged mean current speed increased to 21 cm/sec. The direction of the storm-generated current near the bottom was almost the same as the direction of the current near the surface.

Vector-mean values of the current averaged for a day were not nearly as large as the vector-averaged hourly values of the speed. The direction of the daily averaged values of the current was generally onshore at both the top and bottom of the water column. During February 11-15 when winds were very strong, the entire water solumn appeared to be flowing northwest and west at 30 km/day at the surface and 20 km/day near the bottom.

The preliminary analysis of the current meter data presents a picture basically consistent with that developed from the hydrographic data. The large-scale quasi-steady flow in the eastern region reflects a stronger flow dominated by components that follow the bathymetric contours. The flow on the shelf in the western region is weaker and more variable, at least in the summer.

In addition current meter data have added new insights into the current regime. The clear build-up of the currents during the fall gives a measure of their response to the seasonal change in the wind forcing (downwelling). In addition, the relatively rapid response of the currents to the passage of an intense storm is evident and of considerable interest.

Meteorology

At their regional office in Anchorage, the NWS produces pressure maps of the Alaska area every 6 hours. These were forwarded to PMEL; the pressure fields were digitized and calculations carried out for geostrophic winds, surface winds, wind stress and curl.

A third source of regular wind data was EB-33 station south of Yakutat off the Continental Shelf. It is interesting to compare these three cited independent sources of data, which show that there is substantially better agreement on the north-south component of the winds than for the east-west component. This is not surprising since the east-west winds depend on the north-south pressure gradients, not very well resolved by any of the available data. In contrast to this, the north-south winds depend primarily on pressure data along the coast, which is fairly well sampled in the inputs to the NWS.

Long-shore wind stress proves to be fairly sensitive to the onshore-offshore pressure gradients. This component of the stress is also of fundamental importance in diagraming the upwelling or downwelling cycles as well as the potential path of any spilled pollutants. The appropriate scale length for the pressure field normal to the Alaskan coastline must be determined so as to address these questions properly. In an effort to look at these variables, some lower atmosphere measurements were made in February in conjunction with a cruise of the NOAA Ship *Oceanographer*.

Early in February there was an extreme outflow of cold continental air which caused a very unstable air-sea temperature difference of approximately 8°C. This could be expected to result in intense air-sea heat exchange with subsequent modification of the atmospheric boundary layer. Radiosonde data from a station line normal to the coast showed that the boundary layer grew quickly in the first 30 to 50 km off the coast. This may well define the appropriate scale for wind shear along the coast.

From these data, a simplified concept of this cold air breakout was developed (Fig. 42). The question of influence of these breakouts on the coastal weather patterns, or frequency of occurrence, is of considerable interest in this study.

Diagnostic Modeling

A diagnostic circulation model is being developed for use with the hydrographic data and wind stress data. This model can be used with various combinations

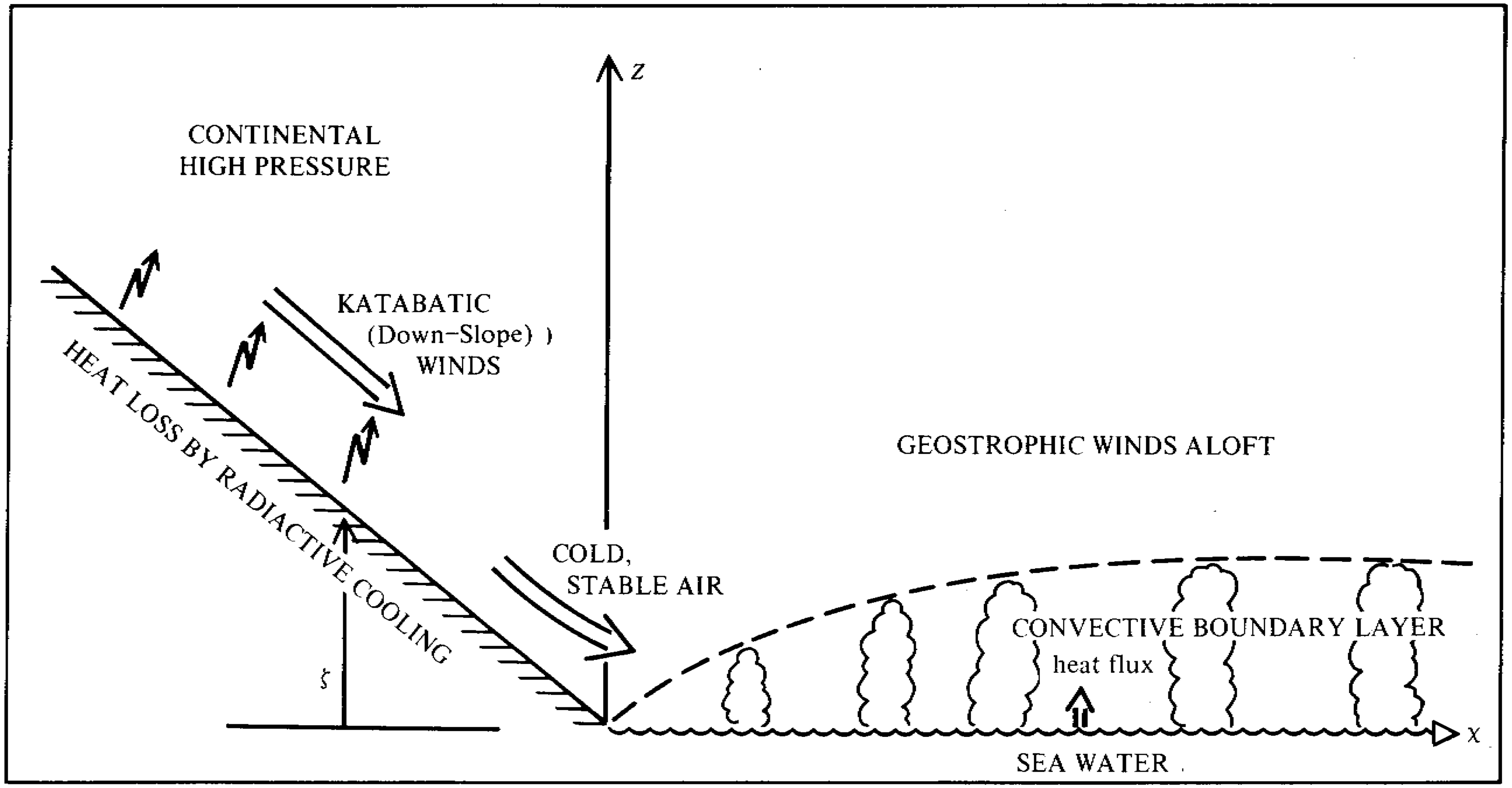

Figure 42. Simplified model of cold air advection and boundary layer formation during winter breakout.

of boundary conditions and compared with the results from the current meter measurements. The theoretical and software development is nearly complete. Tests have used idealized geometries and simplified density distributions. In addition, a preliminary run has been made using a realistic geophysical configuration. This run used boundary conditions (sea-surface elevation around the perimeter of the region) derived from the July 1974 hydrographic data, but included no wind stress or stratification. The resulting sea surface elevation and direction of flow are given in Fig. 43.

Only the dominant flow characteristics are presented, and thus the weaker circulation between Middleton Island and Prince William Sound does not appear. The clockwise gyre along the outer boundary of the region is evident. In addition, the appearance of the relatively stronger currents along the edge of the shelf in the vicinity of the Alaska Stream is encouraging. In every case the direction of the flow is consistent with the directions observed from current meter moorings. The continuity constraints imposed by the geometry of the system clearly make it possible to put together a dynamically consistent representation of the flow. With careful numerical modeling, the implications of the limited observational data can be greatly extended.

Thus far, the hydrographic data, direct current measurements, and numerical modeling studies have contributed to a reasonably coherent description of the general flow characteristics of the region. A preliminary understanding of the dominant seasonal changes seems within grasp. The shorter period variations and possibilities of anomalous situations have been indicated, but to date the cases have not been definitively described. Large quantities of valuable data remain to be analyzed. Key problems that should be addressed by the ongoing research have been identified.

CONCLUSIONS

In preliminary findings, the hydrographic data have revealed the persistence of the warm layer, associated with the Alaska Stream, moving along the bottom at the 150 m level. This clearly offers a relatively warm region for benthic animals in the Outer Continental Shelf region. In addition, the warmest season for this domain is in winter when temperatures are higher than 6.5°C.

The hydrographic data and general understanding of wind patterns suggest a relatively strong onshore motion of surface waters during the fall and winter. Contrasted to this, during the summer there is weak offshore motion, thus leaving the dominant flow along bathymetric contours. This suggests that the study of oil spill trajectories for the Gulf of Alaska by Stewart *et al.* (1974) may be

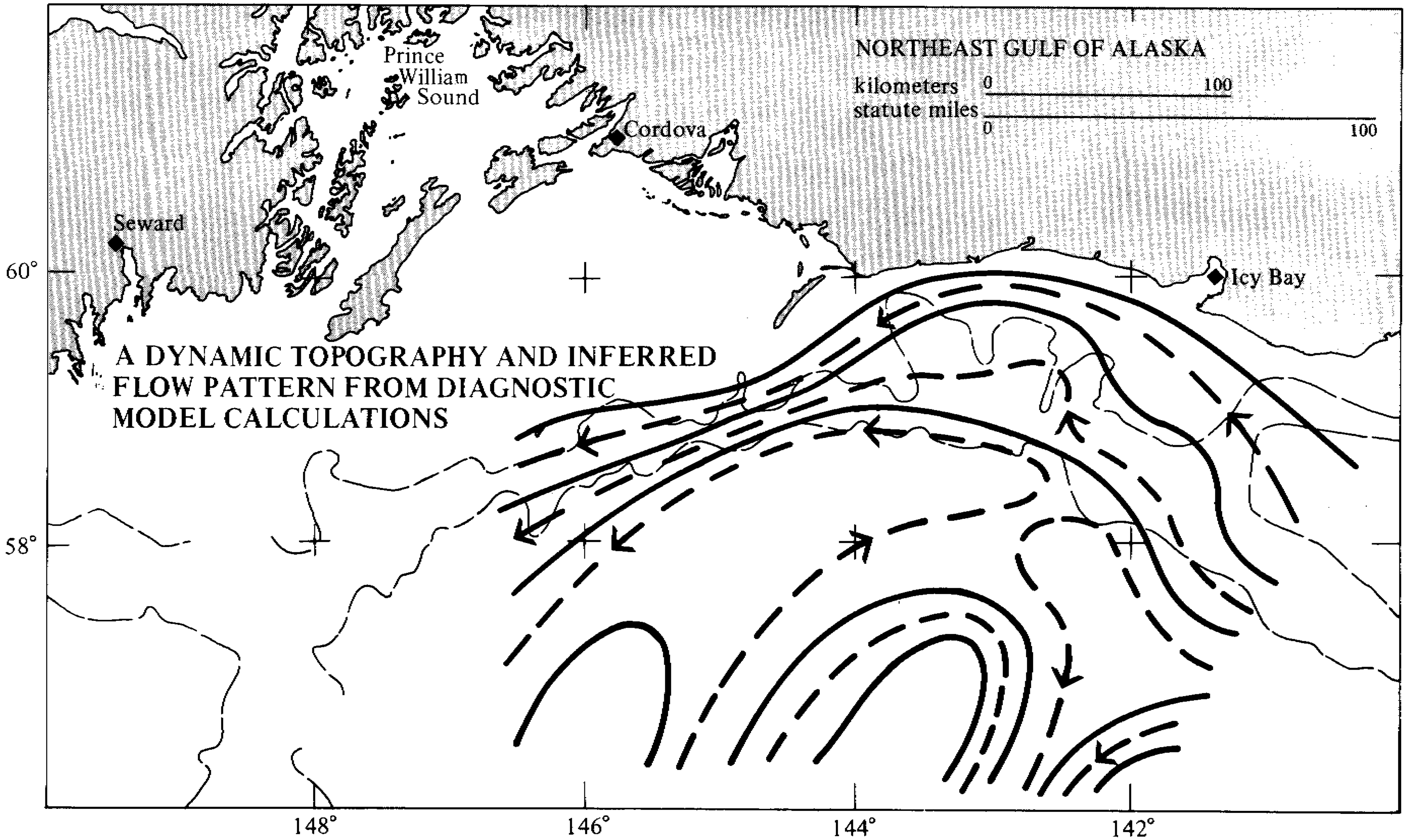

Figure 43. Sea surface elevation and direction of flow.

in error when it predicts probabilities of oil transported onshore higher in summer than in winter. In reviewing that report, it appears that the authors used wind data from a coastal station that was perhaps strongly influenced by fiord topography (e.g., Seward). In addition, the wind drift term in their model did not include any consideration of Ekman dynamics. This would tend to cause their trajectories to go to the left of a more realistic drift (Tayfun _et al_. 1973). The surface transport calculations of Bakun (1973) seem to represent a more realistic basis for trajectory modeling.

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10. GEOLOGY[1]

INTRODUCTION

The U.S. Geological Survey began its field program in the Gulf of Alaska OCS in September and October 1974 with a cruise to the study area aboard the University of Washington's *R/V Thomas G. Thompson.* This cruise completed all the marine geophysical parameters outlines in the "Scientific Plan for Marine Geology and Seismicity Baselines." Sediment sampling was not attempted from the *Thompson.* Two later cruises aboard NOAA ships, *Surveyor* (April-May 1975) and *Cromwell* (May-June 1975) added more geophysical data and approximately 400 sediment samples. In all, over 12,000 km of high resolution seismic data were collected within the study area.

The required level of navigational accuracy necessary for the data collection and replication was obtained. On the *Surveyor* and *Thompson,* the majority of navigation was "Satellite Navigation" joined by periods of dead reckoning. On the *Cromwell* navigation was generally dead reckoning using Raydist as a guide. All maps and charts produced from these data are internally consistent and relatively correct in the sense of absolute position. In fact, it is estimated that the data collected are as good as 99% of all previous oceanographic surveys. Fig. 44 shows the location of the *Thompson* tracklines, Fig. 45, the *Surveyor* tracklines and Fig. 46, the *Cromwell* sediment samples.

The "Scientific Plan" outlines end products as (1) surface sediment distribution, (2) major geologic features, (3) suspended sediment analysis, (4) geochemistry and (5) earthquake location. The first two are described in detail in this report. Three and four are not included as no data were collected in FY 75.

SURFACE SEDIMENT DISTRIBUTION - NORTHERN GULF OF ALASKA

During September and October 1974, high resolution seismic profiles covering approximately 6500 km of tracklines (Fig. 44) were collected from the Northern Gulf of Alaska aboard the *R/V Thomas G. Thompson.* Analysis of the profiles plus shipboard descriptions of surface sediment samples collected in May and June 1975 by the NOAA *FRS Townsend Cromwell* (Fig. 46) were used to generate a surface sediment distribution map (Fig. 47) for the northern Gulf of Alaska between Montague Island and Yakutat Bay.

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[1] Extracted from B. Molnia, P. Carlson, T. Bruns, and P. Quinterno (1975): Environmental Assessment of the Northeastern Gulf of Alaska U.S.G.S.-N.E.G.O.A. Geology Project, FY 75 Year End Report to NOAA, U.S. Department of Commerce.

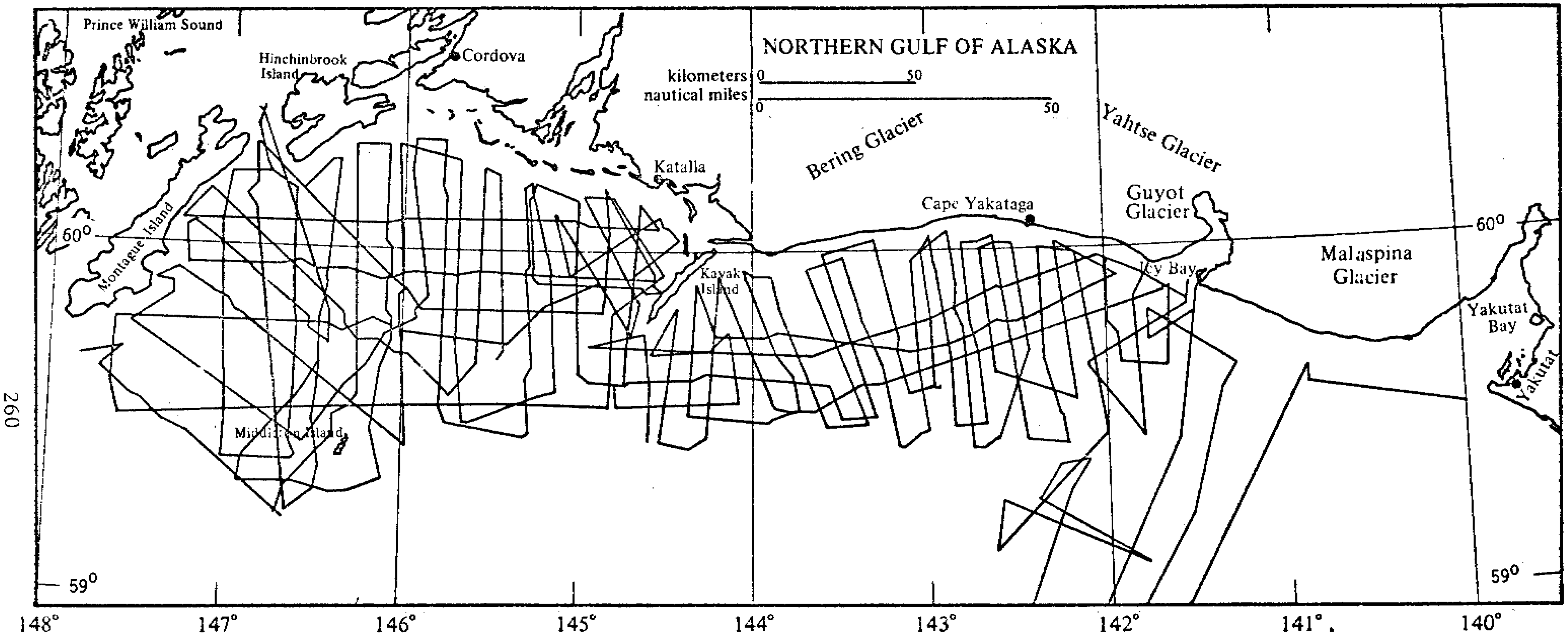


Figure 44. Trackline map of the R/V Thomas G. Thompson *cruise (September - October, 1974).*

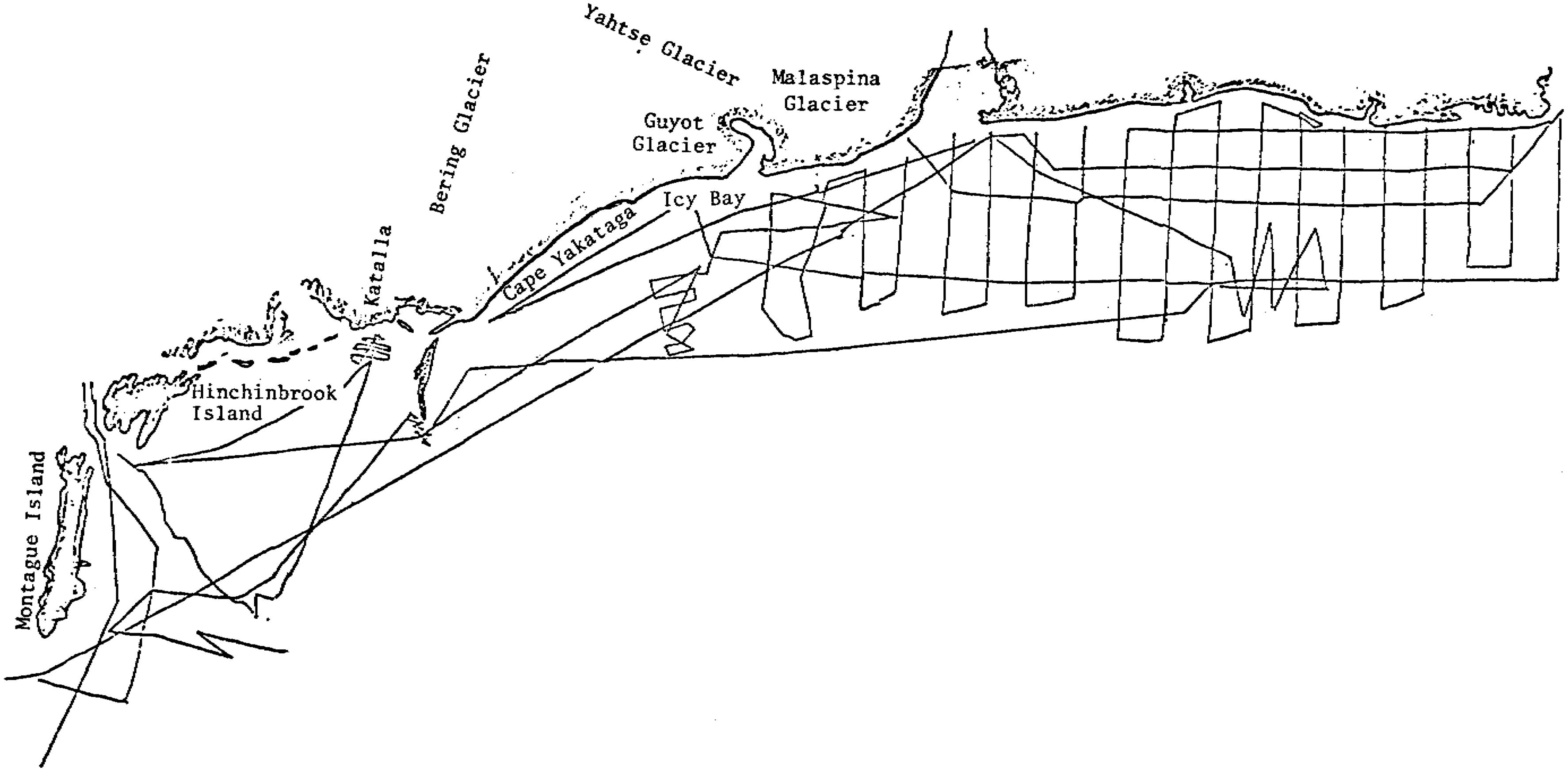
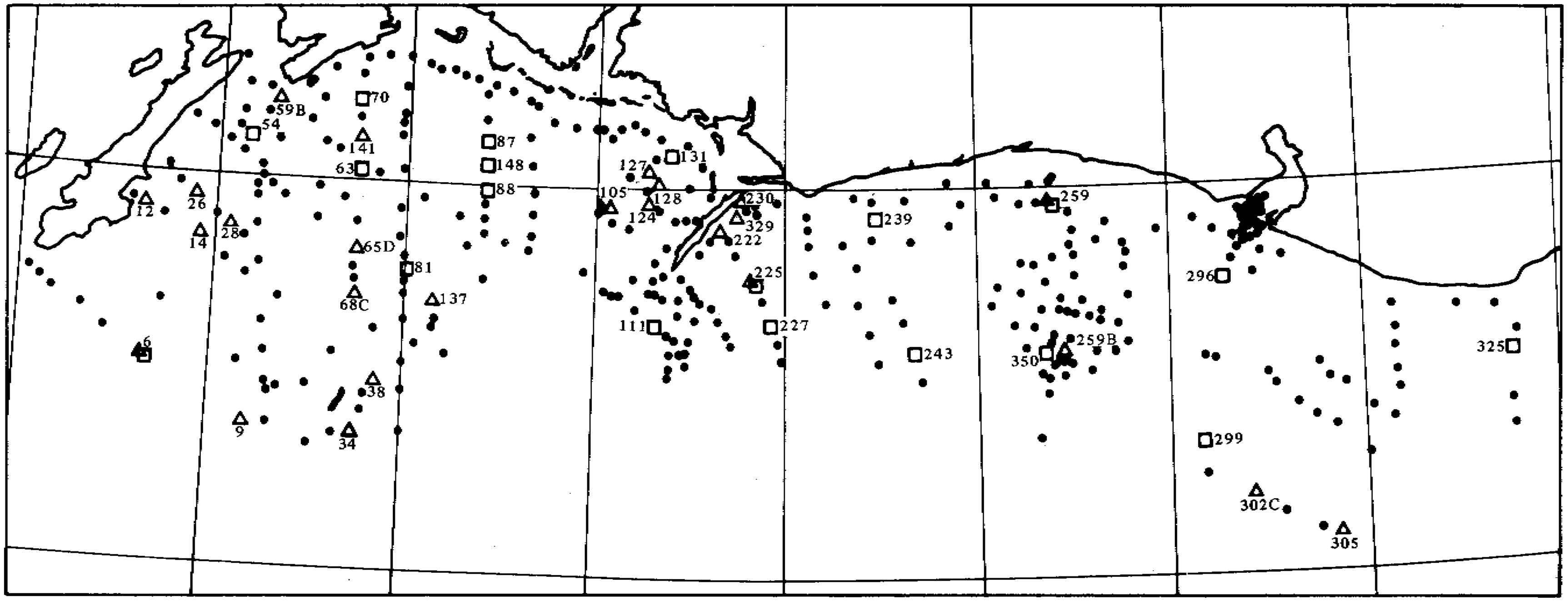
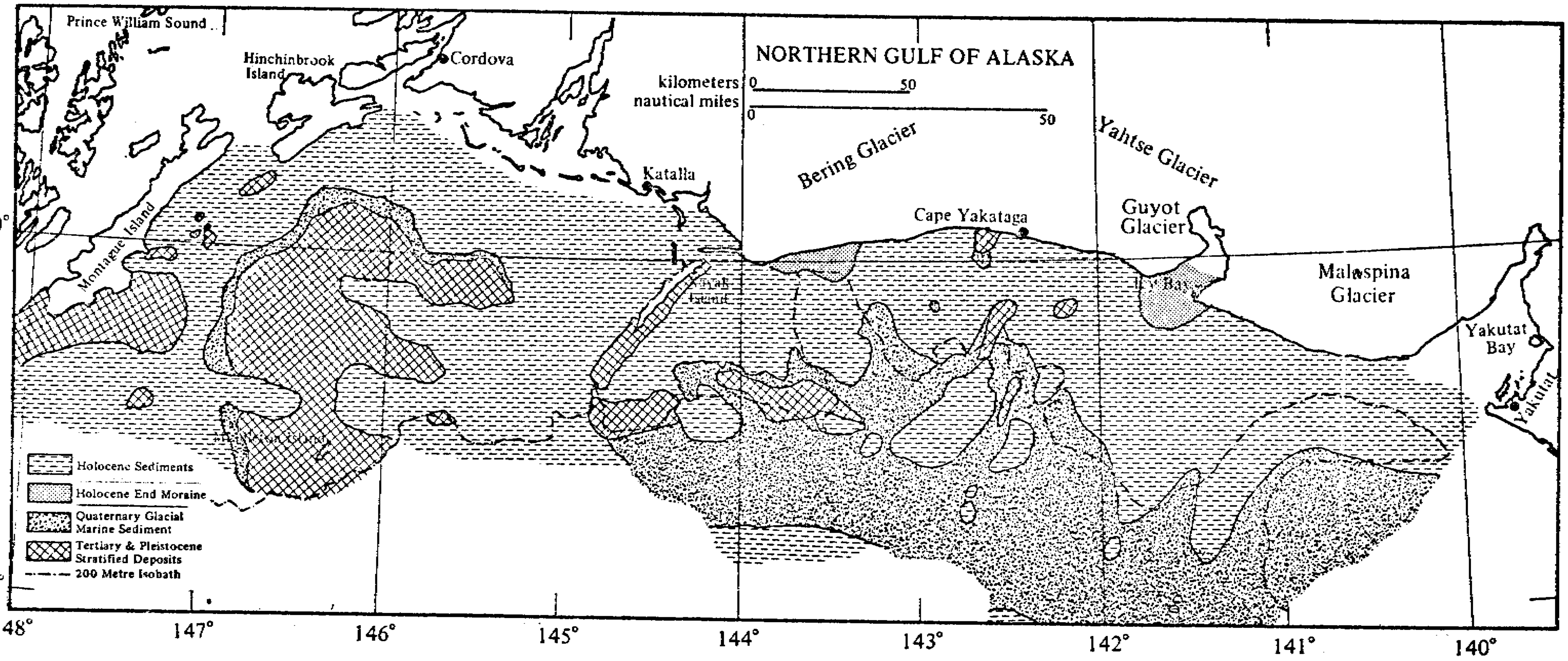


Figure 45. Trackline map of the R/V Surveyor *cruise (April - May, 1975).*



•□ΔLocation of FRS *Townsend Cromwell* samples.
□Location of NEGOA samples analyzed for clay mineralogy.
ΔLocation of foraminiferal samples.

Figure 46. Location of FRS Cromwell *samples.*



Figures 47 and 48. Surface sediment distribution of major sedimentary units - Northern Gulf of Alaska.

Four major sedimentary units occur on the sea floor of the Continental Shelf in the map area. These units, which are characterized by their seismic signatures, are: (A) Holocene sediments; (B) Holocene end moraines; (C) Quaternary glacial marine sediments; and (D) Tertiary and Pleistocene lithified deposits (Fig. 48).

The ages used for material mapped are based on relative stratigraphic positions and not on any isotopic dates. The term Holocene is applied to sediment presently accumulating and to end moraines formed in historic time. The term Quaternary is applied to glacial marine deposits that are interpreted as having been deposited on the Continental Shelf during Pleistocene time when sea level was lowered eustatically. This unit also may include Holocene ice-rafted sediment. The Tertiary and Pleistocene ages applied to the stratified sedimentary rocks, which are often folded, faulted, and truncated (Fig. 48), are based on similarities in lithology and structure to onshore lithified deposits (Plafker, 1967). Stratigraphically, Holocene sediment present always overlies Quaternary glacial marine sediment or Tertiary and Pleistocene lithified deposits. The Quaternary glacial marine material present overlies the lithified material.

Holocene sediment blankets the entire nearshore area between Hinchinbrook Island and the south end of Kayak Island. In addition, Holocene sediment comprises the surface fill in the Hinchinbrook Sea Valley and covers the area south of Tarr Bank and north of Middleton Island. Holocene sediment also occurs in a series of isolated pods toward the outer edge of the Continental Shelf. Analyses of *Cromwell* samples show Holocene sediment to be predominantly clayey silt with a small component. The maximum observed thickness of Holocene sediment was about 300 m in the vicinity of the Copper River. Profile A shows a portion of this area (Fig. 49).

Holocene end moraines are found at the mouth of Icy Bay and south of the Bering Glacier. A portion of the Bering Glacier moraine is shown in Profile B (Fig. 50). Morainal sediments were also collected south of the Malaspina Glacier and at the mouth of Yakutat Bay. Until the latter two areas can be profiled in more detail and their limits delineated, they will not be included as end moraines on the sediment distribution.

Quaternary glacial marine sediments are found in a narrow arc bordering the north and west side of Tarr Bank and in a large arc offshore 20 km or more, paralleling the shoreline between Kayak Island and Yakutat Bay.

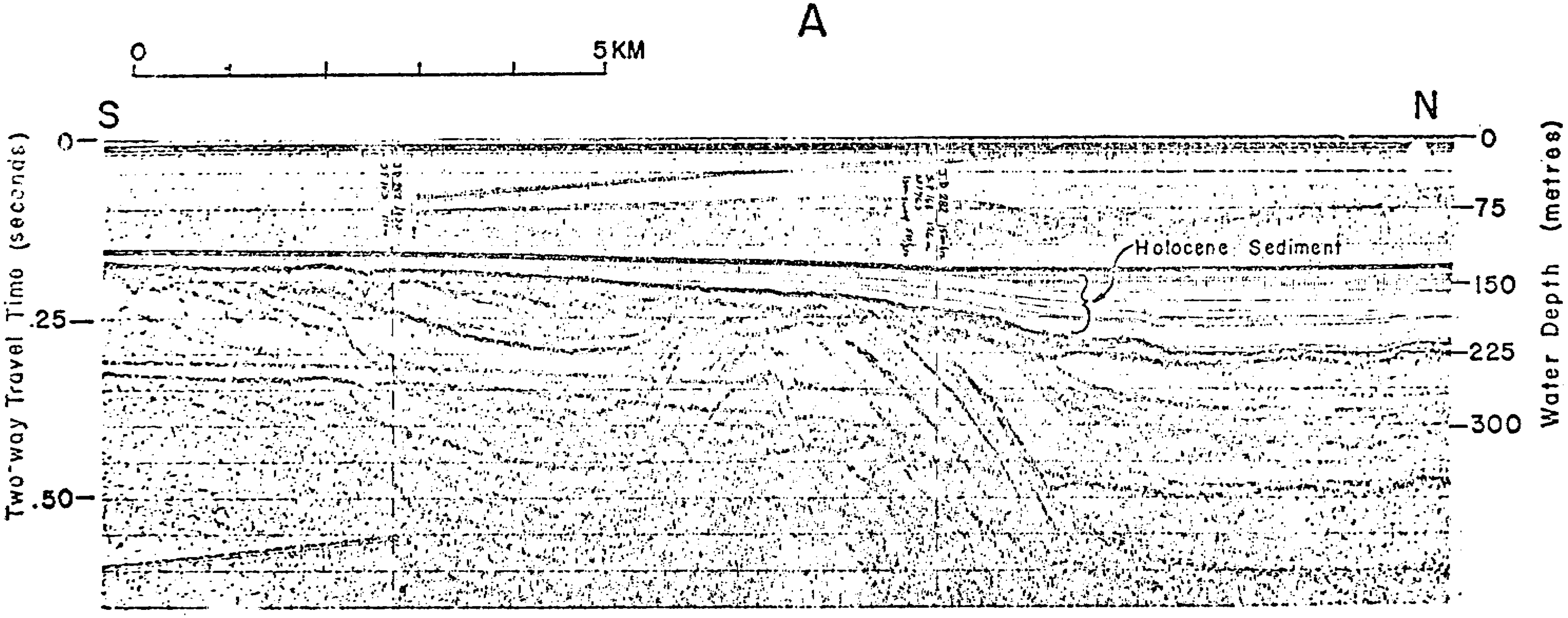


Figure 49. Holocene sediment overlying folded stratified deposits south of Copper River (Vertical Exaggeration ∿9X).

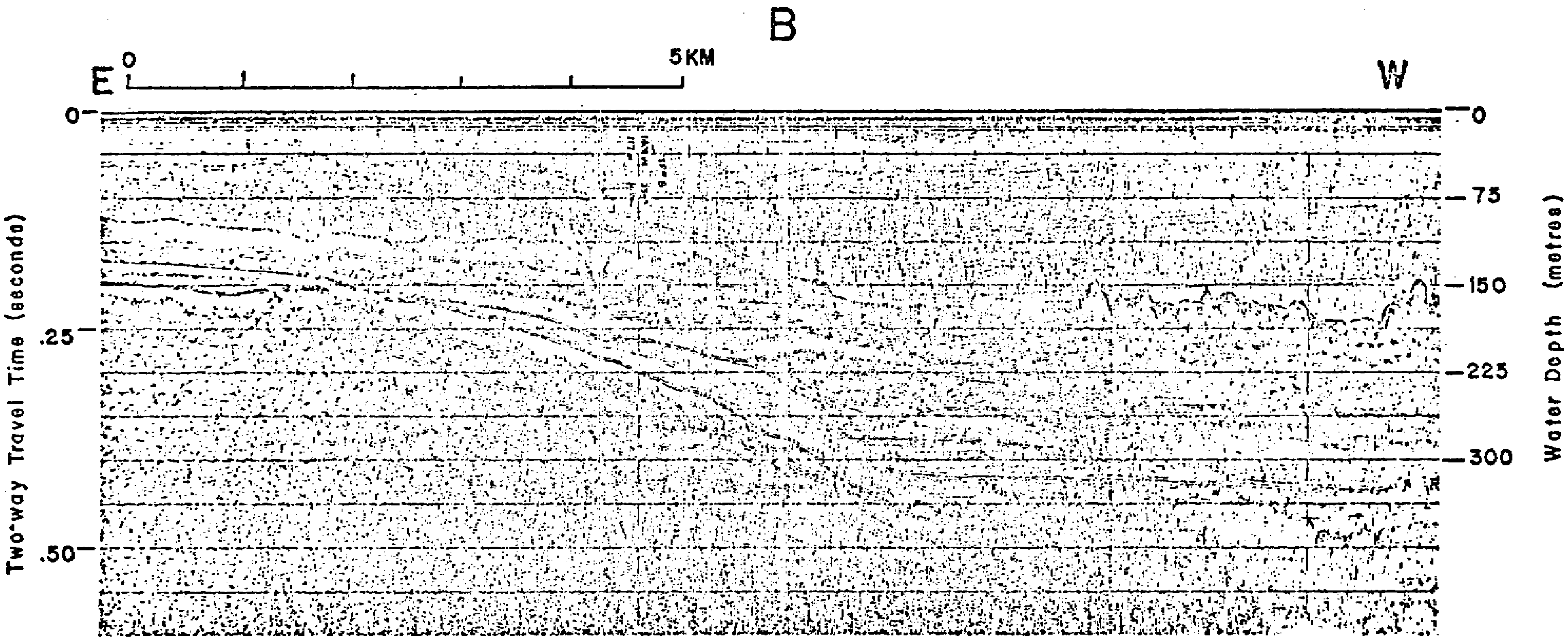


Table 50. A portion of the Holocene Bering Glacier end moraine (V.E. ~9X).

Glacial marine sediment collected by the *Cromwell* was generally a pebbly or sandy mud. Profile C shows a characteristic area of glacial marine sediment (Fig. 51).

Tertiary or Pleistocene stratified sedimentary rocks, which often are folded, faulted and truncated, crop out on Tarr Bank, offshore of Montague Island and in several localities southeast and southwest of Cape Yakataga. In addition, bedrock was examined at two localities between Cape Hinchinbrook and Middleton Island (at Seal Rocks and Wessels Reef) in June 1975. Seal Rocks consist of well indurated sandstone and argillite that are indistinguishable from the Orca Formation of Montague and Hinchinbrook Islands (Winkler, 1973). Wessels Reef is composed of friable sandstone and granule conglomerate that is similar lithologically to rocks of the Katalla Formation on Kayak Island (Plafker, 1974; Winkler, pers. commun., 1975). Dart cores were attempted at many of the outcrop areas during the *Cromwell* cruise. Frequently, the dart core barrel was dented but no sample was recovered. Additional sampling is needed to better characterize the nature of the lithified deposits. Folded stratified deposits on Tarr Bank are shown in Fig. 52. Sampling on Tarr Bank revealed a number of areas covered by a thin veneer of modern sediment (approximately one meter in thickness). This veneer of sediment is not detectable on the seismic profiles because of the transparency of the sediments and/or the limited resolutions (<2m) of seismic systems and is not shown on the sediment distribution map.

HOLOCENE SEDIMENT THICKNESS

Productive evaluation of environmental problems involving instability of the seafloor and areas of excessive erosion and deposition requires a knowledge of the thickness of Holocene sediments.

High resolution seismic profiles collected on the cruise of the *R/V Thomas G. Thompson*, September-October, 1974 were used to construct the isopach map of NEGOA (Fig. 53). Navigation instrumentation used to locate the seismic lines included the Decca HiFix, Satellite, Loran A, and Radar. Shipboard sediment descriptions recorded on the cruise of the *FRS Cromwell*, May-June, 1975 were used to aid interpretation of the seismic data.

The four different sedimentary units in the OCS area (Molnia and Carlson, 1975) have characteristic seismic signatures. The two youngest sedimentary units, both of which are Holocene, mantle much of the OCS region. One consists largely of clayey silt and is characterized on seismic profiles by

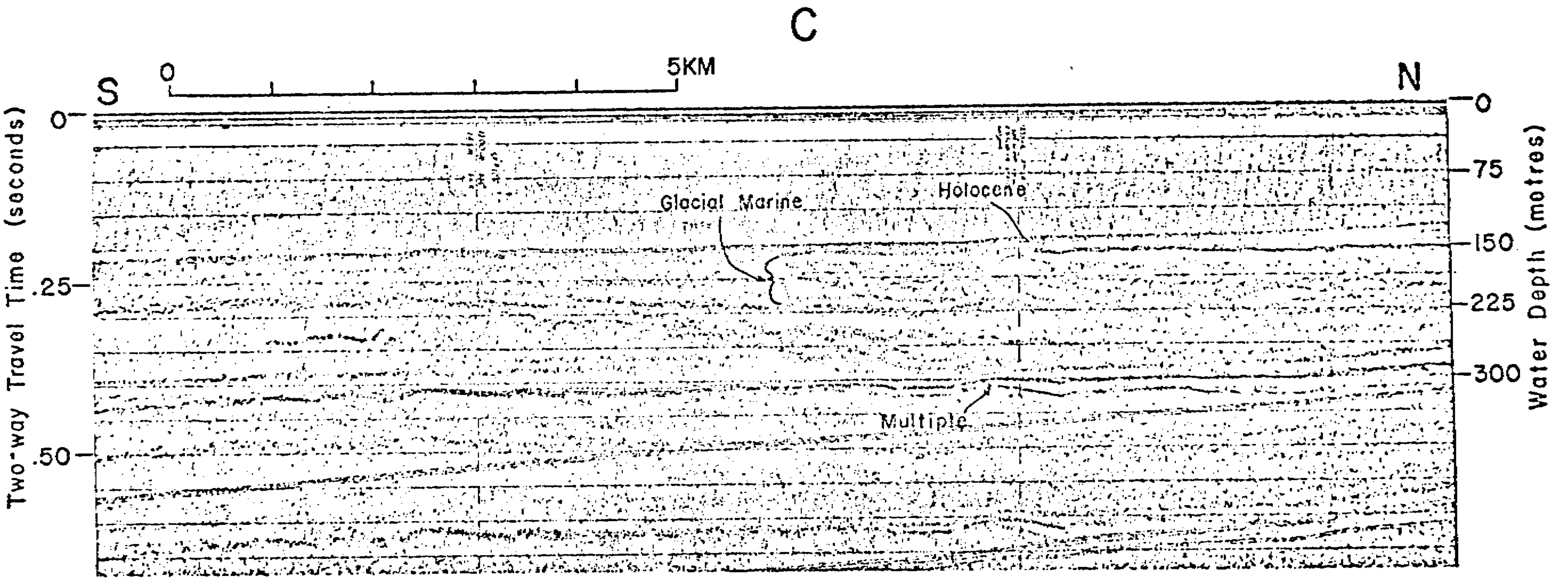


Figure 51. Quaternary glacial marine sediment filling Bering Trough (V.E. ∿9X).

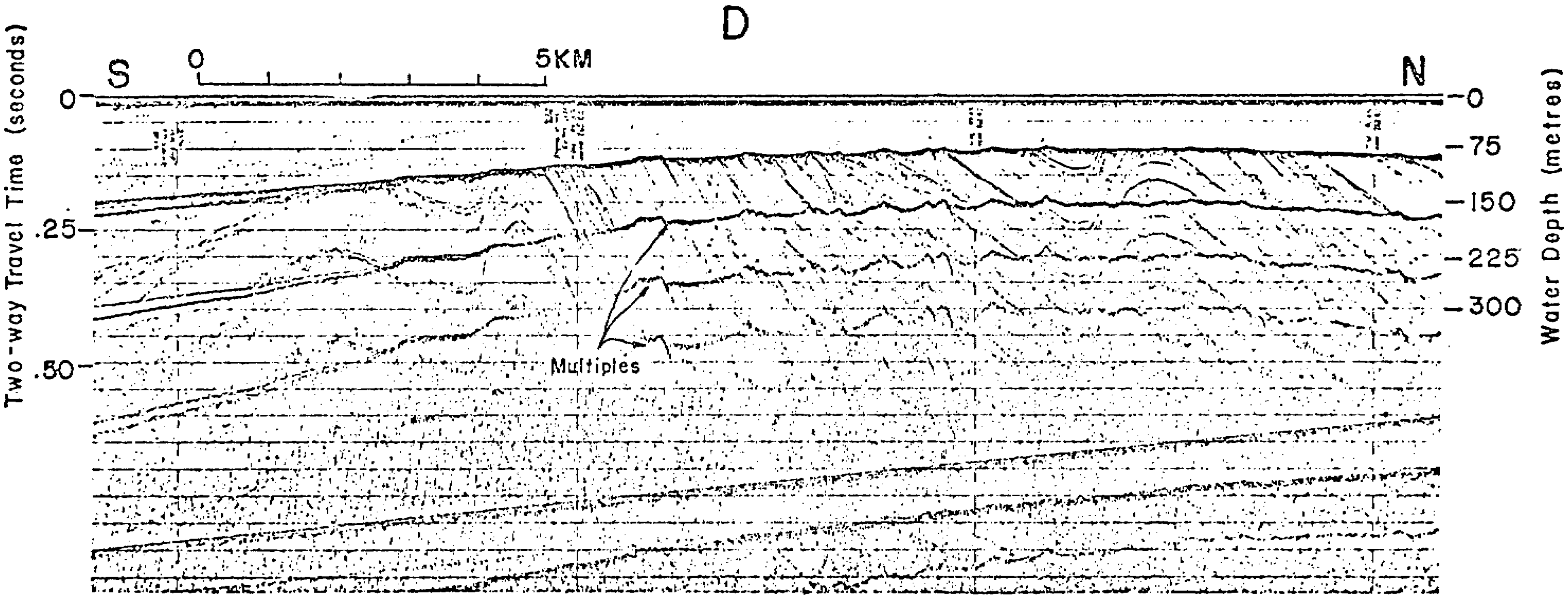


Figure 52. Seismic profile showing folded Tertiary and Pleistocene stratified deposits on Tarr Bank (V.E. ∿9X).

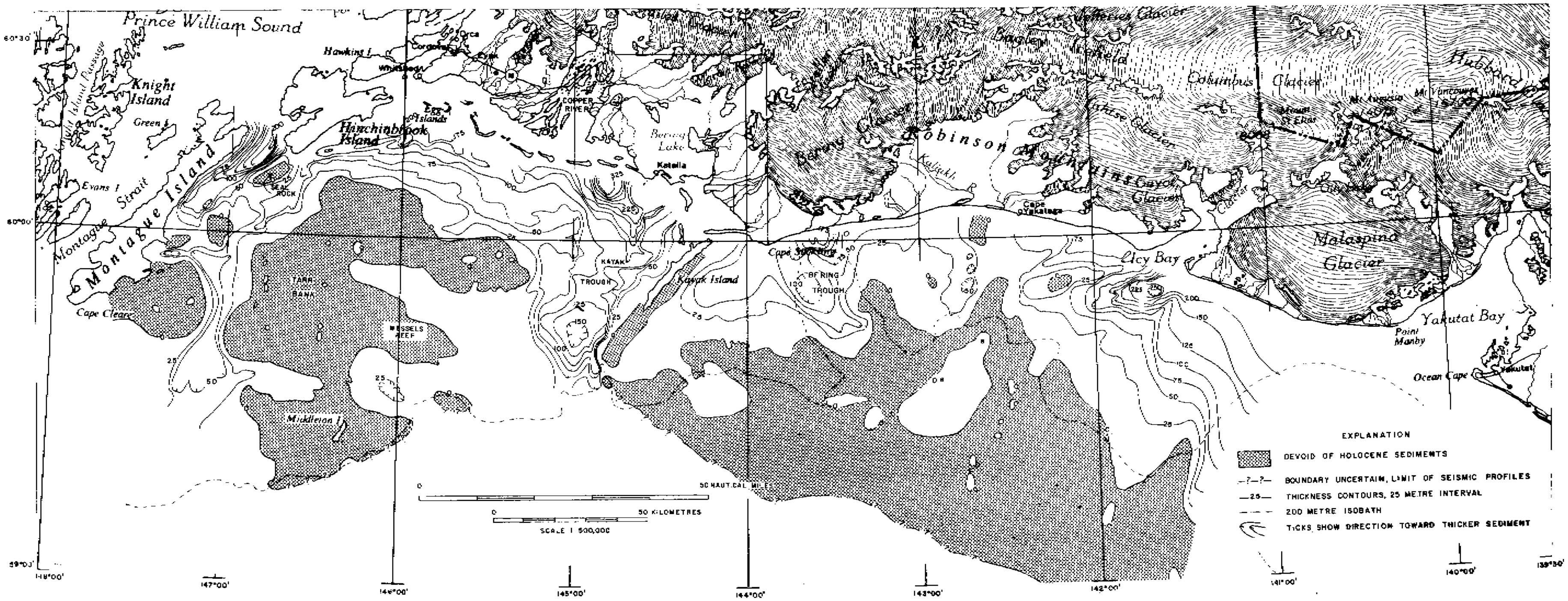


Figure 53. Preliminary isopach map of holocene sediments, Northern Gulf of Alaska.

relatively horizontal and parallel reflectors (Fig. 49); exceptions are in areas where slides or slumps have developed and the resulting reflectors are very much disrupted (Carlson, Bruns, and Molnia, 1975) and seaward of the barrier islands of the Copper River where the principal sediment is fine sand and the reflectors are highly irregular. The second Holocene unit is present off the Bering and Malaspina Glaciers where the most recent end moraines show a jumbled mass of irregular reflectors (Fig. 50). The Holocene unit is underlain in some parts of the OCS by a glacial marine unit of pebbly mud characterized on the profiles by very irregular, confused, distorted reflectors (Fig. 51). Because of its stratigraphic position between Holocene and older rocks ranging from Tertiary to Pleistocene in age, a Quaternary age was assigned to this unit. Its unique seismic signature separates it from the overlying Holocene sediments and therefore it is not included within the isopached unit. In other areas of the OCS, the glacial marine unit is absent and the Holocene unit is underlain directly by folded, faulted and in many places truncated, stratified sedimentary rocks which are probably Tertiary or Pleistocene in age (Fig. 52).

Distribution of Holocene Sediments

Holocene sediment is present throughout much of the OCS area in thicknesses varying from less than 5 meters to greater than 300 meters. The wedge of Holocene fine sand to clayey silt, which makes up the Copper River prodelta, is the thickest of all modern sediments measured, reaching a thickness of about 350 meters just southeast of the main channel of the Copper River.

Other thick sequences of Holocene sediment are: (1) seaward of Icy Bay near Malaspina Glacier (260 m), (2) south of the Bering Glacier (200 m), (3) between Hinchinbrook and Montague Island (250 m), and (4) at the southwest end of Kayak Trough (155 m).

Areas Devoid of Holocene Sediment

The largest area free of Holocene sediment in the western half of the map (Fig. 54) is an irregularly shaped topographic high that includes Tarr Bank and the Middleton Island platform. Truncated, folded, and faulted sedimentary strata of probably Tertiary age appear to crop out at the seafloor on these banks and are flanked by a thin band of Quaternary glacial marine pebbly mud along the west and north sides (Molnia and Calson, 1975). Within this area of Tertiary outcrop are small depressions filled with Holocene silty clay from two to 20 meters in thickness. Our sediment sampling suggests that much of Tarr Bank (and similar areas of the OCS tentatively identified as devoid of Holocene sediment) could be covered by a thin veneer (<2 m) of Holocene mud. This Holocene cover is not detectable on the seismic profiles because of limitations in the resolution of the seismic systems and/or because of the transparent nature of the sediment.

Smaller areas east of Montague Island and southwest of Hinchinbrook Island (Fig. 44), are also devoid of Holocene sediment, and apparently consist of Tertiary bedrock at the surface. One of these, Seal Rocks, a small group of islands 5 km southwest of Hinchinbrook Island, is composed of well-indurated flyschlike sandstone and argillite that is identical to the Orca Formation found on both Montague and Hinchinbrook Islands (Winkler, 1973). Wessels Reef, an intertidal shoal on Tarr Bank about 15 km northeast of Middleton Island, exposes friable sandstone and granule conglomerate that is similar lithologically to rocks of the Katalla Formation on Kayak Island (Plafker, 1974; Winkler, oral comm., 1975).

The largest area devoid of Holocene sediments in the eastern half of the map extends along the continental slope from south of Kayak Island to the easternmost seismic profile line off the Malaspina Glacier (Fig. 53). Much of this slope area consists of glacial marine pebbly mud. In addition, four areas of older folded and faulted sedimentary rocks crop out along the outer shelf and upper slope (Molnia and Carlson, 1975). In a few places along the slope, some thin patches of Holocene sediment (2-20 m thick) cover the older materials. Three other areas on the shelf where older folded and faulted sedimentary rocks crop out at the seafloor are the Kayak Islands platform and two structural highs near Cape Yakataga.

Sources of Sediment

The main sources of Holocene sediment in this OCS region are the Copper River, which, according to Reimnitz (1966), annually supplies 107 x 10^6 metric tons of detritus, and the two large piedmont glaciers (Bering and Malaspina). The sediment being supplied from the two glaciers is at present primarily suspended matter, the plumes of which can be detected more than 30 km from shore on satellite imagery of the region (Reimnitz and Carlson, 1974). A secondary but significant source of fine sediment is wind, which in the fall of the year often blows down the Copper River gorge with sufficient force to carry dark clouds of silt many kilometers into the northern Gulf of Alaska (Molnia and Carlson, 1975a).

The sediment, whether supplied by river, glacial runoff, or wind, is subject to the rigors of the nearshore currents which, with the exception of local eddies, move in a counterclockwise direction similar to the offshore Alaska Current (Reimnitz and Carlson, 1974). This counterclockwise movement transports the suspended sediment in a westerly direction. Much of the Copper River sediment is being carried into Prince William Sound through channels north and south of Hinchinbrook Island. Sediments which are part of the Bering Glacier runoff plume are carried around Kayak Island. Complex gyres of turbid water have been seen on both sides of Kayak Island on satellite imagery (Reimnitz and Carlson, 1974). It is likely that some of the suspended sediment settles out over Kayak trough. However, the high resolution seismic profiles indicate that very little of the suspended matter from either the Copper River or from sources east of Kayak Island accumulates on Tarr Bank or the Middleton Island platform. This lack of sediment on these topographic highs may perhaps be due to the scouring action of the frequent storm waves that are particularly large and forceful during the winter season of intense low pressure activity in the Gulf of Alaska.

Clay Mineralogy of Sediment Samples

Nineteen sediment samples collected during the cruise of the *FRS Cromwell* in June 1975 (Fig. 54) were processed and analyzed for the quantity and type of clay minerals present. Mineralogy was determined by x-raying magnesium saturate <2µ clay samples with a Norelco defractometer. The quantity of each clay mineral present was determined by a peak-area technique described by Hein, Scholl, and Gutmacher (in press).

Chlorite was the predominant clay mineral present, averaging 52.6%. It ranged from a low of 37% to a high of 60%. Illite was second in abundance averaging 37.8% with a range of 30 to 56%. Kaolinite was third in abundance averaging 9.2% with a range of 7 to 10%. Montmorillonite was the least abundant clay present, averaging 0.6% with a range of 0-3%. No other clays were detected but quartz, feldspars and amphibole was present in the clay sized fraction. Table 88 summarizes the percentage of clay minerals persent in each sample.

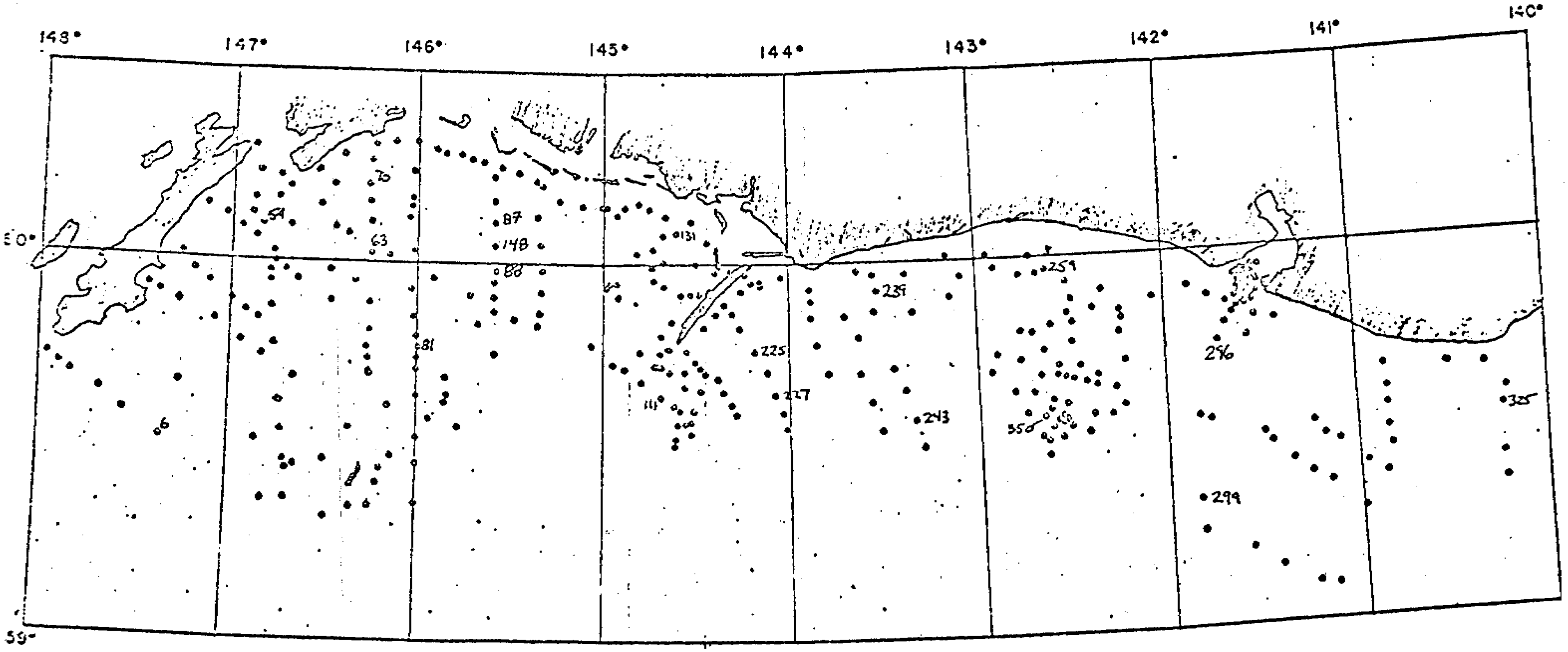


Figure 54. Location of NEGOA samples analyzed for Clay Mineralogy.

Table 88. Percentage of clay minerals present.

Sample #	Montmorillonite %	Illite %	Kaolinite & Chlorite %	Kaolinite %	Chlorite %
63	3	35	62	9	53
6	3	36	61	9	52
148	0-1	39	61	9	52
131	0-1	37	63	9	54
296	0	30	70	10	60
243	0	35	65	10	55
350	0	33	67	10	57
225	0	33	67	10	57
88	1	40	58	9	49
70	0	56	44	7	37
325	0	45	55	8	47
227	0	35	65	10	55
87	0-1	54	46	7	39
81	0-1	37	63	9	54
259	0	31	69	10	59
299	0	35	66	10	55
239	0	34	66	10	56
54	0	39	61	9	52
111	0-1	34	66	10	56

Benthonic Foraminifera and Calcareous Nannoplankton

Twenty selected samples from the northeastern Gulf of Alaska (Fig. 55), taken from the undisturbed upper 2 cm of sediment in grab samples or box cores, were examined for Quaternary benthonic foraminifera. For seven of these samples, a microsplitter was used to take representative splits of approximately 350 specimens from the greater than 150µ portion; foraminifera were counted and the relative frequency percentages of benthonic foraminiferal species determined. On the basis of the percentage distributions, four faunal assemblages were distinguished. Cursory examination of the remaining thirteen samples showed that most samples could be assigned to one of these four groups. Characteristics of the faunal assemblages are as follows:

Group I (6 samples--stations 28, 34, 124, 137, 141, 305). *Cassidulina californica*, *C. limbata* and *C. subglobosa* dominant; *Cibicides lobatulus* and *Angulogerina fluens* present in significant numbers; foraminiferal fragments common; the tests of most calcareous foraminiferal specimens present are opaque; arenaceous specimens less than 10% of total.

Group II (4 samples--stations 12, 14, 59b and sample from Resurrection Bay). *Nonionella pulchella*, *Globobulimina auriculata*, and *Nonion labradoricum* dominant; specimens very well preserved; arenaceous specimens greater than 10% of total.

Group III (7 samples--stations 26, 38, 105, 127, 128, 225 and 258). Approximately 30% of the specimens are arenaceous and consist mainly of *Haplophragmoides subglobosum*, *Recurvoides turbinatus*, *Adercotryma glomeraturm* and *Alveolophragmium crassimargo;* the calcareous foraminifer, *Epistominella pacifica* is present in most samples; specimens very well preserved.

Group IV (2 samples--stations 6,9). *Uvigerina peregrina*, *Cassidulina teretis* and *C. californica* dominant; arenaceous specimens greater than 10% of total.

Although the Group I faunal assemblage is widespread throughout the area studied, it occurs only at stations with the coarsest sediment. Of the 6 samples assigned to this group, 2 are sandy gravels and 4 are sandy or pebbly muds.

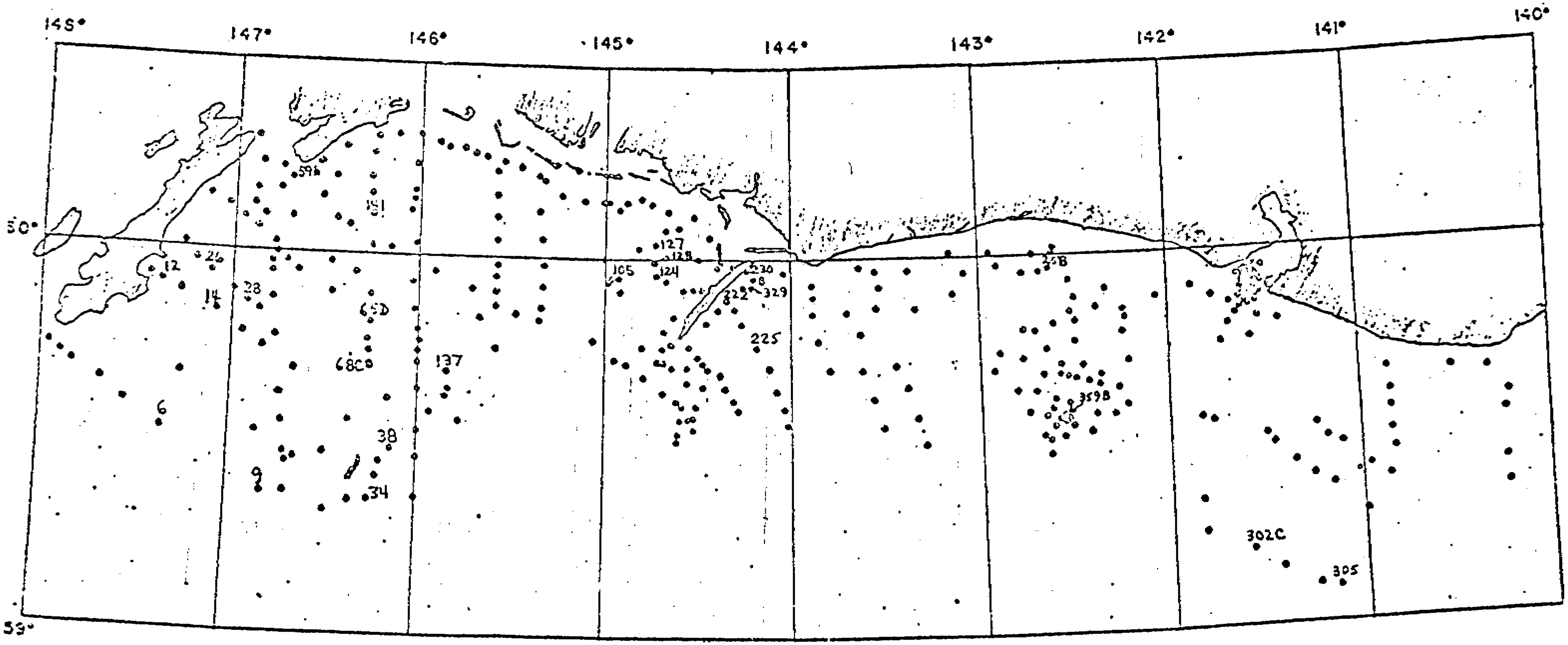


Figure 55. Location map showing positions of foraminiferal samples (numbered) together with all samples collected on the Cromwell cruise of May - June, 1975.

Of the 13 samples with Group II, III, and IV faunal assemblages, 11 are muds and 2 are sandy muds. Group II and IV assemblages occur only west of Middleton Island.

Well-consolidated sediment was obtained from the bottoms of dart and gravity cores at stations 65D, 68C, 222, 230, 302C, 329, and 359B (Fig. 55). Samples from these stations, as well as 2 samples from a beach approximately 5 miles southeast of Lituya Bay (PC-1 and PC-2) and one from Wessells Reef, were examined for pre-Quaternary calcareous nannoplankton and benthonic foraminifera. According to David Bukry (USGS), most samples were barren of nannofossils; where nannofossils were present, they were either Quaternary or not age-diagnostic. Preliminary study of pre-Quaternary benthonic foraminifera by Weldon Rau (State of Washington and U.S. Geological Survey) indicates a middle to outer shelf environment of deposition and a late Miocene to Pliocene age for station PC-1. The foraminiferal assemblage from station 302C, an area southwest of Yakutat Sea Valley, suggests a Pliocene or Pleistocene age and deposition on the shelf, probably well away from littoral depths. The fauna from station 359B, on the northwest side of Pamplona Ridge, is within the Pliocene-Pleistocene age range and is quite probably Pleistocene; depositional environment was probably outer to middle shelf. A sample from station 329 contained a very shallow water fauna no older than Pleistocene and quite probably of Holocene age.

Glauconite, a green iron-rich mineral, occurs as internal casts in the tests of foraminifera in several samples collected from the top 2 cm of sediment as well as from one sample (station 222) taken from the bottom of a dart core. As slow or negative sedimentation rates and slightly reducing conditions are necessary for the formation of glauconite, further study of the distribution of this mineral in samples from the northeastern Gulf of Alaska may provide information on depositional environments.

Another topic that is being pursued is the species composition and geographic distribution of living benthonic foraminifera. Samples from the undisturbed upper 2 cm of sediment from grab samples and box cores were preserved in buffered formalin and stained with Sudan Black B according to the procedure described by Walker and others (1974) Specimens that were living at the time of collection can be recognized because they contain protoplasm which will be stained in dark blue-black.

Preliminary Structural Interpretation of Part of the Offshore Gulf of Alaska Tertiary Province

This report provides a preliminary structural interpretation of a portion of the offshore Gulf of Alaska Tertiary Province (GATP) between Icy Bay and Montague Island. The seismic data on which this report is based are being made publicly available in an open file (von Huene and others, 1975).

The GATP is a compound continental margin basin made up almost entirely of terrigenous clastic rocks with minor coal intercalated with subordinate mafic volcanic and volcaniclastic rocks. The topography, basin architecture, structural style, and seismotectonic activity within the GATP, to a considerable extent, reflect the interactions that have occurred during late Cenozoic (post-Oligocene) time along the interface between the North American continent and the Pacific Ocean basin. As a consequence of these movements the western part of the GATP adjacent to the Aleutian Trench and arc is essentially a zone of comprehensive deformation along which the Pacific oceanic plate is underthrusting the continental margin. The easternmost part of the province is a zone of shear in which the oceanic plate is moving laterally past the continent along the Queen Charlotte transform with related strike-slip faults. The central part of the province is a zone of combined compression and shear due to oblique underthrusting of the continental margin (Plafker, 1969). Both the availability of structural traps for petroleum accumulation and the geologic hazards in the GATP are a direct result of its unique setting in an arc-transform transition zone.

The sedimentary sequence in the GATP ranges in age from Paleocene through Pleistocene (Plafker, 1971). It is broadly divisible into (1) a thick lower unit of well-indurated, intensely deformed deep marine to continental rocks, mainly of Paleocene and Eocene age, and (2) an upper unit, largely of bedded marine sedimentary and volcanic rocks of Oligocene through Pleistocene age, that is notably less deformed and indurated. Most of the known indications of petroleum in the basin are in rocks of the younger sequence, which has a composite thickness on the order of 6,100-7,600 m. The early Tertiary sequence is too indurated and too intensely deformed to have more than modest potential for petroleum.

Data Interpretation

During September and October, 1974, the U.S. Geological Survey collected 6575 km of marine geophysical data in this area. These data consisted of gravity, magnetic, single channel seismic reflection profiles, and five reversed seismic refraction profiles. Interpretation of offshore structure is derived mainly from the unprocessed analog single channel air gun seismic records with line spacings of between 9 and 15 km, and acoustic penetration of generally less than two seconds (two-way time). Interpretation is complicated by the relatively shallow penetration achieved and by the presence of persistent water bottom multiples, especially in areas of shallow dip.

Preliminary interpretation of the data indicates that the offshore GATP is structurally complex and consists of several areas with markedly differing structural styles. Complexity in the near-surface section appears to increase from east to west. The accompanying map (Fig. 56) shows offshore structural contours and trends in the near surface based on a highly interpretative study of the available data. For comparison, major onshore structural trends also are depicted, and have been evaluated previously by Plafker (1971). Offshore contours are in unmigrated, two-way travel time (seconds); no attempt has been made to convert to depth due to lack of adequate velocity control. Mapping of the horizons is based on dip projections, record chracteristics, and the assumption that geologic horizons are relatively conformable within the near surface, thereby allowing projection of mapped horizons based on the dip of overlying events. This assumption appears valid based on the available data. The structural contouring represents primarily the shallow structure, probably within the upper part of the Yakataga Formation of late Miocene and younger age (Plafker, 1971). Although the configuration of the deeper basins as shown must be considered to be speculative, the relatively shallow structural highs are probably more accurately shown. It is not possible to determine from the data the presence or absence of deeper structural complexities. By analogy with the adjacent onshore geology, the deeper offshore structure may be considerably more complex than the indicated near surface structure.

Structural contours in the area between Kayak Island and Icy Bay are shown on two different horizons. The westernmost horizon is structurally the deeper of the two by from 3/4 to 1 second. Here the section appears to thicken towards the shelf edge, particularly in the area where the change in horizons occurs. Total section penetrated is a maximum in the area around Icy Bay and thins to the west, based on the truncation at the ocean bottom of recognizable events on the seismic records. No estimate of total thickness of section in

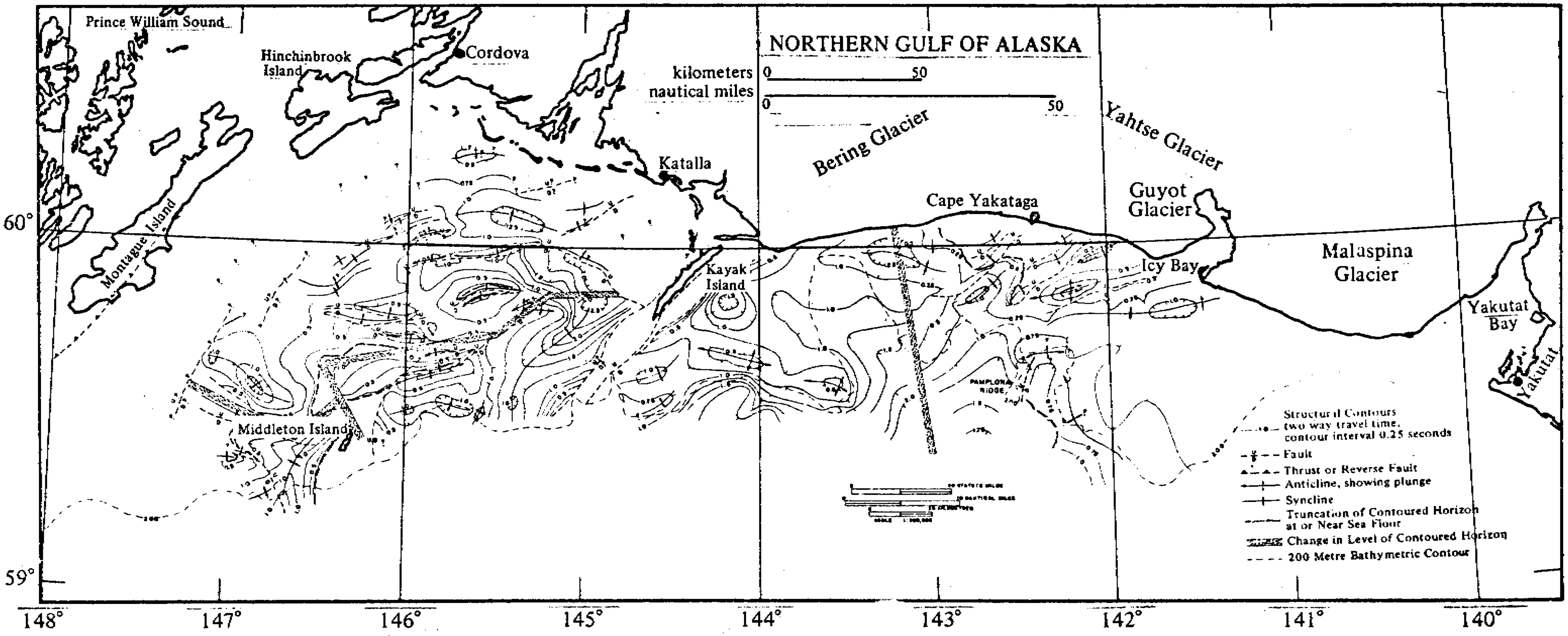


Figure 56. Preliminary offshore structural map of the Northern Gulf of Alaska.

the basin is possible from the reflection data because of the shallow penetration. However, relatively low velocities encountered in the sedimentary column on the five seismic refraction lines that were acquired during 1974 suggest a clastic section, predominantly sandstone and shale, as much as 12 km thick in the eastern part of the area south of Icy Bay and at least 9 km thick southeast of Kayak Island (Ken Bayer, personal communication).

Structural contours in the area between Kayak Island and Montague Island are shown on three different horizons. Due to the structural complexity and lack of data in critical places, no adequate determination can be made of the relationship between these horizons. It appears that the contoured horizon between Kayak Island and Middleton Island is structurally deeper than the contoured area landward of it; no comparison is possible for the area southwest of Middleton Island due to the complexity of the Middleton Island Platform. Contouring is more speculative in this area than that between Icy Bay and Kayak Island. Shoreward of the contoured areas, and in the area immediately west of Kayak Island, acoustic basement appears to be high, and the structure is not well defined with the available marine data. No contouring was possible due to this lack of definition.

Offshore Structural Features

Between Icy Bay and Kayak Island the shelf is underlain by two types of structures. The first type is a series of asymmetric linear folds that trend obliquely across the shelf, roughly between northeast-southwest and east-west. These structures are apparently more open and less complex than those on the adjacent land areas. Some of the offshore anticlines are bounded on the southeast by north-dipping thrust displacement. The second type of structure is a large shelf-edge arch east of Kayak Island trending sub-parallel to the coast and with very gentle surface dip. Between this arch and the coast is a broad downwarp as much as 48 km wide within which there are some upwarped areas. A possibly similar arch occurs southwest of Icy Bay at the shelf edge although more data is required to define the nature of the structure in this area. Between Pamplona Ridge and the shelf edge high to the west, no structure is revealed on the profiles, although weak indications of deeper structural complexity are seen on one line extending off the edge of the shelf into deep water.

The shelf between Kayak and Middleton Island includes a broad zone of complex structures trending between east-west and northeast-southwest, sub-parallel to major on-land structures and to the eastern Aleutian Trench. Structural highs tend to be asymmetric and bounded by thrust faults on their south or southeast limbs. Uplift, deformation and faulting are greater than on the Icy Bay structural features, and the crests of many of the highs appear to have undergone extensive erosional truncation apparently exposing complexly deformed Tertiary rocks at or near the seafloor. Northwest of Middleton Island are two large northwest-southeast trending high areas separated by a deep basin. These complex structures, which are divergent from the Icy Bay and Kayak-Middleton trends, show severe deformation and probable faulting on the flanks of the highs, and no structure is resolvable within the cores. Middleton Island lies on the northwest flank of a large northeast-trending structural high and appears to be separated from the northwest trending structures by a relatively deep basin. Although most of the highs between Kayak and Montague Islands are shown as closed anticlines, lack of definition in the profiles does not preclude these highs from being primarily the result of block faulting. If so, the presence of closure as shown may not be entirely accurate.

Submarine Slides and Nearsurface Faults

In the Gulf of Alaska, because oil and gas leasing of the Outer Continental Shelf (OCS) is proposed in the very near future and because the NEGOA region is subject to intense seismic activity (Page, 1975), it seems timely to delineate areas of the OCS that are susceptible to potential hazards from ground shaking, fault displacement or ground failure. Therefore the purpose of this map (Fig. 57) is to provide: (1) preliminary information regarding areas of present and potential submarine slides and/or slumps and, (2) approximate locations of nearsurface faults.

Data Collection

The data used for this map were collected on the September-October, 1974 cruise of the *R/V Thomas G. Thompson* (Fig. 45) (von Huene and others, 1975). These data include three types of continuous acoustic profiles, using as sound sources a 3.5 kHz transducer, two minisparkers (800 joules) and two 40 in^3 air guns. Several types of navigation equipment were used because of intermittent power and equipment failures; the instruments included Decca Hi Fix, Satellite, Loran A and Radar.

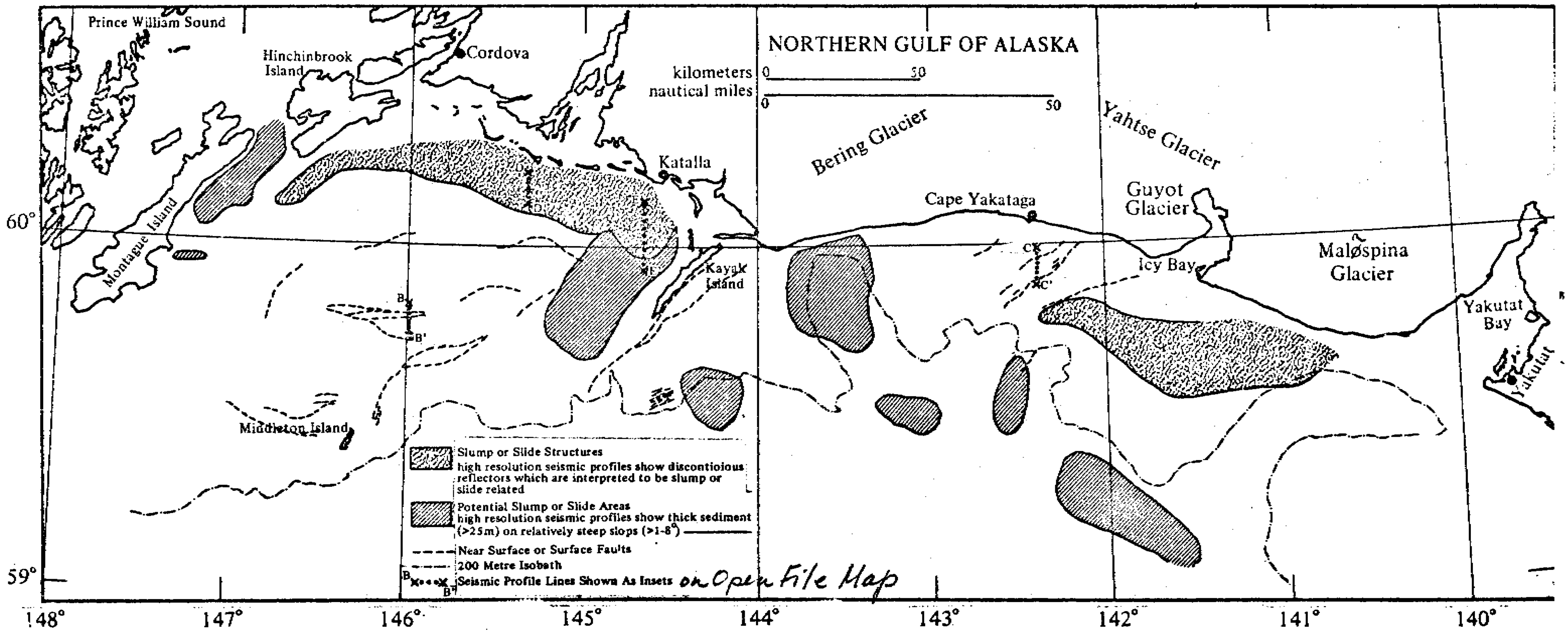


Figure 57. Areas susceptible to potential seismic hazards.

Nearsurface Faults

The traces of the nearsurface and surface faults were interpreted largely from minisparker records (Figs. 58 and 59); airgun and 3.5 kHz records were used as additional aids.

In most cases the faults cut strata that are similar to and may be equivalent to the upper Yakataga Formation (Fig. 58) which Plafker (1967) indicates is middle Miocene to lower Pleistocene. Often these strata are covered only by a thin veneer of Holocene sediment (Fig. 59) and in many places crop out at the seafloor (Fig. 58). A few of the faults appear to cut Holocene sediments (Fig. 59). Additional interpretation of the age and sense of motion for these faults will not be attempted here--further study is needed.

The nearsurface faults thus far detected occur in four main parts of the OCS area: (1) south of Cape Yakataga, (2) on or adjacent to the Kayak Island platform, (3) on Tarr Bank and (4) near Middleton Island.

Slides and Potential Slides or Slumps

Seismic profiles from two parts of the map area (Fig. 57) show disrupted bedding and irregular topographic expression commonly associated with submarine slides or slumps (Figs. 60 and 61). The slumped section south of Icy Bay and southwest of the Malaspina Glacier (about 1770 km^2 in surface area) has a gradual slope of less than $1/2^{o}$, but is in an area of thick Holocene sediment (>150 m).

Similarly the second area where slump structures were seen in the seismic records, an area of about 1730 km^2 along the Copper River prodelta, the slope is gentle ($\sim 1/2^{o}$), but a thick wedge of Holocene sediment (>200 m) has accumulated rapidly. According to Morgenstern (1967), in regions with high rates of sedimentation, such as deltas, the lag between accumulation and consolidation gives rise to excess pore pressure and the sediment is thus weaker; such underconsolidated material is prone to slumping. The Copper River prodelta was investigated with seismic profiling equipment by Reimnitz (1972) shortly after the 1964 Alaska earthquake. He attributed the slump structures visible in the upper part of the section to this earthquake. These slump structures are similar in size and shape to the slump structures visible on present profiles over this same area (Fig. 60).

Acoustic profiles show a massive submarine slide at the east edge of the Copper River (Fig. 61). This 17 km-long slide with a volume of about 5.9 x $10^{11}m^3$ (Carlson and Molnia, 1975) moved down a slope of about one degree to the bottom of Kayak Trough. Sediment samples collected from the upper meter

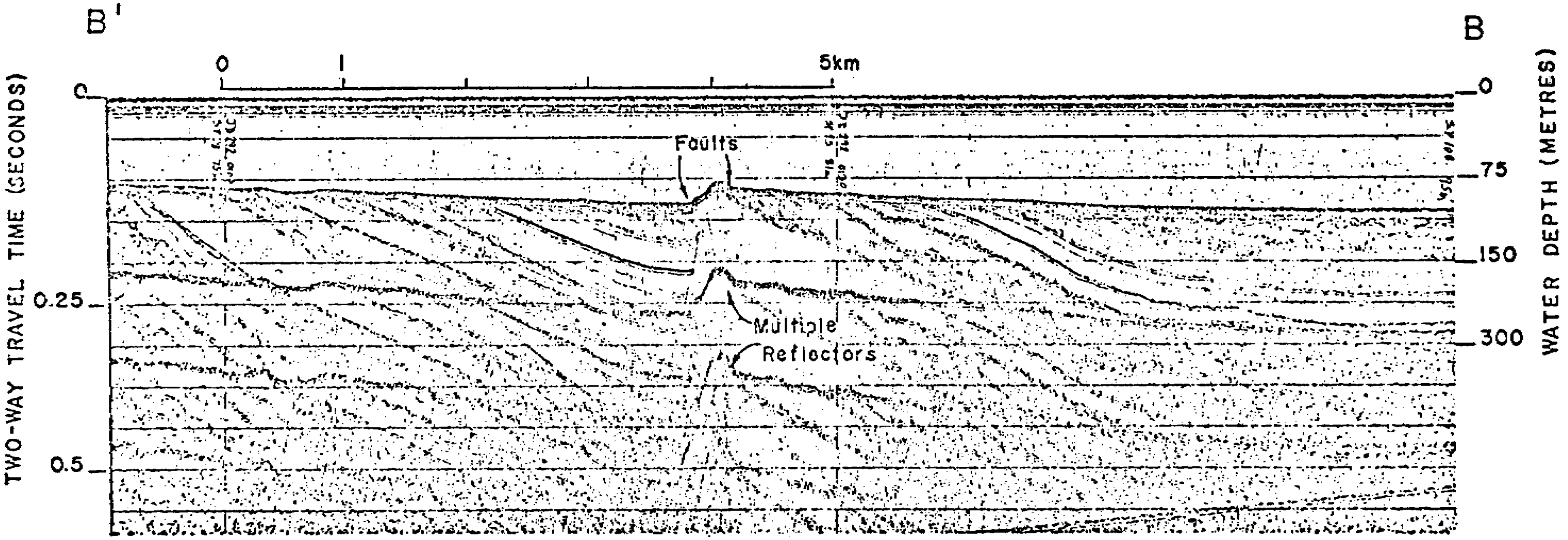


Figure 58. Minisparker profile showing older faulted and folded strata (Tertiary-Pleistocene) cropping out at the seafloor (Vertical Exaggeration (VE) ≃ 10X).

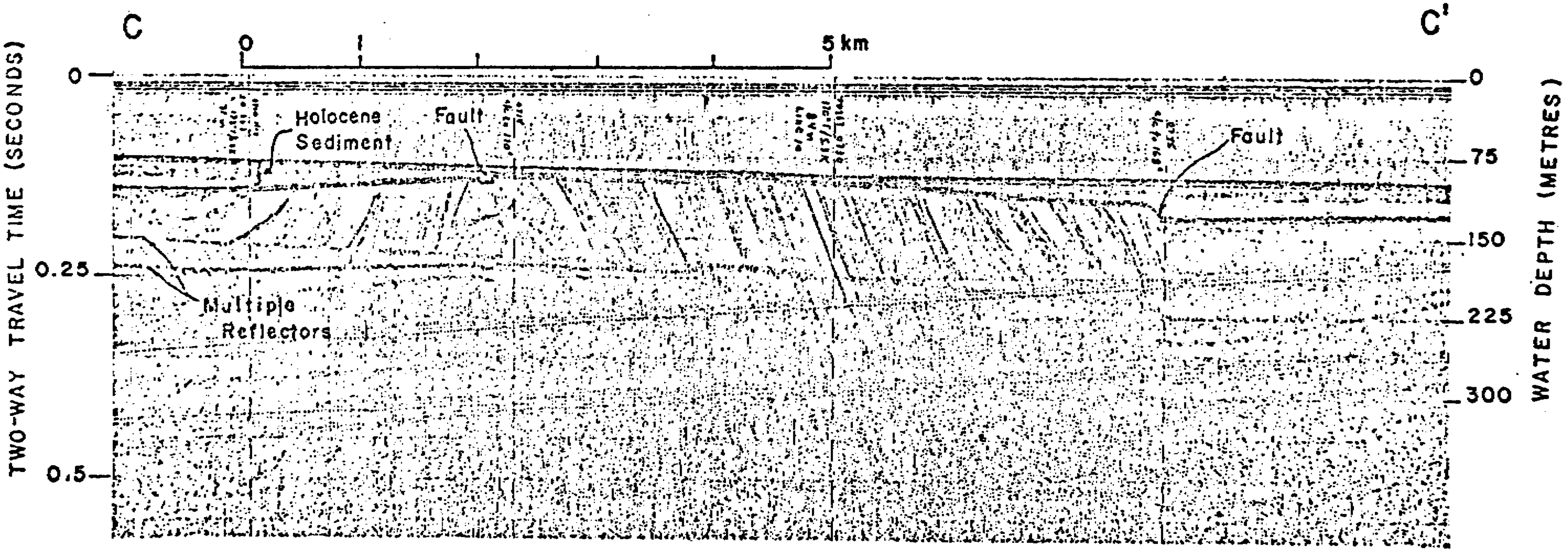


Figure 59. Minisparker profile south of Cape Yakataga showing older faulted and folded strata (Tertiary-Pleistocene?) overlain by thin blanket of Holocene sediment (V.E. ≃ 10X).

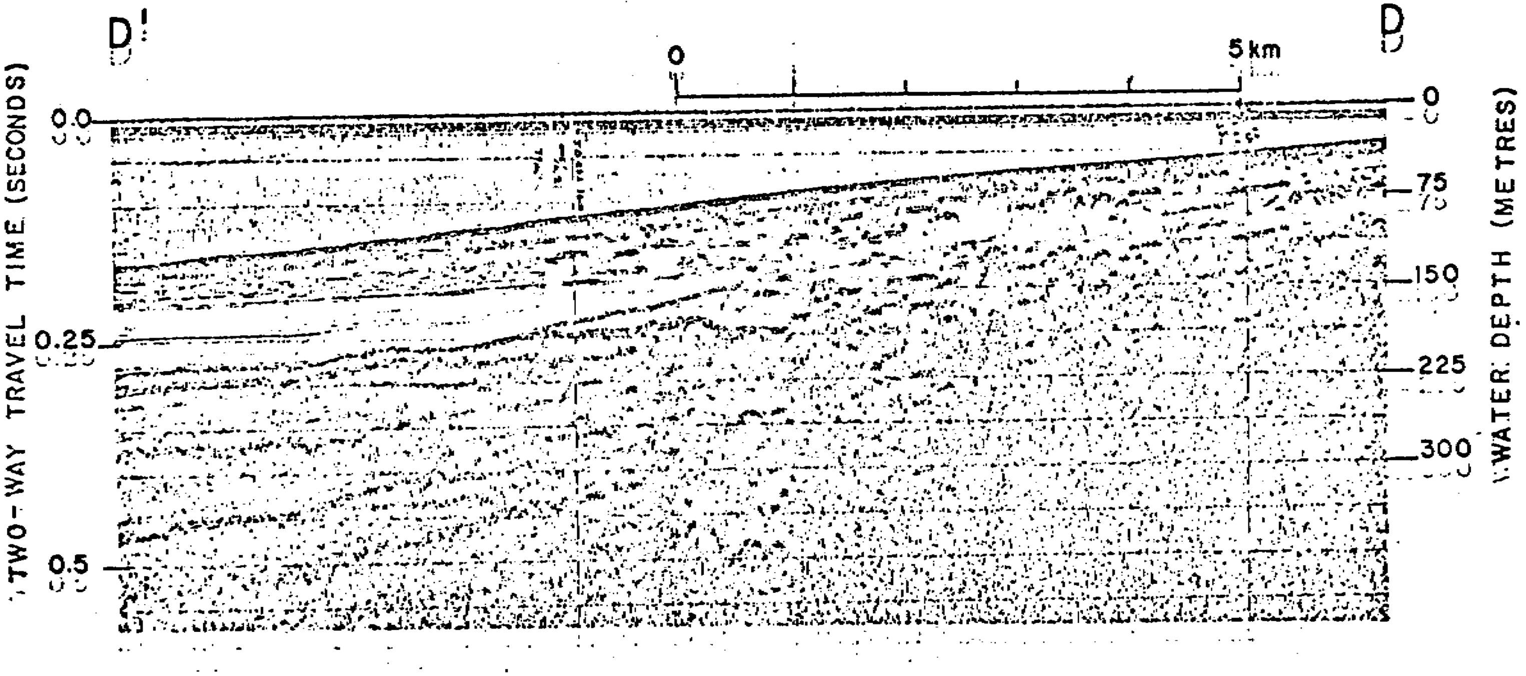


Figure 60. Minisparker profile showing slump structures (disrupted reflectors) in Copper River prodelta sediments (V.E. ≃ 10X).

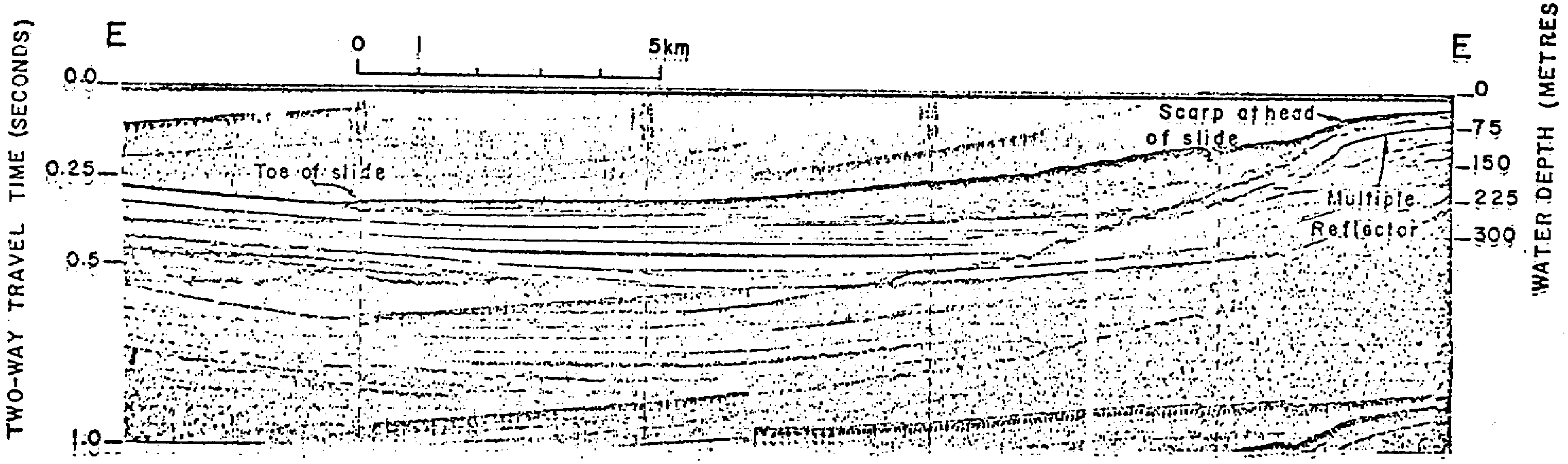


Figure 61. Minisparker profile of massive slide in Holocene sediments south of Katalla (V.E. ≃ 10X).

of this slide consist of a structureless, gray silty clay of extremely low strength (laboratory tests with a vane shear yielded a peak shear strength of .02 kg/cm^2).

The areas on the map (Fig. 57) indicated as potential slide or slump zones were delineated based on thicknesses of Holocene sediment and relative steepness of slopes. Slump or slide features were not prominent on the profiles; however, because of the sediment thickness (>25 m) and slope steepness (>1-8°) there is a possibility of ground failure in these areas if a large earthquake provides rapid ground acceleration or if a large tsunami or storm wave disrupts the seafloor. Such catastrophic events were experienced by many communities in the Prince William Sound region and along the shoreline of the Gulf of Alaska during the 1964 Alaska earthquake (Grantz and others, 1964; Coulter and Migliaccio, 1966; and Plafker and others, 1969).

SUMMARY

During FY 75, the USGS collected over 12,000 km of high-resolution seismic data and over 400 sediment samples in the NEGOA field area. Interpretation and analysis of the data is ongoing and the maps and reports presented here are continuously being updated. Due to the late date of sediment sampling (May - June 1975) complete sediment analyses are not yet available. However, this portion of the program is underway with a high priority and will be completed before sampling is attempted next field season. A number of data gaps still exist and it is expected to fill them early next field season. The data presented in this report are being released in USGS Open File.

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