OCS Study
MMS 91-0038

MARINE BIRDS AND MAMMALS OF THE UNIMAK PASS AREA: ABUNDANCE, HABITAT USE AND VULNERABILITY

Final Report

By

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DISCLAIMER

ACKNOWLEDGEMENTS

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The financial support of the Minerals Management Service (MMS) of the Department of the Interior is gratefully acknowledged. Individuals of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce in Anchorage, Alaska, have been supportive and helpful throughout this project. We would particularly like to thank Laurie Jarvela for his patience and his assistance with the various stages of report preparation. The officers and crew of the R/V *Miller Freeman* were extremely helpful and understanding on all cruises.

Many individuals deserving of recognition but not acknowledged here receive credit in the Acknowledgements sections of the various chapters in this volume.

Joe C. Truett and Kenneth Kertell assembled and edited the final version of this volume. In this endeavor they strived to leave unaltered the basic content of various sections, but they sometimes prepared new illustrations and edited the text to improve clarity and to respond to NOAA and MMS review comments.

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Chapter 1

INTRODUCTION

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INTRODUCTION

Unimak Pass is the major passage linking the northeastern Pacific Ocean to the eastern Bering Sea. It also lies on the great circle route between the Orient and the west coast of North America. It is trafficked by fishing and cargo vessels, tankers, barges, and warships. Oil industry vessels supporting offshore exploratory activities in western and northern Alaska transit the pass. In the event of a major oil discovery, tanker and support vessel use of the passage is expected to markedly increase, thus increasing the probability of accidents which could result in oil spillage and regional damage to biota.

In anticipation that portions of the Bering Sea (St. George Basin, North Aleutian Shelf, Navarin Basin, Norton Sound) were to be leased for petroleum exploration, a series of meetings was convened over the past several years to assess the status of environmental knowledge of these areas. The syntheses resulting from these meetings were used to evaluate the environmental hazards to and potential environmental damages from activities in the leased areas. Although spatially removed from the actual lease areas, Unimak Pass was consistently identified as a region of utmost biological importance and was considered to be potentially at risk from outer continental shelf (OCS) activities in any or all tracts. Information needed for understanding of the biological processes in the pass were identified and additional research recommended.

The Unimak Pass area is perceived to have relatively high habitat values, as suggested by consistently intensive use by seabirds and marine mammals. Reconnaissance surveys by the U. S. Fish & Wildlife Service indicate that, in summer, well over one million seabirds nest on islands in the area. During spring and fall, millions of birds and thousands of marine mammals migrate through the pass. Large numbers of these apex predators feed in the area throughout the year, which is suggestive of high and sustained productivity. A lack of quantitative information on the nature and extent of use of the Unimak Pass area by marine birds and mammals has prevented NOAA and MMS from adequately determining the risks posed to bird and mammal populations by current activities or by the increased activity that might result from OCS oil and gas development.

As a first step toward filling information needs, OCSEAP in summer 1985 initiated a review of available data related to the Unimak Pass environment. This review (Truett and Craig 1986) described to the extent possible the faunal distributions in the pass area.

Based on this review and previous synthesis meetings, NOAA identified research needed to provide a better understanding of the important ecosystem processes in the Unimak Pass area, with special reference to marine birds and mammals. The objective of the research was to enable managers to predict the ecological effects of man's activities in the area. In response to this need for additional information, OCSEAP issued a solicitation (Number WASC-86-00074) for proposals to conduct research. A contract was subsequently awarded to LGL Alaska Research Associates, Inc. This report describes the results of the research conducted under this contract.

OBJECTIVES

The goal of this project was to develop information that could be coupled with oil spill trajectory predictions to assess risks posed to marine birds and mammals by OCS oil and gas activities in the Unimak Pass area. The specific objectives were to:

(1) Characterize the seasonal intensity of use of Unimak Pass habitats by marine birds and mammals, identifying particularly important concentration areas;

(2) Relate the seasonal distributions, abundances, and activities of marine bird and mammal species to insular and persistent oceanographic features such as currents, tiderips, and upwelling areas;

(3) Evaluate the vulnerability of marine birds and mammals to oil spills in the Unimak Pass area in terms of individual species abundances, locations, seasons, species' sensitivities to oil, and Alaska and world population sizes; and

(4) Investigate nocturnal seabirds at nesting colonies in the Krenitzin Islands with a view to improving census techniques.

CONTENT OF THE REPORT

The primary emphasis in this study was placed on determining the distributions and abundances of marine birds and mammals. One of our overall objectives, however, was to relate the distributions of these organisms to features in their environment. To do this necessitated considerable study effort in describing the marine habitats that were sampled for birds and mammals. In particular, we attempted to characterize oceanographic conditions, especially the spatial extent of various water masses and the occurrence of areas of marine upwelling. Further, we looked for patterns in the distributions of key prey species (zooplankton and forage fish) that might provide insights as to how the oceanographic features could be influencing bird or mammal distributions.

The descriptions of the physical environment and the prey resources of the study area provide an important background for the chapters on birds and mammals. These background chapters are not intended as exhaustive disciplinary summaries; rather, they focus on information expected to help explain bird and marine mammal distribution patterns.

The report contains the following chapters:

(1) INTRODUCTION
(2) PHYSICAL PROCESSES AND HYDROGRAPHY
(3) ZOOPLANKTON ABUNDANCE AND DISTRIBUTION
(4) FORAGE FISH ABUNDANCE AND DISTRIBUTION
(5) MARINE BIRD ABUNDANCE AND HABITAT USE
(6) MARINE MAMMAL ABUNDANCE AND HABITAT USE
(7) COASTAL MARINE BIRDS AND MAMMALS
(8) SEABIRD COLONIES
(9) ABUNDANCE, DISTRIBUTION, AND VULNERABILITY TO IMPACT OF BIRDS AND MAMMALS: A SYNTHESIS
(10) APPENDICES

STUDY AREA

The study area encompassed Unimak Pass and adjacent waters within a distance of approximately 50 km, including the Krenitzin Islands group. The limits of the area of interest were defined by the rectangle bounded by latitudes 53°30'N and 55°00'N and longitudes 164°00'W and 166°30'W (Fig. 1).

RESEARCH APPROACH

Several criteria were used in designing the research approach. These are briefly described below.

(1) The general scope of work described in the solicitation. Although seemingly self-evident, this research unit is not simply a continuation of previous study efforts in the area, nor is it intended to fill all data gaps relating to all birds and marine mammals.

(2) The species and groups of emphasis. The approach was intended to optimize collection of data relating to the key study species. Key species were selected based on expected abundances in the study area and expressed interests by NOAA. Data on other species were also collected as long as this did not detract from fulfillment of the primary objectives. In terms of bird and marine mammal surveys, this meant that observers recorded all birds and mammals

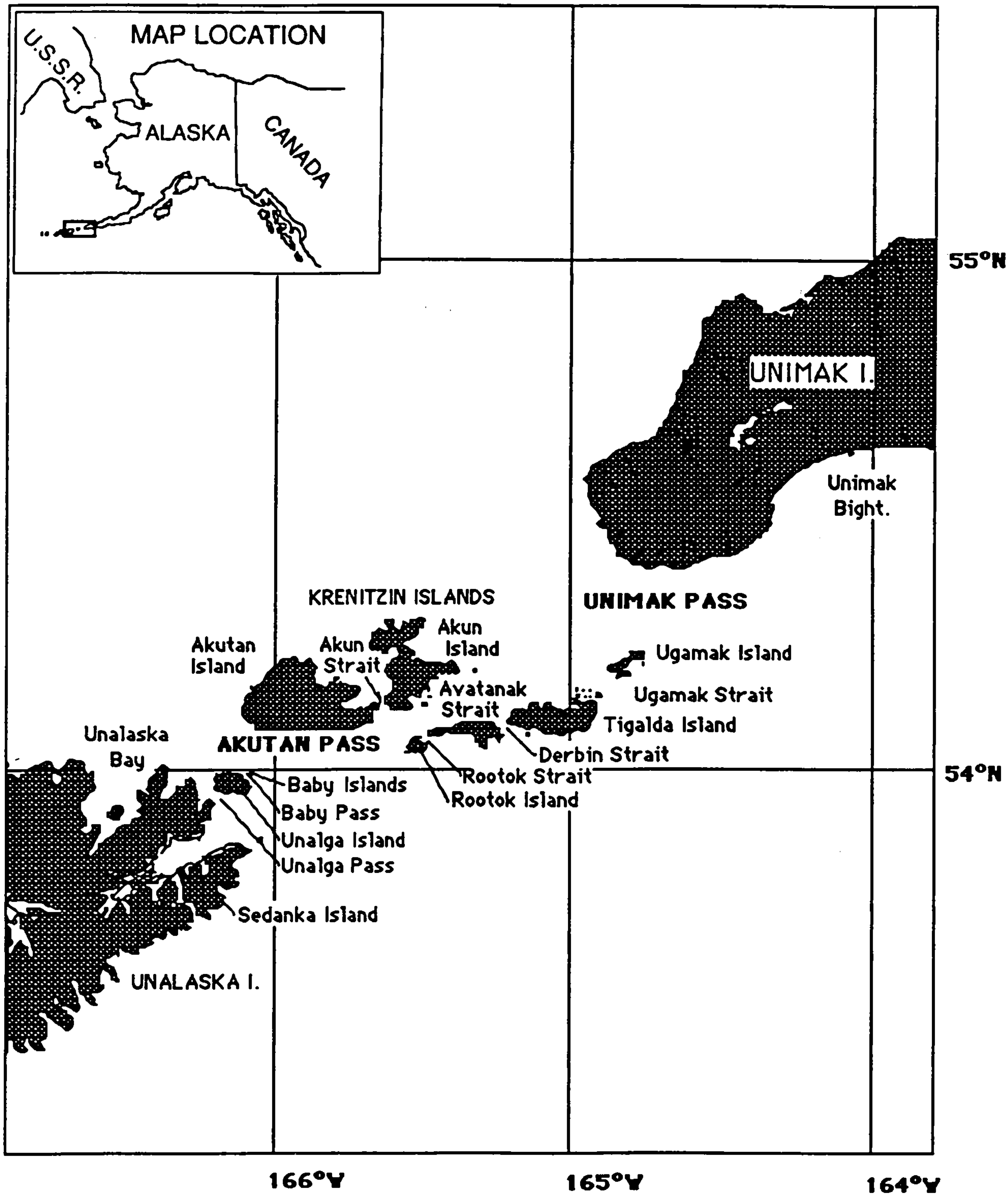

Figure 1. Place names in the Unimak Pass study area, Alaska

seen, but that spatial coverage and intensity of sampling was intended to maximize information obtained about the key species.

(3) The desirability of developing hypotheses for testing. Experience in other programs, such as the North Aleutian Shelf study (LGL 1987), has shown that addressing specific objectives in the form of questions or hypotheses provide answers that permit critical evaluation of the research project and its success. Very general objectives such as describing the distributions and abundances of marine birds have no logical termination; such programs are easy to design but hard to evaluate. Our approach was to derive a set of specific hypotheses we wished to investigate and to design research appropriate for testing them. Collection of general distribution and abundance data was accomplished only as convenient during the process of addressing specific hypotheses.

(4) The desirability of determining causes for observed distributions. As part of several research programs in the Bering Sea, bird and mammal data have been collected concurrently with oceanographic or other biological information (e.g., PROBES and North Aleutian Shelf studies). These studies had developed hypotheses about bird/mammal distributions in relation to such features as fronts, upwellings, and prey concentrations. It was desirable that this study provide direct evidence for testing various hypotheses about such associations, e.g., do auklets aggregate in areas of zooplankton concentration that result from upwellings? Our approach was to collect ancillary data from other disciplines, especially oceanography and zooplankton and fisheries ecology, in a manner and location that would help determine reasons for observed bird/mammal distributions.

In summary, our general approach was to conduct an interdisciplinary study focused on answering specific questions about why key species distributed themselves in specific ways within the study area. By virtue of the platfrom provided and the opportunity it offered for sampling oceanographic phenomena and prey availability, the proposed program was a predominantly shipboard study.

STUDY ELEMENTS

The proposed field sampling effort had five components. These were (1) broad-scale marine surveys for birds and mammals, (2) environmental characterizations of the marine areas surveyed, (3) detailed characterizations of areas of high use by birds, (4) surveys of birds and mammals near coastlines, and (5) seabird colony studies.

Broad Scale Surveys

This component of the program dealt directly with fulfillment of the first objective of the requested work--to characterize the seasonal intensity of use of Unimak Pass habitats by marine birds and mammals, identifying particular concentration areas. The work was conducted as a series of broad-scale surveys to measure bird and marine mammal abundance in area habitats. This effort comprised the major attempt to collect distribution and abundance information on a seasonal basis. The questions to be addressed by this effort included:

(1) How did the passes between the Bering Sea and Pacific Ocean compare in terms of their usage by the key species?

(2) What were the marine habitat preferences, by season, of the key species?

(3) What factors (biotic, oceanographic, and geographic) were the best predictors of abundance of key species?

(4) How did abundance of key species vary on a seasonal basis?

Transects were distributed by habitat and sampled during three seasons--fall (September), winter (January-February), and spring (April-May). We arbitrarily delimited habitats by criteria we believed would influence bird and mammal distribution and that could be spatially defined. The two main criteria we used were (1) horizontal location with respect to the islands and passes and (2) water depth.

Surprisingly few studies are available that demonstrate predictable affinities of birds and mammals with any but gross categories of marine habitats (e.g., coastal, nearshore, shelfbreak). That is, statistical associations with oceanic domains have been demonstrated, but physical parameters measured have tended to explain relatively little variability in abundance. The importance of prey abundance, oceanographic features (water temperature, depth), and proximity to geographic features (seabird colonies, Izembek Lagoon, and Unimak Pass) in determining seabird abundance were evaluated in preliminary analyses for the North Aleutian Shelf studies (LGL, unpubl. data). Location features, especially the nearness to Unimak Pass, appeared to be the most important predictors of seabird abundance. The distributions of some birds (e.g., Common Murre, seaducks, Leach's Storm-Petrel) are known to be related to water depth. General observations of the distributions of some of the prey (e.g., benthos) of birds and mammals suggest further that water depth is an important habitat criterion.

Based on these apparent animal/habitat relationships, we subdivided ship-navigable parts of the study area into "habitats" to be surveyed. Our initial classification was a nested one. The top level of this classification consisted of three geographic zones—a central band comprising the passes and inter-island straits, Bering Sea waters, and Pacific Ocean waters. Within each of these zones, habitats were subdivided by depth class, delimited as <50 m, 50-100 m, 100-200 m, 200-400 m, 400-800 m, >800 m. There is an insignificant portion of Unimak Pass >100 m, and depths >800 m occur only in the Pacific Ocean part of our study area. In the analyses presented within this report, this habitat breakdown is refined.

The passes and straits zone was spatially heterogeneous in habitat qualities (e.g., distances from islands, passes, colonies). We sampled the various passes (Unimak, Akutan, Unalga, and Baby) and straits (Akutan, Avatanak, Derbin, and Ugamak) and compared their relative use by birds. Unimak Pass was subdivided into eastern, central, and western parts because we already knew marine organisms to use these parts differently. For example gray whales are restricted to the east side of the pass, but humpback whales are found largely on the west side.

We recognized the Pacific Ocean side of Unimak Pass as being different from the Bering Sea side for two reasons. First, the passes are quite shallow relative to areas to the north and south, and species preferring deeper waters may treat the passes and straits zone as a barrier, and thus inhabit depth zones in only one region. The two oceanic zones also differ in large-scale oceanographic characteristics, most notably in the spatial extent of areas of upwelling and in the presence of distinct current systems.

We did not propose to occupy a set of fixed transects during every cruise. We anticipated that the vagaries of weather in the study area would frustrate any attempt to accomplish too rigid a sampling design. Rather, we proposed to conduct similar levels of sampling intensity among zones. This permitted a more flexible sampling schedule; e.g., during major storms we moved the ship to alternate sides of the Aleutian chain as required. It proved possible to repeat most major survey lines during each cruise; hence there was a great deal of overlap in sites sampled among cruises.

Environmental Characterization

Sampling to characterize oceanographic conditions and prey availability was usually done at night. This sampling included periodic bongo net samples (oblique and horizontal) and CTD casts. Surface prey samples were also taken, initially with a tucker trawl until this device was irreparably damaged. Surface bongos were later substituted. Abundance and species composition of forage fish were sampled using a Marinovich mid-water trawl. Most sample stations where CTD, zooplankton, and fish samples were collected were reoccupied on each cruise.

Characterization of High-Use Areas

Areas of pronounced concentration in bird use were subjected to more intensive sampling of environmental conditions and/or collections of birds for food habits analysis. Extra sampling generally entailed spatially restricted night sampling, occupation of a station for most of a day (or 24 hrs), or supplemental daytime sampling.

We did not perform a large-scale feeding study of marine birds; however, some collecting of marine birds for food habits analysis was required to compare what they ate with relative abundances of prey items available. Specific diet-related questions addressed were:

- What are the Crested Auklets eating when they are in their winter flocks? The most likely alternatives were copepods or euphausiids. If the birds were eating copepods, we proposed to identify the prey to species, because particular copepod species are associated with specific water masses. These data would provide indirect information on sources of the water in which the birds were feeding.

- What is the principal prey of the murres in winter? Food habits of murres have been intensively studied and we would expect that the large flocks of primarily Common Murres would prey on forage fish. Fisheries investigations in the area of interest have failed to find appreciable quantities of forage fish in winter; therefore, it seemed possible that the murres ate invertebrates in winter.

- What is the most important component in the diet of the late summer aggregations of shearwaters? In the nearby North Aleutian Shelf, shearwaters appear to shift from a diet of euphausiids at the start of the season to fish (sand lance) by the end of their stay (Troy and Johnson 1987). Methods to measure the distributions of these two groups of potential prey are quite different; hence it seemed necessary to collect shearwaters to determine which prey group should be measured.

Surveys in Coastal Environments

The preliminary list of key species included several—seaducks, Glaucous-winged Gull, sea otter, and Steller sea lion—that are primarily coastal and ineffectively sampled by shipboard surveys. Our approach to survey these groups was to conduct small boat surveys following the coastline of the islands in the Krenitzin group, censusing and mapping locations of these species.

Colony Studies

The seabird colony studies in the Krenitzin Islands, funded incrementally as Phase II of this investigation, formed a rather discrete study unit not closely linked to the marine investigations.

CRUISE SUMMARY

Three cruises were dedicated to this study. These cruises, all using the NOAA ship R/V Miller Freeman, were as follows:

MF-86-10	18 September 1986-7 October 1986	fall
MF-87-02	14 February 1987-9 March 1987	winter
MF-87-05	21 April 1987-14 May 1987	spring

Summary maps showing the approximate locations of stations occupied for taking various samples and measurements appear in the disciplinary sections that follow. A complete listing of the types and location of the samples taken is provided in Chapter 10. APPENDICES (this volume).

LITERATURE CITED

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Chapter 2

PHYSICAL PROCESSES AND HYDROGRAPHY

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SUMMARY

The purpose of this study was to examine the spatial and temporal distributions of temperature, salinity, and nutrient (nitrate, nitrite) levels in the Unimak Pass area as a basis for helping to explain observed distributions of vertebrates and their prey. Distributional analyses for these water quality variables were based on shipboard CTD casts and water samples taken on transects through the area, and on inspection of remote-sensing analyses of sea surface temperatures. Shipboard sampling was conducted in fall (late September-early October), winter (late February-early March), and spring (late April-early May).

Interpretations of the collected data supported and amplified the general findings of other investigators who have studied the region's oceanography. Findings with important implications for vertebrate food webs in the area were as follows:

(1) Four different water masses seemed to occur in the study area as a whole, based on surface salinities and mixing regimes. These were Alaska Coastal Current Water (east side of Unimak Pass adjacent to Unimak Island, surface salinity < 31.8 ppt), Shelf Break Water (north and west of Unimak Pass, surface salinity >32.6 ppt), Tidally-Mixed Water (no vertical structure, occurring in shallow areas near the Krenitzin Islands), and what we called Gulf of Alaska Water (structured water of intermediate surface salinities, widely distributed in deeper, western parts of the study area).

(2) Low-salinity Alaska Coastal Current Water was confined in all seasons to the eastern parts of Unimak Pass. Its farthest westward extension occurred in spring.

(3) Water temperatures changed most among seasons in shallow water, particularly where Alaska Coastal Current Water prevailed. The seasonal temperature range of deep water was typically within that of shallow waters.

(4) Reverse thermoclines were encountered in the water column in winter and spring, but were generally below the foraging depths of most seabirds. Thus, even should invertebrate or fish prey concentrate at these features, it would be of little consequence to birds.

(5) Water quality distributional characteristics indicated that upwelling of deep Gulf of Alaska Water south of Unimak

Pass and its subsequent transport through the pass was probably an uncommon event. Rather, it seemed that upwelling probably occurred a few to several hundred km farther west in the Aleutian chain, and that this water moved eastward along the north side of the chain, eventually reaching the Unimak Pass area. This is consistent with recent findings by other workers. An area of high surface salinity, suggesting local upwelling, was present during the fall immediately northwest of Unimak Pass.

(6) Nutrient analyses of water samples collected along transects through and parallel to Unimak Pass supported the oceanographic evidence for upwelling patterns. Nitrate/nitrite distributions indicated a source of nutrients to Unimak Pass proper that came from the north and/or west and was depleted to the east. There was local evidence of vertical mixing in the Krenitzin Islands and some other areas near Unimak Pass. Transport of deep-ocean nutrients through Unimak Pass from the south appeared unlikely.

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INTRODUCTION

A major objective of the Unimak Pass study was to relate the seasonal distributions, abundances, and activities of marine birds and mammals to oceanographic features and processes. This section helps to address this objective by examining the spatial and temporal distributions of temperature, salinity, and nutrients in waters of the study area.

Unimak Pass (Fig. 1) is the shallowest and easternmost of the passes situated in the eastern Aleutian Islands. The pass is approximately 18 km wide at its narrowest point and generally is less than 100 m deep; this is relatively shallow in comparison with major passes farther west in the Aleutian chain.

The study area encompassed Unimak Pass and adjacent waters within about 50 km of the pass. Included are the western half of Unimak Island and the northeastern tip of Unalaska Island. Passes, straits, and islands included are Akutan (including Baby) and Unalga passes; Ugamak, Derbin, Avatanak, Rootok, and Akun straits; and Ugamak, Tigalda, Avatanak, Akun, Rootok, Akutan, Unalga, and the Baby islands.

Areas within 10 km of land and in the narrow straits between islands are generally less than 60 m deep. Several shallow banks lie within Unimak Pass and at the western end of Unimak Island. The southeastern portion of the study area includes part of Davidson Bank, where the northern Gulf of Alaska continental shelf is relatively wide and depths are less than 100 m. Southernmost reaches of the study area approach the continental shelf break (1000 m deep). Northeasternmost stations are in Bering Sea continental shelf waters; some of the northwestern stations are on the Bering continental slope.

CURRENT STATE OF KNOWLEDGE

What was known prior to the present study about the circulation and water chemistry in Unimak Pass and vicinity is summarized in this section. For two reasons, studies conducted in adjacent regions are the major sources of information. First, previous to this study little work had been done in Unimak Pass proper. Second, processes taking place in nearby areas strongly influence circulation and resultant water quality in Unimak Pass. The following discussion is excerpted largely from Hood (1986).

Gulf of Alaska

In the northern Gulf of Alaska, the predominantly westward-flowing water masses transfer water into the Bering Sea through the Aleutian passes

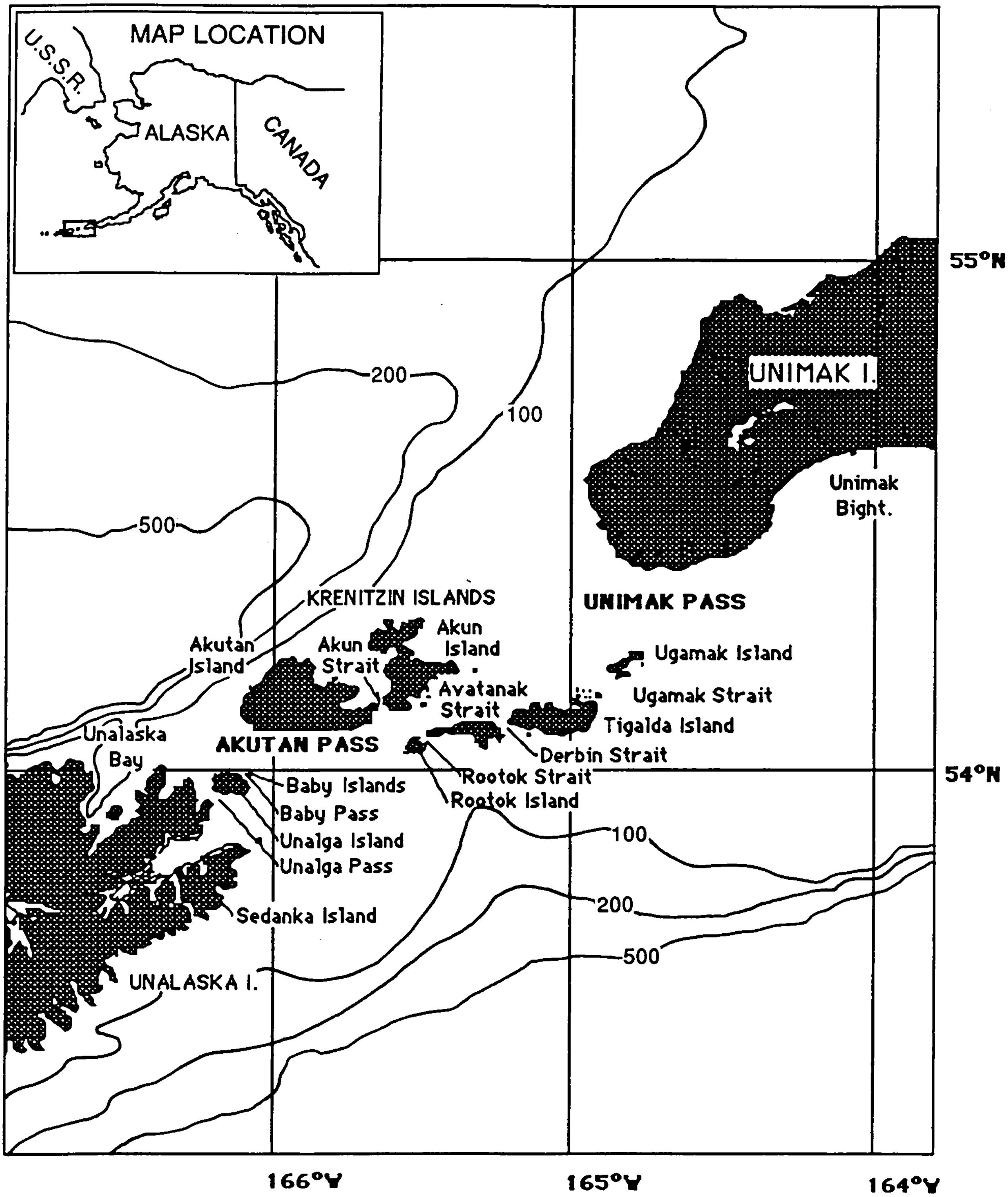

Figure 1. Place names and bathymetry (m) in the Unimak Pass area, Alaska.

(Fig. 2). The major currents that influence flow in the vicinity of Unimak Pass are the Alaska Coastal Current and the Alaska Stream (Hood 1986).

The Alaska Coastal Current (also called the Kenai current in the northern Gulf of Alaska) is a coastal flow that originates in the eastern Gulf of Alaska along the shores of British Columbia and follows the coast first northward to the northern Gulf and then southwest to Unimak Pass (Schumacher and Reed 1980, Schumacher et al. 1982). The speed of this current is between 10 and 20 cm/s throughout its length, except near the Kenai Peninsula where it intensifies to as much as 100 cm/s.

The Alaska Stream parallels and is adjacent to the Coastal Current, but is off the shelf. It moves in the same general direction at (usually) higher speeds. It is formed in the eastern Gulf of Alaska as a result of the bifurcation of the Subarctic Current, which is the eastern and poleward boundary of the large, counterclockwise Subarctic Gyre.

Upstream from Unimak Pass, the Coastal Current waters near the coast may have salinities as low as 26 ppt due to freshwater discharges. (These discharges may actually drive the Alaska Coastal Current.) But as the Coastal Current waters move westward toward Unimak Pass, river input becomes much less and salinities moderate to 31 or 32 ppt in the vicinity of the pass. (Salinities in Alaska Stream surface waters south of the pass approach 33 ppt.)

Temperatures in the Coastal Current waters are more variable seasonally than those in the deeper Alaska Stream water. In the vicinity of Unimak Pass, surface temperatures of shelf waters may range from slightly above 0° C in winter to as high as 10° C in some areas in summer (Craig 1987). Temperatures of Alaska Stream water in winter range from <3° C to > 5° C, depending on depth; summer temperatures near the surface are a few degrees higher.

Aleutian Passes and Bering Sea

Historically, there have been numerous attempts to determine which Aleutian Chain passes accommodate the flows of various water masses that move from the northern Gulf of Alaska into the Bering Sea (Hood 1986). In this study the concern was mainly with the water masses making important contributions to waters in the Unimak Pass area.

Schumacher et al. (1982) summarized the available data on exchange of water through Unimak Pass and concluded that most of the Alaska Coastal Current moved through the pass. Water of salinity less than 31.75 ppt, which these authors defined as Alaska Coastal Current water, dominates the surface regime on the eastern side of the pass, and currents in the pass tend to follow the isobaths. Waters with such low salinities are not found west of Unimak Pass along the Aleutian Chain.

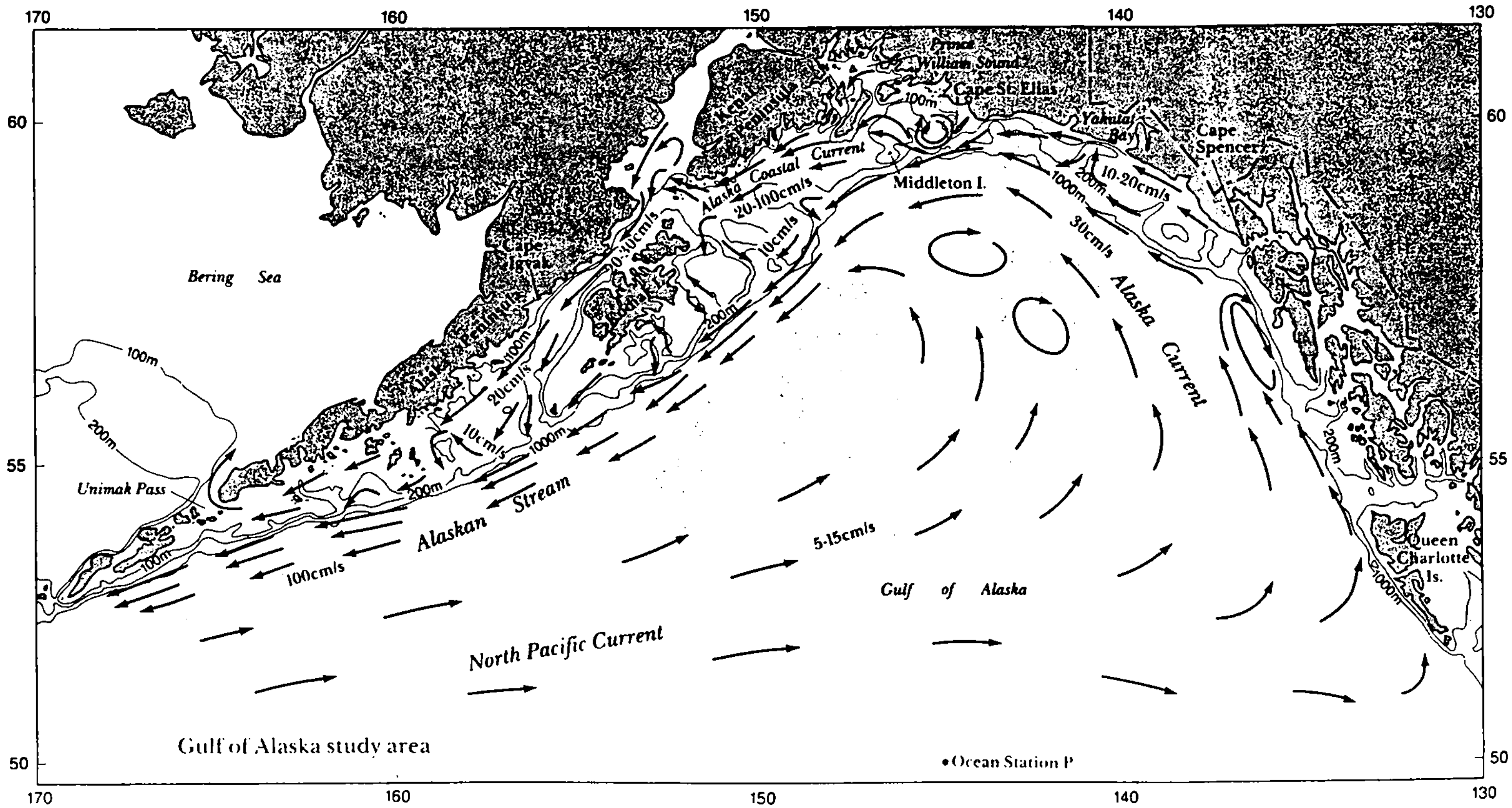

Figure 2. Schematic representation of the major currents in the Gulf of Alaska (from Reed and Schumaker 1986).

More recently, Nof and Im (1985), using theoretical modeling of suction through broad ocean passes, provided interpretations supporting this idea. Their model predicted that a separated boundary current encountering a broad gap on its righthand side is sucked in its entirety into the adjacent basin; such a current flowing along a wall with a series of broad gaps (similar to the situation in the eastern Aleutian chain) will enter only the first gap. When they applied the model to Unimak Pass, it showed the Alaska Coastal Current flowing through the pass and then moving northeast along the Bering Sea side of the Alaska Peninsula. An analysis of the relevant salinity data available for the period 1929-1974 (a total of 1342 stations) revealed that water with similarly low salinity appeared on both sides of the Alaska Peninsula east of Unimak Pass but not west of the pass, thus supporting the model.

In contrast, waters of the offshore Alaska Stream do not appear to penetrate the easternmost Aleutian passes, but instead flow into the Bering Sea through passes farther to the west. Near Strait, near the western end of the Aleutian Chain, seems to accommodate much of this water (Hughes et al. 1974, Favorite 1974).

The presently accepted scheme of surface circulation in the Bering Sea adjacent to the Aleutian chain shows a current flowing from at least the central portion of the chain eastward to Unimak Pass. Takenouti and Ohtani (1974) identified Alaska Stream type water along the north side of the Aleutian Islands, including the area immediately north of Unimak Pass. This water has homogeneous temperatures between 4° and 5° C down to 100-m depths, and homogeneous salinities to the same depths. The major component of this current seems to turn northward to form the Shelf Break Current upon reaching the shelf break just north of the pass (Kinder and Schumacher 1981).

Variability in Flow

The passage of low-pressure storm systems along the Aleutian storm track strongly influences the water quality as well as the strength and direction of water flow in the Unimak Pass area. The intensity of storms is greatest in the winter months, October through April, during which an average of one storm every four or five days crosses the Bering Sea and the Gulf of Alaska, generally from west to east.

These storms bring strong winds, nearly continuous cloud cover, and warm, moist air ahead of cold fronts. The moisture is intercepted by high mountain ranges in the coastal areas of the Gulf of Alaska, generating runoff that dilutes Alaska Coastal Current water, ultimately affecting water salinity in the Unimak Pass area.

The direction of the wind field during these storms strongly influences the differences in water levels across Unimak Pass, and consequently the direction and magnitude of flow through the pass. The passage of a low across the Aleutians in the vicinity of Unimak Pass tends to increase the flow into the Bering Sea as the front moves through, due to the easterly and southerly winds. The dominant storm winds tend to be easterly, and under these winds the surface waters south of the Alaska Peninsula tend to converge on the coast, causing down-welling. On the Bering Sea side, the coastal waters tend to diverge, causing upwelling. As the storm passes, the flow relaxes and reverses its direction.

During summer the low-pressure systems are weaker and tend to migrate farther north. A high-pressure system is established over the Gulf of Alaska, causing a periodic shift in wind patterns from easterly to westerly with consequent coastal divergence of water and limited upwelling south of the Alaska Peninsula.

Though flows through Unimak Pass from the Gulf of Alaska into the Bering Sea periodically reverse, as described above, Schumacher et al. (1982) found reversals to occur in only 18% of the spring and 31% of the summer observations. Mean flow was three times greater in spring than in summer.

Upwelling and Nutrients

In 1966, Dugdale and Goering (1967) observed a high nutrient content in waters near Unimak Pass and suggested that it was caused by deeper Pacific Ocean water passing over the shallow sill of Unimak Pass and effecting vertical transport, a form of upwelling. Subsequently, Kelley et al. (1971) measured the partial pressure of CO_2 in the surface waters of sites in the eastern Aleutians to detect and map areas of upwelling.

The CO_2 technique for detecting and measuring upwelling is based on changes in the levels of carbon dioxide in the water as it rises to the surface. Near the sea surface, use of CO_2 by phytoplankton during periods of primary productivity (and by animals in the formation of calcareous shells) lowers the partial pressure of CO_2 below that of the overlying air mass. Recycling of organic carbon and dissolution of calcium carbonate in the water column release CO_2; this occurs at all depths in the water column and increases the CO_2 values. Thus, below the euphotic zone, where photosynthesis does not occur, the CO_2 produced by recycling accumulates, and if these deeper waters are brought to the surface, they are supersaturated in CO_2 with respect to the atmosphere.

Because of the very large difference in CO_2 levels between surface waters (values as low as 125 microatmospheres) and deeper waters (values as high as 600 microatmospheres), measurement of the surface value of CO_2 is probably the most sensitive method available for mapping upwelling in high latitudes. The conventional method of mapping sea surface temperatures is less useful at higher latitudes than in more temperate areas because there is a small vertical range of temperatures and upwelled water is not always colder than the adjacent surface waters.

Kelley et al. (1971) used the CO_2 technique to map upwelling along the eastern Aleutian Islands. During June and September, these authors found Unimak Pass waters to be undersaturated in CO_2 with respect to the atmosphere, in contrast to high supersaturated values at the deeper Samalga and Amukta passes some 300-400 km to the west. The high values in the west were interpreted as resulting from the upwelling of deep Gulf of Alaska water as it flowed through Samalga and Amukta passes; the low values at Unimak Pass were interpreted to be caused by primary productivity having stripped CO_2 from the surface waters. The waters at Unimak Pass could well have been originally upwelled farther west in Aleutian passes; if this was the case, it could easily have lost its CO_2 to phytoplankton as it moved eastward in the euphotic zone.

Additional studies in the eastern Aleutians (Kelley and Hood 1974, Hood and Kelley 1976) disclosed high CO_2 levels in surface waters near Unimak Pass indicating that water had been brought from depth in the Krenitzin Islands-Unimak Pass area as well as in the Samalga Pass area. The values near Samalga Pass were so large that the authors believed them to have certainly been caused by upwelling from 150- 200-m depths; those near Unimak Pass were smaller and were interpreted to have been the result of tidal mixing.

Although physical and biological clues support the idea of a nutrient-enriched area in the vicinity of Unimak Pass, nutrient analyses in the area have been limited. Koike et al. (1979, 1982) occupied sampling stations along a transect through the pass on 30 July 1978. They found chlorophyll-a and nitrate concentration patterns not inconsistent with the idea of upwelling along the Aleutian Chain west of Unimak Pass. Off the shelf immediately northwest of Unimak Pass, chlorophyll-a concentrations were high and nitrate concentrations were low, both suggesting a high level of primary productivity (Koike et al. 1982). In the southeastern (narrowest) part of Unimak Pass and east of the pass south of the Alaska Peninsula (possibly located within the Alaska Coastal water moving through the pass), chlorophyll-a concentrations were lower and nitrate concentrations higher.

METHODS

Shipboard CTD Transects

Hydrographic (CTD) stations in the Unimak Pass study area were occupied on three cruises of the R/V Miller Freeman: 18 September - 7 October 1986 (Fig. 3), 14 February - 9 March 1987 (Fig. 4), and 21 April - 14 May 1987 (Fig. 5). A total of 254 stations was sampled during the three cruises. Summaries of station locations, dates, casts, and times of day are given in Appendices A-C.

A model 9040/9041 Plessey/Grundy CTD system was used to record and calculate water temperature, salinity, density (sigma-t), and geopotential anomaly (∂-d) for each meter of the cast. The values recorded by the CTD were checked against salinity samples obtained from rosette-mounted 5-L Niskin bottles and temperatures obtained from deep-sea reversing thermometers mounted on these bottles. Station depths ranged from 40 to 2195 m, but actual cast depth seldom exceeded 800 m.

The CTD data tape, and calibration and quality control information, were sent to the Institute of Marine Science, University of Alaska, Fairbanks, for reduction. The resulting product was a tabulation, suitable for analyses on personal computers, that listed temperature, salinity, sigma-t, and geopotential anomaly averaged over 1-m intervals.

These reduced data were then presented as vertical profile plots for each of the four water quality variables. Surface hydrographic data for the entire study area collected during a cruise were presented as horizontal contour plots of temperature and salinity. These vertical and horizontal plots were then used as a basis for characterizing water masses.

Remote Sensing Thermal Analyses

Horizontal distributions of sea-surface temperatures were also evaluated on the basis of remote sensing information. Satellite images showing surface temperature distributions in the vicinity of Unimak Pass were obtained from the Gilmore Creek NASA Tracking Station in Fairbanks. Photographic images were based on the 4Z and 94Z infrared enhancement curves and covered the period 25 February - 6 March 1987. For some days when cloud cover was minimal, up to two images were available.

Cartographic presentations of sea-surface temperature were available from NOAA/NWS Sea Surface Thermal Analysis charts. These charts present horizontal contours of temperature for the northern Gulf of Alaska

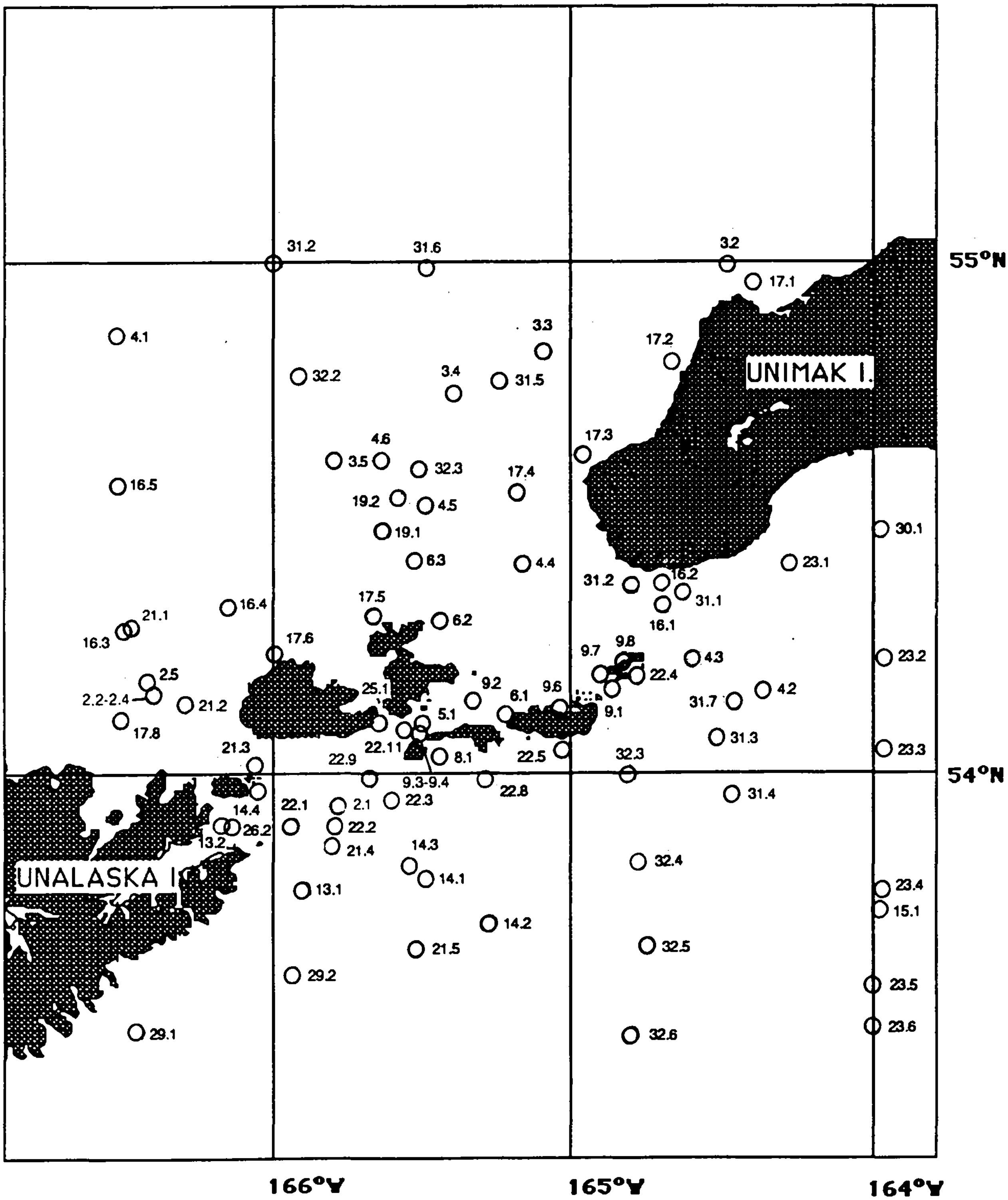

Figure 3. Locations of CTD stations sampled during the fall 1986 cruise, 18 Sept-7 Oct, in the Unimak Pass area, Alaska.

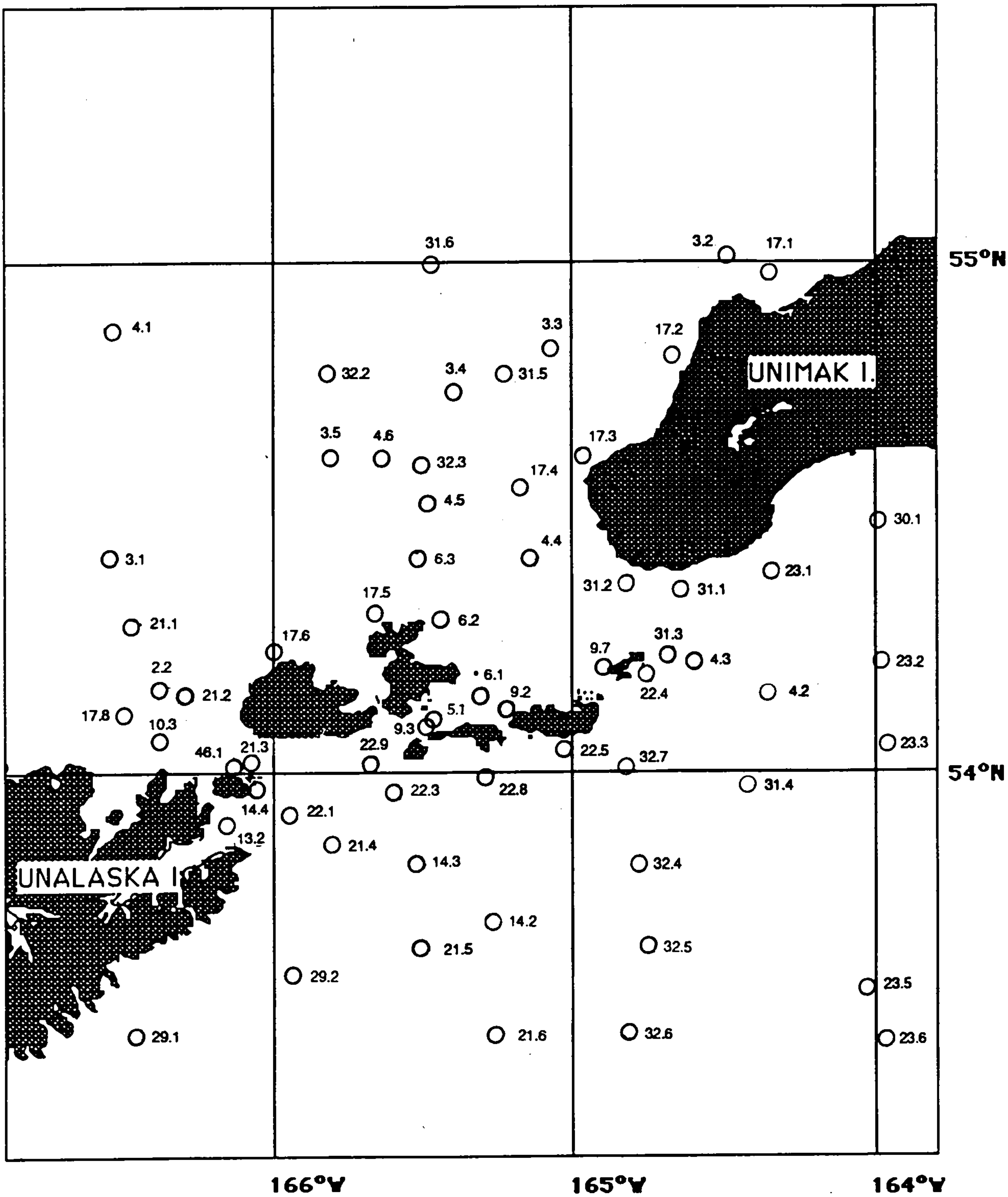

Figure 4. Locations of CTD stations sampled during the winter 1987 cruise, 14 Feb-9 March, in the Unimak Pass area, Alaska.

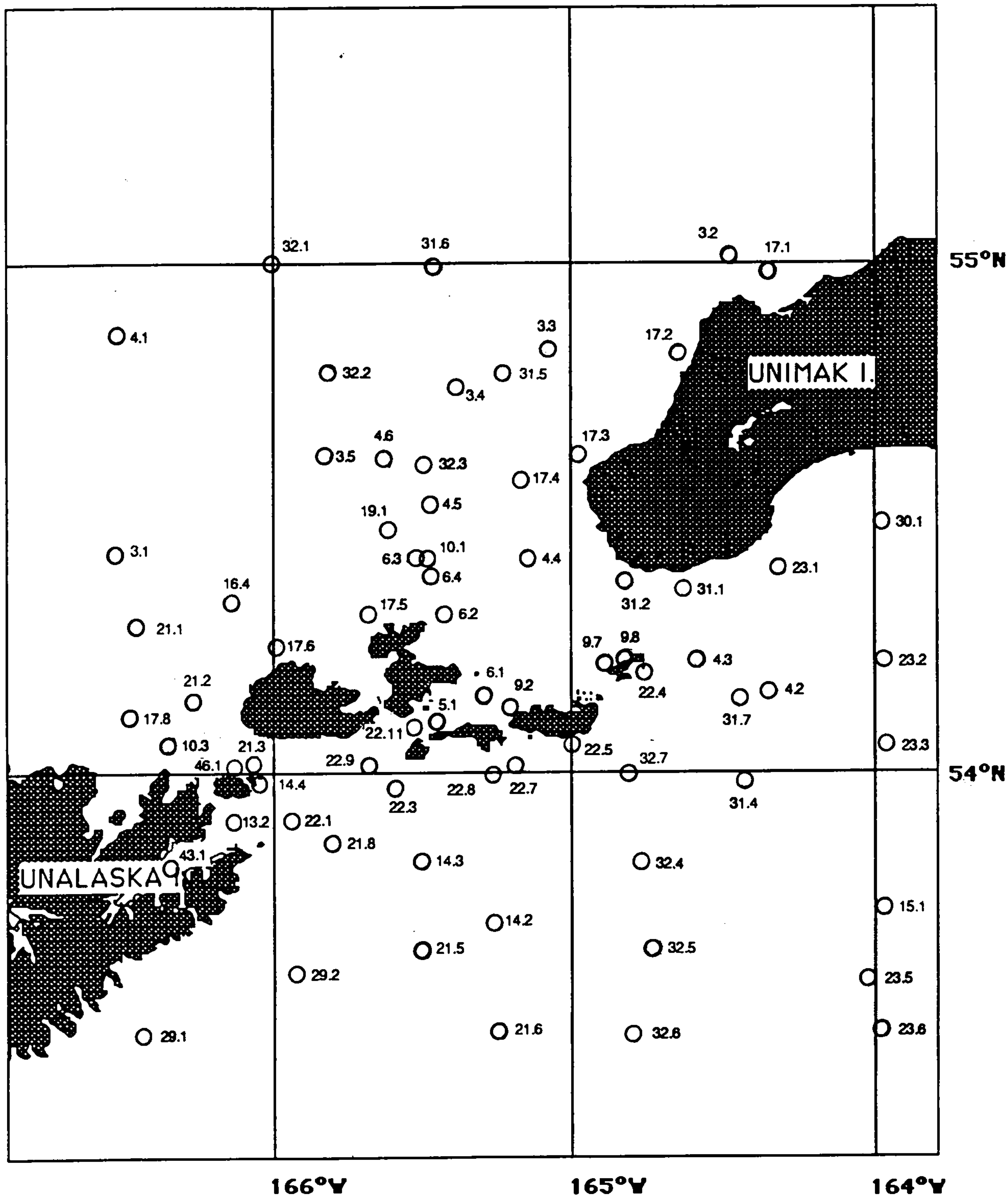

Figure 5. Locations of CTD stations sampled during the spring 1987 cruise, 21 April-14 May, in the Unimak Pass area, Alaska.

and Bering Sea at relatively coarse scales. Charts covered the entire period of each cruise, and generally several days or weeks on either end of the cruise.

Time Series Stations

Four stations were sampled repeatedly (approximately every two hours) for changes in water mass properties due to tidal fluctuations. Station 26.2 (330 m) at the mouth of Beaver Inlet was sampled seven times on 7 October 1986 (Table 1). Station 21.3 (70 m) in Akutan Pass north of the Baby Islands was sampled six times between 2000 hrs AST on 6 March and 0600 hrs AST on 7 March 1987 (Table 2). Station 6.4 (100 m) at the eastern edge of Unimak Pass near Akun Island was sampled six times between 2100 hrs ADT on 7 May and 0700 hrs ADT on 8 May 1987 (Table 3). Station 21.1 (1040 m), approximately 30 km north of Unalaska Bay, was sampled five times on 11 May 1987 (Table 4).

Nutrients and Upwelling

Measurements of the vertical and horizontal distributions of nitrate/nitrite were made using water samples collected along three transects near Unimak Pass (Fig. 6). An along-shelf transect (Stations 3.1-3.5) was conducted north of Unimak Pass. Two transects were conducted through study area passes: Transect 21 (Stations 21.1-21.5) ran through Akutan Pass and Transect 4 (Stations 23.3 and 4.2-4.6) ran through Unimak Pass.

Water samples were collected from the water column at various depths at stations along transects. These samples were immediately frozen in 250 ml bottles. At the University of Alaska in Fairbanks, analyses for nitrate/nitrite and ammonia were carried out using standard methods (Strickland and Parsons 1972) adapted to a Technicon Autoanalyzer.

RESULTS

Water temperature, salinity, and nutrient distributions in the Unimak Pass area as measured during the 1986 and 1987 cruises of the R/V Miller Freeman are presented in the following subsections. Surface distributions of properties are shown; these help characterize water mass habitats for surface-feeding seabirds. The locations of strong pycnoclines, where prey of diving seabirds could be concentrated, are also described. Apparent tidal effects on oceanographic properties in the study area are presented. Vertical and horizontal distributions of nitrates, and what this implies about characteristics of upwelling in the Unimak Pass area, are identified.

Table 1. Times, depths, and positions for Station 26.2 time-series casts at the mouth of Beaver Inlet in Unalga Pass, Unimak Pass area, Alaska.

Station	Date	Time (ADT)	Depth (m)	Latitude (°N)	Longitude (°W)
26.2a	07-Oct-1986	05:20	305	53.9023	166.1058
26.2b	07-Oct-1986	07:11	310	53.9027	166.1150
26.2c	07-Oct-1986	09:13	312	53.9018	166.1035
26.2d	07-Oct-1986	11:13	320	53.9017	166.1277
26.2e	07-Oct-1986	13:12	329	53.9012	166.1255
26.2f	07-Oct-1986	15:03	330	53.9070	166.1295
26.2g	07-Oct-1986	17:08	241	53.8940	166.1058

Table 2. Time, depths, and positions for Station 21.3 time-series casts in Akutan Pass north of the Baby Islands, Unimak Pass area, Alaska.

Station	Date	Time (AST)	Depth (m)	Latitude (°N)	Longitude (°W)
21.3a	06-Mar-1987	20:21	43	54.0237	166.0613
21.3b	06-Mar-1987	22:01	48	54.0247	166.0448
21.3c	07-Mar-1987	00:08	63	54.0258	166.0737
21.3d	07-Mar-1987	02:07	53	54.0213	166.0647
21.3e	07-Mar-1987	04:03	44	54.0218	166.0742
21.3f	07-Mar-1987	06:04	71	54.0273	166.0877

Table 3. Time, depths, and positions for Station 6.4 time-series casts north of Akun Island on the east side of Unimak Pass, Alaska.

Station	Date	Time (ADT)	Depth (m)	Latitude (°N)	Longitude (°W)
6.4a	07-May-1987	21:02	102	54.3900	165.4890
6.4b	07-May-1987	22:57	98	54.3912	165.4920
6.4c	08-May-1987	01:00	97	54.3897	165.4967
6.4d	08-May-1987	03:00	97	54.3895	165.4962
6.4e	08-May-1987	05:02	102	54.3912	165.4893
6.4f	08-May-1987	07:18	102	54.3918	165.4893

Table 4. Times, depths, and positions for Station 21.1 time-series casts north of Unalaska Bay, Unalaska Island, Alaska.

Station	Date	Time (ADT)	Depth (m)	Latitude (°N)	Longitude (°W)
21.1a	11-May-1987	04:09	975	54.2985	166.4590
21.1b	11-May-1987	06:08	1040	54.2950	166.4548
21.1c	11-May-1987	20:07	1017	54.2970	166.4617
21.1d	11-May-1987	22:34	1024	54.2965	166.4587
21.1e	12-May-1987	00:05	1016	54.2962	166.4627

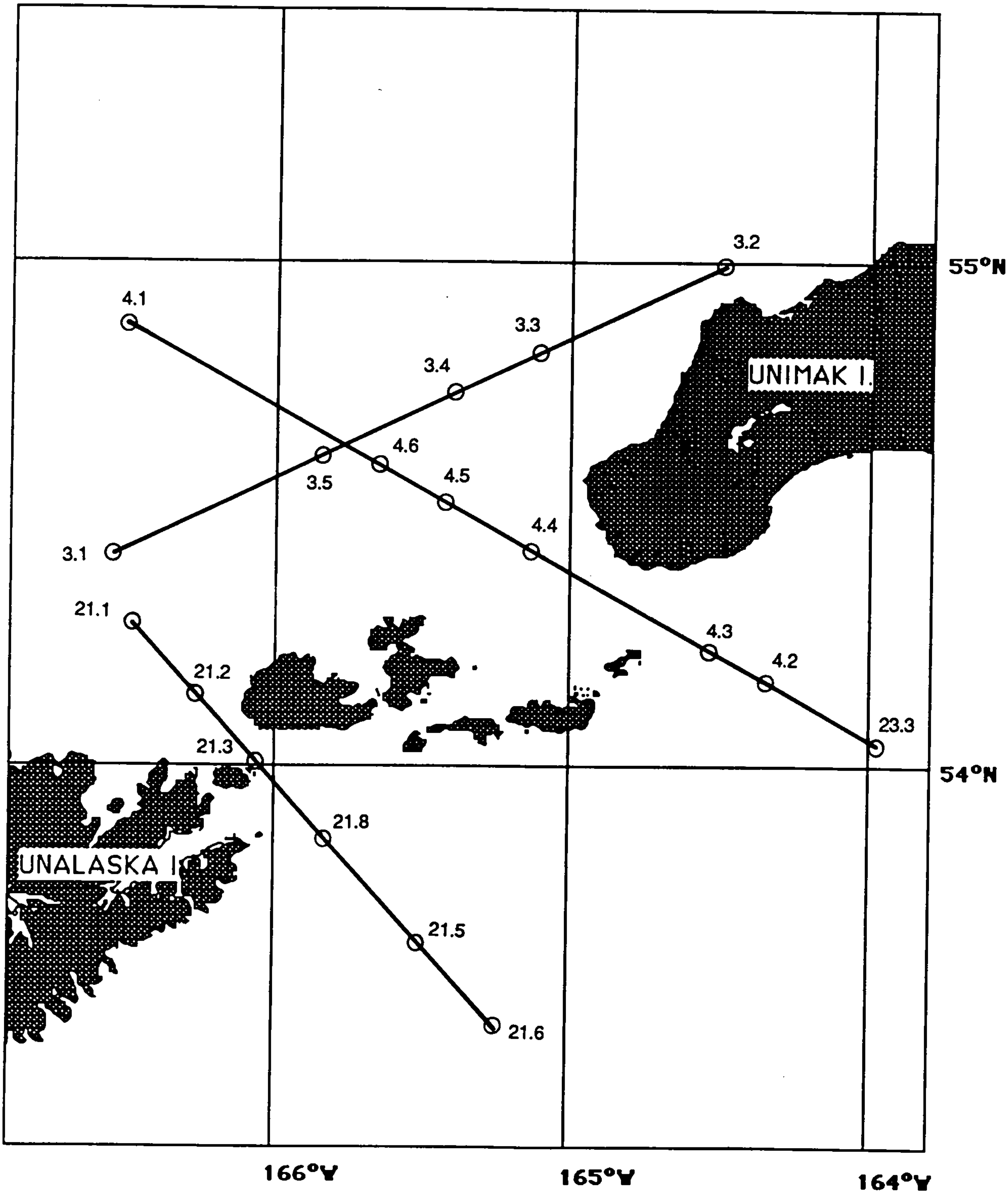

Figure 6. Transects along which nitrate and nitrite measurements were made, Unimak Pass, Alaska. Station numbers are indicated.

Temperature and Salinity Distributions

Distributions of temperature and salinity in fall, winter, and spring, as measured by shipboard CTD sampling and remote sensing (temperature), are presented in this section. CTD results shown represent summaries based on analyses of data acquired at sampling stations; these data are shown in greater detail in Chapter 10. APPENDICES at the end of this volume.

Fall 1986 : CTD Transects

Horizontal differences in study area sea surface temperatures were larger (6.7-11° C) during the fall cruise period than in winter or spring. During fall, the warmest water occurred in the southeastern corner of the study area near the edge of the Gulf of Alaska continental shelf (Fig. 7). The coolest water was found surrounding Akutan and Akun islands in the central portion of the study area. A warm body of water east of Unalaska Island, which also corresponded with relatively saline water (see below), may have indicated the presence of a warm oceanic eddy in the eastern portion of the study area.

Surface salinities ranged from 31.5-32.8 ppt during the fall and were lowest immediately adjacent to Unimak Island (Fig. 8). Following the suggestion of Hood (1986) that water of salinity less than about 31.8 ppt represents Alaska Coastal Water, we see that this water mass maintained its identity through the pass on the east side of the pass and around to the northeast of Unimak Island (cf Fig. 8; Schumacher et al. 1982). A saline body of water that occurred east of Unalaska Island corresponded with the area of a proposed eddy discussed above. The most saline water was found northwest of Unimak Pass over the continental slope of the Bering Sea.

Vertically well-mixed waters were encountered at Avatanak Strait (Station 6.1), Ugamak Strait, north of Ugamak Island (Station 9.7), in Unalga Pass at the mouth of Beaver Inlet (Station 13.2), at Baby Pass (Station 14.4), at Akutan Pass (Station 21.3), at the south side of Akun Strait (Station 25.1), and south of Akutan Island (Station 26.2) (Chapter 10: Appendix B-1, this volume). Water depths at these locations were shallow, ranging from 35 to 82 m, except for Station 26.2 which had a depth of 300 m. Surface-to-bottom temperature and salinity gradients at these well-mixed stations varied by only 0.01-0.11° C and 0.01-0.06 ppt, respectively.

During this cruise, stratified waters occurred over deep water, mainly at distances greater than 25 km from the nearest land mass (Chapter 10: Appendix A, B-1; this volume). For 22 stations that exhibited a high degree of stratification, mean vertical temperature gradients were 3.7° C and average thermocline thickness was 24.5 m. Three highly stratified stations occurred near land: Station 30.1 in Unimak Bight, Station 31.3 northeast of Ugamak Island in Unimak Pass, and Station 31.7 southeast of Ugamak Island.

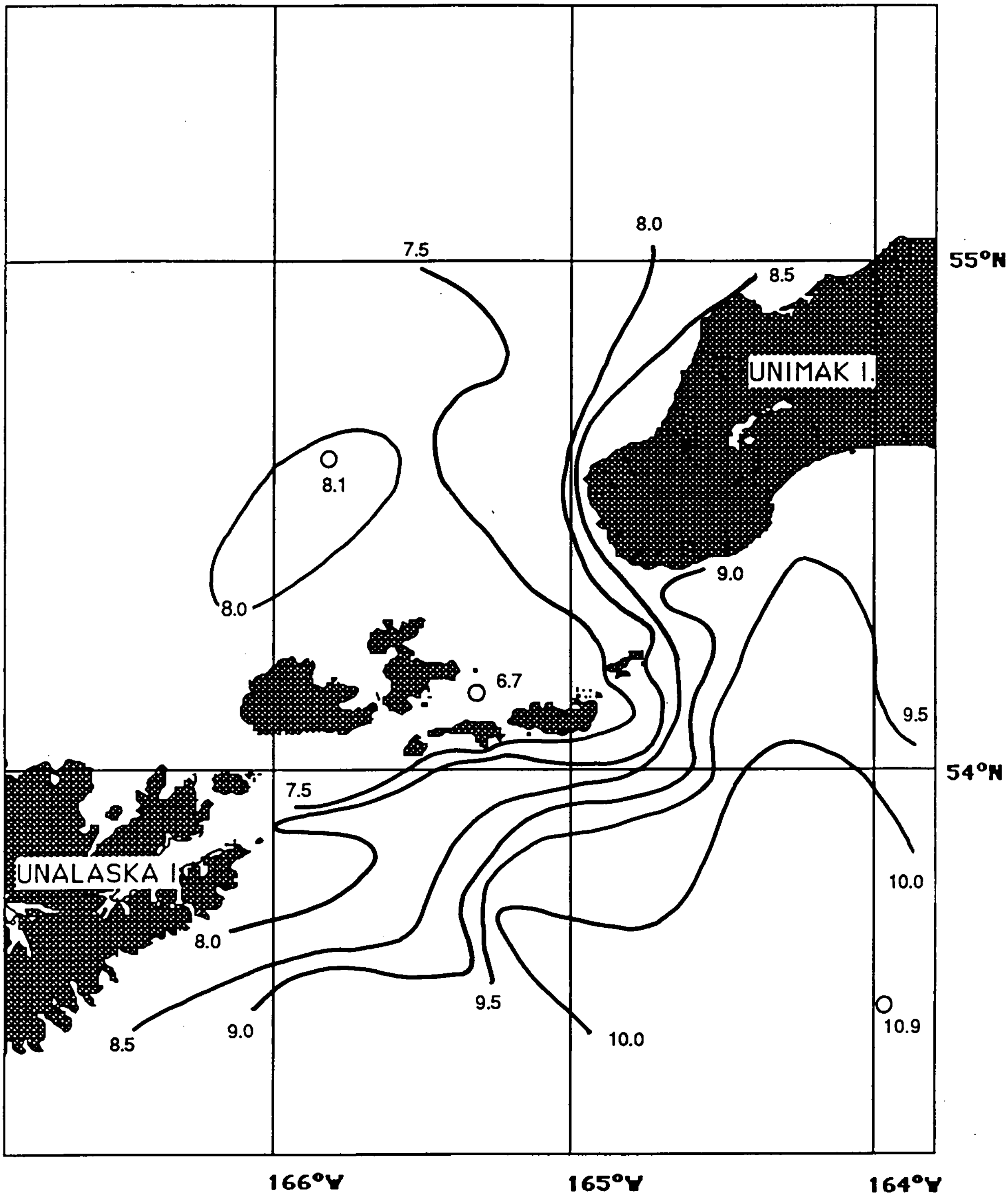

Figure 7. Sea surface temperatures (degrees C) in the Unimak Pass area, Alaska during the fall cruise, 18 Sept-7 Oct, 1986.

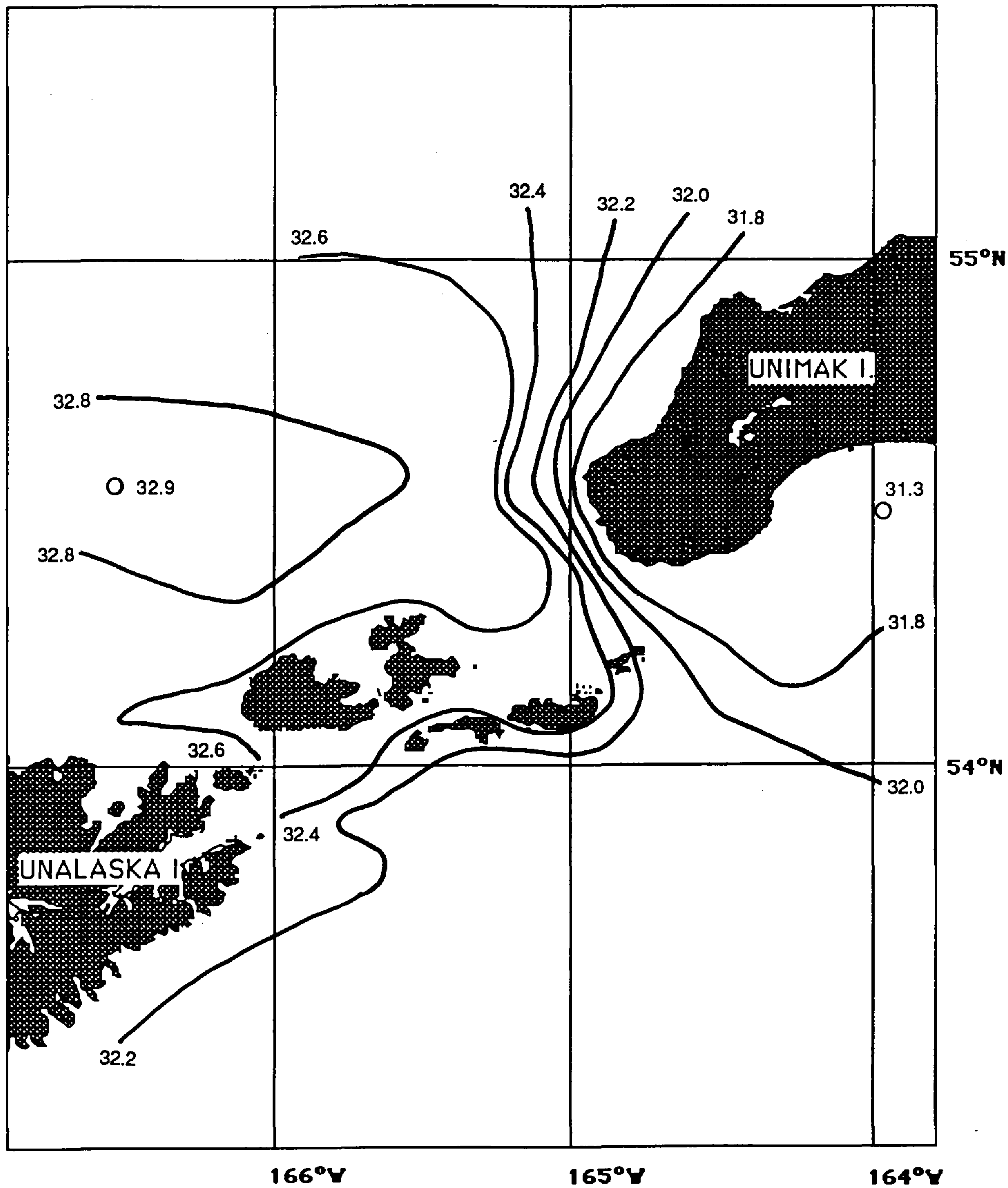

Figure 8. Sea surface salinities (ppt) in the Unimak Pass area, Alaska, during the fall cruise, 18 Sept-7 Oct, 1986.

Winter 1987 : CTD Transects

Winter sea-surface temperatures at stations in the Unimak Pass area ranged from 3.0 to 4.5° C. Warmest waters occurred in the southernmost portions of the study area at the edge of the Gulf of Alaska continental shelf (Fig. 9). Coolest waters were found to the south and north of Unimak Island.

Surface salinities during the winter (31.0-32.5 ppt) were again lowest around Unimak Island, but Alaska Coastal Water (<31.8 ppt) extended farther west than during the fall season (compare Figs. 8 and 10). In the southeast corner of the study area, salinities exceeded 32.4 ppt. The most saline water (>32.8 ppt) occurred in the Bering Sea north of Unalaska Island. Well-mixed waters occurred in Avatanak Strait (Stations 5.1, 6.1), Rootok Strait (Station 9.3), Ugamak Strait (Station 9.7), Akutan Pass (Station 21.3), the west side of Unalga Island (Station 14.4), the south side of Unimak Pass (Station 31.2), the south side of Ugamak Island, and the waters north of Unimak, Akun, and Akutan islands (Chapter 10; Appendix B-2, this volume). Depths at well-mixed stations ranged from 24-100 m. Vertical (surface-to-bottom) temperature and salinity gradients at 15 well-mixed stations varied by only 0.01-0.08° C and 0.01-0.2 ppt, respectively, over the entire water column.

At many stations, surface temperatures were 0.5-1.0° C colder than they were 100-200 m deeper, a reportedly common feature in the study area during winter (Dodimead et al. 1963). Winter advection and cooling of surface waters created situations where "reverse" thermoclines (increasing temperature with depth), were most pronounced at deeper stations. Most stations during the winter cruise did not reveal strong pycnoclines within the foraging depths of seabirds, although some casts did indicate gradual pycnoclines at depths exceeding 100 m (Chapter 10; Appendix B-2, this volume)

Spring 1987: CTD Transects

The range of sea surface temperature during spring (3.3-6.0° C) was greater than during winter but less than in the fall. As in the fall, warmest waters were at the edge of the continental shelf in the southeastern portion of the study area (Fig. 11). Coolest waters were situated north of Unimak Island. Most of the remaining portion of the study area had surface temperatures of 4.0-4.5° C.

During spring, the 31.8 ppt isoline (limit of Alaska Coastal Water) stretched from the southeastern part of the study area past Tigalda Island and then north to more than 50 km offshore from Unimak Island (Fig. 12). At no other season was the apparent westward extent of Alaska Coastal Water greater. The most saline water (32.4-32.8 ppt) was located north of Unalaska Island over the Bering Sea continental slope, as during the fall and winter cruises.

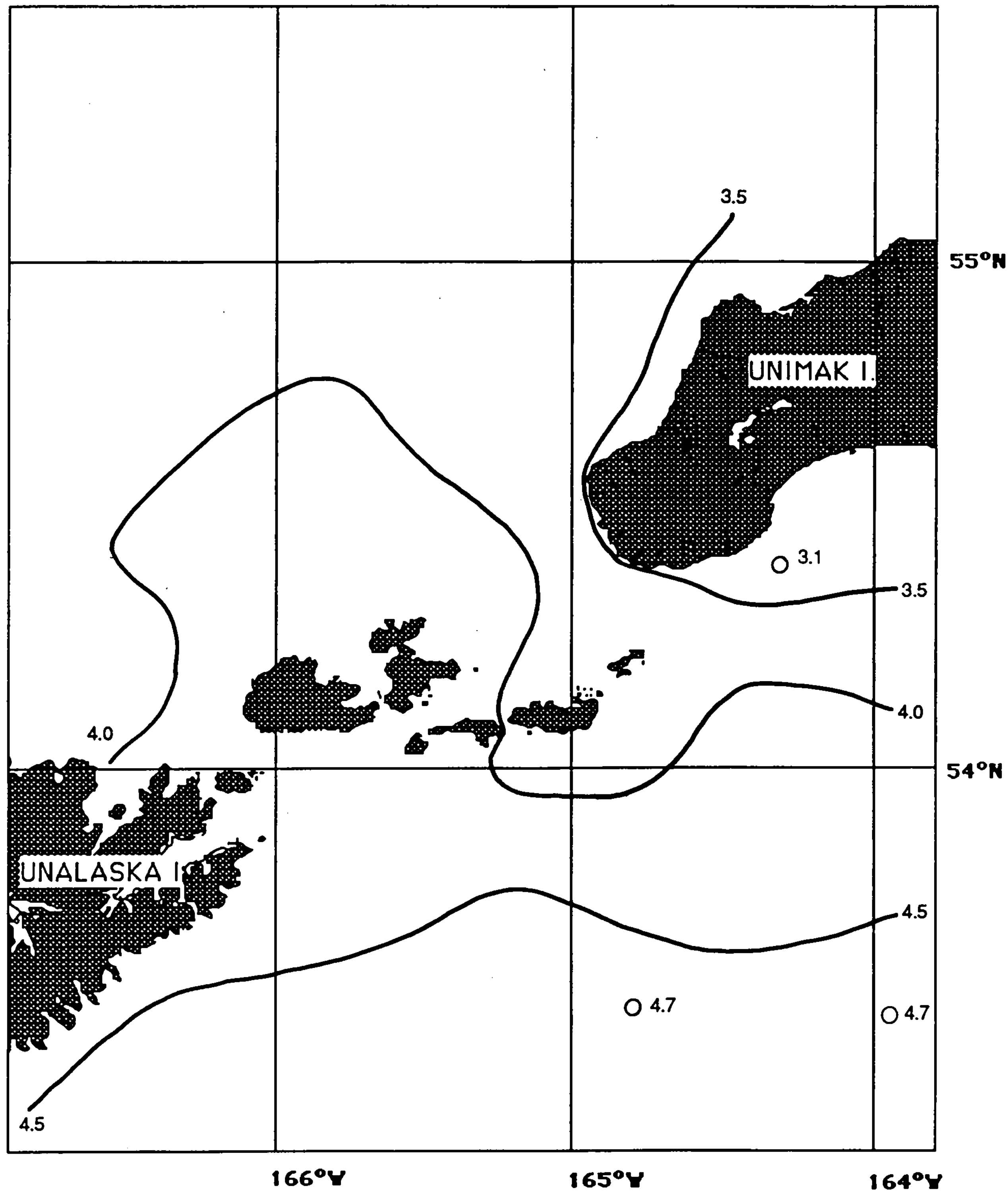

Figure 9. Sea surface temperatures (degrees C) in the Unimak Pass area, Alaska during the winter cruise, 14 Feb-9 March, 1987.

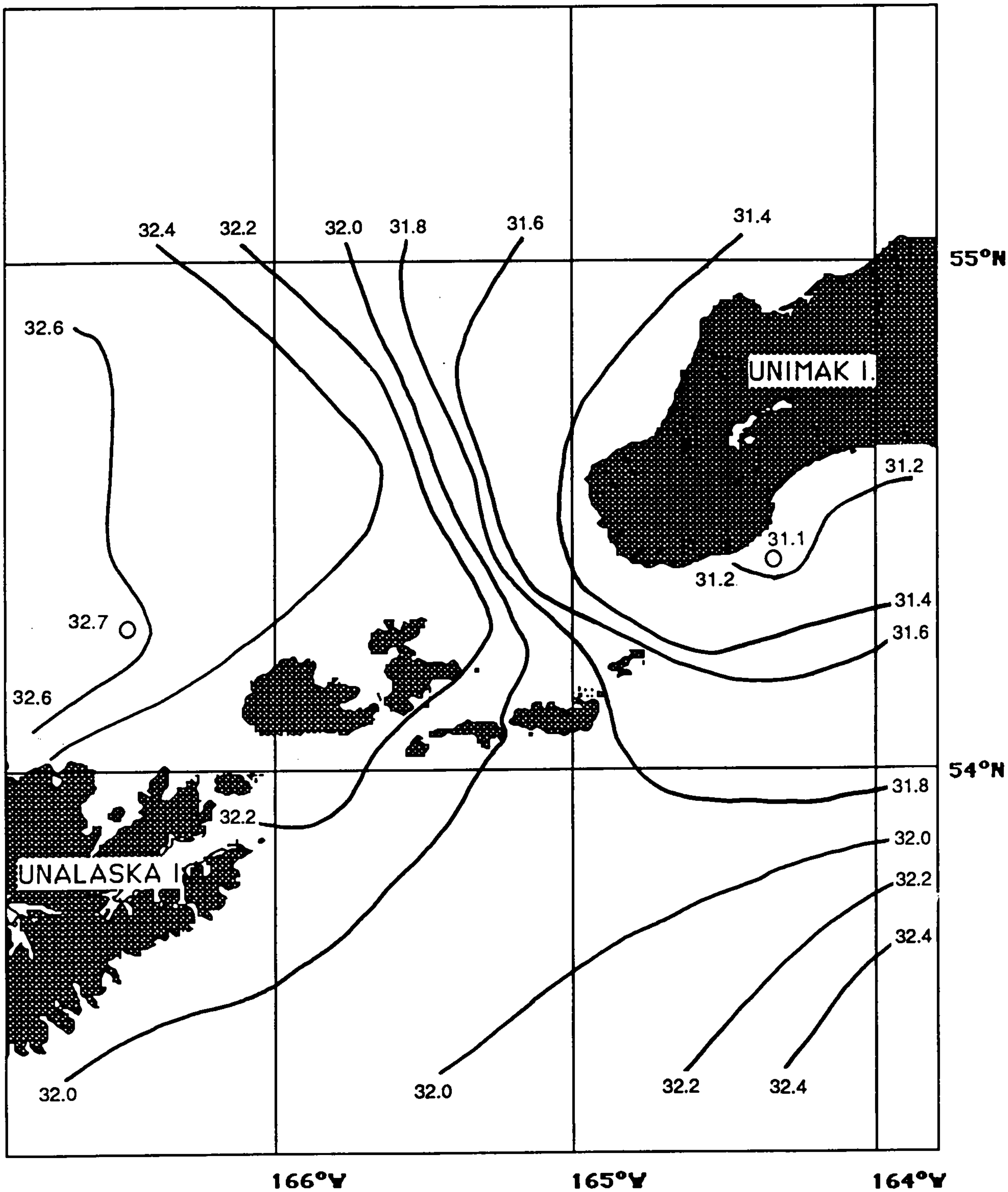

Figure 10. Sea surface salinities (ppt) in the Unimak Pass area, Alaska, during the winter cruise, 14 Feb-9 March, 1987.

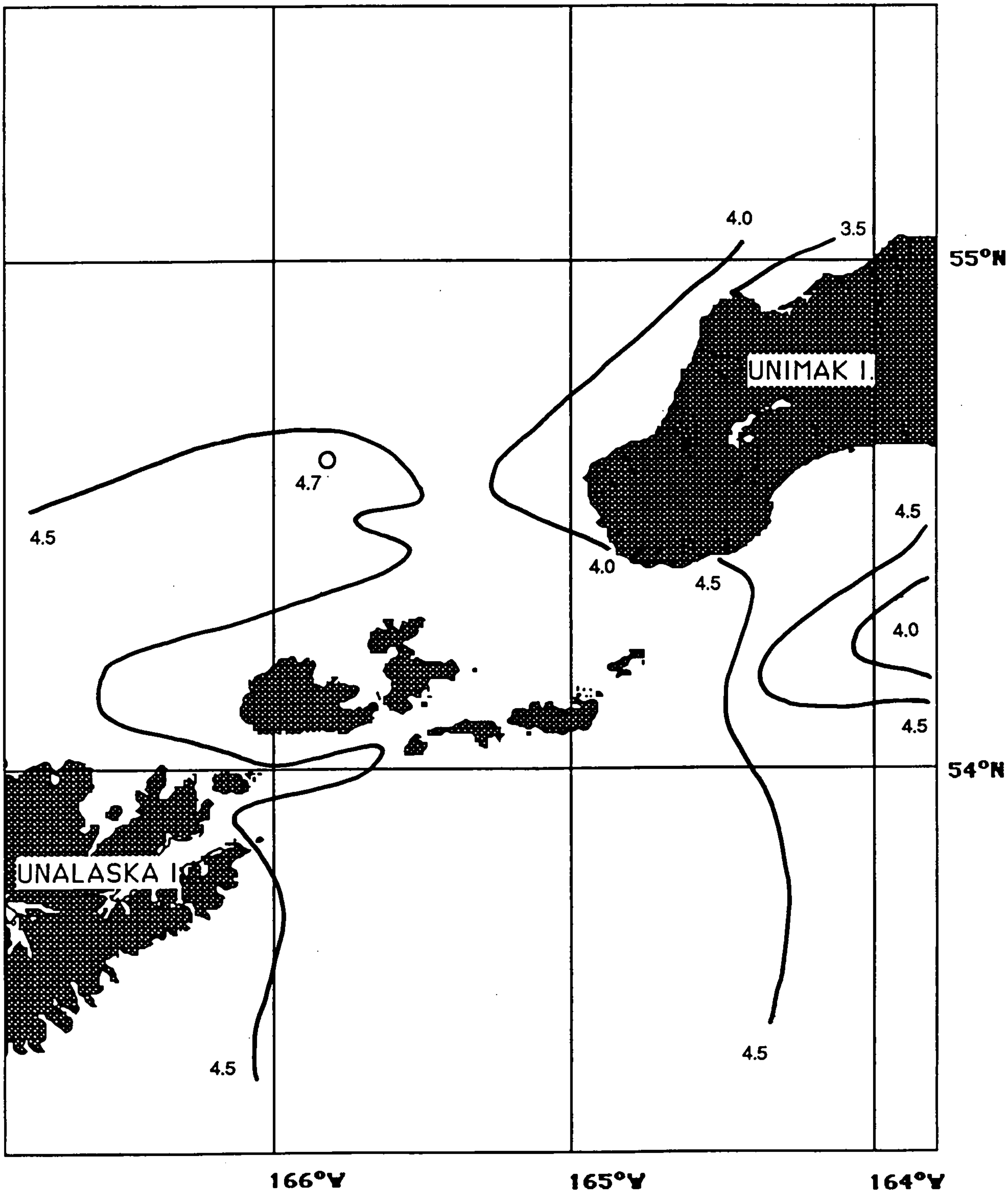

Figure 11. Sea surface temperatures (degrees C) in the Unimak Pass area, Alaska during the spring cruise, 21 April-14 May, 1987.

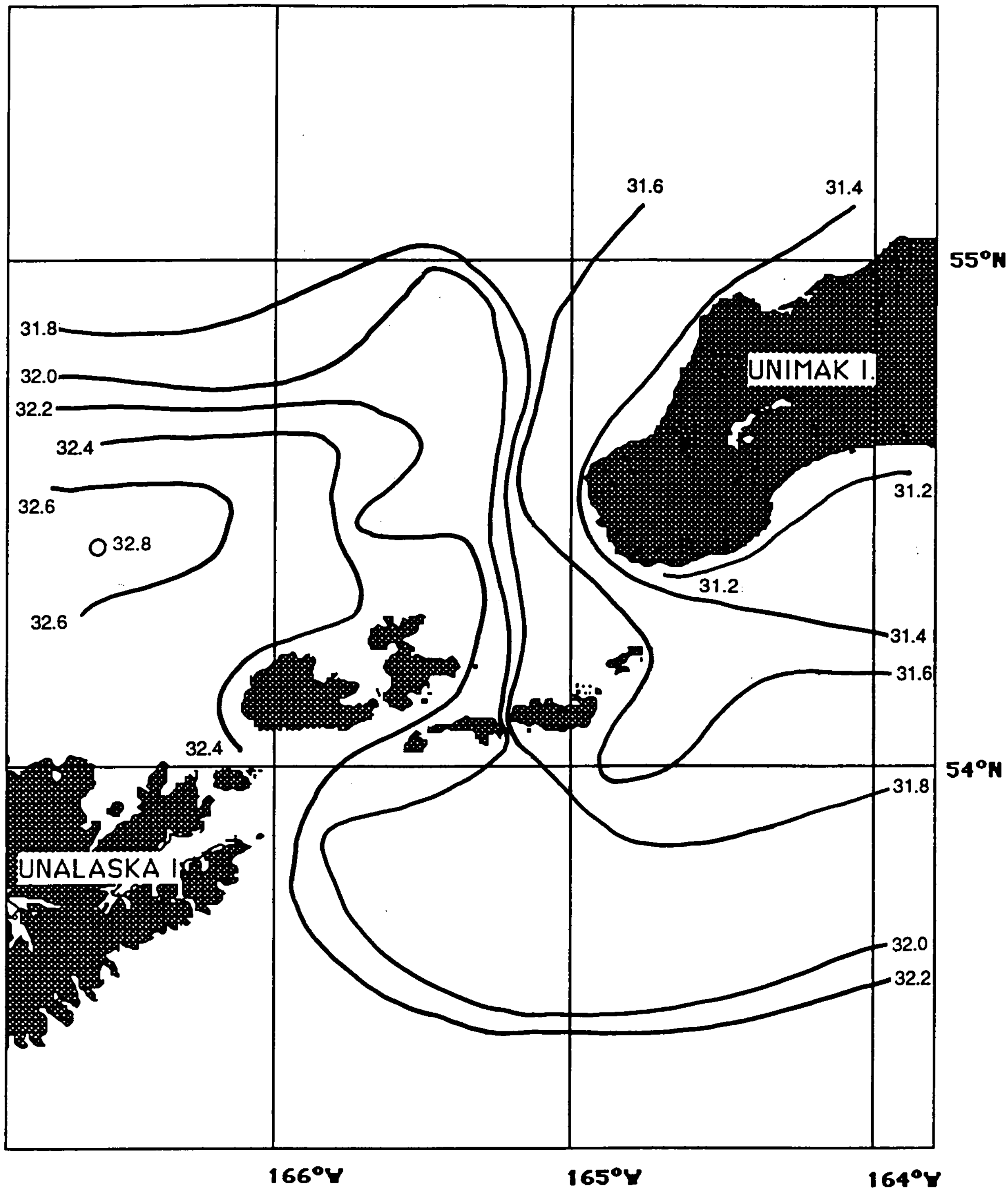

Figure 12. Sea surface salinities (ppt) in the Unimak Pass area, Alaska, during the spring cruise, 21 April-14 May, 1987.

Well-mixed waters occurred in Avatanak Strait (Stations 5.1, 6.1), Akutan Pass (Station 21.3), east of Unalga Pass (Station 22.1), on the east side of Unimak Pass (Station 31.2), the northwest side of Tigalda Island (Station 9.2), north and south of Ugamak Island (Stations 9.8 and 22.4, respectively), south of the Baby Islands near Baby Pass (Station 14.4), north of Unimak Island (Stations 17.1, 17.2, 17.3), and southeast of Sedanka Island (Station 29.2) (Chapter 10; Appendix B-3, this volume). Water depths at these well-mixed stations varied from 28-100 m. Vertical property gradients varied from 0.001-0.07° C and 0.01-0.20 ppt over the entire water column.

Few stations had strong pycnoclines in the water column during spring (see Chapter 10: Appendix A, B-3; this volume). As in winter, some stations showed "reverse" thermoclines with surface temperatures 1.0-1.5° C colder than those at depth (e.g., Station 15.1). Most shallow stations typically showed vertical temperature and salinity gradients of only a few tenths of a degree centigrade or tenths of a ppt, respectively.

Winter 1987 : Infrared Imagery

Seven infrared images from the 4Z enhancement curve were obtained for the Unimak Pass study area between 28 February and 6 March 1987. Four additional images from the 94Z curve were obtained between 2 and 5 March 1987. Satellite-detected isotherms were oriented primarily southeast to northwest, normal to the Alaska Peninsula and eastern Aleutian arc. As shown by the CTD data from shipboard stations, the warmest surface waters were in the southern part of the study area near the edge of the Gulf of Alaska continental shelf. Coldest waters were to the north and east of Unimak Island. This band of cold water expanded and contracted in an onshore-offshore direction by about 8-12 km during the 8-day period. For the most part, surface waters were isothermal in the immediate study area, and no strong horizontal gradients were detected by the imagery.

All Cruise Periods : Sea Surface Thermal Charts

Sea Surface Thermal Analyses charts (based on remote-sensing data) showed the same general patterns in surface temperature distributions as did the CTD shipboard measurements. Surface temperatures varied from 8 to 11° C during the fall cruise period. Although the scale of isotherm presentation was too coarse to provide much detail for the Unimak Pass study area, colder water (<8° C) was present northwest of Unimak Pass during 17-18 and 26-28 September. Charts for the winter period showed surface temperatures of 3-4° C, except for 29 February to 3 March when a water mass 5-6° C was present north and west of Akun, Akutan, and Unalaska Islands. During the spring cruise period, surface temperatures varied from 3-6° C and no patterns were evident from the charts.

CTD Casts for Tidal Effects

Time series CTD casts at four stations provided insight into the effects of tides on property distributions in the water column. Casts were made during all seasons sampled.

On 7 October 1986 seven casts were conducted at Station 26.2 east of Unalga Island (Table 1). Patterns in vertical property gradients varied little during the seven cast periods. At 0520 ADT (Station 26.2a), waters were slightly more stratified than during the other casts, but temperatures still varied only by 0.08° C and salinity by 0.06 ppt from top to bottom. The most mixed periods occurred at 1312 hrs (Station 26.2e) and 1708 hrs ADT (Station 26.2g). Property gradients were least apparent during these periods. The CTD casts indicate that mixing persisted throughout the 12-hr sampling period.

On 1 March 1987 Station 21.3 was sampled once, and on 6-7 March it was sampled six times (Table 2). All casts showed that vertical property gradients varied little among cast periods. Top-to-bottom temperatures and salinities varied by no more than 0.03° C and 0.05 ppt, respectively.

On 7 and 8 May 1987, six casts were made at Station 6.4 north of Akun Island on the east side of Unimak Pass (Table 3). This time-series showed the greatest variation among cast periods. The first three casts (from 2300 to 0100 hrs) showed a relatively pronounced pycnocline starting at about 25 m and extending to 60 m. The pycnocline was less abrupt during the next three casts (0300 and 0700 hrs on 8 May). Surface values of sigma-t varied from 25.6 to 25.8. The three earliest casts noted above had the lowest sigma-t values. Thus, from 2100 hrs on 7 May to 0100 hrs on 8 May, less dense water occurred at the station. The three late casts had a small (0.02° C) "reverse" thermocline extending from 10 to 20 m.

On 11 and 12 May 1987 Station 21.1 north of Unalaska Island was sampled five times (Table 4). Even though this station was deep (ca. 500 m), vertical temperature gradients ranged only from 3.6 to 4.7° C. Three of the five casts (Stations 21.1a and b on 11 May, Station 21.1 on 12 May) showed a 0.15° C "reverse" thermocline at 25 m. All five casts showed "reverse" thermoclines at 150 m, and from 250 to 300 m. Sigma-t patterns were similar for all five casts, indicating little change in vertical property gradients with respect to tidal period at this station.

Nutrient Distributions and Upwelling

Nitrate concentrations in the water column varied both spatially and temporally, as shown by water samples taken at sampling stations in spring, fall, and winter (Figs. 13-15). Nitrates tend to be rapidly consumed by phytoplankton in surface waters and are generally found in low concentrations. High levels of nitrates in surface waters are indicative of upwelling. The patterns of nitrate variation observed suggest that upwelling occurred on the Bering Sea side of the Aleutians; the gradient in surface nitrate concentrations along the Aleutians indicated that most upwelling was located to the west of our study area.

Surface nitrate concentrations in the along-shelf transect during March 1987 (Fig. 6) were greatest (>20 μM) north of Unalaska and Akutan islands over the continental slope of the Bering Sea (Fig. 13). In Unimak Pass, surface nitrate concentrations were higher during winter and at the northern stations (Figs. 14 and 15). Transects of temperature and salinity show that this area was well-mixed during each season of the study (see Chapter 10: Appendix A).

DISCUSSION

Several results from this study confirm the findings of previous investigations relative to the distributions of physicochemical qualities of water and the sources of water masses. Distributions of salinity, temperature, and nutrient levels allow refinement of some of the previous notions about water sources, water quality distributions, and the effects of these on the biota.

Low-salinity (<31.8 ppt) Alaska Coastal Current Water (ACW) was confined to the east side of Unimak Pass near Unimak Island. This pattern persisted for all three seasons when cruises were conducted, though ACW extended farthest west in spring. A region of relatively rapid surface temperature change from east to west indicated the presence of a front, somewhere about the middle of Unimak Pass proper, that separated ACW from the adjacent water mass to the west. The nitrate concentrations measured in this study also indicated the presence of a front in the same area west of Unimak Island. No water with the characteristics of ACW occurred west of Unimak Pass on the Gulf of Alaska side of the Aleutians.

Water temperatures changed more among seasons in and near shallow areas, as would be expected due to the greater mass and consequent temperature stability of the waters off the shelf vs. water on the shelf. Water in winter and spring was warmest nearest the shelf breaks, particularly the Gulf of Alaska shelfbreak to the south. Conversely, in fall, temperatures closest to shore were warmer that those near deeper waters, again as expected because of the shallower on-shelf water being warmed the preceding summer.

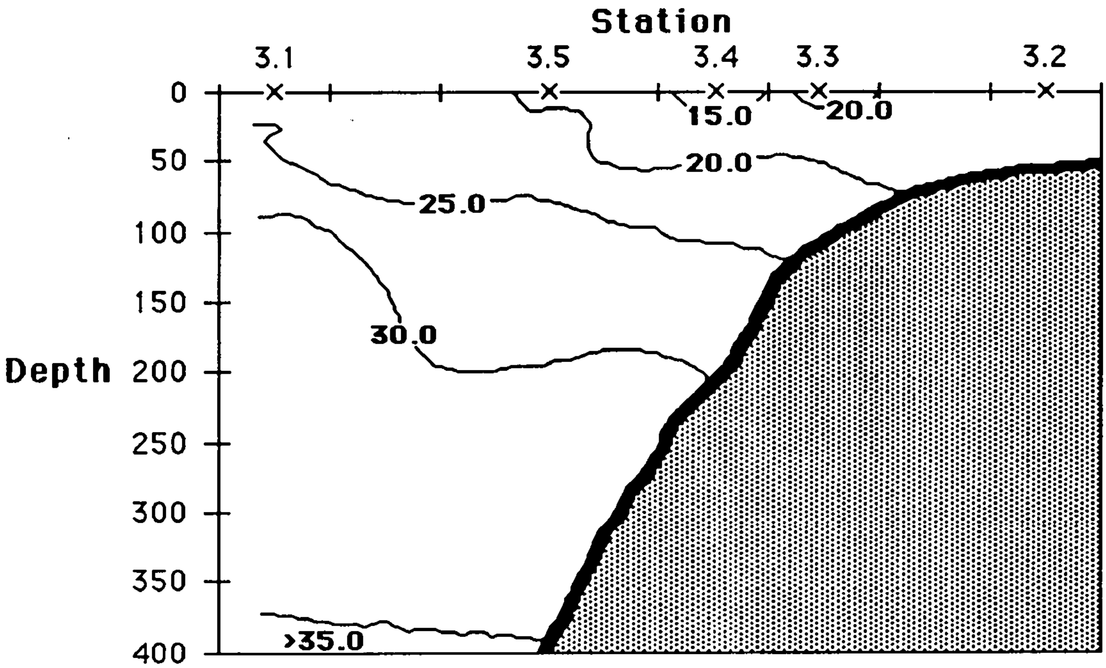

Fig. 13. Isolines of nitrate (in µM) on the north Aleutian Shelf during March 1987, Unimak Pass area, Alaska (see Fig. 5 for station locations).

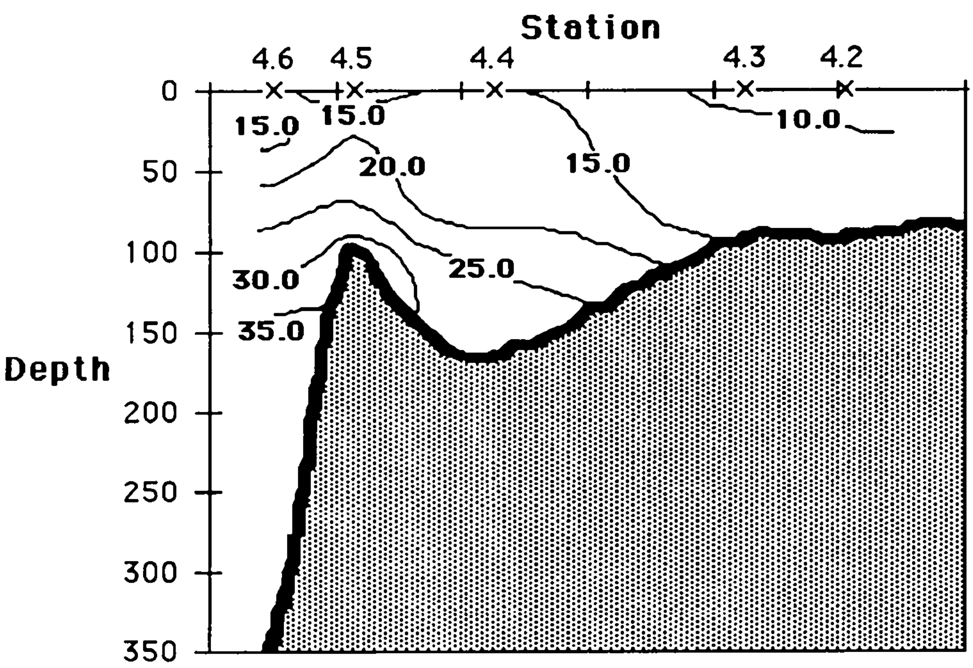

Fig. 14. Isolines of nitrate (in µM) through Unimak Pass during September 1986 (see Fig. 6 for station locations).

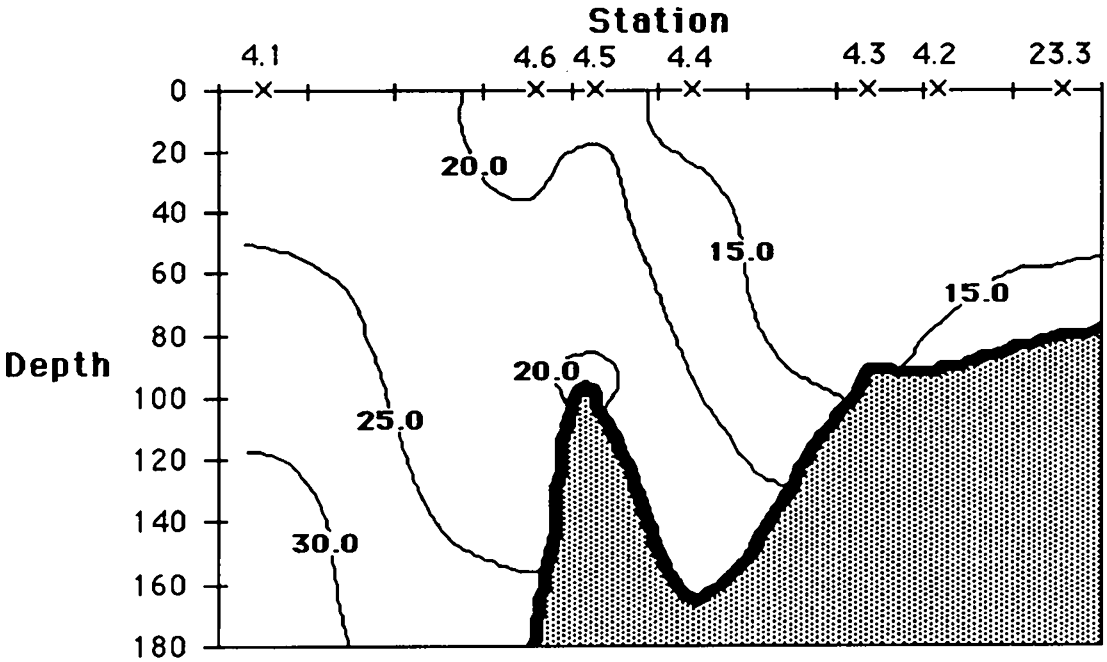

Fig. 15. Isolines of nitrate (in μM) through Unimak Pass during February 1987 (see Fig. 6 for station locations).

Vertical casts revealed that, in winter and spring, cold water formed near the surface as a result of winter cooling and convection. A zone of warmer water lay under this layer and over colder water, resulting in patterns of "reverse" thermoclines; these thermoclines occurred at depths beyond the normal foraging depths of most seabirds.

Nitrate surface concentrations greater than 15 µM in the middle of both Unimak and Akutan passes provided evidence that mixing was supplying nutrient-rich water to the euphotic zone in these areas. The enrichment appeared to come from the northwest, as indicated by increases in surface concentrations in that direction.

Nutrient concentrations were highest west of Unimak Pass during both the fall and winter cruises. Within the pass, isolines of nutrient concentration sloped downward to the southeast. This argues against upwelling occurring as the result of deep Gulf of Alaska water being vertically transported over the shallow sill of Unimak Pass. Rather, as suggested above, the nutrient enrichment probably comes from the west as a result of upwelling on the north side of the Aleutian Chain.

Four different water masses appeared to be present during each of the three cruises. These water masses are characterized below with respect to their mixing regimes and surface salinities, conservative properties which vary little seasonally in contrast to surface temperature. Typical distributions of water masses in the study area are illustrated in Figure 16.

Alaska Coastal Current Water (ACW) was identified by surface salinities <31.8 ppt and occurred only on the east side of Unimak Pass. It appeared to represent the Alaska Coastal Current swinging in a U-turn around the end of Unimak Island, as had been reported by earlier workers.

Shelf Break Water (SBW) seemed to occur on the north side of the Aleutians over or near the Bering Sea shelf break, as reported by Kinder and Schumacher (1981). Water in this area was characterized by surface salinities >32.6 ppt and occurred only in the northwestern portion of the study area north of Unalaska and Akutan islands.

What in this report is called Gulf of Alaska Water (GAW; surface salinities between 31.8 and 32.6 ppt) was prevalent on the Gulf of Alaska side of the island arc and extended through the western part of Unimak Pass to the north-central portion of the study area. GAW occupied the greatest areal extent of the four water mass types.

Tidally-mixed Water (TMW) was characterized by little or no variation in property gradients between surface and bottom waters. TMW occurred in

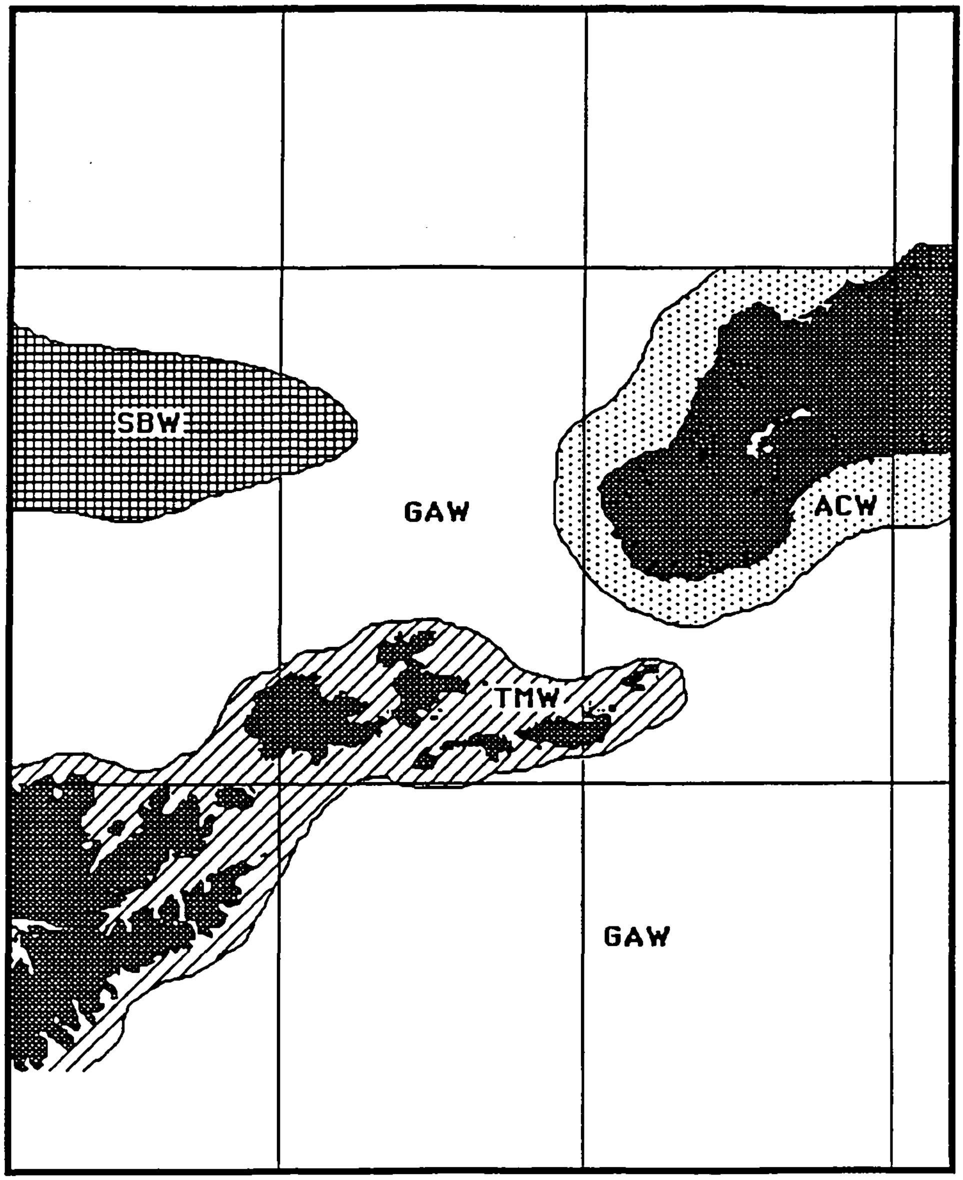

Figure 16. Schematic map of the principal water masses in the Unimak Pass area, Alaska (ACW=Alaska Coastal Water; GAW=Gulf of Alaska Water; SBW=Shelf Break Water; TMW=Tidally-mixed Water). Actual boundaries varied between cruises.

relatively shallow (<100 m) waters, generally within 25 km of land, and was the dominant water mass in Akutan and Unalga passes; Ugamak, Derbin, Avatanak, Rootok, and Akun straits; and around all islands except Unimak Island. TMW appeared to be most similar to GAW with respect to its salinity and temperature regime.

Typical Alaska Stream Water, with temperatures of 4-5° C and salinities of 32.9 ppt down to 100 m (Takenouti and Ohtani 1974), was not encountered in this study.

RECOMMENDED FURTHER RESEARCH

The combined results of this study and the North Aleutian Shelf Ecological Process Study (Truett 1987) document a gradient in nutrient availability, and a generally parallel trend in biological activity, oriented from west to east along the north side of the eastern Aleutians and the Alaska Peninsula. The source of the nutrients which promote the rich concentrations of birds and other marine life in these areas is evidently to the west of the Unimak Pass study area. Further sampling to the west would be useful to identify the origins of these nutrients, which are suspected to be near Samalga Pass.

Additional sampling for nutrients would be useful, especially during the fall when the major concentrations of marine birds occur in the northwest part of Unimak Pass. Unfortunately, we did not do a west-east nutrient transect during fall. Otherwise, the oceanographic needs for the purposes of the marine bird and mammal studies are largely filled, though there is probably still much of interest in this area for oceanographers who have broader objectives.

ACKNOWLEDGEMENTS

We are indebted to the the entire crew of the Miller Freeman for their cooperation and assistance in making this cruise such a success. The concern and interest expressed by all personnel from the galley through the engineering department and the deck crew was beyond our expectations.

Of particular note are the efforts of the ship's survey technician, Dan Dougherty, who operated the CTD and performed all the calibrations and made all the ancillary collections. Dan also routinely checked for any oceanographic features, such as pycnoclines, that would influence the depths we wished to sample for nutrients. We are deeply indebted for his help.

Chirk Chu of the Institute of Marine Science, University of Alaska, Fairbanks, reduced the voluminous CTD data tapes into more useful and accessible forms for our analysis. We appreciate his quick work.

Jo Young prepared the base map for use in the graphics. Terry Carpenter, Robert Dillinger, Benny Gallaway, and Joe Truett provided useful edits of various drafts.

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APPENDICES

Appendix A. Station number, date, time, depth, and location for stations on fall cruise MF-86-10.

Station	Date	Time	Depth	Latitude	Longitude
(ADT)	(m) (°N)	(°W)			
2.1	19-Sep-1986	04:23	7	53.9390	165.7787
2.2	19-Sep-1986	08:43	219	54.1608	166.3563
2.3	19-Sep-1986	10:33	415	54.1575	166.3745
2.4	19-Sep-1986	11:35	622	54.1705	166.3787
2.5	19-Sep-1986	12:26	830	54.1825	166.3982
3.2	20-Sep-1986	04:20	57	55.0050	164.5198
3.3	20-Sep-1986	07:09	101	54.8327	165.1063
3.4	20-Sep-1986	08:26	201	54.7508	165.3997
3.5	20-Sep-1986	11:21	388	54.6173	165.8000
4.1	20-Sep-1986	14:29	176	54.8647	166.5050
4.3	21-Sep-1986	10:19	97	54.2295	164.6255
4.2	21-Sep-1986	11:39	92	54.1663	164.3868
4.4	21-Sep-1986	14:35	166	54.4203	165.1723
4.5	21-Sep-1986	16:06	99	54.5315	165.4890
4.6	21-Sep-1986	17:38	346	54.6213	165.6390
9.1	22-Sep-1986	04:36	69	54.1730	164.8870
9.2	22-Sep-1986	06:48	53	54.1218	165.2320
9.3	22-Sep-1986	08:43	63	54.0850	165.5000
6.1	22-Sep-1986	10:46	66	54.1520	165.3342
6.2	22-Sep-1986	12:01	161	54.3063	165.4420
6.3	22-Sep-1986	13:06	97	54.4243	165.5195
14.1	23-Sep-1986	08:13	93	53.8002	165.4863
14.2	23-Sep-1986	09:50	187	53.7147	165.2832
15.1	23-Sep-1986	15:01	344	53.7453	164.0072
13.1	24-Sep-1986	04:09	128	53.7780	165.8968
14.4	24-Sep-1986	06:07	60	53.9712	166.0485
13.2	24-Sep-1986	07:50	75	53.9047	166.1450
14.3	24-Sep-1986	11:27	104	53.8257	165.5332
8.1	24-Sep-1986	13:57	73	54.0432	165.4353
5.1	24-Sep-1986	15:39	96	54.1052	165.4962
16.1	25-Sep-1986	05:33	62	54.3345	164.7177
16.2	25-Sep-1986	06:26	47	54.3792	164.7292
17.4	25-Sep-1986	09:20	86	54.5583	165.1930
17.3	25-Sep-1986	10:54	61	54.6340	164.9833
17.2	25-Sep-1986	13:43	57	54.8158	164.6995
17.1	25-Sep-1986	15:20	40	54.9680	164.4335
17.8	26-Sep-1986	05:54	413	54.1087	166.4932
16.3	26-Sep-1986	09:00	1560	54.2875	166.4747
16.4	26-Sep-1986	12:56	841	54.3320	166.1438
16.5	26-Sep-1986	15:25	439	54.5667	166.4970
17.6	27-Sep-1986	05:01	57	54.2342	165.9943
19.1	27-Sep-1986	07:23	168	54.4775	165.6262
19.2	27-Sep-1986	10:12	129	54.5397	165.5520
17.5	27-Sep-1986	12:33	66	54.3095	165.6585
21.1	28-Sep-1986	10:14	1220	54.2942	166.4613

Appendix A (cont.)

21.2	28-Sep-1986	12:18	102	54.1443	166.2728
21.3	28-Sep-1986	15:13	39	54.0233	166.0553
21.4	28-Sep-1986	16:34	86	53.8647	165.8042
21.5	28-Sep-1986	18:32	141	53.6662	165.5175
23.1	29-Sep-1986	03:59	86	54.4168	164.3077
23.2	29-Sep-1986	05:48	75	54.2378	163.9998
23.3	29-Sep-1986	08:06	78	54.0587	164.0010
23.4	29-Sep-1986	10:05	119	53.7825	163.9995
23.6	29-Sep-1986	15:15	1000	53.5112	164.0357
23.5	29-Sep-1986	17:09	1100	53.5952	164.0333
22.1	30-Sep-1986	07:18	108	53.9035	165.9372
22.2	30-Sep-1986	09:28	78	53.9045	165.7863
22.3	30-Sep-1986	10:41	94	53.9532	165.5953
25.1	30-Sep-1986	12:44	59	54.1018	165.6362
9.4	30-Sep-1986	13:43	75	54.0870	165.5010
9.6	01-Oct-1986	06:53	35	54.1333	165.0633
9.7	01-Oct-1986	07:57	55	54.2020	164.9215
9.8	01-Oct-1986	09:50	49	54.2245	164.8472
22.4	01-Oct-1986	11:45	40	54.2012	164.8020
22.5	01-Oct-1986	14:04	61	54.0547	165.0448
22.1	02-Oct-1986	05:10	66	54.0952	165.5572
22.8	02-Oct-1986	06:32	90	53.9995	165.2925
22.9	02-Oct-1986	08:53	89	53.9988	165.6713
29.2	02-Oct-1986	12:04	98	53.6140	165.9292
29.1	02-Oct-1986	14:18	101	53.4992	166.4355
30.1	03-Oct-1986	05:20	86	54.4870	164.0080
31.1	03-Oct-1986	08:49	66	54.3632	164.6578
31.2	03-Oct-1986	09:55	48	54.3750	164.8242
31.3	03-Oct-1986	13:06	95	54.0800	164.5533
31.4	03-Oct-1986	14:26	109	53.9652	164.4492
31.6	04-Oct-1986	05:09	126	54.9988	165.4930
31.5	04-Oct-1986	08:10	146	54.7758	165.2497
32.3	04-Oct-1986	09:59	173	54.6032	165.5152
32.2	04-Oct-1986	12:24	200	54.7840	165.7292
32.1	04-Oct-1986	14:28	138	54.9997	165.9985
32.6	05-Oct-1986	06:05	2000	53.4930	164.8245
32.5	05-Oct-1986	09:00	313	53.6718	164.7742
32.4	05-Oct-1986	10:22	103	53.8358	164.8005
32.3	05-Oct-1986	12:31	93	54.0022	164.8323
31.7	05-Oct-1986	14:18	86	54.1495	164.4893
26.2	07-Oct-1986	05:20	305	53.9023	166.1058
26.2	07-Oct-1986	07:11	310	53.9027	166.1150
26.2	07-Oct-1986	09:13	312	53.9018	166.1035
26.2	07-Oct-1986	11:13	320	53.9017	166.1277
26.2	07-Oct-1986	13:12	329	53.9012	166.1255
26.2	07-Oct-1986	15:03	330	53.9070	166.1295
26.2	07-Oct-1986	17:08	241	53.8940	166.1058

Appendix B. Station number, date, time, depth, and location for stations on winter cruise MF-87-02.

Station	Date	Time	Depth	Latitude	Longitude
(AST)	(m) (°N)	(°W)			
31.2	17-Feb-1987	03:06	64	54.3772	164.8510
31.5	17-Feb-1987	06:25	144	54.7810	165.2460
31.6	17-Feb-1987	08:03	126	54.9938	165.4817
23.6	17-Feb-1987	18:38	1912	53.4908	164.0045
23.5	18-Feb-1987	00:12	1738	53.5920	164.0625
31.4	18-Feb-1987	03:50	115	53.9782	164.4598
31.3	18-Feb-1987	06:26	77	54.2392	164.7137
4.1	18-Feb-1987	18:22	176	54.8642	166.5202
4.6	18-Feb-1987	22:46	342	54.6208	165.6382
4.5	19-Feb-1987	00:31	99	54.5315	165.4883
4.4	19-Feb-1987	02:19	161	54.4235	165.1695
4.3	19-Feb-1987	04:52	86	54.2238	164.6215
4.2	19-Feb-1987	06:10	93	54.1613	164.3888
23.3	19-Feb-1987	07:59	82	54.0587	164.0005
29.1	19-Feb-1987	16:51	104	53.4978	166.4337
29.2	19-Feb-1987	21:35	97	53.6167	165.9252
21.5	19-Feb-1987	23:21	148	53.6617	165.5150
17.1	22-Feb-1987	18:58	40	54.9807	164.3962
17.3	23-Feb-1987	18:37	60	54.6282	164.9952
17.2	23-Feb-1987	21:53	60	54.8223	164.6973
3.3	24-Feb-1987	02:54	103	54.8330	165.1052
3.2	24-Feb-1987	06:04	57	55.0117	164.5167
3.1	24-Feb-1987	18:59	574	54.4255	166.5210
3.5	24-Feb-1987	22:54	393	54.6200	165.8052
3.4	25-Feb-1987	01:15	206	54.7472	165.4032
17.4	25-Feb-1987	04:14	88	54.5605	165.1995
22.9	25-Feb-1987	19:14	91	54.0225	165.6765
13.2	25-Feb-1987	21:40	137	53.9050	166.1343
14.4	25-Feb-1987	23:11	59	53.9743	166.0410
9.3	26-Feb-1987	01:42	88	54.0952	165.4933
9.2	26-Feb-1987	04:08	60	54.1300	165.2347
6.1	26-Feb-1987	05:40	66	54.1558	165.3267
10.3	26-Feb-1987	18:49	84	54.0662	166.3660
2.2	26-Feb-1987	20:35	291	54.1662	166.3578
46.1	26-Feb-1987	22:27	29	54.0152	166.1203
17.8	27-Feb-1987	02:27	706	54.1167	166.4742
17.6	27-Feb-1987	06:16	96	54.2433	165.9922
32.6	27-Feb-1987	19:38	1673	53.5038	164.8332
14.2	27-Feb-1987	23:32	192	53.7133	165.2810
14.3	28-Feb-1987	01:55	105	53.8270	165.5245
22.3	28-Feb-1987	03:54	99	53.9655	165.5953
22.1	28-Feb-1987	06:25	91	53.9223	165.9400
30.1	28-Feb-1987	18:54	108	54.4977	164.0290
23.2	28-Feb-1987	21:18	75	54.2262	164.0162
32.4	01-Mar-1987	01:16	107	53.8275	164.8065
22.5	01-Mar-1987	03:40	61	54.0525	165.0497
22.8	01-Mar-1987	05:56	73	54.0028	165.2898
21.3	01-Mar-1987	19:34	77	54.0190	166.0287

Appendix B (cont.)

21.1	01-Mar-1987	22:36	1085	54.2955	166.4517
21.2	02-Mar-1987	01:29	123	54.1533	166.2728
21.4	02-Mar-1987	04:48	88	53.8673	165.8010
21.5	02-Mar-1987	06:47	146	53.6667	165.5133
21.6	02-Mar-1987	08:32	1006	53.4960	165.2710
22.4	02-Mar-1987	18:55	51	54.2005	164.7885
32.5	02-Mar-1987	22:16	326	53.6692	164.7747
32.7	03-Mar-1987	01:41	87	54.0177	164.8472
22.8	03-Mar-1987	03:58	84	53.9935	165.3105
22.5	03-Mar-1987	05:42	68	54.0503	165.0600
5.1	03-Mar-1987	20:57	104	54.1103	165.4738
9.7	03-Mar-1987	23:41	53	54.2088	164.9195
31.1	04-Mar-1987	01:45	66	54.3622	164.6637
23.1	04-Mar-1987	03:43	110	54.3968	164.3765
17.5	04-Mar-1987	18:11	80	54.3163	165.6668
6.2	04-Mar-1987	19:53	143	54.3065	165.4547
6.3	04-Mar-1987	21:58	95	54.4217	165.5282
32.2	05-Mar-1987	00:35	196	54.7823	165.8215
32.3	05-Mar-1987	03:03	173	54.6062	165.5143
3.2	05-Mar-1987	18:44	58	55.0240	164.5270
3.3	05-Mar-1987	21:17	104	54.8335	165.1052
3.4	05-Mar-1987	23:01	210	54.7485	165.4092
3.5	06-Mar-1987	00:55	393	54.6188	165.8053
3.1	06-Mar-1987	04:44	569	54.4245	166.5275
21.3	06-Mar-1987	20:21	43	54.0237	166.0613
21.3	06-Mar-1987	22:01	48	54.0247	166.0448
21.3	07-Mar-1987	00:08	63	54.0258	166.0737
21.3	07-Mar-1987	02:07	53	54.0213	166.0647
21.3	07-Mar-1987	04:03	44	54.0218	166.0742
21.3	07-Mar-1987	06:04	71	54.0273	166.0877

Appendix C. Station number, date, time, depth, and location for stations on spring cruise MF-87-05.

Station	Date	Time	Depth	Latitude	Longitude
(ADT) (m)	(°N)	(°W)			
22.1	23-Apr-1987	21:38	105	53.9122	165.9405
22.3	23-Apr-1987	23:14	94	53.9740	165.6048
22.5	24-Apr-1987	02:16	61	54.0530	165.0227
23.2	24-Apr-1987	06:45	75	54.2220	164.0158
29.1	24-Apr-1987	19:48	103	53.4983	166.4378
29.2	24-Apr-1987	22:26	96	53.6173	165.9283
14.3	25-Apr-1987	01:14	106	53.8253	165.5268
14.2	25-Apr-1987	03:18	192	53.7107	165.2875
32.6	25-Apr-1987	06:26	2195	53.4890	164.8345
21.1	25-Apr-1987	19:12	1050	54.2920	166.4568
21.2	25-Apr-1987	21:59	106	54.1465	166.2703
21.3	25-Apr-1987	23:52	46	54.0200	166.0668
21.8	26-Apr-1987	02:39	88	53.8660	165.8110
21.5	26-Apr-1987	04:46	144	53.6592	165.5193
21.6	26-Apr-1987	07:04	1175	53.4932	165.2762
32.5	26-Apr-1987	1;:21	392	53.6570	164.7712
32.4	26-Apr-1987	22:14	106	53.8293	164.8013
15.1	27-Apr-1987	03:35	450	53.7355	164.0198
23.5	27-Apr-1987	06:05	1700	53.5953	164.0768
32.1	27-Apr-1987	19:25	140	55.0035	165.9975
32.2	27-Apr-1987	21:50	190	54.7900	165.8262
32.3	28-Apr-1987	00:39	182	54.6092	165.5133
17.5	28-Apr-1987	04:06	86	54.3203	165.6957
17.6	28-Apr-1987	06:15	102	54.2538	165.9930
17.1	28-Apr-1987	19:03	42	54.9853	164.3930
17.2	28-Apr-1987	21:45	60	54.8260	164.6922
17.3	29-Apr-1987	00:18	66	54.6242	165.0047
17.4	29-Apr-1987	02:01	81	54.5727	165.1973
19.1	29-Apr-1987	04:29	182	54.4832	165.6307
22.9	29-Apr-1987	19:16	93	54.0148	165.6897
5.1	29-Apr-1987	21:22	106	54.1055	165.4695
6.1	29-Apr-1987	23:29	68	54.1573	165.3247
9.2	30-Apr-1987	01:19	58	54.1312	165.2337
22.7	30-Apr-1987	03:05	86	53.9960	165.2218
22.8	30-Apr-1987	05:09	87	53.9957	165.2953
32.7	30-Apr-1987	19:38	91	53.9990	164.8470
22.4	30-Apr-1987	22:03	46	54.2005	164.7948
9.8	30-Apr-1987	23:59	50	54.2243	164.8582
9.7	01-May-1987	01:53	56	54.2155	164.9158
22.5	01-May-1987	04:04	61	54.0522	165.0387
22.7	01-May-1987	05:49	79	54.0278	165.1687
6.2	01-May-1987	19:06	146	54.3105	165.4527
6.3	01-May-1987	21:24	98	54.4275	165.5257
16.4	02-May-1987	00:39	779	54.3417	166.1378
17.8	02-May-1987	05:26	640	54.1148	166.4757
22.1	02-May-1987	19:37	94	54.0942	165.5488
46.1	02-May-1987	21:53	31	54.0168	166.1257
14.4	02-May-1987	23:40	39	53.9843	166.0453

Appendix C (cont.)

13.2	03-May-1987	01:35	118	53.9108	166.1313
43.1	03-May-1987	03:38	235	53.8238	166.3423
3.2	04-May-1987	19:22	57	55.0132	164.5207
3.3	04-May-1987	22:49	107	54.8302	165.1157
3.4	05-May-1987	01:12	202	54.7563	165.4073
3.5	05-May-1987	04:12	392	54.6230	165.8263
3.1	05-May-1987	07:25	556	54.4347	166.5282
23.3	05-May-1987	19:10	80	54.0537	164.0065
4.2	05-May-1987	20:41	91	54.1630	164.3877
4.3	05-May-1987	21:51	91	54.2263	164.6242
4.4	05-May-1987	23:49	171	54.4233	165.1777
4.5	06-May-1987	01:13	98	54.5323	165.4917
4.6	06-May-1987	02:12	342	54.6183	165.6405
4.1	06-May-1987	07:01	175	54.8647	166.5238
10.1	06-May-1987	19:29	93	54.4218	165.5430
10.3	07-May-1987	06:41	83	54.0628	166.3547
6.4	07-May-1987	21:02	102	54.3900	165.4890
6.4	07-May-1987	22:57	98	54.3912	165.4920
6.4	08-May-1987	01:00	97	54.3897	165.4967
6.4	08-May-1987	03:00	97	54.3895	165.4962
6.4	08-May-1987	05:02	102	54.3912	165.4893
6.4	08-May-1987	07:18	102	54.3918	165.4893
31.5	09-May-1987	03:27	146	54.7840	165.2562
31.6	09-May-1987	06:01	125	54.9970	165.4843
23.6	09-May-1987	20:12	1990	53.4965	164.0320
31.4	10-May-1987	01:10	112	53.9847	164.4698
31.7	10-May-1987	02:18	89	54.1503	164.4855
23.1	10-May-1987	04:38	97	54.4035	164.3620
30.1	10-May-1987	06:52	103	54.4962	164.0260
31.1	10-May-1987	19:19	66	54.3607	164.6683
31.2	10-May-1987	21:26	60	54.3778	164.8575
21.1	11-May-1987	04:09	975	54.2985	166.4590
21.1	11-May-1987	06:08	1040	54.2950	166.4548
21.1	11-May-1987	20:07	1017	54.2970	166.4617
21.1	11-May-1987	22:34	1024	54.2965	166.4587
21.1	12-May-1987	00:05	1016	54.2962	166.4627

Chapter 3

Zooplankton Abundance and Distribution

by

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SUMMARY

The purpose of this study was to measure the distribution and abundance of invertebrate taxa important in bird and mammal food webs in the Unimak Pass area, and to evaluate these distributions with respect to oceanographic processes and features. Existing information suggested that zooplankton and cephalopods would dominate the invertebrate diets of these animals. However, invertebrate sampling concentrated on only zooplankton because of the difficulty in sampling cephalopods.

Euphausiids and copepods, the zooplankton groups expected to dominate pelagic environments and vertebrate diets, were sampled in the water column and at the surface by nets deployed from aboard the R/V *Miller Freeman*. Sampling was conducted in fall (late September-early October 1986), winter (late February-early March 1987), and spring (late April-early May 1987) along cruise transects through the Unimak Pass area.

Estimates of invertebrate wet-weight biomass and composition by major taxa (e.g., copepods, euphausiids) and temporal and spatial trends in abundance (biomass) were described.

Major findings and their implications are as follows:

(1) Proportions of the total biomass that major zooplankton groups contributed varied seasonally. Gelatinous zooplankton (jellyfish) dominated spring catches northeast of Unimak Pass in the vicinity of the well-known "slime bank" on the North Aleutian Shelf, but was inconsequential in other seasons and places. Euphausiids formed the overwhelming majority of non-gelatinous zooplankton biomass during fall and winter, and a slight majority in spring. Copepods were scarce in fall and winter but nearly equalled the biomass of euphausiids in spring.

All these abundance patterns were predictable to some extent. Jellyfish are frequently found to be abundant northeast of Unimak Pass. Euphausiids always tend to increase in dominance over the shorter-lived copepods in winter, and spring blooms of copepods typically cause their biomass to increase in proportion to that of slower-reproducing taxa.

(2) Spatial patterns of biomass distribution of euphausiids changed markedly between the fall and remaining cruises. During fall, euphausiids were widely distributed except in

the Alaska Coastal Current, and the highest biomasses were found in the Gulf of Alaska Water north of the Krenitzin Islands. Winter and spring locations of high biomass levels were remarkably similar with highest biomasses being in the Alaska Coastal Water (north). Clusters of high biomass were within 50 km of land a) immediately west of Unimak Island, b) in the Krenitzin Islands, and c) southeast of the Krenitzins.

(3) Relative proportions of euphausiid biomass in the water column vs. at the surface varied seasonally. Euphausiids were much more common in the water column in winter than they were at the surface; this pattern reversed in spring. This pattern was also somewhat predictable, because euphausiids are known to gather in breeding swarms at the surface in spring.

(4) In fall and winter, copepod scarcity masked any clear patterns of their biomass distribution in space, but in spring, large biomasses appeared at this time west of Unimak Island in a "corner" of the shelf break. This area corresponds to a region that appears to receive an influx of nutrients upwelled at passes in the Aleutian chain west of the unimak Pass area but transported eastward along the north side of the Aleutians to the shallow waters north of Unimak Island. Secondary peaks in abundance were in the Unimak Pass proper/Krenitzin Islands area. Surface and water-column centers of abundance generally coincided in space.

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INTRODUCTION

One of the objectives of the Unimak Pass study was to relate the seasonal distributions, abundances, and activities of marine bird and mammal species to insular and persistent oceanographic features such as currents, tide rips, and upwelling areas. The rationale for this objective was that birds and mammals had been observed to sometimes concentrate in apparent response to such oceanographic phenomena. It has been hypothesized further that this concentrating behavior might be in response to locally high densities of invertebrate components of food webs caused by ocean fronts or sites of upwelling. Studies of invertebrates were therefore designed to measure the distributional abundances of taxa important in vertebrate food webs and to relate these distributions to oceanographic processes or features.

CURRENT STATE OF KNOWLEDGE

Extensive sampling for invertebrates in the eastern Aleutian Islands and Unimak Pass has been in the past largely restricted to commercially-important species, mainly crabs. But sampling of other groups has been carried out in nearby regions of the Bering Sea and North Pacific, and the results suggest much about the invertebrate communities that exist in the study area. Thus the following discussions are based on information collected both within the study area and in nearby areas. Emphasis is on those invertebrate groups important to vertebrate consumers—zooplankton (copepods, euphausiids) and nektonic cephalopods (squids). Most of the information on non-commercial species comes from the recent study of the North Aleutian Shelf (LGL 1987).

Zooplankton

Very little sampling for zooplankton has been conducted in the Unimak Pass area, but general circulation patterns (see Schumacher et al. 1982, Hood 1986) suggest that the communities from the study area should resemble those of nearby shelf and oceanic waters. Zooplankton sampling has been most prevalent on the adjacent North Aleutian Shelf (NAS) and other areas of the Bering Sea. The following discussions are mainly drawn from Thomson (1987), and other studies in the southeastern Bering Sea.

Zooplankton biomass measured on the NAS during 1984 and 1985 was extremely low compared with that of offshore Bering Sea shelf waters, other arctic waters, and other marine waters in general (Thomson 1987). Other Bristol Bay nearshore waters are, like the NAS, typically low in zooplankton biomass. Total zooplankton biomass on the NAS was found by Thomson (1987) to be highest in June and July. The biomass peak on the NAS and other inshore areas (July/August) was later than that on the outer shelf (May) or middle shelf (early June). Biomass on the NAS was lowest in September, probably as a result of jellyfish predation.

Relative abundances among zooplankton taxa changed among seasons on the NAS (Thomson 1987). Chaetognaths were the dominant invertebrate taxon in winter, but decreased in abundance through spring and summer. Copepods generally increased in abundance from a January low to a late spring (May) high, sometimes remaining abundant into late summer. Abundance of euphausiids showed no marked seasonal differences. Decapod larvae and fish larvae both increased in absolute biomass from a January low to a July high. Carnivorous zooplankton were dominant in winter; the abundance of herbivores began increasing in April with onset of the spring bloom, and generally increased through July.

The most important zooplankton taxa in terms of their apparent importance to vertebrate food chains in the southeastern Bering Sea are copepods and euphausiids (see Craig 1987, Troy and Johnson 1987a,b). Information on these and other groups follow.

Copepods

The eastern Bering Sea has been depicted as having two major copepod communities, an oceanic and outer-shelf (oceanic) community and a middle-shelf and coastal (shelf) community. These may mix to some extent along the outer shelf, and probably in the Unimak Pass area as well. Near the coast, a distinct nearshore community may also occur. These communities are found consistently in hydrographically-defined domains (Cooney 1981).

The oceanic community is dominated by the large copepods (*Calanus cristatus*, *C. plumchrus*, *Eucalanus bungii*, and *Metridia pacifica*) that overwinter at ocean depths beyond the shelf edge and migrate upward in large numbers in spring to take advantage of phytoplankton blooms at the surface. The shelf community is dominated by the small copepods (*Acartia longiremis*, *Pseudocalanus* spp., and *Oithona similis*) that overwinter on the shelf and survive in low numbers until spring. Shelf waters adjacent to ocean depths contain a mixture of these dominants, at least in summer. Motoda and Minoda (1974) note that a copepod, *Centropages abdominales*, described by Cooney (1981) as a nearshore species, is abundant in the shallow waters around Unimak Pass.

Because there has been limited zooplankton sampling in the past in the Unimak Pass area, it has not been clear whether the copepod community is more typically an oceanic or a shelf type. Discussions by Smith and Vidal (1986) on the transport of oceanic forms onto the outer portion of the southeastern Bering Sea shelf lend support to the idea that oceanic-type copepods might dominate in western parts of the Unimak Pass area because of the proximity of deep waters and the probable strong effect of upwelling.

But because of the effect of the Alaska Coastal Current near Unimak Island on the east side of Unimak Pass (Schumacher et al. 1982), shelf copepods might be expected to be dominant there.

Cooney (1978, 1981) and Smith and Vidal (1986) discuss the tendency for spring-summer standing crops of, and production by, copepods to be relatively large in outer shelf and shelf break waters of the southeastern Bering Sea. This high production is attributed to two interacting factors. First, spring and summer phytoplankton production is relatively high in the shelf break area, probably enhanced by nutrients upwelling from depth. Second, the shelf break and outer shelf copepod communities are dominated by oceanic species that overwinter (and reproduce) at depth and move to the surface in sufficient numbers in spring to consume most of the primary production. In contrast to conditions on the outer shelf and break, the inner shelf copepods greet the spring plankton bloom in low numbers, consuming only a small proportion of the primary production.

Because high primary production and dominance by oceanic copepods may characterize at least the western portions of the Unimak Pass area, high copepod productivity may occur in much of that area. By similar logic, one would expect the more eastward pass areas near Unimak Island to have relatively low copepod production and biomass, given that shelf waters and shelf copepods may dominate that area.

Euphausiids

Smith and Vidal (1986) believed that euphausiids are prominent in southeastern Bering Sea food webs. Craig (1987) and Troy and Johnson (1987a) found euphausiids to dominate diets of many fishes and birds on the North Aleutian Shelf. Essentially no information about their importance to vertebrates in Unimak Pass is available in the literature.

Similarly to copepods, euphausiids in the southeastern Bering Sea appear to be distributed according to major hydrographic domains. It has been generally agreed that two communities exist—an oceanic community occupying the outer shelf, shelf break, and oceanic waters, and a shelf community found in the middle shelf and coastal waters. A "mixed" community occupies a zone of overlap on the outer shelf (Motoda and Minoda 1974).

Reasons for this segregation of euphausiid communities have not been as clearly explained as they have been for the copepod communities. Motoda and Minoda (1974) note that *Thysanoessa longipes* prefers higher-salinity water than *T. raschii*; but over large parts of the range of *T. raschii* in the middle and inner shelf of the southeastern Bering Sea, salinities are not appreciably different from those of the oceanic and outer shelf areas dominated by *T. longipes*. Perhaps temperatures in winter habitats are a crucial factor, as they are with copepods.

The dominant euphausiids of the oceanic community are *Thysanoessa longipes* and *T. inermis*; the dominant species of the shelf community is *T. raschii* (Motoda and Minoda 1974, Minoda and Marumo 1975, Cooney 1981). Few reports specifically characterize the euphausiid community of the Unimak Pass area, though it appears likely that both oceanic and shelf species occur in the study area. Oceanic species may dominate in more westerly parts of the study area because of the nearness of the deep ocean environment and the apparent prevalence of upwelling. Shelf species may be common in eastern parts because of the probable influence of the Alaska Coastal current.

Dagg (1982) showed that, in the southeastern Bering Sea, *Thysanoessa* individuals eat mostly phytoplankton, but they can derive most of their energy requirements from phytoplankton only if the phytoplankton standing stocks reach bloom levels. At sub-bloom levels, they consume more copepods and other crustaceans, and fish and invertebrate eggs. Because they are more readily omnivorous than copepods, their standing stocks exhibit less drastic depressions between phytoplankton bloom periods than do stocks of copepods.

Dagg (1982) maintained that euphausiids are probably not sufficiently abundant to contribute prominently to Bering Sea carbon budgets. However, Motoda and Minoda (1974), Craig (1987), and Troy and Johnson (1987a) noted that they are important as foods of Bering Sea fishes and birds. Further, Minoda and Marumo (1975) found euphausiids to be an important part of the standing stock of zooplankton in the Bering Sea. Motodo and Minoda (1974) believed that their low biomass representation in many sampling efforts may simply have been caused by avoidance of sampling nets.

Euphausiids in general, and *Thysanoessa* in the Bering Sea (Dagg 1982), tend to aggregate in swarms, to become stratified in the water column, and to migrate vertically on a diurnal cycle. Typically, *T. raschii* and *T. inermis* migrate toward the surface at night and to the bottom during daylight hours (Dagg 1982), except during the breeding season in late spring and early summer, when they may swarm at the surface both day and night (Ponomareva 1966).

Other Zooplankton

Other important components of the zooplankton community in the southeastern Bering Sea, and possibly of the Unimak Pass area as well, are pelagic (mainly hyperiid) amphipods and chaetognaths. Hyperiid amphipods are important prey of vertebrates, and chaetognaths are major predators of other zooplankton. *Parathemisto* is the major amphipod, with *P. pacifica* occurring largely in the outer shelf and oceanic areas and *P. libellula* assuming dominance in middle shelf and coastal areas (Motoda and Minoda 1974, Cooney 1981). Among the chaetognaths, *Sagitta elegans* is abundant in the oceanic and all shelf zones; *Eukrohnia hamata* is also common in the oceanic realm (Cooney 1981).

Both the amphipod *Parathemisto* and the chaetognath *Sagitta* are largely carnivorous; in and near the study area they probably feed mainly on copepods. *Parathemisto* is an important food source for some vertebrates, particularly birds (e.g., Short-tailed Shearwaters and, to a lesser extent, murres and Black-legged Kittiwakes—Hunt et al. 1981); *Sagitta* is seldom listed as an important food item for vertebrates.

Summary

The Unimak Pass zooplankton community is likely to exhibit similarities to those of surrounding waters because of the existing circulation patterns and the tendency for zooplankton to be more-or-less passively transported. Most data are available from the nearby southeastern Bering Sea, where the two principal zooplankton communities have been aptly described by Cooney (1981) as (1) an oceanic and outer-shelf community dominated by large, interzonal copepods, the hyperiid amphipod *Parathemisto pacifica,* the chaetognaths *Sagitta elegans* and *Eukrohnia hamata,* and the euphausiids *Thysanoessa longipes* and *T. inermis;* and (2) a middle-shelf and coastal community dominated by small copepods, the amphipod *Parathemisto libellula,* the chaetognath *Sagitta elegans,* and the euphausiid *Thysanoessa raschii.* Between the relatively stable middle-shelf water and that of oceanic origin, the zooplankton community becomes a mixture of shelf and oceanic species. Because the waters of Unimak Pass are very near the southeastern Bering Sea and exhibit some qualities of both outer-shelf and coastal areas, it is likely that Unimak Pass zooplankton communities also include representatives from both these domains.

Cephalopods

Squids and octopuses are of considerable importance to vertebrate consumers, particularly mammals, in the southeastern Bering Sea, the northern Gulf of Alaska, and probably in Unimak Pass (Fiscus 1982, Lowry et al. 1982). Existing information about their populations and their trophic significance comes largely from areas adjacent to Unimak Pass, and even these data are scarce.

Squid

Wilson and Gorham (1982a), referencing Okutani (1977), indicate that at least 10 species of squid are relatively abundant in the Bering Sea and/or the northern North Pacific. Ronholt et al. (1986) note that the red squid, *Berryteuthis magister*, accounted for nearly 85% of the total squid biomass in demersal trawl catches in the Aleutians from Attu to Unimak Pass.

Most information on squid distribution near the Unimak Pass area has been obtained from stomach analyses of whales, seals, and salmon (Wilson and Gorham 1982a). This information suggests that squid concentrate in areas with abrupt changes in depth, in areas of upwelling along the continental slope or slopes of underwater ridges, near oceanic islands, and in areas of convergence and divergence (Wilson and Gorham 1982a, quoting Lipinski 1973, and Okutani and Nemoto 1964). The Unimak Pass area would therefore appear to be excellent habitat for squids.

Wilson and Gorham (1982a) examined records of individual catches of squids by National Marine Fisheries Service (NMFS) trawling and by foreign fleet trawling and seining in the southeastern Bering Sea and the northern Gulf of Alaska. High catches of the squids *Berryteuthis magister*, *Onychoteuthis banksii*, and unidentified squids were clustered along the southeastern Bering shelf break and slope and along the Aleutian chain. This reflected to some extent the areas receiving greatest fishing pressure, but probably also showed squid habitat preferences for these areas. Highest abundances of squids caught by trawl in 1980 were near passes in the eastern and western Aleutians.

Fiscus (1982) observed a pattern in the diets of marine mammals that may suggest something about squid distribution in the Unimak Pass area. He noted that, over the continental shelf, fish were more common than squids in mammal diets, but that over the continental slope and in the deep seas, squids became much more important.

Squids are major foods for many mammal species. Most of the small cetaceans, several of the large cetaceans, and most pinnipeds prey on squids (Fiscus 1982). Fiscus noted that most marine mammals that forage along the continental slope or in the deeper oceanic waters of the North Pacific Ocean and Bering Sea have squids as major parts of their diets.

Octopus

Use of octopuses as important prey by marine mammals and other vertebrates in the southeastern Bering Sea has been noted by several authors (Feder and Jewett 1981, Fiscus 1982, Lowry et al. 1982). It is likely that octopuses may be used by these vertebrates in the Unimak Pass area.

The distribution and abundance of octopuses in and near Unimak Pass are difficult to determine from existing data. Analyses of NMFS trawl survey data, observations of divers and biologists, and foreign fleet catch data from the northern Gulf of Alaska and the southeastern Bering Sea (Wilson and Gorham 1982b) show octopuses to have somewhat similar distributions to squids in these areas—catches seem to be concentrated along the Bering shelf break, with sporadic catches in the eastern Aleutians.

Ronholt et al. (1986) found octopuses occurring at low densities (relative to squids) throughout the eastern Aleutians; densities were somewhat higher immediately north of the study area in the Bering Sea at 1-200 m depths. The historical octopus catch (trawls and crab pots) in the eastern Aleutians has been generally small and variable among years (ADFG 1985). Identified species in the catch included *Octopus dolfeini* (the giant Pacific octopus) and *Opisthoteuthis californiana* (the flap-jack devilfish).

METHODS

Sampling for zooplankton was done at night at a series of stations along the survey lines censused for marine birds and mammals the preceding (or sometimes the following) day. Locations of zooplankton sample sites are shown in Figures 1-3. Listings of all zooplankton samples are found in Chapter 10 (Appendix C-1, C-2, C-3).

Zooplankton samples were collected by oblique tows with paired (505µ and 333µ) 0.6-m-diameter bongo nets. Nets were equipped with General Oceanics 2030 flowmeters. The oblique tows sampled the water column to a maximum of 200 m.

Another set of samples was collected from the surface waters. Initially a Tucker trawl was used for sampling this zone but after the net was irreparably damaged, bongo nets were used for this purpose as well.

As the nets were lifted from the water they were hosed down with seawater to move all the zooplankton into the cod end cups. The 505µ mesh cup was emptied into a fine net, the excess water was gently squeezed out, and the solid material was transferred to a graduated cylinder where the zooplankton volume was measured by displacement. The volumes of large organisms (>0.1ml), such as fish, were measured separately. In the case of gelatinous plankton (jellyfish), the gelatinous material was separated from the other zooplankton and the volume measurements were made separately.

After the volume measurement was complete, the non-gelatinous portion of the sample was examined and subdivided if necessary, and a visual estimate of taxonomic composition was made. The initial step was to remove any large or scarce organisms, which were counted and recorded separately. The remainder was split into approximately equal groups by dividing the pile of organisms in a Petri dish into halves, quarters, or eighths. One of the piles was then sorted by major taxonomic group (copepod, amphipod, euphasiid,

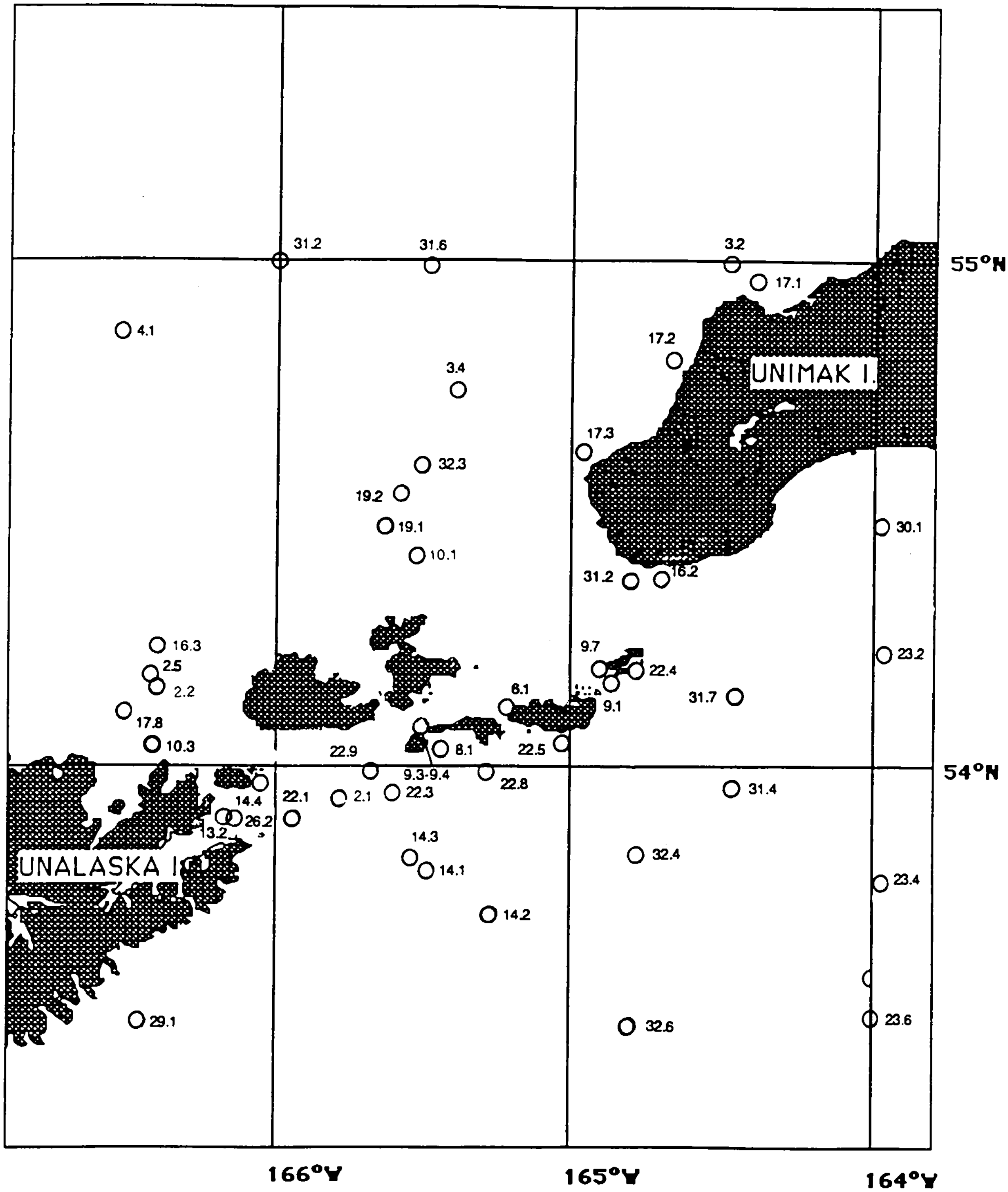

Figure 1. Locations of zooplankton sampling stations during fall 1986, Unimak Pass area, Alaska.

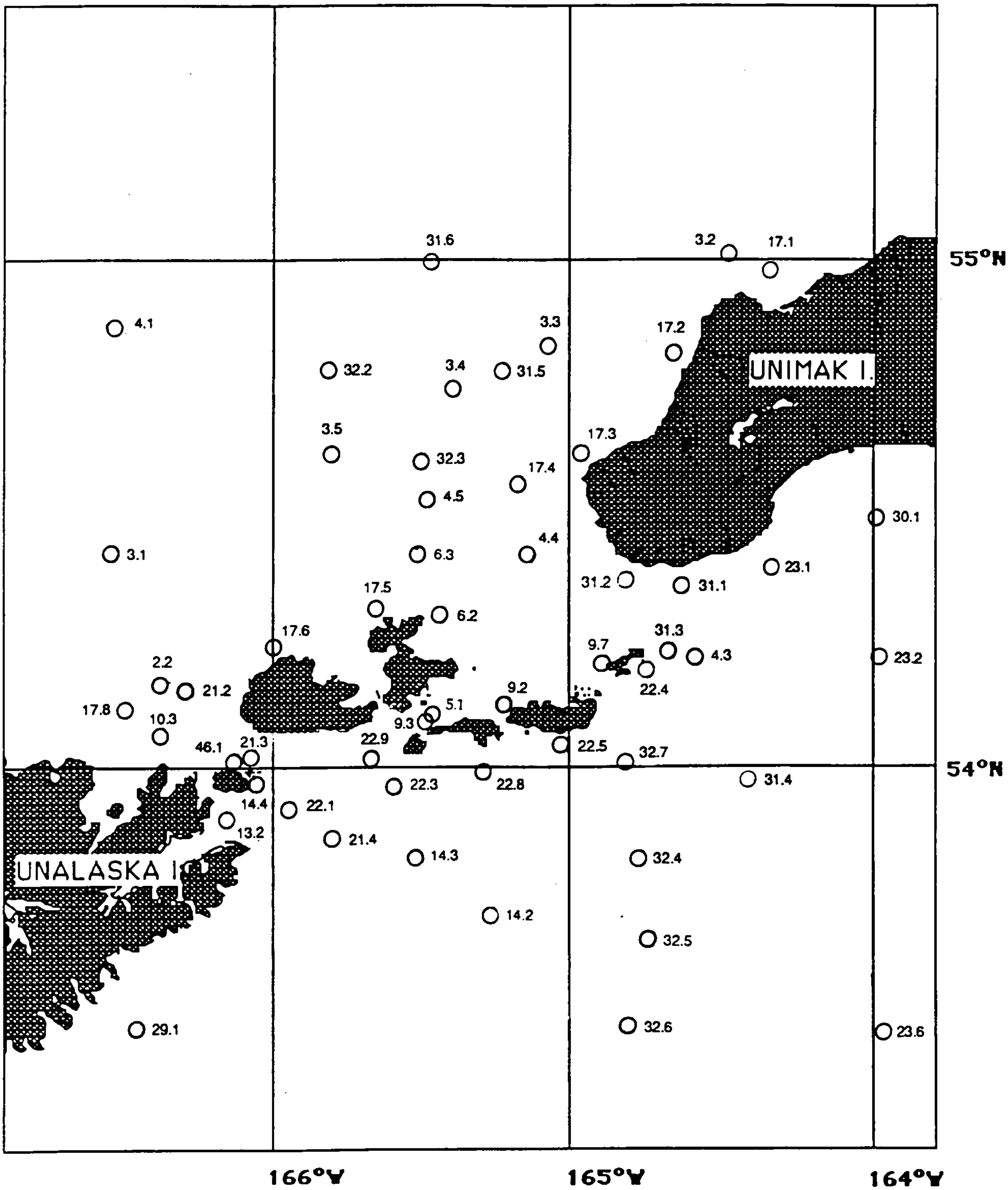

Figure 2. Locations of zooplantkton sampling stations during winter 1987, Unimak Pass area, Alaska.

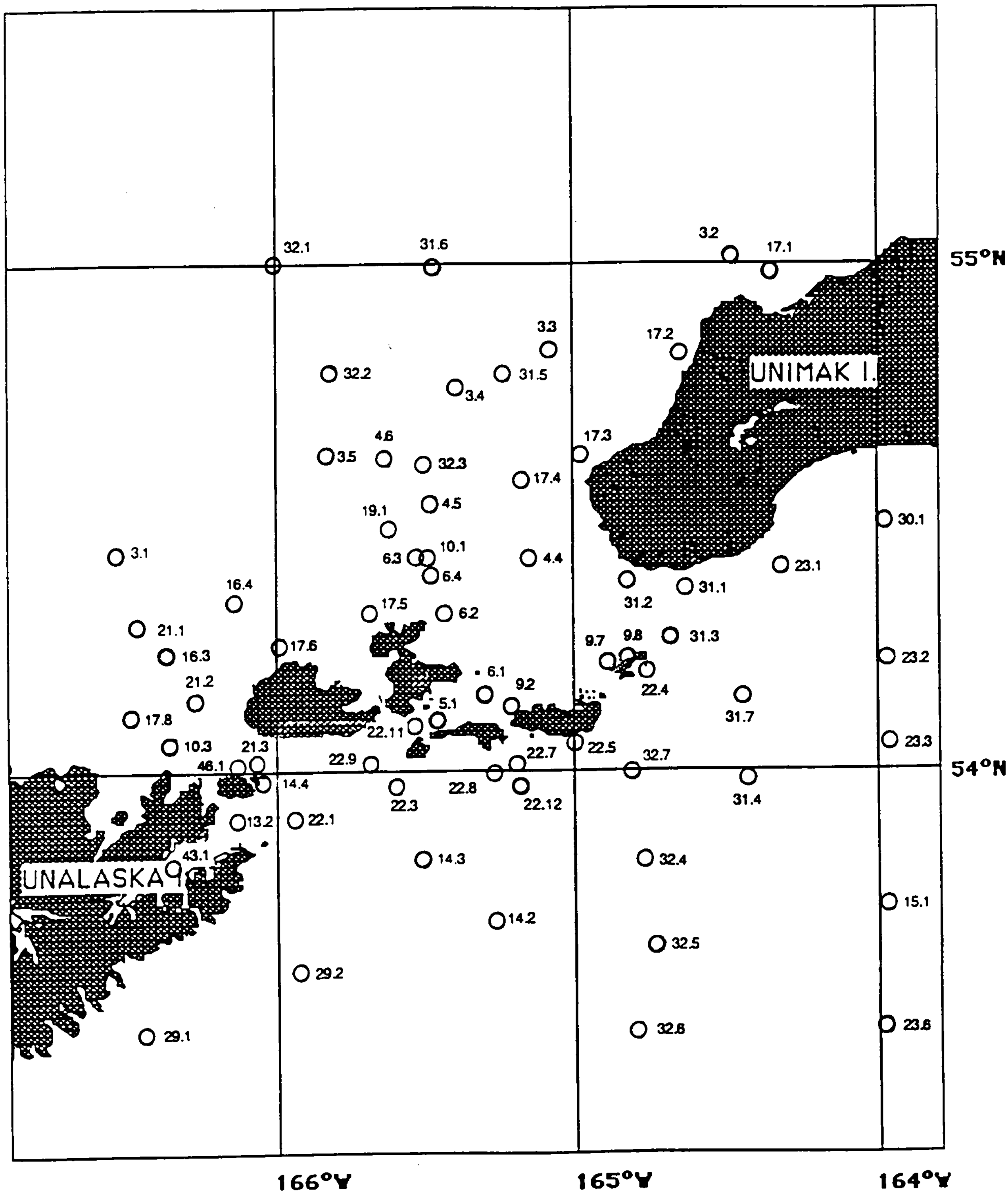

Figure 3. Locations of zooplankton sampling stations during spring 1987, Unimak Pass area, Alaska.

cephalopod, pteropod, chaetognath, larval fish, ctenophore) and the relative wet-weight biomass of each sorted group was estimated and recorded as percent composition for that level of subdivision. The biomass of each group was estimated as:

$$\text{biomass (g/m}^3\text{)} = \frac{\text{total sample volume (ml) x proportion taxon}}{\text{volume water filtered}}$$

The entire sample (minus jellyfish) was preserved in formalin.

RESULTS

Distributional abundances of zooplankton as indicated by surface and water-column sampling are presented below. Because devices capable of effectively sampling other invertebrates (e.g., cephalopods) were not employed, data about those groups are not presented. As will be shown, euphausiids and copepods dominated the invertebrate samples, so the main focus is on these groups.

General Biomass Distribution and Composition

Biomass estimates (g/m^3 wet wt) of invertebrates in the surface layer (data from surface tows) and integrated over the water column (data from oblique tows) are presented in this section. Biomass estimates are segregated by the water mass (Fig. 4) in which the samples were taken. Descriptions of these water masses and their temporal changes in spatial extent can be found in Chapter 2 (PHYSICAL PROCESSES AND HYDROGRAPHY) of this report.

Fall

Fall biomass estimates for euphausiids, copepods, and total zooplankton at the surface and in the water column of the major water masses, based on average catches within each water mass, are shown in Figs. 5 and 6. Isolines of zooplankton biomass, based on catches at each station, appear in Figs. 7 and 8.

Total zooplankton biomass in the water column was generally greatest immediately northwest of Akutan Pass (Fig. 7), but spots of local abundance appeared elsewhere. No clear association of biomass levels with any particular water mass was evident, although markedly higher biomasses were recorded in the GAWn (approximately double that of most other areas). The Alaska Coastal Current, especially the southern portion, supported very low biomasses of invertebrates. Euphausiids comprised by far the highest proportion of the total in all areas except the ACW where gelatinous zooplankton predominated.

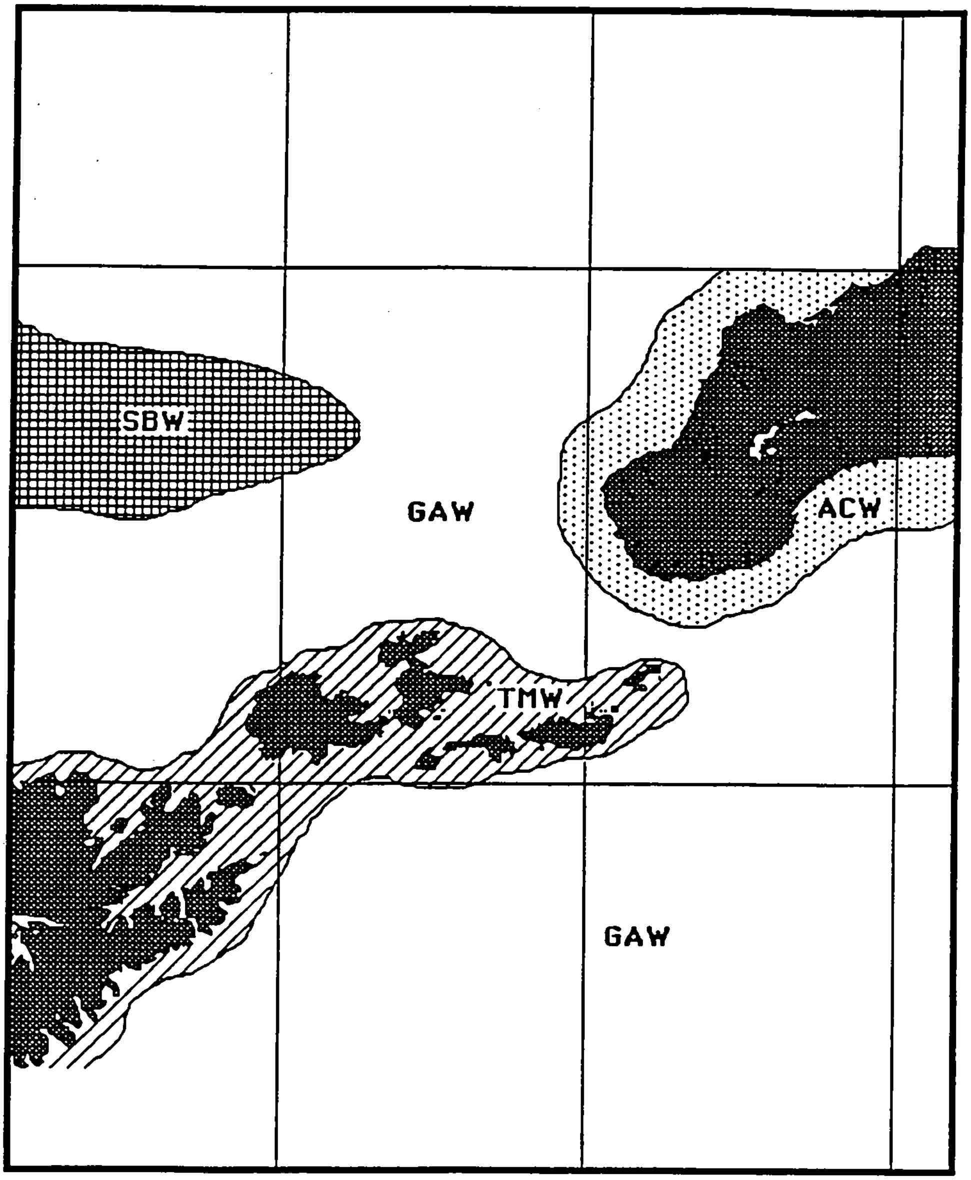

Figure 4. Schematic map of the principal water masses in the Unimak Pass area, Alaska (ACW=Alaska Coastal Water; GAW=Gulf of Alaska Water; SBW=Shelf Break Water; TMW=Tidally-mixed Water). Actually boundaries varied among cruises.

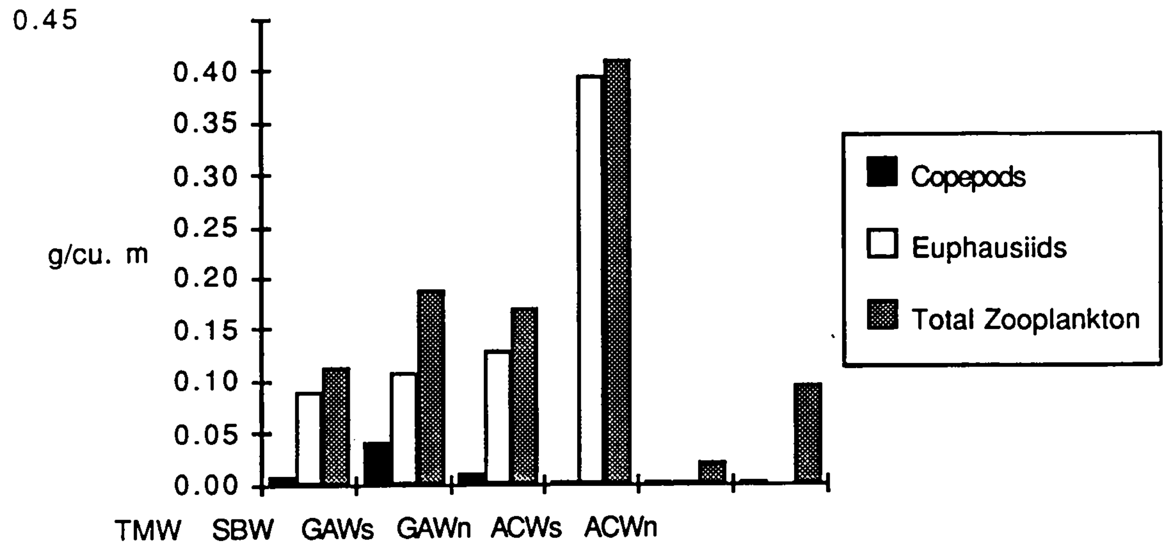

Figure 5. Abundances of zooplankton groups (grams per m^3) in the principal water masses during fall as determined by oblique tows. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

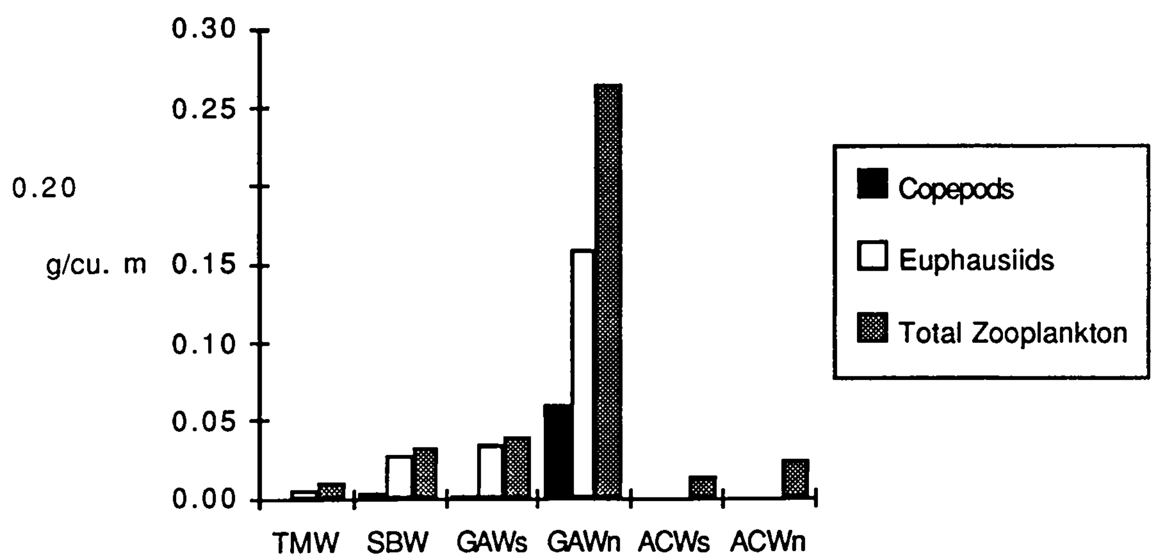

Figure 6. Surface abundances of zooplankton groups (grams per m^3) in the principal water masses during fall as determined by surface Tucker trawls, Unimak Pass area, Alaska. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

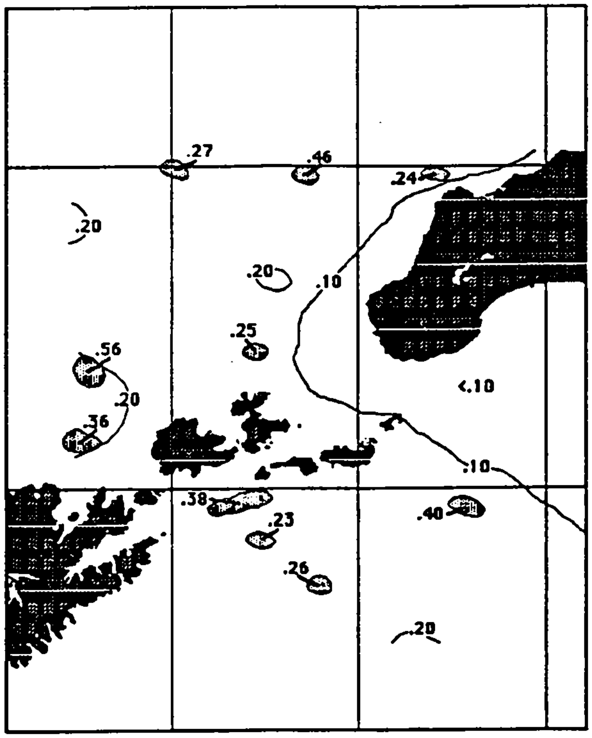

Figure 7. Isolines of total water-column zooplankton abundance (grams/m^3) as determined by oblique tows during fall in the Unimak Pass area, Alaska.

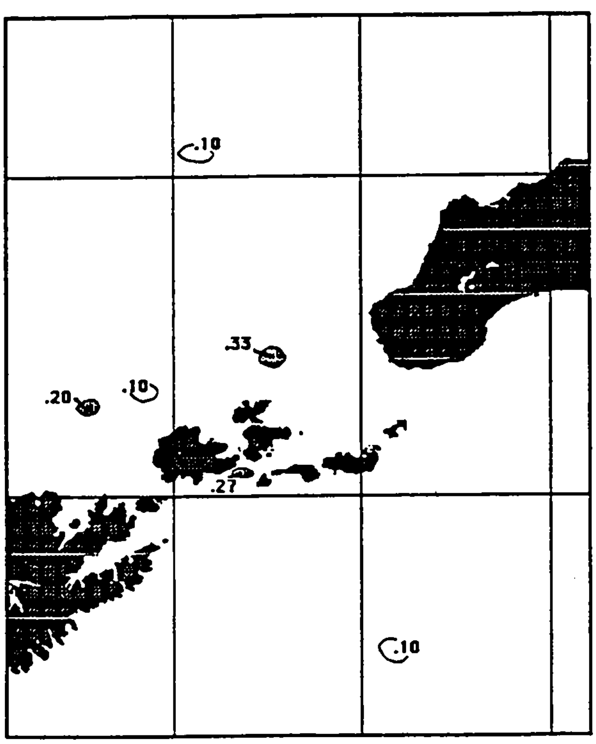

Figure 8. Isolines of total surface zooplankton abundance (grams/m^3) as determined by tucker trawls during fall in the Unimak Pass area, Alaska.

Zooplankton surface biomass was highest in the GAWn, especially north of Unimak and Akutan passes (Fig. 6). Elsewhere, except for an isolated high catch in Avantanak Strait, surface zooplankton were scarce. Except in the ACW where gelatinous zooplankton predominated, euphausiids comprised by far the highest proportion of surface biomass totals.

On average, both euphausiid and total zooplankton biomass levels per unit water volume were far greater in subsurface than in surface waters (compare Figs. 5 and 6).

Winter

Winter biomass estimates for euphausiids, copepods, and total zooplankton at the surface and in the water column of the major water masses, based on average catches within each water mass, are shown in Figs. 9 and 10. Isolines of zooplankton biomass, based on catches at each station, appear in Figs. 11 and 12. General patterns of winter abundance of zooplankton are discussed below.

Total zooplankton biomass in the water column was generally greatest immediately west and northwest of Unimak Island (Figs. 9 and 11), but spots of local abundance appeared elsewhere. No clear association of biomass levels with any particular water mass was evident, although the deepest areas and those farthest to the southeast had lowest biomasses. Euphausiids comprised the highest proportion by far of the total in all areas.

Zooplankton surface biomass was greatest in offshore areas south of Unimak Pass (Figs. 10 and 12). On average and in most water masses, euphausiids comprised by far the highest proportion of surface biomass totals; this group was responsible for the anomalously high total surface biomass south of the pass.

On average, both euphausiid and total zooplankton biomass levels per unit water volume were far higher in subsurface than in surface waters (compare Figs. 11 and 12). Zooplankton biomasses were low in surface waters north and northwest of Unimak pass and relatively high south of the pass; the converse distributional trend was evident in subsurface waters.

Spring

Spring biomass estimates for euphausiids, copepods, and total zooplankton at the surface and in the water column of each major water mass are shown in Figs. 13 and 14. Isolines of total zooplankton biomass, based on catches at sampling stations, are shown in Figs. 15 and 16. Patterns of spring

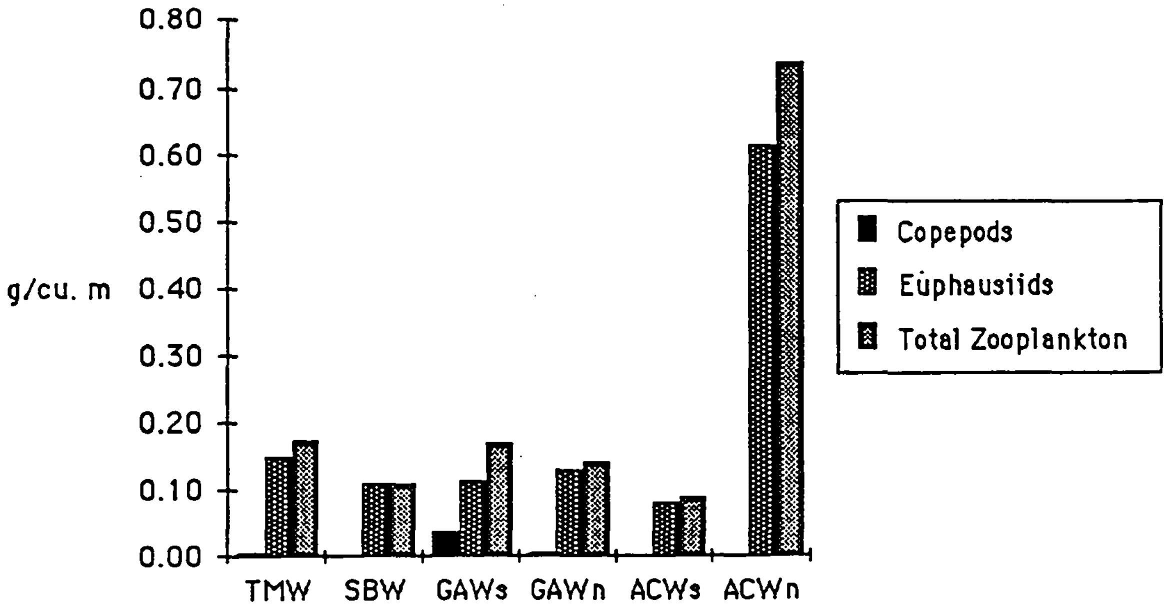

Figure 9. Water-column abundances of zooplankton groups (grams/m^3) in the principal water masses during winter as determined by oblique tows, Unimak Pass area, Alaska. TMV = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

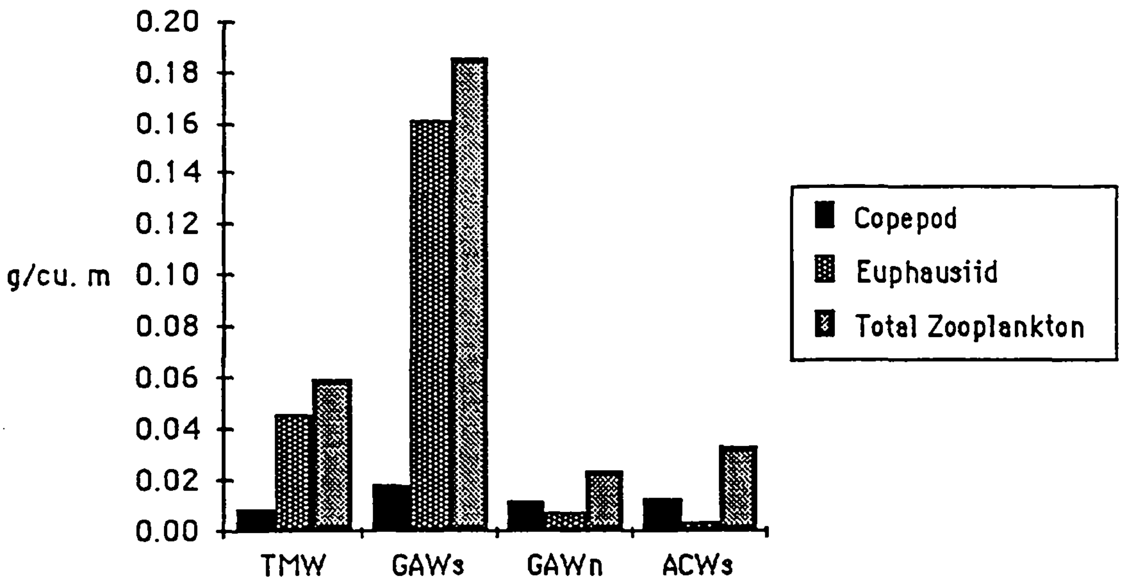

Figure 10. Surface abundances of zooplankton groups (grams/m^3) in the principal water masses during winter as determined by surface bongo tows, Unimak Pass area, Alaska. TMV = Tidally-mixed Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south).

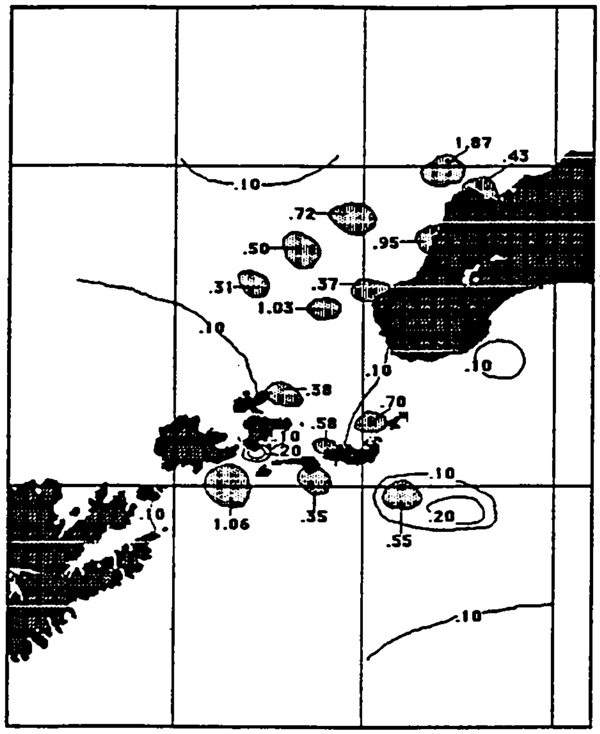

Figure 11. Isolines of total water-column zooplankton abundance (grams/m^3) as determined by oblique tows during winter in the Unimak Pass area, Alaska.

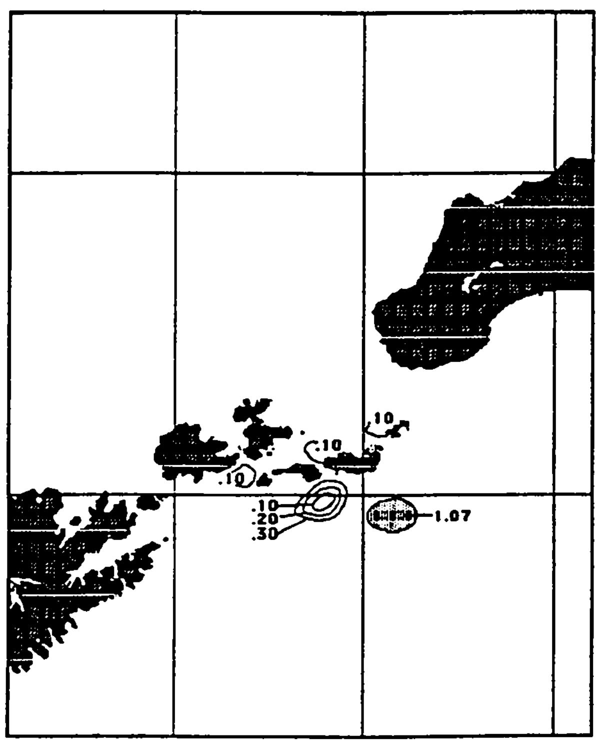

Figure 12. Isolines of total surface zooplankton abundance (grams/m^3) as determined by bongo tows during winter in the Unimak Pass area, Alaska.

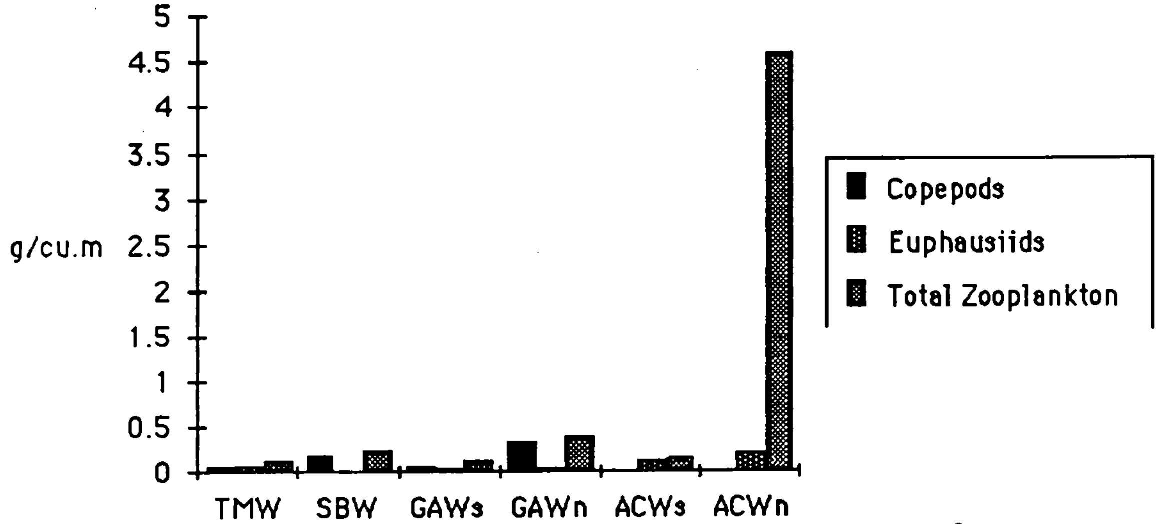

Figure 13. Water-column abundances of zooplankton groups (grams per m^3) in the principal water masses during spring as determined by oblique tows, Unimak Pass area, Alaska. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

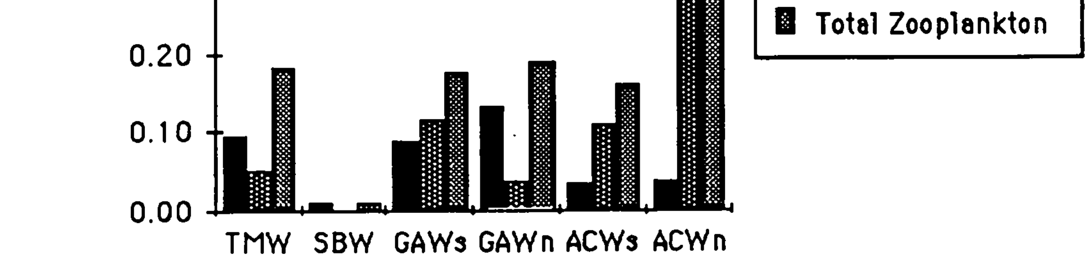

Figure 14. Abundances of zooplankton groups (grams per m^3) in the principal water masses during spring as determined by surface tows, Unimak Pass area, Alaska. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

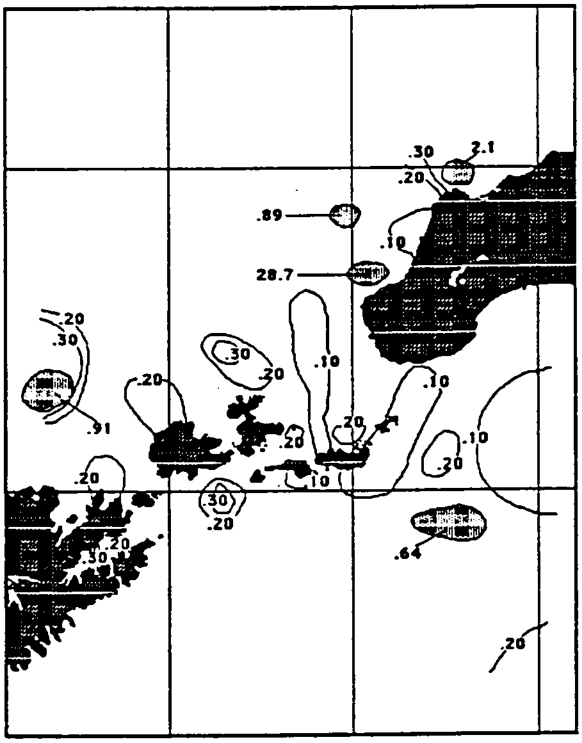

Figure 15. Isolines of total water-column zooplankton abundance (grams/m^3) as determined from oblique tows during spring in the Unimak Pass area, Alaska.

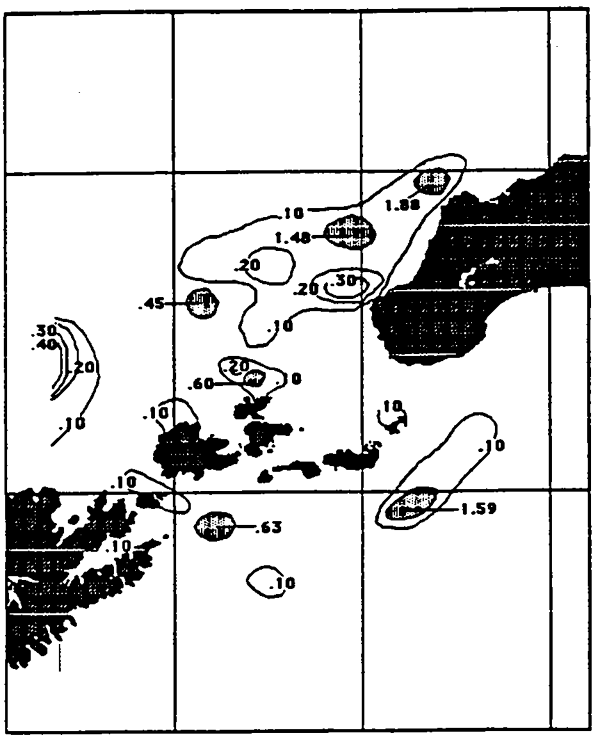

Figure 16. Isolines of total surface zooplankton abundance (grams/m^3) as determined by surface tows during spring in Unimak Pass area, Alaska.

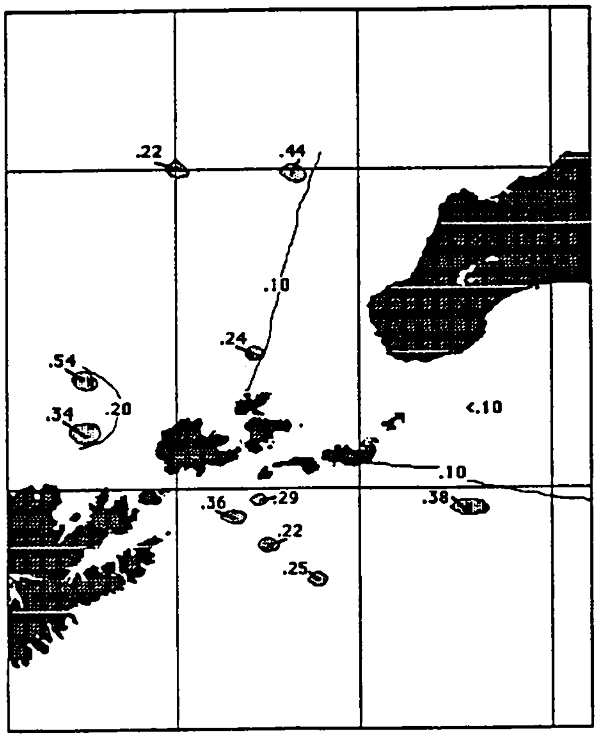

Figure 17. Isolines of euphausiid abundance (grams/m^3) in the water-column as determined from oblique tows during fall in the Unimak Pass area, Alaska.

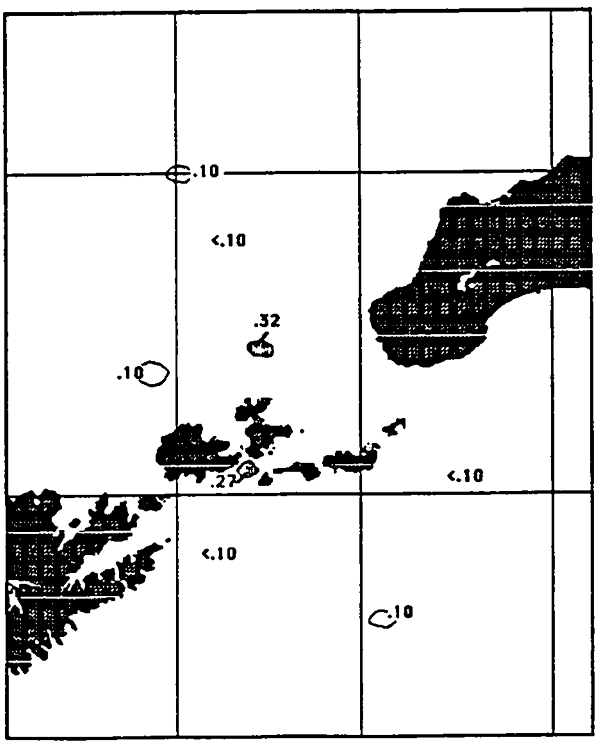

Figure 18. Isolines of euphausiid abundance (grams/m^3) at the surface as determined from tucker trawls during fall in the Unimak Pass area, Alaska.

Euphausiids were much less numerous in the surface waters than in the water column. Highest surface catches of eupahusiids were north of Akun Island in Unimak Pass and in Avatanak Strait (Fig. 18).

Winter

Euphausiids were particularly abundant in the water column in winter in two areas—immediately west and northwest of Unimak Island and among the Krenitzin Islands (Fig. 19). In comparison, they were uncommon in other areas. Their absence from stations far from land was conspicuous.

Euphausiids were abundant at the surface in winter in only a small area immediately southeast of the Krenitzin Islands (Fig. 20); this general area also had high water-column abundances. Their surface biomass was very low elsewhere relative to water-column abundances, and in general, surface and water-column biomass distribution patterns were not similar.

Spring

Water-column abundances of euphausiids in spring (Fig. 21) were generally lower than they were in winter (Fig. 19), though the locations of highest biomass (i.e., west of Unimak Island, southeast of Unimak Pass proper, and among the Krenitzin Islands) coincided with high-biomass areas in winter. They were not abundant far from land or near shelf breaks.

Locations of surface abundances of euphausiids in spring (Fig. 22) generally paralleled those of subsurface abundances (Fig. 21), and one area of spring surface abundance (southeast of the Krenitzin Islands) coincided generally with the only area of winter surface abundance (Fig. 20).

Converse to the winter vertical distribution, surface biomasses in spring were higher than those in the water column. This reflects expectations, because euphausiids are known for assembling in surface swarms in the spring (Ponomareva 1966).

Copepods

Knowledge about the distributional abundances of copepods may be important in two ways. First, distribution of copepod biomass may reflect the distributional patterns of primary production, the primary food source of copepods, and thus may indicate something about patterns of upwelling. Second, copepod distributions may help explain some of the distributions of vertebrate predators that depend on them as a food base. The distributions observed in the present study are described below.

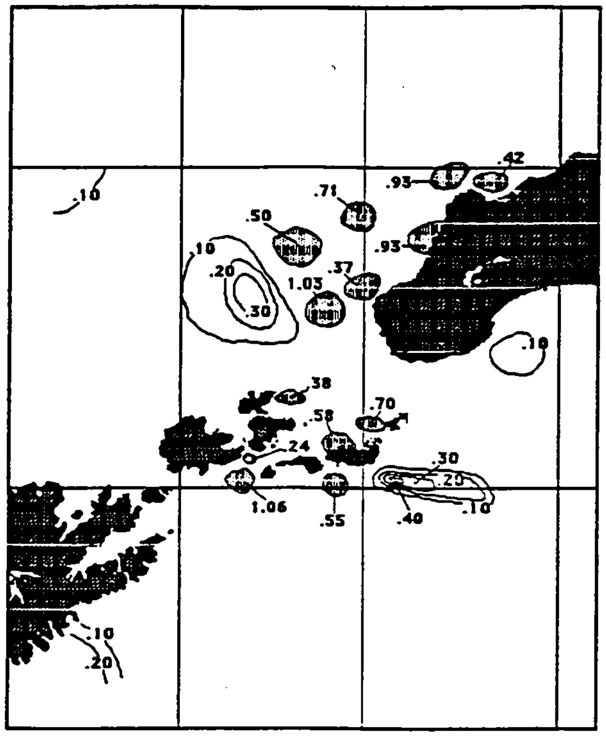

Figure 19. Isolines of euphausiid abundance (grams/m^3) in the water column as determined from oblique tows during winter in the Unimak Pass area, Alaska.

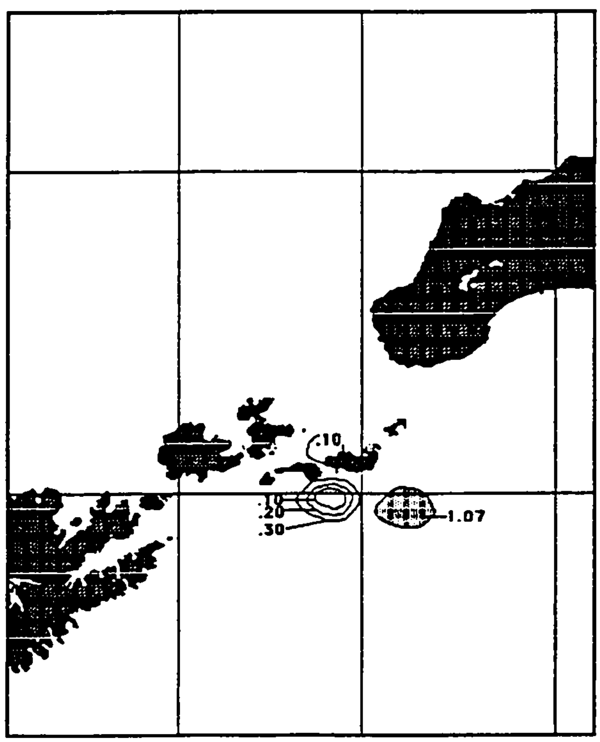

Figure 20. Isolines of euphausiid abundance (grams/m^3) at the surface as determined by bongo tows during winter in the Unimak Pass area, Alaska.

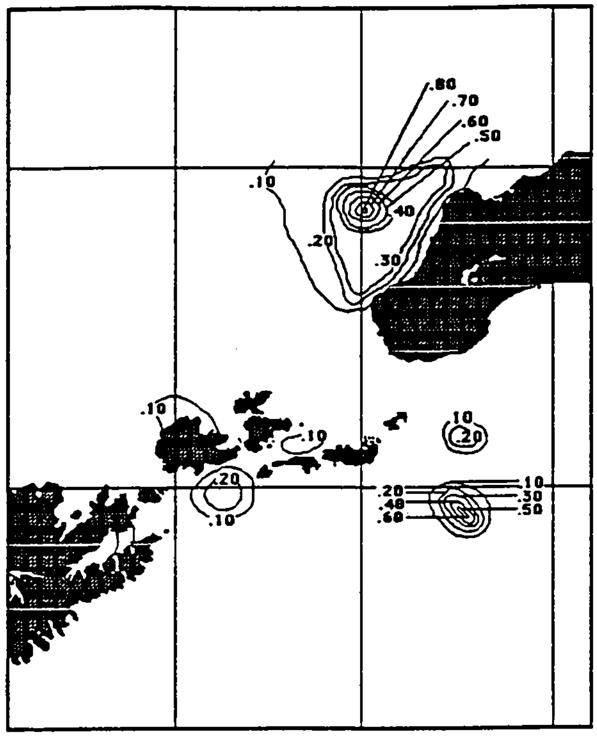

Figure 21. Isolines of euphausiid abundance (grams/m^3) in the water column as determined from oblique tows during spring in the Unimak Pass area, Alaska.

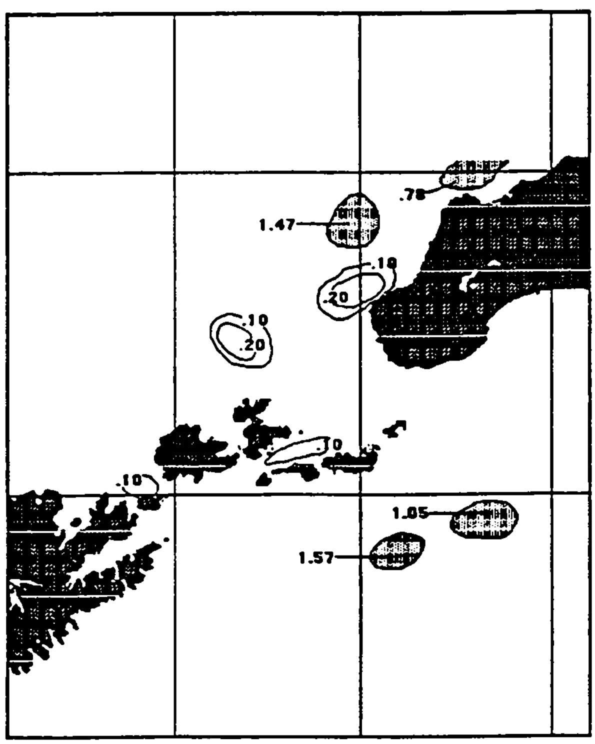

Figure 22. Isolines of euphausiid abundance (grams/m^3) at the surface as determined by surface tows during spring in the Unimak Pass area, Alaska.

Fall

Both water-column biomasses (Fig. 23) and surface biomasses (Fig. 24) of copepods in the Unimak Pass area during fall were very low in comparison with euphausiid biomass levels. The only samples with biomasses ≈ 0.1 g/m^3 were taken at the surface in Unimak Pass north of Akun Island (GAWn), and in the water column north of Akutan Pass (SBW).

Winter

Both water-column (Fig. 25) and surface biomasses (Fig. 26) of copepods in the Unimak Pass area in winter were very low in comparison with euphausiid biomass levels. The only samples with average biomasses larger than 1.0 g/m^3 were taken at the surface immediately southeast of the Krenitzin Islands, a location that also had high biomasses of surface and water-column euphausiids in winter.

Spring

Both water-column (Fig. 27) and surface biomasses (Fig. 28) of copepods in spring were appreciably larger than in fall (see Figs. 23 and 24) or in winter (see Figs. 25 and 26). (Because copepod populations respond quickly to spring phytoplankton blooms, this change was not unexpected.) Water-column biomasses were generally higher than surface levels. Biomasses of copepods in this season approached those of euphausiids, as would be expected because of the more rapid reproductive response capability of copepods to an increase in food supply.

Water column abundances at this time (Fig. 27) were greatest immediately north of Unalaska Island and in Unimak Pass proper. This pattern possibly reflects an influx of nutrient-rich water to this area, perhaps from upwelling or tidal mixing (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume). Sites of surface abundance (Fig. 28) were widely scattered in a variety of locations, not with any apparent correlation with water mass distributions or transport patterns.

DISCUSSION

As we have seen, techniques used for sampling invertebrates selectively captured zooplankton, the presumed major food bases of most vertebrate species of interest in this study. Because the main interest was in the importance of zooplankton as food sources, distributional abundances have been measured in biomass units. The discussions that follow focus on apparent patterns of biomass distribution in space and time, and the likely reasons for these distributions.

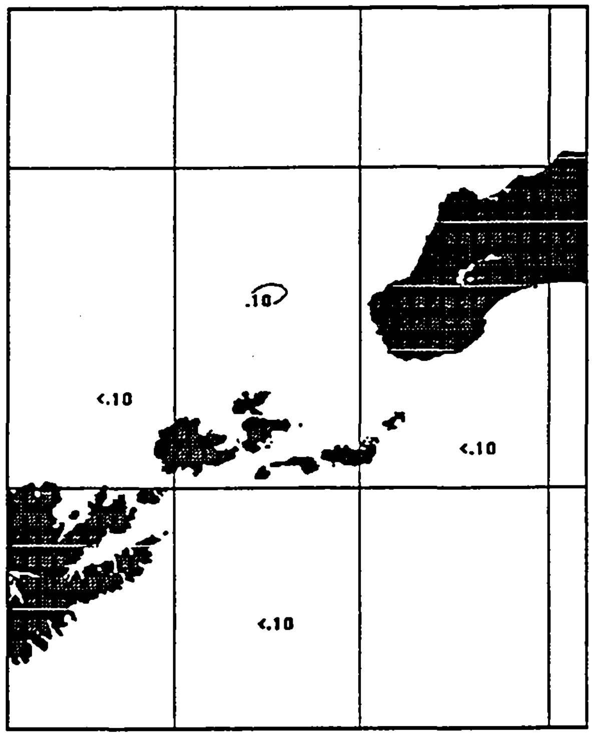

Figure 23. Isolines of copepod abundance (grams/m^3) in the water column as determined by oblique tows during fall in the Unimak Pass area, Alaska.

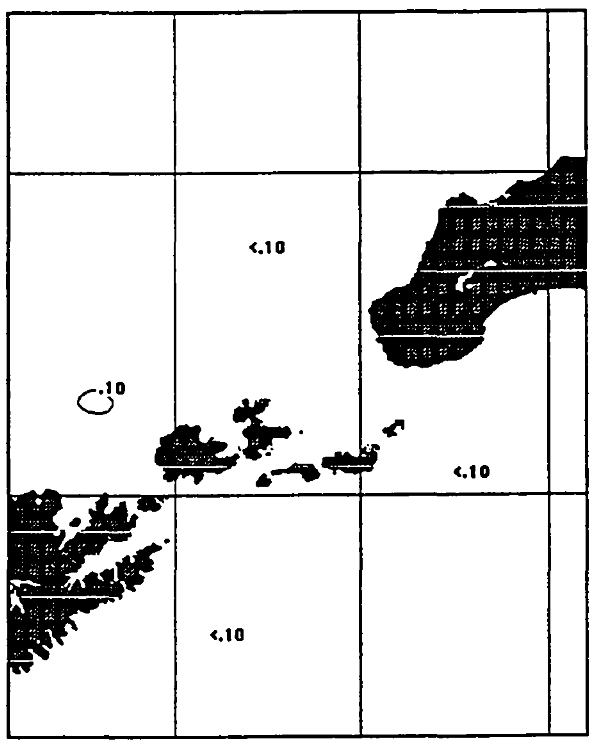

Figure 24. Isolines of copepod abundance (grams/m^3) at the surface as determined by tucker trawls during fall in the Unimak Pass area, Alaska.

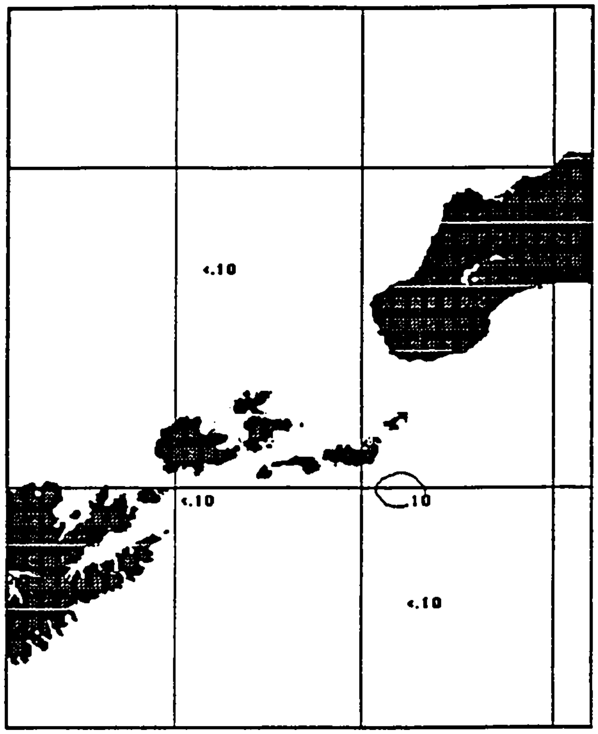

Figure 25. Isolines of copepod abundance (grams/m^3) in the water column as determined by oblique tows during winter in the Unimak Pass area, Alaska.

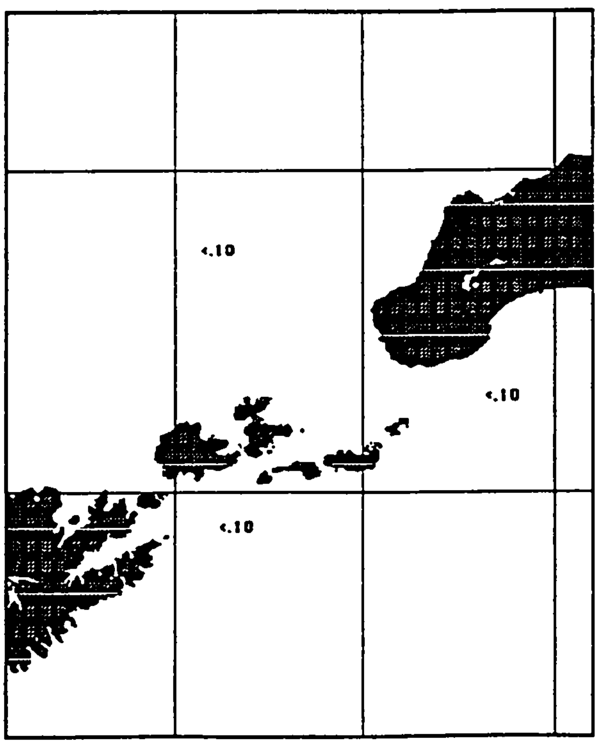

Figure 26. Isolines of copepod abundance (grams/m^3) at the surface as determined by bongo tows during winter in the Unimak Pass area, Alaska.

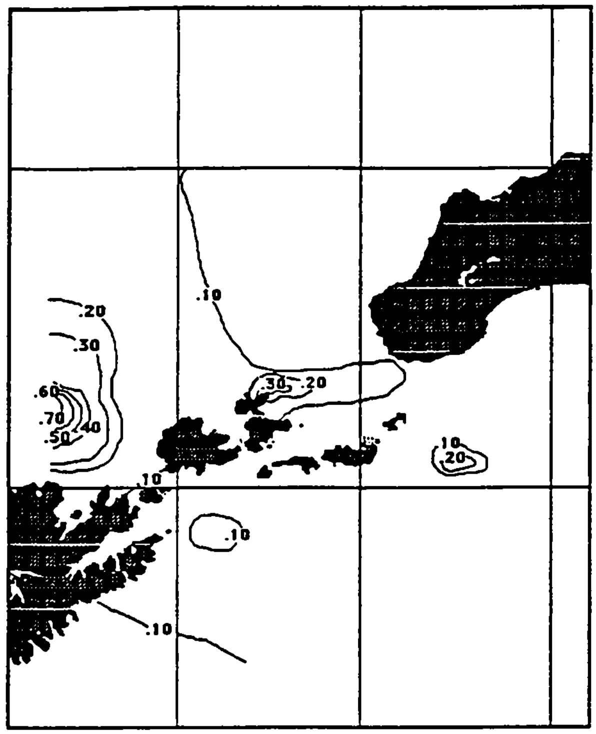

Figure 27. Isolines of copepod abundance (grams/m^3) in the water column as determined oblique tows during spring in the Unimak Pass area, Alaska.

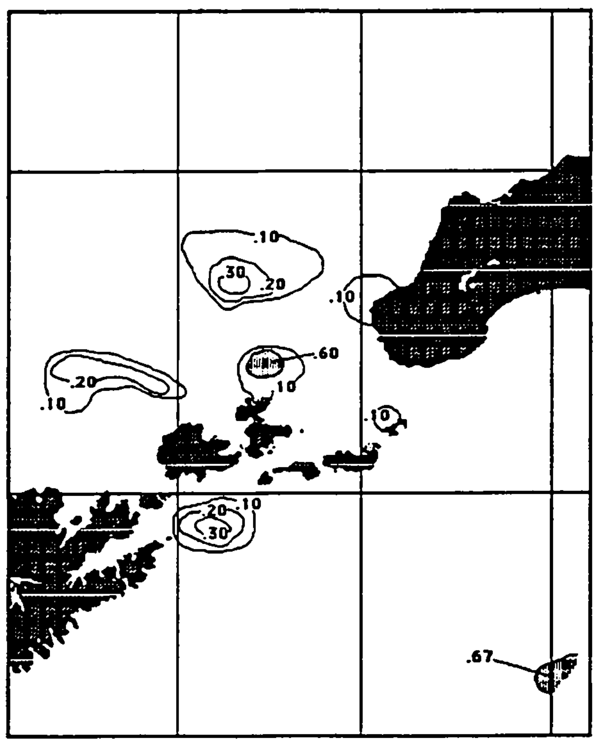

Figure 28. Isolines of copepod abundance (grams/m^3) at the surface as determined by surface tows during spring in the Unimak Pass area, Alaska.

Seasonal Taxonomic Composition

The overwhelming majority of the non-gelatinous zooplankton biomass in fall and winter, and the slight majority in spring, was comprised of euphausiids. (Gelatinous zooplankton, or jellyfish, were exceedingly abundant in spring in the northeast part of the study area, a location known as the "slime bank".) Copepods formed the next most important group.

Seasonal catch patterns for euphausiids were generally as would be expected. In fall and winter, euphausiid abundance in the water column was much higher than at the surface; this pattern reversed in spring. Euphausiids typically gather at the surface in spring to breed (Ponomareva 1966); this phenomenon was presumably what caused the higher spring surface catches and lower water-column catches.

Seasonal variation in copepod abundance reflected the normal spring population growth pattern in subarctic copepods. Copepod biomass was very low in fall and winter, but increased dramatically by the late April-early May sampling period in probable response to increased phytoplankton growth in spring. This same seasonal pattern in copepod abundance has been observed on the adjacent North Aleutian Shelf (Thomson 1987).

Euphausiid Distribution vs. Oceanographic Processes

Highest biomasses for euphausiids occurred in the fall around the Krenitzin Islands with occasional high biomasses in deeper water. The only region of low biomass was the Alaska Coastal Water (north and south) zone around Unimak Island. In winter, euphausiid biomass was concentrated in shelf areas within 50 km of land, mostly in the immediate vicinity of Unimak Pass (west of Unimak Island, in the Krenitzin Islands, and southeast of the Krenitzins). Areas farther offshore and near the shelf breaks had, in comparison, very low euphausiid populations.

Reasons for this pattern of distribution are not clear, particularly since winter bird diets in the area (see Chapter 5: MARINE BIRD ABUNDANCE AND HABITAT USE, this volume) suggest that the euphausiid community is dominated by *Thysanoessa inermis*, a species thought to be affiliated more with oceanic areas than with shelf waters (see Current State of Knowledge, this chapter). Perhaps the vertical mixing that appears to bring water from off the the oceanic regime into the Unimak Pass-North Aleutian Shelf area (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume) plays a role in concentrating oceanic euphausiids in this shelf area.

In spring, euphausiid biomass distributions were remarkably similar to the winter distributions. Concentrations were on the shelf: west of Unimak Islands, among the Krenitzin Islands, and immediately southeast of Unimak

Pass. The few bird stomachs that contained euphausiids in spring again contained the oceanic species *T. inermis.*

Copepod Distributions vs. Oceanographic Processes

In fall and winter, copepods were so scarce in samples that no strong inferences about distributional patterns were possible. There was some indication, however, that copepods were more abundant near the Unimak Pass-Krenitzin Islands area (up to 50 km from shore) than elsewhere.

In spring, copepod biomasses were larger and patterns of distribution clearer. Water-column biomass was greatest immediately north of Unalaska Island, at the expected point of entry into the study area of upwelled, nutrient-rich water from the west (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume); a less prominent surface concentration was also noted in this area. Smaller water-column and surface concentrations also appeared in the Unimak Pass-Krenitzin Islands area, which overlapped a winter-spring concentration area for euphausiids as described above.

Samples in the extreme southeastern corner of the study area, beyond the Gulf of Alaska shelf break, showed an anomalously high copepod concentration in comparison with that of shelf-edge waters elsewhere in the study area. This could have been caused by conditions in Pacific oceanic waters that were impinging on the shelf.

RECOMMENDED FURTHER RESEARCH

The data collected during the present investigations have revealed that, throughout most of the study area and during most of the cruises, euphausiids were the most abundant prey available for marine birds and mammals. The diet information collected also indicated that the seabirds present were preying predominantly on this group. The major gap in our zooplankton sampling is the absence of summer sampling. In the adjacent NAS region, mid-summer was a period of high densities of euphausiids and thus seabirds, but, as has been seen in other comparisons, trends can be very different in the Unimak and NAS areas. Summer sampling would be required to fill this information gap.

ACKNOWLEDGEMENTS

We are indebted to the the entire crew of the Miller Freeman for their cooperation and assistance in making this study a success.

We thank CDR Taguchi, who found ways to accommodate our innumerable trips through (and residence in) all passable passes in the Krenitzin Islands. LT Brian Hayden (FOO) made arrangements for all our

requests and accommodated last-minute changes in plans, allowing us to obtain all our samples where and when we wanted them.

Denis Thomson provided valuable suggestions for the conduct of this study and insights based on his knowledge of the adjacent North Aleutian Shelf. Dan Daugherty, the Chief Biological Survey Technician of the R/V Miller Freeman provided tremendous assistance during all nighttime sampling. The completeness of our survey would not have been possible without his assistance. Ruth Reigel sorted the fall cruise samples. Michael Bradstreet developed the shipboard procedures for estimating biomasses of the major prey. Sue Saupe also provided tremendous aid in sampling and sorting during the winter cruise. Dale Herter and Michael Bradstreet helped with sorting during the winter and spring cruises.

We thank Terry Carpenter, Robert Dillinger, Benny J. Gallaway, and Laurie Jarvela for their comments on versions of this report.

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Chapter 4

FORAGE FISH ABUNDANCE AND DISTRIBUTION

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SUMMARY

The purpose of this study was to describe the spatial and temporal distribution of forage fishes in the Unimak Pass area and assess this as a basis for explaining the distributions of marine birds and mammals of the region. Distributional analyses of these fish were based on mid-water trawls taken in association with marine bird and mammals surveys and measurements of physical and biotic attributes of the environment. Shipboard sampling was conducted in fall (late September-early October), winter (late February-early March), and spring (late April-early May). The forage fish data were interpreted in light of water mass distributions and characteristics described in Chapter 2 (PHYSICAL PROCESSES AND HYDROGRAPHY) of this volume.

The major findings were as follows:

(1) Young-of-the-year pollock were extremely abundant during fall within the tidally mixed waters around the Krenitzin Islands.

(2) Lanternfish were present in intermediate abundance during all cruises in the deep (> 1000 m) portions of the Gulf of Alaska. It was uncertain if large numbers of this potential prey species were ever within the foraging ranges of most seabirds.

(3) In most portions of the study area and during most seasons, forage fish were relatively uncommon and thus probably did not attract marine birds and mammals to the area.

(4) The paucity of forage fish in fall, winter, and spring seasons was consistent with the general patterns exhibited on the adjacent North Aleutian Shelf, where small fish were numerous only during summer (the season not sampled during the Unimak Pass surveys). But there were typically more forage fish in the Unimak Pass area than on the North Aleutian Shelf, especially during fall.

(5) Bottom fish were not sampled as part of this study, in part because very little sea-floor habitat was within the foraging ranges of birds. The presence of cormorants in coastal habitats indicates that fish were probably available there year-round.

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INTRODUCTION

The waters of the southern Bering Sea and the North Pacific Ocean are among the world's richest fishing grounds. These waters support an abundant and diverse fish fauna—over 300 fish species occur there, about 20 of which are of major commercial importance. Many of the area's birds and mammals are piscivorous, eating largely forage fish, at least in some areas and seasons.

The objective of this study was to assess the distributional abundances of the important forage fish species in the Unimak Pass area. The information collected would be presented such that the potential influence of forage fish abundances in space and time on the distributions and abundances of birds and mammals could be examined.

CURRENT STATE OF KNOWLEDGE

The eastern Bering Sea has long been the focus of fisheries studies and a vast body of information has accumulated. Many of the studies conducted there include some sampling stations near the eastern Aleutian Islands; some conducted in other locations provide pertinent information about species and populations which also occur in the study area. Studies include several comprehensive research programs and publication series: Outer Continental Shelf Environmental Assessment Program (OCSEAP), National Marine Fisheries Service, Northwest and Alaska Fisheries Center (NMFS/NWAFC), Alaska Department of Fish and Game (ADFG), Processes and Resources of the Bering Sea Shelf (PROBES), International North Pacific Fisheries Commission (INPFC), International Pacific Halibut Commission (IPHC), and the Soviet Fisheries Investigations in the Northeastern Pacific (Moiseev 1963). In addition, Bering Sea fish resources are monitored annually by state and federal agencies (ADFG, NMFS/NWAFC).

Not unexpectedly, much of this research and monitoring effort has been directed at commercial species (salmon, halibut, pollock, and sole). Information on forage fish has come primarily from OCSEAP or other ecosystem research programs, or from incidental catches made in studies of commercial species. In this section the available information about the distribution and abundance of forage fish in the Unimak Pass area is summarized, drawing largely upon Craig (1986). Descriptions of fishes commonly designated as groundfish and inshore fishes (partially comprised of forage fishes) are also included because species in these groups not commonly called forage fishes are eaten by birds and mammals and were caught during sampling in this study.

Forage Fishes

The term "forage fish" refers to species that are abundant, small in size, and significant in the diets of non-human consumers. Important forage fish species in the eastern Aleutians include herring, capelin, and sand lance. Available information is largely restricted to herring; little is known about the other two species.

Herring

Pacific herring are distributed nearly continuously around Alaska (Hart 1973). Herring form a significant component of the eastern Bering Sea food web and are the basis of an important commercial fishery.

Spawning populations in the eastern Aleutian Islands comprise a relatively small part of the overall herring biomass in the eastern Bering Sea, but the study area is an important feeding area for herring, including stocks spawned elsewhere in the eastern Bering Sea. Scale-pattern analyses indicate that about 80% of the herring harvested at Unalaska Island are from Bristol Bay (Togiak stock) with 10% from farther north (Nelson Island) and 10% from Port Moller (Walker and Schnepf 1982, Lebida et al. 1984, Rogers and Schnepf 1985). Herring stocks south of the Alaska Peninsula, however, do not appear to mix with Bering Sea stocks (Grant and Utter 1980, Rogers and Schnepf 1985).

The following description of herring in the eastern Aleutians is based largely on recent reports by Malloy (1985) and ADFG (1985). It is supported by more general reviews (Macy et al. 1978, Barton and Wespestad 1980, Barton and Steinhoff 1980, Wespestad and Barton 1981, Warner and Shafford 1981, Wespestad and Fried 1983, Lewbel 1983, Gilmer 1984, LGL 1986, Schwarz 1986, Fried and Wespestad 1985)

Distribution In and Use of the Study Area. Herring spawn in the Aleutians from late April to mid-July (ADFG 1985). Their eggs are deposited both intertidally and subtidally on aquatic vegetation. After the eggs hatch, the larvae remain in nearshore areas until summer and fall, when they move offshore. Patterns of habitat use differ between local and non-local herring stocks. Local stocks are small and are thought to be less prone to migrate long distances than non-local stocks.

Local stocks occur at several places, the principal one being Unalaska Bay. Small stocks are also found in Makushkin and Akutan bays, and possibly in Beaver Inlet. Spawning sites within Unalaska Bay are reported to occur at Nateekin Bay, Captains Harbor and Wide Bay (McCullough 1984). Spawning elsewhere in the study area is likely but undocumented. Local stocks may reside in the eastern Aleutian Islands year-round, but their distribution is not clear due to the large influx of non-local stocks in summer, when herring are distributed throughout much of the study area. Some herring remain in the study area through fall and winter. The winter concentration is small compared to those near the Pribilof Islands, and it is not clear that the Unimak Pass area is used regularly by herring during the winter months. It seems probable that at least the winter concentrations of herring in Unalaska, Akutan and Akun bays are of local stock origin as herring in other areas of Alaska are known to overwinter close to their spawning sites (e.g., Carlson 1980).

The dominant stocks of herring in the eastern Bering Sea are non-local and undertake extensive annual migrations among wintering, spawning and feeding areas. The eastern Aleutian Islands lie along one of these herring migration routes. The largest wintering concentration of these stocks occurs northwest of the Pribilof Islands, more than 700 km from their major spawning area in northern Bristol Bay (Shaboneev 1965, Rumyantsev and Darda 1970, Wespestad and Barton 1981). After spawning, many fish migrate westward along the Alaska Peninsula as far as Unalaska Island, where they feed in summer. These herring are harvested in a food/bait fishery (3200 mt total harvest) which operates over the approximately 90-mi distance between Tigalda Island and Makushkin Bay; most fishing occurs within about a 5-mi radius of shore-based processing facilities in Unalaska and Akutan bays (Malloy 1985).

Malloy (1985) notes that early accounts of herring in the Unalaska area describe both an early summer run (late June to late July) and a late summer run (late August to early September), but that in current years there seems to be a steady harvest of herring from mid-July through mid-September. Within this summer period the availability of herring is not entirely dependable—weather conditions seem to determine daily movements and behavior patterns. Herring are therefore not always available in "traditional" harvest locations (Malloy 1985).

Trophic Relationships. Herring are an important component of the eastern Bering Sea food web—they are the prey of many seabirds, marine mammals and other fishes (Pace 1984). Of the potentially harvestable population, Lavaestu and Favorite (1978) estimated that 95% is needed by these consumers, leaving only 5% available to the commercial fishery. Herring feeding habits in the study area have not been examined but are presumably similar to those occurring at other locations. ADFG (1985) provides the following summary:

(1) Herring larvae and postlarvae feed on ostracods, small copepods and their nauplii, small fish larvae, and diatoms (Hart 1973). The first foods eaten by larval herring may be limited to relatively small, microscopic plankton that the

larvae must nearly collide with to notice and capture. Early food items may be comprised of more than 50% microscopic eggs (Wespestad and Barton 1981).

(2) Juveniles consume mostly crustaceans such as copepods, amphipods, cladocerans, decapods, barnacle larvae, and euphausiids. Consumption of some small fish, marine worms, and larval clams has also been documented (Hart 1973). In the western Bering Sea–Kamchatka area in November and December, the diet of juveniles has consisted of chaetognaths, mysids, copepods, and tunicates (Kachina and Akinova 1972).

(3) Adults in the eastern Bering Sea in August ate 84% euphausiids, 8% fish fry, 6% calanoid copepods, and 2% gammarid amphipods. Fish fry, in order of importance, were walleye pollock, sand lance, capelin, and smelt. During spring months, food items were mainly *Parathemisto* (Amphipoda) and *Sagitta* (chaetognath). After spawning (eastern Bering Sea), adults preferred euphausiids, copepods (*Calanus* spp.), and arrow worms (*Sagitta* spp.) (Dudnik and Usoltsev 1964). In areas of demersal feeding, stomach contents of herring included polychaete worms, bivalve molluscs, amphipods, copepods, juvenile fish, and detritus (Kachina and Akinova 1972). Barton (1979) found cladocerans, flatworms (Platyhelminthes), copepods, and cirripeds in herring captured during spring months. Rather than exhibiting a preference for certain food items, adult herring feed opportunistically on any large organisms predominating among the plankton in a given area (Kaganovakii 1955).

Important Physical Habitat Factors. Spawning areas provide the best examples of important physical habitat qualities. In the Bering Sea, spawning occurs in the intertidal or subtidal zone on rocky headlands or in shallow lagoons and bays (Barton 1979, Warner and Shafford 1981). Preferred spawning substrates are aquatic vegetation, particularly rockweed (*Fucus*), kelp (*Laminaria*), and eelgrass (*Zostera*). As mentioned above, spawning areas have been located at only three sites in the study area, but others probably exist.

Population Limiting Factors. Herring stocks in the eastern Bering Sea have undergone large fluctuations in abundance over the past 20 years similar to those undergone by clupeid fishes world-wide. Year-class strengths of herring were particularly high in 1957; there were lesser peaks in 1962, 1968, 1974 and 1977. The 1977 year class has in recent years constituted a large portion of the annual commercial harvest of herring in the food/bait fishery at Unalaska Island. The apparent absence of younger fish in this fishery would seem to suggest that harvests may decline in the near future.

Wespestad and Fried (1983) noted that many explanations and hypotheses have been offered concerning the causes of recruitment variability, but most recognize that environmental factors, rather than harvest levels, may be most important in controlling year-class strength unless spawning stocks have fallen below a critical threshold level. It is generally believed that most of the variation in year-class strength is determined during early life history and that water temperature is probably an important factor (Wespestad and Fried 1983)—there is some correlation between the occurrence of warmer waters and increased survival of herring (e.g., Pearcy 1983). Other factors such as predation and availability of suitable spawning habitat could also be contributing factors. Pearcy (1983) concludes that:

> Environmental variables that affect year-class success of herring probably range from single, short-term events such as a storm or freshet that affect the survival of cohorts in an isolated inlet to large-scale events that affect the productivity and circulation of large areas of the northeastern Pacific for a year or more. The synchrony of strong year classes in distant stocks during El Niños supports the idea that large-scale ocean events are important. But we lack information on interannual differences in oceanographic conditions in the northern North Pacific, as well as on specific mechanisms on how varying ocean conditions modify year-class success of herring.

Capelin

Capelin range throughout the Bering Sea (Warner and Shafford 1981) and are presumably abundant in the study area at various times of year. A hundred years ago Turner (1886) remarked "Among the Aleutian Islands these fish abound in incredible numbers." Capelin are generally found in large schools offshore, except during the breeding season when they migrate shoreward to spawn (Macy et al. 1978, Paulke 1985).

Spawning occurs in northern Bristol Bay and along the north side of the Alaska Peninsula, but the eastern Aleutians have not been surveyed for spawning capelin. Along the Alaska Peninsula, schools of spawners are most abundant in mid-May to mid-June; they spawn on pebble-covered beaches and shallow shoals (Barton 1979). Their sticky eggs adhere to the substrate until they hatch, whereupon the larvae move offshore in late summer and fall. The nearshore zone thus serves as both a breeding habitat for adults and a feeding ground for larvae and fry.

Capelin feed primarily on small crustaceans such as copepods, euphausiids, amphipods and decapod larvae, and small fish. Capelin are eaten by salmon, cod, marine mammals and seabirds (Hart 1973, Macy et al. 1978, Vesin et al. 1981). Fiscus et al. (1964) found that the Unimak Pass area was a favored summer feeding ground for fur seals which consumed vast quantities of capelin that had congregated there.

Sand lance

Pacific sand lance is one of the most abundant forage fishes in the eastern Bering Sea, including the eastern Aleutian area. The limited information about this species has been reviewed by Trumble (1973) and Macy et al. (1978). More recent studies have examined sand lance on the north side of the Alaska Peninsula (LGL 1986, Isakson et al. 1986) and near Kodiak (Dick and Warner 1982).

Along the Alaska Peninsula, sand lance were most abundant during mid- to late summer (July-September) in nearshore waters less than 35 m deep. Their distribution was very patchy—they would form dense schools in shallow water or be partially buried in unconsolidated sediment (Hart 1973, Macy et al. 1978, Dick and Warner 1982). LGL (1986) reported that sand lance in this area consumed a variety of prey in May (euphausiids, copepods, amphipods, mysids, polychaetes and eggs) but mainly copepods in September .

Sand lance in the study area probably spawn in late fall or winter (Macy et al. 1978, Dick and Warner 1982). They may spawn intertidally (Dick and Warner 1982) or at depths of 25-100 m in areas having strong currents (Trumble 1973). These fish require particular substrate compositions for burrowing and presumably spawning. Their adhesive eggs probably hatch in about three months depending on water temperatures. After hatching the larvae become pelagic and widely distributed in the Bering Sea.

Groundfishes

The term "groundfish" refers to a diverse group of fishes that usually inhabit near-bottom offshore waters. It is a term of convenience and encompasses not only flatfishes living directly on the seabottom but also species like pollock which often dwell near the bottom but may be pelagic as well. In addition, many groundfish species have pelagic egg and larval stages.

The Bering Sea is well known for its abundance of groundfish (summarized by Hood and Calder 1981, Lewbel 1983, ADFG 1985, and others). Much of the commercial catch occurs along the continental shelf break adjacent to Unimak Pass and just south of Unimak Pass. The region of highest catches is popularly known as the "Golden Triangle" (between

Unimak Pass, the Pribilof Islands, and Amutka Pass). Because of the commercial value of this resource, a vast amount of information describing groundfish in the Bering Sea and western Gulf of Alaska has accumulated. But the information from the commercial fishery is of relatively little importance with respect to an assessment of forage fish because the large size of the fish targeted and the depths at which they occur precludes their use as prey by most organisms of interest (some marine mammals being important exceptions).

Pollock are emphasized in this report, both because of the numerous reports of marine mammals eating them and because young occur in great abundance in the study area and are heavily preyed upon by some seabirds. Several sources of information are directly pertinent. In 1980 NMFS and Japan conducted a joint survey of groundfish resources in Aleutian Island waters (Ronholt et al. 1982, Wilderbuer et al. 1985, Ronholt et al. 1986). NMFS (1975-81) also surveyed shrimp (and fish) resources in the bays around Unalaska Island. Other information sources include the composition of fishes in commercial fisheries north of Unimak Pass and surveys conducted south of Unimak Pass by NMFS and IPHC.

Distribution In and Use of the Study Area

The broad array of sampling stations indicates that a considerable sampling effort has occurred for groundfish in and around the study area. The list of species caught is long, but two species—walleye pollock and Pacific cod—clearly dominate the groundfish community in the eastern Aleutian Islands. Data show that pollock were abundant in all regions surveyed on the north and south sides of the eastern Aleutians (NMFS 1975-81, Blackburn et al. 1980, IPHC 1980-85, Ronholt et al. 1986) and Pacific cod were abundant in most of these regions. Five additional fishes—rock sole, flathead sole, arrowtooth flounder, Atka mackerel, and Pacific ocean perch—were a dominant species in at least one of the regions surveyed.

Beyond this regional distribution, numerous temporal and spatial differences are exhibited by groundfish species in the study area. Four groundfish surveys, each describing a different portion of the groundfish community in the study area, are briefly summarized below.

Survey 1: **Bays of Unalaska Island (NMFS 1975-81).** Small-mesh trawl surveys were conducted over a several-year period in several bays around Unalaska Island. Pollock, mostly juveniles, were by far the most abundant fish present; the occurrence of other common species differed among bays. Highest catches were recorded in Unalaska and Scan bays, largely due to high catches of pollock. If pollock are excluded, catches in the largest bays (Unalaska, Makushkin, Beaver

Inlet) were about four times greater than in the remaining smaller bays.

Survey 2: **Eastern Aleutian Islands (Ronholt et al. 1986).** A trawl survey was conducted on both the Bering and Pacific sides of the eastern Aleutian Islands, June-November 1980. Trawl depths averaged 230 m (range 31-725 m). Pollock and Pacific cod were abundant on both sides of the islands, but differences among the other species were noted north and south of the Aleutians. Pacific ocean perch and giant grenadier were generally restricted to the Pacific side, with Atka mackerel and Greenland turbot occurring on the Bering side.

Survey 3: **Domestic trawl fishery, north Unimak Pass (Blackburn et al. 1980).** This fishery was conducted in winter (February-March 1980), generally along the 100–fathom contour north of Unimak Pass and Akun Island. Pacific cod accounted for 81% of the catch. The sampling gear used in this survey and in Survey 2 differed, probably accounting for the differences in catch compositions obtained in these surveys.

Survey 4: **Unimak Bight survey (IPHC 1980-85).** Trawl surveys in Unimak Bight located south of Unimak Island are conducted almost annually by IPHC. Trawl depths in this area are typically 27-110 m. Although the Unimak Bight area extends beyond the immediate study area, the data are useful to illustrate annual variability in the catches of groundfish. In these surveys, four species—rock sole, Pacific cod, arrowtooth flounder, and pollock—accounted for 67% of the catch, averaged over the period 1980-85. These results differ considerably from those mentioned above (Survey 2) where Pacific ocean perch accounted for 30% of the sample on the Pacific side of the study area. At least part of this difference is due to the sampling gear used. IPHC trawls are rigged to catch flatfish (i.e., the trawl hugs the sea-floor and has a vertical opening of only 4-5 feet), whereas the NMFS trawls have a much larger opening (20 feet) and thus would catch more "semi-demersal" fish.

Pollock constitute about 80% of the commercial groundfish harvest in the Bering Sea and the eastern Aleutian Islands. The pattern of total groundfish harvests is largely a reflection of the pollock catches.

Pollock catches on the Bering and Pacific sides of the eastern Aleutians differ somewhat (Ronholt et al. 1986). The fish are apparently more abundant on the Pacific side where the population estimate (88,171 tons) and catch per unit effort (56 kg/ha) are higher than on the Bering side (53,725 tons, 42 kg/ha). (Note that these values pertain only to the bottom-dwelling segment of the pollock population; the mid-water segment was not sampled during this survey. In the Bering Sea, only about 8% of the pollock biomass occurs on the bottom [Ronholt et al. 1986].) Pollock on the Bering side tended to be smaller and younger fish: mean length = 41.0 cm and mean age = 3.9 years on the Bering side, and length = 45.9 cm and age = 5.9 years on the Pacific side. Pollock on the Bering side also tended to inhabit shallower waters than those on the Pacific side.

These differences were also reflected in catches of fish within the bays of Unalaska Island where pollock were by far the dominant species. Pollock, mostly juveniles, are 3-20 times more abundant in bays on the northern side of the island than on the southern side. Pollock in Unalaska Bay catches included large fish (approximately 30-55 cm) similar in size to those caught farther offshore on both the Bering and Pacific sides of the Aleutians, but also smaller fish (approximately 15 cm) not caught offshore. This may represent either a habitat preference by juvenile pollock or it may simply result from gear selectivity (trawls used in the bays have smaller meshes). In any case, using these same data, Walters et al. (1985) reported that one-year-old pollock were fairly abundant and widespread in the bays of Unalaska Island in 1980 and less so in 1981.

Pollock use the study area and adjacent waterbodies for spawning (February-June), feeding, migration, and overwintering. In some years spawning occurs in the region north of Unimak Pass and so the pelagic eggs may be initially concentrated adjacent to the study area. Feeding occurs in the bays of Unalaska Island and throughout the study area. In the Bering Sea spawning and feeding migrations tend to be on/off the continental shelf (Maeda 1972, Takahashi and Yamaguchi 1972). Migration between the Bering Sea and the Gulf of Alaska is apparently restricted, as indicated by slight genetic differences between Bering Sea and Gulf of Alaska populations of pollock (Grant and Utter 1980). During winter, the pollock tend to concentrate along the deep outer shelf, extending pelagically into the Aleutian Basin.

Pollock food habits have been summarized by ADFG (1985) as follows. Larvae from the Bering Sea consume mainly copepod nauplii and eggs and adult copepods (especially *Oithona similis*, Clark 1978). Juveniles (less than 35 cm) consume mainly copepods, euphausiids and amphipods. Adults (greater than 35 cm) consume mainly euphausiids, small pollock, and other fish (gadids, cottids, hexagrammids and zoarcids) (Bailey and Dunn 1979). Fish comprise 70% of the diet of adults (Smith et al. 1978).

Factors Affecting Distribution and Abundance

Because of the commercial importance of groundfish, factors affecting their distribution and abundance have received considerable attention (e.g., Alverson et al. 1964; Moiseev 1963; Favorite et al. 1977; Hood and Calder 1981;

Laevastu and Marasco 1982, 1984; Wooster 1983; Favorite 1985; and others). Although a review of these studies and hypotheses regarding population regulation is beyond the scope of this report, discussion of several important features of groundfish populations follow. First, fluctuations in abundance are a comon characteristic of marine fish populations, including groundfish. Fluctuations may be short-term (several years) and long-term (decades), responding to abiotic factors (e.g., water temperature, current patterns) and biotic factors (e.g., food abundance, predation, fishing pressure, changes in migration patterns). These factors, or combinations of factors, occasionally result in the production of a strong year-class of fish for a given species, and this year-class then supports much of the commercial catch of that species for several years. Conversely, a combination of strong biotic factors and poor abiotic conditions could combine to produce a collapse.

Water temperature is a key factor affecting year-class strength. The effect may be direct (e.g., warm temperatures may provide better growing conditions and more food for larval stages) or indirect (e.g., cold temperatures may reduce predator populations—Laevastu and Marasco 1984). Indeed, temperature affects most phases of the life cycle of these fishes. Temperature influences overwintering, migration to spawning grounds, timing of spawning, and all aspects of fish energy budgets (the amount of food ingested, the digestion rate, and general metabolic rate).

Other factors affecting groundfish distributions in the study area include seabed topography and substrate characteristics. Many species are closely associated with the shelf break which is located immediately north and south of the eastern Aleutians. This association might be a preference for a particular water depth, temperature, or substrate; it may be due to increased productivity along the shelf break resulting from upwelling of nutrient-rich water; or it may reflect an "edge effect" where species diversity and abundance is greater at the juncture of different habitats.

Inshore Fishes

The relatively narrow band of water adjacent to the shoreline supports one of the most diverse biological communities in the Unimak Pass environment. In this zone may be found a variety of fishes that demonstrate a great amount of variation in utilization of inshore waters. Included are species that only spawn there, those that only feed there, and those entirely limited to inshore waters. Unlike salmon, herring, and groundfish, this fish community receives little use by man. However, this group merits consideration because of direct trophic links to several commercially-harvested species. Further, as discussed in previous sections, salmon, herring, and some groundfishes may themselves spend considerable periods of time in inshore waters.

Knowledge of inshore fishes in the eastern Aleutians is very limited. Some species are mentioned in early records (Turner 1886, Scheffer 1959, FWS 1974). The most complete listing is provided by Wilimovsky (1964), who collected 103 species in the intertidal zone of the eastern Aleutian Islands. Twenty-seven families of fish were represented, including flounders (8 species), salmonids (6), greenlings (5), rockfishes (4), and cods (4), but sculpins (28) were the dominant group, and Wilimovsky notes, "No other faunae in the world contain such a high proportion of cottoid (sculpin) forms". Hubbard (1964) provides additional information about 33 species from the intertidal waters of Umnak Island.

Simenstad et al. (1977) provide a description of the inshore fishes at Amchitka Island west of the Unimak Pass area; these fish populations probably resemble those in our present study area. These authors describe two inshore communities characterized in the following paragraphs.

Inshore Rock-Algae Community

This community is characterized by a diverse assemblage of fishes intimately associated with the extensive algal growth dominating the rocky nearshore coast. Abundant submarine algal growths cover subtidal rock terraces. Most conspicuous are the dense kelp beds of *Alaria fistulosa* which sometimes extend to the 20–m depth contour; these beds increase the structural complexity of the habitat available to fish. The spatial heterogeneity and diversity of the algal growth and associated food resources are responsible for the abundance and diversity of fishes. Representative fishes in this community are the rock greenling, red Irish lord, northern ronquil, silverspotted sculpin, great sculpin, dusky rockfish, and Pacific cod. For the most part, this assemblage consists of sedentary bottom fishes; however, a few occupy the kelp canopy (dusky rockfish, silverspotted sculpin, and some less abundant snailfish species). Although the latter fishes move freely about the kelp blades either singly (silverspotted sculpin, snailfish) or in schools (dusky rockfish), the bottom-associated fishes appeared restricted to a particular site.

During winter when the kelp forest is greatly thinned, the pelagic fishes descend into the subtidal zone and its lush *Laminaria* growth. Other species also move into deeper water in winter, perhaps to avoid wave action or to follow food resources.

Intertidal Community

These fish inhabit the surge channels and tide pools of the rocky intertidal zone. Although this assemblage can be considered an extension of the inshore rock-algae community, it has some distinctive species. Common fishes in tide pools include the crescent gunnel, high cockscomb, ribbon prickleback, juvenile great sculpin, sharpnose sculpin, and spotted snailfish.

Fish densities in the tide pools averaged 98 fish per 3-6 m^3 tide pool (range 20-250 fish). During high tide when the intertidal zone is flooded, adult rock greenling, anadromous Dolly Varden, and coho salmon are present. This habitat also provides a nursery ground for juvenile fishes. Simenstad et al. (1977) found that the prey of these fishes (amphipods, mysids) play an important role in the transfer of energy from algae-based detritus to the inshore fish community.

Additional information about inshore fishes is available for another region closer to the study area—the northern coastline of the Alaska Peninsula (LGL 1986, Isakson et al. 1986). However, since the habitats there are not similar to those in the Unimak Pass area, it follows that the fish communities and habitat usage are not the same and so these data are not included here. The northern coastline of the Alaska Peninsula consists primarily of exposed sand-gravel beaches in contrast with the generally rocky coastline (interspersed by small sections of beach) of the eastern Aleutian Islands.

METHODS

The forage fish community of the Unimak Pass study area was sampled during three seasonal cruises. These cruises, all using the NOAA ship R/V *Miller Freeman* were as follows:

MF-86-10	18 September 1986-7 October 1986	fall
MF-87-02	14 February 1987-9 March 1987	winter
MF-87-05	21 April 1987-14 May 1987	spring

The sampling design for the overall study consisted of a series of survey lines organized to provide bird and marine mammal transect coverage parallel and perpendicular to isobaths within the study area. Sampling to describe the biotic and physical environment, including forage fish, occurred at stations distributed along the bird and mammal transects, usually where perpendicular and parallel tracks intersected. These stations were occupied the night following completion of the bird and mammal censuses. In most cases fishing occurred in the morning or evening, either just prior to or following the censuses. The locations of sampling stations are shown in Figures 1 - 3.

Sampling for forage fish was done using a Marinovich midwater trawl. The net was 50' long and 33' in diameter. The mesh was graduated (3, 2.5, 2, 1.25") with a 0.5" liner to help retain the small forage fish. This was the same net as was used in the North Aleutian Shelf Ecological Process study (Craig 1987). Captured fish were identified, measured, and weighed.

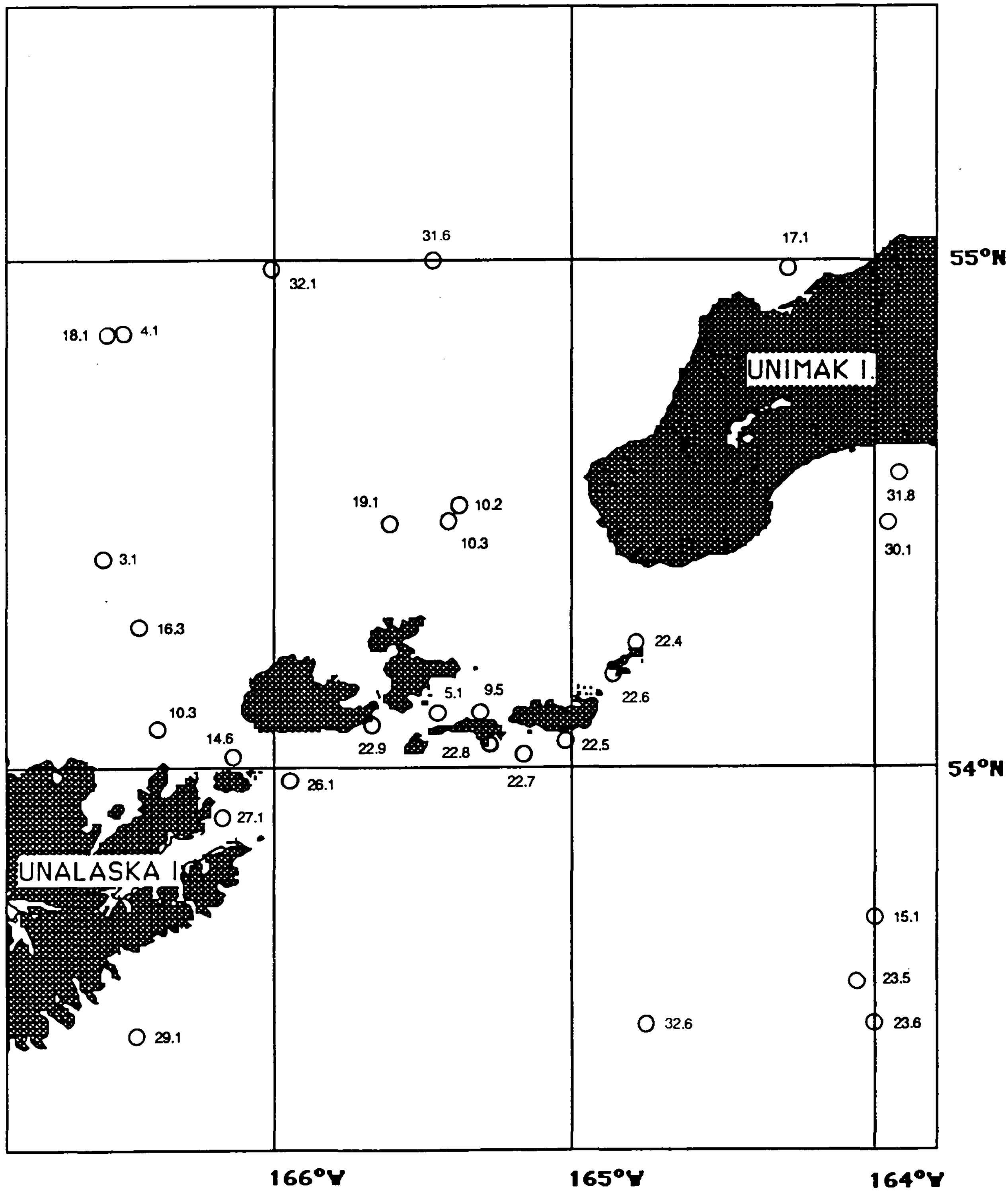

Figure 1. Locations of midwater trawl stations sampled during the fall, 1986, cruise, Unimak Pass area, Alaska. Sampling station numbers are shown.

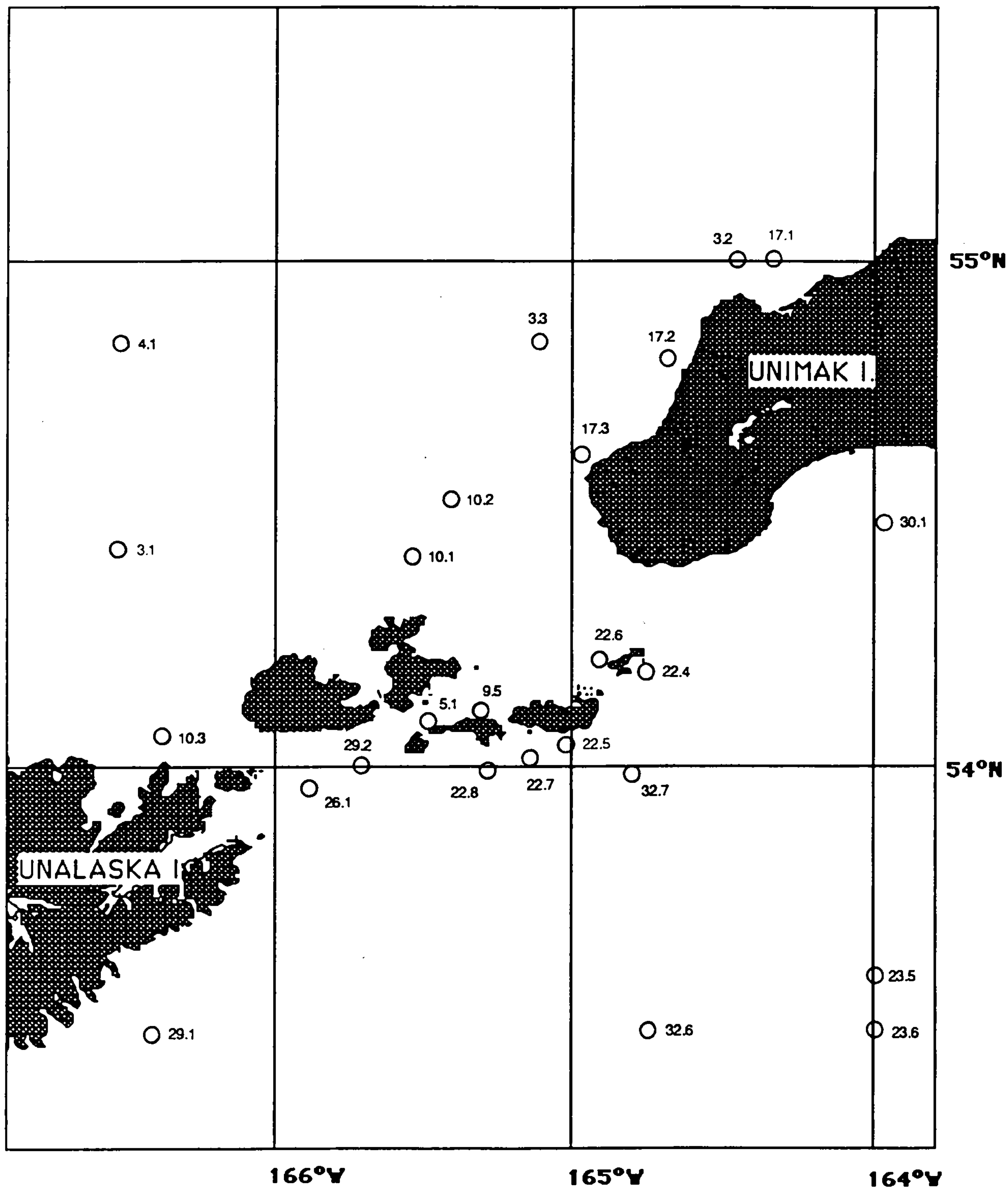

Figure 2. Locations of midwater trawl stations sampled during the winter, 1987, cruise, Unimak Pass area, Alaska. Sampling station numbers are shown.

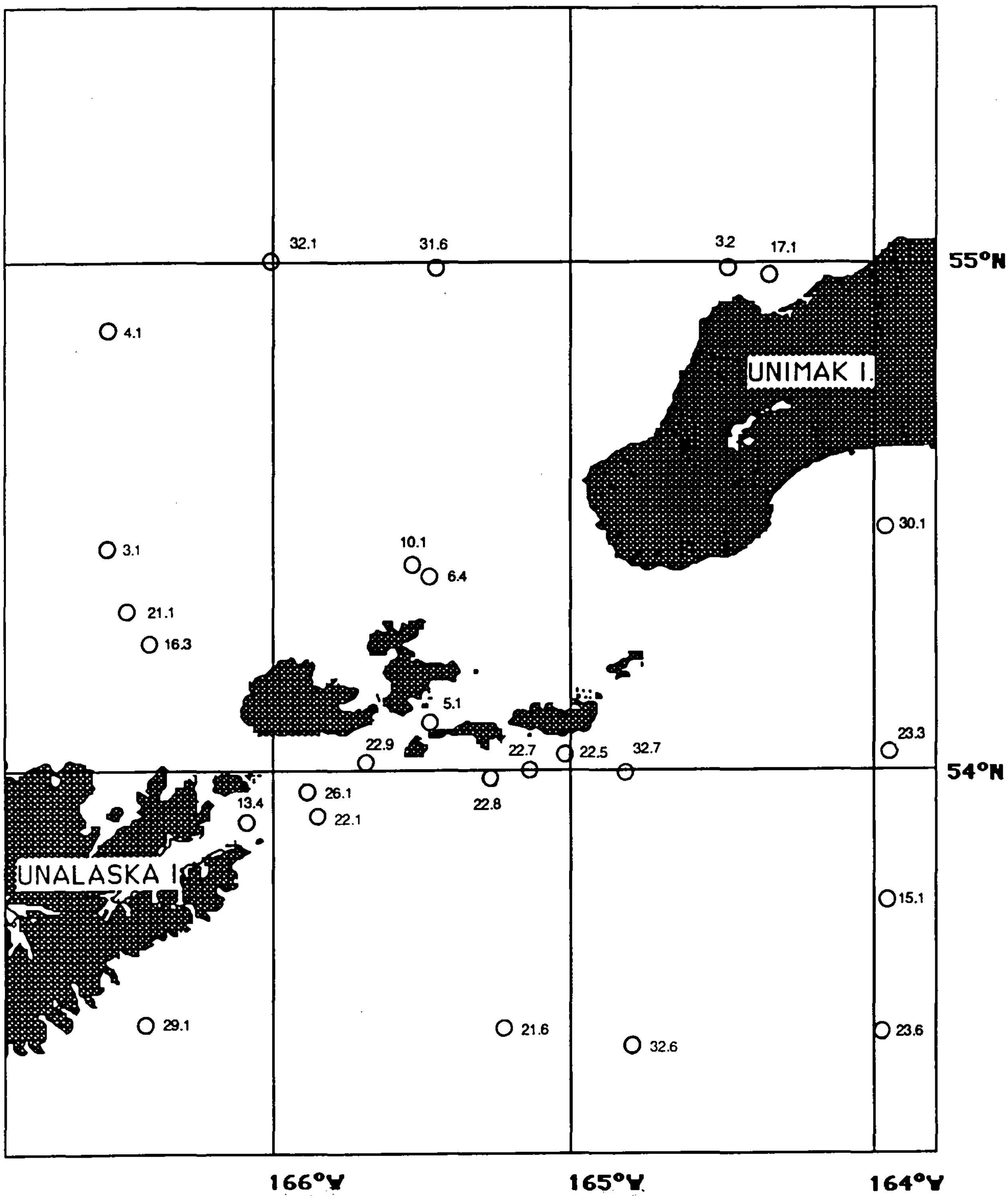

Figure 3. Locations of midwater trawl stations sampled during the spring, 1987, cruise, Unimak Pass area, Alaska. Sampling station numbers are shown.

RESULTS

Fish catches in the Unimak Pass study area varied markedly among seasons and watermasses (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume, for distributions and descriptions of watermasses). Only a few species were ever abundant in catches (Table 1). These were pollock, lanternfishes (multiple species, primarily northern lampfish *Stenobrachius leucopsarus* and bigeye lanternfish *Protomyctophum thompsoni*), and on one occasion the bathylagid northern smoothtongue (*Leuroglossus stilbius*).

Fish catches were at their highest during the fall cruise. Pollock (young-of-year) were the most numerous forage fish available to bird and mammal predators. This prey was most concentrated in the Tidally Mixed Waters (TMW) around the Krenitzin Islands (Fig. 4). Lanternfishes were also caught in abundance, in both the north and south portions of the Gulf of Alaska Water (GAWn and GAWs). These catches were made in the deep-water portions of the study area. The GAWn also yielded good numbers of northern smoothtongues during this cruise.

Fish were more scarce in winter than in fall (Table 1). The only fish species common in any catches in winter were lanternfishes and these were abundant only in the extreme south of the study area in the deep portions of the GAWs. Most of the Bering Sea (Shelf Break Water [SBW] and GAWn) and the waters around the Krenitzin Islands (TMW) were virtually devoid of forage fish (Fig. 5). Fish, primarily pollock, were present in the Alaska Coastal Water (ACWn and ACWs) but most of these fish were too large to be prey to most birds (the average mass of 49 pollock caught was 869 gm). There were, however, small numbers of capelin captured in the ACWs; winter was the only cruise during which this species was captured.

In spring even fewer fish were caught than in winter (Table 1). Only lanternfishes were captured in any abundance and these were restricted to the deep southerly portions of the GAWs (Fig. 6).

DISCUSSION

Patterns of abundance of forage fish were very simple. Lanternfishes were found in moderate abundance at all times only in the deep waters of the Gulf of Alaska and in the deep parts of the Bering Sea during the fall cruise. Small pollock were very abundant during the fall, especially in the mixed waters around the Krenitzin Islands. With these few exceptions, most of the study area appeared to have relatively low abundances of pelagic forage fishes. There were, no doubt, additional fish present on or near the sea floor that were missed by midwater trawls. Indeed the occasional rock dredge or trynet sample taken during the winter cruise produced fish, most commonly flatfish

Table 1. Numbers of fish caught per 30 min haul by trawl, averaged by watermass and season. (SBW=Shelf Break Water, TMW= Tidally Mixed Water, GAW=Gulf of Alaska Water, ACW=Alaska Coastal Water, n=north [Bering Sea], s=south [Gulf of Alaska].).

Fall	N	Squid	Pollock	Myctophid	Bathylagid	Capelin	Other	Total
SBW	6	0.2	26.8	0.0	0.0	0.0	0.5	27.5
TMW	12	0.0	539.8	0.3	0.0	0.0	1.6	541.6
GAWn	3	7.3	0.0	72.0	64.7	0.0	0.0	144.0
GAWs	6	0.5	62.8	28.7	0.0	0.0	0.5	92.5
ACWn	1	0.0	10.0	0.0	0.0	0.0	3.0	13.0
ACWs	1	0.0	10.0	0.0	0.0	0.0	5.0	15.0
Winter								
SBW	1	2.0	0.0	0.0	0.0	0.0	0.0	2.0
TMW	10	0.0	0.1	0.0	0.0	0.0	1.7	1.8
GAWn	3	0.0	0.3	3.0	0.0	0.0	0.3	3.7
GAWs	4	4.0	0.0	50.8	0.0	0.0	0.8	55.5
ACWn	5	0.0	21.6	0.0	0.0	0.0	1.2	22.8
ACWs	2	0.0	36.0	0.0	0.0	6.0	2.0	44.0
Spring								
SBW	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TMW	6	0.0	0.2	0.0	0.0	0.0	5.3	0.3
GAWn	7	0.0	0.7	0.0	0.0	0.0	0.0	0.7
GAWs	8	0.6	0.4	58.6	0.1	0.0	2.4	59.8
ACWn	2	0.0	2.0	0.0	0.0	0.0	6.5	2.5
ACWs	4	0.0	1.0	0.3	0.0	0.0	1.5	1.3

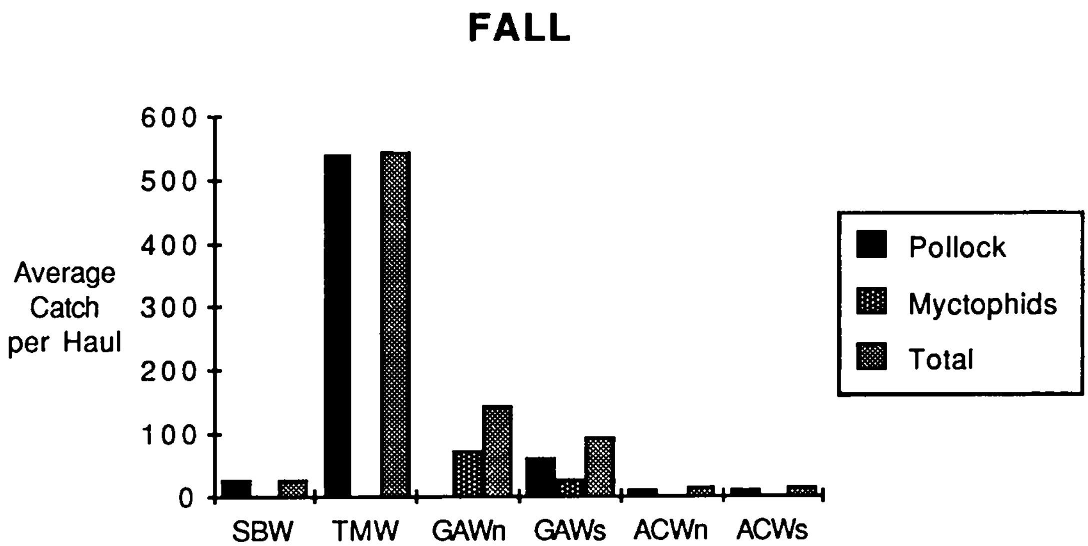

Fig. 4. Catch distribution by water mass of forage fish near Unimak Pass during the fall cruise (SBW=Shelf Break Water, TMW= Tidally Mixed Water, GAW=Gulf of Alaska Water, ACW=Alaska Coastal Water, n=north (Bering Sea), s=south (Gulf of Alaska).

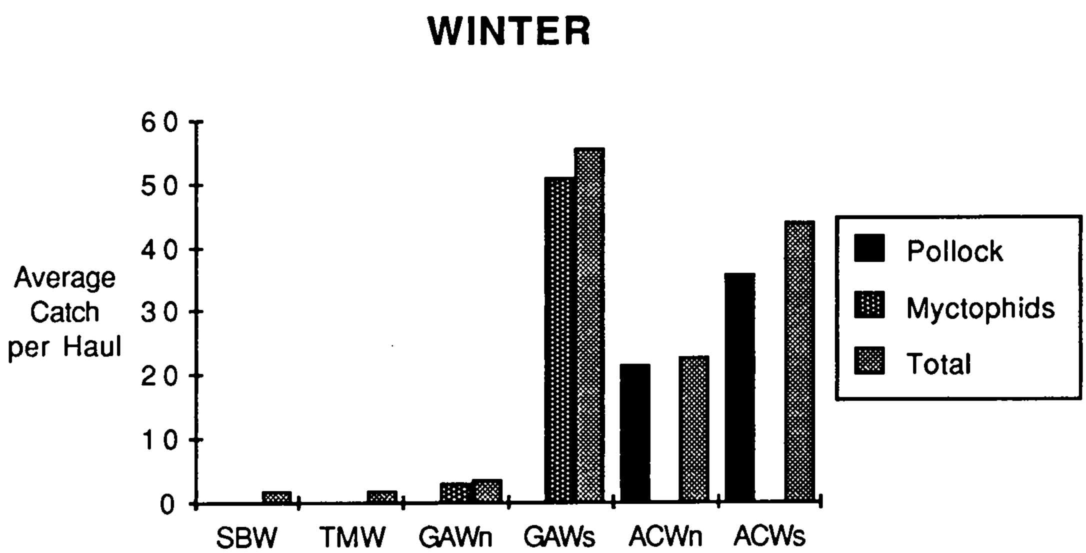

Fig. 5. Catch distribution by water mass of forage fish near Unimak Pass during the winter cruise (SBW=Shelf Break Water, TMW= Tidally Mixed Water, GAW=Gulf of Alaska Water, ACW=Alaska Coastal Water, n=north (Bering Sea), s=south (Gulf of Alaska).

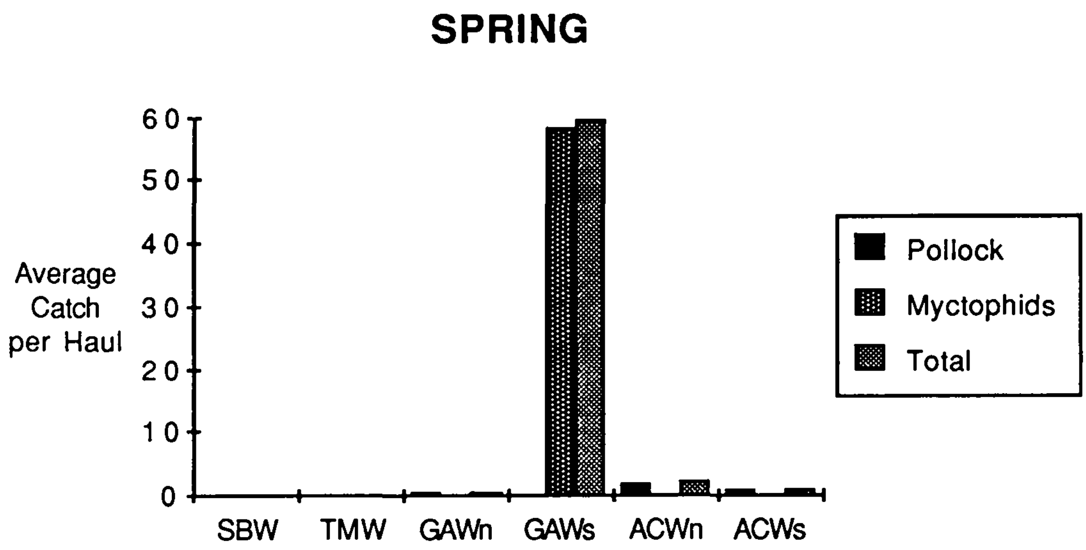

Fig. 6. Catch distribution by water mass of forage fish near Unimak Pass during the spring cruise (SBW=Shelf Break Water, TMW= Tidally Mixed Water, GAW=Gulf of Alaska Water, ACW=Alaska Coastal Water, n=north (Bering Sea), s=south (Gulf of Alaska).

and sand lance. The bottom fish were probably regular prey for birds, such as cormorants, that foraged in shallow water.

This assessment of the availability of forage fish contrasts markedly with the review of existing data provided in the introduction and with the results of similar surveys in the adjacent North Aleutian Shelf (NAS). Some key forage fish that were expected to occur were largely absent from our samples (herring, sand lance, and capelin). The scarcity of these fish in samples was probably caused partly by the lack of sampling in summer, during which time spawning for herring and capelin occurs in the eastern Aleutians. In the NAS herring and capelin were captured in large numbers only in late May through early June (Craig 1987); sand lance occurred in the water column over a longer period but still only during summer. Forage fish were abundant in the Unimak Pass area during the fall, and in the very deep waters (>1000 m) of the Gulf of Alaska throughout the year; at these times forage fish were scarce on the NAS.

Because forage fish were scarce in deep water in much of the study area, there were few instances in which to expect many piscivorous birds or mammals to be present. The young-of-year pollock in the Krenitzin Islands were readily available to seabirds and their location and timing was such that they were present adjacent to the large colonies of Tufted Puffins during the chick-rearing period. Puffins were frequently seen feeding in these areas and monitoring of chick meals at puffin colonies in this area documented that pollock were the predominant prey (S. Hatch, USFWS, pers. comm.). Lanternfish occur regularly in the diets of some seabirds (e.g. Red-legged Kittiwakes) and must come up from depth near or to the surface at times (night), although very few were caught in surface sampling or bongos. Lanternfish vertical migrations are extensive and well documented and their presence in surface waters may have been more prevalent than we documented (Case et al. 1977, Scott and Scott 1988) . There was little indication of an association between seabird distribution and that of lanternfishes. The birds most restricted to the deep waters where lanternfishes occur—albatrosses, Mottled Petrel, Leach's Storm-Petrel—were quite uncommon. Dall's porpoises, which are known to prey extensively on lanternfishes, did have a distribution that reflected the distribution of forage fish; i.e., in winter and spring it corresponded to lanternfish distribution.

RECOMMENDED FURTHER RESEARCH

The data collected during the present investigations indicated that, through most of the study area and during most of the cruises, there were relatively few forage fish available for marine birds and mammals. The diet information collected (see Chapter 5: MARINE BIRD ABUNDANCE AND HABITAT USE, this volume) also indicated that the seabirds present were preying much more heavily on zooplankton than on fish. Therefore, further effort documenting the distribution and abundance of forage fish becomes a rather low priority in terms of research needs in this area. The major exception to this conclusion is that, if a summer sampling period could be arranged, sampling for forage fish would be of value. In the adjacent NAS summer sampling documented a greatly increased availability of forage fish and a corresponding increase in bird use of this resource. Also, capelin abundance in Unimak Pass is reportedly high during the summer and is thought to attract fur seals to this area at that time.

ACKNOWLEDGEMENTS

We are indebted to the the entire crew of the Miller Freeman for their cooperation and assistance in making this study such a success.

We thank CDR Taguchi, who found ways to accommodate our innumerable trips through (and residence in) all passable passes in the Krenitzin Islands. LT Brian Hayden (FOO) made arrangements for all our requests and last-minute changes in plans, allowing us to obtain all our samples where and when we wanted them. We also appreciate his assistance in keying out unusual fish. The persistence of the ship's fishermen is greatly appreciated. They found humor in making repeated attempts to document the absence of small fish even when we could see and ignore the presence of large numbers of larger fish.

The review of fisheries of the Unimak Pass area draws extensively, frequently with little or no modification, from a review by Peter Craig. The portions presented here are for completeness and for the convenience of the reader. We appreciate his thoroughness and organization. Extensive editing of drafts of this chapter were provided by Robert Dillinger and Joe C. Truett.

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Chapter 5

MARINE BIRD ABUNDANCE AND HABITAT USE

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SUMMARY

Seasonal shipboard surveys were conducted to assess abundance and distribution patterns of marine birds in the Unimak Pass area. These patterns were related to marine habitat (water masses) as determined by ancillary environmental sampling. Specimens were collected for dietary analysis. A summary of pertinent findings includes the following:

(1) Overall density of marine birds in this area was highest in winter (425 birds/km^2), intermediate in fall (281 birds/km^2), and lowest in spring (80 birds/km^2).

(2) Fall populations were strongly dominated by Short-tailed Shearwaters, and winter populations by Crested Auklets; during spring, dominance by any single species was less evident than during the previous seasons.

(3) During fall, Short-tailed Shearwaters exhibited the highest densities in Shelf Break Water near the shelf break in the Bering Sea but were also abundant in the Gulf of Alaska Water mass, north of the island chain. These areas of abundance correspond to the north ends of the two major passes in the study area—Unimak and Akutan.

(4) In winter, the Crested Auklet exhibited highest densities in the Alaska Coastal Water mass, north of Unimak Island. An additional major concentration area was located in Akutan Pass.

(5) In spring, abundance of birds was more equitable among water masses than was observed during other seasons, but bird densities were low overall.

(6) A main finding of the dietary analyses was the importance of *Thysanoessa* euphausiids to marine birds, including Short-tailed Shearwaters and Whiskered Auklets during the fall, Whiskered Auklets and Common Murres in winter, and Whiskered Auklets in spring. This study contributed substantially to the known food habits of Whiskered Auklets.

(7) Of the five species subjected to dietary analyses, only Tufted Puffins did not use euphausiids to a significant degree. The puffins collected had fed largely upon *Gonatus* squid in fall and *Ammodytes* fish during spring. Near the breeding islands they were known to prey primarily on juvenile pollock.

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INTRODUCTION

Unimak Pass is one of the major migration corridors for bird populations entering and leaving the Bering Sea (Strauch and Hunt 1982, Thorsteinson 1984). The abundance of birds in the Unimak area is so large and regionally important that potential impacts in this area (resulting from increased vessel traffic) are listed as being of concern even for developments spatially removed, such as the Navarin Basin. An estimate of 1.1 million shearwaters in the pass has been made in the fall (see Armstrong et al. 1984). The mean density of all species using the pass in summer was estimated by Strauch and Hunt (1982) to be 224 birds/km^2 or 720,000 birds in the pass area. Hunt et al. (1982) identified the Unimak Pass area as one of the regions in the southeastern Bering Sea with consistently highest densities of seabirds and thus potentially of great sensitivity with respect to oil spills.

The purpose of this study was to conduct systematic shipboard surveys to determine marine bird use of the Unimak Pass area. While the study largely constituted a descriptive effort, the objectives were to relate temporal and spatial habitat use patterns of marine birds to water masses and available prey densities. In this chapter we present a synthesis of available information pertaining to key species and species groups of marine birds, descriptors of habitats used by these organisms in time and space, and food habits information.

CURRENT STATE OF KNOWLEDGE

General

Regional summaries of seabirds in or near the area of interest have been compiled for the Unimak Pass area (LGL 1986), North Aleutián Shelf (Armstrong et al. 1984), and St. George Basin (Strauch and Hunt 1982). The most comprehensive study of breeding seabirds in the area is that of Nysewander et al. (1982). Summaries of the status of breeding colonies were obtained from the USFWS seabird colony database (provided by Art Sowls). Similarly, updated pelagic seabird summaries were obtained from the pelagic seabird database (provided by D. Forsell, USFWS). Additional unpublished data were obtained from the North Aleutian Shelf (NAS) Ecological Process Study (Troy and Johnson 1987). Much of the life history information for seabirds in the Bering Sea (presented below) was summarized from Lewbel (1983). The available literature emphasizes insular areas and the Bering Sea portion of the study area. Relatively little information exists for the Gulf of Alaska south of the Krenitzin Islands.

The Unimak Pass area has been envisioned by some as filling an important trophic role for birds in the Bering Sea ecosystem. Although only about 0.03% of the midshelf primary productivity is funnelled into birds

(Schneider and Hunt 1982), their consumption of particular resources (e.g., walleye pollock) may be substantial. Armstrong et al. (1984) reasoned that the impact of birds on pelagic prey resources was probably greatest at a few specific areas, one being Unimak Pass.

Two species of endangered birds—Aleutian Canada Goose and Short-tailed Albatross—have been found within the Unimak Pass/eastern Aleutian Islands area. The Short-tailed Albatross occurred regularly in this area before its population was reduced to the brink of extinction. Bones of this species are found in archaeological diggings in our study area (e.g. Rauzon 1976, Yesner and Aigner 1976). A juvenile Short-tailed Albatross was reported NW of Akutan Island (at 54°29'N, 166°13'W) as recently as August 1985 (see Gibson 1985). Neither species is known to breed in the study area (it is quite distant from the historical breeding distribution of Short-tailed Albatross) nor does the study area contain areas of regular use. Aleutian Canada Geese have been encountered during the breeding season on Aiktak Island in 1981 and 1982, but evidence of nesting has not been found (Forsell 1983a,b). An estimated 50 pairs of Aleutian Canada Geese nest on Chagulak Island just west of our area of interest (Bailey and Trapp 1984), and another small isolated population occurs on Kaliktagik Island east of Unimak Pass (Hatch and Hatch 1983).

High densities of seabirds, generally resulting from large aggregations, are frequently found in and near Unimak Pass. Surveys show that Glaucous-winged Gulls, auklets (primarily Crested Auklets), shearwaters (primarily Short-tailed Shearwaters), Common Murres, and Black-legged Kittiwakes are the most numerous species (Table 1).

Abundance varies markedly with season (Tables 1 and 2). For example, kittiwakes and shearwaters peak during summer; Crested Auklets and murres peak during winter. Birds relatively numerous through most of the year are Glaucous-winged Gull, Northern Fulmar, Black-legged Kittiwake, cormorants (Red-faced), and auklets.

Shipboard transect results, as contained in the USFWS pelagic database (Table 2), show some important characteristics of the eastern Aleutian area by virtue of including transects between islands and within some smaller passes. Of particular interest is the high densities of small alcids, particularly Whiskered Auklets. These transects were censused opportunistically, often while observers ferried between specific areas, and do not permit a rigorous comparison for either temporal or spatial trends.

Approximately 1.1 million seabirds attend nesting colonies in the Fox Islands (Table 3). The predominant nesting species are Tufted Puffin, Fork-tailed Storm-Petrel, and Leach's Storm-Petrel. This total includes about 50% of the Alaska population of Whiskered Auklet (*Aethia pygmaea*) and about 45% of the Alaska population of Tufted Puffin (*Fratercula cirrhata*). The composition of the breeding seabird community in this area differs markedly

Table 1. Densities of marine birds (#/km^2) in Unimak Pass area, Alaska (Cape Mordvinof to Akun Island) recorded during North Aleutian Shelf aerial surveys (data from work of Troy and Johnson 1987).

SPECIES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Red-throated Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Pacific Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Common Loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
loon	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
grebe	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Northern Fulmar	0.9	2.2	1.3	0.3		0.2		2.0		5.2	0.0	0.1
shearwater-dark	0.0	0.0	0.0	0.0		64.5		46.5		0.2	0.0	0.0
Fork-tailed Storm-Petrel	0.0	0.0	0.0	0.0		1.5		0.5		0.2	0.0	0.0
cormorant	3.2	0.3	0.0	0.2		1.0		2.4		1.5	3.5	0.3
Emperor Goose	0.0	0.0	0.0	0.3		0.0		0.0		0.0	0.0	0.0
Brant	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Mallard	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Common Eider	0.5	0.2	0.0	0.0		0.0		0.0		0.0	0.0	0.0
King Eider	0.7	3.8	0.2	0.7		0.0		0.0		0.0	0.0	1.2
Steller's Eider	0.1	1.1	0.1	0.0		0.0		0.0		0.1	0.0	0.9
Harlequin Duck	0.0	0.0	0.0	0.1		0.0		0.0		0.0	0.3	0.0
Oldsquaw	0.0	2.3	0.6	0.4		0.0		0.0		0.0	0.0	0.4
scoter	2.7	1.0	1.8	1.0		0.0		0.0		0.0	0.1	0.3
Red-breasted Merganser	0.0	0.0	0.0	0.0		0.3		0.0		0.0	0.0	0.0
duck	0.0	0.0	0.3	0.0		0.2		0.0		0.0	0.0	0.0
Bald Eagle	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Rock Sandpiper	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
small sandpiper	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
phalarope	0.0	0.0	0.0	0.0		0.0		0.9		1.0	0.0	0.0
shorebird	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
jaeger	0.0	0.0	0.0	0.0		0.0		0.1		0.0	0.0	0.0
Bonaparte's Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Mew Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Herring Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Glaucous-winged Gull	5.5	31.6	18.2	19.8		2.0		75.9		13.8	131.6	3.7
Glaucous Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Black-legged Kittiwake	0.0	0.1	0.4	3.2		5.7		11.7		5.0	0.1	0.1
Sabine's Gull	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
tern	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Murre	0.6	67.3	1.0	14.8		0.1		0.2		0.1	0.1	0.1
Pigeon Guillemot	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
murrelet	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
auklet	71.3	0.0	8.1	80.7		0.2		0.2		0.1	2.8	9.0
Tufted Puffin	0.0	0.0	0.0	0.0		0.6		4.2		0.0	0.0	0.0
Horned Puffin	0.0	0.0	0.0	0.1		0.0		0.0		0.0	0.0	0.0
alcid	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Common Raven	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Snow Bunting	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
passerine	0.0	0.0	0.0	0.0		0.0		0.0		0.0	0.0	0.0
TOTAL	85.7	110.0	32.2	121.6		76.3		144.6		27.2	138.7	16.2

Table 2. Densities of marine birds (#/km2) in the Unimak-Krenitzin Islands area, Alaska (FWS seabird colony database).

SPECIES	April-May	June-Aug	Sept-Oct	Nov-March
loons				0.05
Black-footed Albatross			0.06	
Northern Fulmar	0.56	4.91	15.43	1.16
total shearwaters	0.19	829.08	418.76	0.38
Fork-tailed Storm-Petrel		1.62	0.77	0.12
total cormorants	1.51	0.77	0.21	1.48
duck-goose	0.01			0.03
Oldsquaw	2.99			0.03
Harlequin Duck				0.13
Black Scoter				0.05
White-winged Scoter			0.01	
eider	0.36			
total phalaropes	2.43	4.39	0.56	0.00
total jaegers		0.18	0.01	
gull		0.08		0.03
Glaucous Gull		0.01		
Glaucous-winged Gull	0.94	1.24	3.47	5.70
Thayer's Gull		0.00		
kittiwake		0.47	0.78	4.64
Black-legged Kittiwake	0.49	0.52	2.24	0.45
Red-legged Kittiwake		0.01	0.03	
Arctic Tern		0.00	0.07	
alcid	1.87	1.35	2.07	3.85
small alcid	0.16	2.32		
small dark alcid	0.12			
total murres	18.60		2.92	11.74
Pigeon Guillemot	0.22	0.10		
Ancient Murrelet	1.36	1.17	0.33	
Cassin's Auklet	0.21	0.06	0.06	
Parakeet Auklet	0.02	0.00	0.31	0.16
auklet	0.60			
Crested Auklet	0.18	0.02	0.58	30.63
Least Auklet	2.60	0.49		0.18
Whiskered Auklet	11.31	3.27	0.01	
Horned Puffin	0.10	0.48	0.65	0.47
Tufted Puffin	25.64	25.28	4.09	0.42
TOTAL	72.47	877.82	453.42	61.70
Number of Transects	67	103	39	24
Area Sampled (sq. km)	82.3	126.4	220.5	37.9

Table 3. Seabird colonies of the eastern Aleutian Islands and Unimak Pass area, Alaska. Values listed are the most representative estimates in the FWS Alaska seabird colony database (ID numbers given in column headings). Asterisks denote possible nesting but population size unknown.

SPECIES	23-002 Unalga Island	23-004 South Amaknak Island	23-005 Egg Island	23-015 Triangle Ear	23-018 West Hive Bay	23-019 East Hive Bay	23-020 South-west Udagah	23-043 Eider Point
Fork-tailed Storm-Petrel	*		200000					
Leach's Storm-Petrel	*		70000					
Cormorant	52							
Double-cr Cormorant	250		82	6				
Pelagic Cormorant				2		8	*	
Red-faced Cormorant	144		488			6	18	30
Common Eider	50							
Black Oystercatcher			14					
Glaucous-winged Gull			1346	140				
Pigeon Guillemot	135	*	350				*	
Ancient Murrelet			5000					
Cassin's Auklet			2000					
Whiskered Auklet			10					
Horned Puffin	189	20	*	65				
Tufted Puffin	35		163316		130		270	
TOTAL	855	20	442606	213	130	14	288	30

SPECIES	23-045 Hog Island	23-046 Tanaskan Bay Island	23-047 Dushkot Island	23-048 Round Island	23-049 Islet at North Sedanka Island	23-050 Old Man Rock	23-051 Cape Morgan	23-052 Reef Point
Double-cr. Cormorant					72		46	8
Pelagic Cormorant					6			
Red-faced Cormorant					*	2	784	1036
Black Oystercatcher		21	7	4				
Glaucous-winged Gull	200	180	800					4
Black-legged Kittiwake			32					
Pigeon Guillemot	142	198	96	86			20	34
Horned Puffin	54						4	6
Tufted Puffin		3106	3645	11504	130		1000	
TOTAL	396	3505	4580	11594	208	2	1854	1088

Table 3 (cont.)

SPECIES	23-053 Lava Point	23-054 Kiliuik Bay & Nest Rock	23-055 Kisselen Bay	23-056 Eriskine Bay	23-057 McIver Bight Island	23-058 Mist Triangle	23-059 Auket Island
Fork-tailed Storm-Petrel							200
Leach's Storm-Petrel							300
Pelagic Cormorant						42	
Red-faced Cormorant	1408						
Black Oystercatcher		7	17	5			6
Glaucous-winged Gull	6	32	150	16			
Black-legged Kittiwake			28				
Pigeon Guillemot		4		42			30
Ancient Murrelet							200
Cassin's Auklet							3500
Horned Puffin	32			36			*
Tufted Puffin			112	100	40		41696
TOTAL	1446	43	307	199	40	42	45932

SPECIES	23-060 Tangagm Island	23-061 Excelsior Island	23-062 Adokt Island	23-063 Koschekt Island	24-001 Rootok Island	24-003 Mt. Gilbert Akun Island	24-004 2.5 mi North Sennet Point	24-005 Scotch Cap Rock
Fork-tailed Storm-Petrel	1500	2000	1000	2500	*			
Leach's Storm-Petrel	1500	2500	1000	2500	*			
Double-cr. Cormorant					20	6		
Red-faced Cormorant	*	98	142		68	150	30	200
Black Oystercatcher	16	12	28	26		2		
Glaucous-winged Gull		30	60	130	20	200		
Common Murre		12						
Pigeon Guillemot	150	115	70	34	8			
Ancient Murrelet	600	400	700	300				
Cassin's Auklet		2000	40					
Whiskered Auklet	2	4	*	2				
Horned Puffin			40	*	74			
Tufted Puffin	27331	40201	25492	10998				
TOTAL	31099	47372	28572	16490	190	358	30	200

Table 3 (cont.)

SPECIES	24-006 Sealion Point	24-007 Cave Point	24-008 Cape Mordvinof	24-009 Derbin Island	24-010 Tigalda Island	24-011 Ugamak Island	24-012 Kaligagan Island	24-013 Cape Luke
Fork-tailed Storm-Petrel				600	*		7500	
Leach's Storm-Petrel				800	*		5500	
Cormorant			*					
Double-cr. Cormorant	*			108				
Pelagic Cormorant	50							
Red-faced Cormorant	560	1000	*		164		280	60
Common Eider					10			
Black Oystercatcher				12	*	4		
Glaucous-winged Gull				1318	100		2000	
Black-legged Kittiwake			*					
Aleutian Tern			*					
Common Murre				23			300	
Pigeon Guillemot				34	270	142	328	
Ancient Murrelet				100			1000	
Cassin's Auklet							50	
Whiskered Auklet				4	*		18	
Horned Puffin			*	6	304	268	20	*
Tufted Puffin	30		*	9485	*	130	111082	*
TOTAL	640	1000	0	12490	848	544	128078	60

SPECIES	24-014 Slice Island	24-015 Derbin Strait Islets	24-016 Tanginak Island	24-017 Tangik Island	24-018 Puffin Island	24-019 Poa Island	24-020 Jackass Point	24-021 South Island, Akun Strait
Fork-tailed Storm-Petrel	*		*	4500	800	5000	*	
Leach's Storm-Petrel	*		*	300	100	700	*	
Double-cr. Cormorant			8				214	
Pelagic Cormorant			245					
Red-faced Cormorant			455	38			98	
Black Oystercatcher				16	6	15	*	
Glaucous-winged Gull			182	350		1060	163	
Black-legged Kittiwake			346					
Common Murre			880					
Thick-billed Murre			220					
Pigeon Guillemot		122	12	18	45	15		
Ancient Murrelet				350	200	1000		
Whiskered Auklet	*		*	10	10	25		4
Horned Puffin	*		4					
Tufted Puffin	260	130		20228	35374	33484	340	
TOTAL	260	252	2352	25810	36535	41299	815	4

Table 3 (cont.)

SPECIES	24-022 North Island, Akun Strait	24-023 Surf Bay Islets	24-024 Akun Head	24-025 Pinnacle by Little Bay	24-026 Kaligagan Islets #2	24-027 Kaligagan Islets #3	24-028 Kaligagan Islets #6
Fork-tailed Storm-Petrel	200				600		*
Leach's Storm-Petrel	*				300		*
Double-cr. Cormorant			24				
Red-faced Cormorant	10	4	210	12			8
Common Eider		*					
Black Oystercatcher	10	2			14	1	
Glaucous-winged Gull		90	15	27	44	54	167
Aleutian Tern		*					
Pigeon Guillemot	162	4			30	40	
Ancient Murrelet	400				500		*
Cassin's Auklet	*				300		*
Parakeet Auklet	*						
Whiskered Auklet	4	*			10		*
Horned Puffin	8	*					2
Tufted Puffin	53372		306	196	15198		668
TOTAL	54166	100	555	235	16996	95	845

SPECIES	24-029 Kaligagan Islets #4	24-030 Kaligagan Islets #1	24-031 Kaligagan Islets #5	24-032 Aiktak Island	24-033 Round Island	24-034 Don Pinnacle Ugamak	24-035 Battery Point
Fork-tailed Storm-Petrel		36		15000	*	*	
Leach's Storm-Petrel		40		8500		*	
Double-cr. Cormorant				84			30
Pelagic Cormorant				62			
Red-faced Cormorant			28	1588			192
Common Eider							*
Black Oystercatcher	2	8		49			
Glaucous-winged Gull	30		60	2750	126		60
Common Murre			55	12600			22
Thick-billed Murre				2400			
Pigeon Guillemot	50	132	12	68			*
Ancient Murrelet		*		1000			
Cassin's Auklet		100		*			
Whiskered Auklet		8		6	*	*	
Horned Puffin				32			130
Tufted Puffin		5508	260	102428	262	1000	
TOTAL	82	5832	415	146567	388	1000	434

Table 3 (cont.)

SPECIES	24-036 Talus Point	24-037 Akutan Harbor Islets	24-038 Akutan Point	24-039 North Head	24-040 Pt 2 km east of Light	24-041 Light	**TOTAL**
Fork-tailed Storm-Petrel							**241436**
Leach's Storm-Petrel							**94040**
Cormorant					*	*	**52**
Double-cr. Cormorant			4				**962**
Pelagic Cormorant			4				**419**
Red-faced Cormorant	108		636	90			**10145**
Common Eider							**60**
Black Oystercatcher	*						**304**
Glaucous-winged Gull		44					**11954**
Black-legged Kittiwake							**406**
Aleutian Tern							**0**
Common Murre							**13892**
Thick-billed Murre							**2620**
Pigeon Guillemot	*	58					**3056**
Ancient Murrelet							**11750**
Cassin's Auklet							**7990**
Parakeet Auklet							**0**
Whiskered Auklet			2				**119**
Horned Puffin	65	24	66				**1449**
Tufted Puffin		40	2500				**721387**
TOTAL	173	166	3212	90	0	0	**1122041**

from that of many areas in Alaska, particularly elsewhere in the Bering Sea, in that murres and kittiwakes are a minor component. Rather, burrowing seabirds and notably nocturnal species (storm-petrels, Ancient Murrelet, Cassin's Auklet) are numerically dominant.

Detailed work on the breeding biology of birds in this area is lacking; however, seabirds are probably present on the colonies from at least April through November. Egg laying probably commences during May and hatching in late June. Fledging of Leach's Storm-Petrels (*Oceanodroma leucorhoa*) and Tufted Puffin may occur as late as October or November. Many aspects of the seabird colonies in this area are more fully discussed in Chapter 8 (SEABIRD COLONIES) of this volume.

The waters around the eastern Aleutians are especially important to nesting birds. In this area seabirds have short flying times to a variety of marine environments, including a broad continental shelf, a precipitous shelf break, and deep oceanic expanses. In addition, the eastern Aleutians have many deep and protected bays and inlets, and a tidal flow which creates rip tides within the straits and passes.

Key Species and Groups

In this section we summarize some of the available survey information for key study species. As in most survey programs such as this all species encountered were recorded. Nonetheless, it was important to identify the key species so that the study design could be optimized for them. The spatial distribution of sampling effort in an area as diverse as our study region can greatly influence resultant abundance indices and their comparability with neighboring and future efforts. To select key study species required a close examination of the existing data in the context of study objectives.

Examination of Tables 1 and 2 reveals that meaningful attempts to rank species in importance (using abundance as a measure of importance) is not an easy task. Differing lists can be derived based on survey type (ship vs. aerial), season, or abundance criteria (maximum vs. average). Based on the aerial surveys and using maximum abundance as the selecting criterion the five key species groups would be Glaucous-winged Gull, auklets (Crested), shearwaters (Short-tailed), murres (Common), and Black-legged Kittiwake. If persistence is incorporated as a selection criterion this list is changed to Glaucous-winged Gull, Northern Fulmar, Black-legged Kittiwake, cormorants (Red-faced), and auklets (Crested). The differences between these lists reflects the changing composition of the region's avifauna. Species such as the shearwaters and murres reach very high densities but only for short portions of the year (shearwaters in summer, murres in winter). Inclusion of Northern Fulmar and cormorants in the second list reflects their year-round residence in the study area at, on average, moderate levels of abundance.

The shipboard surveys indicate a somewhat different list of key species. Based on maximum densities, the five most numerous species are shearwaters, Tufted Puffin, murres, Northern Fulmar, and Crested Auklet. Only maximum density was used in this selection as ship surveys did not have the same temporal coverage in the study area as aerial surveys. Differences in shipboard vs aerial studies probably reflect a combination of disparities in spatial and temporal coverage. Shipboard work emphasizes the spring/summer period when species such as shearwaters dominate the avifauna. Coverage by the shipboard work also ranged further west than the aerial surveys, thus sampling a somewhat different region. Finally, the aerial surveys permit sampling closer to shore, accounting for the higher abundance of coastal species such as gulls and cormorants than have been observed in the farther-offshore shipboard surveys.

Agency objectives and scientists' opinions strongly influenced key species selection. The solicitation for this study listed alcids and seaducks as groups on which to focus. The discussion above listed several alcids occurring in abundance in the study area, but no seaducks. Seaducks are shown in Table 1 to be an important component of the winter avifauna; as a group, they tend to remain in coastal areas and are only infrequently encountered in high numbers during shipboard surveys (e.g., Table 2). Focal species identified at the MMS-sponsored conference on Monitoring Seabird Populations (November 1984) were murres, Tufted Puffins, Whiskered Auklets, and seaducks; the table summary also listed Glaucous-winged Gull. This source adds Whiskered Auklets to the list of birds already under consideration. Whiskered Auklets reached appreciable densities on some cruises (Table 2) in the area, but available data did not indicate that this species was a dominant component of the avifauna. This species is of interest because of its restricted distribution (more or less endemic to the Aleutians) and relative abundance in our study area.

The Short-tailed Albatross, an endangered species, has been recorded within our study area. Findings of bones by archaeologists in middens indicate that this species was relatively numerous in the area in the past. Sightings of this species away from its breeding island are quite rare but some have been made within our study area, but the probability of encounter is so slight that study designs should not be altered to learn more about this species.

Combining all these measures of importance is a subjective endeavor. In doing so, we have given greatest weight to the objectives identified in the solicitation for this study, followed by the suggestions of the monitoring conference, and finally to abundance based on existing survey data. The target groups resulting from this subjective process are:

- seaducks
- Whiskered Auklet
- Crested Auklet
- shearwaters
- murres
- Tufted Puffin
- Glaucous-winged Gull

Below are brief accounts of the life histories of these species or groups as well as some additional species that figure prominently in the study results.

Northern Fulmar (*Fulmarus glacialis*).

The Northern Fulmar occurs year-round in the Unimak Pass area. The eastern Bering Sea population is estimated to be near one million and is concentrated at a few breeding locations (Sowls et al. 1978). All but a few thousand breed in three areas: Chagulak Island in the Aleutians, the Pribilof Islands, and St. Matthew/Hall islands. No fulmars are known to nest in the Krenitzin Islands.

During the summer fulmars at sea are concentrated along the shelfbreak and outer shelf near the Pribilof Islands and south to Unimak Pass, often in close association with fishing fleets. They are markedly less common in the shallow waters of Bristol Bay and the inner shelf (Hunt et al. 1981c). In winter, most fulmars leave the Bering Sea for the north Pacific; however, some are still present in ice-free waters north and west of the Pribilof Islands and towards Unimak Pass. Birds from many areas, particularly northern colonies, use the pass as a migration corridor. Fulmar numbers are generally lower in the pass area than in the shelfbreak waters to the northwest and southeast. Murie (1959) suggested that fulmars in the Aleutian Islands are most abundant in rip tide areas and offshore of their breeding colonies. Cahn (1947) also mentioned congregations of fulmars within the passes of the eastern Aleutians, especially during late summer and winter. Densities may reach up to 17 birds/km^2 in Unimak Pass in the fall (Gould 1982)

Fulmars feed by surface-seizing (Ashmole 1971). They prey on cephalopods, crustaceans and fish. Fulmars have become habituated to scavenging fish offal from fishing vessels as a major food source (Hunt et al. 1981c).

Short-tailed (*Puffinus tenuirostris*) and Sooty Shearwaters (*P. griseus*).

Both of these species occur in the study area. Unfortunately, they cannot be consistently differentiated during pelagic surveys and many identifications are suspect. Because of this, specific areas of abundance for each species are difficult to delimit. In general it appears that Sooty Shearwaters are most abundant in the Gulf of Alaska whereas most Short-tailed Shearwaters occur within the Bering Sea. There is a zone of overlap in the southern Bering Sea and both species occur in our area of interest. Reported densities and distributions of shearwaters in the Bering Sea, in which species are not named, usually reflect movements of Short-tailed Shearwaters because this species probably accounts for >90% of all shearwaters in that area (e.g., Troy and Johnson 1987).

Unlike other key species, these shearwaters nest in the southern hemisphere and migrate to the North Pacific for the northern summer (their nonbreeding season). From May through September the Short-tailed Shearwater is the most abundant species in the Bering Sea. They are typically found over the continental shelf, with only moderate numbers occurring over the shelf break. In the Bering Sea they are frequently concentrated near and within the 50-m isobath. Flocks of at least 100,000 are common, and flocks of over 1,000,000 have been reported. Concentrations of over 1,000,000 shearwaters have been recorded feeding in Unimak Pass in July and movements in excess of 25,000 birds/hour over several hours have been recorded during April and May (FWS, unpubl. data).

Although frequent mention is made of large numbers of shearwaters in association with Unimak Pass, other passes in the area are also used and/or transited by these species. Guzman (1981) mentions major concentrations at Akutan Pass and Trapp (1975) describes movements in Baby Pass.

Shearwaters feed mainly by pursuit diving but also exhibit surface seizing feeding behavior (Hunt et al. 1981a). They probably feed entirely within the upper 5 m of the water column. In the North Aleutian Shelf study area (slightly overlapping the east portion of the present study area), Short-tailed Shearwaters were found to prey largely on euphausiids and sand lance with the proportions varying seasonally (Troy and Johnson 1987).

Fork-tailed Storm-Petrel (*Oceanodroma furcata*).

Both the Fork-tailed Storm-Petrel and the Leach's Storm-Petrel (*O. leucorhoa*) nest in the Aleutians in large numbers (Sowls et al. 1978). Leach's Storm-Petrels are rarely seen in the Bering Sea except at the breeding colonies; they apparently forage to the south of the Aleutian chain in deep oceanic waters of the North Pacific (Hunt et al. 1981c).

Fork-tailed Storm-Petrels are restricted to the Pacific Ocean. They breed from the Kurile Islands through the Aleutians, along the southern and southeastern coasts of Alaska, and south to northern California (Sowls et al. 1978). Nesting populations in the Aleutians may be on the order of three million birds, based on the estimate by Sowls et al. (1978). However, the currently documented breeding population is only 875,000.

Fork-tailed Storm-Petrels are quite commonly sighted in Bering Sea waters. Aerial and shipboard surveys by Hunt et al. (1981c) and Gould et al. (1982) suggest a summer population on the order of three to six million storm-petrels feeding in the eastern Bering Sea. The pelagic distribution of Fork-tailed Storm-Petrels during the summer is as follows: storm-petrels are rarely found north of 58 degrees (Hunt et al. 1981c) and are most numerous at the shelfbreak and on the outer shelf (Hunt et al. 1982). Although absolute densities over deep oceanic waters are lower than at the outer shelf and the shelf break, Fork-tailed Storm-Petrels are among the most numerous birds in deep water areas. In a winter survey in the southeastern Bering Sea, Fork-tailed Storm-Petrels were seen only over deep waters (Hunt et al. 1981c).

Fork-tailed Storm-Petrels feed by surface-seizing or pattering on the surface (Hunt et al. 1981c) and probably feed at night, at least during the breeding season (Quinlan 1979). Food habits are poorly known, but squid, fish, euphausiids and fish offal are eaten by adults (Day 1980, Hunt et al. 1981a). Invertebrates brought to chicks by adult storm-petrels at Wooded Islands included calanoid copepods, euphausiids, gammarid amphipods, cephalopods, and shrimp (Quinlan 1979). Fish found in these food loads included cottids, gadids, myctophids and scorpiniformes (Quinlan 1979).

Red-faced Cormorant (*Phalacrocorax urile*).

Red-faced, Pelagic (*P. pelagicus*), and Double-crested cormorants (*P. auritus*) all occur in the area of interest, but the Red-faced Cormorant predominates. Nelson (1976) estimated the three species occurred in a 6:2:1 ratio at Unimak Island during the fall but their abundance as breeding birds in the area of interest is roughly 20:1:2 (Table 3). Red-faced Cormorants nest on cliffs; in the Pribilofs they are restricted to portions of cliffs less than 200' (Hickey 1976, Troy and Baker 1985). Nests are constructed at least partially of seaweed.

Red-faced Cormorants are probably year-round residents through most of their range, although some movement is evident in the Aleutian Islands because their population levels are lower in the winter than during the breeding season (Byrd et al. 1980). A southward movement of cormorants, predominantly Red-faced, was recorded through Unimak Pass from 7 April to 26 May 1976 (Nelson and Taber, FWS, unpubl. data). Gill et al. (1979) thought it unlikely that this was the result of cormorants wintering in the Bering Sea, but other surveys (LGL 1986) suggest that cormorant densities in northern Unimak Pass peak during winter (Table 1).

Cormorants feed near shore and are seldom seen more than a few km from their breeding colonies during the nesting season. A few are seen in small numbers in the open ocean during spring and fall (Hunt et al. 1981c, LGL 1986). Their feeding method is pursuit-diving (Ashmole 1971). Fish are the primary prey, but decapods (shrimp and crab) and amphipods are also eaten. Sculpins were the most frequently taken fish. Cormorants appear to be restricted to foraging close to land near the bottom (Hunt et al. 1981a).

Seaducks.

Surprisingly little information is available on seaduck use of the study area. The most detailed survey available is that of Arneson (1980), but that study consisted of a single winter aerial survey. Nonetheless, his study, other opportunistic observations, and findings in the adjacent North Aleutian Shelf (LGL 1986) all point to a high potential for use of the study area by wintering waterfowl. Use of the area by molting seaducks (as occurs in the NAS) has not been investigated.

During a winter survey of coastal areas in the Fox Islands, Arneson (1980) found a mean density of 94 birds/km^2, mostly waterfowl and shorebirds. The highest density (3240 birds/km^2), mostly waterfowl, was found around Samalga Island to the west of our area of interest. At this latter location sea ducks accounted for 416 birds/km^2 of the total density.

Unimak Pass has been shown to be an important migration corridor for waterfowl by Gill et al. (1979). Steller's Eiders (*Polysticta stelleri*) winter primarily along the south side of the Alaska Peninsula from Unimak Pass to Kodiak Island. Common Eiders (*Somateria mollissima*) migrate in large numbers from the Gulf of Alaska into the Bering Sea but there are few records from Unimak Pass. Presumably most of these birds pass directly over the Alaska Peninsula (Gill et al. 1979). Although never reaching the high densities characteristic of other seaducks within our study area, Common Eiders are probably the predominant nesting duck as most of the others occur primarily as winter residents.

Most of the western Canadian, an unknown portion of the Siberian, and all of the Alaskan breeding populations of King Eiders (*Somateria spectabilis*), are thought to winter in the southern Bering Sea and Bristol Bay (Bellrose 1976). In the major wintering area, birds tend to congregate in the eastern Aleutians and off the major lagoons along the western Alaska Peninsula. During normal ice years, birds usually do not begin to increase along the Alaska Peninsula until after November. They are not reported to arrive in the eastern Aleutians until early December (Cahn 1947).

Concentrations of wintering Black Scoters occur in Prince William Sound, around Kodiak Island, along the Alaska Peninsula, and throughout the Aleutian Islands (Bellrose 1976).

Seaducks as a group feed on benthic invertebrates. There is considerable specialization among species, but the groups expected to predominate in the study area, scoters and King Eiders, feed primarily on bivalve molluscs.

Glaucous-winged Gull (*Larus glaucescens*).

Glaucous-winged Gulls are in many respects an overlooked seabird. Most regional species accounts tend to omit this species. The summaries in Tables 1 and 2 show this species to be consistently among the most numerous species encountered. Its abundance varies seasonally with peak densities occurring in summer and fall, at least in coastal areas.

Glaucous-winged Gulls are omnivorous and are opportunistic foragers. Their diet includes a variety of intertidal organisms, fish, garbage, offal, and other prey. Most foraging occurs in nearshore habitats, especially during the breeding season, but some gulls may be found quite far offshore. Because of their opportunistic foraging behavior, the diet of Glaucous-winged Gulls is prone to great geographic variability.

Black-legged Kittiwake (*Rissa tridactyla*).

Black-legged Kittiwakes are circumpolar in distribution and are numerous in the eastern Bering Sea, with the breeding population estimated at a minimum of 750,000 (Sowls et al. 1978). Population indices derived from aerial and shipboard censuses indicate the presence of 1-3 million kittiwakes in summer and 3-4.5 million in fall over the eastern Bering Sea (Gould et al. 1982).

Nesting colonies of Black-legged Kittiwakes occur throughout the Aleutian Islands, the Bering Sea, and the Gulf of Alaska; however, there are no major nesting areas within the study area. The pelagic distribution during all seasons may be characterized as low density and dispersed in the southern sector of the Bering Sea. Hunt et al. (1982) described a tendency for higher densities to be observed between the 100 m isobath and deeper waters of the shelfbreak, and for lower densities to occur between the 50- and 100-m isobaths.

In winter, most Black-legged Kittiwakes leave the Bering Sea, although this species still occurs in low densities during the winter north of the Aleutians, on the shelfbreak, and in oceanic waters north of the Pribilofs. Kenyon (1949) reported few in the Gulf of Alaska and northeastern Pacific; however, kittiwakes are more common along the California coast and over a broad zone of deep oceanic water south of the Aleutians. Gould et al. (1982) described kittiwakes as virtually absent from shallow waters of Bristol Bay in winter, but present in "fair numbers" over shelfbreak and oceanic waters. Probably most of the kittiwakes breeding in colonies in the Bering Sea concentrate in the western portion of their major wintering area south of the Aleutians.

Northward displacement begins in mid-March with intensive movements occurring through straits of the eastern Aleutian ridge in April. Fall migration through Unimak Pass occurs from the middle of September and into late October (Nelson 1976). For the eastern Bering Sea population, there is a broad and gradual movement from breeding colonies to wintering areas south of the Aleutians.

The feeding method of kittiwakes is primarily dipping; however, surface-seizing and occasionally shallow pursuit-diving is employed (Hunt et al. 1981a). Fish are primary prey, but crustaceans (euphausiids, amphipods) and cephalopods are also consumed. In the North Aleutian Shelf area, euphausiids were heavily preyed upon during May (Troy and Johnson 1987).

Common Murre (*Uria algae*).

Both Common and and Thick-billed murres (*U. lomvia*) are abundant and widespread in the southeastern Bering Sea. The species differ in many aspects of their biology and distribution; it is unfortunate that it is frequently difficult to distinguish between them during surveys. The available information suggests that Common Murres are much more numerous within the study area, and thus they are emphasized here.

Within our area of interest, relatively few (approximately 17,000) murres nest. Of these, the vast majority are Common Murres although both species are present. Murres make greatest use of the study area during migration and winter. A substantial number of subadult (nonbreeding) birds may summer along the Bering Sea coast of the study area (D. Forsell, USFWS, pers. comm.).

Autumn migration through Unimak Pass is also quite protracted, extending from late July through October. Peak movements have been recorded during the last week of August and again during the middle of October (USFWS, unpubl. data). The return spring migration through Unimak Pass into the Bering Sea commences in late March, peaks in late April, and continues into May.

Our aerial survey data (Table 1) show peak numbers of murres in Unimak Pass during late winter and spring. Numbers were rather variable and suggest considerable local movement. During February 1986, murres were the most numerous species in this area. Their distribution on occasion appeared to parallel (to the west) the distribution of Crested Auklets. During the January 1985 cruise, some 100,000 murres were estimated to have been seen on a single occasion in this region.

Murres feed by diving, often attaining depths of 110-130 m (Forsell and Gould 1980). Fish are the principal prey, but invertebrates are often an important constituent of the diet. Common Murres tend to feed within a few km of shore in water 50 m or less in depth, whereas Thick-billed Murres may feed tens of kilometers to sea in deep water (Roseneau and Springer 1982). Common Murres prey on nearshore mid-water fishes (e.g., cod, sand lance, and capelin), whereas Thick-billed Murres use demersal fishes. Invertebrates consumed by both species, in approximate order of importance, include shrimps, amphipods, euphausiids, cephalopods and polychaetes (Roseneau and Springer 1982). There is considerable regional variability in diet; murres on the Pribilof Islands take walleye pollock extensively, whereas murres in Norton Sound prey on sand lance and arctic cod (Hunt et al. 1981a).

Whiskered Auklet (*Aethia pygmaea*).

The Whiskered Auklet is known to nest only on some 40 islands in the Aleutian chain; all but 9 of these are in the Fox Island group. The total population is estimated to be at least 25,000 (Byrd and Gibson 1980), although colony censuses have documented breeding sites of only 6,800 birds (Sowls et al. 1978, Nyswander et al. 1982). This species is particularly difficult to census and it is likely that additional breeding sites will be found.

Whiskered Auklets are less colonial than other *Aethia* auklets, having widely scattered nest sites (Nyswander et al. 1982). On Buldir Island nests are located in talus or under beach boulders, in cavities similar in size to those of Least Auklets (Knudtson and Byrd 1982). Whiskered Auklets lay a single egg.

Whiskered Auklets have been seen in large flocks along the Aleutian chain. The spring distribution tends to be more clumped than the summer distribution. In the Andreanof Islands of the Aleutian chain, Byrd and Gibson (1980) found a greater number of Whiskered Auklets in spring than during the breeding season. Areas in the Aleutian chain where concentrations have been noted include Tigalda Island to Baby Pass (particularly Baby Pass and Avatanak Strait), Unimak Pass, Herbert Island to Yunaska Island, near Seguam Island and Great Sitkin Island, near Segula Island and at Buldir Island. Large flocks (up to 10,000) may be found in tide-rip areas (Byrd and Gibson 1980; Gould et al. 1982).

In winter, Whiskered Auklets are presumed to be distributed near the breeding areas (Byrd and Gibson 1980). In November 1964, at least 1100 Whiskered Auklets collided with a ship in the Islands of the Four Mountains (Dick and Donaldson 1978).

Whiskered Auklets feed by diving (Ashmole 1971). Feeding concentrations are nearly always restricted to tide-rip areas (Byrd and Gibson 1980, Nyswander et al. 1982). Little is known of food habits, but limited data suggest that they feed primarily on crustaceans, including copepods, amphipods, larval crabs, and isopods. Mollusk eggs and fish have also been reported as food items (Day 1980).

Crested Auklet (*Aethia cristatella*).

The Crested Auklet has its population center in the Bering Sea where an estimated two million nest in Alaskan waters. The nesting biology of this species will not be elaborated upon as it is not known to nest in our area of interest although large colonies are found to the west in the Aleutian chain.

Overall, insufficient data are available to accurately describe the wintering distribution of auklets. Most small auklets leave the Bering Sea in fall, wintering along the Aleutian chain and in the open North Pacific. Kodiak Island is a known wintering area for Crested Auklets (Gould et al. 1982). A large concentration of Crested Auklets was found in the Bering Sea north of Unimak Island as part of the NAS investigation (Troy and Johnson 1987); population estimates indicated that hundreds of thousands of birds were present.

Crested Auklets feed by diving (Ashmole 1971) and specialize in preying on zooplankton at moderate ($\approx$ 40 m) depths (Hunt et al. 1981a). At the Pribilof Islands, Crested Auklets take mostly euphausiids, with secondary reliance on amphipods (Hunt et al. 1981a). Searing's (1977) results at St. Lawrence Island indicated that Crested Auklets were almost completely dependent on calanoid copepods. Unfortunately, no auklets were collected as part of the NAS investigations to determine their winter diet in this area.

Tufted Puffin (*Fratercula cirrhata*).

The Tufted Puffin is the most numerous breeding seabird in the study area, having an estimated breeding population in excess of 700,000. Not surprisingly, they are also frequently encountered in high densities during aerial and, especially, shipboard surveys. High densities often occur in areas well removed from the nesting colonies.

Tufted Puffins have a wide nesting distribution, extending from northern Alaska (Cape Lisburne) south to California. Of a worldwide population of 6.25—8 million, perhaps 25% nest in the eastern Bering Sea. Within Alaska, most of the major colonies occur within our study area.

Wehle (1980) has summarized information on all puffin species; unless otherwise specified, the following information is drawn from his work. Tufted Puffins usually nest in earthen burrows on cliff edges of sea slopes. They lay only one egg and are apparently capable of re-laying if their first egg is lost. Breeding phenology on Buldir Island was as follows: arrival before 1 May; peak laying 5-19 June; peak hatching 19 July-2 August; fledging 2-15 September (G.V. Byrd and R.H. Day, unpublished data). Food availability and feeding conditions appear to influence the duration of the nestling period. Most young are flightless when they leave the nest. Fledging success (young fledged per eggs hatched) was 60-70%. Most chick mortality occurs within two weeks after hatching.

While on the colonies, these birds feed over the continental shelf, seldom straying beyond it (Harrison 1977; Gould 1977, 1978). Following breeding, Tufted Puffins immediately resume a pelagic existence and do not linger over inshore waters near the colonies. This species has no well-defined migration. The population disperses over the open ocean, usually off the continental shelf, following breeding. Occasional large concentrations have been sighted in tide-rip areas in Aleutian passes (Hunt et al. 1981c, Gould et al. 1982). By November, birds are seldom found over the continental shelf and most have left the Bering Sea.

Puffins feed by pursuit-diving, mostly within 15 m of the surface. Generally, fish are the most important component of their diet, although in some areas squid have been found to be important. Crustaceans are consumed in lesser amounts. Sand lance and capelin are the most common prey items fed to nestling puffins, and growth rates of young are the greatest when these fish predominate in food loads brought to nestlings. When the primary prey species are not available, Tufted Puffins tend to prey mainly on cephalopods, or on cod, sculpin, and greenlings.

METHODS

Distribution and Abundance

The distribution and abundance of marine birds were assessed using shipboard surveys. Shipboard counts suffer from the problem that the organisms being censused can move much more rapidly than the counter; this fact alone makes reliable density estimation impossible (Burnham et al. 1980). Many *ad hoc* methods of minimizing this inherent bias have been employed but their accuracy is unverifiable. Surveys near shore are impossible using deep-draft ships (the minimum sampling depth from the R/V *Miller Freeman* was approximately 20 m, and much more in areas of irregular bottom). On the other hand, use of a ship as a sampling platform permits more detailed study of the smaller organisms that are missed or cannot be identified from the air. The ship also allows more precise documentation of certain important behaviors that cannot be ascertained from the air. Most importantly, use of a ship permits concurrent measurements of prey availability and oceanographic conditions—information that is critical when trying to determine correlative and/or probable causative factors for bird and marine mammal distributions.

Counts of marine birds were made during three cruises of the R/V *Miller Freeman*—fall 1986 (18 Sept. - 7 Oct.), winter 1987 (14 Feb. - 9 Mar.), and spring 1987 (21 Apr. - 14 May). Surveys were made while the ship was at or near full speed (≈ 15 kts). Transects were defined as 10-minute intervals as is the customary protocol for conducting marine bird surveys in Alaska. The biologist censused from the flying bridge using a 90° or 180° arc. We attempted to repeat as close as possible all major survey tracks each cruise (Figs. 1-3) and to augment coverage in areas of particular interest when concentrations were found.

Birds were recorded as being in one of four distance increments parallel to the course of the boat: 0-100m, 100-200m, 200-300m, and >300m. Calculations of densities were based on the first three bands only; the fourth zone was used to record off-transect sightings of major seabird concentrations and whales.

During the survey of each transect, location and environmental conditions were recorded. The most important characteristics were time, coordinates of starting and end points, speed, and depth. Weather information, including cloud cover, sea state, precipitation, wind speed, and air and sea surface temperatures were obtained hourly from the ship's log.

Analyses included tests for differences in abundance among cruises as a measure of seasonal differences in abundance. The major summary analysis of the marine bird studies is a compilation of transect results by water mass as delimited in Chapter 2 (PHYSICAL PROCESSES AND HYDROGRAPHY) of this volume. These same water masses were also used to characterize prey, forage fish and zooplankton, abundance patterns.

Two of the water masses, the 'Gulf of Alaska Water' (GAW) and the 'Alaska Coastal Water' (ACW) were subdivided into northern and southern (Bering and Pacific) masses. In the case of the Gulf of Alaska Water, the two regions were discontinuous and hence logically analyzed separately. As discussed earlier, the Alaska Coastal Water retained it's integrity as it passed through Unimak Pass. However, based on prior studies and the nitrate data, we anticipated that effects of potential upwelling would be manifest on the Bering Sea component of this water mass but not the Pacific side. The exact point of division had to be selected subjectively; we used Seal Cape, the narrowest portion of the Pass, as the dividing point. Thus, most of Unimak Pass itself is in the northern portion of the Alaska Coastal Water mass.

Food Habits

Stomachs of birds shot at sea from small boats were used for food habits analyses. Species and numbers of birds collected, as well as dates and locations of collections, are shown in Table 4.

Shortly after each collection was made, a solution of 5% formalin was injected into the birds to prevent post-mortem digestion of food material. As

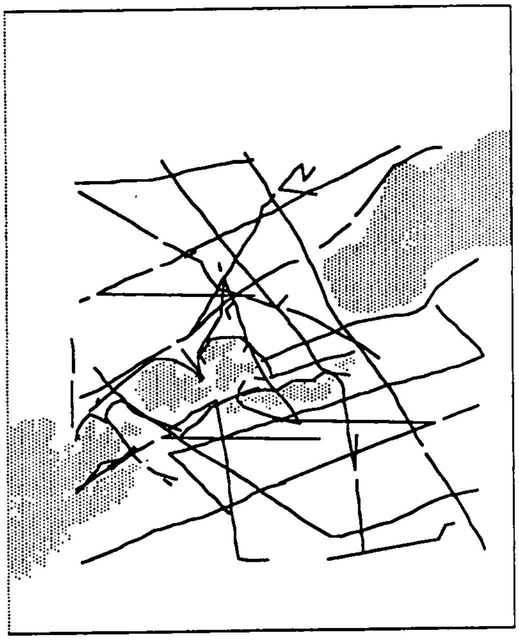


Figure 1. Transect lines for marine bird surveys during fall, 1986, Unimak Pass area, Alaska.

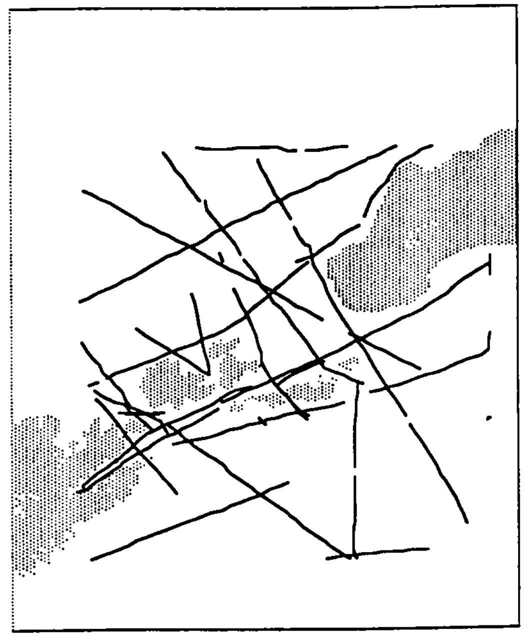


Figure 2. Transect lines for marine bird surveys during winter, 1987, Unimak Pass area, Alaska.

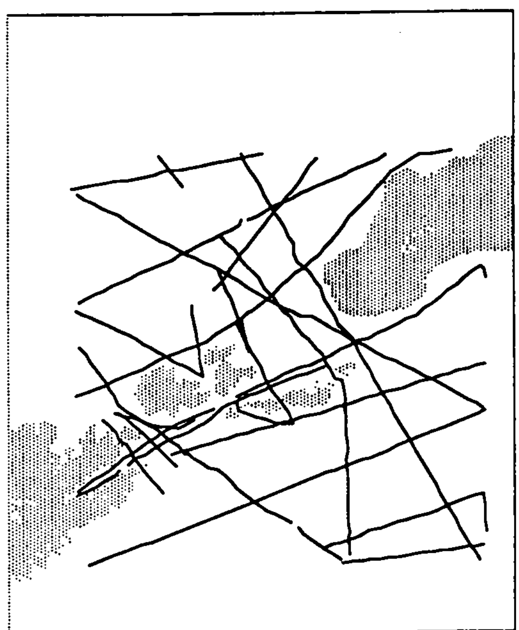


Figure 3. Transect lines for marine bird surveys during spring, 1987, Unimak Pass area, Alaska.

Table 4. Dates and locations of birds collected for food habits studies in the Unimak Pass area, Alaska.

Cruise	Date	Station	No. and Species Collected*
Fall	25 September 1986	17.9	10 STSH
	27 September 1986	10.3	5 WHAU
	4 October 1986	????	5 TUPU
	6 October 1986	26.2	1 TUPU, 4 WHAU
Winter	1 March 1987	9.5	5 WHAU
	3 March 1987	9.2	3 COMU
	3 March 1987	Derbin Str.	2 WHAU
	6 March 1987	21.3	2 WHAU, 9 CRAU
Spring	30 April 1987	22.8	1 COMU
	30 April 1987	8.1	5 WHAU
	2 May 1987	53°51.6'N 165°52.1'W	4 COMU, 2 TUPU
	10 May 1987	31.2	3 COMU, 2 TUPU

* STSH = Short-tailed Shearwater, COMU = Common Murre, TUPU = Tufted Puffin, WHAU = Whiskered Auklet and CRAU = Crested Auklet.

soon as possible thereafter, the birds' stomachs were removed and preserved in 10% formalin in whirlpacks for subsequent laboratory analysis.

In the laboratory, each stomach was removed from its whirlpack and stomach contents were washed into a 153 µm sieve. Contents were sorted and the food items identified and counted. Identifications were made to species when possible. When no identifiable parts were present, an "intelligent guess" as to contents was made. For example, unknown crustacean parts would be recorded as *Thysanoessa* spp., and not as unidentified crustacea, if other birds collected in the area had been eating *Thysanoessa*. Subsampling was undertaken when the total sample weight exceeded about 10 g. A subsample of 1-3 g was taken such that the subsample was 1/5, 1/10 or 1/20 of the total weight.

For each prey species present in a sample, length measurements were made of up to 10 randomly-selected individuals. Measurements were made only on intact invertebrate items. When only otoliths of fish were found, fish lengths and estimated weights at ingestion were calculated following Springer et al. (1984). The proportion of estimated weight ascribable to a given fish taxon was used to calculate the amount of unidentifiable fish material ascribable to the same taxon.

RESULTS

Distribution and Abundance

Seasonal Abundance

Abundances of most marine bird species differed markedly among the three cruises (Table 5). Of the species sufficiently numerous to permit statistical testing for differences in abundance (testing the null hypothesis that the number of birds per sampling effort was not different among cruises), all had highly significant departures from equal abundance among cruises.

Fall. Most species peaked in abundance during the fall cruise. This was particularly true of procellariids (except Leach's Storm-Petrel), larids, and puffins. Although many species were relatively common during fall, the total density of marine birds was lower than that observed during the winter, and considerably higher than during the spring cruise.

Despite the relative abundance of most species during the fall, a few species comprised most of the total. Short-tailed Shearwater was overwhelmingly the most common species, accounting for almost two-thirds of all birds seen. Next in abundance was Black-legged Kittiwake, which accounted for an additional 15% of all sightings. Three additional species were common (here defined as occurring at densities ≥ 10 birds/km^2)—Whiskered

Table 5. Densities of marine birds based on results of ship-based transects, Unimak Pass area, Alaska. Test results for differences in abundance among cruises (seasons) are shown.

SPECIES	Fall 86	Winter 87	Spring 87	Chi-sq	prob
Loon	**0.024**	0.007	0.006	11.439	< 0.005
Western Grebe	0.001	0.000	0.000		
Black-footed Albatross	**0.045**	0.000	0.000	57.415	< 0.005
Laysan Albatross	0.009	0.000	0.012		
Northern Fulmar	**9.927**	5.323	5.068	1522.335	< 0.005
Mottled Petrel	0.005	0.000	0.000		
Sooty Shearwater	**0.931**	0.000	0.021	1126.927	< 0.005
Short-tailed Shearwater	**186.282**	0.005	39.123	162407.300	< 0.005
Fork-tailed Storm-Petrel	**1.424**	0.002	0.079	1615.463	< 0.005
Leach's Storm-Petrel	0.001	0.000	**0.024**	28.376	< 0.005
Red-faced Cormorant	*0.017*	0.167	0.155	90.256	< 0.005
Cormorant	0.048	**0.488**	0.186	292.788	< 0.005
Tundra Swan	0.000	0.002	0.000		
Emperor Goose	0.003	**0.025**	0.000	28.492	< 0.005
Canada Goose	**0.024**	0.000	0.001	27.007	< 0.005
dark goose	**0.023**	0.000	0.000	28.707	< 0.005
King Eider	0.000	**0.483**	0.000	685.750	< 0.005
Eider	*0.003*	0.025	0.019	12.694	< 0.005
Harlequin Duck	0.005	0.007	0.007		
Oldsquaw	0.000	**1.901**	0.219	2160.613	< 0.005
Black Scoter	0.007	0.003	0.003		
White-winged Scoter	0.000	**0.049**	0.007	52.045	< 0.005
Merganser	0.001	0.000	0.000		
duck	0.001	0.002	0.000		
Bald Eagle	0.001	0.013	0.003		
Peregrine Falcon	0.007	0.000	0.001		
Gyrfalcon	0.001	0.000	0.000		
plover	**0.025**	0.000	0.000	32.085	< 0.005
Black Oystercatcher	0.000	0.000	0.001		
Wandering Tattler	0.000	0.000	0.001		
Ruddy Turnstone	0.003	0.000	0.000		
Least Sandpiper	0.000	0.000	0.001		
Rock Sandpiper	0.001	0.000	0.000		
Dunlin	0.005	0.000	0.000		
small Sandpiper	0.005	0.000	0.001		
Phalarope	**3.527**	0.000	0.000	4459.765	< 0.005
Jaeger	**0.043**	0.000	0.012	33.634	< 0.005
Mew Gull	**0.040**	0.012	0.000	32.889	< 0.005
Herring Gull	0.004	0.002	0.001		
Glaucous-winged Gull	**5.124**	3.120	2.304	835.417	< 0.005
Glaucous Gull	0.004	0.002	0.001		
Black-legged Kittiwake	**42.090**	2.370	1.712	44620.640	< 0.005
Red-legged Kittiwake	**0.039**	0.000	0.007	34.713	< 0.005
Sabine's Gull	0.021	0.000	0.000		
Arctic Tern	**0.023**	0.000	0.000	28.707	< 0.005
Aleutian Tern	0.003	0.000	0.000		
Tern	0.007	0.000	0.000		
Common Murre	0.390	**8.681**	1.560	7922.198	< 0.005
Thick-billed Murre	0.004	0.263	**2.463**	2757.625	< 0.005

Table 5. (cont.)

SPECIES	Fall 86	Winter 87	Spring 87	Chi-sq	prob
Murre	0.144	**14.177**	4.724	11431.560	< 0.005
Pigeon Guillemot	*0.001*	0.103	0.154	104.519	< 0.005
Murrelet	0.176	0.017	**0.859**	735.240	< 0.005
Whiskered Auklet	16.289	*11.007*	15.348	701.360	< 0.005
Crested Auklet	0.122	**317.751**	4.768	436878.900	< 0.005
Auklet	3.890	**58.459**	0.333	70688.090	< 0.005
Rhinoceros Auklet	0.008	0.000	0.000		
Tufted Puffin	**9.904**	0.077	0.495	11221.500	< 0.005
Horned Puffin	**0.180**	0.030	0.022	134.230	< 0.005
alcid	0.027	*0.008*	0.039	11.550	< 0.005
Common Raven	0.004	0.007	0.000		
Water Pipit	0.000	0.000	0.010		
pipit	0.000	0.000	0.001		
Savannah Sparrow	0.000	0.000	0.001		
Lapland Longspur	0.005	0.000	**0.055**	60.312	< 0.005
passerine	**0.128**	0.000	0.007	145.077	< 0.005
Total	281.031	424.588	79.822		
Area Sampled (km^2)	748.772	593.974	670.452		

Auklet, Northern Fulmar, and Tufted Puffin. These five species accounted for 94% of the birds seen.

Winter. The highest overall density of marine birds occurred during the winter cruise. The sightings were, however, restricted to a smaller set of species than was the case during the fall. At least three-quarters of all birds enumerated were Crested Auklets, and probably many more Crested Auklets were included as unidentified auklets, the second most common species group. Murres were the next most numerous group, although they were an order of magnitude less numerous than the auklets. Of the identified murres, Common Murres were overwhelmingly in the majority, and most unidentified murres were probably of this species. The only other species occurring in densities ≥ 10 birds/km^2 was Whiskered Auklet. Although the density data show this species to be less common during this cruise than during the other two cruises, it is likely that the density was underestimated during the winter cruise. The winter deficit of Whiskered Auklets is probably hidden in the unidentified auklet category. This species often mixed in large groups of Crested Auklets such that it was impossible to accurately separate them. Many mixed groups had to be coded simply as auklets. These three species—Crested Auklet, Common Murre, and Whiskered Auklet—accounted for approximately 97% of all marine birds present during the winter cruise.

Several of the uncommon species occurred in their highest densities during the winter cruise. These were cormorants (most of those identified were Red-faced Cormorants), Emperor Goose, and seaducks (particularly King Eider, Oldsquaw, and White-winged Scoter). Most of these species were quite rare in the areas sampled by the ship.

Spring. The spring season had the lowest densities of marine birds of all our cruises. Overall densities were only one-fifth of those recorded during the winter cruise, which ended about a month prior to the start of the spring cruise. This illustrates the dynamic nature of bird populations during times of migration. It was obvious that most winter birds had left for breeding areas and that few of the summer birds were yet present. Indeed, the most numerous species during the spring cruise, Short-tailed Shearwater, was recorded in appreciable numbers only towards the end of the cruise. The only other common species observed during this cruise was Whiskered Auklet. (Note that Whiskered Auklet was the only species that was considered common during all cruises.) These two species comprised 68% of all the sightings.

The most diverse avifauna was recorded during the spring cruise. It was not dominated as much by a few species of overwhelming abundance as it was in fall and winter.

Among the less common species that made up a sizable proportion of the total birds seen were Northern Fulmar, murres, and Crested Auklet. Thick-billed Murres made up the largest proportion of the identified murres and reached their peak abundance during this cruise. Rarer species that reached their peak abundance during the spring cruise were Leach's Storm-Petrel, murrelets (Ancient Murrelets in particular), and Thick-billed Murre. That migration was underway was exemplified by occurrence of passerine birds, especially Lapland Longspur, during the marine transects.

Spatial Distribution

Fall. The greatest concentrations of marine birds during the fall cruise were in the Bering Sea or among the Krenitzin Islands; relatively few birds were seen in the Gulf of Alaska by comparison (Fig. 4). Comparison of the distribution of the marine birds revealed a rather consistent area of concentration in the northern portion of Unimak Pass, just north of Akun Island. Northern Fulmar, Short-tailed Shearwater, phalaropes, Black-legged Kittiwake, and Tufted Puffin all occurred in large numbers in this area.

Akutan Pass was another concentration area. This pass itself was the major concentration area for Whiskered Auklets (thousands of birds). Whiskered Auklets were closely associated with the Krenitzin Island group; however, except for Akutan Pass itself, the largest aggregations were in the Gulf of Alaska, south of the passes between the islands. The highest concentration of Common Murres was also within Akutan Pass but this species was not numerous during this time of year. A major concentration of Short-tailed Shearwaters was present in the Bering Sea just north of Akutan Pass.

A few other less common species also peaked in abundance in the passes and straits region among the islands. These included cormorants (Fig. 5), murrelets (especially in Beaver Inlet), and Horned Puffins (south side of Unimak Island). The only species showing a particular affinity for the Gulf of Alaska away from land was Black-footed Albatross, which occurred primarily in the deep water at the southern boundary of the study area.

Winter. The winter season brought considerable change in the species composition of the avifauna. Waterfowl were prominent only during this season. Even from shipboard surveys, seaducks were regularly encountered. Although waterfowl were present in the straits and passes of the Krenitzin Islands (especially Akutan Pass), the coastal waters north of Unimak Island supported their largest concentrations. Prominent in this regard were Cape Sarichef for Oldsquaws and Cape Mordvinof for King Eiders (Fig. 6).

Gulls, similarly to waterfowl, were also more important in winter than in fall. Both Glaucous-winged Gull and Black-legged Kittiwake were common

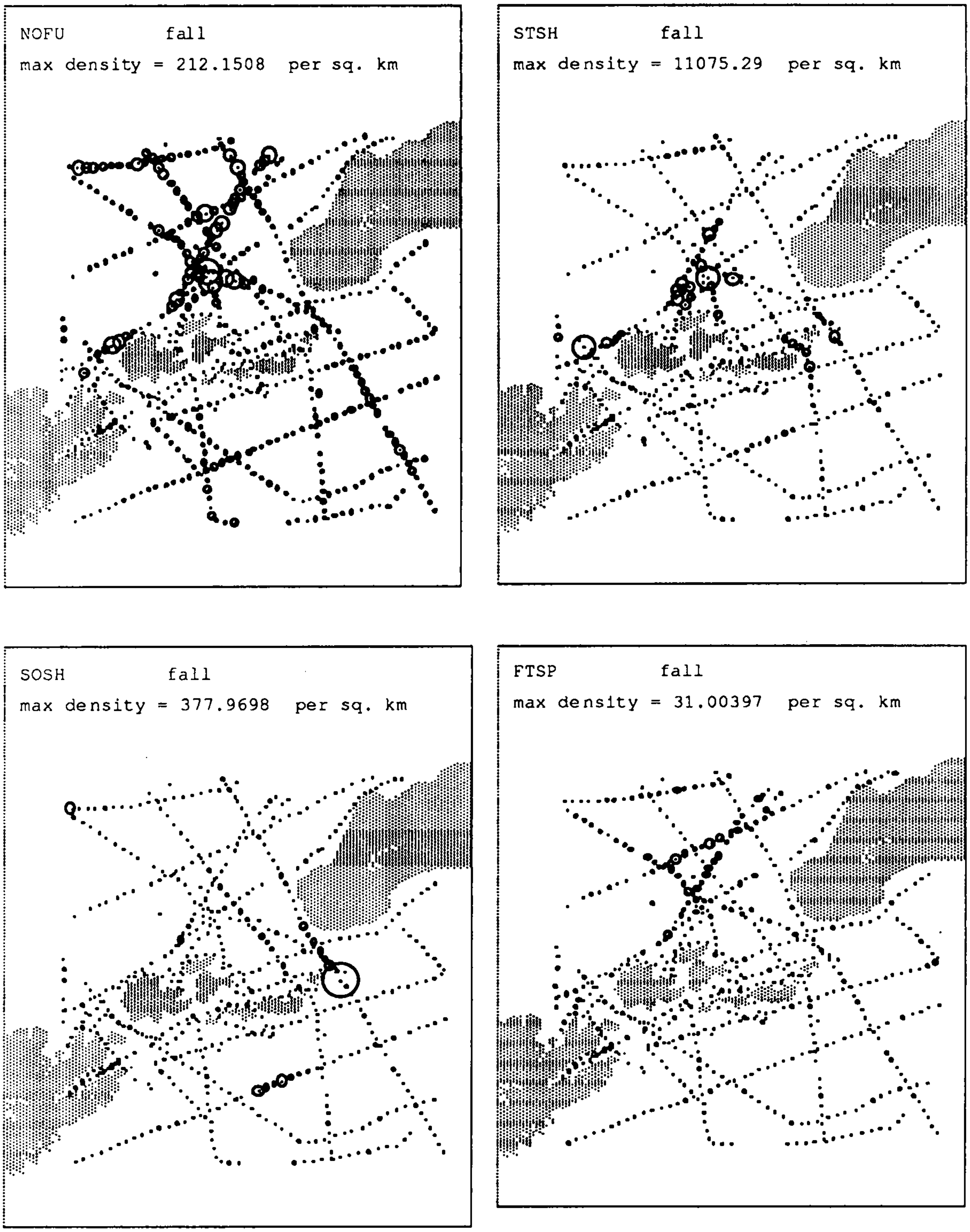


Figure 4. Distribution of marine birds recorded on ship-based transects (each dot represents a transect) during fall, 1986, Unimak Pass area, Alaska. Density of birds is proportional to the area of the circle; the maximum density (largest circle) is listed at the top of each map. (NOFU = Northern Fulmar, STSH = Short-tailed Shearwater, SOSH = Sooty Shearwater, FTSP = Fork-tailed Storm-Petrel)

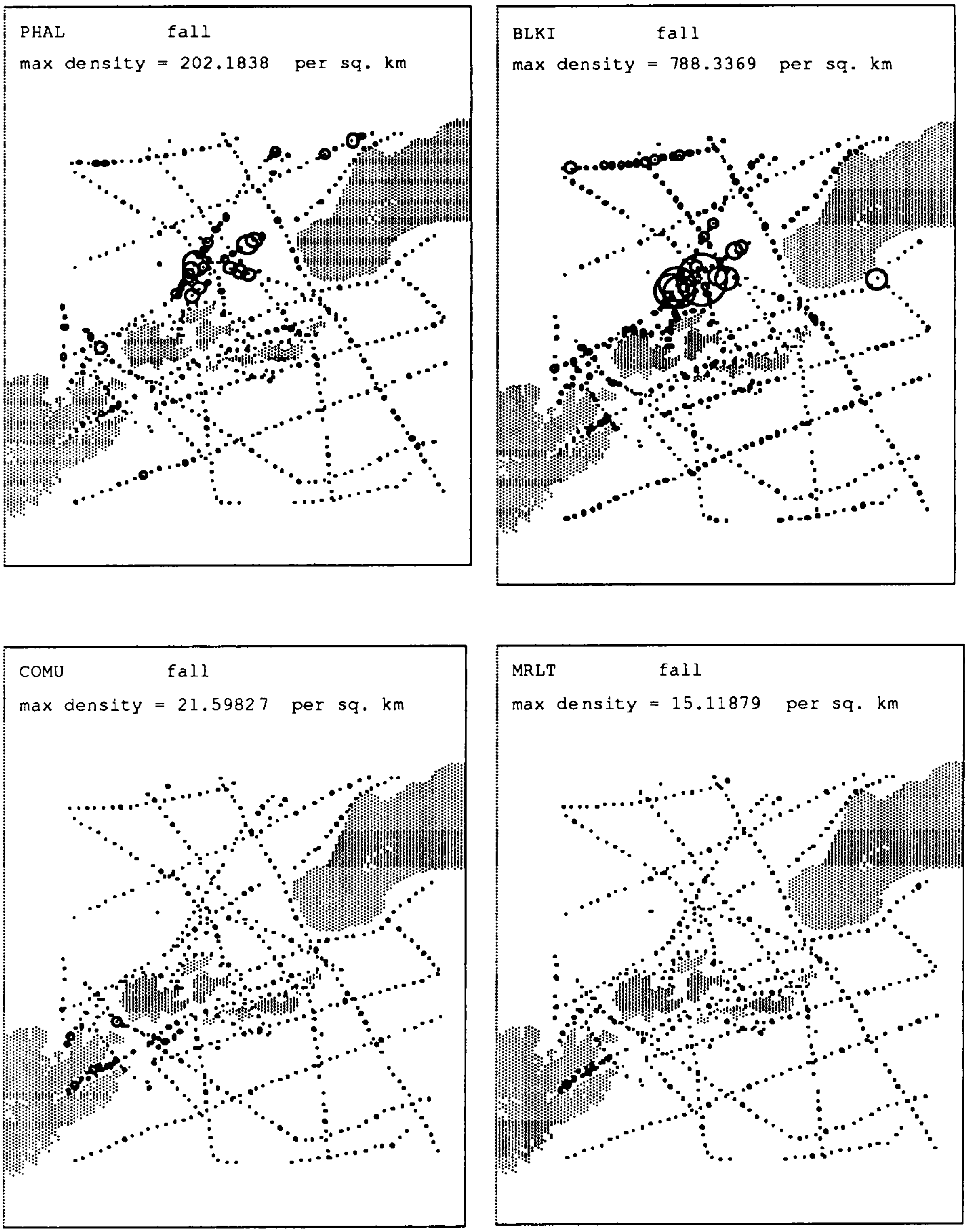


Figure 4 (cont.). (PHAL = Phalarope, BLKI = Black-legged Kittiwake, COMU = Common Murre, MRLT = Murrelet)

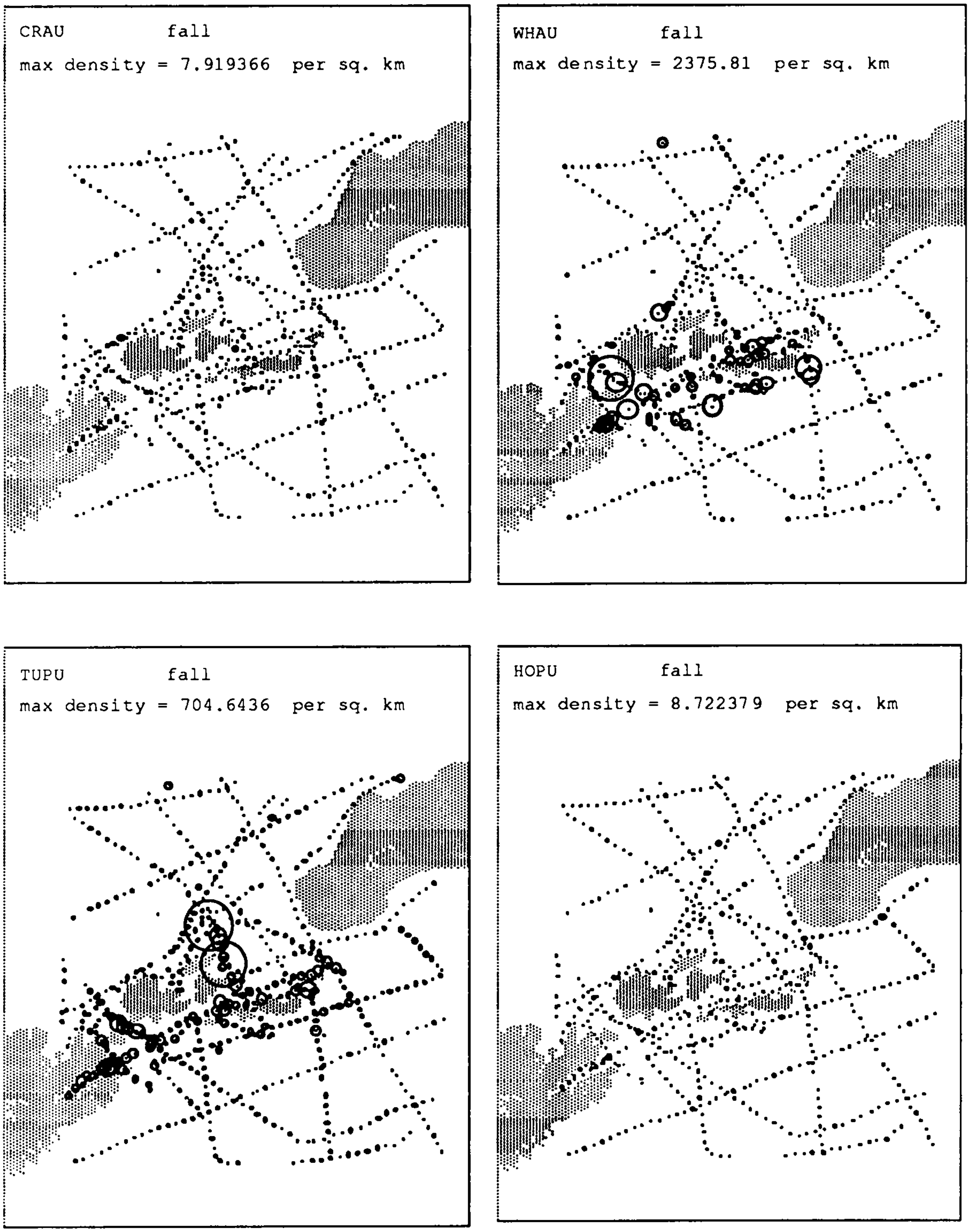


Figure 4 (cont.). (CRAU = Crested Auklet, WHAU = Whispered Auklet, TUPU = Tufted Puffin, HOPU = Horned Puffin)

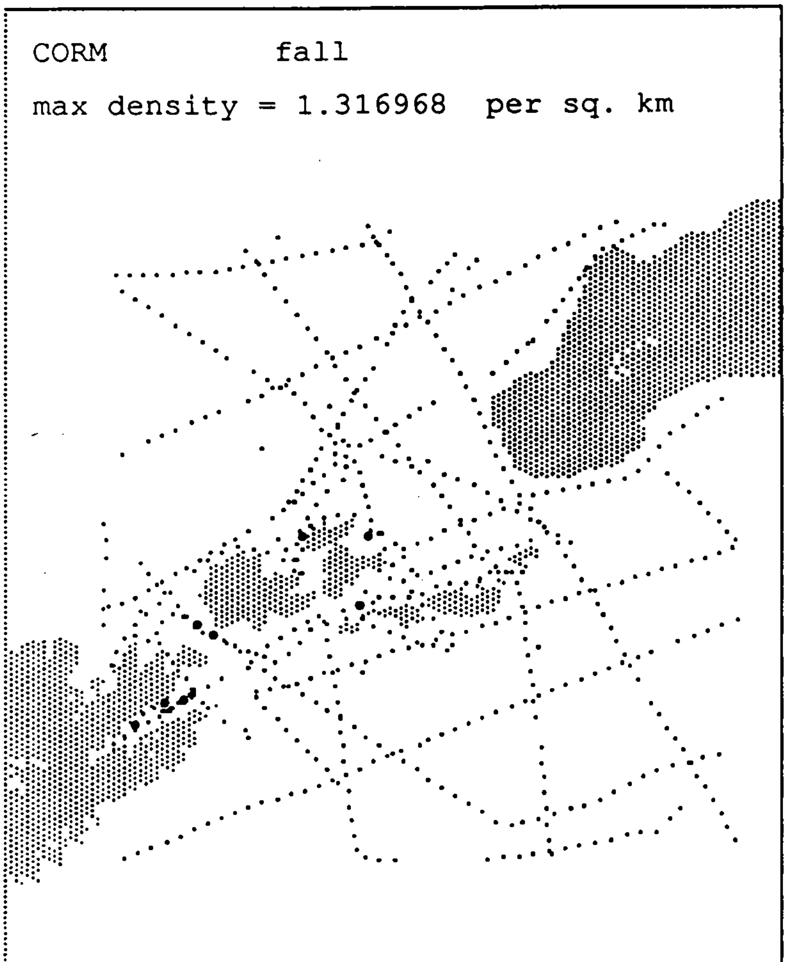


Figure 5. Distribution of cormorants (CORM) as determined from shipboard transects during fall, 1986, Unimak Pass area, Alaska. This species was largely restricted to the straits and passes of the Krenitzin Islands.

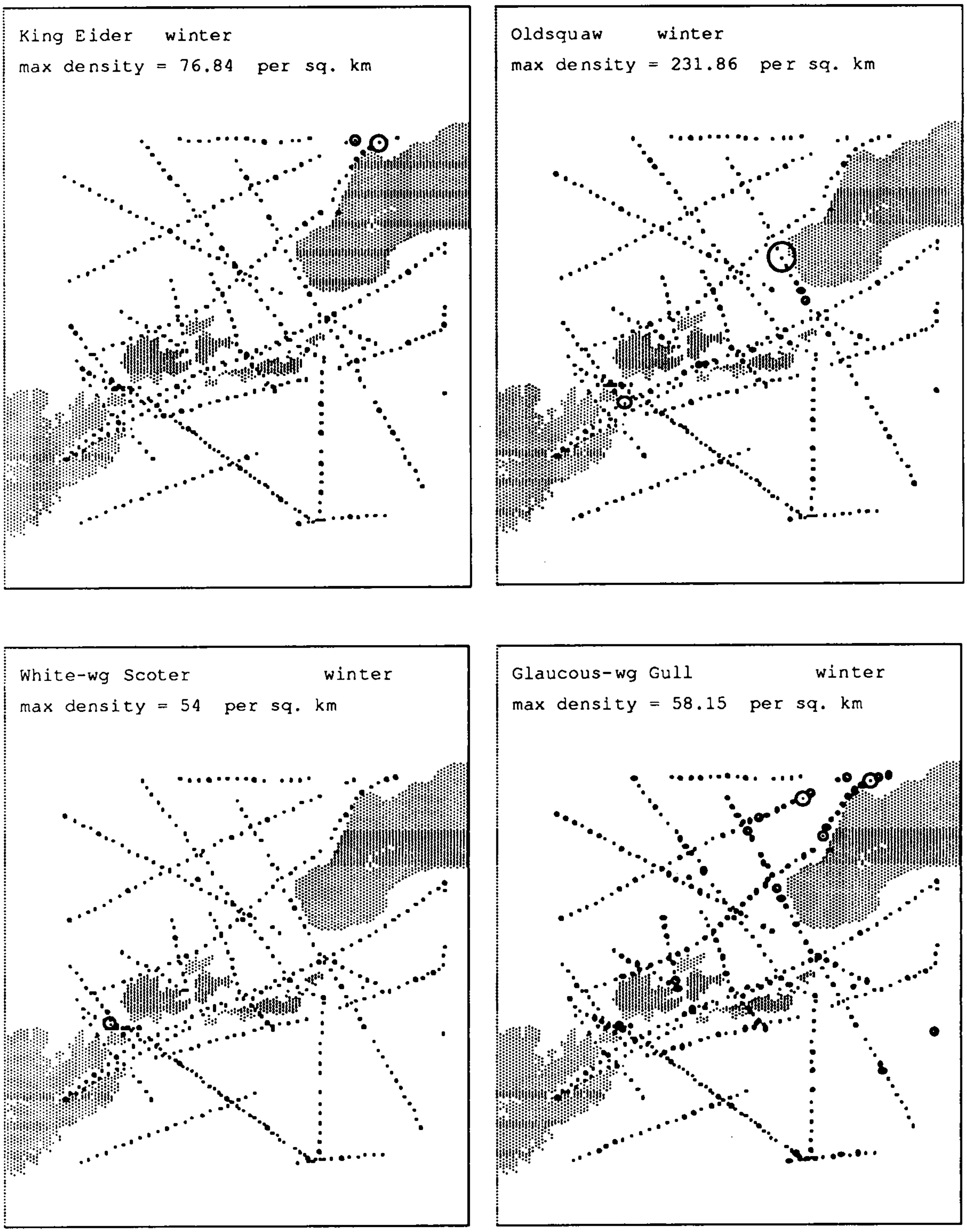


Figure 6. Distribution of marine birds recorded on ship-based transects (each dot represents a transect) during winter, 1987, Unimak Pass area, Alaska. Density of birds is proportional to the area of the circle; the maximum density (largest circle) is listed at the top of each map.

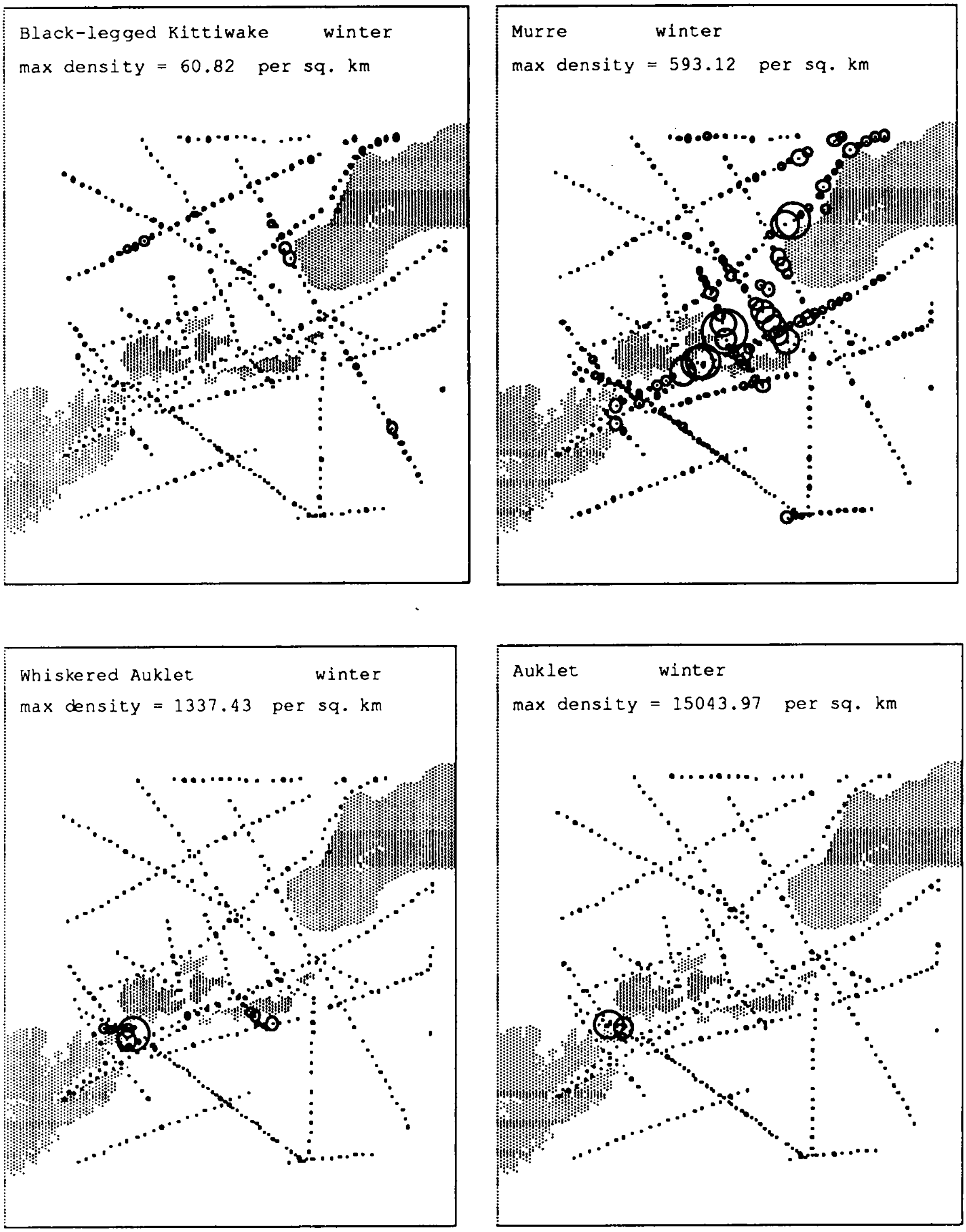


Figure 6 (cont.)

and widespread, but their distributions were dissimilar. Glaucous-winged Gulls were most numerous close to land, especially north of Unimak Island. In contrast, Black-legged Kittiwakes were most numerous in the deeper parts of the study area, both in the Bering Sea and, to a lesser extent, in the Gulf of Alaska. Large numbers were also found in Unimak Pass itself off Cape Sarichef.

Some of the most common birds during winter were murres, primarily Common Murre. Murres also were the birds most characteristic of the passes and straits in our study area. These birds were particularly numerous in Unimak Pass, Avatanak Strait, and the coastal waters north of Unimak Island, especially off Cape Sarichef.

The two species having the highest concentrations of all marine birds were the auklets. Crested Auklet was by far the most numerous species recorded during the winter, locally occurring at maximum densities in excess of 10,000 birds/km^2 (Fig. 7). Whiskered Auklets were also numerous but their densities were an order of magnitude less than those of Crested Auklets. Although overlapping in distribution, the two species of auklets were frequently spatially separated. Both species were abundant in Akutan Pass, with Baby Pass supporting the highest concentrations. The incredible number of auklets in Baby Pass and the fact that both species were mixed resulted in many individuals being unidentified as to species in this area. Whiskered Auklets were restricted to the immediate vicinity of the Krenitzin Islands with the only other concentration area during this cruise being in Derbin Strait. Crested Auklets, in contrast, had their center of distribution in the coastal waters north of Unimak Island; Akutan Pass was a notable but disjunct concentration area for this species.

The areas of greatest bird density in winter were 1) the north side of Unimak Island, 2) Akutan Pass, and 3) Avatanak Strait. This represents a considerable change from the fall cruise in that during winter more birds were found close to land and the concentration areas were farther east in Unimak Pass itself.

Spring. Marine birds were less concentrated in spring than during other seasons. Individual species frequently occupied specific geographic regions of concentration, but their location and extent of concentration varied markedly among the species (Fig. 8). Northern Fulmar, for example, was widespread in the Bering Sea but infrequent elsewhere, the only species so distributed. The gulls continued to be common, with the winter pattern of Glaucous-winged Gulls close to land and Black-legged Kittiwakes in deeper water persisting. The kittiwakes were virtually absent from the Bering Sea (except near the passes), in contrast with their winter distribution.

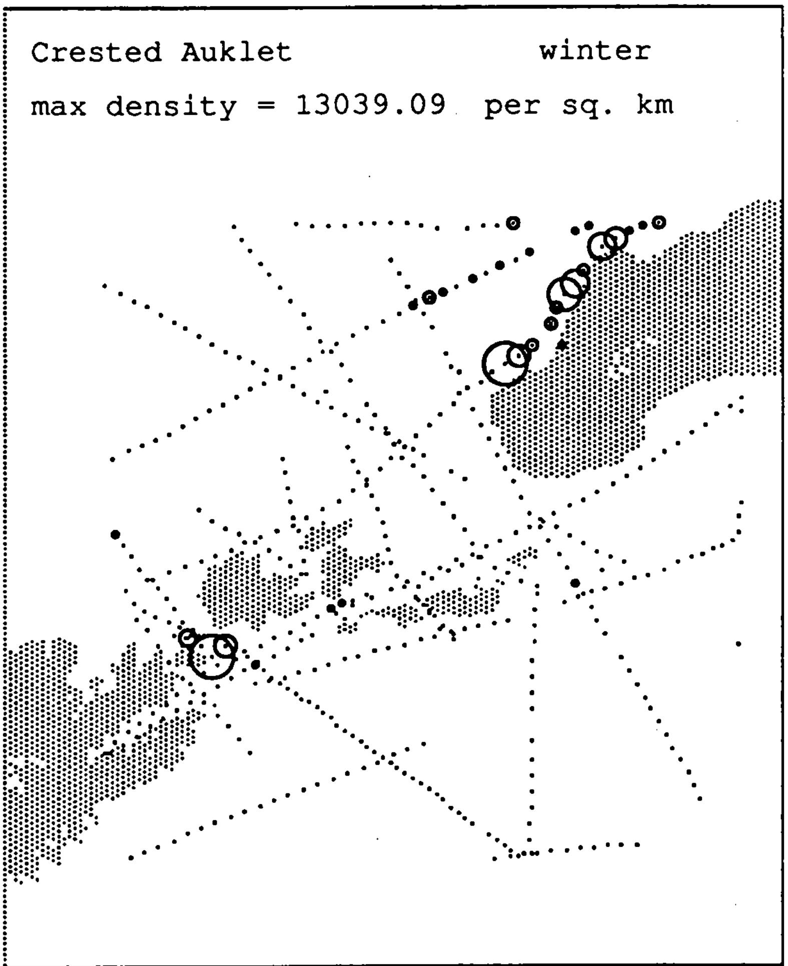


Figure 7. Distribution of Crested Auklets as determined from ship-based transects during winter, 1987, Unimak Pass area, Alaska.

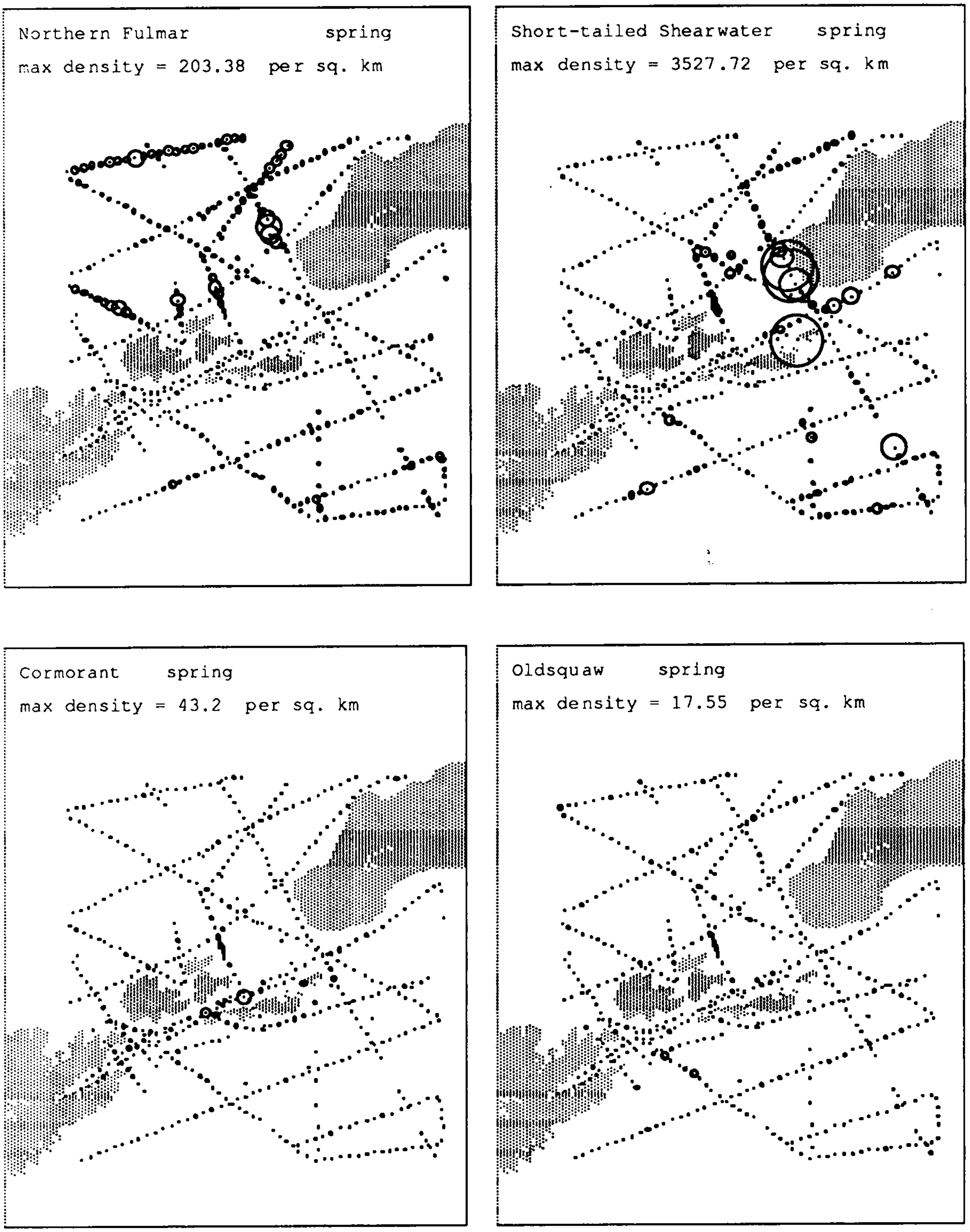


Figure 8. Distribution of marine birds recorded on ship-based transects (each dot represents a transect) during spring, 1987, Unimak Pass area, Alaska. Density of birds is proportional to the area of the circle; the maximum density (largest circle) is listed at the top of each map.

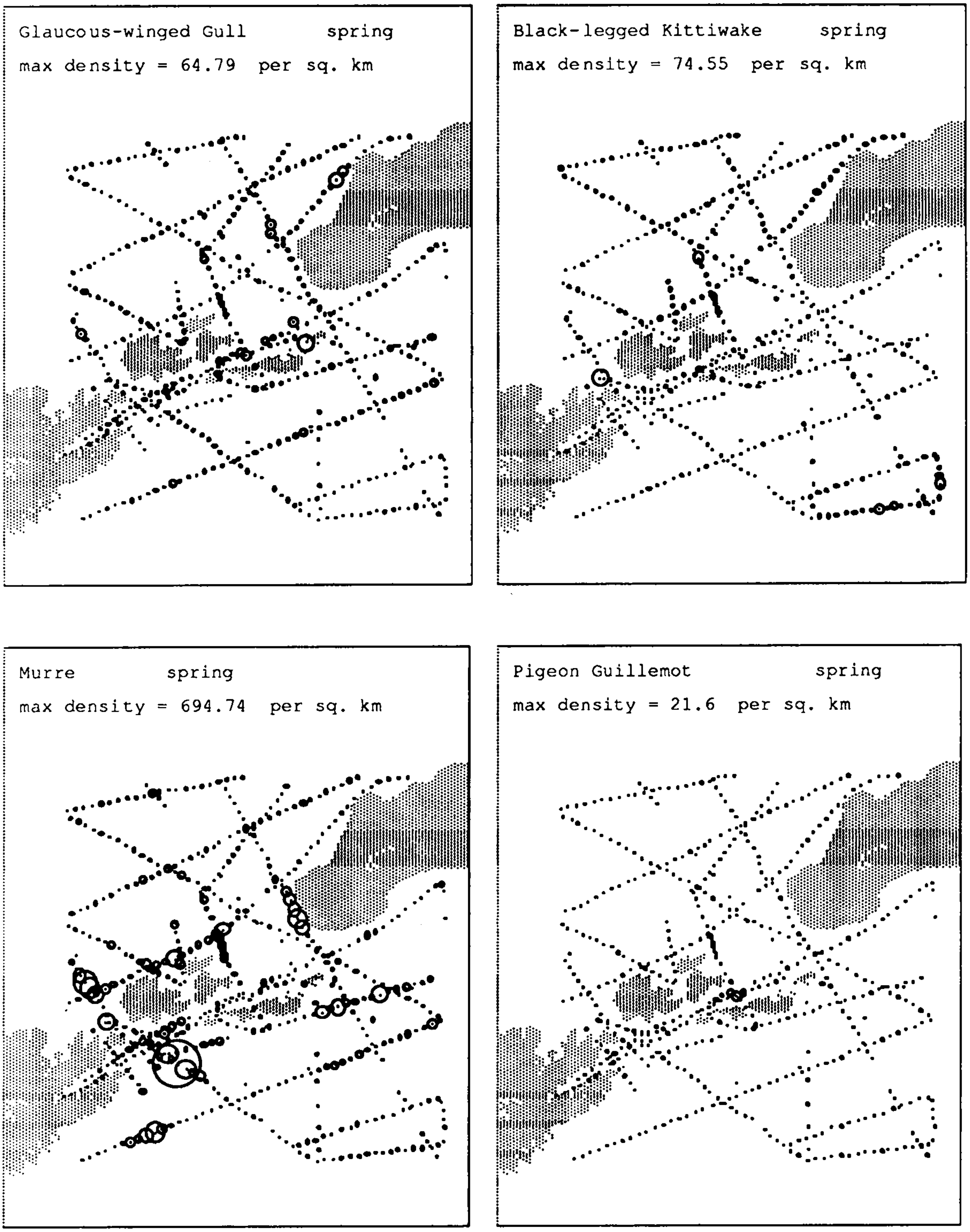


Figure 8. (cont.)

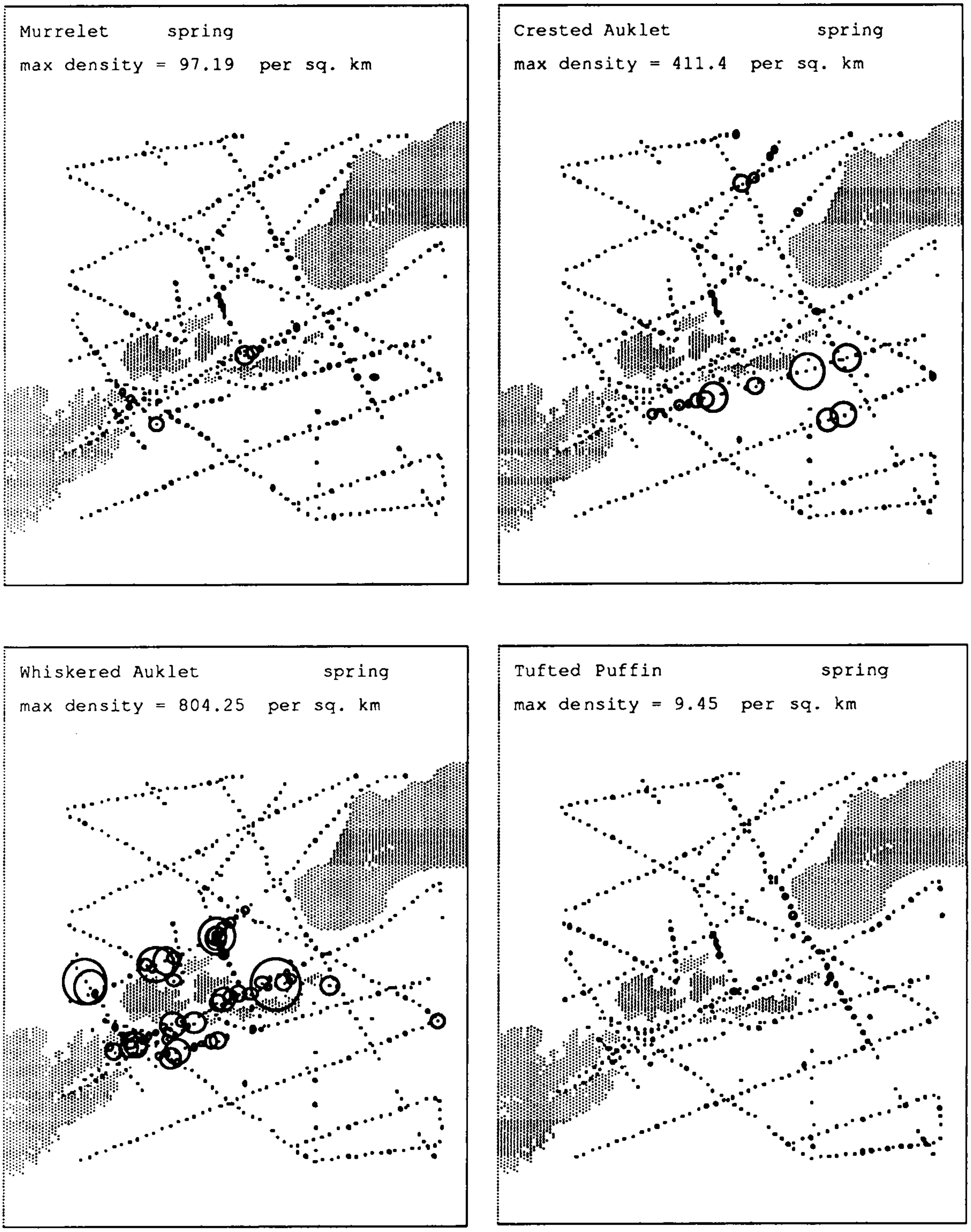


Figure 8. (cont.)

Short-tailed Shearwaters were just starting to arrive in the study area during the cruise. The distribution map (Fig. 8) reveals more birds in the Gulf of Alaska than in the Bering Sea; concentration occurred in the eastern parts of Unimak and Ugamak passes. Some species breeding in the area were more abundant than in winter; these tended to peak in abundance within the Krenitzin Islands area. Examples are cormorants, Pigeon Guillemot, murrelets (primarily Ancient Murrelet), and Tufted Puffins. Murres continued to be one of the most numerous groups, but during spring they were much more dispersed than during the winter and occurred in concentrations off the passes, especially south of Akutan Pass, rather than within the passes and straits as had been observed in winter. Part of the change in distribution might have been due to the higher porportion of Thick-billed Murres recorded during the spring.

The auklets continued to be numerous and to have interesting distributional patterns. The concentration areas of Crested Auklets were not at all coincident with those observed during the winter. In spring this species was found primarily south of the Krenitzin Islands opposite the passes. Whiskered Auklets were much more widespead than during the winter; they were found thoroughout Avatanak Strait and in the Bering Sea opposite the Krenitzin Islands passes. There was a relatively limited area of overlap between these two species (south of Akutan Pass).

Associations with Water Masses

Fall. In fall, marked differences in abundances of marine birds were evident among water masses (Table 6). The highest densities occurred in the Shelf Break Water (SBW) due to the extreme abundance of Short-tailed Shearwaters and Black-legged Kittiwakes in water of this type. During the fall cruise, the spatial extent of this water mass was more extensive than was observed during other cruises, occupying much of the northwest corner of the study area. Shearwaters were also abundant in the adjacent Gulf of Alaska Water north of the islands (GAWn); however, Black-legged Kittiwakes were abundant only in the Shelf Break Water (SBW).

The Alaska Coastal Water was quite depauperate in birds in both the north (ACWn) and south (ACWs) regions. Horned Puffins reached their peak abundance in the southern portion of this water mass; however even here they were quite rare.

Oceanic areas in the Gulf of Alaska (GAWs) had very low bird densities. One species, Black-footed Albatross, was restricted to this area.

Although absolute densities in the Tidally Mixed Water (TMW) were substantially lower than in the more structured water masses to the north,

Table 6. Average densities of the most common marine birds sighted during ship-based transects in fall, 1986, by water mass in the Unimak Pass area, Alaska. The highest density of each species is shown in bold face.

	SBW	TMW	GAWn	GAWs	ACWn	ACWs
Black-footed Albatross	0.00	0.00	0.00	**0.07**	0.00	0.00
Northern Fulmar	**12.92**	0.41	7.31	3.83	0.77	0.21
Short-tailed Shearwater	**265.89**	26.29	139.14	11.62	9.06	2.29
Sooty Shearwater	0.28	0.04	**1.05**	0.63	0.59	0.09
Fork-tailed Storm-Petrel	**3.07**	0.01	0.59	0.08	0.05	0.00
cormorant	0.00	**0.06**	0.00	0.00	0.01	0.05
phalarope	3.93	0.17	**4.96**	0.14	1.75	0.00
Black-legged Kittiwake	**100.71**	1.10	5.52	0.61	1.58	6.27
Common Murre	0.02	**0.47**	0.06	0.08	0.17	0.12
murrelet	0.01	**0.14**	0.02	0.02	0.10	0.12
Crested Auklet	0.02	0.05	**0.20**	0.03	0.01	0.00
Whiskered Auklet	0.96	**22.45**	2.38	2.86	1.21	0.05
Tufted Puffin	1.91	**9.96**	2.13	1.47	0.95	0.94
Horned Puffin	0.03	0.03	0.13	0.04	0.11	**0.99**
Total	389.75	61.17	163.48	21.48	16.36	11.13

Table 7. Average densities of the most common marine birds sighted during ship-based transects in winter, 1987, by water mass in the Unimak Pass area, Alaska. The highest density of each species is shown in bold face.

	SBW	TMW	GAWn	GAWs	ACWn	ACWs
Northern Fulmar	0.48	0.47	1.00	0.25	**10.57**	0.18
cormorants	0.22	**0.61**	0.00	0.01	0.14	0.01
Emperor Goose	0.00	**0.03**	0.00	0.00	0.00	0.00
Oldsquaw	0.00	0.26	0.05	0.00	**3.44**	0.00
White-winged Scoter	0.00	0.02	0.00	0.00	**0.07**	0.00
King Eider	0.00	0.02	0.00	0.00	**1.19**	0.00
Glaucous-winged Gull	0.59	0.57	0.78	0.45	**4.43**	0.51
Black-legged Kittiwake	1.76	0.13	1.70	0.41	**2.69**	0.36
Common Murre	0.33	13.01	1.53	1.77	**20.32**	2.42
Pigeon Guillemot	**0.11**	0.10	0.00	0.00	0.00	0.00
murrelets	0.00	**0.01**	0.00	0.00	**0.01**	0.00
Crested Auklet	22.59	80.58	0.08	0.03	**595.64**	3.79
auklets	35.26	**59.26**	0.12	0.00	0.06	0.07
Whiskered Auklet	0.00	**11.47**	0.03	0.04	0.00	0.07
Tufted Puffin	0.00	0.01	**0.08**	0.03	0.03	0.01
Horned Puffin	0.00	0.01	**0.02**	0.01	0.01	0.01
Total	61.34	166.55	5.40	2.99	638.62	7.44

several species were largely restricted to this water mass. Most striking in this regard were Whiskered Auklet and Tufted Puffin. Cormorants, murrelets, and Common Murres were also most frequent in the TMW.

In general, the ACW was used little by birds. Outside of this water mass, bird use of the Bering Sea side of the chain was high relative to that on the Gulf of Alaska side.

Winter. Use of the various water masses during winter differed markedly from the use observed during the fall cruise. The highest densities occurred in the ACW by a large margin (Table 7). Very striking was the contrast between the south and north components; almost all the birds occupied the northern portion. Crested Auklets made up the greatest proportion of birds encountered in this water mass; however, many other species reached their peak abundance here. Other common species in the ACWn were Northern Fulmar and Common Murre. Several species of seaducks and gulls also reached peak abundance in this area.

Likewise, the TMW seemed more important to birds in winter than in fall. Whiskered Auklets were still largely confined to this water mass, but even higher densities of Crested Auklets were seen using these areas. Common Murres were also numerous in TMW, although their densities were not as high as in the Alaska Coastal Water. Most of our encounters with Emperor Geese and cormorants were in Tidally Mixed Waters, though neither species was common in the areas surveyed by the ship.

Gulf of Alaska Water (GAW) had a dearth of birds. The northern portion had slightly more birds than the south. Both Tufted and Horned puffins peaked in abundance in the northern segment (GAWn), but puffins were generally rare throughout this area during winter.

The Shelf Break Water mass (SBW) was much reduced in area during the winter as compared to the fall. Water of this character was identified in two areas, one north of Unalaska Island, the other at the northern extreme of the study area. A more complete picture might have revealed the two parts of SBW to have been connected west of our study area. Moderate densities of birds, almost all auklets (presumably mostly Crested Auklets), were found in this water mass.

Overall, the winter results show that the Gulf of Alaska continued to have relatively few birds, as in fall. Bird use of the western segment of the Bering Sea habitats was greatly reduced relative to the fall cruise, whereas habitats under the influence of the Alaska Coastal Water in the eastern portion were heavily used by marine birds. Tidally Mixed Water was more important to birds during winter than during fall.

Spring. Bird density was more equitable among water masses during the spring cruise than during other times (Table 8), although overall densities were relatively low. The highest densities of marine birds occurred in the Alaska Coastal Water and, although the northern portion was again the most important, the portion south of Unimak Island had more birds than was observed during any other cruise. In both ACWn and ACWs, Short-tailed Shearwaters predominated.

Gulf of Alaska Water had similar overall bird densities in both northern and southern sectors, but the species composition was different between the two. In the south, where densities were highest of all cruises, Common Murres were the most frequent species. In the north, Whiskered Auklets predominated (although this species was more numerous in the Tidally Mixed Water).

In marked contrast to the results of the fall cruise, the Shelf Break Water was the least used in spring of any water mass. No species peaked in abundance in this habitat.

As mentioned above, the Tidally Mixed Water continued to be the major habitat for Whiskered Auklets. Although several species peaked in abundance here—murrelets, Pigeon Guillemot, cormorants—only Whiskered Auklets occurred in appreciable numbers.

Food Habits

Short-tailed Shearwater

We found no significant differences in the diets of four male versus six female Short-tailed Shearwaters in the occurrence of various food taxa (all hypergeometric probabilities >0.05/n, where n = no. of taxa compared). (The birds were not aged, but one of the females had a well-developed brood patch, indicating sexual maturity.) Therefore, we grouped males and females for the following description of shearwater diet.

The 10 birds contained 9,980 food items, of that all but three were *Thysanoessa* euphausiids. Two of the stomachs each contained a single *Parathemisto abyssorum* and a third stomach contained a single squid beak (probably representing a *Gonatus* squid of about 3.8 g, based on equations given in Clarke [1962]).

Food loads ranged from 0.007-34.7 g. Of the euphausiids that were identified to species (many items could be identified only to genus), *Thysanoessa inermis* formed 67-100% of observed diet wet weight in the ten stomachs, *T. spinifera* formed 0-33%, and *T. raschii* formed 0-2%. Overall, *T. inermis* formed 75.3% of identified euphausiid material, *T. spinifera* formed

Table 8. Average densities of the most common marine birds sighted during ship-based transects in spring, 1987, by water mass in the Unimak Pass area, Alaska. The highest density of each species is shown in bold face.

	SBW	TMW	GAWn	GAWs	ACWn	ACWs
Northern Fulmar	4.58	0.12	4.86	1.55	**5.86**	1.32
Short-tailed Shearwater	0.23	1.96	6.21	6.01	**82.53**	27.02
Fork-tailed Storm-Petrel	0.03	0.00	0.02	**0.12**	0.03	0.03
cormorants	0.00	**0.42**	0.01	0.00	0.13	0.05
Oldsquaw	0.20	0.08	0.02	**0.32**	0.16	0.09
Glaucous-winged Gull	0.45	0.85	**0.97**	0.91	2.72	0.90
Black-legged Kittiwake	0.57	0.74	0.94	1.10	**1.20**	0.40
Common Murre	2.21	5.17	4.48	**8.33**	3.14	2.41
Pigeon Guillemot	0.00	**0.23**	0.00	0.00	0.00	0.00
murrelets	0.00	**0.92**	0.10	0.23	0.18	0.30
Crested Auklet	0.00	1.26	0.22	3.83	1.82	**7.57**
auklets	0.00	**0.20**	0.12	0.11	0.16	0.15
Whiskered Auklet	0.00	**16.88**	8.30	2.68	0.03	0.61
Tufted Puffin	0.03	0.25	0.13	0.24	0.26	**0.30**
Total	8.28	29.10	26.37	25.43	**98.23**	41.16

Table 9. Lengths of identified euphausiids found in stomachs of Short-tailed Shearwaters collected in fall, 1986, and spring, 1987, in the Unimak Pass area, Alaska.

Taxon	Mean	S.D.	No. measured
Thysanoessa inermis	11.1	0.7	10
	11.2	1.0	10
	11.8	1.3	10
	11.1	3.8	10
	8.8	5.5	10
	13.7	3.0	10
	7.4	4.9	10
	10.9	1.3	10
all stomachs	10.8	3.2	80
Thysanoessa spinifera	12.4	2.1	8
	12.7	1.5	3
	15.8	6.4	4
	11.4	1.4	10
	12.5	0.6	4
	11.6	4.4	5
	13.6	1.7	5
	12.5	2.0	10
all stomachs	12.8	2.7	49
Thysanoessa raschii	10.3	2.7	6

24.0%, and *T. raschii* formed 0.2%. Identified euphausiids formed 29.7% of total euphausiid wet weight.

Mean lengths of *Thysanoessa inermis* ranged between 7.4-13.7 mm in eight stomachs where measurements were made. *T. spinifera* lengths ranged between 11.6-15.8 mm in eight stomachs. The *T. inermis* and *T. spinifera* present in the stomachs were similar in size (Table 9; Mann-Whitney U = 55; P>0.1).

Tufted Puffin

Ten Tufted Puffins were collected during the study for food habits analysis. Four adults and two juveniles were collected in fall (October), and four adults were collected in spring (May).

In fall, adult diets were dominated by squid (probably *Gonatus* spp.), which represented 57% of prey wet weight in the four stomachs. Squid was followed in order of dominance by gadid sp. (most likely pollock but possibly Arctic cod, *Boreogadus saida* [24.4%], saffron cod, *Eleginus gracilis* [17.7%], and unidentified fish), *Nucella* gastropods, unidentified gastropods, euphausiids, hyperiid amphipods and calanoid copepods (each less than 0.5%).

In the two juveniles collected in fall, squid formed 97.2% of diet wet weight, and unidentified fish comprised 2.5%. Decapods and copepods each contributed less than 0.5% to the juvenile diets.

On a numerical basis, squid (represented mostly by beak remnants) formed 17% of 29 items enumerated in adult stomachs and 95% of the 257 items enumerated in the stomachs of juveniles. Based on known ratios between squid beak lengths and body weights, most of the squid ingested were small; estimated wet weights ranged from 0.2 - 2.4 g. Otoliths and flesh from two unidentified cod and two saffron cod were found in one adult stomach. Estimated mean lengths of the fish were 76 and 15 mm for the unidentified cod (based on otolith-length relationships from arctic cod) and 58 and 7 mm for the saffron cod.

Most of the fall specimens of Tufted Puffin were collected in areas distant from the Krenitzin Islands (near the southern limit of the study area in deep water). Closer to the Krenitzins most puffins were seen carrying fish, and samples of prey brought to chicks in the nesting colonies were predominantly small pollock (S. Hatch, USFWS pers. comm.).

In the spring collection of puffins, one of the females had an empty stomach and the other female and two males contained 101.7 g of food material. Of this amount, 99.6% was *Ammodytes*, 0.4% was unidentified sculpins, and 0.1% was *Nucella* gastropods. Measurable *Ammodytes* were present in two stomachs, differing significantly in size between the two samples (105 and 18 mm [n=9], vs. 63 and 37 mm [n=8], $t=-2.94$, $P<0.02$).

Common Murre

Eleven Common Murres were collected during the study, and all but one stomach contained food. Stomachs of three adult females were analyzed from winter collections and those of seven birds (two adult males, two adult females, two subadult females, and one unaged male) from spring collections.

The three females in winter had been feeding exclusively on two species of *Thysanoessa* euphausiids (9.4 g of total food material in the three stomachs). Identified euphausiids were 26% of the total material; 96% of this was *T. inermis* and 4% was *T. spinifera* . Measurable *T. inermis* were present in two stomachs and were similar in size (grand mean of 17.2 mm; $t=1.8$, $P>0.05$). Only two of the seven identified *T. spinifera* were measurable; these were 14.5 and 0.7 mm.

Birds collected in spring contained a total of 163.3 g of food material, but almost all of it (161.6 g) was from two birds. Wet weight composition of the total diet was 98.9% *Ammodytes* (present in two stomachs), 1.0% unidentified fish (present in two stomachs), 0.1% *Thysanoessa* euphausiids (present in three stomachs) and <0.1% *Parathemisto* amphipods and *Gonatus* squid (each present in one stomach). In the two stomachs where *Ammodytes* could be measured, mean lengths were similar (grand mean of 111 mm; $t=1.3$, $P>0.05$). The lengths of *Thysanoessa inermis* present in the one stomach where they were measurable ranged from 2.7 to 16.2 mm ($n = 10$).

Whiskered Auklet

Twenty-three Whiskered Auklets were collected for food habits studies: nine in fall, nine in winter, and five in spring (Table 10).

During fall, the wet-weight biomass composition of diets was 93.3% euphausiids, 2.6% unidentified crustacea, 1.5% *Neocalanus plumchrus* (a copepod), 1.1% each of *Nucella* gastropods and unidentified gammaridean amphipods, 0.3% unidentified gastropods, and 0.2% unidentified fish. Only 11% of the euphausiid material could be identified to species; *Thysanoessa inermis* formed 70% and *T. spinifera* 30% of this material.

Diet of winter birds was again dominated by euphausiids (99.8% of observed wet weight). Stomachs also contained small amounts of the copepods *Calanus glacialis, Neocalanus plumchrus,* and *Candacia columbiae* (0.2%) and traces of fish (<0.1%). Only 24% of the euphausiid material was identified to species; *T. inermis* formed 92%, *T. longipes* 7%, and *T. spinifera* 1% of this material.

Table 10. Age and sex compositions and collection locations of Whiskered Auklets collected for food habits studies, 1986 and 1987, Unimak Pass area, Alaska.

Cruise	Age/Sex*	Station	Date(s) Collected
Fall	3 ADM	26.2	10 October 1986
	1 SAM	26.2	10 October 1986
	2 UNM	10.3	27 September 1986
	3 UNF	10.3	27 September 1986
Winter	2 ADM	9.5,21.3	1 March 1987, 6 March 1987
	1 SAM	21.3	6 March 1987
	2 UNM	Derbin Str.	3 March 1987
	2 ADF	9.5	1 March 1987
	1 SAF	9.5	1 March 1987
	1 UNU	9.5	1 March 1987
Spring	1 ADM	8.1	30 April 1987
	2 UNM	8.1	30 April 1987
	1 UNF	8.1	30 April 1987

* AD = adult, SA = sub adult, UN = unknown age, M = male, F = female, U = unknown sex.

In spring, euphausiids (all identified material was *T. inermis*) formed 99.3% of the diet, followed by *Neocalanus plumchrus* (0.4%) and fish (0.3%).

The euphausiid *Thysanoessa inermis* was the dominant food taxon in all three collections. The average length of measured *T. inermis* declined through the study: 13.6 mm in the fall, 12.1 mm in the winter, and 11.2 mm in the spring.

Crested Auklet

During the winter cruise, nine Crested Auklets (2 adult males, 3 subadult males, and 4 subadult females) were collected. None was collected in other seasons.

Diet of Crested Auklets was mainly euphausiids (99.9%) with traces of the amphipod *Hyperia galba* (0.1%) and *Metridia pacifica* (<0.1%). Fourteen percent of the euphausiid material was identified to species; *Thysanoessa inermis* formed 80%, *T. spinifera* formed 12%, and *T. longipes* formed 8%. Mean lengths of *T. inermis* ranged from 9.5 to 14.8 mm in eight stomachs.

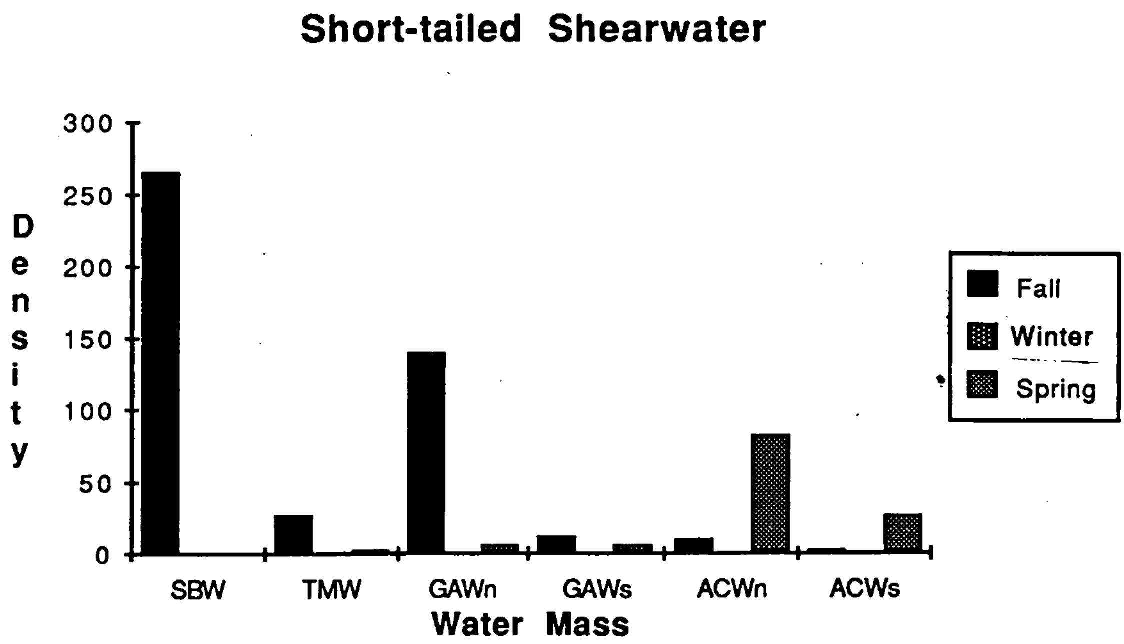
DISCUSSION

Seasonal Abundance

Most species recorded during this study exhibited rather substantial seasonal variations in abundance. Most of this was expected based on findings of other studies and on knowledge about the biology of the study species. Perhaps the only key species that could be considered to be resident in relatively constant levels of abundance was the Whiskered Auklet. Although this species is little studied, and thus details of its biology poorly understood, existing information suggested that it wintered near its breeding grounds. Seasonal changes in its abundance would thus be largely due to reproductive output and mortality, rather than to seasonal movement or migration.

Some comparisons between the present study and the nearby North Aleutian Shelf studies (Troy and Johnson 1987) with respect to seasonal abundances of Crested Auklets and Short-tailed Shearwaters are of interest. These two species seasonally dominated the avifauna in both areas.

Both studies reported a large wintering aggregation of Crested Auklets on the northwest side of Unimak Island. The Unimak Pass study found that substantial numbers of Crested Auklets also occurred in the tidally mixed waters of the Krenitzin Islands (Fig. 9), and that Akutan Pass was another, though secondary, center of abundance.



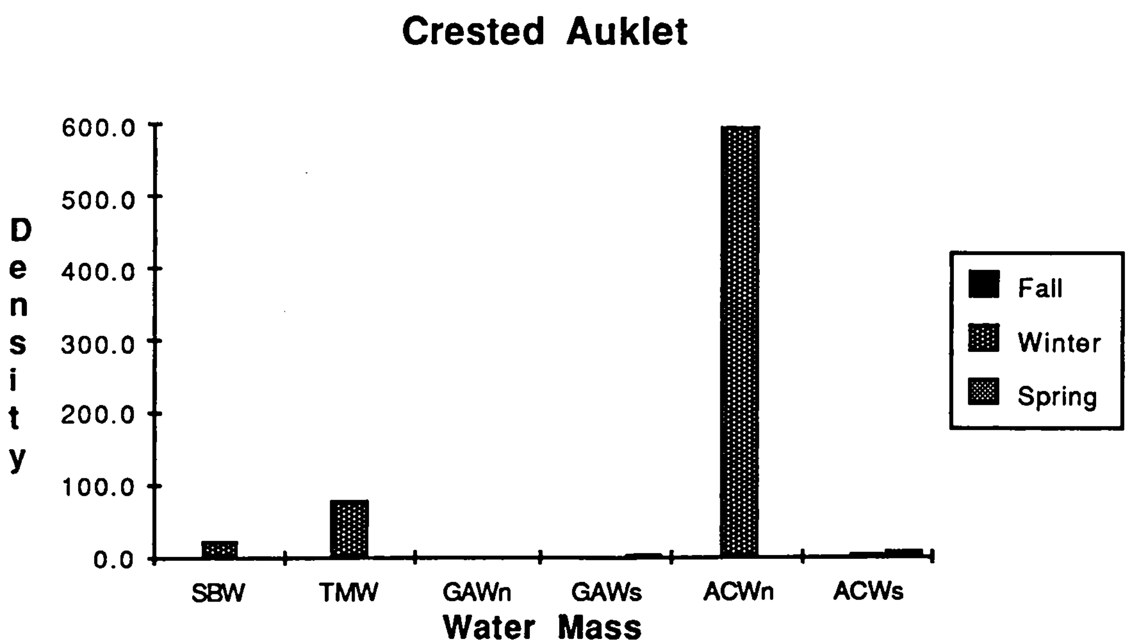


Figure 9. Average densities of Short-tailed Shearwater and Crested Auklets by water mass during fall, 1986, and winter and spring, 1987, in the Unimak Pass area, Alaska. Density estimates are based on results of ship-based surveys. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

Short-tailed Shearwaters, virtually absent from the North Aleutian Shelf during fall, reached their peak abundance in the Unimak Pass study area at this time. This difference between the two areas seems attributable to differences in water masses present. As this study's results of densities by water mass show (Fig. 9), few shearwaters were present in fall in the Unimak Pass area in the Alaska Coastal Water; this was the only water mass sampled by the North Aleutian Shelf study. In spring, Short-tailed Shearwaters in the Unimak Pass area were almost restricted to the Alaska Coastal Water. It was during spring, a few weeks later than the timing of the Unimak Pass spring cruise, that shearwater abundance soared in the North Aleutian Shelf, supporting the idea that water mass distributions affected relative abundances between the two areas.

Spatial Distribution

Fall. The distributional maps for fall (Fig. 4) reveal some important patterns at both coarse and fine scales. On a broad scale it is evident that relatively few marine birds were present in the Gulf of Alaska away from land. However, many birds must use this region at some times, or even regularly, during the fall. The incredible number of shearwaters present to the north presumably pass through this area in fall during their southward migration, although it is possible they exit to the west (e.g., Samalga Pass). The Tufted Puffins breeding in the Krenitzin Islands must also make at least temporary use of the Gulf of Alaska. During our surveys we regularly encountered fledged puffins swimming south away from the Krenitzin Islands, and molting puffins, presumably subadult birds, were also found, albeit in low numbers, in the deepest part of the study area. It appears that puffins rapidly transit this area for regions beyond the study area. This same passage must be made on a more regular basis by the hundreds of thousands of nesting Leach's Storm-Petrels in the study area; this species was rarely recorded on transects yet it apparently transits the Gulf of Alaska portion of the study area between each visit to the nest to forage in the deep waters to the south.

The highest densities of birds were found in the Bering Sea and in the Krenitzin Islands. In this area most birds were found to the west of Unimak Pass; i.e., outside of the influence of the Alaska Coastal Current.

Perhaps the most important finding was a local concentration area involving many species located north of Akun Island in the northwestern portion of Unimak Pass. This area harbored spectacular concentrations of shearwaters, puffins, phalaropes and other birds. This region corresponds to an area of presumed upwelling, being an isolated location having salinities similar to the Shelf Break Water rather than the surrounding Gulf of Alaska

Water. It was in this area that we also had our highest catches of zooplankton (primarily euphausiids) in surface tows.

Winter. During the winter cruise, the broad-scale distributions of most marine birds revealed both a contraction and shift relative to the fall season. Most birds had vacated the deeper areas and more were concentrated near land. The passes and straits of the Krenitzin Islands and Unimak Pass thus had large numbers of birds. The change in distribution appeared as an expansion eastward such that large concentrations, especially of Crested Auklets, were now present in the Alaska Coastal Water north of Unimak Island. Murres were numerous but, as was found in the NAS studies, they were concentrated west of the Crested Auklets. In this study we found that their abundance extended west from Cape Sarichef through Avatanak Strait, at least to Akun Strait.

On a more local scale, major concentrations of birds, again mostly auklets, were found in Akutan Pass (Crested and Whiskered auklets) and Derbin Strait (Whiskered Auklets) within the Krenitzin Islands area. Sampling in the passes and straits of the Krenitzin Islands revealed high (though variable) abundances of invertebrate prey.

The Slime Bank area north of Unimak Island where the Crested Auklets were aggregated was found to have major concentrations of euphausiids within foraging range of the auklets. The observation that murre concentrations were west of the auklets (as noted in the NAS studies) may be due to the greater depth range of murres. Both groups were feeding on euphausiids as indicated by dietary analyses.

Spring. During spring there were fewer birds present than during the prior cruises and these were more dispersed. The net result was that concentrations of birds were much less noticeable than during the other cruises.

The importance of passes was perhaps most noticeable at this time of year. All the largest aggregations were present in or, more usually, just off passes. These included Short-tailed Shearwater migrants through Unimak and Ugamak passes, murres south of Akutan Pass, and auklets off most passes of the Krenitzin Islands. The auklets demonstrated an interesting distributional pattern—Crested Auklets occurred south of the Krenitzins and Whiskered Auklets were north of and within the Krenitzins.

The zooplankton distribution data indicate that in spring the major concentrations of euphausiids still occurred along the north side of Unimak Island. This was not where the birds were but, based on existing knowledge, where the shearwaters were heading. The relatively high abundance of birds near passes but the low zooplankton catches there may indicate that tidal action resulted in regular but ephemeral concentrations of prey that the birds were able to exploit but that we missed. Zooplankton availability may increase during periods of high currents when we were unable to sample within or near the passes.

Associations with Water Masses

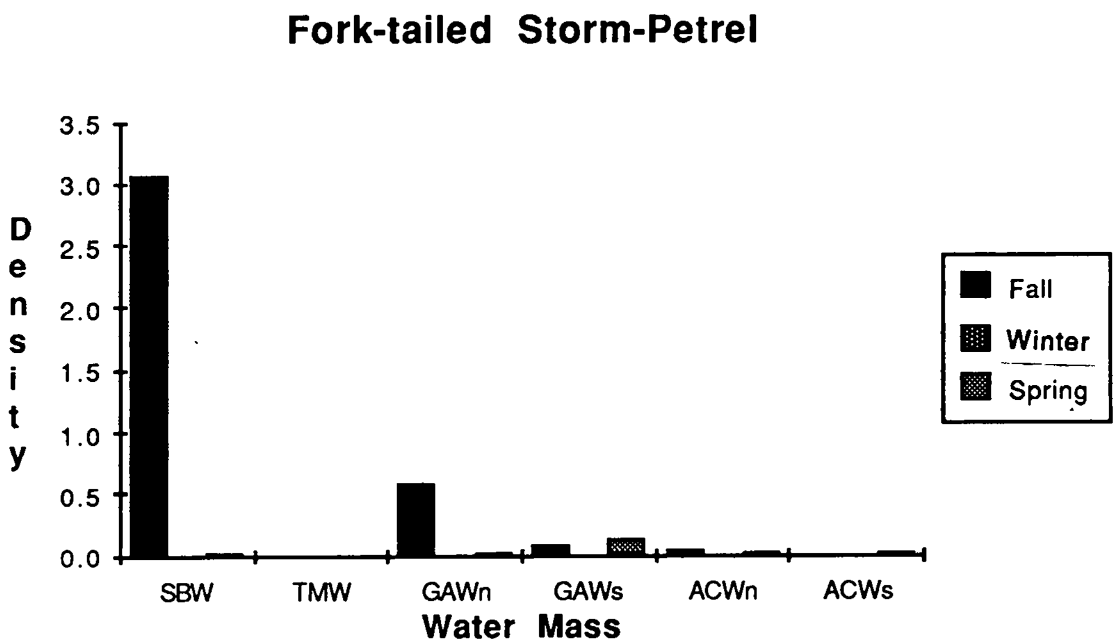
All the species examined exhibited rather striking associations with particular water masses or with subsets of water masses, as indicated above by the seasonal influence of water masses on Crested Auklet and Short-tailed Shearwater. Examples from some of the other key species are summarized here.

Two species—Fork-tailed Storm-Petrel and Black-legged Kittiwake—were characteristic of Shelf Break Water (Fig. 10). Both these species were rare except during fall. In the North Aleutian Shelf area, Black-legged Kittiwakes were most frequent during the nesting season near colonies (Troy and Johnson 1987). In the case of the Unimak Pass area, we had neither a summer survey nor the presence of colonies of these species, so predictions would be difficult to make about their summer distribution.

Fulmars showed a fair bit of variability in water mass use, with some seasonal trends apparent (Fig. 11). They peaked in the Shelf Break Water during fall and in the Alaska Coastal Water (north) during winter and spring. In both spring and fall they were frequent in the Gulf of Alaska Water in the north, but not in the south. Tidally Mixed Waters and the Alaska Coastal Water (south) were also rarely used. Their distribution may be partly explainable by the distribution of fishing fleets, as this species is prone to scavenging for offal. However, at all times they tended to stay in the Bering Sea, even though fishing vessels occupied the Gulf of Alaska side of the study as well as the Bering side.

Glaucous-winged Gulls provided a much simpler picture (Fig. 11). Seasonal variability appeared minimal. The highest densities were located in the Alaska Coastal Water (north), but all water masses were used. Glaucous-winged Gulls are the most consistently encountered seabird of the Unimak Pass and North Aleutian Shelf areas.

Somewhat surprising was the distribution of seaducks (Fig. 12). Seaducks were identified as a key study group because it was suspected that major wintering concentrations might be found in the Krenitzin Islands. As will be confirmed later (Chapter 7: COASTAL MARINE BIRDS AND MAMMALS, this volume) there were indeed seaducks present but no major concentrations. Populations along the North Aleutian Shelf (Troy and Johnson 1987) were substantially larger. Similarly, our census data revealed higher seaduck densities in the northern Alaska Coastal Water (i.e., along Unimak Island adjacent to the North Aleutian Shelf) than in the Tidally Mixed Water of the Krenitzin Islands. The association with the ACW may be



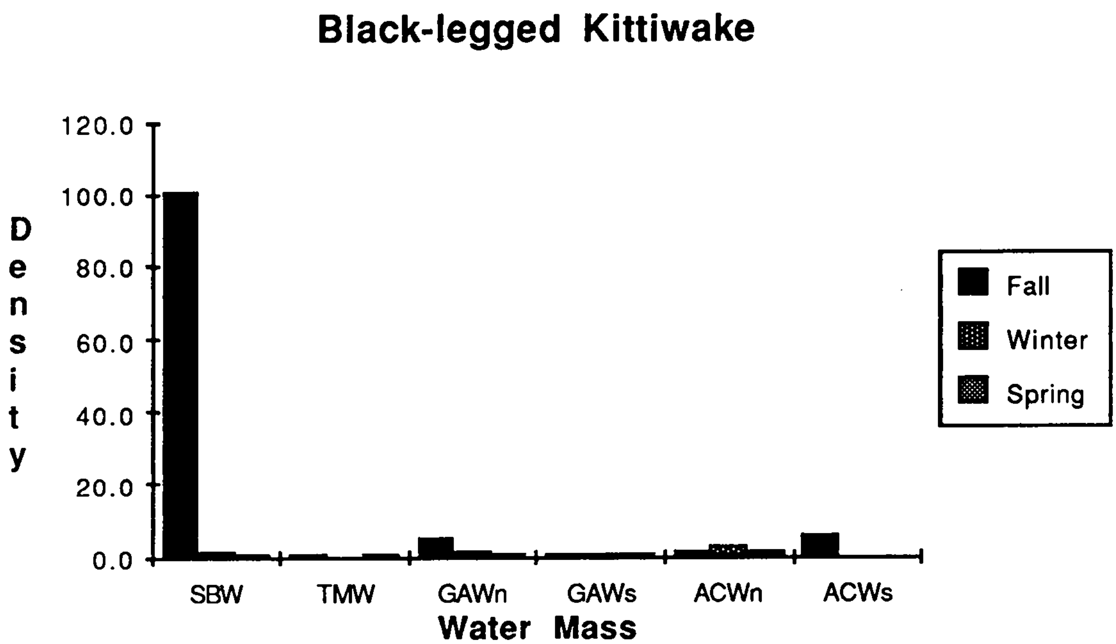
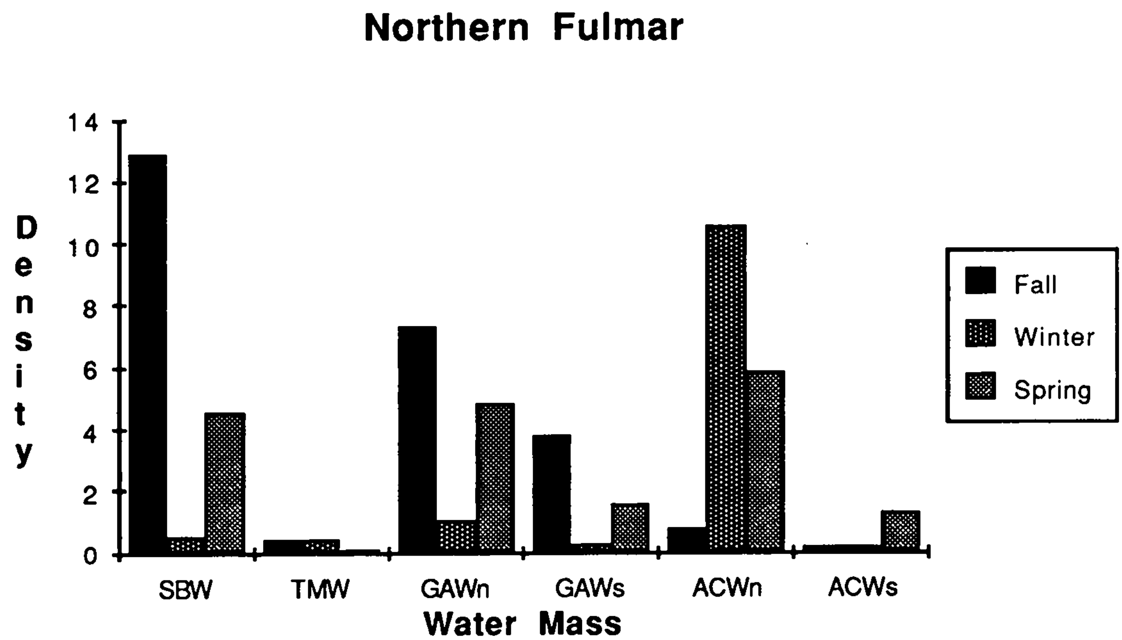


Figure 10. Average densities of Fork-tailed Storm-Petrel and Black-legged Kittiwake by water mass during fall, 1986, and winter and spring, 1987, in the Unimak Pass area, Alaska. Density estimates are based on results of ship-based surveys. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.



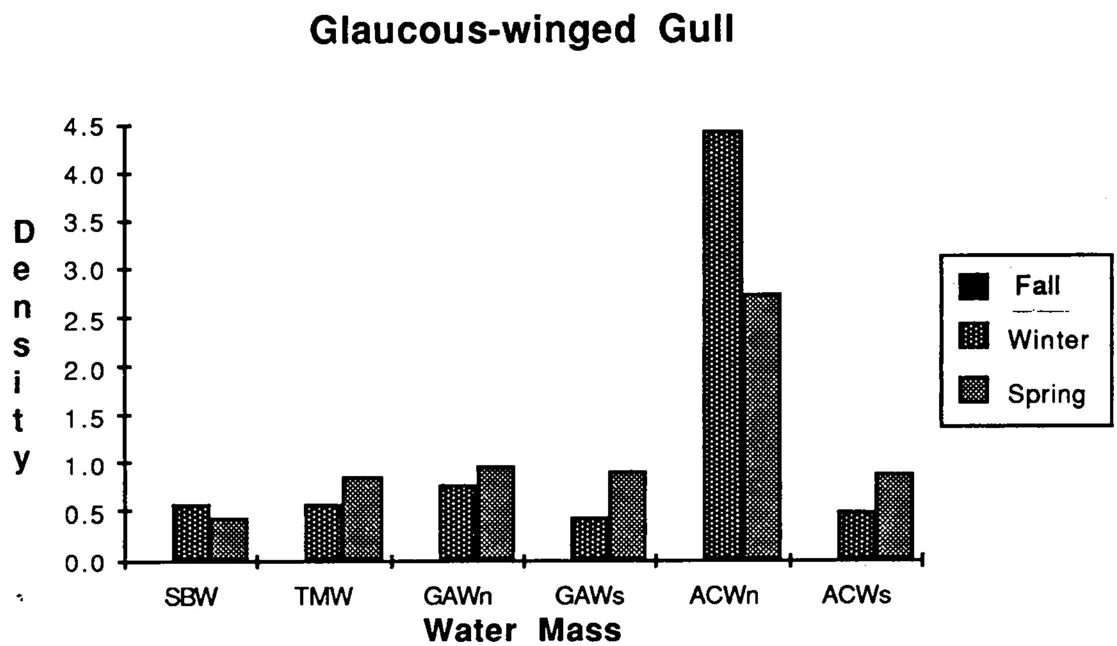
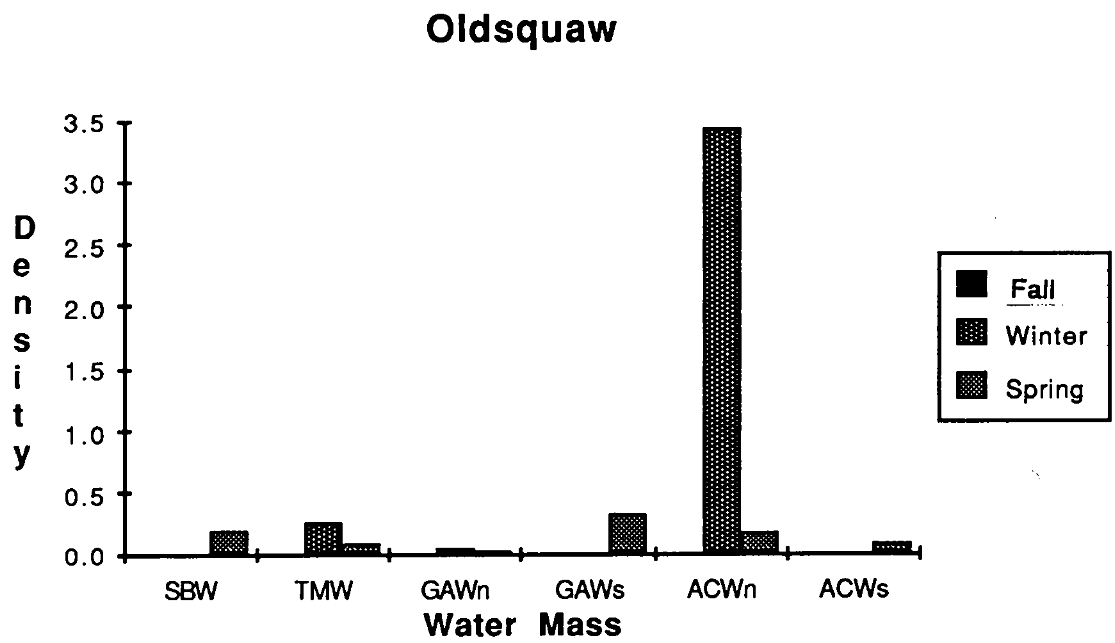


Figure 11. Average densities of Northern Fulmar and Glaucous-winged Gull by water mass during fall, 1986, and winter and spring, 1987, in the Unimak Pass area, Alaska. Density estimates are based on results of ship-based surveys. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs=Alaska Coastal Water south.



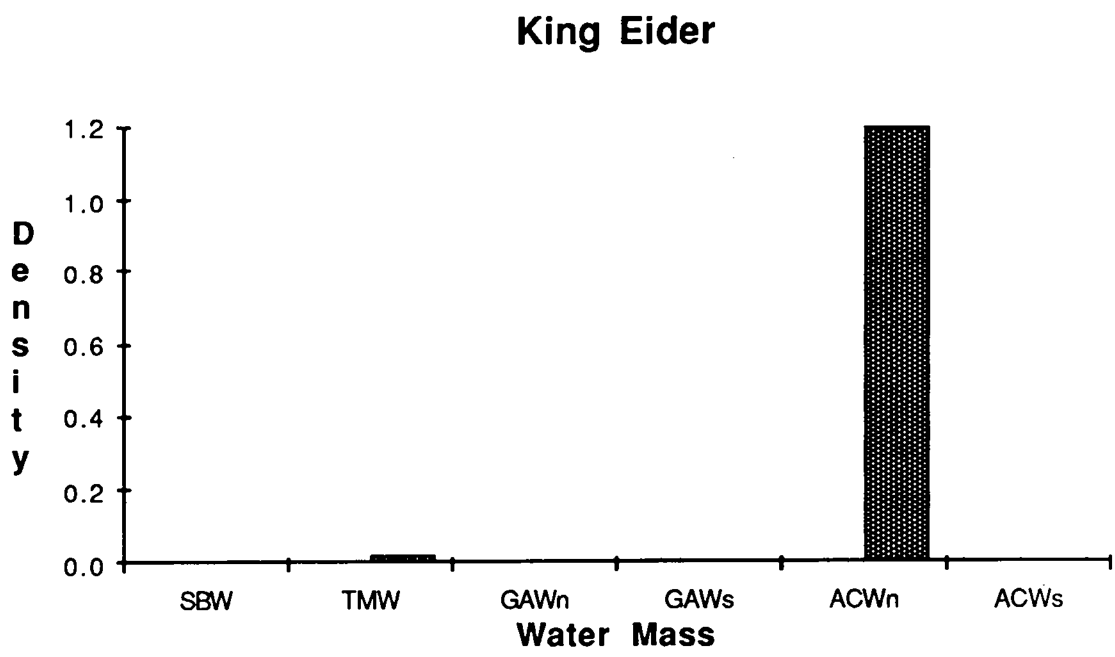


Figure 12. Average densities of Oldsquaw and King Eider by water mass during fall, 1986, and winter and spring, 1987, in the Unimak Pass area, Alaska. Density estimates are based on results of ship-based surveys. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

partly depth-related, because the ACWn occupies most of the shallow water (≤ 50 m) sampled, and the seaducks are all bottom feeders and cannot forage in the deeper areas. However, Nyström and Pehrsson (1988) suggested that salinity also is an important habitat barrier for wintering diving ducks, and the ACW in general is the least saline water mass in the study area.

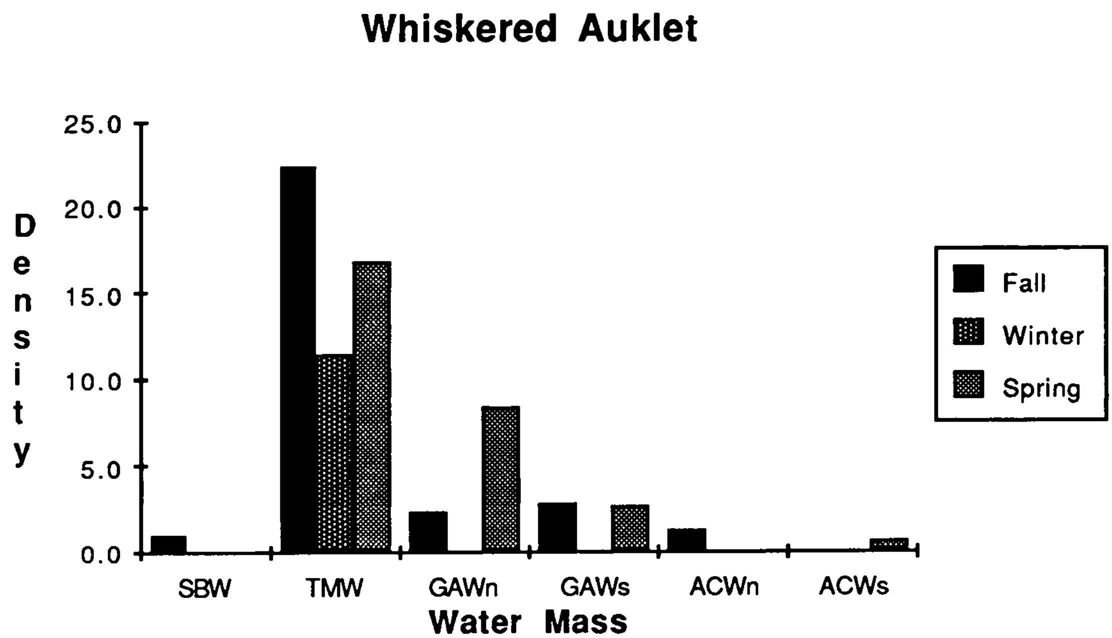
The Tidally Mixed Water had the most distinctive avifauna. The species most characteristic of this habitat were Whiskered Auklet and Tufted Puffin (Fig. 13). Whiskered Auklets were always present and always predominantly within this water mass. They ventured into the Gulf of Alaska Water both north and south of the Krenitzin Islands but in relatively low numbers. The puffins, in contrast, were present only during fall. They are known to nest abundantly in the Krenitzin Islands and, during nesting, to do most of their foraging near the colonies; during winter, they disperse. The fall cruise occurred while most birds were still feeding nestlings.

Several studies have documented concentrations of seabirds associated with oceanographic features. Some parallels between our results and those of other investigators are apparent. For example, Brown (1988) found that wintering Dovekies (*Alle alle*), the only auklet common in the Atlantic, were attracted to boundary fronts and dense swarms of zooplankton near the shelf break off maritime Canada. The huge auklet concentrations in the Unimak Pass area seemed associated with zooplankton swarms (though not with fronts *per se*). Both Brown's and our studies did find that auklets were associated with dense swarms of zooplankton.

Food Habits

A main finding of the dietary analyses was the importance of *Thysanoessa* euphausiids, especially *T. inermis,* to some birds. *T. inermis* has the center of its distribution in Alaskan waters in the Pacific Ocean (Brinton 1962), and in the Bering Sea is typically an oceanic species, sometimes common over shelf margins (Cooney 1979). In this study, *T. inermis* was found to be important to Short-tailed Shearwaters and Whiskered Auklets during the fall; to Common Murres, Whiskered Auklets and Crested Auklets in the winter; and to Whiskered Auklets in the spring. The importance of euphausiids in the diet of Short-tailed Shearwaters was demonstrated earlier by Krasnow and Sanger (1982) and Sanger (1983).

Previous to this study, the diet of Whiskered Auklets was virtually unknown. Byrd and Gibson (1980) and others have noted that these birds are found in close association with tide rips and other surface water discontinuities in the Aleutians. This study found that the birds were taking *Thysanoessa* euphausiids almost exclusively, regardless of the season. Copepods, including *Calanus glacialis, Neocalanus plumchrus,* and *Candacia columbiae* were taken in only trace amounts.



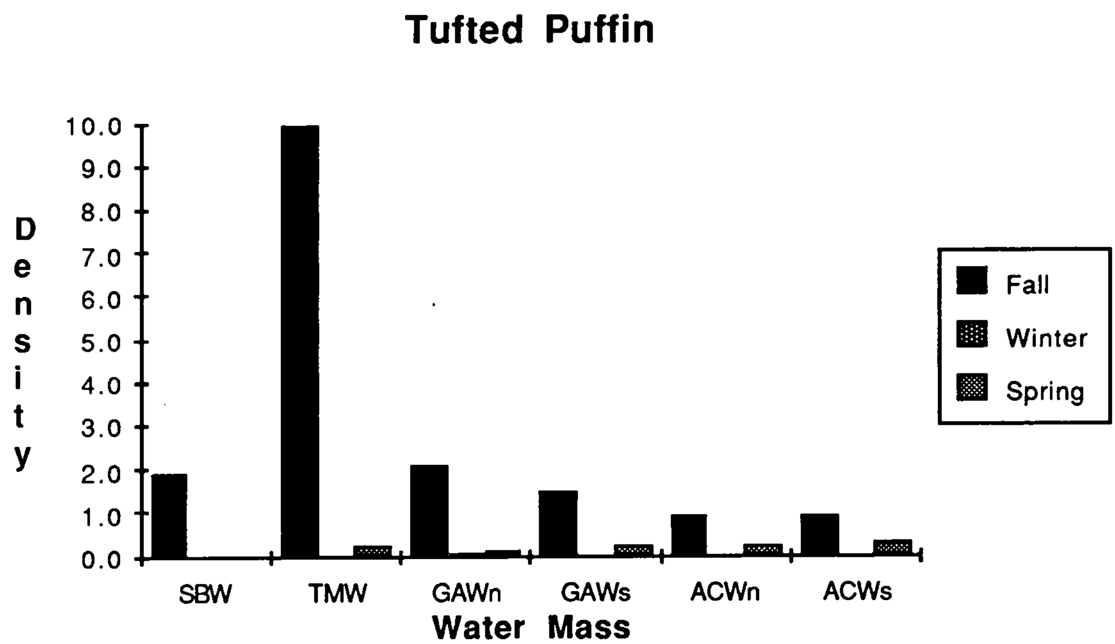


Figure 13. Average densities of Whiskered Auklet and Tufted Puffin by water mass during fall, 1986, and winter and spring, 1987, in the Unimak Pass area, Alaska. Density estimates are based on results of ship-based surveys. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

Crested Auklets are well known to specialize on euphausiids during the breeding season (Bedard 1969, Hunt et al. 1981a, Bradstreet 1985). Bedard (1969) found that Crested Auklets took other invertebrate types early in the breeding season, and Krasnow and Sanger (1982) found the mysid *Acanthomysis* to be dominant in stomachs of two birds collected in January near Kodiak Island. Sanger (1983) found that amphipods and copepods, in addition to mysids, were important food items. In this study, Crested Auklet diet was composed almost solely of euphausiids, with *Thysanoessa inermis* predominating; only traces of amphipods (*Hyperia*) and copepods (*Metridia*) were found.

In this study, the stomachs of three Common Murres collected in winter contained *Thysanoessa* euphausiids. Elsewhere, winter diet is largely fish (Tuck 1960, Baltz and Morejohn 1977, Blake et al. 1985), though Sanger (1987) found mysids and shrimp to be important in Kachemak Bay, Alaska, in winter. Common Murres are also known to feed on euphausiids during the summer (e.g. Hunt et al. 1981a, Schneider and Hunt 1982, Bradstreet 1985), though the diet then is usually dominated by fish.

In spring, the stomach contents of seven murres collected in this study were mostly *Ammodytes*, although euphausiids occurred in more stomachs than did fish. Blake et al. (1985) reported seasonal changes in the diets of Common Murres collected in the North Sea, but the changes noted were mainly among species of fish. In their samples, invertebrate remains (polychaete jaws) occurred mainly in winter.

Of the five species collected, only Tufted Puffins did not use euphausiids to a significant degree. The puffins collected depended largely on small *Gonatus* squid during the winter and *Ammodytes* fish during the spring. Other observations indicated that small pollock were important, at least as food for nestlings, during the fall. Wehle (1982) found that adult and subadult Tufted Puffins collected in the western Aleutians during the summer relied primarily on squid—squid occurred in 85% of 106 stomachs and fish occurred in 26%.

RECOMMENDED FURTHER RESEARCH

Temporally, our surveys occurred during three of the four seasons. Missing was sampling during summer, a period of intensive bird use of the adjacent North Aleutian Shelf and probably the Unimak Pass area. Summer also corresponds to the breeding season, when large numbers of seabirds are known to use the Krenitzin Islands.

Spatially, our coverage was rather complete and, in conjunction with the North Aleutain Shelf studies, provides good coverage of much of the region. Missing in comparable coverage are the region to the southeast (south side of the Alaska Peninsula) and to the west. Although there are known areas of importance along the south side of the Alaska Peninsula, those areas immediately adjacent to our study area did not appear to support large numbers of birds during the seasons surveyed. The southern portion of the Alaska Coastal Current was the most consistently poor area for birds. Thus we would not recommend research in this area as a priority. In contrast, the observation of intensive bird use of areas off passes, especially on the north side of the Aleutian Islands, and the observations of major nutrient influxes from the west into the northern parts of the Unimak Pass area (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume), suggest that further research in the waters north and west of Unimak Island is high priority.

The main areas of research that would best complement what we have done thus far are:

1) To conduct an additional cruise similar to the ones described in this report during the summer season, perhaps late June and early-July, and

2). To conduct a study similar to the Unimak Pass investigation that extends coverage as far west as Samalga Pass in the Aleutian chain.

ACKNOWLEDGEMENTS

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We are indebted to the entire crew of the *Miller Freeman* for their cooperation and assistance in making this cruise such a success. The concern and interest expressed by all personnel from the galley through the engineering department and the deck crew was beyond our expectations. We appreciate the efforts of the OODs and quartermasters in making the endless annotations on the echosounder tracings

The assistance provided by a few individuals deserves special mention. CDR Taguchi found ways to accommodate our innumerable trips through all passable passes in the Krenitzin Islands. LT Brian Hayden (FOO) accommodated all our requests and last minute changes in plans allowing us to obtain all our samples where and when we wanted them. He also prepared a chart overlay detailing our accomplishments.

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Chapter 6

Marine Mammal Abundance and Habitat Use

by

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SUMMARY

Shipboard surveys were conducted to census abundance and distribution of marine mammals in the Unimak Pass area in fall, 1986, and winter and spring, 1987. Important findings include the following:

(1) The overall density of marine mammals in the area was highest in fall (0.223 mammals/km^2), lower in winter (0.104 mammals/km^2), and lowest in spring (0.076 mammals/km^2).

(2) Dall's porpoises were in all seasons the most numerous of the marine mammals; their abundance patterns among seasons paralleled the patterns described for all species combined. During winter and spring, Dall's porpoises were restricted to the deeper portions of the study area but during fall they were much more widespread.

(3) Northern fur seals were never encountered with high frequency in the study area but they were the second most numerous mammals in the fall when they peaked in abundance (0.039 mammals/km^2). Most fur seals were encountered in the Bering Sea portion of the study area.

(4) Sea otters were the only other marine mammals commonly encountered in areas sampled by shipboard surveys. They were found primarily among the Krenitzin Islands but also close to Unimak Island. Sea otters were considerably more numerous in the fall than during winter and spring (0.029/km^2 vs. $\approx$0.008/km^2).

(5) Humpback whales were encountered during fall north of Unimak Pass in an area noted by prior investigators to have relatively high abundances of this species.

(6) Fin whales were encountered during spring in and north of Unimak Pass.

(7) High numbers of several marine mammals, including Dall's porpoises, sea otters, and humpback whales were found in fall in an area of potential upwelling located northeast of Akun Island.

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INTRODUCTION

Unimak Pass is one of the major migration corridors for mammal populations entering and leaving the Bering Sea (Thorsteinson 1984). The diversity and seasonal abundance of marine mammals that occur in and adjacent to Unimak Pass and along the continental slope can be found in no other part of Alaska and perhaps the world (Braham et al. 1982), though the ecological significance of the region to marine mammals is not yet fully understood.

An oil spill in Unimak Pass could potentially impact major portions of regional populations of some species. Major portions of populations of humpback, fin, and gray whales and northern fur seals move seasonally through the pass. Indeed, gray whale passage through the Aleutian Chain appears to be restricted to Unimak Pass itself, though humpback and fin whales also use other Aleutian passes. A spill large enough to significantly oil waters of the pass in early spring or late fall could expose great numbers of fur seals and gray whales to hydrocarbon contaminants. Mortalities of fur seals during these periods would likely be high.

Additional information on marine mammal use of the area is needed to help assess potential impacts from development. The purpose of this study was to help evaluate the seasonal abundances and distributions of marine mammals in Unimak Pass habitats to help fill this need.

CURRENT STATE OF KNOWLEDGE

Many surveys of marine mammals, especially those for endangered whales, have included the Unimak Pass area in their regions of coverage. These survey programs were usually broad scale with the eastern Bering Sea serving as the study area. Consequently, sampling within a small area such as the eastern Aleutians has been very limited, and the precise locations of sightings made in the Unimak Pass area are often difficult to ascertain.

However, these studies are useful for placing the eastern Aleutian region in perspective with reference to the surrounding Bering Sea and North Pacific. Particularly useful reviews were provided by Leatherwood et al. (1983), Lowry et al. (1982b), Truett and Craig (1986), Thorsteinson (1984), and Hameedi (1982). Materials from these reviews were drawn upon extensively in the species summaries that follow.

The selection of marine mammal species on which to focus survey effort is easy because few are sufficiently abundant for surveys of them to provide meaningful information. The RFP requested that northern fur seals receive emphasis, and this species is among those that have been most frequently encountered in previous surveys. Other species of greatest abundance include sea otter, Steller sea lion, Dall's porpoise, and gray whale (Tables 1 and 2). Although now rare, several species of endangered whales were formerly frequent in this area. Life history information of these five abundant species and brief summaries of the endangered whales and a few additional species of regular occurrence are provided below.

Key Species

Gray Whale (Eschrichtius robustus)

The gray whale is the most numerous and thoroughly-studied whale occurring within the study area. It is a coastal species with regular, well-defined patterns of migration. Although formerly classed as an endangered species because it had been reduced to low populations by intensive whaling, gray whales have recovered to population levels at or near their pre-exploitation stock size (Reilly 1984, Reeves and Mitchell 1988). Despite this recovery, gray whales are still officially considered a threatened species. Results of the numerous recent studies of this species have been summarized by Lowry et al. (1982a, b).

The majority of the 17,000 eastern Pacific gray whales (Rugh 1984, Reilly 1984) migrate annually from breeding/calving lagoons off Baja California and mainland Mexico to feeding grounds that extend from the central Bering Sea northward and eastward into the Chukchi and Beaufort seas. All of the gray whales entering the Bering Sea travel through Unimak Pass (Rugh and Braham 1979, Braham et al. 1982, Hessing 1981). Scattered groups summer along much of the migration corridor although none have been reported residing within our study area. The nearest regularly-used summering areas are Nelson Lagoon on the north side of the Alaska Peninsula (Gill and Hall 1983) and Kodiak Island south of the Peninsula (Leatherwood et al. 1983).

The northward migration occurs in two pulses, the first consisting of nonparturient adults and immature animals, the second principally of females and their calves of the year (Rugh 1984). These migrants move through Unimak Pass near the eastern shore (=west coast of Unimak Island) between March and June (Rugh and Braham 1979, Braham 1984, Rugh 1984) and then continue along a narrow coastal corridor into Bristol Bay. A few may migrate directly northwestward to the Pribilof and St. Matthew islands.

The southbound migration has not been as clearly described. Based on shore censuses of gray whales migrating through Unimak Pass in fall 1977-79, Rugh (1984) concluded that the exodus from the Bering Sea occurs from late October through early January, with peak numbers passing during mid-November and mid-December. As in spring, the whales remain very close to the eastern shore as they transit the Unimak Pass area. Rugh (1984) found no

Table 1. Densities of marine mammals ($/km^2$) in Unimak Pass recorded during North Aleutian Shelf aerial surveys (Troy unpubl.).

SPECIES/SEASON	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Sea Otter	0.03	0.02	0.03	0.02		0.08		0.05		0.08	0.15	0.12
Steller's Sea Lion	0.27	0.60	0.35	1.42		0.00		0.04		0.13	0.00	0.66
Northern Fur Seal	0.00	0.02	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Pac. White-sided Dolph	0.00	0.00	0.00	0.01		0.00		0.00		0.00	0.00	0.00
Harbor Porpoise	0.01	0.00	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Dall's Porpoise	0.00	0.00	0.00	0.00		0.01		0.00		0.01	0.00	0.00
Gray Whale	0.00	0.00	0.00	0.03		0.01		0.00		0.00	0.00	0.03
TOTAL	0.30	0.65	0.38	1.51		0.10		0.10		0.23	0.15	0.80

Table 2. Densities of marine mammals ($/km^2$) in the Unimak-Krenitzin Islands area (FWS pelagic database).

SPECIES/SEASON	April-May	June-Aug	Sept-Oct	Nov-March
Dall's Porpoise		0.19	0.03	
Killer Whale	0.04			
Minke Whale		0.01		
Sea Otter		0.04		
pinniped		0.01		
Steller's Sea Lion		0.13	0.07	
Northern Fur Seal		0.08	0.13	0.18
Harbor Seal		0.01		

whales more than 3.7 km west of Unimak Island; the whales observed were at a median distance of 0.5 km. from shore.

Gray whales apparently feed during migration (Braham 1984, Norris 1979), although the frequency and intensity of feeding during migration is much less than during the summer. Gray whales feed almost exclusively on nektobenthic, epifaunal, and infaunal invertebrates. Primary prey in certain parts of the northern Bering and Chukchi seas are ampeliscid and gammarid amphipods that form dense mats. The distribution of gray whales during the summer is probably determined by the presence of large amphipod beds. Important amphipods in the summer diet include *Amphelisca macrocephala, Lembos arcticus, Anonyx nugax, Pontoporeia femorata, Eusirus* sp., and *Atylus* sp. (Zenkovich 1934, Tomlin 1957). Gray whales also consume polychaetes, small bivalves, gastropods, mysids, and herring (Zimushko and Lenskaya 1970, Frost and Lowry 1981, Nerini 1984).

Dall's Porpoise ***(Phocoenoides dalli)***

Dall's porpoise is distributed widely within the cool temperate to subpolar waters of the North Pacific. Probably the most numerous cetacean in the area of interest, Dall's porpoise is present year-round. They are most abundant in deep pelagic waters and in areas along the continental shelf break. Summer observations, particularly those in June and July (e.g., Kawamura 1975, Wahl 1978), indicate that Dall's porpoises are abundant near the Aleutians and along the edge of the continental shelf, particularly between the Pribilof Islands and Unimak Pass. Migratory movements are not well understood but seasonal movements evidently occur (Braham et al. 1982). The distribution shifts southward in winter, with some animals leaving the Bering Sea (Fiscus 1980).

Analyses of the stomach contents of porpoises caught in the Bering Sea and Aleutian Islands region by the high seas salmon gillnet fishery have provided some information on their foods. Mizue and Yoshida (1965) and Mizue et al. (1966) found mostly squid and small amounts of fish bones and shrimps in stomachs collected between May and August 1964 and 1965. Stomach contents from 457 Dall's porpoises taken during the 1978 and 1979 fishing seasons have been described in Crawford (1981). Squids, mostly belonging to the family Gonatidae, were the major volumetric (90%) constituent of the stomachs. Euphausiids occurred in about 4% of the stomachs in insignificant quantities. Fishes were identified and enumerated, based on otoliths: 33 species of epi- and meso-pelagic fishes were found. Over 94% of the number of otoliths recovered were from fishes of the family Myctophidae (principally *Protomyctophym thompsoni*). In 1978, sand lance occurred in substantial numbers and pollock occurred in small numbers; Atka mackerel were found in low numbers both 1978 and 1979. Fishes eaten ranged from 20 to 480 mm in length, with a modal size of 60-70 mm, based on partially digested whole specimens. No differences in quantities or types of prey were found among porpoises of different sex, stages of maturity, or reproductive state.

Dall's porpoises feed primarily upon a deep-water-based food web. Small meso- and bathypelagic fishes and cephalopods are the primary prey type. Squids, especially those of the family Gonatidae, are heavily utilized by Dall's porpoise. Myctophids constitute over 94 percent of all the fish consumed by Dall's porpoise (Crawford 1981), with capelin, herring, hake, sand lance, cod, and deep sea smelts also constituents of their diet (Kajimura et al. 1980). Many of these prey species undergo a diel vertical migration toward the surface at night. Preliminary data suggest that Dall's porpoise take advantage of this movement by feeding primarily at night. Kajimura et al. (1980) reported the items occurring in stomachs of seven animals collected near Unimak Pass and in the Bering Sea from June to October 1960-68; these porpoises had been preying on squid, capelin, and pollock.

Dall's porpoise may be of particular interest or concern in terms of environmental monitoring because of studies in the northwestern Pacific where this species has been shown to be accumulating heavy metals—zinc, nickel, lead, cadmium, manganese, and copper (Fujise et al. 1988). Porpoises from the northwestern Pacific and the Bering Sea are also accumulating PCBs and other persistent organochlorides (Subramanian et al. 1988).

Steller Sea Lion *(Eumetopias jubatus)*

This species is most numerous in and near the Aleutian Islands, where they are year-round residents. The total estimated population for the eastern Aleutians (including Amak Island and Sea Lion Rock) is 30,000. (The Alaska population is estimated to be in excess of 250,000 [Fiscus et al. 1981].) During winter there is apparently an influx of sea lions into the eastern Aleutians and northeastern Pacific Ocean. Numerous haulout areas and a few rookeries are known from the area of interest.

Important pupping areas are Cape Morgan on Akutan Island and Ugamak Island in Unimak Pass; these two sites account for over 55 percent of the total animals (15000-35000) seen on breeding islands or sites in the eastern Aleutians (Braham et al. 1980).

Sea lions are regularly found in midshelf waters (Scheffer 1958, King 1964, Schusterman 1981). Their pelagic occurrence is most likely related to food searching. Pollock compose roughly 80% (wet-weight volume) of the sea lion diet. Other fish (flatfish, capelin, herring, salmon, cod, cottids) and invertebrates (squid predominate) make up the rest of their diet (Braham et al. 1982, Lowry et al. 1982b). Most studies of Steller sea lion food habits have been made southeast of our area of interest. Fiscus and Baines (1966) reported on a small sample from the Unimak Pass area and found the prey ranking to be capelin, sand lance, sculpins, pollock, flatfish, and Atka mackerel.

Sea lion populations have followed a downward trend in the eastern Aleutian Islands (and some other portions of the Bering Sea including Amak Island, Pribilof Islands) since the late 1970's. For example counts at the haulout areas on Unimak Island including Sea Lion Point/Cape Sarichef, Oksenof Point, and Cape Mordvinof were as high as 4,000 in 1960, but less than 100 in 1975-77. The current status of the sea lion population is unknown, but between 1971 and 1975 the decline was estimated to be 50 percent (Braham et al. 1982). (Mathisen and Lopp [1963] noted 50,000 in 1957, whereas Braham et al. [1980] found fewer than 25,000 in 1975 to 1977.) The causes for these apparent changes are unknown; however, the apparent decline in the eastern Aleutians corresponds to a concurrent increase in commercial groundfish fisheries that presumably competed for preferred foods (Braham et al. 1980). Fowler (1982) has recently suggested that entanglement with net fragments in areas of intense foreign fishing may be a significant source of mortality for fur seals, and the same may be true for sea lions.

Northern Fur Seal *(Callorhinus ursinus)*

Over 70% of the world's population of northern fur seals breeds and pups on the Pribilof Islands (Kajimura et al. 1980, Kozloff 1981, Braham et al. 1982). Numbers of fur seals breeding in the Pribilof Islands have been decreasing markedly during the years preceding (and during) this study. Mortality of fur seals due to entanglement in marine debris is believed to have contributed significantly to the trend of reduced population size (Fowler 1982, 1987).

From late May through early November, most of these animals are found in the Bering Sea. During the summer, adult females and subadult animals range far from the Pribilof Islands in search of prey. Most of these animals appear to move south towards the shelf break, but others disperse widely over the shelf, including into midshelf waters. An unknown number of adult males may overwinter in Bristol Bay (Braham et al. 1982). During winter most seals remain 46 to 93 km offshore. The information on the pelagic distribution of fur seals indicates that the Bering side of our area of interest is an area of relatively high density of fur seals. All the eastern Aleutian passes, but apparently primarily Unimak (Braham et al. 1982), serve as migration corridors in spring (April-June) and fall (August and November).

Fur seals feed primarily at night and early in the morning. In areas where food species remain in upper water layers, fur seals are known to feed actively throughout the day. Their major foods remain the same each year, changing only in rank of importance. In the Bering Sea their diet consists of squid, pollock, seal fish (*Bathylagus* sp.), salmon, and lamprey (Scheffer 1950).

Kajimura et al. (1980) reported that fur seals collected in the Bering Sea had been feeding primarily on capelin, pollock, Atka mackeral, deep sea smelt, and gonatod squids (*Berryteuthis magister* and *Gonatopsis borealis*). Lander and Kajimura (1976) state that fur seals feeding over the continental shelf tend to feed on fishes, while in areas beyond the shelf they feed mostly on squids.

The most complete analysis of fur seal feeding habits appears to be a series of reports which were prepared using the pelagic collections of fur seals made by the US and Canada during 1958 to 1974 as the data base (Perez and Bigg 1981a, b). Fishes of the gadid and osmerid families and squid of the gonatid family made up the most important components in the fur seals' diet in the eastern Bering Sea. The primary species taken were walleye pollock, capelin, and *Berryteuthis magister*. In the Unimak Pass area, the most important prey species was capelin during all months. The second most important were the squid *Berryteuthis* in June, pollock in July and August, *Berryteuthis* again in September, and Atka mackerel in October. Perez and Bigg (1981b) found that the diet for both male and female fur seals was essentially similar in general pattern of diversity, preference, and importance of prey within the diet.

Sea Otter *(Enhydra lutris)*

Sea otters were formerly widespread and abundant throughout the southern Bering Sea, but by the early 1900's hunting had reduced the population to a small colony near Unimak Island and perhaps a few individuals in the Fox Islands. During the past 70 years the numbers of sea otters have increased remarkably, but large areas of uninhabited or partially repopulated habitat remains (Schneider 1981). The area of highest abundance just barely encroaches on our area of interest, extending from mid-Unimak Island east beyond Izembek Lagoon.

Four separate colonies became established in the Fox and Krenitzin islands during the 1960's. All are growing, but they amount to only a few hundred animals, and most of the reproductive animals remain concentrated in small areas (Schneider 1981). Use of our area of interest was no doubt substantially greater in the past than it is today.

Sea Otters are shallow-water animals rarely seen in water deeper than 55 m. But Leatherwood et al. (1983) reported "significant numbers of individuals to depths of 128 m." During summer otters are more widely distributed (less confined to the nearshore) and some are found in the deep water north of the Aleutians (Leatherwood et al. 1983).

As winter advances sea otters move to the west and possibly south of the peninsula. If a southward migration occurs, False Pass has been hypothesized to be the route (see Armstrong et al. 1984).

Sea otters eat a wide variety of bottom-dwelling invertebrates and will also eat fishes if the invertebrate population becomes depleted (Kenyon 1969, Calkins 1978). The diets of sea otters in the Bering Sea area have not been comprehensively examined; preliminary results of ongoing OCSEAP studies indicate that otters may feed predominantly on yellowfin sole. Other prey include crabs, snails, shrimp, and bivalve molluscs in unknown proportions. In the Aleutian Islands, benthic invertebrates (mostly sea urchins) comprised the entire diet of newly-established otter populations, whereas fishes were the major prey of long-established populations, probably due to changes in prey availability (Estes et al. 1982). Sea otters are highly opportunistic feeders and will exploit and often deplete whatever food sources might be available.

In or near to our area of interest, Kenyon (1969) reported on two sea otters collected in 15-20 fathoms of water north of Unimak Island (July 1960). By volume they contained 63% clam, 17% hermit crab, 14% fish (greenling), and 5% tanner crab.

Endangered Whales

Several endangered whales were once sufficiently numerous to form the basis of a shore-based whaling industry situated on Akutan Island. Two species—fin and humpback whales—were the most numerous within our area of interest and are still the most regularly encountered. Other species were never as numerous in the study area, due either to lower abundance or to more peripheral centers of abundance. These whales are described here (fin and humpback in the most detail) because of the particular interest in them as endangered species and because they formerly occupied the Unimak Pass area. Most of these populations remain severely depressed even though whaling ceased in this area in 1939. Aerial surveys of this area in the summer of 1984 failed to locate any of these species except fin whale (Stewart et al. 1987).

Fin Whale *(Balaenoptera physalus)*

Fin whales were formerly abundant in the southeastern Bering Sea and along the south side of the Aleutian Islands. This abundance is shown by the large numbers of fin whales killed by shore-whalers operating from Akutan (Reeves et al. 1985.), by Japanese whalers operating around the Aleutians and along the continental shelf northwest from Akutan towards the Pribilofs (Nemoto 1963), and by Soviet whalers operating with pelagic fleet expeditions to the eastern Bering Sea (Berzin and Rovnin 1966, cited in Leatherwood et al. 1983). The take by the Akutan fishery indicates that fin whales were relatively abundant near Unalaska and Akutan islands.

The Japanese take in particular suggests an affinity of fin whales for the shelf edge north of the Aleutians. There were heavy catches from 1954 to 1964 in the waters between ca. 54°N and 55°N and 165°W and 172°W (Nemoto

1963, Nishiwaki 1966, Nasu 1966). This productive whaling ground for fin whales is centered on our area of interest. Nasu (1974) attributed concentrations of fin whales northwest of Unalaska Island to the presence of an oceanic front and associated high marine productivity. Observations by Japanese scouting boats indicate that fin whales continued (1965-1979) to exist at relatively high levels of abundance in our area of interest (Wada 1980), particularly in the Unimak Pass area and along the 100 m contour north of there. Lowry et al. (1982b) list the area "north of Unalaska Island" as one of the areas where fin whales are most often sighted.

All of the sightings of fin whales made by Leatherwood et al. (1983) were in water less that 110 m, indicating that this species regularly inhabits continental shelf waters. However, Leatherwood et al. (1983) did not record any fin whales in our area of interest. Stewart et al. (1987) report two sighings of fin whales during the summer of 1984 just west of Akutan Island in Akutan Pass.

Leatherwood et al. (1983) encountered fin whales in the Bering Sea only between April and September. Most are presumed to be present for only the six-to-eight month spring-to-fall period. but there are records from off the Commander and Aleutian islands through October and November (Votrogov and Ivashin 1980). Some fin whales reportedly winter in the Bering Sea, e.g., near the Commander Islands (Barabash-Nikiforov 1938), and others may winter at the ice edge near St. Matthew Island (Brueggeman et al. 1983). The "American" stock may migrate annually between Baja California and the Bering and Chukchi seas (Lowry et al. 1982b). Migration into the Bering apparently takes place through both Unimak and Akutan passes (Stewart et al. 1987).

Fin whales prey within the pelagic food web; they are probably the most polyphagous of the baleen whales (Lowry et al. 1982b). In the Bering Sea they consume a larger number of species than in the Antarctic, where they eat almost exclusively euphausids (Nemoto 1957). Their diet appears to change from year to year and from location to location, depending on whether euphausids, copepods, fishes, or squids are most abundant.

The diet of 156 fin whales taken on the continental shelf consisted of 97 percent fish (mostly pollock) and only 3 percent copepods; the pollock were apparently restricted to fish less than 30 cm. Herring and capelin are also frequently eaten. Fin whales also eat arctic cod, saffron cod, Pacific cod, Atka mackerel, rockfish, sand lance, smelt, Japanese anchovy, Pacific saury, chum salmon, among others (Tomilin (1957). Squid are occasionally taken.

In the Bering Sea, *Thysanoessa inermis* is the most important euphausiid prey of fin whales, as well as most other baleen whales. This euphausiid forms extensive swarms over the continental shelf margin from July to September (Nemoto 1970). *Calanus cristatus* is the most important copepod prey of fin whales in the Bering Sea (Nemoto 1959). Only the copepodite-5 stage, an immature form which is present in near-surface waters, is eaten by the whales. Copepods tend to be an important food item in spring and early summer when water temperatures are low; later in the year euphausids assume greater importance.

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is another endangered species occurring within the area of interest, formerly in some abundance. At least 1793 humpbacks were landed at Akutan from 1914 to 1939 (Leatherwood et al. 1983). Humpbacks were caught mainly in the Pacific, Unimak Pass, and the Bering Sea just north of the pass (Reeves et al. 1985, Stewart et al. 1987). During the early 1960's large numbers of humpbacks could still be found around the eastern Aleutians and south of the Alaska Peninsula from 150°W to 170°W (Rice 1974). Berzin and Rovnin (1966, cited in Leatherwood et al. [1983]) considered "the center of the summer habitat" of humpbacks in the North Pacific to be between 145°W and 170°W south of the Aleutians, and "to the north of Unimak Strait."

Recent observations indicate that humpbacks continue to be widely distributed during summer on the continental shelf of the southeastern Bering Sea (mostly outside our area of interest) (Nemoto 1978, Strauch 1984) and in the Unimak Pass area (Braham et al. 1982). All observations of humpback whales made by Leatherwood et al. (1983) were in shallow shelf waters less than 154 m deep.

The sightings in the Unimak Pass area demonstrate that humpbacks are there, mainly along the narrow shelf to the west of the pass. Judging by seasonal plots, humpbacks expand their range during summer and fall into many parts of the southeastern Bering Sea as well as along both the north and south sides of the Aleutians. Humpback whale use of the Unimak Pass area is likely to be predominantly from April through October.

Humpback whales prey within the pelagic food web. In the North Pacific, both zooplankton and fishes are major foods of humpbacks (Nemoto 1959, Kawamura 1980, Winn and Reichley 1984). In the northern part of the North Pacific, Nemoto (1959) found only euphausids in 203 of 272 stomachs containing food. Fifty-three stomachs contained only fishes, and the remainder a combination of fishes and euphausids. Squids were present in only two stomachs. The pollock in the diet were predominantly of fish 40-50 cm in length (larger than the size class selected by fin whales). Near Attu and south of Amchitka humpbacks ate Atka mackerel (Nemoto 1957); whereas in other parts of the Aleutians they fed on euphausids and pollock (Nemoto 1959). Other fish eaten by humpbacks include herring, capelin, sand lance, smelt, cods, salmon (pink and chum), rockfishes, greenling, saffron cod, and arctic cod (Nemoto 1959, Tomilin 1957).

Right Whale (*Eubalaena glacialis*)

Right wales occur in northern waters (north of 50^{o} N) only during the summer (April-September). They were formerly taken by aboriginal hunters in the Aleutian Islands (Mitchell 1979) and by commercial whalers based at Akutan (see Leatherwood et al. 1983). Two records are from Unimak Pass itself. Modern sightings of this very rare animal are quite infrequent (see summary in Leatherwood et al. 1983) and no positive records from our study area are evident. (Many records are presented by general region that sometimes include portions of our area.) There are records for the Bering Sea as recent as 1982 (Brueggeman et al. 1983), hence this species may still use the Unimak Pass area during migration.

Blue Whale (*Balaenoptera musculus*)

Another endangered species, the blue whale, is not to be expected to occur in appreciable numbers within the study area. Historically, vessels based at the Akutan whaling station regularly took blue whales, and at least 1,000 were taken between 1914 and 1939 (Leatherwood unpubl. data). Evidently most of these were killed south of the Aleutian chain, many near Davidson Bank (Birkeland 1926). Rice (1974) considered the area south of the Aleutian Islands between 160°W and 18^{o}W to have been a major summer concentration area. The available information suggests that the Bering Sea portion of our study area was historically of little importance to blue whales.

Sei Whale (*Balaenoptera borealis*)

Sei whales prefer subtropical to cold temperate pelagic regions and avoid polar and shallow coastal waters (Tomilin 1957). Like other balaenopterids, sei whales apparently migrate to lower latitudes in winter and to high latitudes in summer. Thus, they would be expected well south of our area of interest during winter months. In summer, sei whales reportedly are common along the Aleutian Islands (Murie 1959, Masaki 1977, Nemoto and Kawamura 1977). Sei whales were rarely taken by the shore whalers at Akutan during the first 40 years of the twentieth century (Leatherwood, unpublished data), but the population has been dramatically reduced since the early 1960's when intensive whaling began for this species.

Sperm Whale (*Physeter macrocephalus*)

Most sperm whale hunting historically took place south of the 40°N latitude (Townsend 1935, Banister and Mitchell 1980); however, some were taken by the Akutan whalers (Birkeland 1926, Leatherwood unpubl. data). In the Unimak Pass area, they presently occur mainly during summer and fall, in or near Unimak Pass and on the continental slope west of the pass.

Sperm whales are said to arrive near the Aleutians in March (some may overwinter there), and large numbers appear in the eastern Bering Sea by April (Berzin and Rovnin 1966). The greatest concentration in the Bering Sea is reportedly to the north of Atka Island (Omura 1955, Berzin and Rovnin 1966). In September, many of the sperm whales that summered near the Aleutians begin to move south. Only males have been recorded in the Bering Sea; females usually remain south of 45°N. Sperm whales show a clear preference for deep waters at the shelf edge, on the continental slope, or over offshore canyons. The distribution in the eastern Bering Sea mapped by Nishiwaki (1966) based on Japanese whaling data, and by Berzin and Rovnin (1966) based on their own observations supplemented by Soviet whaling data, shows a remarkably close correlation with the shelf edge. The narrow width of the shelf along the south side of the eastern Aleutians ensures that sperm whales appear regularly within our area of interest.

Other Mammals

A few additional species of marine mammals occur regularly within the study area. None were identified as a key species for purposes of our study.

Minke Whale (*Balaenoptera acutorostrata*)

The minke whale has a worldwide distribution. Because of its small size, it was not a major target of commercial whalers in most areas until the reduction in populations of larger, more valuable species required a shift in whaling effort. The lack of whaling effort has resulted in a poor historical record for this species in comparison with records for the previously discussed whales.

Minke whales are common during the spring and summer months in the Bering Sea and coastal Gulf of Alaska (see Stewart and Leatherwood 1985). Frost et al. (1982) stated that this species is most abundant in the Aleutians from May to July. The minke whale is the most numerous baleen whale in the study area (Braham et al. 1977).

Minke whales are found in shallow shelf waters as well as deep areas far from shore (Lowry et al. 1982b, Strauch 1984, Armstrong et al. 1984). It has been suggested that minke whales occupy the St. George Basin year-round, with greatest concentrations in summer (May to July) near the eastern Aleutian Islands (Braham et al. 1982). Sightings indicate that winter densities are lower and that the animals are generally found farther from shore during winter.

Direct evidence concerning diets of minke whales in the southeastern Bering Sea is sparse, but Frost and Lowry (1981) indicated that euphausids and pelagic and semidemersal fishes, including herring, are taken. Leatherwood et al. (1983) reported seeing minke whales swim through (and presumably feed upon) schools of fish (thought to be herring) in Bristol Bay.

Killer Whale (*Orcinus orca*)

Killer whales occur in all oceans and may be encountered in marine waters anywhere. Killer whales occur both north and south of the Aleutians. They seem more abundant in the eastern islands (Braham et al. 1977), where they occur primarily on the continental shelf in waters less than 200 m deep and along the 200 m contour northwest to 60°N (Braham and Dahlheim 1982, Braham et al. 1982). They probably occur year round within the area of interest. Surveys by Leatherwood et al. (1983) indicated that killer whales make equal use of continental shelf, continental slope, and pelagic waters.

Killer whales are opportunistic feeders and have one of the most diverse diets of any of the marine mammals. Worldwide the diet includes seals, sea lions, cetaceans, fishes, sharks, seabirds, sea turtles, and squids (Rice 1968, Caldwell and Caldwell 1969). Pods of whales use coordinated feeding behavior when preying on marine mammals (e.g., Smith et al. 1981) and perhaps also on fishes (herring) (Steiner et al. 1979). Lowry et al. (1987) described an incident of killer whales pursuing a minke whale and causing it to beach itself at Unalaska Bay, within our study area.

Harbor Porpoise (*Phocoena phocoena*)

Little detailed information is available regarding the distribution of this small cetacean. Records within the Aleutians are not numerous (Murie 1959, Alaska Maritime National Wildlife Refuge 1981). Seasonal shifts in abundance suggest that migrations of some sort occur (Leatherwood and Reeves 1978) but data are insufficient to detail the patterns. In southern portions of harbor porpoise range, they are generally seen near the coast in waters less than 20 m deep (Leatherwood and Reeves 1978). Very little of our study area, and none of it accessible by ship, is this shallow. Leatherwood et al. (1983) did not encounter this species in our area, although they did frequently record harbor porpoises within Bristol Bay, generally (79% of sightings) nearshore of the 128m contour.

Harbor Seal (*Phoca vitulina*)

Harbor seals occur in littoral waters throughout the Unimak Pass area. Concentrations occur at the Baby Islands and off the northwest end of Tigalda Island and Rootok Island (Braham et al. 1977, Everitt and Braham 1978). The population throughout the eastern Aleutian Islands is estimated to be approximately 4,000 seals (Everitt and Braham 1978, 1980, Braham et al. 1977). In comparison with populations on the Alaska Peninsula and elsewhere in the Aleutians, these are relatively small populations; they appear to be resident, breeding on the islands and feeding year-round in adjacent waters.

Haulouts are used for resting, molting, and care of young. Seals haul out on sand bars and other areas exposed by the tides, and more animals have been observed hauled out at low than at high tides (Everitt and Braham 1980). Peak use of haulout areas occurs during the molt in June and July and apparently tapers off in September and October when seals spend more time in the water.

METHODS

Distributions and abundances of marine mammals were assessed using shipboard rather than aircraft-based surveys. Ship-based surveys have several advantages. Use of a ship as a sampling platform permits more detailed study of the smaller organisms that often cannot be detected or identified from the air. The ship allows more precise documentation of certain important behaviors that cannot be ascertained from the air. Most importantly, use of a ship permits concurrent measurements of prey availability and oceanographic conditions—information that is critical when trying to determine correlative and/or probable causative factors for marine mammal distributions.

Unfortunately, shipboard counts suffer from the problem that the organisms being censused move much more rapidly than the counter; this fact alone makes reliable density estimation impossible (Burnham et al. 1980). While this problem is not as extreme with marine mammals as it is with birds, it still remains. Dall's porpoise is an example of a marine mammal that frequently overtakes ships. This species also provides problems in density estimation since it appears to be attracted to vessels. Many *ad hoc* methods of minimizing this inherent bias have been employed but the accuracy of none of them is verifiable. Another problem is that surveys near shore are impossible using deep-draft ships. For example, the minimum sampling depth from the R/V *Miller Freeman* was approximately 20 m, and much more in areas of irregular bottom. Within the Unimak Pass study area it was rarely feasible to conduct shipboard transects in water less than 50 m depth.

Counts of marine mammals were made concurrently with surveys of marine birds during three cruises of the R/V *Miller Freeman*--fall (18 Sept 7-Oct 1986), winter (14 Feb-9 Mar 1987), and spring (21 Apr-14 May 1987). Surveys were made along predetermined survey lines while the ship was at or near full steam. Many lines were surveyed repeatedly each season to ensure sampling of all major depth classes and (expected) oceanographic domains (e.g., survey lines passed through Gulf of Alaska and Bering Sea sides of the Aleutians and all passes and straits within the Krenitzin Islands). Transects were defined as the segments of survey lines covered each 10-min interval, as is the customary protocol for conducting marine surveys in Alaska. The biologist censused from the flying bridge, counting all animals seen within a 90° arc.

Marine mammals seen were recorded as being in one of four distance increments parallel to the course of the boat: 0-100 m, 100-200 m, 200-300 m, and >300 m. Calculations of densities were based on sightings in the first three bands only; the fourth zone was used to record off-transect sightings. Due to the low number of encounters of marine mammals, calculations were based on animals seen in the entire 300 m wide transect.

During the conduct of each transect, observers recorded the time, date, ship speed, water depth, and location coordinates of starting and end points. Weather information included temperature, cloud cover, sea state, precipitation, wind speed, and temperature (air and sea surface), and was obtained hourly from the ship's log. During most survey periods, the ship's echosounders were run to provide a qualitative record of prey availability. Both 100 kHz (invertebrate) and 38 kHz (fish) recorders were used. Sea surface temperatures were recorded using a temperature probe affixed to the side of the ship near the waterline, or as recorded at the seawater intake of the ship, just below the surface.

Analyses conducted included tests for differences in mammal abundance among cruises (seasons) and summaries of densities in each water mass (Chapter 10, Appendix A). Because these water masses were also used to characterize zooplankton abundance patterns (see Chapter 3: ZOOPLANKTON ABUNDANCE AND DISRIBUTION, this volume), we were able to discuss apparent correlations between distributions of the mammals and the invertebrates. To separate the northern parts from the southern parts of Gulf of Alaska Water and Alaska Coastal Water (see Chapter 10, Appendix A), we arbitrarily drew a line joining points of land across the narrowest portion of Unimak Pass. Thus, most of Unimak Pass itself is in the northern portion of the Alaska Coastal Water.

Locations of all on-transect sightings were transferred onto maps of the study area on which the survey lines were depicted. Each sighting location was plotted at the midpoint of the transect on which the marine mammal was seen. Finally, maps were prepared that represented the densities of mammals by circles of varying sizes; the area of each circle was proportional to the density of the animals recorded.

RESULTS

Seasonal Abundance

The abundance of most marine mammals species differed appreciably among the three cruises (Table 3). Three species—sea otter, northern fur seal,

Table 3. Densities of marine mammals by cruise along with test results for differences in abundance among cruises (seasons).

SPECIES/SEASON	Fall 86	Winter 87	Spring 87	χ^2	prob
Sea Otter	0.029	0.007	0.009	13.739	< 0.005
Steller's Sea Lion	0.003	0.002	0.000		
Northern Fur Seal	0.039	0.000	0.000	48.971	< 0.005
Harbor Seal	0.004	0.000	0.000		
Killer Whale	0.005	0.000	0.009		
Dall's Porpoise	0.139	0.074	0.051	32.910	< 0.005
Gray Whale	0.000	0.000	0.003		
Minke Whale	0.004	0.003	0.001		
Fin Whale	0.000	0.000	0.003		
small whale	0.000	0.002	0.000		
sea mammal	0.000	0.017	0.000		
Total	0.223	0.104	0.076		
Area Sampled (km^2)	748.772	593.974	670.452		

and Dall's porpoise—were sufficiently numerous to permit statistical testing for differences in abundance (testing the null hypothesis that the number of mammals enumerated in proportion to the sampling effort was not different among seasons). All of these had very significant ($p < 0.005$) departures from equal abundance among cruises.

Fall

Most species peaked in abundance during the fall cruise. This was true of all species for which testing for seasonal changes in abundance could be done. The total density of marine mammals during the fall was twice as high (0.223 mammals/km^2) as during any other season.

The most numerous species of marine mammal encountered at sea during the fall (and in all other seasons) was Dall's porpoise. Next in abundance was northern fur seal, the key mammal study species. Third in abundance was sea otter. The observation that the sea otter was one of the most numerous mammals encountered on transects indicates the overall rarity of marine mammals, since sea otters are primarily coastal in distribution and would not have been expected to occur in most of the study area.

Two humpback whales were encountered northeast of Akun Island near the area of seabird concentrations, though they were not seen on a transect. This was our only sighting of this endangered species during the three cruises for this study.

Winter

The winter cruise results indicated that the overall density of marine mammals was approximately half of that present during the fall cruise. Dall's porpoise continued to be the most numerous species, and all other species were very infrequent. Minke whales were at or near their maximum abundance among all three cruises (the unidentified small whale could have been a minke whale).

Spring

Results of the spring cruise suggested that marine mammals were scarcest at this season. Overall densities were only one-third of those recorded during the fall cruise. Dall's porpoise continued to be the most numerous marine mammal species encountered. This was the only cruise during which gray and fin whales were encountered.

Another cetacean seen only during the spring cruise was Baird's beaked whale (*Berardius bairdi*). A small pod of these whales (≈ 5 animals) was seen repeatedly on 11 May 1987 while we occupied a time-series CTD station north of Unalaska Island, at location 54.17.8° N 166.27.2° W (station 21.1). This location was in the restricted area of deep water (≈ 1000 m) on the Bering Sea side of our study area.

Spatial Distribution

Fall

Most marine mammals sightings were within the Bering Sea (Fig. 1). The only species encountered that were not seen in the Bering Sea were killer whale (one sighting south of Ugamak Strait) and minke whale (one sighting south of Rooktok Island). Within the Bering Sea there was a tendency for most mammal sightings to be northeast of Akun Island, in the northern portion of Unimak Pass. This was particularly true of Dall's porpoise but was also evident for sea otter. The single harbor seal seen was also there. Northern fur seals were restricted to the Bering Sea west of Unimak Pass.

Winter

The winter sightings of marine mammals indicate a southern shift in distribution relative to fall (Fig. 2). Minke whales and sea otters were seen only within the protected waters of the Krenitzin Islands. The only Steller sea lion encounter during a shipboard transect was also in this area, in Unalga Pass (the sighting cannot be discriminated from a transect point in Fig 2). Dall's porpoise sightings were restricted to the southernmost portions of the study area in the deep waters of the Gulf of Alaska.

Spring

During the spring cruise marine mammals were somewhat more diffuse than during the other two cruises, and fewer were seen in the Krenitzin Islands (Fig. 3). Dall's porpoises were found in the two regions of deep water in the study area--the portion of the Bering Sea north of Akutan Pass (most sightings were in this area) and the deep Gulf of Alaska water at the southernmost limits of the study area. As during previous cruises killer whales were found close to the Krenitzin Islands. A minke whale appeared to be feeding within the Krenitzin Islands at station 22-11 (54°05.7N 165°33.1 W) while we were sampling with bongos.

Two endangered whale species were found during the spring cruise. Fin whales were seen just north of Unimak Pass. Gray whales were encountered close to Unimak Island on both the Bering Sea and Gulf of Alaska sides of the Island.

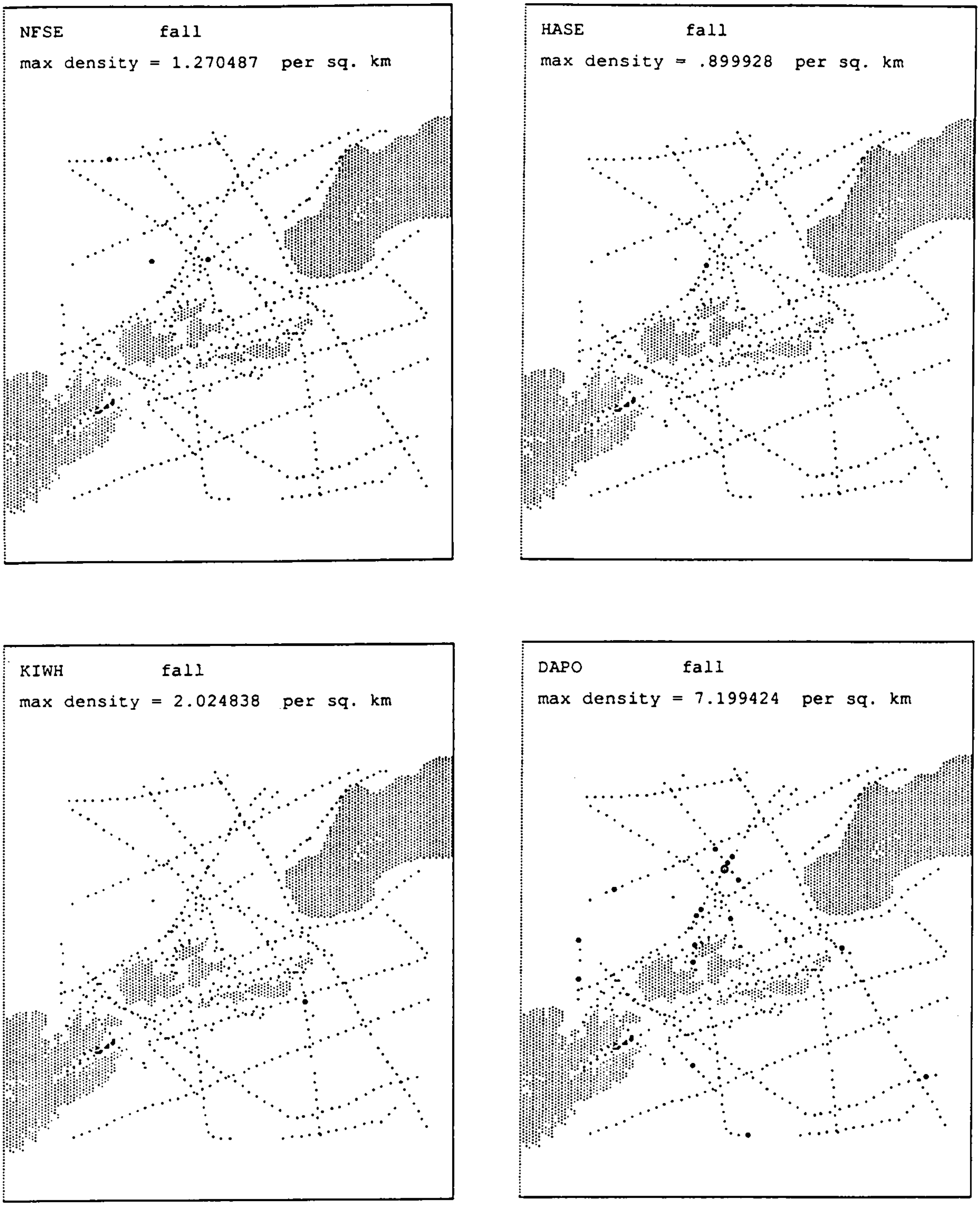
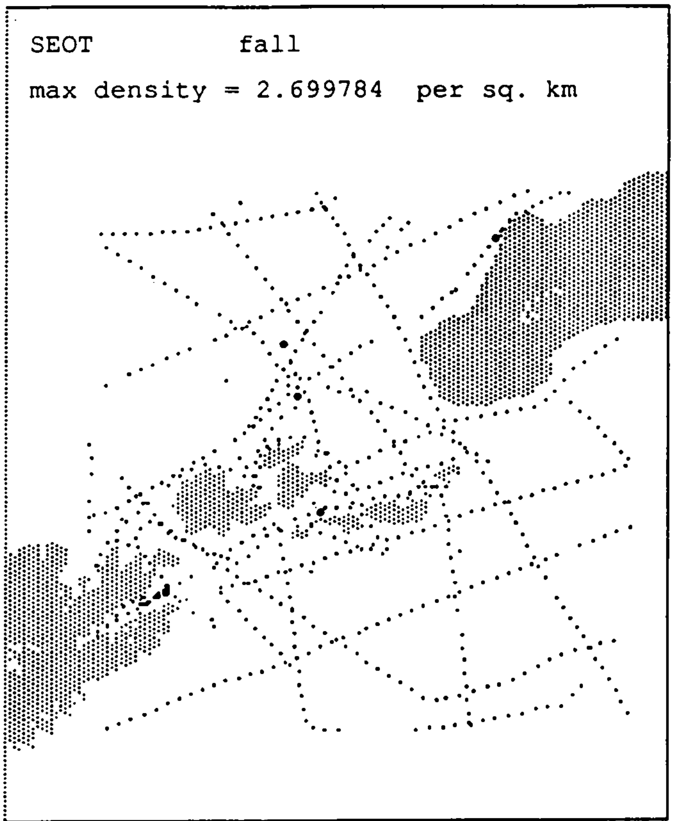


Figure 1. Distribution of marine mammals recorded on transects during the fall cruise (Each dot represents a transect surveyed). Density of mammals is indicated by the size of the circle; area of the circle is proportional to the density. The maximum density is listed at the top of each map. (DAPO=Dall Porpoise, SEOT=Sea Otter, KIWH=Killer Whale, MIWH=Minke Whale, NFSE=Northern Fur Seal, HASE= Harbor Seal.)



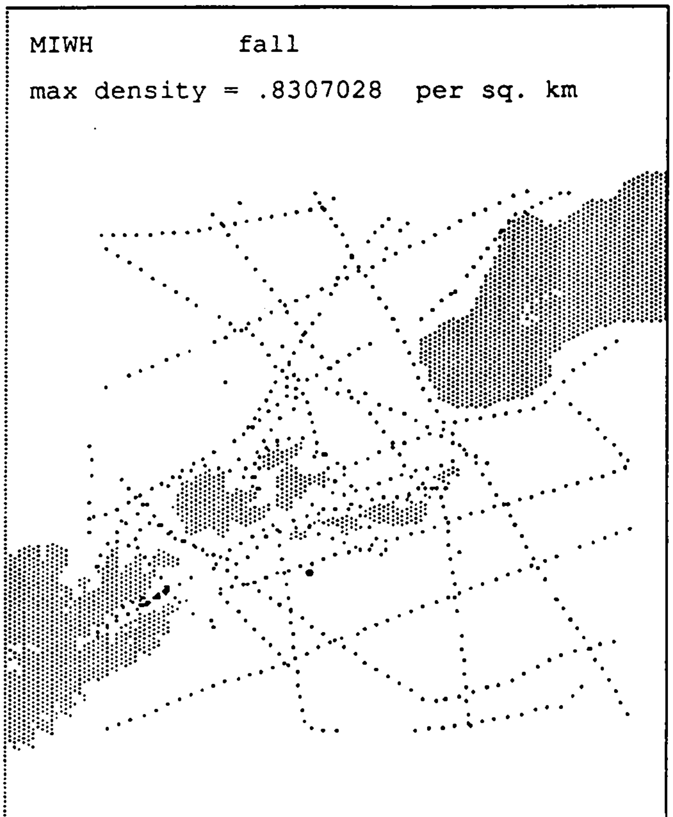


Figure 1 (cont.)

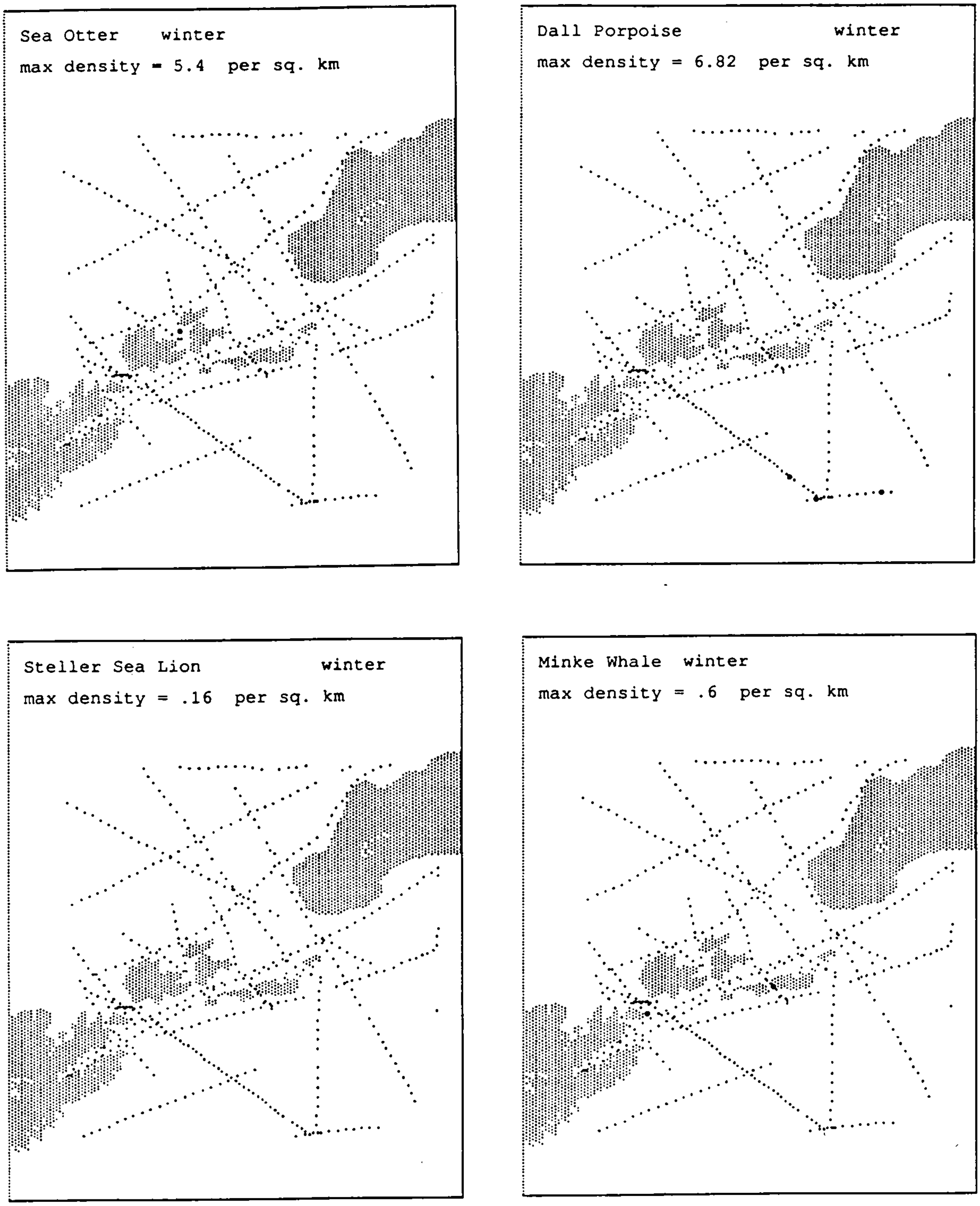


Figure 2. Distribution of marine mammals recorded on transects during the winter cruise (Each dot represents a transect surveyed). Density of mammals is indicated by the size of the circle; area of the circle is proportional to the density. The maximum density is listed at the top of each map.

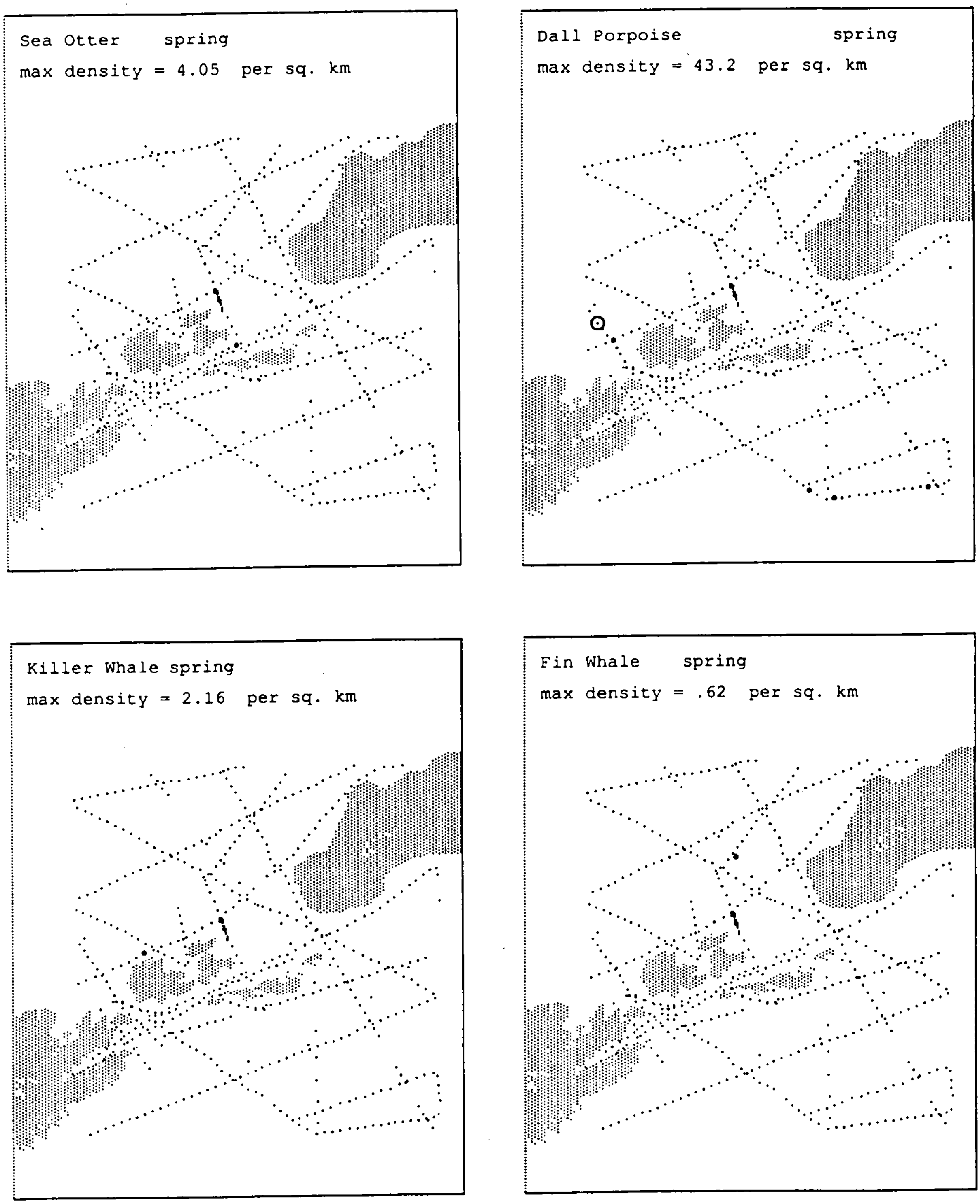


Figure 3. Distribution of marine mammals recorded on transects during the spring cruise (Each dot represents a transect surveyed). Density of mammals is indicated by the size of the circle; area of the circle is proportional to the density. The maximum density is listed at the top of each map.

Associations with Water Masses

Fall

Marked differences in abundances of marine mammals were evident among water masses (Table 4). The highest densities occurred in the Gulf of Alaska Water north of the pass (GAWn) and relatively high densities were found in the Shelf Break Water (SBW). (see Chapter 10, Appendix A for water mass distributions.) In both these water masses Dall's porpoise contributed most to the high densities (this species was the most common marine mammal in all water masses except the Tidally Mixed Water [TMW]). GAW was the only water mass where minke whales were found on transect. SBW was the water mass favored by northern fur seal. This species was also present in moderate abundance in the GAW (north and south) but very rare elsewhere.

The Alaska Coastal Water was quite depauperate in marine mammals in both the north (ACWn) and south (ACWs) regions. Not a single marine mammal was seen on transect in the south portion of this water mass. The northern portion of the ACW had relatively few marine mammal; however, harbor seals were at highest densities in this area.

Although absolute densities in the Tidally Mixed Water (TMW) were substantially lower than in the more structured water masses to the north, two species—sea otter and killer whale—were largely restricted to this water mass. Sea otter was the most numerous marine mammal recorded on transects within the TMW.

Winter

Use of the various water masses during winter differed markedly from the use observed during the fall cruise. No marine mammals were encountered on transects in the SBW or the GAWn, the two transects with the highest densities during the fall. As in the fall, the ACWs was lacking in marine mammals.

The highest densities, by an order of magnitude, occurred in the GAWs (Table 4). Only one species, Dall's porpoise, contributed to this density. Similarly, the ACWn was dominated by a single marine mammal species; in this case only sea otter was recorded on the transects.

The Tidally Mixed Water had the most diverse marine mammal fauna with three species recorded on transects. Minke whale was found only in this water mass during the winter cruise. The appearance of Steller sea lion during the winter cruise highlights the importance of the qualification "on transect". Sea lions occurred in this region quite abundantly during all seasons, as will be shown in Chapter 7 (COASTAL MARINE BIRDS AND

Table 4. Average densities by water mass of the most common marine mammals sighted during each of the three cruises. The highest density of each species is shown in bold face. See Appendix 1 for water mass distribution. SBW=Shelf Break Water, TMW= Tidally Mixed Water, GAW=Gulf of Alaska Water (north and south), ACW=Alaska Coastal Water (north and south).

	WATER MASS					
SPECIES	SBW	TMW	GAWn	GAWs	ACWn	ACWs
Fall						
Northern Fur Seal	**0.042**	0.005	0.019	0.014	0.000	0.000
Harbor Seal	0.003	0.000	0.000	0.000	**0.006**	0.000
Sea Otter	0.014	**0.029**	0.000	0.000	0.013	0.000
Dall's Porpoise	0.105	0.020	**0.174**	0.046	0.039	0.000
Killer Whale	0.000	**0.007**	0.000	0.000	0.000	0.000
Minke Whale	0.000	0.000	**0.005**	**0.005**	0.000	0.000
Total	0.164	0.061	**0.197**	0.064	0.058	0.000
Winter						
Steller Sea Lion	0.000	**0.002**	0.000	0.000	0.000	0.000
Sea Otter	0.000	0.004	0.000	0.000	**0.009**	0.000
Dall's Porpoise	0.000	0.000	0.000	**0.098**	0.000	0.000
Minke Whale	0.000	**0.004**	0.000	0.000	0.000	0.000
Total	0.000	0.009	0.000	**0.098**	0.009	0.000
Spring						
Sea Otter	0.000	0.011	0.000	0.000	0.005	**0.305**
Dall's Porpoise	0.000	0.013	0.015	**0.090**	0.000	0.000
Killer Whale	0.000	**0.013**	0.000	0.000	0.000	0.000
Gray Whale	0.000	0.000	0.000	0.000	**0.005**	0.004
Fin Whale	0.000	0.000	**0.008**	0.000	0.000	0.000
Total	0.000	0.038	0.023	0.090	0.011	**0.309**

MAMMALS), this volume, but its behavior of hauling out on beaches during the day resulted in there being virtually no sea lions observed during ship board surveys. They were seen around the ship during night operations, however.

Spring

In spring, marine mammals were found in all water masses except the SBW. The highest densities occurred in the Alaska Coastal Water south; sea otters accounted for almost all the marine mammals in this area.

GAWs had the next highest density of marine mammals in spring; Dall's porpoise was the only species recorded on transect. This species was also the most numerous marine mammal in GAWs, GAWn, and TMW. The GAWn area was the only water mass in which fin whales were recorded in spring.

The Tidally Mixed Water continued to support the most diverse marine mammal fauna. Dall's porpoise and killer whale tied as the most numerous species. Sea otters were also present although not as numerous as in the ACWn.

DISCUSSION

Seasonal and Spatial Distribution

Most species recorded during this study exhibited rather substantial seasonal variations in abundance and distribution. Overall abundance of marine mammals was highest during the fall and decreased with each successive cruise. Presumably abundance increases again later in the spring or during the summer. In the case of some migratory species such as the northern fur seal the lower abundance in spring than in fall may indicate that they pass through rapidly in spring but loiter in the area during fall migration, or that our spring surveys coincided less with migration timing than did fall surveys

Dall's porpoise, minke whale, and sea otter were the only species present during every cruise. Dall's porpoise was the most numerous marine mammal in all seasons, but their distribution changed markedly each season. They were widespread in the fall, shifted to the extreme south in the winter, and restricted themselves to very deep waters in the spring. They possibly were found in the deep waters of the Bering Sea in winter, but since this habitat was quite restricted in our study area they could have been overlooked. Minke whales and sea otters were found near the Krenitzin Islands during all seasons but they, especially the sea otter, ranged farther from land during the fall.

Some comparisons between the present study and the similar North Aleutian Shelf (NAS) studies (Troy and Johnson 1987) are of interest. Although the study areas were adjacent and even overlapped slightly, the patterns of distributions and abundances of their mammals seemed often dissimilar. The season of highest marine mammal abundance in the North Aleutian Shelf was during summer, a season for which we are lacking comparable data from the Unimak Pass area. Northern fur seal, Dall's porpoise, and minke whale all peaked in abundance in the North Aleutian Shelf at this season. Stewart et al. (1987) found Dall's porpoise, killer whale, harbor porpoise, fin whales, and unidentified beaked whales within our area of interest during aerial surveys during the summer of 1984. Except for the Dall's porpoise, most of these cetaceans were close to the Krenitzin Islands (as were many of the Dall's porpoises). Overall abundance on the North Aleutian Shelf was at a minimum during the fall, the period when it peaked in the Unimak Pass area. Distributional patterns of individual key species in these areas are discussed below; unless otherwise noted the data from the NAS studies pertain to shipboard results since these are most comparable with data from the Unimak Pass studies.

Sea Otter

Sea otter abundance in the NAS was always at least an order of magnitude greater than in the Unimak Pass area. This is not too surprising since virtually all of the NAS was suitable for sea otters (the area was generally less than 50 m deep) whereas a great deal of the Unimak Pass study area would not have been expected to harbor sea otters.

The seasonal trends in census results also contrasted sharply. Sea otters were most numerous in the NAS during winter and lowest in the fall, opposite to the pattern in Unimak Pass. Aerial surveys in the NAS, which provided better coverage of the shoreline areas where most otters were present, showed highest densities to occur in October, but did confirm that winter was also a high abundance period for otters. High winter densities on the NAS may have been caused by influxes of otters from ice-bound waters farther northeastward and perhaps also from the Krenitzin Islands.

Steller Sea Lion

One conclusion that can be drawn from both the Unimak Pass and NAS studies is that shipboard surveys are inappropriate for censusing Steller sea lions. The shipboard surveys in both cases revealed only trivial numbers of this large pinniped. However, in both studies independent means of surveying shorelines (the coastal surveys in Unimak Pass and aerial surveys in the NAS) revealed a large number of sea lions present on the beaches. The NAS aerial surveys revealed that sea lion abundance peaked during winter and spring, especially in the portion of the study area near Unimak Pass.

Northern Fur Seal

As mentioned above, northern fur seal abundance in the NAS peaked during the summer, perhaps because of seals foraging afar from the Pribilof rookeries. Unfortunately we have no Unimak census data from this season. At other seasons, patterns of abundance were similar between Unimak Pass and NAS, i.e., fur seals were present only during the fall. Abundance in fall appeared to be considerably higher in the Unimak Pass area (density of .039 vs .006 fur seals per km^2).

Killer Whale

Killer whale abundance appeared to be similar in both study areas. They occurred on transects only during the fall in the NAS but were also present in spring in Unimak Pass.

Dall's Porpoise

Dall's porpoises were quite rare in the NAS. They peaked in abundance in summer during a period when the middle oceanographic domain moved uncharacteristically shoreward, as shown by both the aerial and shipboard surveys. The only other NAS sightings were during spring but in much lower densities than occurred at any time in the Unimak Pass area. Based on the peak occurrence of Dall's porpoise in fall in Unimak Pass, we would have expected most sightings in the NAS to be during the fall, but none was recorded at this season. Since Dall's porpoise is a deep-water species, its absence from the NAS is not surprising.

During winter and spring, Dall's porpoises were largely restricted to the deep-water portions of the Unimak Pass study area. These areas corresponded to the areas where myctophids, a key prey of this porpoise, were captured in the mid-water trawls. During the fall, however, Dall's porpoises were much more widespread than myctophids, perhaps indicating that the porpoises were feeding on other prey, such as the abundant small pollock, at this season.

Gray Whale

Similar maximum densities of gray whales (0.003 whales per km^2) occurred in both study areas although they occurred in different seasons. Most shipboard sightings of this whale in the NAS were during fall, whereas most were recorded in the Unimak Pass study area in spring. The NAS aerial surveys revealed that the highest densities occured during spring, and that the timing of fall migration was much later than the fall cruise for the Unimak Pass study. In both studies the sampling for gray whales was marginal since the majority of gray whales migrate through the area in waters too shallow for surveying from a ship.

Minke Whale

Minke whales were present in the NAS during spring and summer (highest density) whereas in the Unimak study area they appeared to be year-round residents, peaking in abundance in the fall.

Endangered Whales

The low numbers of endangered whales recorded was no doubt influenced by their rarity and perhaps also by the timing of the cruises. A somewhat later cruise in spring or earlier cruise in fall may have turned up a few more summering individuals. Nemoto (1957) found that dense swarms of euphausiids (*Thysanoessa inermis*) occurring between July and September, were the major prey of all baleen whales in the Bering Sea.

Another factor may have been that concentrations of copepods, which form the major prey of several baleen whales including right whales, were too low along our transects to attract whales. A few stations we sampled had abundances in excess of 1 g wet wt m-3; however, Wishner et al. (1988) found average densities of copepods in patches frequented by right whales off New England to be 4 times as high as our maximum values. It is not clear why we did not find higher copepod densities.

Associations with Water Masses

All the species examined exhibited rather striking associations with particular water masses or with subsets of water masses. As was found with birds, there was considerable temporal variation among species in their associations with water masses.

Northern fur seal, present only during fall, was most common in Shelf Break Water (Fig. 4). Except for Alaska Coastal Water, other water masses within the Bering Sea also were used, but not to the same extent.

Three cetaceans—Dall's porpoise, fin whale, and minke whale—appeared to be most commonly associated with Gulf of Alaska Water (Figs. 5, 6, and 7). In previous discussions, we noted that minke whales were associated with the Krenitzin Islands, which are surrounded by Tidally Mixed Water (TMW). But as best we can determine they were in the GAW (both north and south), although near the islands, and only during winter were they clearly in the TMW. Fin whales were rarely seen and then only in the spring, but they were unambiguously in the GAWn. Dall's porpoises exhibited some seasonal variation in where they occurred, but most of this

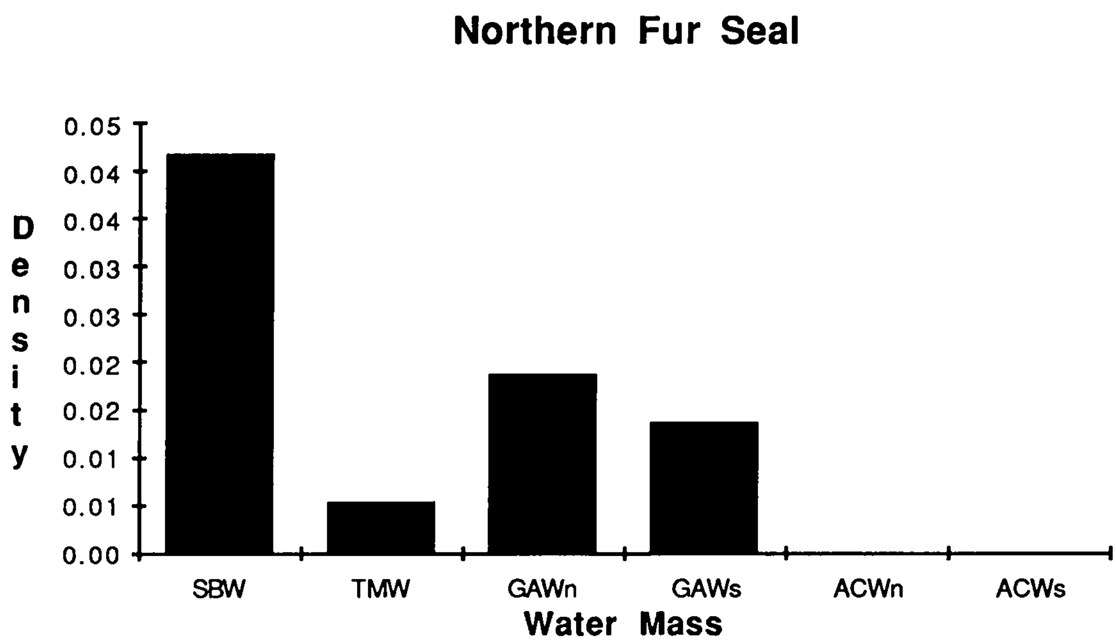


Figure 4. Summary of densities of northern fur seal by water mass during the fall cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

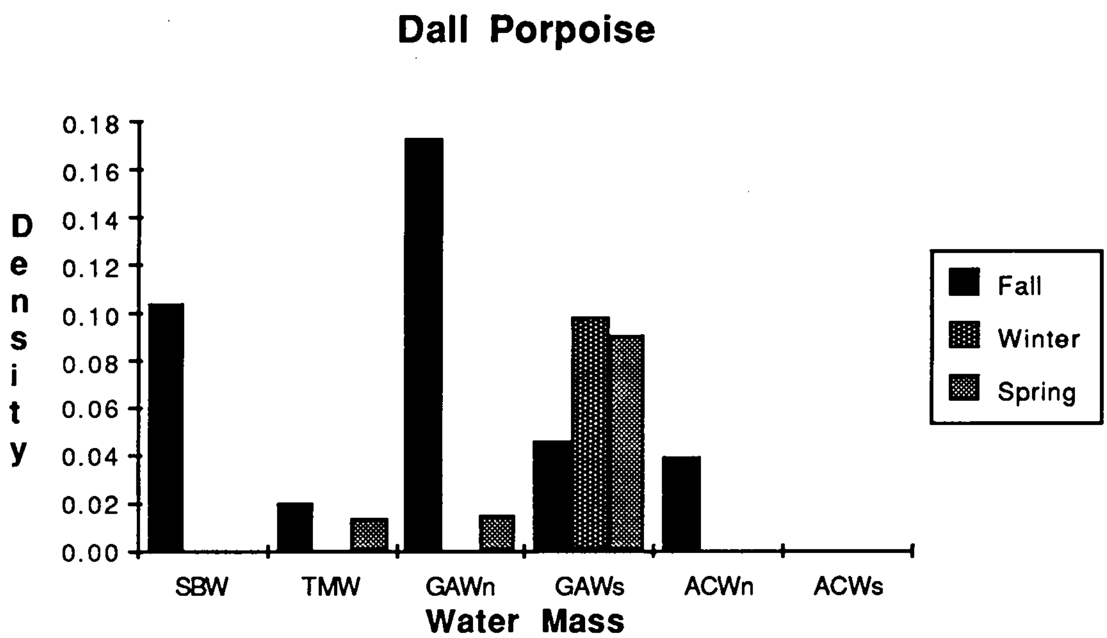


Figure 5. Summary of densities of Dall's porpoise by water mass during the three cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

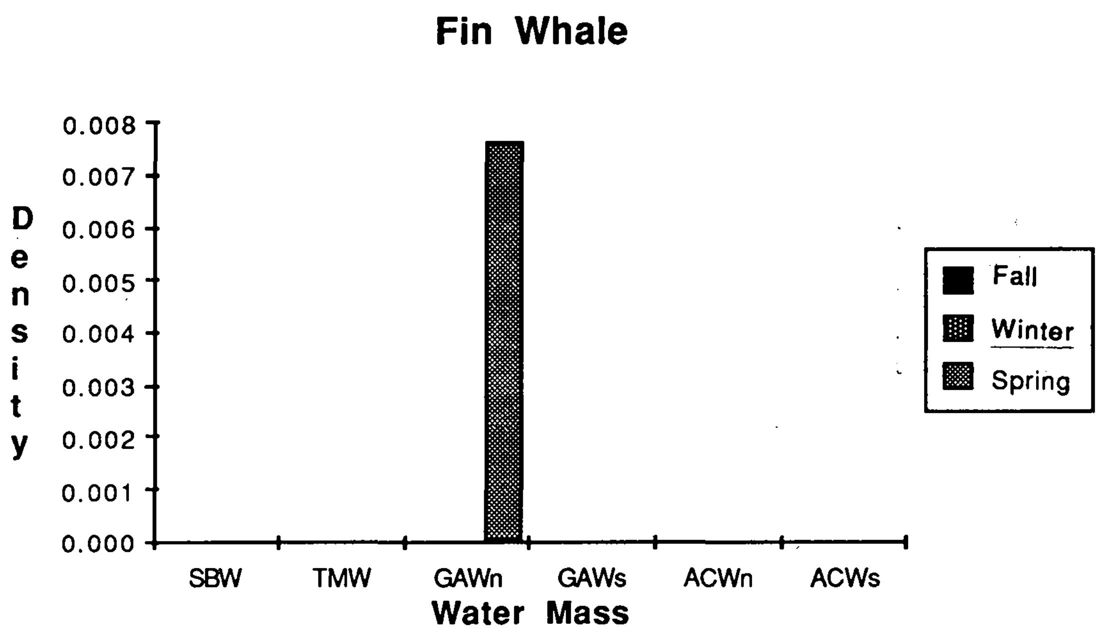


Figure 6. Summary of densities of fin whale by water mass during the three cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

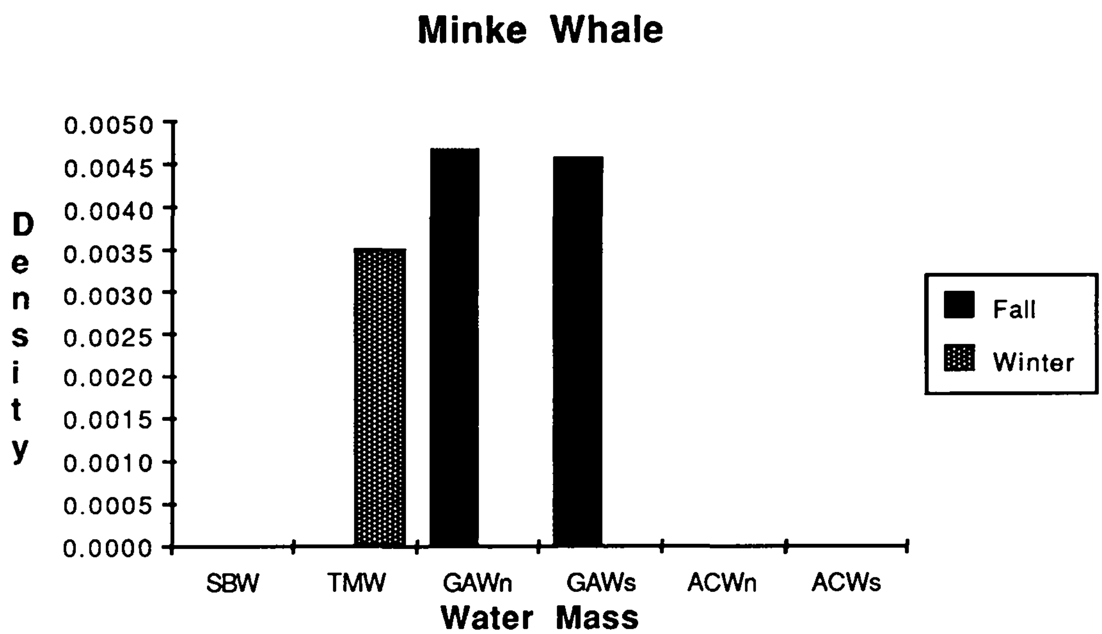


Figure 7. Summary of densities of minke whale by water mass during the fall and winter cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

variation seemed to be north-to-south movement in GAW masses. During the fall porpoise numbers were relatively high in the SBW.

The Tidally Mixed Water had the most distinctive fauna. Minke whales seemed to be associated with the TMW, at least seasonally; other species more clearly associated with the TMW were Steller sea lion and killer whale (Fig. 8). Note that none of these were particularly numerous species in the areas covered by shipboard surveys, but both were restricted to TMW.

Harbor seal, sea otter, and gray whale were found primarily in the Alaska Coastal Water (Figs. 9 and 10). Harbor seals were recorded only during the fall cruise, when they were most numerous in the ACWn. Large numbers are known to frequent the waters near the Alaska Peninsula so this result is not surprising. Considering the coastal nature of this species we did not expect to encounter very many, which was the case; the occurrence of this species in the SBW was surprising. Sea otters were found in water masses near coasts, as would be expected. They were most reliably found in the TWM and ACWn, but the highest density recorded was in the ACWs during spring. Gray whales were also recorded where they would be expected, i.e., only within the ACW.

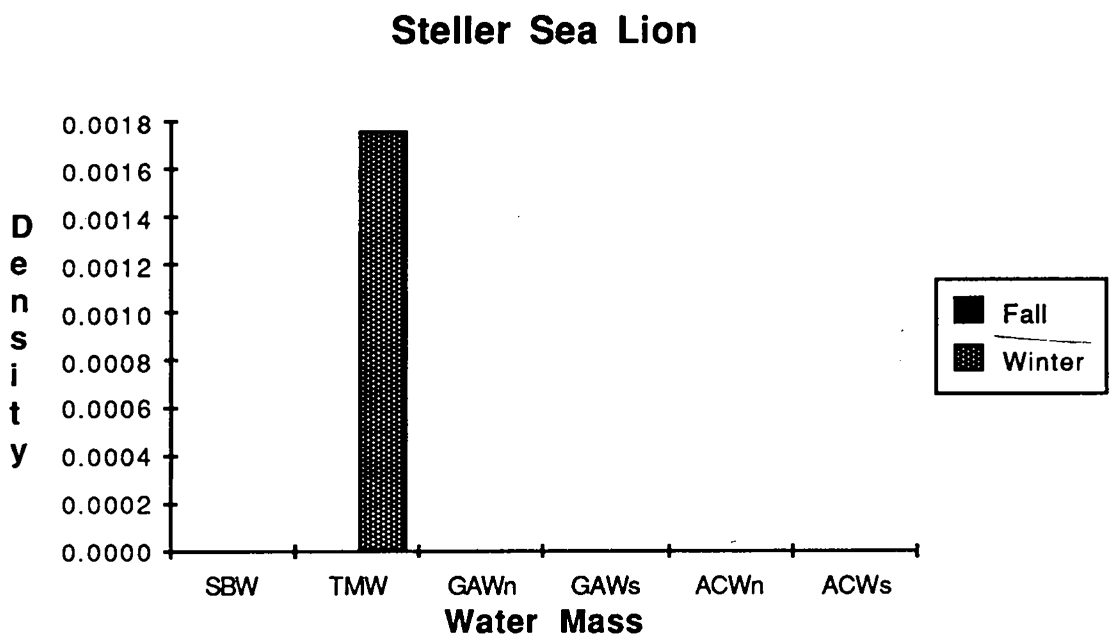
RECOMMENDED FURTHER RESEARCH

Despite relatively intensive sampling, we saw few northern fur seals and endangered whales. There could be two reasons--either the Unimak Pass area does not support many of these species or we were sampling at inappropriate times. To some degree both of these are probably true.

With respect to temporal coverage, we failed to sample in the summer season, the period when past surveys in neighboring areas such as NAS have indicated the highest use by many marine mammals. Further, the periods of spring and fall migration are long and the brief three-week periods of our surveys probably did not adequately sample migration use of the study area by all species. The best use of the spring and fall surveys probably was to document the presence of species and clarify general habitat associations.

Our failure to find any or many marine mammals also may indicate that they were truly absent or scarce. We expected to encounter few endangered whales in any case, but the historical evidence indicates that many of the areas of concentration for them were at the periphery of our study area, i.e., north of Unalaska Island and south of our study area, e.g. Davidson Bank.

In terms of the potential impacts of OCS development, the Davidson Bank area may be rather remote from potential sea traffic through Unimak Pass and thus removed from immediate concern. However, the areas immediately to the west of the Unimak Pass study area are probably of more interest because they seem to support higher concentrations of marine



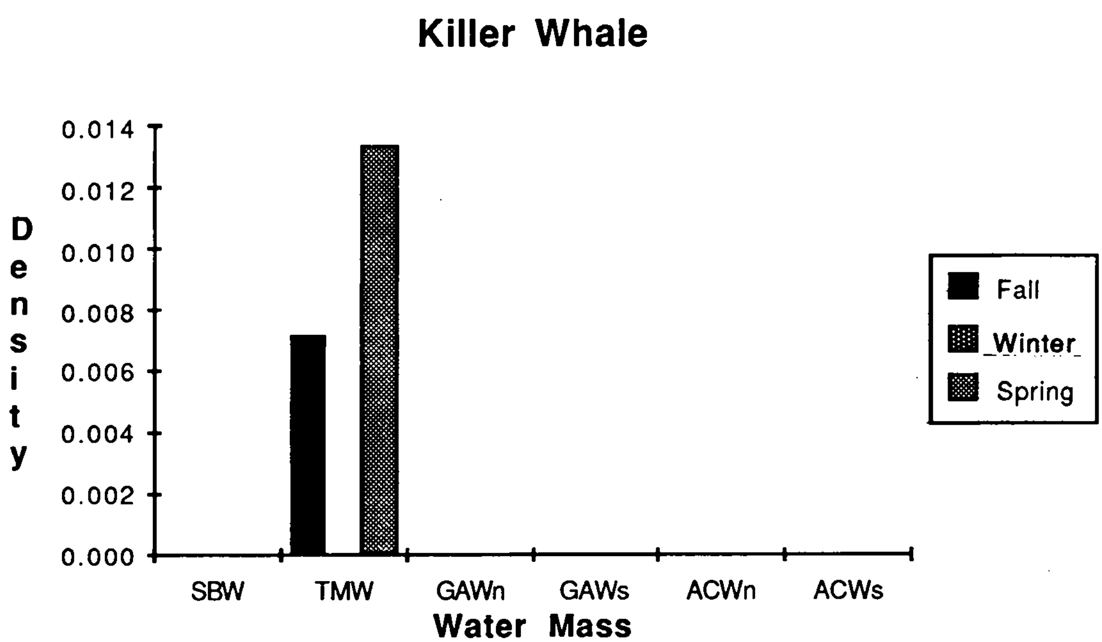


Figure 8. Summary of densities of Steller sea lion and killer whale by water mass during the three cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

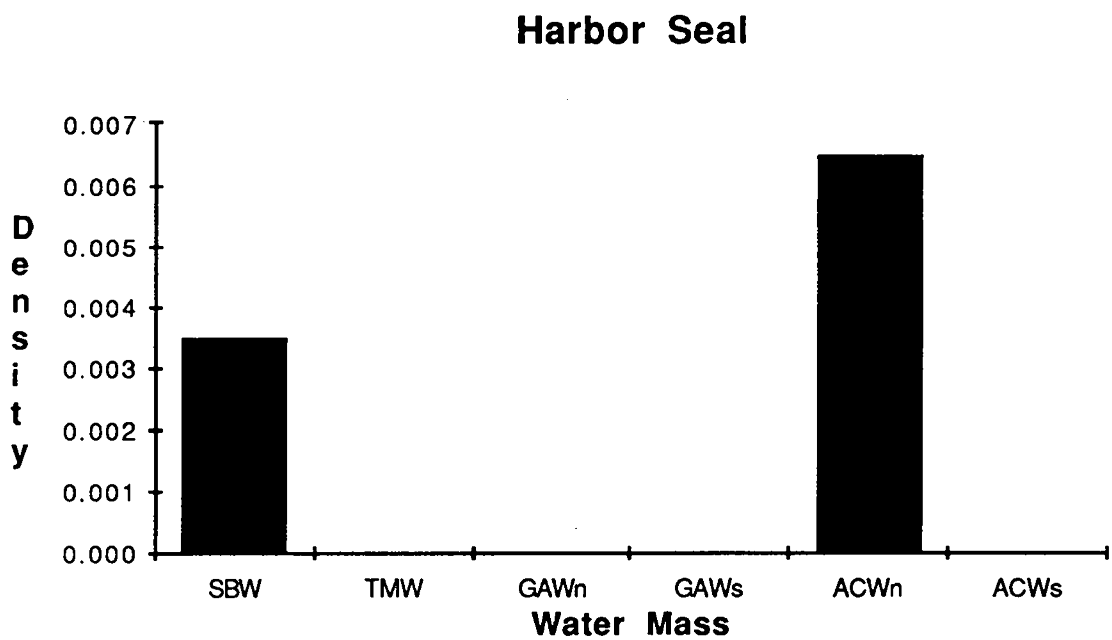
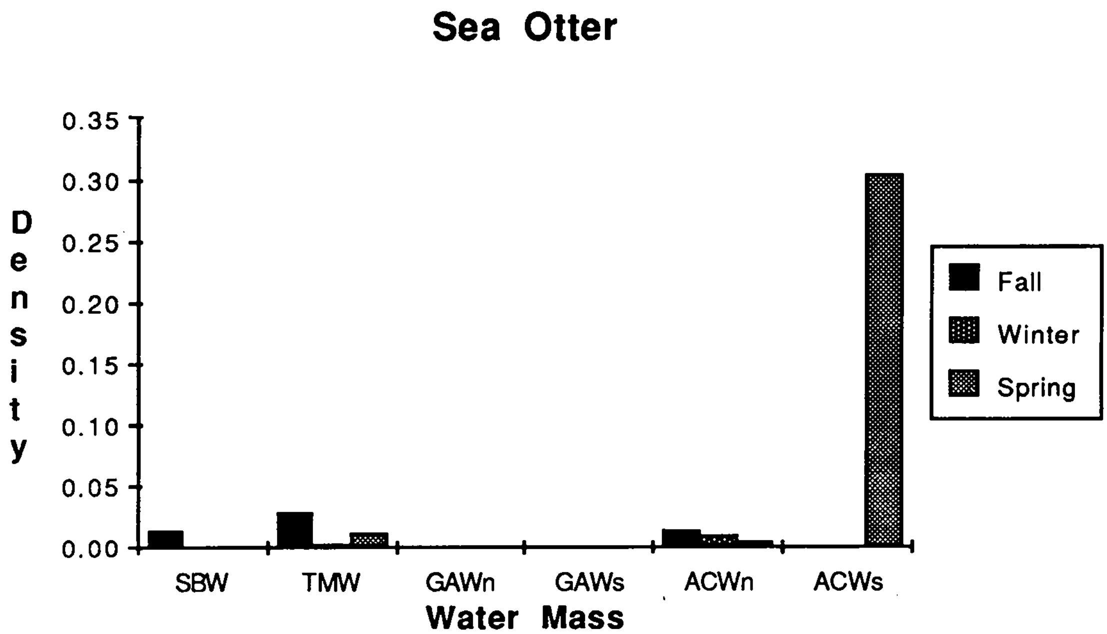


Figure 9. Summary of densities of harbor seal by water mass during the fall cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.



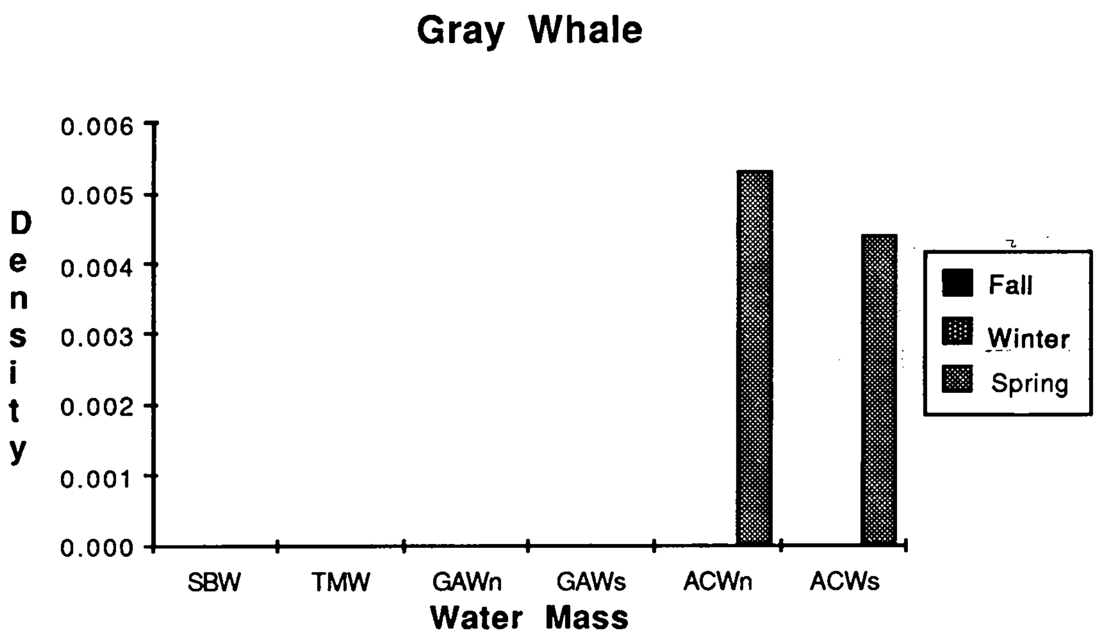


Figure 10. Summary of densities of sea otter and gray whale by water mass during the three cruises. Water masses are as follows: SBW=Shelf Break Water; TMW=Tidally Mixed Water; GAWn=Gulf of Alaska Water northern (Bering Sea) portion; GAWs=Gulf of Alaska Water south; ACWn=Alaska Coastal Water north (Bering Sea); and ACWs= Alaska Coastal Water south.

mammals and to be near potential oil-development activities as well. Our studies indicate that the areas of marine mammal and other biological concentrations in the Unimak Pass area are the result of nutrient flow from the west and are thus functionally linked to areas of upwelling outside of our study area.

The main areas of research that would benefit from continued effort and would complement what we have done thus far are:

(1) Conduct an additional cruise similar to the ones described in this report but during the summer season, perhaps in late June and early-July .

(2) Conduct a study similar to the Unimak Pass investigation but shift the study area to extend coverage as far west as Samalga Pass.

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The assistance provided by a few individuals deserves special mention. CDR Taguchi found ways to accommodate our innumerable trips through all passable passes in the Krenitzin Islands. LT Brian Hayden (FOO) accommodated all our requests and last minute changes in plans, allowing us to obtain all our samples where and when we wanted them. He also prepared a chart overlay detailing our accomplishments.

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Chapter 7

COASTAL MARINE BIRDS AND MAMMALS

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SUMMARY

Small boats were used to survey coastal environments (within 1 km of the shore) not accessible to research ships. Several species or species groups of marine birds and mammals commonly found in the Unimak Pass area are largely restricted to these environments. Most (88 to 99 percent) of the coastline of the Krenitzin Island group (including Unalga and Baby Islands) was censused during the fall, winter, and spring seasons of 1986-1987. Pertinent findings included the following:

(1) The total number of marine birds in coastal environments remained remarkably constant among seasons, but relative abundances of species varied dramatically among seasons, as follows:

- Species reaching peak abundance during fall included cormorants, Black Oystercatcher, and Tufted Puffin.
- Birds reaching peak abundance in winter included Red-necked Grebe, Emperor Goose, most seaducks, Bald Eagle, Mew Gull, Whiskered Auklet, and Horned Puffin.
- Species reaching peak abundance in spring were Common Eider, Harlequin Duck, Red-breasted Merganser, Glaucous-winged Gull, murres, Pigeon Guillemot, and Ancient Murrelet.
- Numbers of Horned Grebes, Peregrine Falcons, and Common Ravens were similar during all surveys.

(2) Thirty-one seabird colonies and 16 active Bald Eagle nests were observed in the study area.

(3) Steller sea lions were least common during winter, but numbers increased in spring and were highest in fall. At least nine haul-out areas were located. Historical records indicate that regional populations have declined since surveys began in 1957.

(4) Harbor seals were present on every island surveyed. Haul-out locations were identified during each season. Numbers of animals seen at haul-outs and in the water were highest in spring and lowest in winter. Feeding habitat for harbor seals in the Unimak Pass area appears

limited in area when compared with available feeding habitat in the nearshore zone of the North Aleutian Shelf. This may account for the marked differences in numbers of hauled out animals observed between these two areas--less than 100 animals in the Unimak Pass area vs. thousands in the North Aleutian Shelf area.

(5) Sea otters were present around all of the islands in the Krenitzin Island group, and densities observed in fall 1986 and spring 1987 exceeded those reported on any previous survey. Six areas were identified that had consistently large numbers of sea otters.

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INTRODUCTION

Several species or species groups of marine birds and mammals commonly found in the Unimak Pass area are largely restricted to coastal environments, generally within 1 km of shore. Pelagic surveys conducted from large research ships are often ineffective in sampling this component of the marine fauna because of the shallow water conditions favored by major faunal aggregations of some of these species (e.g, roosting flocks of birds, hauled-out groups of mammals, and mammal or bird feeding assemblages).

As part of the Unimak Pass study, small boat surveys were conducted to enumerate marine bird and mammal populations using coastal habitats in the Krenitzin Islands, including Unalga and the Baby Islands (Figs. 1 and 2), during each of the three pelagic sampling periods (fall, winter, and spring). In this section of the Unimak Pass report, we describe these coastal surveys and discuss the findings.

CURRENT STATE OF KNOWLEDGE

Coastal-oriented marine bird species or species groups common in the Unimak Pass region include grebes, cormorants, Emperor Goose, seaducks, shorebirds, gulls, and Pigeon Guillemot. Several marine mammal species are also largely restricted to this coastal zone. These include Steller sea lion, harbor seal, and sea otter. A brief discussion of these important species and species groups is presented below.

Grebes

The Horned Grebe is the most common grebe in the Krenitzin Islands area and is the only one discussed here. It breeds across the northern half of North America and in northern Eurasia, and winters in the Pacific from the Aleutian Islands south to Japan and California (AOU 1983). It is primarily a coastal marine species during the non-breeding period, at which time it occurs as scattered individuals or in small flocks in a variety of coastal habitats.

Cormorants

Three species of cormorants--Double-crested, Red-faced, and Pelagic--are common in coastal areas of the Krenitzin Islands. Individuals of these species are present year-round within the area. However, migrations of short distances do take place, particularly by the Pelagic Cormorant, the most northerly-breeding species. This species nests as far north as the central Chukchi Sea coast of Alaska, but retreats southward in fall as sea ice covers its nearshore feeding areas. Small numbers of Red-faced and Double-crested cormorants also nest in areas that are covered in winter by sea ice (e.g.,

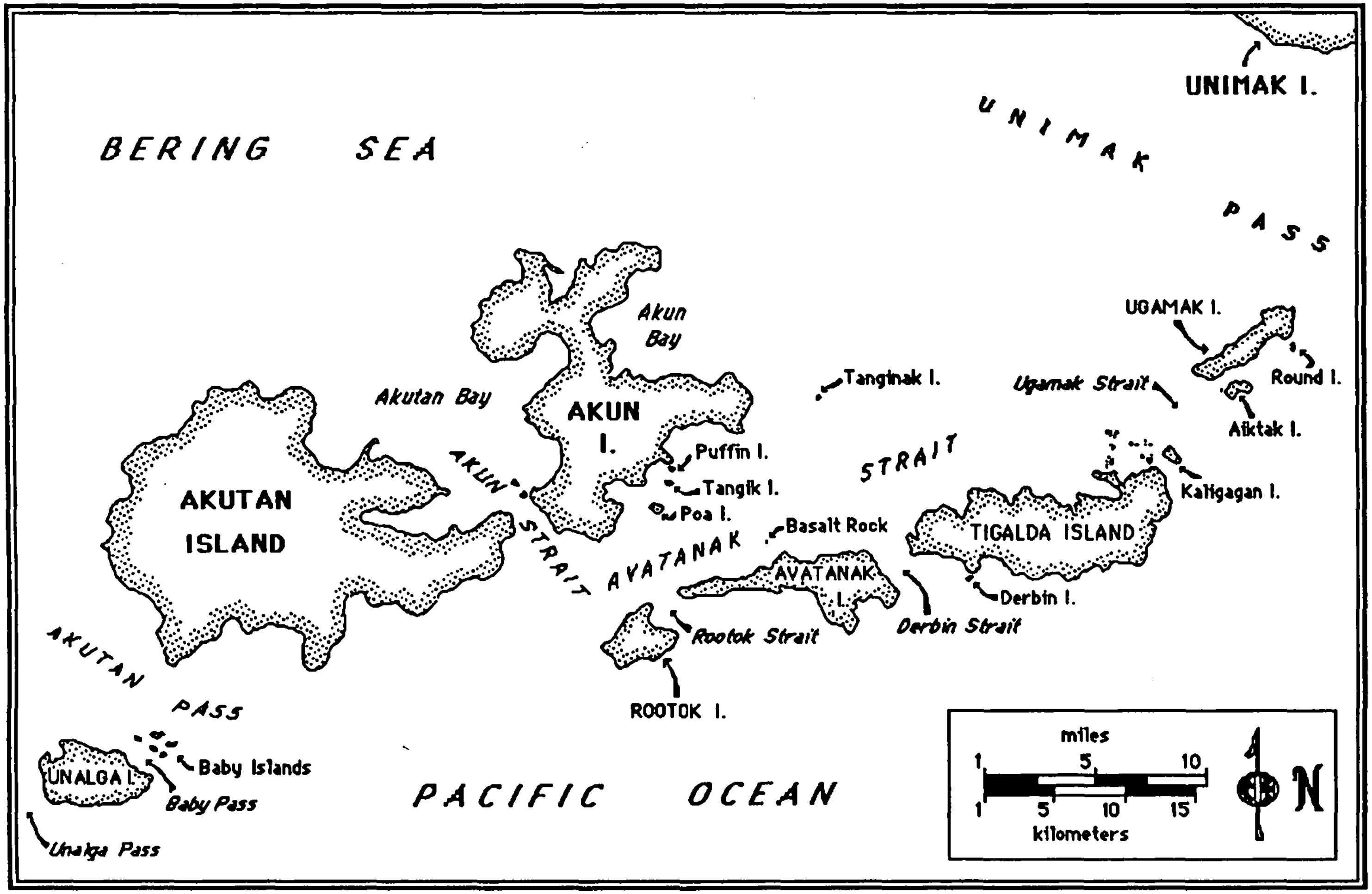

Figure 1. Place names of islands and passes in the Krenitzin Islands and adjacent islands sampled during coastal surveys, Unimak Pass area, Alaska.

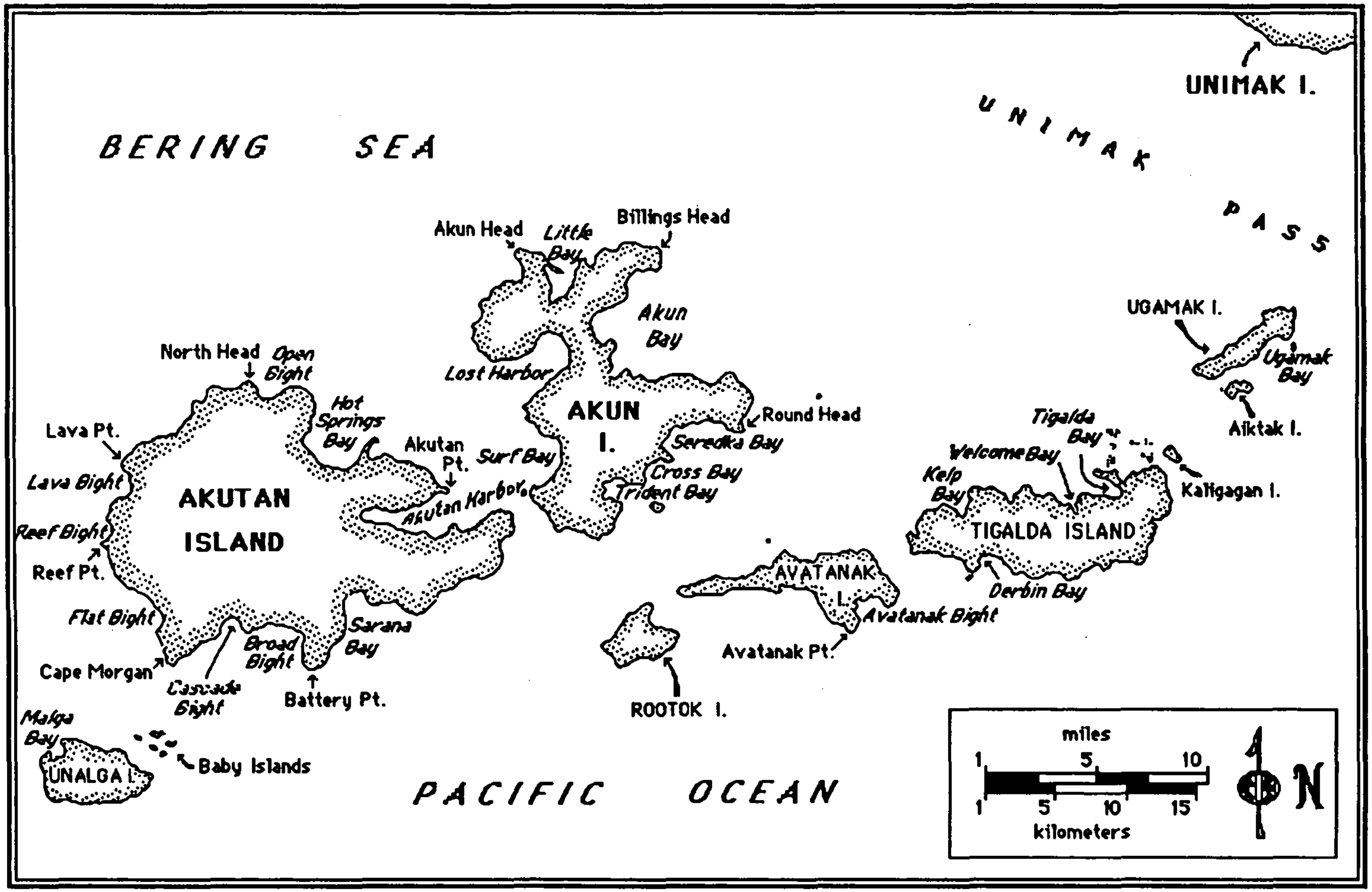

Figure 2. Place names of bays and points in the Krenitzin Islands and adjacent islands sampled during coastal surveys, Unimak Pass area, Alaska.

northern Bristol Bay) and may similarly migrate short distances southward in winter.

Cormorant numbers in the North Aleutian Shelf region adjacent to the Unimak Pass area varied only slightly among seasons in 1985-86 (LGL 1987: Table 6.3). Highest densities were recorded during the non-breeding period (October, January, and March). The North Aleutian Shelf, similarly to Unimak Pass, was not ice-covered in winter.

Emperor Goose

This goose breeds in western Alaska and northeastern Siberia in much the same kind of tundra habitat as other northern geese. However, unlike other geese, it spends the winter in marine habitats of the Aleutian Islands, the Alaska Peninsula, and the Kodiak Archipelago. Its diet in winter is not well known, but is believed to include marine algae and also benthic invertebrates from rocky substrates (Eisenhauer and Kirkpatrick 1977). Emperor Geese may be present in the eastern Aleutians in small numbers at any time of year; however, they are most common there from November through April.

Seaducks

Although the North Aleutian Shelf area immediately to the northeast of Unimak Pass provides good habitat for wintering seaducks (LGL 1987), the Krenitzin Islands appear to have far less suitable habitat. The North Aleutian Shelf is dominated by a broad, shallow nearshore zone with gravel, sand, or mud substrates and several large, shallow lagoon systems. The fine, unconsolidated substrates probably harbor large populations of molluscs (clams, mussels, etc.) and epibenthic crustaceans (primarily amphipods), important food for several species of seaduck (White-winged and Black scoters, and Common, King, and Steller eiders). Nearshore habitats in the Krenitzin Islands are characterized by a narrow band of shallow water with a steep bottom profile, rocky substrates, numerous kelp beds, and relatively few, small lagoons. These characteristics appear to limit the numbers and species of seaducks wintering there.

One of the most abundant species in the eastern Aleutians, and probably in the Krenitzin Islands, is the Harlequin Duck. This seaduck is common in the nearshore zone of these islands where it feeds on gastropod molluscs and other invertebrates commonly found on rocks and kelp fronds (Dzinbal and Jarvis 1984, LGL 1987). Unlike the large flocks typical of scoters and eiders, Harlequin Ducks are found most frequently as isolated individuals, in pairs, or in small flocks.

Shorebirds

The rocky shorelines common in the Krenitzin Islands are poor habitat for most shorebirds. In addition, the Aleutian Islands lie outside of the major migration pathways for shorebirds moving between arctic nesting areas and wintering sites in lower latitudes. Large migrating flocks of shorebirds typical of much of southern coastal Alaska do not regularly reach even the eastern Aleutians. The only species occurring regularly in the Krenitzin Islands--American Black Oystercatcher and Rock Sandpiper--are both permanent residents in rocky shoreline habitats.

Gulls

Two of the most common species of gull in the eastern Aleutians are Glaucous-winged Gull and Black-legged Kittiwake. These species are opportunistic feeders and, although abundant on the coast, can occur far out to sea.

The Glaucous-winged Gull is the most common coastally-oriented large gull species found in the Aleutians. Studies in the western Aleutians indicate these gulls are very opportunistic, feeding primarily on invertebrates, fish, and other seabirds, depending on the availability of prey (Trapp 1979). While largely resident within their range, a certain proportion of local populations may undergo seasonal movements (Butler et al. 1980).

Black-legged Kittiwakes are widely abundant in the Bering Sea, and frequently occur in coastal habitats where they nest on cliffs. Large flocks frequently roost in a variety of shoreline habitats, often with other gulls.

Pigeon Guillemot

The Pigeon Guillemot is by far the most coastally-oriented alcid in the Aleutian Island region. Pigeon Guillemots feed in shallow nearshore waters, and generally occur as isolated individuals or in small flocks (rarely numbering into the hundreds or thousands) along rocky coasts. The Aleutian Islands provide prime habitat for this species, which nests in crevices on cliffs or under beach boulders (Nysewander et al. 1982). Pigeon Guillemots feed primarily on a variety of small fishes caught in kelp beds and other nearshore habitats (Sowls et al. 1978).

Steller Sea Lion

Although Steller sea lions cross large expanses of open water (such as the Gulf of Alaska) on migrations, they are typically found close to shore throughout their North Pacific range. This species breeds in large rookeries, generally on gravel or sand beaches.

Fifty-one rookeries (haul-outs) of this species have been identified throughout its range (Loughlin et al. 1984). Haul-out sites may be on beaches or rocky islands and headlands, frequently near productive feeding areas. Two of these presently occur in the Krenitzin Islands, one on eastern Ugamak Island and one at Cape Morgan, Akutan Island. Other haul-outs are known and have been previously censused in the Krenitzins. A decline in numbers of sea lions in the eastern Aleutian Islands over the last few decades has been documented (Braham et al. 1980, Loughlin et al. 1984).

Harbor Seal

This pinniped is present in coastal Alaska from the central Bering Sea throughout the Aleutian Islands and the Gulf of Alaska. Harbor seals prefer coastal habitats, feeding in shallow waters and hauling out on sand or mud bars, or on rocks and reefs exposed at low tides. The populations in the eastern Aleutian Islands are much smaller than those farther east along the north shore of the Alaska Peninsula (LGL 1987). No large haul-outs are known in the Krenitzin Islands, though several sites consistently used by small numbers of animals were identified in this area by Everitt and Braham (1980) who reported a maximum count of 2,208 harbor seals in the Krenitzin Islands in August 1976.

Sea Otter

Sea otters, though once abundant throughout the Aleutian Islands, were heavily harvested during the 1800s for their fur. By the early 1900's the fur trade had reduced their populations to a few small colonies in the eastern Aleutians, one on the north side of Unimak Island and several smaller groups in the Fox Islands (Schneider 1981). During the following 70 years (up to 1980) sea otter populations increased remarkably in the eastern Aleutian Islands, but some vacant or only partially repopulated habitat remains. All islands in the Krenitzin Islands group contained sea otters by 1976-77, but known breeding concentrations were recognized only in the Tigalda/Ugamak Island area.

METHODS

Habitats used by coastal marine birds and mammals in the eastern Aleutian Islands are probably most efficiently censused by air or small boats, and each method has its advantages and disadvantages. Aerial surveys, although fast and efficient in covering large areas, result in population estimates that are frequently biased because small body size or elusive habits make some species difficult to census from the air. Surveys by small boat can be more time-consuming and are affected to a greater extent by weather, but use of boats can bring observers closer to the animals being censused and allows the observers to stop to count large aggregations. Coastal censuses via small boat in Sweden have recently been shown to provide results highly correlated with relatively accurate shore-based counts of gulls and waterfowl (Haldin and Ulfvens 1987).

Because of the relative accuracy of boat surveys, and because we had ready access to several types of small boats based aboard the R/V *Miller Freeman*, we conducted small boat coastal surveys. Details of these surveys follow.

During each of the R/V *Miller Freeman* cruises (fall, winter, spring), we deployed one of the three small boats on board to conduct coastal surveys near the Krenitzin Islands. Surveys took 6-8 days to complete and required most of each daylight period (Figs. 3, 4, and 5).

Surveys were dependent on weather and sea conditions. We were unable to obtain complete coverage in any study period due to rough weather; nonetheless, we surveyed from 88 to 99 percent of the coastline of the Krenitzin Islands (including Unalga and the Baby Islands) during each period. The circumferences of all islands surveyed are given in Table 1. Total distances surveyed in each of the three study periods were: Fall—461 km; Winter—406 km; and Spring—448 km.

Two types of boat were used to conduct coastal surveys; the type used during each survey depended on weather conditions, the tasks to be completed, and the mechanical condition of the boats. We conducted surveys on 14 days (out of 21 survey days) in an 8-m aluminum-hull launch equipped with an inboard V-6 diesel engine and small cabin. The survey party consisted of one observer and three crew members who were responsible for operation of the boat. We conducted the remaining surveys in a 5-m inflatable boat, equipped with a fiberglass hull and 70 hp outboard engine. Surveys using this craft required only the observer and a driver.

The survey format consisted of a belt transect, the width of which extended seaward from the coast approximately 200 m and landward of the coast about 10 m. We counted all birds and mammals observed in this area. Obvious aggregations of birds and mammals farther offshore and on the tundra were also noted, but were recorded as off-transect sightings. The survey boat proceeded at a slow, consistent speed parallel to land at a distance of approximately 100 m. We were forced to vary the boat's distance from shore on numerous occasions due to submerged rocks and dense beds of kelp (*Alaria* sp. and *Nereocystis* sp.), but the area surveyed did not change.

Observations were recorded on a portable tape recorder. Observers noted the species, number of individuals, age and sex (if possible), behavior (e.g., swimming, flying, diving, roosting, hauled-out), and habitat (e.g., type of beach substrate, cliff, offshore rock, kelp bed, open water). Additional

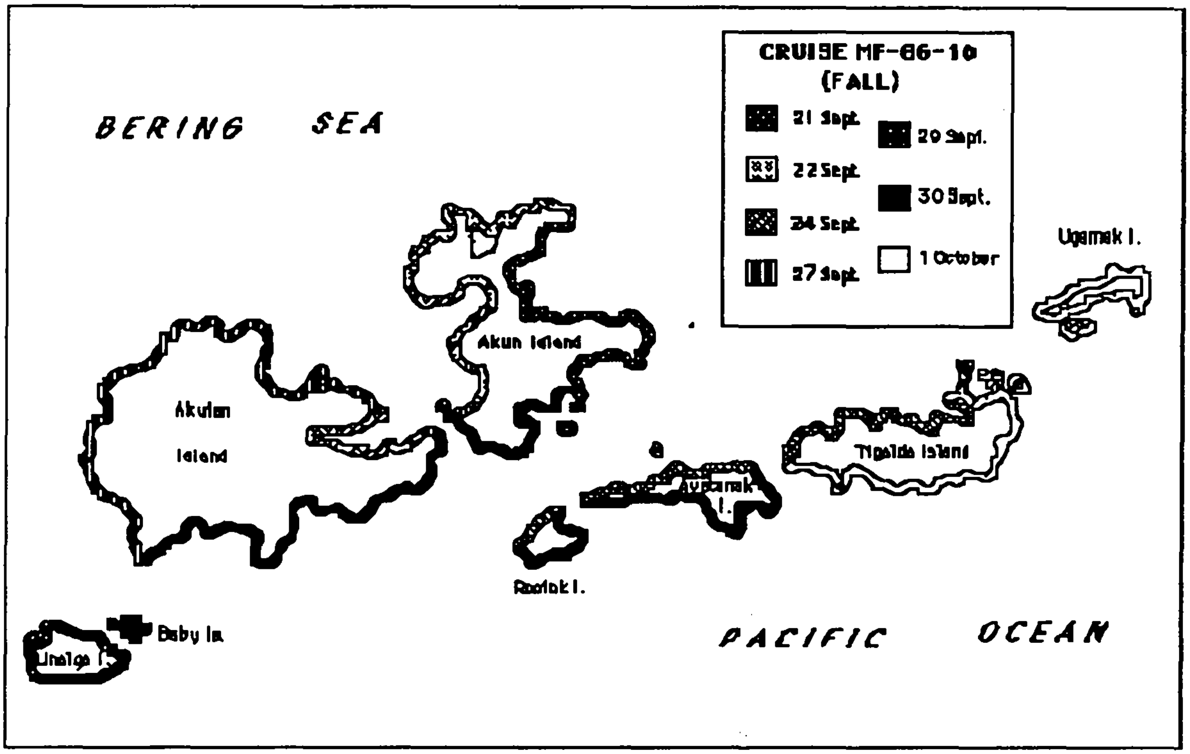

Figure 3. Dates and locations of coastal transects in fall 1986.

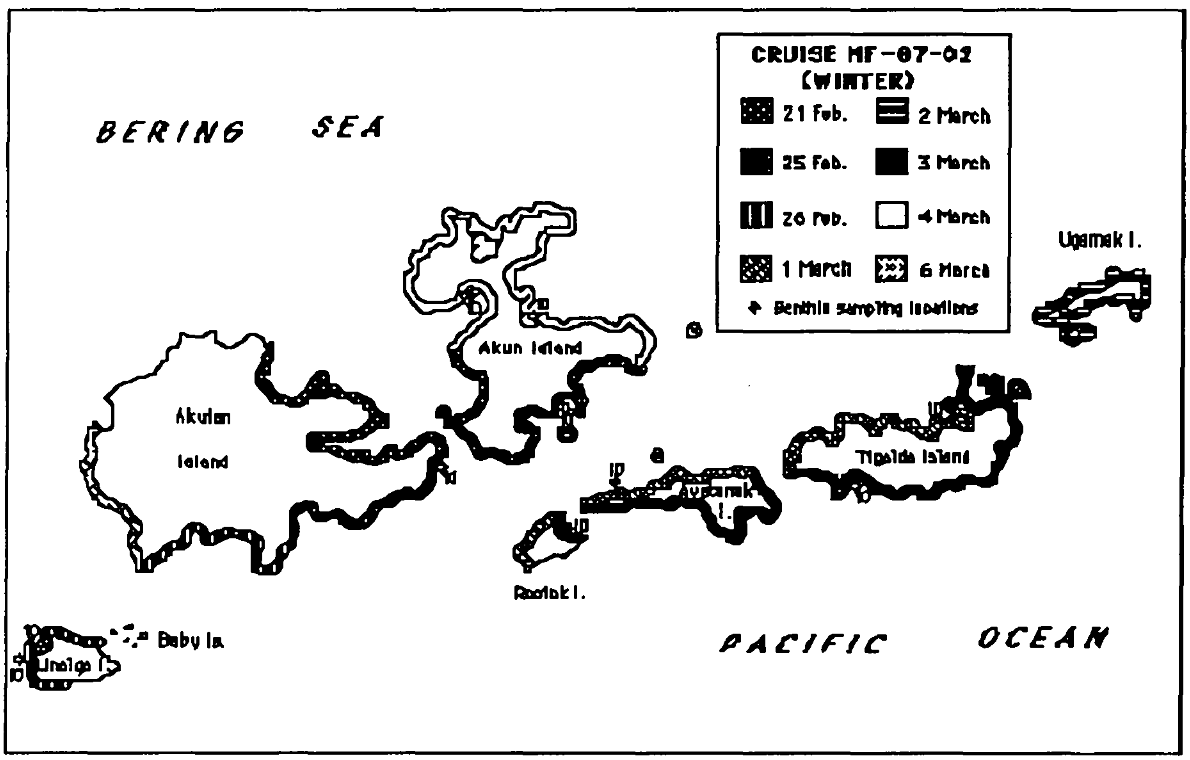

Figure 4. Dates and locations of coastal transects in winter 1987.

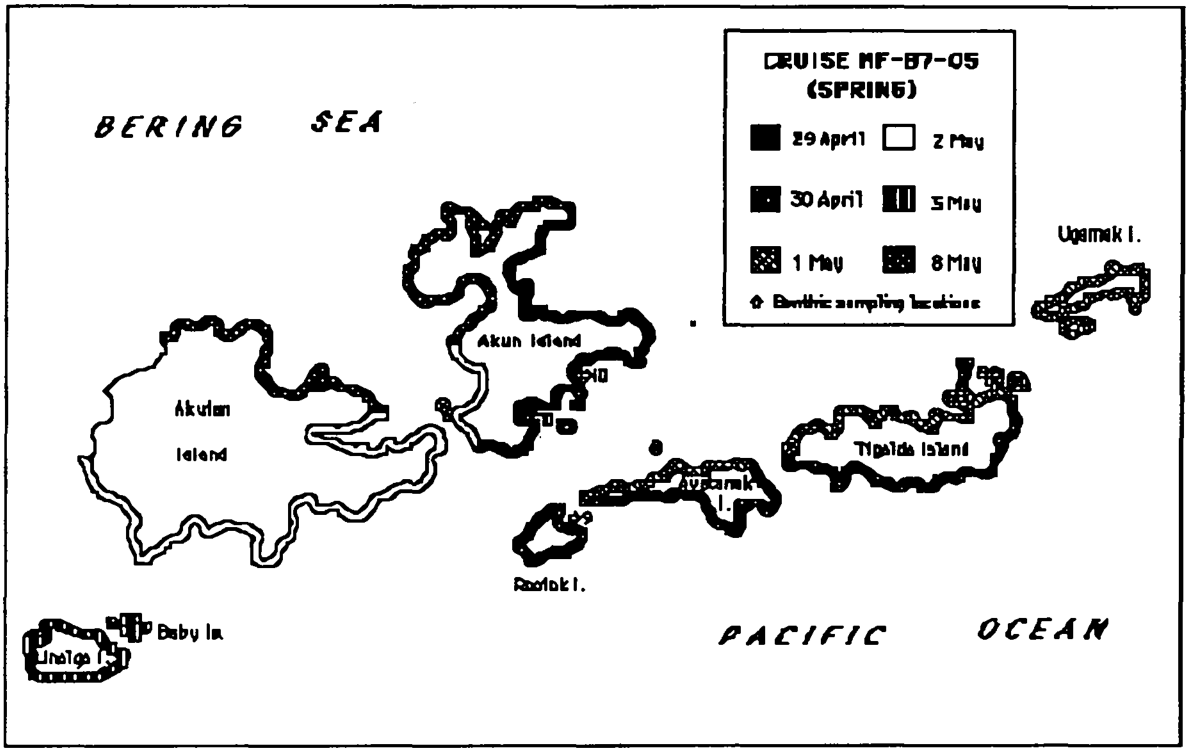

Figure 5. Dates and times of coastal transects in spring 1987.

Table 1. Approximate circumferences of the islands and island groups surveyed by small boat.

Island	Circumference (km)
Unalga	30.8
Baby Islands	11.5
Akutan	117.7
Akun (Includes Poa, Tangik, Puffin, and Tanginak Islands, and two islands near Akun Strait)	125.3
Rootok	17.7
Avatanak	43.8
Tigalda (Includes Kaligagan and Derbin Islands and islets northeast of the main island)	85.4
Ugamak (Includes Aiktak and Round Islands)	31.1
Total	463.3

information, coded later onto computer forms, included start and end times, weather and sea conditions, and tidal stage.

To match sighting records geographically among surveys, observations were recorded within 252 subsections (segments) of the coastline. Each segment was approximately 0.5 km in length, and was identified in the field by orienting to recognizable coastal features. We mapped these segments during the first study period and used identical maps during each succeeding survey, recording and coding observations within these segments.

Among-season comparisons of bird and mammal populations were based on sightings from only those coastline segments sampled all three seasons. Segments of coast sampled during only one or two cruises (Fig. 6) were excluded from these comparisons.

RESULTS AND DISCUSSION

Most species of marine birds and mammals utilizing the coastal zone of the Krenitzin Islands varied in abundance among the three seasons of the study (Table 2). Numbers recorded (Table 2) represent minimum estimates of abundance, because some individuals of all species were probably missed during surveys (individuals seen off the transect are not included in Table 2.). Numbers of very small birds (e.g. rock sandpipers, most passerines) are probably appreciably under-represented because of the difficulty in detecting them on shoreline substrates.

Discussions of the major groups of birds and marine mammals encountered during the surveys are presented below.

Marine Birds

Total numbers of birds observed during the Krenitzin Island coastal surveys were remarkably similar among seasons (Table 2). This was not necessarily expected, because seasonal proportions of many species varied dramatically. Species or species groups that peaked in abundant in the fall included cormorants, Black Oystercatcher, and Tufted Puffin. Those reaching peak abundance in winter included Red-necked Grebe, Emperor Goose, most seaducks (except Common Eider, Harlequin Duck, and Red-breasted Merganser), Bald Eagle, Mew Gull, Whiskered Auklet, and Horned Puffin. Those reaching peak abundance in spring included the breeding seaducks, Glaucous-winged Gull, murres, Pigeon Guillemot, and Ancient Murrelet. Only a few species (Horned Grebe, Peregrine Falcon, and Common Raven) were nearly equally abundant during fall, winter, and spring surveys.

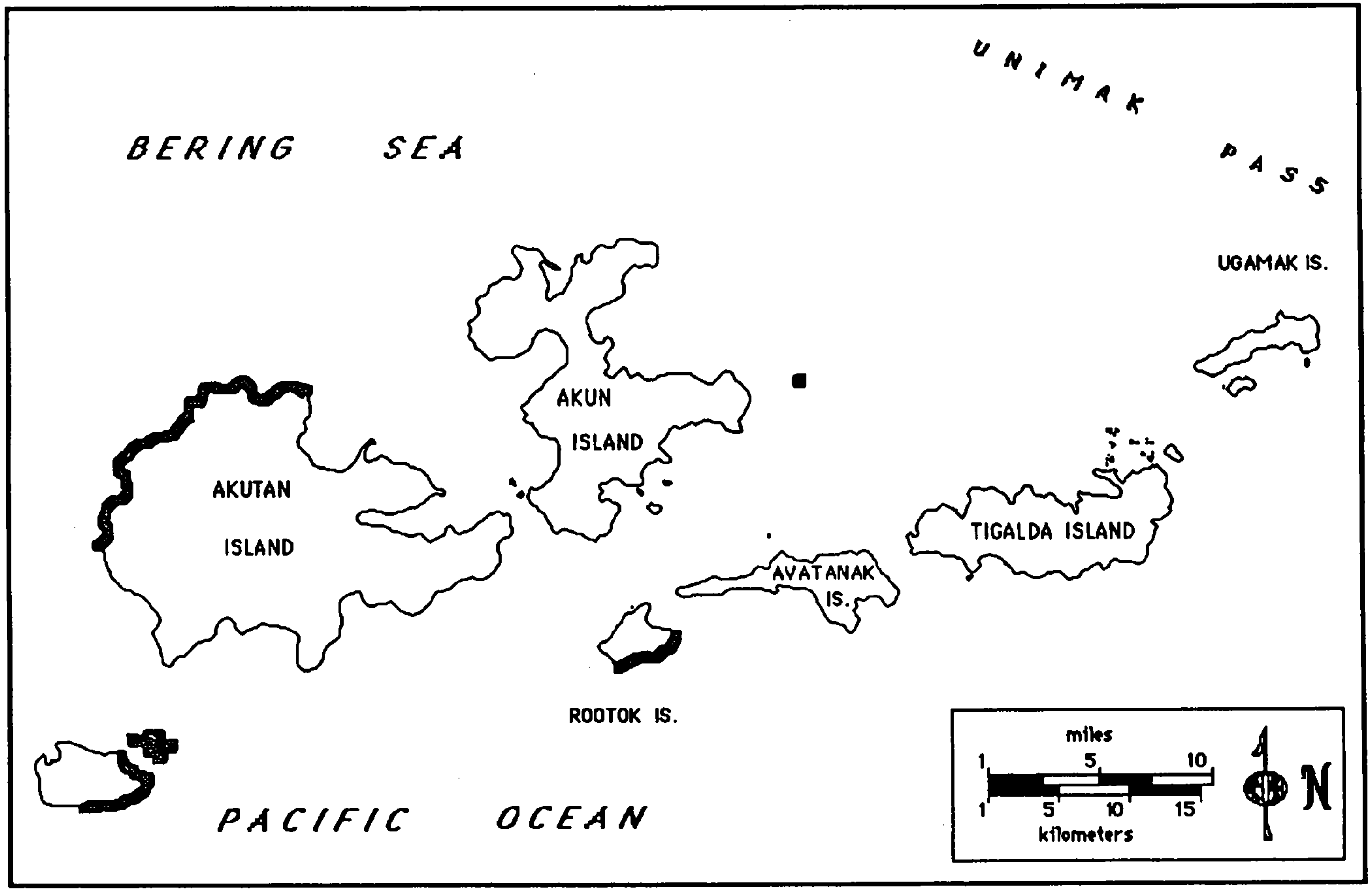

Figure 6. Portions of the coastline of Krenitzin Islands not surveyed on every cruise (shaded). Comparisons of counts between surveys do not include any transect segments in these areas.

Table 2. Numbers of birds and mammals seen within the coastal zone of the Krenitzin Islands (Unalga I. to Ugamak I.) during coastal surveys. Only sightings for those transects sampled during all seasons are included.

Species	Fall	Winter	Spring
Red-throated Loon	1	0	0
Pacific Loon	7	0	0
Common Loon	3	1	0
Yellow-billed Loon	0	0	1
Unidentified Loon	0	7	0
Horned Grebe	31	37	44
Red-necked Grebe	2	15	1
Western Grebe	1	0	0
Double-crested Cormorant	470	313	722
Pelagic Cormorant	160	1310	767
Red-faced Cormorant	838	58	940
Unidentified Cormorant	3121	1128	218
Emperor Goose	444	1457	18
Brant	0	0	1
Canada Goose	0	0	9
Green-winged Teal	63	45	12
Mallard	20	48	8
Northern Pintail	8	0	22
Northern Shoveler	0	0	6
Greater Scaup	0	5	1
Common Eider	39	102	117
King Eider	9	1208	101
Steller's Eider	86	1441	0
Unidentified Eider	7	0	8
Harlequin Duck	3948	3347	6426
Oldsquaw	0	140	4
Black Scoter	64	1385	48
Surf Scoter	0	2	0
White-winged Scoter	90	460	102
Common Goldeneye	0	20	2
Bufflehead	0	137	23
Red-breasted Merganser	14	29	36
Total Non-resident Seaducks	256	4794	288
Bald Eagle	75	232	192
Rough-legged Hawk	0	0	9
Golden Eagle	0	1	0
Peregrine Falcon	6	6	3
Unidentified Ptarmigan	0	0	2
Black Oystercatcher	247	75	165
Rock Sandpiper	18	33	2
Mew Gull	7	105	0
Herring Gull	1	0	0
Glaucous-winged Gull	5641	3136	7951
Black-legged Kittiwake	3251	0	16

Table 2, cont.

Species	Fall	Winter	Spring
Common Murre	35	12	1
Thick-billed Murre	0	3	3
Unidentified Murre	21	70	300
Pigeon Guillemot	173	174	1541
Marbled Murrelet	6	1	0
Ancient Murrelet	0	0	312
Cassin's Auklet	0	1	1
Crested Auklet	0	4	0
Whiskered Auklet	22	6618	923
Rhinoceros Auklet	1	0	0
Tufted Puffin	1263	2	2
Horned Puffin	7	15	3
Common Raven	63	56	66
Winter Wren	0	0	3
Song Sparrow	0	12	27
Snow Bunting	0	53	0
Rosy Finch	0	90	1
Total Birds	20,268	23,397	21,161
Sea Otter	466	322	627
Arctic Fox	1	0	2
Red Fox	2	4	5
Steller's Sea Lion	5248	1361	1419
Harbor Seal	356	187	513
Cattle	0	18	4
European Rabbit	0	0	13
Total Marine Mammals	6090	1874	2936

Loons

Loons were uncommon in the coastal zone of the Krenitzin Islands (Table 2). All four of the common North American species (Red-throated, Pacific, Common, and Yellow-billed) identified on coastal surveys were present in very low numbers. Loons are difficult to identify to species when in winter plumage, and were usually too wary to be approached closely with survey boats. The lack of large numbers on pelagic transects (see Chapter 5: MARINE BIRD ABUNDANCE AND HABITAT USE, this volume) indicates that the Krenitzin Islands/Unimak Pass area is not an important area for loons during the non-breeding period.

Grebes

Three species of grebes were found in the coastal zone. The single Western Grebe seen at Akun Bay (and possibly again at Beaver Inlet) represents a casual occurrence only (the second for the Aleutian Islands--Gibson et al. 1987a). A small influx of Red-necked Grebes occurred in winter (Table 2), but likewise were uncommon. The most common grebe was the Horned Grebe.

Horned Grebes appeared as single individuals or in pairs throughout the study area and were found most frequently in kelp beds or protected bays. Numbers observed did not fluctuate greatly among seasons. Because of the relatively small size and secretive nature of Horned Grebes, some individuals undoubtedly went undetected during each survey.

Cormorants

The three cormorant species are difficult to distinguish from each other, and so numbers of "unidentified cormorants" recorded was large (Table 2), particularly in fall and winter. The ability to distinguish species increased from fall to spring as distinctive breeding plumages were attained. Double-crested Cormorants, because of their larger size, were the easiest of the three to identify, and so most of the unidentified cormorants were probably Pelagic and Red-faced.

Cormorants were among the most common of marine birds using the coastal zone of the Krenitzin Islands; only Harlequin Ducks and Glaucous-winged Gulls were consistently present in equal or greater numbers. Largest numbers of cormorants were present in fall, partly because the surveys were conducted in early fall when breeding birds and their young were probably still present in the area.

Three cormorant species breed in the Krenitzin Islands (Sowls et al. 1978). Spring surveys for all cormorants took place during the initial phases of nesting, so that most of the year's breeders were probably present.

The Double-crested Cormorant is at the westernmost limit of its breeding range in the Fox Islands (of which the Krenitzin Islands are the easternmost group). It appeared to be the least common cormorant species in the Krenitzins in spring. In contrast, Nysewander et al. (1982) found it to be slightly more abundant than the Pelagic Cormorant in the entire Fox Islands group.

We found Pelagic Cormorants to be fewer in number than Red-faced Cormorants in the Krenitzin Islands in spring when nesting was underway, as did Nysewander et al. (1982). Pelagic Cormorants appeared to increase in abundance in the fall and to a greater extent in winter (Table 2). The breeding distribution of this species extends well north of the Krenitzin Islands into areas ice-covered during the winter. Considerable numbers may move south into the Unimak Pass area in winter.

The Red-faced Cormorant was probably the most common breeding cormorant in the Krenitzin Islands. Its winter numbers were very low compared with its numbers in spring and fall, and compared with winter numbers of the other species. Causes of winter scarcity are speculative. Cormorants seen in winter in nearby areas away from the coast were usually identified as Red-faced, so lower numbers seen at the coast may have been caused simply by increased pelagic feeding by this species in winter. Alternatively, high concentrations of Red-faced Cormorants seen in the North Aleutian Shelf nearshore zone (northeast of the Unimak Pass area) from October to March (LGL 1987) may represent a partial winter exodus from breeding areas in the eastern Aleutians.

Emperor Goose

As expected, the highest counts of Emperor Geese were obtained during the winter survey. The Krenitzin Islands are within the winter range of this species, and appear to contain winter habitat, although what constitutes important winter habitat has never been well-defined. Locations of wintering flocks (Fig. 7) indicated that Emperor Geese preferred rock ledges and boulder or rock beaches. They occurred in small flocks and were often seen in association with a bright green alga that grows on wave-washed rocks.

Other Geese

Other geese (one Brant and nine Canada Geese) were seen only in spring. As was the case with shorebirds and dabbling ducks, the eastern Aleutians are outside of major flyways and staging areas for these common continental migrants. The Canada Geese we observed flying over Kaligagan Island may have been Aleutian Canada Geese, an endangered subspecies; however, a positive identification was not obtained.

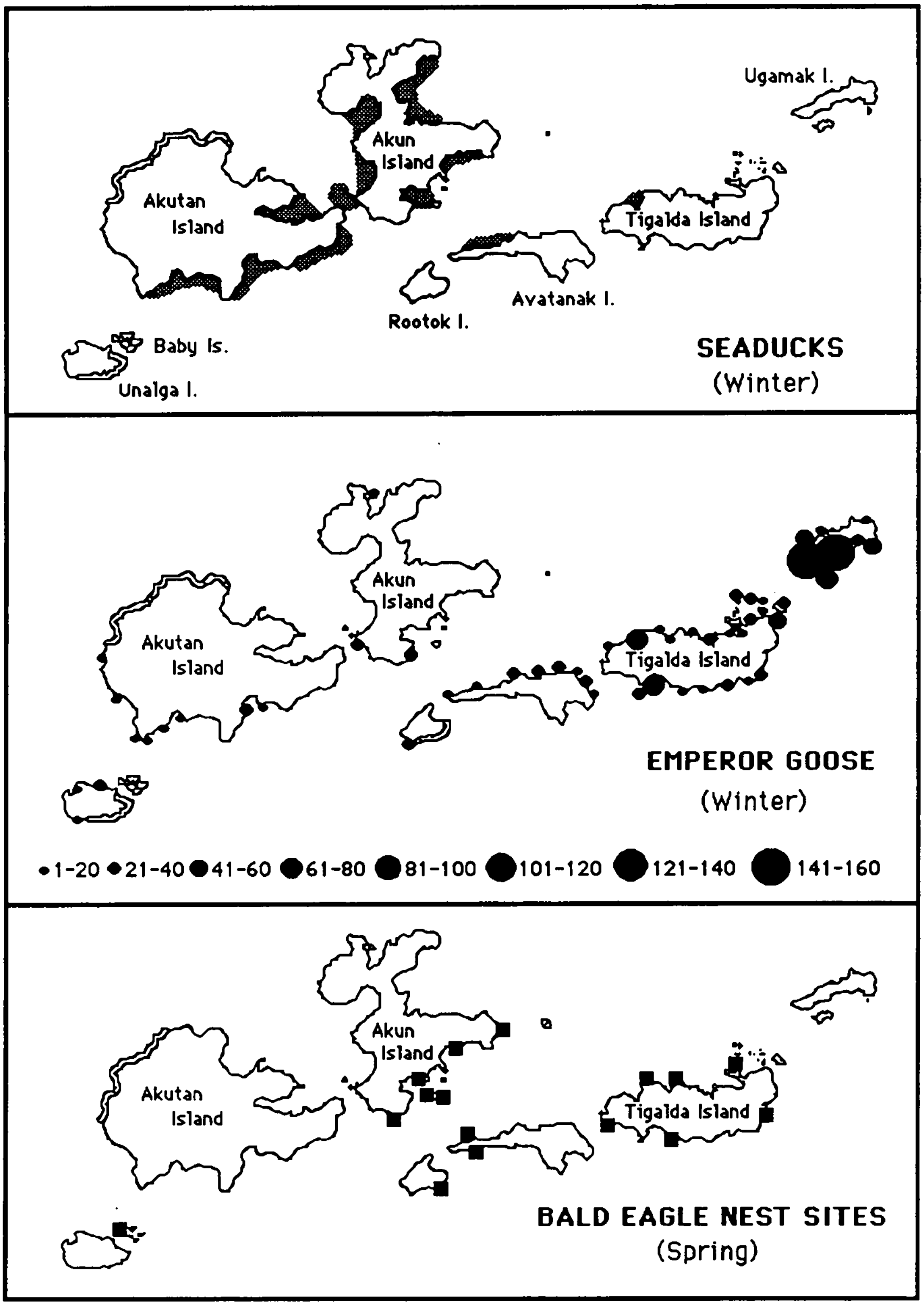

Figure 7. Locations of wintering sea duck concentrations, wintering Emperor Goose sightings, and Bald Eagle nest sites in the Krenitzin Islands. Outlined areas were not surveyed.

Dabbling Ducks

Mallards and Green-winged Teal were observed using coastal habitats at several of the islands surveyed in fall and winter. All of the closely observed teal were of the Aleutian race *Anas crecca nimia*. Both species appeared to prefer lakes and ponds near the coast, but resorted to saltwater habitats if ponds were frozen. These species were least common in spring, possibly because the main movement to inland nesting areas had begun prior to surveys.

Seaducks

Twelve species of seaducks (tribe Mergini) were identified during coastal surveys. Counts were highest during the winter period for all except the locally-breeding species which included Common Eider, Harlequin Duck, and Red-breasted Merganser. Non-resident species included King Eider, Steller's Eider, Oldsquaw, Black Scoter, Surf Scoter, White-winged Scoter, Common Goldeneye, and Bufflehead. These species tended to concentrate in several of the larger bays within the Krenitzin Islands (see Fig. 7). Notable exceptions were King Eiders and White-winged Scoters, which were frequently found in large flocks (100-200 birds) in nearshore waters immediately offshore of headlands, such as north of Unalga Island, southeast of Akutan Island, off the north side of Akun Island, and northeast of Avatanak Island (Fig. 7).

The Harlequin Duck was the most abundant of the resident species; it was one of the most widespread and conspicuous birds in the coastal zone. These birds were typically found as isolated individuals, pairs, or small flocks of under 10 birds. Harlequin Ducks inhabited all major coastal habitats, including kelp beds and open waters adjacent to substrate types ranging from gravel beaches to rock ledges and cliffs.

Harlequin Ducks observed during the fall surveys appeared to be flightless, and birds obviously lacking flight feathers occasionally were observed. Males may have been still flightless by the time of the surveys (molt occurs from July through September), but it is more likely that most of the molters were breeding females, in which molt occurs from August through October (Cramp and Simmons 1977).

Fall and winter abundances of Harlequin Ducks in the Krenitzin Islands were similar, but numbers increased in spring. The Aleutians are known to be an important wintering area for this species (Palmer 1976), and the high numbers in spring may have been caused partly by migrants on their way from the central and western Aleutians to inland breeding areas in northwestern North America.

Common Eiders and Red-breasted Mergansers were present in small numbers throughout the study area. Common Eiders were seen consistently among the Baby Islands; they have been reported to nest there (Nysewander et al. 1982). Mergansers were located consistently along the north shore of Tigalda Island.

Raptors

By far the most abundant raptor present in the coastal zone of the Krenitzin Islands was the Bald Eagle. Highest numbers were counted in winter, and the general influx of birds at this season appeared to last through spring (Table 2). Counts of eagles (and other raptors) were affected by the behavior of the birds. Birds that flushed from perches or that were first observed in the air were easily noted, but some perched birds (particularly those high up on coastal cliffs) may have been missed because the observer's attention was focused on detecting birds on the water and adjacent beaches.

Wintering eagles were attracted to carrion and fish-processing wastes in the Krenitzin Islands. A group of 40 eagles occurred in the vicinity of recently slaughtered cattle on the beaches of Trident Bay, Akun Island, on 25 February 1987. In addition, a concentration of 66 eagles was noted at Lost Harbor, Akun Island, where a fish processing ship was in operation on 4 March.

By the time of the spring survey, many Bald Eagles had initiated nests in the Krenitzin Islands (Fig. 7). Nests were almost invariably placed at or near the tops of sea stacks that were at least somewhat isolated from the mainland of the islands. Again, some nest sites were almost surely missed due to their elevation above the shoreline.

Other raptors observed included Rough-legged Hawk, Golden Eagle, and Peregrine Falcon. Rough-legged Hawks seen in spring were probably local breeders and/or migrants moving to breeding areas farther down the Aleutian chain. Two Golden Eagles (an immature on Avatanak Island on 1 March, 1987, and an adult on Tigalda Island on 3 March) were at the southwestern limit of the species' range in North America (Gibson et al. 1987b). Peregrine Falcons were regularly observed, but many could have been missed if they failed to flush as the survey boat passed. All of the individuals that were observed closely appeared to be of the dark coastal resident race *Falco peregrinus pealei.*

Shorebirds

Only two species of shorebird--Black Oystercatcher and Rock Sandpiper--were observed during the coastal surveys. Oystercatchers usually occurred in small flocks in fall and winter, but by spring had dispersed into isolated (presumably breeding) pairs. Flocks of oystercatchers were most frequently seen in areas with extensive tidal reefs, such as the south sides of Unalga, Rootok, and Ugamak islands, the east side of Tigalda Island, and along Akun Strait.

Black Oystercatchers were probably more reliably censused than Rock Sandpipers because of their larger size and loud calls. Undoubtedly many more Rock Sandpipers were present than were seen during surveys. They are common winter residents over most of the Aleutians (Gabrielson and Lincoln 1959).

Gulls

Only three species of gull--Mew Gull, Glaucous-winged Gull, and Black-legged Kittiwake--occurred in any numbers in the Krenitzin Islands. Mew Gulls were primarily winter visitors in the area; they appear to reach the southwestern limit of their range in Alaska in the Krenitzin Islands (Gabrielson and Lincoln 1959). Almost all (103 of 105) of the individuals seen in winter were among groups of Glaucous-winged Gulls and Bald Eagles gathered near a floating fish processor anchored in Lost Harbor, Akun Island. All these birds were attracted to the fish offal associated with this processor.

The Glaucous-winged Gull was one of the most abundant species found in the coastal zone of the Krenitzin Islands. The highest count occurred in spring when locally-breeding birds were initiating nests (Fig. 8). The lower numbers seen during winter may have reflected local movement offshore or possibly movement farther south at this time of year. Individuals of this species banded at colonies in coastal British Columbia showed a tendency to disperse southward in autumn (Butler et al. 1980). In the nearby North Aleutian Shelf, Glaucous-winged Gulls declined in abundance in winter and used deeper waters than during the breeding periods (LGL 1987).

As was observed on the adjacent North Aleutian Shelf (LGL 1987), Black-legged Kittiwakes were absent from Unimak Pass during the winter. They were seen again during April-May surveys, and were still common in large roosting flocks along the shore of the Krenitzin Islands in late September-early October.

Alcids

Although a wide variety of alcids was seen on the coastal surveys, these birds were also observed outside of the coastal zone, as confirmed by results of the shipboard transects (see Chapter 5: MARINE BIRD ABUNDANCE AND HABITAT USE, this volume). This tendency to range widely suggests that comparisons of coastal abundances of these species between survey periods must be viewed with caution.

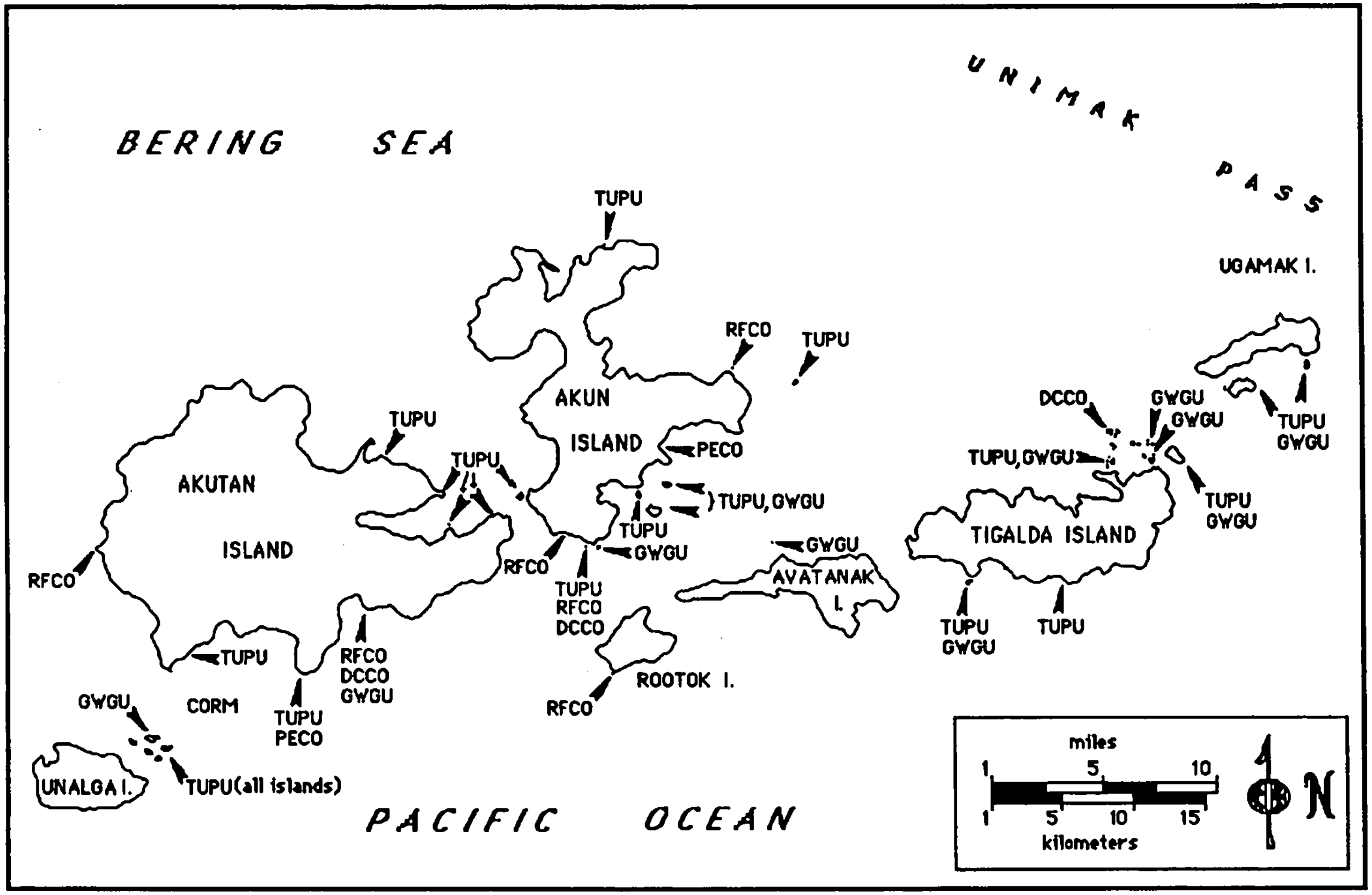

Figure 8. Locations of seabird colonies observed during coastal surveys, Unimak Pass area, Alaska. Only colonies of large and obvious species could be noticed during surveys.

The Pigeon Guillemot preferred shallow coastal waters and so was rarely detected during shipboard transects. Guillemots were seen throughout the study area and were most often observed as scattered individuals, pairs, or small flocks. The large numbers observed in spring probably reflected the return of breeding birds. It is not known where these birds spent the fall and winter.

Other alcid species also showed seasonal peaks in abundance. The high numbers of Tufted Puffins seen on the coastal surveys in fall (Table 2) reflected the presence of breeding birds near colony sites (see Fig. 8). Adults carrying fish into colonies were regularly observed at this season, but insufficient time was spent at each colony to estimate numbers of puffins using the sites.

The relatively high numbers of Whiskered Auklets observed in winter on coastal surveys may reflect only a slight seasonal habitat shift. In winter this species appeared throughout the Krenitzin Islands in small coastal flocks at tide rips and in areas of converging currents near almost all straits and passes. In spring and fall, birds were found in the same straits and passes, but farther from land.

Passerines

The most conspicuous and easily-censused passerine in the Krenitzin Islands was the Common Raven. This resident species was seen in similar densities at all seasons and on all major islands. As was noted for raptors, many individuals that were perched were probably missed unless flushed by the boat. Other passerines were too small to be censused reliably, although the high numbers of several resident species observed in spring probably was caused in part by their greater detectability at this season because of singing by adult males. During the February-March surveys, wintering flocks of Snow Buntings and Rosy Finches were evident against the snow-covered tundra.

Marine Mammals

Steller Sea Lion

Sea lions historically have hauled out at several sites throughout the Krenitzin Islands (Fig. 9), but their numbers in this region appear to have declined since population surveys began in 1957. We occasionally recorded this species on pelagic transects conducted from the R/V *Miller Freeman*, but the majority of sightings were made during the coastal small boat surveys.

Numbers of sea lions observed during the coastal surveys were lowest during winter. Numbers increased slightly in spring and were at their highest

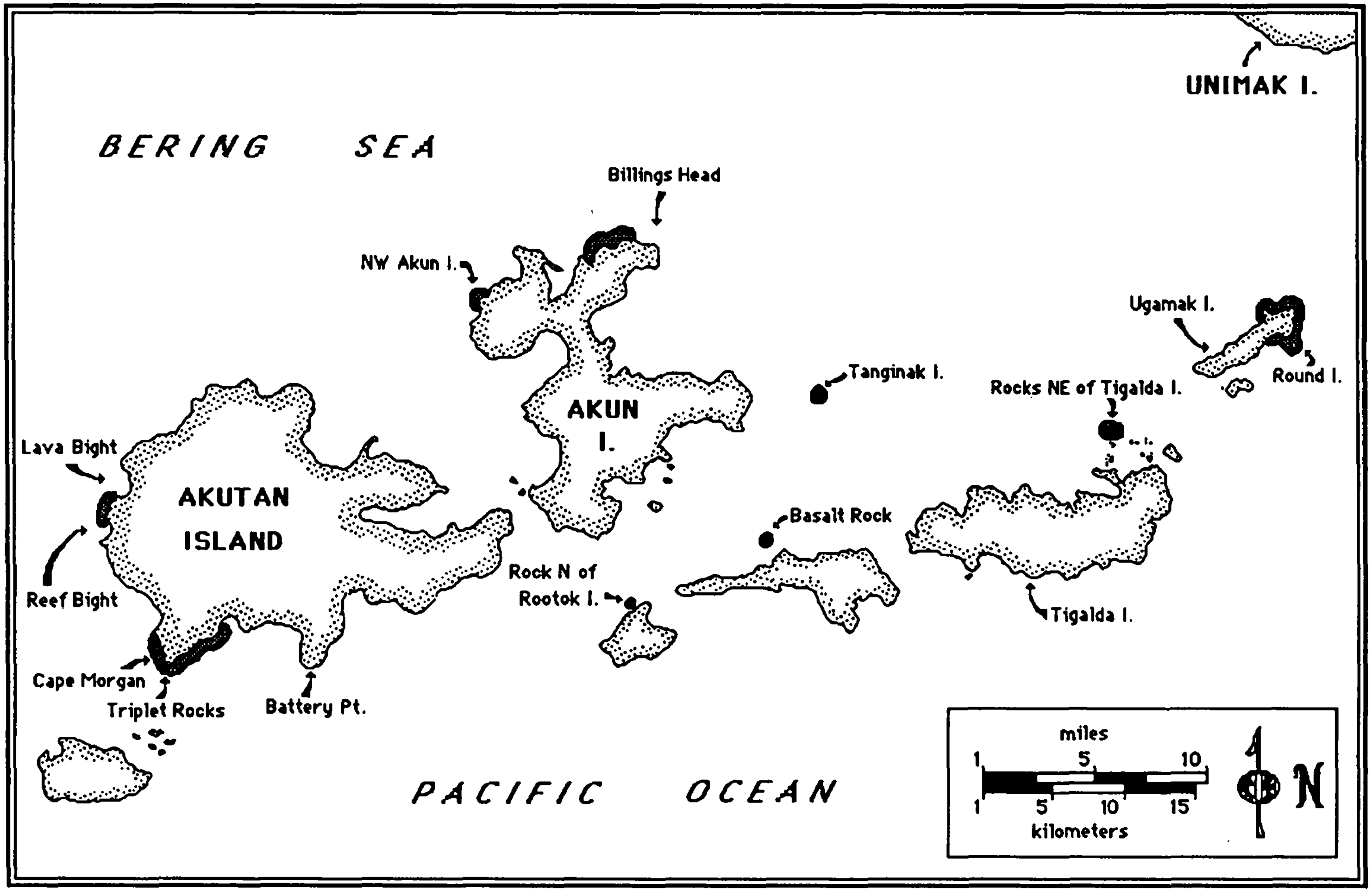

Figure 9. Locations of haulouts of Steller's sea lions in the Krenitzin Islands, Unimak Pass area, Alaska.

levels in fall (see Table 2). In all seasons, most of the sea lions observed were hauled out. A slightly lower percentage of sea lions were seen in the water in fall (5%) than in winter (8%) or spring (9%).

Reasons for the differences in observed population levels (i.e., greater numbers in fall than in winter or spring) may be two-fold. Migration of sea lions to areas farther south has been shown to occur during the breeding season (Loughlin et al. 1984), therefore absolute numbers in the Krenitzin Islands may decline annually during winter and early spring. Also, sea lions generally do not re-occupy rookery sites (where they are most easily observed) in spring until late May to June.

Table 3 provides historical maximum counts of all age classes of sea lions at several haul-out locations in the study area, along with data from this study for comparison. Counts in October 1957 at Cape Morgan (including Reef and Lava bights) and Ugamak Island (including Round Island) were both more than an order of magnitude higher than our 1986 counts in late September (Cape Morgan) and early October (Ugamak). Also, counts we made at these two locations were lower by 10 or 12 percent than those made in October 1976. Despite the many factors that can affect the reliability of counts, the data suggest that population levels of sea lions may still be declining, though perhaps not as rapidly as between the mid-1950s and 1970's.

Harbor Seal

Unlike sea lions, harbor seals were present on every island of the Krenitzins. They were most frequently encountered as solitary individuals swimming near the shore. Those hauled out were mostly in small groups (<10 animals) at numerous and seasonally varying locations along the coast. Occasional small congregations occurred near apparently favored haul-out sites, but these rarely involved more than 20 seals. No haul-outs contained more than 100 animals, which contrasts with the North Aleutian Shelf area where thousands of seals have been documented at haul-out sites (LGL 1987). The deep nearshore waters and steep bottom profiles around the Krenitzin Islands provide less feeding habitat for the harbor seal than do the extensive lagoons, bays, and shallow nearshore zone characteristic of the North Aleutian Shelf.

Numbers of animals seen at haul-out sites and in the water were highest in spring and lowest in winter. Aerial surveys by Everitt and Braham (1980) indicated that numbers of hauled out seals generally increased from June to August as the animals underwent molt. The molt period was probably ended by the time of the fall surveys.

Harbor seals in the Krenitzin Islands hauled out on low rocks, reefs, and islets that were generally awash at high tide. Though haul-out locations varied from season to season (Fig. 10), eight areas harbored at least a few seals

Table 3. Observations of Steller's sea lions at haul-out sites in the Krenitzin Islands. Numbers are based on aerial surveys (previous decades summarized by Johnson et al., in prep.; May 1987 data from R. Merrick, Nat. Mar. Fisheries Serv., pers. comm. 1987) or small boats; (1986-87 data in boldface type from this study). Numbers are based on counts taken from photographs or on visual estimates taken in the field, therefore comparisons should be made with caution. Dashes indicate areas not surveyed.

LOCATION/DATE	1950s	1960s	1970s	October 1980s	Sept.- March 1986	Feb.- May 1987	April- May 1987	1987
Akutan Island	7675	15,720	4019	2533				
Cape Morgan					**768**	**37**	**2**[1]	0
Reef Bight					**293**	**100**	—	253
Lava Bight					**0**	—	—	311
Battery Point					**0**	**0**	**0**	0
Akun Island	1361							
Billings Head	—	2000	2641	760	**1416**	**429**	**305**	100
NW Akun Is.	—	100	10	—	**15**	**0**	**1**	
Tanginak Island	—	600	470	—	—	**52**	—	6+
Rocks NE of Tigalda Island	103	750	190	225	**33**	**106**	**320**	117
S side Tigalda Is.	—	10	314	—	**0**	**0**	**0**	25
Basalt Rock					**0**	**0**	**7**	
Ugamak Island	16,002	19,400	5408	3668	**2399**	**430**	**855**	748[3]
Round Island[2]					**45**	**10**	**32**	
Rock N of Rootok Island	—	—	118	160	**10**	**75**	**85**	113[4]

[1] Sea lions were hauled-out on Triplet Rocks

[2] Included in Ugamak Island counts in previous decades

[3] Includes counts from Round Island

[4] Sea lions were hauled-out on NW shore of Rootok Island

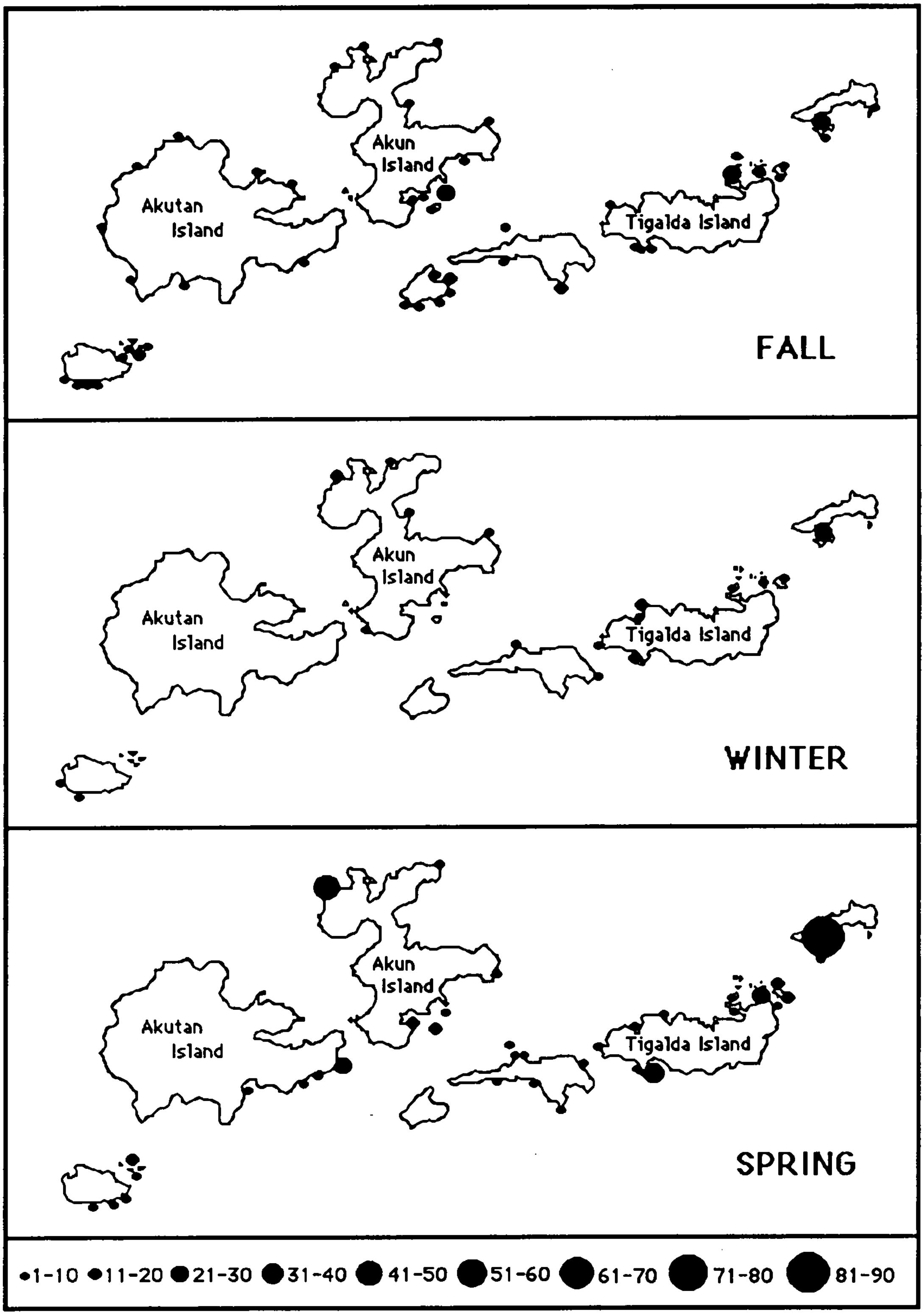

Figure 10. Relative size and locations of harbor seal haulouts observed during each of the coastal surveys in the Krenitzin Islands.

during every season sampled. These areas and highest counts of hauled out animals were:

(1) Coastal rocks along the shore of the southern half of Unalga Island (highest count—8 in spring).

(2) Rocks and reefs among the Baby Islands (highest count—28 in fall).

(3) Rocks on the back side of a sea stack west of Akun Head, Akun Island (highest count—42 in spring).

(4) Rocks among the offshore islands and along the coast near Trident Bay (highest count—32 in fall; none were seen in winter, but nearby boat trouble in winter probably flushed seals from haul-out sites prior to counts).

(5) Basalt Rock and rocks along the adjacent coastline of Avatanak Island (highest count—10 in fall).

(6) Coastal rocks along the shore of Tigalda Island immediately behind Derbin Island (highest count—37 in spring).

(7) Islets, reefs, and rocks northeast of Tigalda Island, including Kaligagan Island (highest count—61 in spring).

(8) Rocks adjacent to, but primarily on the north side of, Aiktak Island (highest count—92 in spring).

There was considerable seasonal variability in haul-out locations and in numbers of seals present (Fig. 10). This variability was particularly noticeable with regard to seal use of Rootok Island and southeast Akutan Island, and to the wide fluctuations at some haul-outs, such as northwest Akun Island and on islets northeast of Tigalda Island. Harbor seals were not seen at haul-out sites of sea lions when sea lions were present.

Sea Otter

Sea otters were present in inshore waters around all of the Krenitzin Islands, including Unalga and the Baby Islands. Numbers observed were highest in the spring and lowest in winter (see Table 2). Sea otters typically were found as isolated individuals or small groups scattered throughout the study area.

Certain areas in the Krenitzin Islands either consistently hosted higher numbers of sea otters at all seasons or contained relatively high concentrations during a given survey period. A concentration area was defined as any area of coastline less than 1 km in length that contained at least 10 sea otters; such areas shifted somewhat among seasons (Fig. 11). Despite seasonal differences, six general areas consistently held relatively large numbers of sea otters:

(1) North shore of Tigalda Island (from Kelp Bay eastward to Kaligagan Island).

(2) North and east shores of Avatanak Island.

(3) Poa and Tangik islands (at times extending to Trident, Cross, and Seredka Bays).

(4) Akun Bay.

(5) North shore of Akun Island including Little Bay.

(6) Akun Strait and/or Akutan Harbor.

Concentrations of sea otters were present within all of these areas during all seasons, from fall to spring. Most of these areas are typified by waters well protected from heavy surf, large swells, or strong currents. Notable exceptions include the north shore of Akun Island (exposed to heavy swells and surf) and Akun Strait (having strong currents), but well-protected embayments used by sea otters occur close to both of these areas (Little Bay and Akutan Harbor, respectively). Sea otters appear to prefer calm bays and other protected waters throughout their range (Kenyon 1969), although they are common and occur far offshore in the unprotected nearshore waters of the North Aleutian Shelf (LGL 1987).

We found apparently higher densities of sea otters in the Krenitzin Islands in fall 1986 and spring 1987 than had been reported on any previous survey since 1957 (Table 4). Although survey methods and island coverage varied greatly among past surveys, and between past surveys and ours, it appears that sea otter populations have increased on all islands, with the exception of Tigalda Island and probably Rootok Island. The breeding concentration reported by Schneider (1981) on Tigalda Island, as well as populations on nearby Unalaska and Unimak islands, represent the most likely sources of sea otters that have colonized the remaining islands in the Krenitzin Group.

It is interesting that Akun Island, which previously contained few sea otters even as late as 1977, consistently had the largest populations in the Krenitzin Islands during our surveys. The populations on Tigalda and Rootok islands may not have changed greatly since 1965 (Table 4), although Brueggeman et al. (1988) found greater numbers on Rootok during an aerial survey in July 1986 than were recorded on our surveys. Surveys of sea otters may yield highly variable estimates even when numbers are stable, due to the

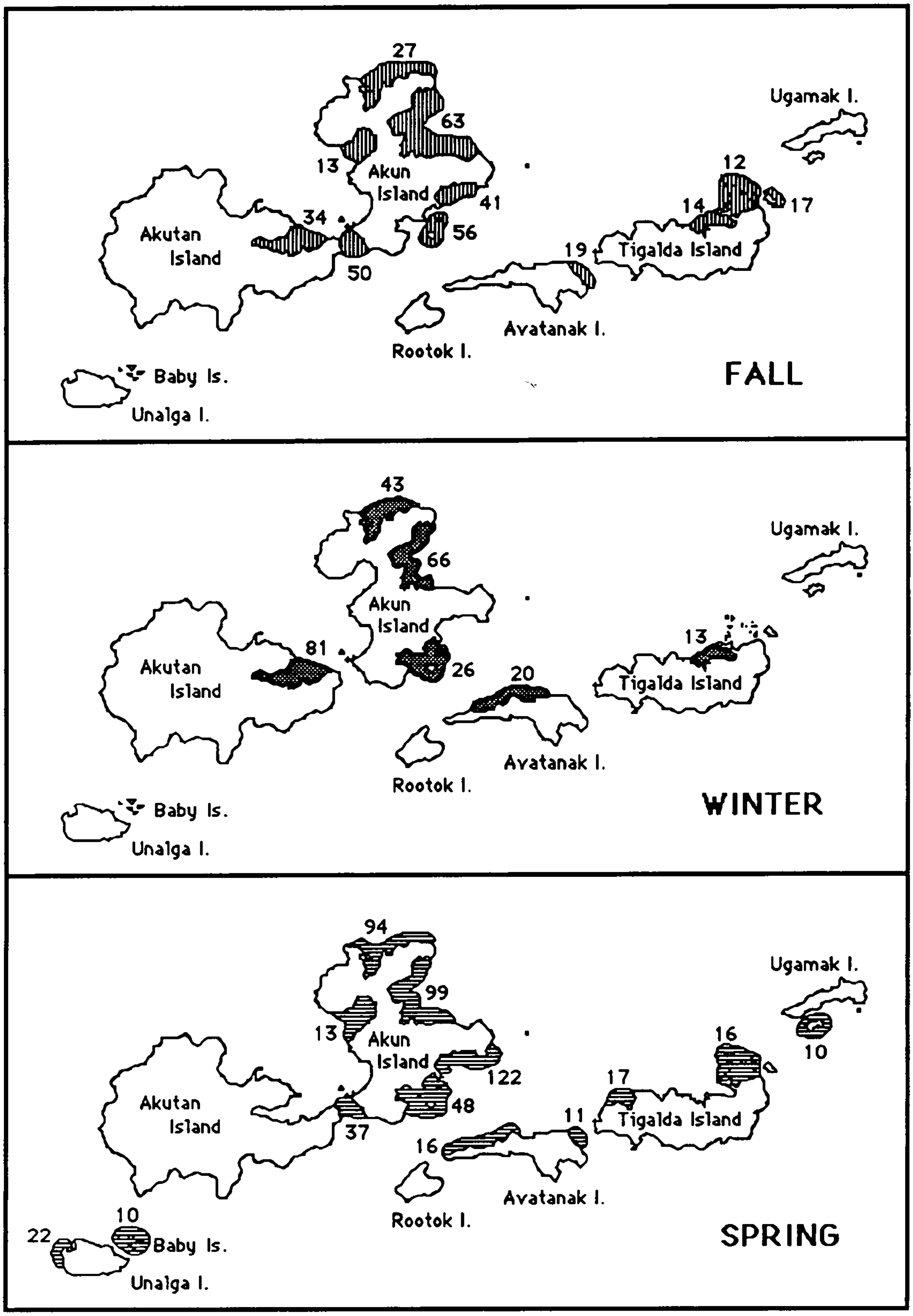

Figure 11. Concentration areas of sea otters in the Krenitzin Islands.

Table 4. Summary of significant sea otter sighting in the Krenitzin Islands, 1957 to present. Data for 1957-1977 are from Schneider (1981) and represent several USFWS aerial surveys by C. Lensink and K. Kenyon (1957-1969; specific reports not listed), and aerial surveys for ADF&G by K. Schneider (1976) and P. Arneson (data gathered during bird studies, 1976-77). Data for July 1986 are from aerial surveys by Brueggeman et al. (in prep.). Data for September 1986 to May 1987 (boldface type) are from small boat surveys done for this study. Dashes indicate islands or island groups not surveyed. Asterisks (*) denote partial surveys.

Island or Island Group	1957	1960	1962	1965	1969	June 1975	Aug. 1975	1976-77	July 1986	Sept.-Oct. 1986	Feb.-March 1987	Apr.-May 1987
Ugamak/Aiktak	—	0	0	0	0	0	5	1	—	**13**	**3**	**15**
Tigalda/Kaligagan	5	11	3	32	49	59	73	53	0*	**58**	**40**	**51**
Avatanak	—	0	—	2	0	0	4	1	—	**36**	**21**	**33**
Rootok	—	0	—	0	2	0	1	4	15	**6**	**2***	**1**
Akun	—	0	—	—	3	0	3	1	226	**230**[1]	**159**[1]	**431**[1]
Akutan	—	0	—	0	1	0	2	17	146*	**125**	**98***	**75***
Unalga	—	0	—	0	0	0	0	1	7	**18**	**1***	**48**

[1] Includes Tangik, Poa, and Puffin Islands, and islands near Akun Strait but excludes Tanginak Island.

frequent diving rates of this species (Estes and Palmisano 1974) and their inconspicuousness when hauled out and stationary on boulders or rocky beaches.

RECOMMENDED FURTHER RESEARCH

No major concentrations of marine birds were detected during coastal surveys. The steep gradient of coastal waters and lack of protected lagoons in the Krenitzin Islands result in a paucity of habitats for large numbers of coastal birds, especially ducks and shorebirds. Neighboring areas, especially the North Aleutian Shelf to the east and perhaps Samalga Island to the west, support much higher concentrations of these birds. Given these findings, additional coastal surveys for marine birds in this area are probably a low priority. The major informational need is for summer surveys. Although few waterfowl or shorebirds would be expected during the summer, breeding seabirds might be more plentiful at this time. In particular, information on the distribution of and habitat use by Whiskered Auklets might be supplemented by summer work (e.g. in July).

In contrast to the few birds they support, the Krenitzin Islands support relatively large numbers of several marine mammal species. Some species have recently exhibited rather marked changes in abundance. In particular, numbers of Steller sea lions are decreasing, but sea otters are on the increase. Data from summer surveys would be useful to complete a seasonal profile for this area. In addition, because of the dynamic nature of the sea lion and sea otter populations, additional repeat surveys, perhaps at three-year intervals, seem warranted.

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Chapter 8

SEABIRD COLONIES

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SUMMARY

This report describes several facets of a study of seabirds conducted at Egg Island and vicinity in the Unimak Pass area in summer 1987. Studies to develop and test call-count techniques for censusing storm-petrels and other nocturnal, burrow-nesting seabirds were carried out at a seabird colony on Egg Island. A distributional survey of Whiskered Auklets was made on Egg Island and the Baby Islands. Observers also counted Tufted Puffin burrows on study plots on Egg Island and monitored activity and percent occupancy of these burrows. Finally, project personnel identified additional colony locations, important feeding concentrations, and other concentrations of seabirds observed in the vicinity of the islands visited during the summer field studies. The findings are summarized below:

(1) The call-count technique for censusing storm-petrels was found generally inaccurate, time-consuming, and not easily transferable among workers. Sky-counts do offer some potential to monitor population levels of storm-petrels, but even this technique has problems.

(2) Call-counts appear to have promise for estimating numbers of nesting Ancient Murrelets, but the surveys must be well-timed and supported with estimates of the extent to which nesting burrows are used.

(3) Call-count techniques offer good potential for monitoring numbers of Cassin's Auklets, especially when burrow count data are also available.

(4) Whiskered Auklets were present as isolated pairs on vertical cliff faces around the entire perimeter of Egg Island and on two of the Baby Islands surveyed. Observers located 20 calling birds at 17 sites on Egg Island, 44 calling birds at 29 sites on Tangagm Island, and 27 calling birds at 24 sites on Excelsior Island.

(5) From 180,000 to 200,000 Tufted Puffins were estimated to use Egg Island in summer 1987. Puffin burrow density ranged from 0.62 to 0.82 burrows/m^2. Although 98.8 percent of all burrows monitored on sample plots were occupied, occupancy by breeding birds was estimated to be about 35 percent.

(6) The species compositions of the colonies observed in 1987 were found to be similar to those observed for the same colonies in 1982.

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INTRODUCTION

Within the Unimak Pass study area (Fig. 1) there are over 50 colony sites of seabirds (Sowls et al. 1978, U.S. Fish and Wildlife Service, unpubl. data). Several of these have been estimated to contain over 100,000 breeding birds each. Most of the colonies are present on relatively small (generally less than 200 ha), fox-free islands and are located largely in the Krenitzin group.

These colonies are quite different from seabird colonies farther north in the Bering Sea. The latter colonies contain a large proportion of species that visit the colonies by day and nest in the open on sheer cliffs (e.g., kittiwakes, murres, fulmars, cormorants). In the eastern Aleutians and the Unimak Pass area, the above species are either absent or constitute only a small percentage of total birds in most colonies. Colonies here are dominated by Tufted Puffins (a diurnal, burrow-nesting species) and smaller seabirds that visit their underground nest sites only at night (storm-petrels, murrelets, and some auklets).

The habits of these burrow-nesting species present a unique problem to biologists attempting to estimate colony populations and monitor trends in population levels. The techniques in general use for monitoring diurnal cliff-nesters in most cases cannot be applied directly to burrow-nesting species. Therefore, prior to monitoring seabird colony populations in the Unimak Pass area, techniques for conducting census work must be tested.

To meet these needs, the objectives for this study were to investigate methods for quantifying numbers and monitoring populations of seabirds on islands in the Unimak Pass area, with a lesser effort to document the use of surrounding waters by seabirds for feeding and other activities. Specific study objectives were to:

(1) <u>Develop and test census methods for storm-petrels and other nocturnal species</u>—The major emphasis of this objective was to evaluate the call-count technique as a method for producing estimates that could be used to monitor trends in populations of storm-petrels and other nocturnal, burrow-nesting species at colony sites. This technique was attractive in that it has the potential for standard, repeatable surveys, and should cause much less disturbance to nesting seabirds than does inspection of nest burrows.

(2) <u>Conduct a distributional survey of Whiskered Auklets</u>—The goal was to better document the time of day, and period during the breeding season, when calls by Whiskered Auklets could be used for identifying breeding

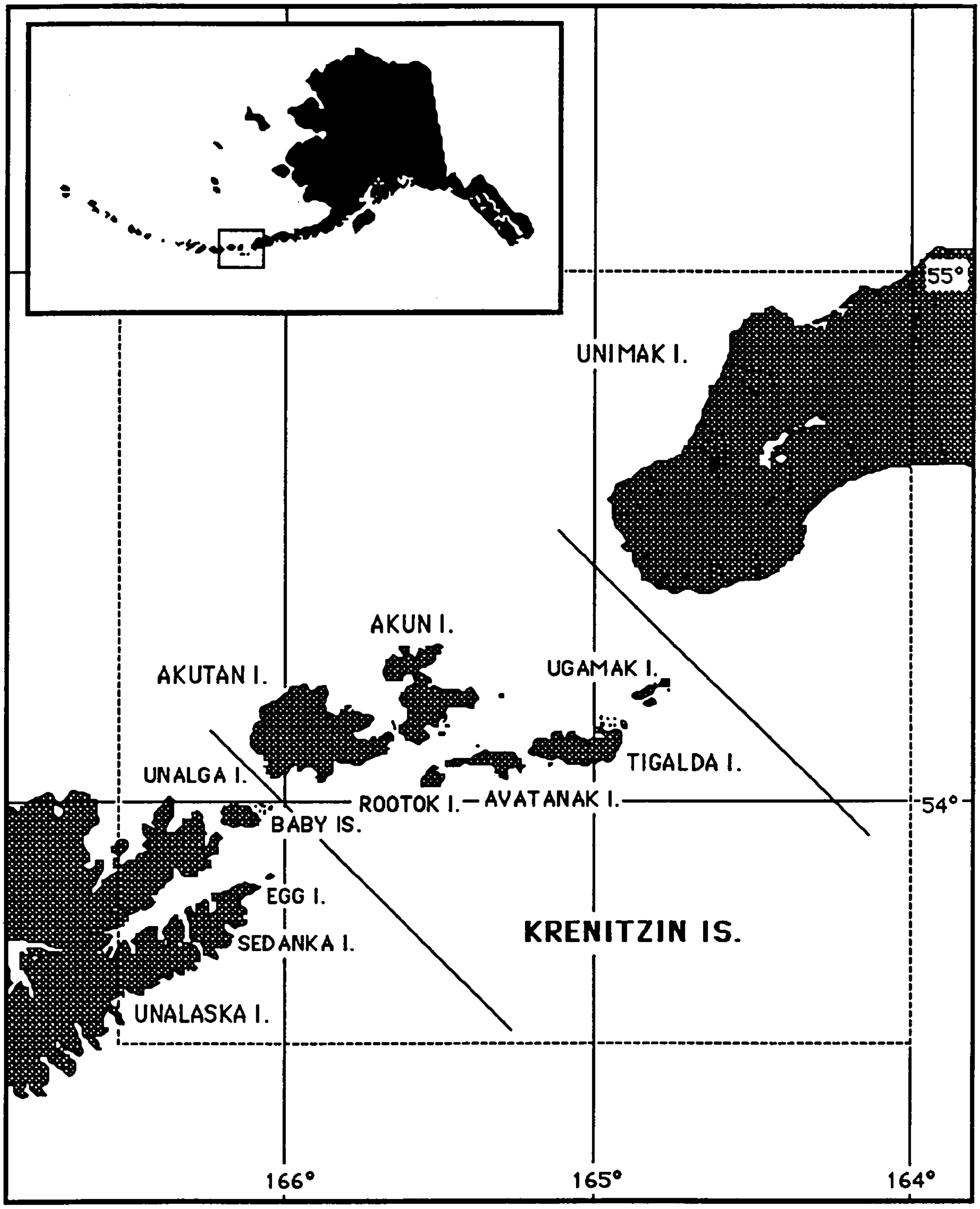


Figure 1. Location of Egg Island and other island groups in the Unimak Pass study area, Alaska.

locations and estimating populations. Several islands in the study area were to be sampled to provide information to compare with previous studies (i.e., Nysewander et al. 1982).

(3) Monitor Tufted Puffins—Specifically, observers were to make counts of burrows on study plots and to monitor activity in and percent occupancy of these burrows. The study plots would be permanently marked, enabling investigators to use the same plots to monitor population trends in future years.

(4) Make general observations of seabird colony sites and other seabird concentrations—This secondary objective was designed to identify additional colony locations, important feeding congregations, and other concentrations of seabirds in the vicinity of islands visited during summer field studies.

CURRENT STATE OF KNOWLEDGE

Breeding Biology of Species Studied

Although over 20 species of seabird may breed in the Unimak Pass study area, census activities were focused on six species that were selected based on their numerical abundance in the study area, vulnerability to offshore petroleum development, and/or restricted geographic ranges. These species were Fork-tailed Storm-Petrel, Leach's Storm-Petrel, Ancient Murrelet, Cassin's Auklet, Whiskered Auklet, and Tufted Puffin. The following sketches summarize basic information on the breeding biology of the major species we studied.

Fork-Tailed Storm-Petrel

Fork-tailed Storm-Petrels are endemic to the North Pacific Ocean where they breed primarily on small, predator-free islands from northern California and the Kurile Islands north to the Aleutians and islands in the Gulf of Alaska (Harrison 1983). Storm-petrels are not known to nest anywhere in the Bering Sea north of the Aleutians (Sowls et al. 1978). Fork-tailed Storm-Petrels are significantly larger than Leach's Storm-Petrels, nest earlier, and, at least at some colonies, return to nests earlier in the evening. Spring arrival dates at most colonies in Alaska probably occur in April. Birds were present on Buldir Island in the Aleutians by late April (Byrd and Trapp in prep.). Laying begins as early as mid-April in the Gulf of Alaska and becomes progressively later westward through the Aleutians, with initiation as late as early June in the western Aleutians. Fork-tailed Storm-Petrels lay a single whitish egg within a nest burrow (Boersma et al. 1980). Burrows average about 0.35 m in length and may occur as natural crevices in rocks, or as burrows in soil excavated by the adult birds. Hatching dates also vary with location; at Buldir Island, hatching occurs primarily from early July through August (Byrd and Trapp in prep.). Storm-petrels may exhibit intermittent incubation, presumably because the metabolic cost becomes too high after several days, causing the incubating bird to depart before its mate has regained enough lipid reserves to take over incubation duties (Boersma and Wheelwright 1979). Fork-tailed chicks require 50-66 days to fledge from the nest (Quinlan 1979, Simons 1981), therefore adults may continue to visit some colonies until early November. Fork-tailed Storm-Petrels produce a scratchy, usually four-note call on the nesting islands.

Leach's Storm-Petrel

This species nests both in the North Atlantic and the North Pacific regions. In the Pacific, it is found breeding on islands from southern Baja California, Mexico, and northern Japan, north to the Aleutians and islands in the Gulf of Alaska. Leach's Storm-Petrels in the north Pacific often nest in mixed colonies with Fork-tails, but tend to nest later in the season. At some colonies, Leach's Storm-Petrels arrive later in the evening than their congeners (Byrd and Trapp in prep., Quinlan 1979). Arrival at Alaskan colonies occurs from mid- to late May, with the onset of laying underway by late May and continuing through July. Laying dates on Buldir Island were recorded as late as 5 August (Byrd and Trapp in prep.). As in Fork-tailed Storm-Petrels, egg neglect is frequent and incubation may take from 41 to 52 days (Byrd and Trapp in prep.). Hatching occurs from early July to early September. Breeding chronology is generally later farther westward in the Aleutian Islands. Chicks require from 63 to 70 days to fledge, therefore activity at some colonies in the Aleutians continues until at least mid-November. Leach's Storm-Petrels give a soft purring call usually in or near the nest burrow, but more commonly produce lengthly cackling calls.

Ancient Murrelet

This species nests from the Queen Charlotte Islands, British Columbia, and Korea northward to the Aleutians and islands in the Gulf of Alaska (Harrison 1983). Ancient Murrelets are unusual alcids in that they lay two eggs rather than one, and the chicks are precocial at birth. The chicks are not fed on land, but are led to the water by the adults at night within a few days of hatching (Jones et al. 1987). Growth of the chicks to fledging takes place completely at sea. The chronology of breeding for Ancient Murrelets is poorly known in Alaska. Indications from British Columbia are that they initiate the clutches relatively early, from late April to late May (Sealy 1976). Clutches are probably initiated later in the Aleutians. Nest sites are either burrows dug in the soil by the adults, or natural cavities, sometimes enlarged by the nesting pair. The eggs are easily identified by the spotted pattern, unlike the plain white shell of other burrow nesters. Average length of incubation is approximately 35 days (Sealy 1976). Ancient Murrelet chicks in the Aleutians probably hatch from late June through July. Adults give two types of calls outside the nesting burrows--a short "chirrup" call, and a longer "song", of several recognizable elements (Jones 1985, Gaston et al. 1988, Jones et al. 1989).

Cassin's Auklet

The most widespread auklet in the Pacific, the Cassin's Auklet nests from Baja California, Mexico, north through the Gulf of Alaska and throughout the Aleutian Islands (Harrison 1983). Few studies of this species have been conducted in the Aleutians, but some information on breeding biology is available from colonies in Southeast Alaska, as well as from British Columbia and California. Cassin's Auklets initiate egg-laying from April through May both in Southeast Alaska and California, and, as is common for almost all auklets, lay a single whitish egg (Thoresen 1964, DeGange et al. 1977). The incubation period averages approximately 38 days (Manuwal 1974, 1979). The small chick is brooded by the adults for a few days, but is then left alone and periodically fed in the burrow for the majority of the remaining nestling period. Fledging occurs after 41 to 50 days (Thoresen 1964). On Forrester Island in Southeast Alaska, chicks fledged from mid-July through August (DeGange et al. 1977). In British Columbia and California, Cassin's Auklets nest in both rock crevices and soil burrows (Manuwal 1974; Vermeer et al. 1979). In the Aleutians, however, most nests are in soil burrows and occur in tight groups among colonies of other species (Nysewander et al. 1982). These researchers, as well as DeGange et al. (1977) and Gaston et al. (1988), found that burrows of Cassin's Auklets could be identified by their typically muddy entrances, characteristic fishy odor, and the frequent presence of feces at the entrance. Cassin's Auklets produce a series of loud, grating calls on the nesting colonies (Manuwal 1974).

Whiskered Auklet

This species is restricted to, and largely resident throughout the year in, the Aleutian, Commander, and Kurile Islands of the northcentral and northwestern Pacific Ocean (Harrison 1983). It has been found to be decidedly nocturnal in the eastern Aleutians (Nysewander et al. 1982). Contrary to its general behavior in the western Aleutians (Buldir Island), where it visits the nesting colonies mainly during the day (Byrd et al. 1983), in the eastern Aleutians, researchers heard Whiskered Auklet calls throughout the night, though most frequently just after dark or just before dawn. Nest sites on Buldir Island in the western Aleutians were found in crevices of talus slopes and under beach boulders (Knudtson and Byrd 1982). In the eastern Aleutians, the birds appeared to nest in rock crevices on sheer cliffs (Nysewander et al. 1982), and on Buldir, they nested within large colonies of Least and Crested auklets. However, in the eastern Aleutians where these other auklets do not breed, Whiskered Auklets were distributed in a low-density pattern similar to that of Pigeon Guillemots and Horned Puffins. Egg-laying by Whiskered Auklets occurred from 24 May to 5 June in 1976 on Buldir Island, and the eggs hatched from 24 June to 8 July (Knudtson and Byrd 1982). Fledglings were first noted on the sea by late July, but most probably fledged on Buldir during the first 10 days of August. Calls of this species include loud, distinctive, gull-like notes given in a rapid series (Nysewander et al. 1982).

Tufted Puffin

This species is more widespread in the North Pacific than are the nocturnal alcids, breeding from islands off the central California coast and the southern Kurile Islands northward to the Chukchi Sea coast at Cape Lisburne and northeastern Siberia (Harrison 1983). The center of breeding abundance is thought to be in the eastern Aleutian Islands, where Nysewander et al. (1982) estimated that over 1 million breed. Although occasionally nesting at low densities in rock crevices, Tufted Puffins are more typically found nesting in large, dense colonies in soil burrows of their own making. In the Gulf of Alaska, Tufted Puffins lay their single whitish eggs from late May through late June. Hatching occurs from late June through mid-August, and fledglings appear on the water any time from mid-August to the end of September (DeGange and Sanger 1986). Tufted Puffins are mostly silent at the nesting colonies, but occasionally give a low growling call not audible at any great distance.

Census Techniques Used By Others

Seabird colonies in the eastern Aleutian Islands were identified and surveyed by Nysewander et al. (1982) during the summers of 1980 and 1981. These broad-based studies documented colony sites and species distribution throughout our study area. The investigators made population estimates for each colony, but they did not evaluate for accuracy those estimates for species in which adults or nests could not be directly counted.

Nysewander et al. (1982) estimated numbers of Tufted Puffins by two techniques: 1) counting burrows on a 10-m-wide census strip extending from the highest puffin burrows down to the lowest, striving for at least 10 strips per colony, and 2) for some smaller islands, counting numbers of burrows directly. Storm-petrel numbers also were estimated by two techniques: 1) counting of burrows on study plots, and 2) call-counts conducted at night. The colony population estimates for storm-petrels obtained by Nysewander et al. (1982) were based primarily on call-counts for most colonies, because the observers found it impossible to count the often low densities of burrows in the wide variety of habitats used for nesting (talus, rock crevices, root systems of heavy grass cover, puffin burrows, and other burrows). They found that the ability to record calls of storm-petrels and other nocturnal seabirds was affected by several variables, and cautioned that "...the estimates of storm-petrels are one of the least precise obtained this field season". They also stated: "The resulting subjective estimates (of storm-petrel numbers) are valuable until better techniques are found. With further research, call counts may be reproducible when carefully correlated with these variables."

STUDY AREA

Summer field activities were based at Egg Island (53°52'N 166°03'W) off the northeast tip of Sedanka Island, and approximately 20 air miles (32 km) from Dutch Harbor (see Fig. 1). Egg Island, located in the western portion of the Unimak Pass area, hosts the largest single seabird colony in the eastern Aleutians. From the main camp on this island short visits were made to nearby islands via inflatable boats, but most of the studies were conducted at the Egg Island colony. The field party of four arrived at Egg Island via amphibious aircraft (Grumman "Goose") on 21 June and remained in the study area continuously until 10 August. Camp locations on Egg Island and the Baby Islands followed those of Nysewander et al. (1982). In addition, camp was moved to the head of Sisek Cove, Sedanka Island, several days prior to departure from the study area, again via amphibious aircraft.

METHODS

Methods tested for monitoring populations of nocturnal seabirds are described in detail in this section. Brief descriptions of how we surveyed for Whiskered Auklets, monitored Tufted Puffin burrow use, and conducted general observations are also included.

Population Monitoring of Nocturnal Seabirds

Field Methods

Plot Setup. To assess potentially useful techniques for monitoring populations of seabirds that visit nesting colonies only at night, we established 20 study plots on Egg Island. On these plots we conducted call-counts and searched for nesting burrows of the four nocturnal species not solely restricted to cliff habitats (i.e., Fork-tailed and Leach's Storm-Petrels, Ancient Murrelet, and Cassin's Auklet) and counted calls of one additional species (Whiskered Auklet). These plots were designed to provide a quantitative evaluation of nesting densities of the first four species in the immediate vicinity of stations at which call-counts were conducted.

We subjectively chose paired plot locations in areas representing high, medium, and low calling frequencies of the storm-petrels (the most common and widespread nocturnal seabirds on the island), and in areas where the two small alcid species (Cassin's and Whiskered Auklets) were present. Because of concerns that calling frequencies and nesting densities varied among the habitats, physiographic features present on the island were also taken into account in locating plots (e.g., coastal cliffs, coastal slopes, interior hills, upland tundra, dense grass habitat, and Tufted Puffin colonies). Locations of study plots are presented in Figure 2. Criteria used in choosing the location of each pair of plots are provided in Table 1.

Study plots were 25 X 25 m square, and were marked on all four corners by flagging tape. We conducted call-counts from a listening post located roughly in the center of the plot and marked with a stake (Fig. 3). Observers moved to and from the listening post via only one trail so as to minimize disturbance to nesting birds. Plots were located in pairs but pair members were separated by over 100 meters. This was done to increase sampling frequency in each habitat, and to provide (at least partially) non-overlapping counts in the same general area. At the end of the study period we removed the listening post markers and permanently marked all plots at the lower left corner with locally-available materials. Bearings for the baselines from this stake, from which the plots could be reproduced, are provided in Table 2.

Call-Counts. We conducted call-counts exclusively on the 20 study plots on Egg Island. During count evenings, one person (the "recorder") conducted call-counts for the entire period of darkness (between 0100 and 0530 hrs Alaska Daylight Time in late June to between 0030 and 0600 hrs ADT by early August). At each plot sampled, 10 counts of 15-30 sec duration each, were conducted every half-hour for each species present. Calls of only one species were recorded during each 15-30 second count. After conducting 10 counts per species on a plot, the recorder moved to the adjacent plot of the pair but did not commence counting until the next half-hour mark was again reached. Moving back and forth between plot pairs every half-hour enabled each recorder to sample two plots per habitat type each night, and the occasional movement helped to reduce counting fatigue. During counts, recorders remained as quiet as possible and in a sitting position facing downhill. On some plots, count posts were located on small mounds or hummocks to elevate the counter above the level of the grass. Counts were taken only during nights when sound interference from background sources (wind and surf) was low enough to hear most calls. Counts were taken on 14 days from 25 June through 3 August 1987. The schedule of counts for each pair of plots is given in Table 3.

We used 15-second to 30-second call-count periods because initial tests indicated that concentration levels of recorders tended to decrease and counters frequently lost track if they listened for longer periods. Recorders used digital stop-watches to record elapsed time, but estimated the 15-30 second intervals to avoid the distraction of using lights for "watching the clock". Thus the recorder used a headlamp for keeping track of 30-min periods and recording data in notebooks, but not for timing the count intervals.

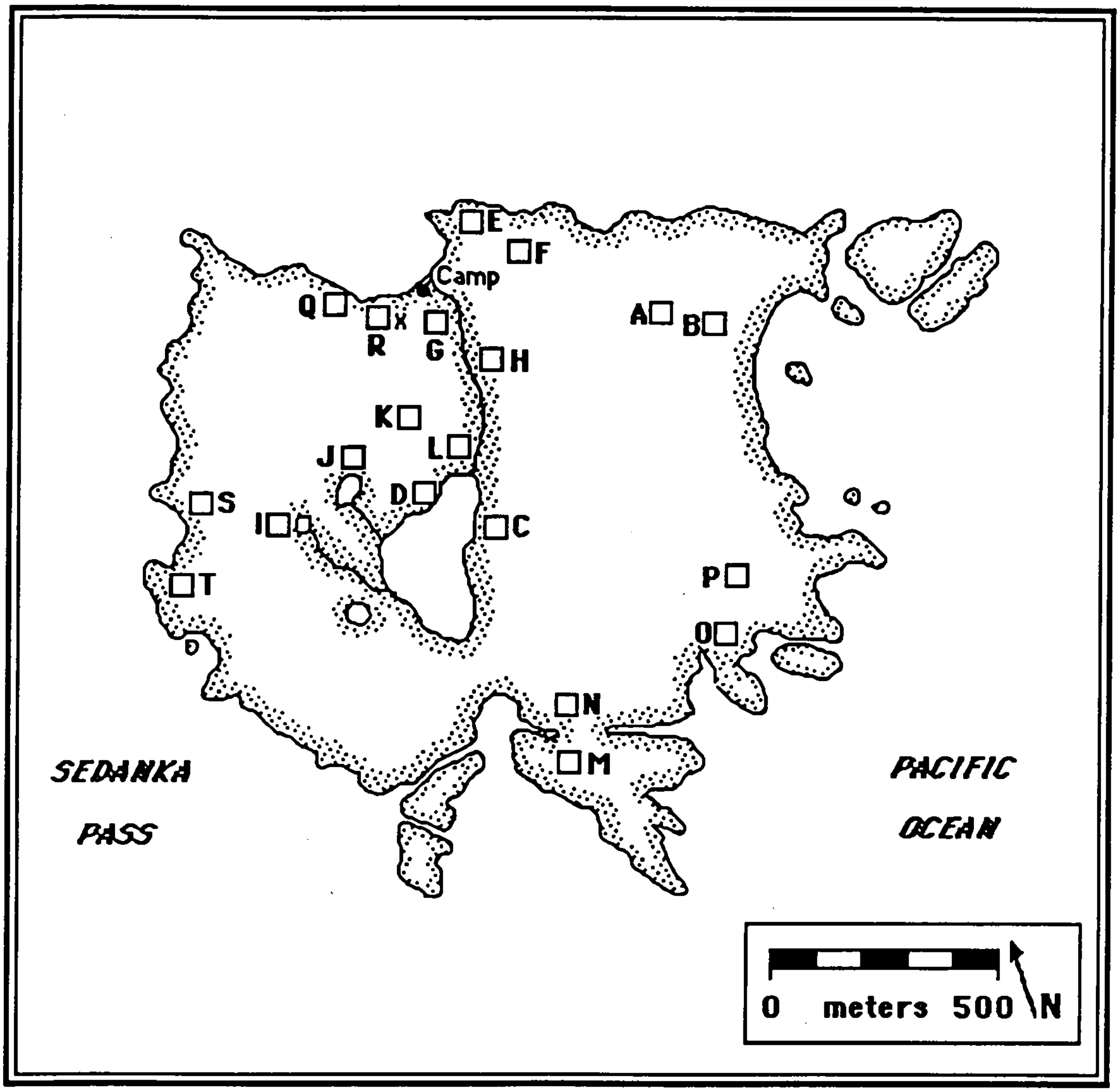


Figure 2. Locations of the 20 study plots established for estimating nest densities and conducting call-counts, Egg Island, Alaska.

Table 1. Characteristics used in selecting study plot locations at Egg Island, Alaska.

Plot	Characteristics
A,B	LOW density storm-petrel calling locations, upland tundra habitat.
C,D	HIGH density storm-petrel calling locations, inland hills habitat.
E,F	MODERATE density storm-petrel calling locations, presence of Ancient Murrelets, Tufted Puffin nesting habitat.
G,H	MODERATE density storm-petrel calling locations, presence of Ancient Murrelets, dense grass habitat.
I,J	MODERATE density storm-petrel calling locations, inland hills habitat.
K,L	MODERATE density storm-petrel calling locations, upland tundra habitat
M,N	HIGH density storm-petrel calling locations, presence of Cassin's Auklets, coastal sea slope habitat.
O,P	MODERATE density storm-petrel calling locations, presence of Cassin's Auklets, coastal sea slope habitat.
Q,R	LOW density storm-petrel calling locations, presence of Ancient Murrelets, cliff habitat.
S,T	MODERATE density storm-petrel calling locations, presence of Cassin's Auklets, Tufted Puffin nesting habitat.

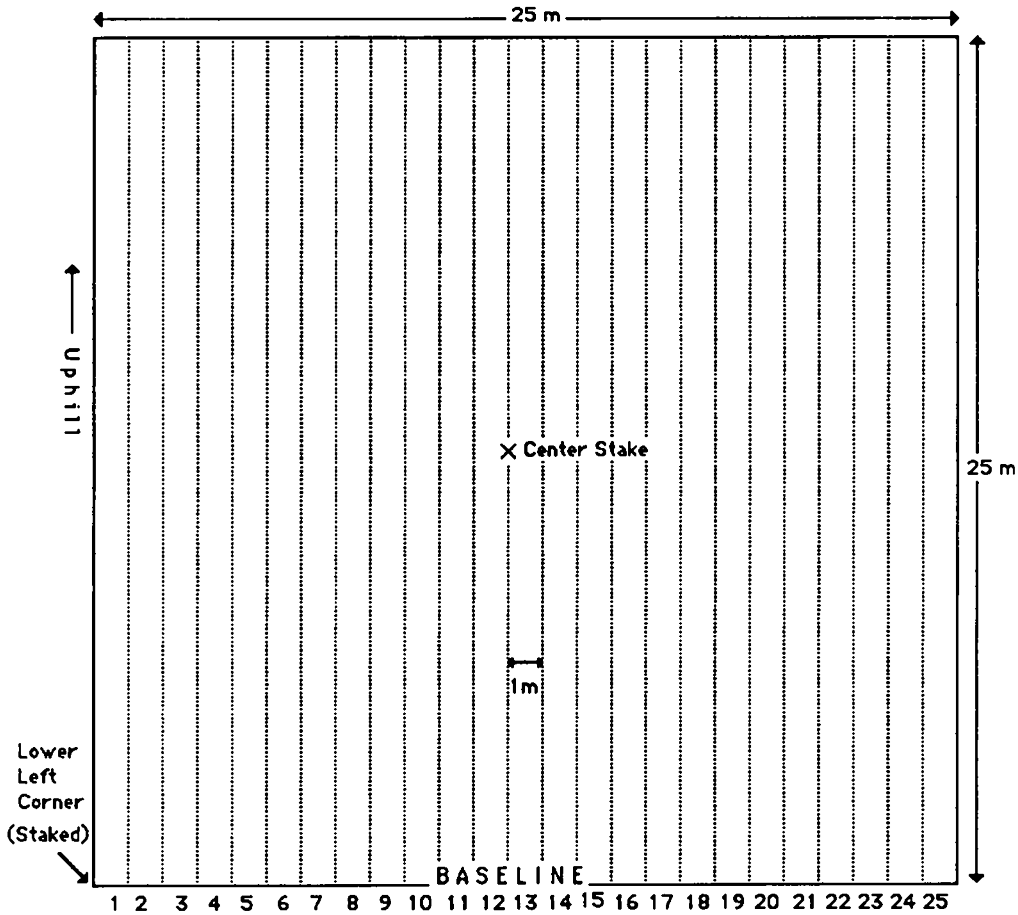


Figure 3. Layout of study plots at Egg Island, Alaska. (All features are imaginary except for the center stake and the flagging at all four corners.)

Table 2. Descriptive information for the 20 study plots at Egg Island, Alaska. Compass bearings for the baselines are based on true north and describe the direction of the baseline from the permanent marker (at lower left corner).

Plot	Baseline bearing	Plot	Baseline bearing
A	52°	K	324°
B	19°	L	276°
C	163°	M	82°
D	352°	N	51°
E	236°	O	47°
F	233°	P	50°
G	238°	Q	250°
H	200°	R	220°
I	352°	S	125°
J	248°	T	125°

Table 3. Schedule of plot coverage for call-counts at Egg Island, Alaska.

Plot Pairs	Dates Censused
A, B	25 June, 5 July*, 16 July, 27 July
C, D	25 June, 3 July, 16 July*, 1 August
E, F	26 June, 30 June, 23 July*, 1 August
G, H	26 June*, 30 June, 16 July, 27 July
I, J	26 June, 3 July, 16 July, 27 July*
K, L**	26 June, 3 July, 17 July*, 27 July
M**, N	27 June, 5 July, 17 July, 1 August*
O, P	27 June*, 5 July, 17 July, 23 July
Q, R	28 June, 3 July*, 22 July, 1 August
S, T	5 July, 17 July, 23 July, 3 August

* Counts which were later deleted from analyses because of significant differences in one person's counts.

**Additional counts were taken on these plots to assess the variation in calling frequencies of Fork-tailed and Leach's Storm-Petrels (Plot L) and Cassin's and Whiskered Auklets and Ancient Murrelets (Plot M) throughout the night and over the breeding season. We conducted these counts on Plot L on 28 June, 6 July, 23 July, and 3 August. We conducted additional counts on Plot M on 6 July and 22 July.

Consensus was required to determine which calls to count. Ideally, one would count only those birds actually using the study plot being censused. This was impossible, however, because the exact edge of each plot and its relationship to the locations of calling birds could not be estimated by the recorder. In addition, the large number of birds (particularly storm-petrels) using Egg Island precluded counting every call heard, because calls tended to blend into a background cacophony of sounds on some parts of the island. To avoid some of these problems and to standardize the sampling methods, we established the following criteria for counting calls:

(1) Only those calls for which the beginning and end of the entire call could be discerned were counted.

(2) Each call was counted, even if several calls were given by a known bird in rapid succession.

(3) All calls that could be heard by the recorder were counted, regardless of how far away the birds may have been.

During each call-count, we recorded location, species, time, level and type of environmental noise, weather, and observer variables (Table 4). The number of species heard varied from two to five species per plot (Figure 4).

Calls of all species were very distinctive, but were variable in duration and intensity of sound. Only one general call type was recorded per species, except for Leach's Storm-Petrel. For this species we noted that two very different call types were regularly produced. The first was a cackle-like call (call type 1), also called the flight call (*sensu* Harris 1974, Hall-Craggs and Sellar 1976, Ainley 1980, Randall and Randall 1986) or the chatter call (*sensu* Grubb 1973, Cramp and Simmons 1977) which was given frequently in flight or on or in the ground. The second was a lower-pitched trill or frog-like call (call type 2), also called the purr call (*sensu* Wilbur 1969, Grubb 1973, Harris 1974, Cramp and Simmons 1977, Randall and Randall 1986) or the chatter call (*sensu* Ainley 1980) which was given less often than type 1 calls and usually by birds on or in the ground. We recorded both types of Leach's Storm-Petrel calls separately on the study plots.

Near the end of the field study period (on 3 and 6 August), we compared the abilities of the four recorders to detect calls. Pairs of recorders seated close together on the same plot coordinated count durations but did not communicate the number of birds counted until all trials (10 repetitions of 15-30 sec. counts) were completed. Each pair of recorders (total of six pairs) counted on each of two plots and for each of three call types (Fork-tailed Storm-Petrel calls and both types of Leach's Storm-Petrel calls). The two plots were selected to assess recorders' abilities to count calls in areas of relatively

Table 4. Data recorded during each nocturnal call-count conducted at Egg Island, Alaska.

Variable	Description
Location	Plot identifier (A to T)
Call Type	Type of call recorded. All call types were species -specific except for Leach's Storm-Petrel, for which two call types were recorded (see text)
Call	Number of calls counted per count period
Count Period	Number of seconds
Cloud Cover	Estimated in tenths
Disturbance (environmental noise)	Estimated on a scale of 0 - 3
	0 = no disturbance 1 = slight wind and/or surf noise audible, but not affecting recorder's ability to detect calls 2 = some loss of detectability due to wind and/or surf noise 3 = strong disturbance from wind and/or surf noise affecting recorder's ability to detect calls
Time counts recorded	Start hour and start minute for each series of 10
Date	Julian date recorded
Recorder	Unique code number assigned to each recorder

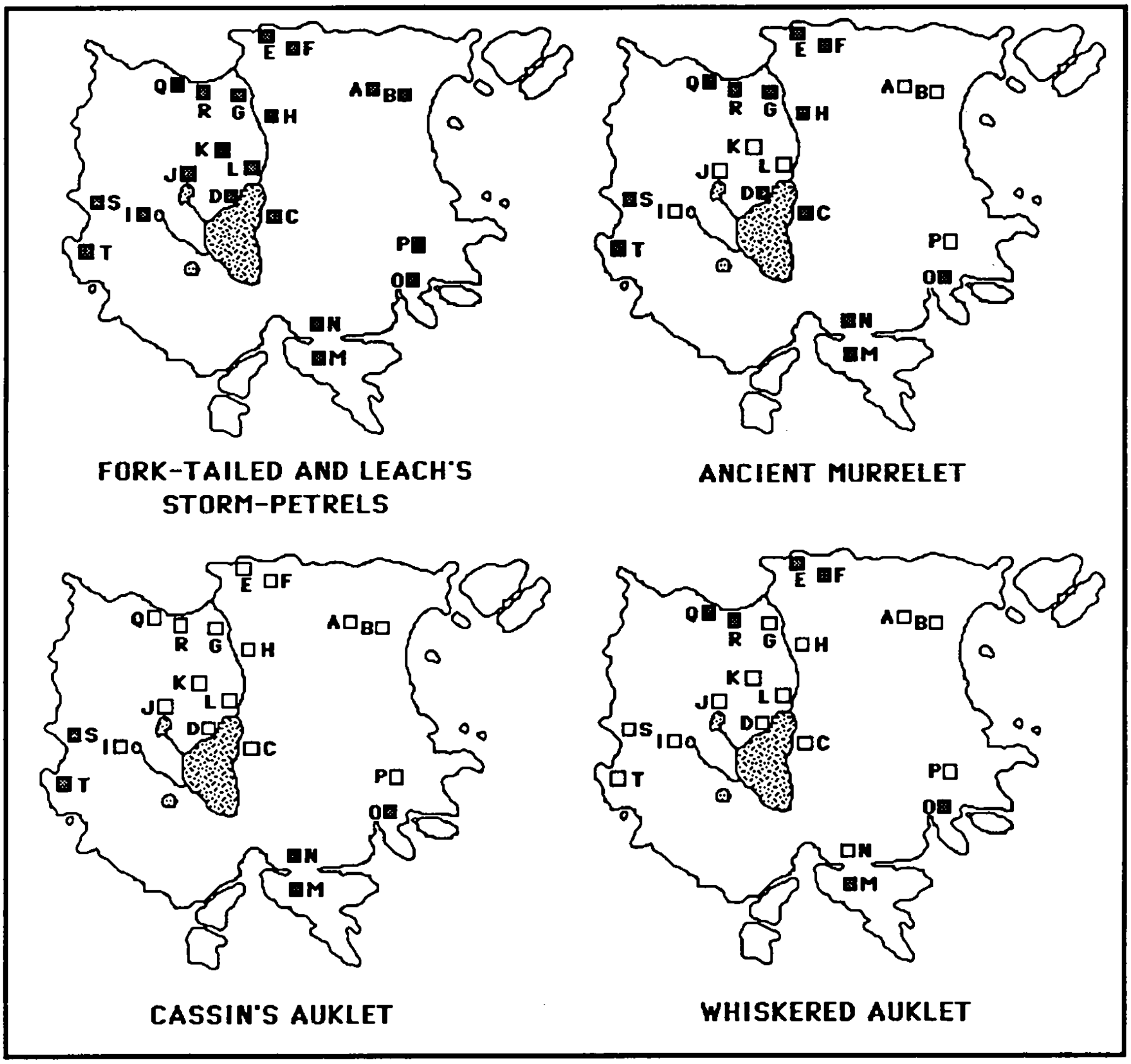


Figure 4. Locations of study plots at Egg Island, Unimak Pass, Alaska, on which the calls of the five nocturnal seabirds were recorded. (see Fig. 1 for location of Egg Island.)

high densities of storm-petrels and in areas with relatively low densities. An additional trial was conducted where Leach's Storm-Petrels were giving type 2 calls on plot L. We could not assess recorders' relative abilities to count either Cassin's or Whiskered Auklets because these species had virtually stopped visiting the island by the dates we conducted the trials. All test counts were completed during the peak (evening) calling period at that time of year (0100 to 0430 hrs).

Burrow Searches. To provide an absolute measure of nesting density of nocturnal, burrow-nesting seabirds on the study plots for eventual correlation with call-counts, we searched each plot for nest burrows during daylight hours. Initial burrow searches were conducted in late June and July; however, the birds in burrows were not disturbed until after call-counts were completed on that plot, generally during late July or August. At this later time, we inspected burrows to obtain species identifications and to note contents.

We initially subsampled all 20 plots to determine densities of burrows and to monitor burrow use. Subsampling involved searching three strip transects 1 x 25 m across each plot. To do this we stretched three 25-m ropes across the plot (along randomly chosen strips from 1-25, see Fig. 3) from the downhill side of the plot (baseline) to the uphill side. Searchers proceeded uphill, inspecting the ground beneath the grass canopy thoroughly for burrows. We marked burrows with small plastic flags placed outside and above the entrance, and inserted 1-2 toothpicks upright and just inside the entrance to determine later whether the burrow was being used by seabirds. (There were no small mammals, reptiles, or amphibians on Egg Island, therefore disturbance of toothpicks would have been caused only by birds.) We rechecked these burrows three times during the field period at approximately 10-day intervals and recorded positions of the toothpicks.

We later searched all plots in their entirety to obtain a measure of nesting density of seabirds for use in correlations with call-counts. To do this we searched consecutive 1-m-wide strips, starting at one side and proceeding across the slope (see Fig. 3). Three persons searched each of three adjacent strips, working uphill. One person carried a meter stick for measurements. Burrow location, depth, contents, and other descriptive information were recorded. After all three strips had been searched, the ropes were moved to the next section of the plot, and the procedures were repeated until the plot was completed.

After call-counts were completed, each burrow was inspected for contents. We attempted to obtain species identifications and breeding status by sight (with use of a flashlight). This method was successful for almost all Ancient Murrelet burrows, but for most storm-petrel and Cassin's Auklet burrows, we were forced to extricate the adult and then feel for the presence of eggs or chicks. If necessary, we enlarged the entrance hole to allow us to reach the nest chamber. However, this was rarely required for storm-petrels, and was usually fruitless for Cassin's Auklets. Burrows of the latter species were frequently over 1 m deep. We could not determine the contents of some burrows that were deep or in rocky habitats.

The methods used to determine nest status differed among species because of interspecific variation in nesting chronology (Fig. 5). Most birds still occupied their burrows during inspection but at some Ancient Murrelet nests, particularly those not found until late July or August, eggs had already hatched and the adults and chicks had departed prior to the first inspection. None of the seabirds seemed to remove hatched eggshells from the nest, and we were therefore able to determine this year's use and hatching success for all species even if adults or chicks were not present.

We could not determine species identifications of storm-petrels solely by inspecting their temporarily abandoned eggs. Egg measurements overlap for these species (Byrd and Trapp in prep.), and egg coloration was not always a distinguishing characteristic. Similarly to the findings of Quinlan (1979), we noted that many eggs of Fork-tailed Storm-Petrels had a ring of faint red speckling around the large end. This trait could not be used for positive identification, however, because a few Leach's Storm-Petrel eggs also showed this attribute, and some eggs of both species were essentially pure white. Chicks of the two storm-petrels could be distinguished; Fork-tailed chicks possessed a coat of much lighter gray down than did Leach's chicks.

Most Cassin's Auklet burrows were highly distinctive later in the breeding season due to their relatively large, muddy entrances, fishy odor, and generally greater depth and tunnel width when compared with burrows of Ancient Murrelets and storm-petrels. Auklet burrows also occurred in relatively dense and isolated colonies; this contributed additional evidence for the identification of individual burrows.

Sky-Counts. An alternative method of counting storm-petrels--the sky-count--was tested briefly. Overflights of storm-petrels were counted on several plots on two nights in each of July and August (Table 5). Recorders themselves faced skyward near the center of each study plot and counted all petrels that flew through their field of vision. (Recorders had little difficulty detecting birds silhouetted overhead in the night sky, even in cloudy weather, but the two species of storm-petrels could not be separated in these observations.) No counts were made during periods of heavy precipitation. On each plot, petrels were counted during 20-31 periods that ranged in length from 27-62 seconds. All counts were conducted between 0200 and 0301 hours.

Analysis Methods

Multiple regression techniques were used to investigate relationships between calling frequency and sky-count data and nesting density. Our overall

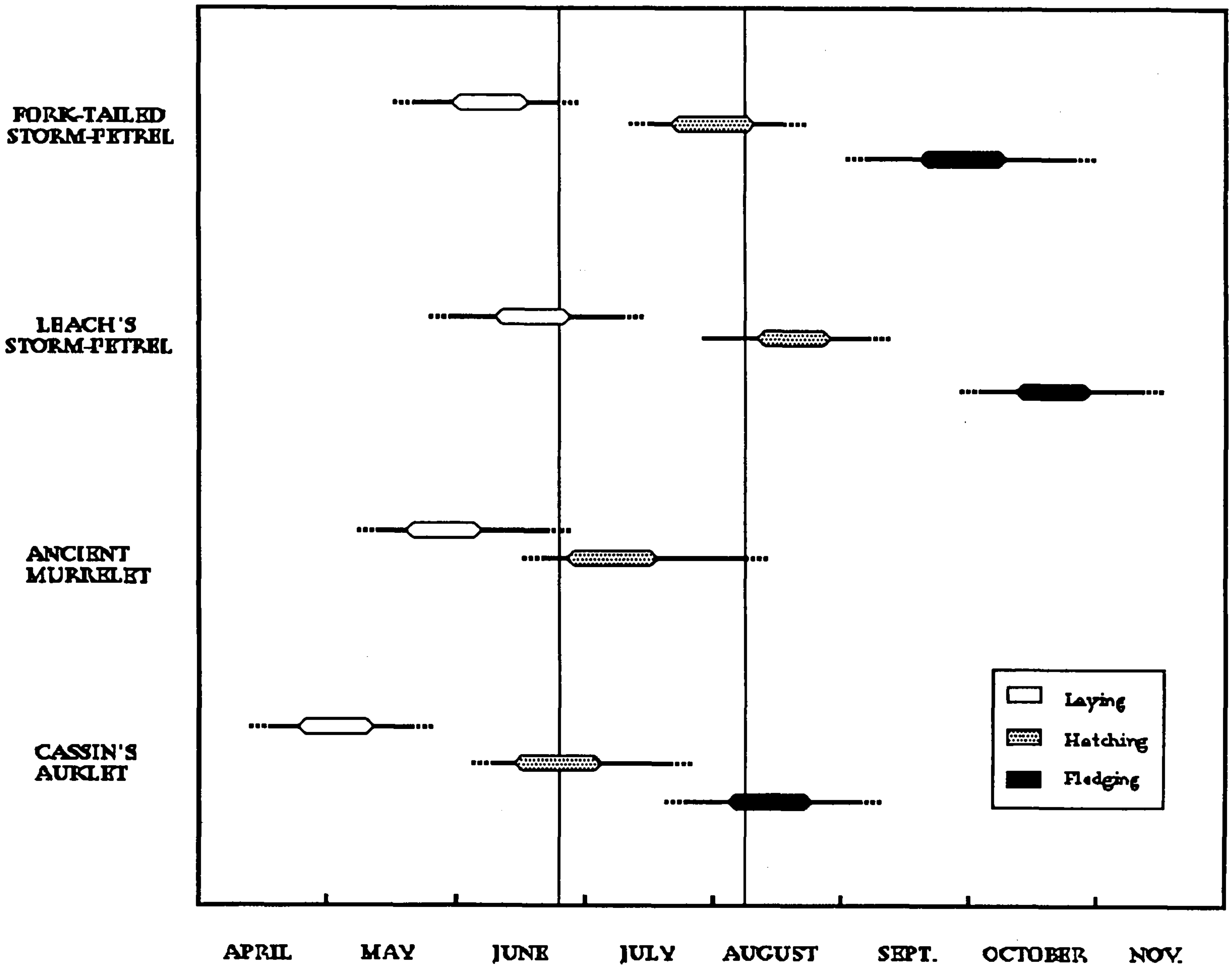


Figure 5. Approximate breeding chronology of the four nocturnal seabirds nesting on the 20 study plots, Egg Island, Alaska.

Table 5. Schedule of sky-counts of storm-petrels at Egg Island, Alaska.

Plot	Date	Sky Counts		
		Number	Total Sec.	Mean Duration(sec)
July Counts				
A	July 10	30	1867	62
B	July 11	30	1362	45
C	July 11	30	1090	36
D	July 11	31	1118	36
G	July 10	30	1028	34
I	July 11	30	1327	44
K	July 11	30	1191	40
L	July 10	30	1159	39
August Counts				
A	Aug. 6	30	1112	37
B	Aug. 6	30	1116	37
C	Aug. 3	30	1060	35
D	Aug. 3	30	813	27
G	Aug. 6	30	1058	35
I	Aug. 3	20	856	43
K	Aug. 3	30	983	33
L	Aug. 6	30	1084	36

goal was to test models that predicted nest density on the basis of calling frequency or sky-counts.

Call-Count Data. Calling frequency for some seabirds varied with such factors as time of day (e.g. Fork-tailed Storm-Petrel, Fig. 6), date, cloud cover, level of background noise, and recorder differences. We used stepwise multiple regression analysis (SMRA) to test for variability attributable to these factors. SMRA equations were used to create predicted calling rates using the case-wise values for each variable. The difference between the predicted rate and the recorded rate was a measure of the residual variance in calling rate. These residual values were then averaged for each plot to provide a measure of the amount of calling that was not explained by the predictor variables. Mean residuals were regressed against the number of nests on each plot to determine whether calling frequency could be used as a predictor of nesting abundance. Separate models were developed for each species and call type.

Data were reduced and transformed as necessary to meet the assumptions of the SMRA procedure and to facilitate analysis. Multiple regression rather than analysis of variance (ANOVA) techniques were used for two reasons: 1) unequal sample sizes and missing cells create problems for several ANOVA procedures, and 2) multiple regression techniques use all data, including continuously distributed data, and are sensitive to order information contained in the data. In these cases, multiple regression techniques are more powerful than are ANOVA techniques.

As described earlier, recorders determined the number of calls detected in 10 multi-second sampling periods at each plot. To determine the mean number of calls per minute, we divided the total number of calls detected during the 10 sampling periods by the total number of seconds and then multiplied by 60. 'Mean calls per minute' was considered as the dependent variable in the multiple regression procedures.

Multiple regression procedures assume that plots of residuals between each independent variable and each dependent variable are normally distributed (i.e. the dependent and predictor variables are linearly related). Time (start hour) and date (Julian day) variables were transformed (through the addition of hour-squared and Julian-day-squared terms) to improve the normality of the residuals.

Burrow Data. During the complete burrow searches of the plots, information required to determine the breeding status or even the species of bird using a burrow was occasionally unobtainable. Situations in which we lacked sufficient information for a given burrow included the following:

1. The burrow appeared to be active (i.e., toothpicks were repeatedly knocked down, fresh dirt was at the entrance, etc.)

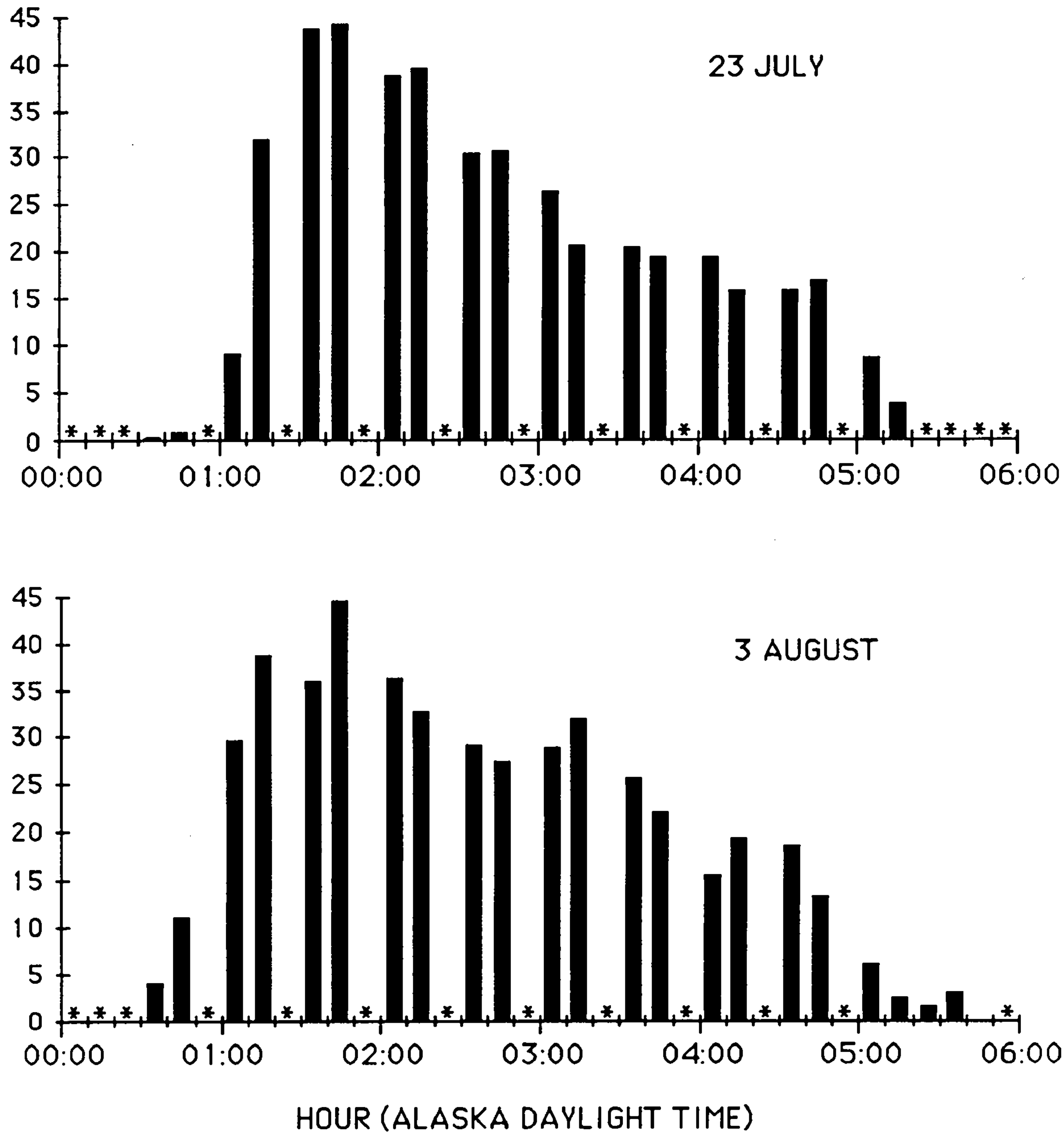


Figure 6. Nocturnal calling rates of Fork-tailed Storm-Petrels at Plot L on two nights. All counts were made by the same recorder. Asterisks (*) indicate ten-minute periods for which no counts were taken.

but no adult was present in the burrow at the time of our visit(s) and no egg was laid.

2. A storm-petrel egg was present (unidentifiable to species) but the adult was absent during visits to the burrow.

3. The burrow was too deep for us to reach the nest chamber and in substrate too rocky to be excavated.

We included in our analysis active burrows in which breeding was not attempted. Old burrows that did not appear to have been used during 1987 were not included as nests. Burrows that were counted as nest sites included any small (usually less than 10 cm in diameter) tunnel at least 10 cm in depth, that contained evidence of recent excavation by birds or other signs of recent use (feathers, fresh droppings).

We assigned burrows to a species whether or not we could identify its occupants. Of the 422 small seabird nest sites located on the 20 study plots, 102 were identifiable only as belonging to some species of storm-petrel, and three could be identified only as a small seabird burrow. We assigned unknown storm-petrel burrows to a species based on proportions of known burrows of the two species on each plot. Resulting numbers were rounded to the nearest whole nest and added to the totals of each species by plot. We assigned three burrows that appeared active but could not be identified to any taxon to the most abundant species of small seabird present in the plot in which they occurred. Final estimates of the number of nest sites used for call-count comparisons are provided in Table 6.

Sky-Count Data. Data were standardized to the number of overflights per minute for each plot on which counts were made. These counts were then regressed against the total numbers of petrel nests (Fork-tailed and Leach's combined) present on the plots (Table 6). Regression analyses were run separately for data collected in July and August.

Whiskered Auklet Studies

We recorded all Whiskered Auklet calls heard on or near study plots. Data recording procedures and definitions of calls counted were identical to the methods described in the previous section on call-count techniques.

We conducted additional nighttime surveys to better quantify the Whiskered Auklet population using Egg Island and the Baby Islands (Tangagm and Excelsior islands). This species appeared to call only from sites on sheer cliff faces, which precluded nest inspection. We conducted censuses by traversing the circumference of the islands along the cliff tops at night, stopping frequently to listen for calls. We surveyed Egg Island on 27 and 29 June, Tangagm Island on 12 July, and Excelsior Island on 13 July. We counted

Table 6. Numbers of active nest burrows estimated for the 20 study plots at Egg Island, Alaska. Actual counts of Tufted Puffin burrows are included, however this species is not included in analysis of call-count data.

Plot	Fork-tailed Storm-Petrel	Leach's Storm-Petrel	Ancient Murrelet	Cassin's Auklet	Tufted Puffin
A	0	0	0	0	0
B	0	1	0	0	0
C	43	23	0	0	0
D	34	10	2	0	0
E	14	19	14	0	481
F	0	5	1	0	285
G	14	1	18	0	0
H	1	1	0	0	0
I	0	0	0	0	0
J	9	0	0	0	0
K	11	8	0	0	0
L	0	9	0	0	0
M	10	15	1	41	0
N	0	10	0	0	6
O	5	16	0	0	0
P	6	0	0	0	0
Q	4	0	3	0	0
R	4	0	3	0	3
S	1	10	0	1	317
T	6	23	0	20	257
Total	162	151	42	62	1349

Whiskered Auklets on Egg Island between 0100 and 0500 hours, and surveyed on the Baby Islands between 0415 and 0545 hours.

Tufted Puffin Studies

We counted nesting burrows of Tufted Puffins and monitored their use on Egg Island on four study plots located within accessible portions of steep slopes. We recorded and monitored all burrows of Tufted Puffins that were found on the initial three survey strips per plot (described below). All burrows on these strips received toothpicks, and we rechecked their status at approximately 10-day intervals. During the complete burrow censuses on the plots, accomplished later in the field season, we recorded all Tufted Puffin burrows on all plots, counting only those that appeared to have been used during the current nesting season. On the study plots used for counting nocturnal seabird calls, we did not extricate adults, eggs, or young or excavate any puffin burrows.

Because many Tufted Puffin nest burrows on Egg Island were greater than 1 m in depth we only rarely observed nest contents of this species on the study plots. We determined the proportion of active-appearing burrows occupied by breeding birds by excavating the entrances of a sample of burrows outside of the study plots. On 6 August, two persons determined the contents of all active-appearing Tufted Puffin burrows on a sample plot 3 x 25 m in size located near the base camp (see Fig. 2). We excavated burrow entrances up to a point at which the contents could be seen with the aid of a flashlight. We did not remove nesting adults, eggs, or young, and we reconstructed burrow entrances to the extent possible following viewing of the contents.

General Observations

We periodically took counts and made estimates of seabird numbers for some species that were highly visible during daylight hours and/or that were relatively uncommon. These counts were made from shore or from inflatable boats and were made with the aid of 8-10X binoculars. Numbers of birds were either counted directly (for flocks of fewer than 100 birds) or estimated by 10's, 100's, or 1000's (for larger groups). We made counts and estimates opportunistically throughout the summer field period. We also made notes on large aggregations of seabirds on waters near the islands we visited.

RESULTS

Population Monitoring of Nocturnal Seabirds

Comparisons of observers' hearing abilities led to our discounting one observer's data. There were 11 significant differences ($P \leq 0.05$) in hearing abilities among the four field personnel counting calls on the study plots

(Table 7). Of the 11 significant differences, all but one involved recorder 2 counting fewer calls than the other member of the pair. Adjustments to this person's counts to make them comparable with data from the other three recorders were not warranted because linear regressions of counts between recorder 2 and other recorders showed little correlation ($r^2 < 0.25$). Counts taken by recorder 2 for all species were not considered in further analyses of call-count data.

Cloud cover, disturbance, time, date, and observer factors explained significant amounts of the variation that occurred in the mean calling rates of all four nocturnal-calling species (Table 8). Case-wise values for the predictor variables were then used to calculate the predicted mean calling rate. The residual variation that remained for each call-count session was then calculated as follows:

Residual variance = predicted mean call rate - actual mean call rate

Residual variances were averaged for all count sessions on each plot (Table 9). The mean residual variance was a measue of the amount of calling that was not explained by cloud cover, disturbance, time, date and observer factors. It was reasonable to expect that this quantity would be correlated with the numbers of birds nesting on the individual study plots.

Despite expectations, regression equations showed that there was no correlation ($P > 0.1$) between mean residual variances in calling rate (Table 9) and the numbers of nests of either storm-petrel species occurring on the 20 plots (Table 10). But regressions using Ancient Murrelet and Cassin's Auklet did show significant correlations between nest numbers and residual variance ($P < 0.02$; Table 10), although sample sizes were smaller (14 and 5 plots, respectively). Residual variation explained 40% and 97% of the variance in nest densities of Ancient Murrelets and Cassin's Auklets (Fig. 7), respectively.

Both storm-petrel species nested within Tufted Puffin burrows, so that on Plots E, F, S, and T (plots with puffins) we almost certainly missed some storm-petrel nests during the burrow searches, because we did not wish to destroy active Tufted Puffin burrows in our search for storm-petrel nests. But when we removed data from puffin plots and re-ran the simple regression analysis for each of the three storm-petrel call types, no improvement in the statistical significance of the re-calculated correlation coefficient was found (Table 11).

A similar approach was undertaken in removing plots representing areas with particularly low or high calling densities of petrels, alone or in combination. Again, however, there was no improvement in the statistical significance of the re-calculated correlation coefficients (Table 11).

Table 7. Results of Wilcoxon Ranked Pairs tests on trials involving pairs of field recorders. Recorders are numbered 1-4 and trials were based on 10 repetitions of approximately 15-sec. counts (except for trials of recorder pair 1:2 on Plot J which were based on approximately 30 sec. counts). The critical region of T is represented by: $-1.6449 \leq a_{0.05} \leq 1.6449$. Significant differences are highlighted in boldface type.

Recorder Pairs	Value of Wilcoxon T: Fork-tailed Storm-Petrel	Value of Wilcoxon T: Leach's Storm-Petrel Call Type 1	Value of Wilcoxon T: Leach's Storm-Petrel Call Type 2
Plot D			
1:2	**2.82**	**2.34**	0.00*
1:3	-0.35	**1.67**	1.00*
1:4	-0.42	-1.29	-0.74
2:3	**-2.21**	-0.54	-0.58*
2:4	**-2.14**	-0.01	1.00*
3:4	-1.02	1.00	0.00*
Plot J			
1:2	**2.82**	**2.50**	**2.57**
1:3	-0.36	0.74	1.51*
1:4	1.62	-0.36	-1.00*
2:3	**-2.86**	-1.12	0.38
2:4	**-2.82**	**-2.11**	1.00*
3:4	1.15	1.18	0.00*
Plot L			
3:4	no count	no count	1.42*

* Trials in which ≥ 50% of counts lacked calls.

Table 8. Multiple regression models relating mean call rate and several predictor variables.

Fork-tailed Storm-Petrel

Mean calls per minute = -53.63 -4.81(HRSTR2) +25.43(HRSTR) +0.28(JULDAY) - 4.27(REC4) - 4.12(DIST3)

Adjusted $r^2 = .4666$ $F = 69.57$ $P<0.001$

Leach's Storm-Petrel (Call type 1)

Mean calls per minute = -36.77 -3.81(DIST2) +11.85(HRSTR) -1.80(HRSTR2) + 0.00075(JULDAY2) +3.42(REC4) +5.48(DIST0) +0.66(CLOUD) - 2.88(REC3).

Adjusted $r^2 = .5567$ $F = 62.85$ $P<0.001$

Leach's Storm-Petrel (Call type 2)

Mean calls per minute = -1.84 +2.50(REC4) +1.48(HRSTR) +3.17(DIST0) - 0.19(HRSTR2) +1.66(DIST1).

Adjusted $r^2 = .2492$ $F = 26.82$ $P<0.001$

Ancient Murrelet

Mean calls per minute = 23.48 -0.11(JULDAY) +1.15(REC3) -1.26(DIST0).

Adjusted $r^2 = .1341$ $F = 14.11$ $P<0.001$

Cassin's Auklet

Mean calls per minute = 14.31 -0.00043(JULDAY2) +4.14(HRSTR) -0.68(HRSTR2) +1.49(DIST1).

Adjusted $r^2 = .3480$ $F = 17.81$ $P<0.001$

Predictor Variables Used In SMRA Equations

CLOUD	Cloud cover in tenths
DIST0	No disturbance present? 0 = no, 1 = yes
DIST1	Slight disturbance present? 0 = no, 1 = yes
DIST2	Some disturbance present? 0 = no, 1 = yes
DIST3	Strong disturbance present? 0 = no, 1 = yes
HRSTR	Hour that counts in sequence started (0 = midnight)
HRSTR2	Start hour squared
JULDAY	Julian date on which counts made (23 June = 174)
JULDAY2	Julian date squared
REC1	Recorder 1 counting? 0 = no, 1 = yes
REC3	Recorder 3 counting? 0 = no, 1 = yes
REC4	Recorder 4 counting? 0 = no, 1 = yes

Table 9. Mean residual variance in call-counts of four nocturnal seabirds nesting at Egg Island, Alaska.

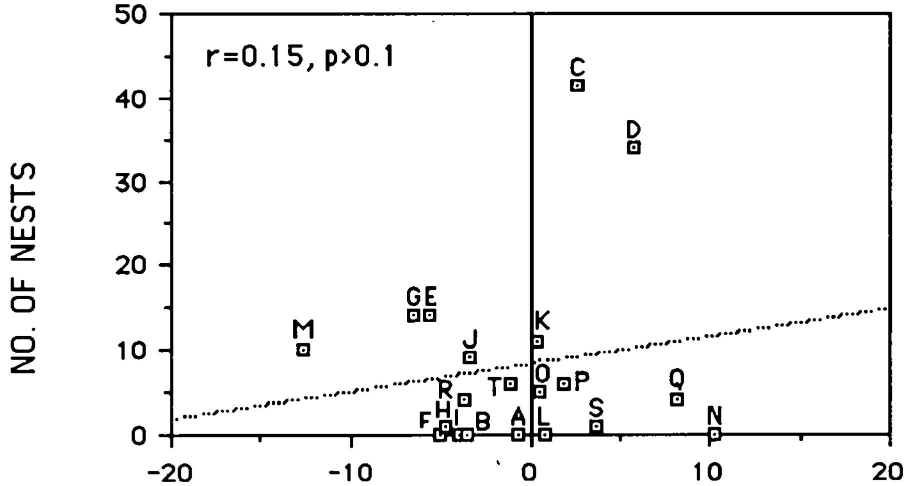
Plot	Mean Residual Variance*				
	FTSP	LCSP (type 1)	LCSP (type 2)	ANMU	CAAU
A	-0.63	1.06	-2.46	—	—
B	-3.57	-1.26	-0.76	—	—
C	3.73	-3.36	0.24	-1.91	—
D	5.75	-0.93	-1.36	-1.41	—
E	-5.60	0.59	-1.11	4.40	—
F	-5.08	-0.11	-1.42	0.12	—
G	-6.59	0.89	-0.07	1.22	—
H	-4.71	2.92	0.16	-1.31	—
I	-3.96	-0.80	0.06	—	—
J	-3.39	1.55	1.93	—	—
K	0.43	3.32	-0.53	—	—
L	0.89	2.64	0.77	-0.05	—
M	-12.69	-4.22	-1.41	-0.92	0.94
N	10.32	-2.72	-2.34	-2.28	-1.30
O	0.47	1.48	1.12	-1.08	-1.74
P	1.93	1.23	2.14	—	—
Q	8.10	-5.71	-0.77	1.96	—
R	-3.71	-8.46	-0.90	2.48	—
S	3.62	-1.18	0.56	-3.37	-0.99
T	-1.19	0.36	0.71	0.74	0.47

* FTSP = Fork-tailed Storm-Petrel, LCSP = Leach's Storm-Petrel, ANMU = Ancient Murrelet, and CAAU = Cassin's Auklet.

Table 10. Regressions between numbers of nests on study plots and mean residual variances in calling rates.

Fork-tailed Storm-Petrel			
Number of nests =	(0.33 * Mean Residual Variance) + 8.36		
	r = 0.15	d.f. = 18	P > 0.1
Leach's Storm-Petrel (Call type 1)			
Number of nests =	-(0.007 * Mean Residual Variance) + 7.55		
	r < 0.01	d.f. = 18	P > 0.1
Leach's Storm-Petrel (Call type 2)			
Number of nests =	(0.07 * Mean Residual Variance) + 7.57		
	r = 0.01	d.f. = 18	P > 0.1
Ancient Murrelet			
Number of nests =	(1.70 * Mean Residual Variance) + 3.17		
	r = 0.63	d.f. = 12	P < 0.02
Cassin's Auklet			
Number of nests =	(14.63 * Mean Residual Variance) + 20.07		
	r = 0.94	d.f. = 5	P < 0.02

FORK-TAILED STORM-PETREL



LEACH'S STORM-PETREL (Call Type 1)

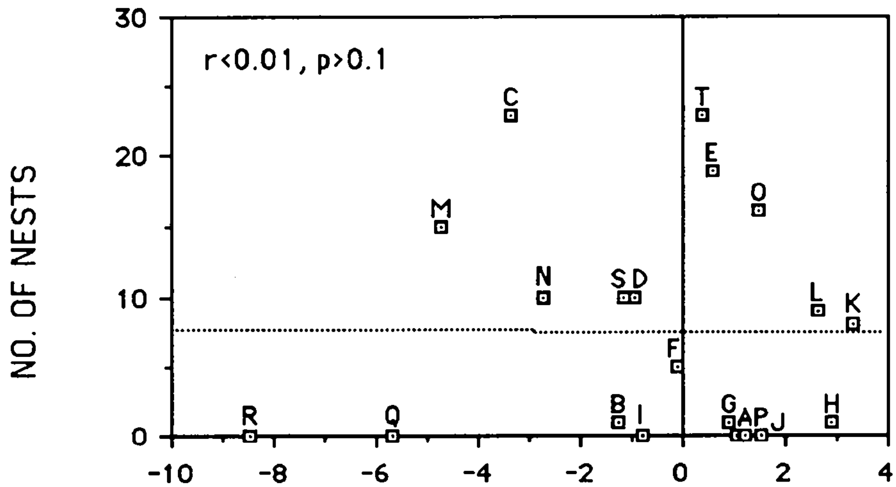


Figure 7. Relationships between the number of nests and mean residual variance in calling rates for three nocturnal seabird species nesting at Egg Island, Alaska. Actual values are plotted. Simple regression lines are also shown.

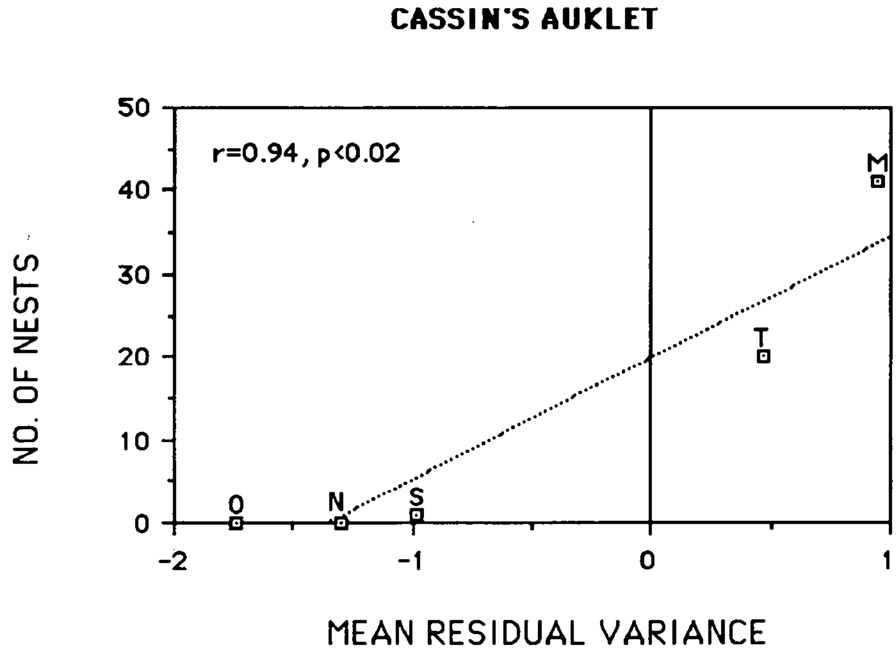


Figure 7 (cont.).

Table 11. Correlation matrix for regressions of number of nests vs. mean residual variances for Leach's and Fork-tailed Storm-Petrels on various sets of sample plots.

	Fork-tailed Storm-Petrel		Leach's Storm-Petrel			
			call type 1		call type 2	
Treatment	r	P	r	P	r	P
All Plots	**0.15**	**>0.1**	**<0.01**	**>0.1**	**0.01**	**>0.1**
Remove Puffin Plots (E,F,S,T)	0.19	>0.1	0.09	>0.1	0.06	>0.1
Remove High Density Calling Plots (C,D,M,N)	0.22	>0.1	0.26	>0.1	0.12	>0.1
Remove Low Density Calling Plots (A,B,Q,R)	0.19	>0.1	0.40	>0.1	0.22	>0.1
Remove High and Low Density Calling Plots	0.32	>0.1	0.11	>0.1	0.19	>0.1
Remove Puffin and High Density Calling Plots	0.12	>0.1	0.39	>0.1	0.24	>0.1

There seemed to be no relationship between the calling rates of storm-petrels, as measured in this study, and the numbers of storm-petrel nests occurring on the sample plots. A relationship may have existed between the calling rate of Ancient Murrelets and Cassin's Auklets and their nest densities.

Overflights of storm-petrels were significantly correlated with the numbers of Fork-tailed and Leach's storm-petrel nests on the eight sky-count study plots during July and August (Fig. 8). This indicated that sky-counts of petrels at marked localities in a colony might serve as a monitoring technique. A disadvantage of this approach was that the two species could not be readily distinguished. This disadvantage might be overcome if call-counts conducted simultaneously with sky-counts could provide a reliable indicator of proportions of each species. However, on plots where sky-counts were conducted, we found no correlation between nest ratios and call ratios of Fork-tailed and Leach's storm-petrels during July (Table 12), suggesting that such an approach may not work.

Whiskered Auklet Studies

Whiskered Auklets were present as isolated (presumably nesting) pairs occupying sites on vertical cliff faces around the entire perimeter of Egg Island and on both of the Baby Islands visited. We heard calls of Whiskered Auklets on only six of the 20 study plots (Fig. 4), all of which were immediately adjacent to coastal cliffs.

The calling pattern of this species was markedly different from that of the other four nocturnal seabirds. Calling by Whiskered Auklets was most pronounced during the early evening hours of darkness, and again just before daylight (Fig. 9), though some calls were heard throughout the night. Activity of the birds on land was usually restricted to those light levels at which it was very difficult for field personnel to obtain identifiable views of the birds against the cliffs without the aid of portable lights. Although a period of calling often occurred just after nightfall, calling was highly variable at this time (Fig. 10) and frequently absent altogether. A greater rate of calling was noted from 0500-0600 hours than at any other period of the night.

We undertook a census of two of the Baby Islands that were previously investigated by Nysewander et al. (1982), and counted Whiskered Auklets during the peak calling period. A total of 44 calling birds (at 29 sites) on Tangagm Island, and 27 calling birds (at 24 sites) on Excelsior Island were found (Fig. 11).

Our censuses of Whiskered Auklets on Egg Island were conducted throughout the night and revealed 20 calling birds (at 17 sites; Fig. 12). This is

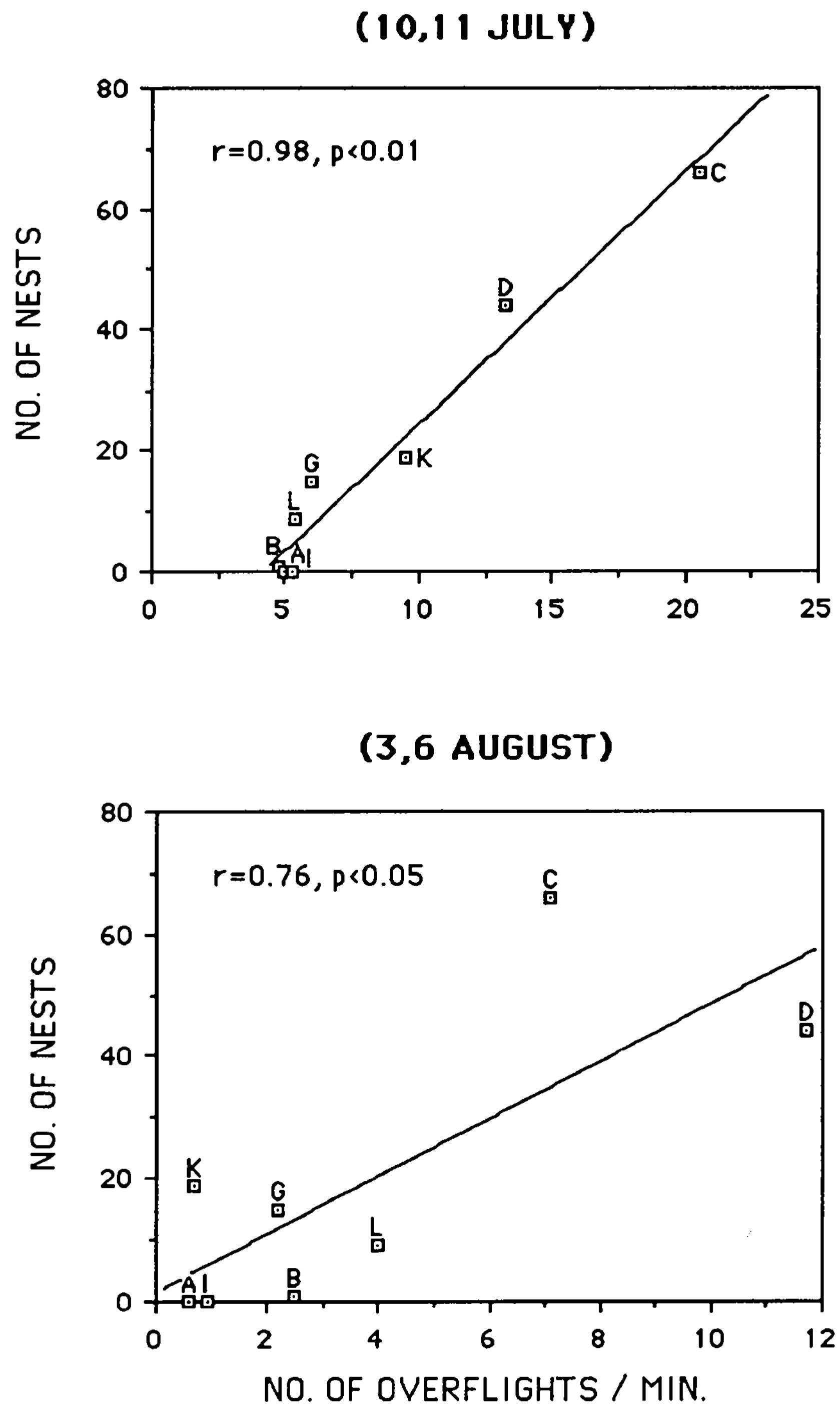


Figure 8. Relationships between the number of nests and the number of overflights of storm-petrels (both Fork-tailed and Leach's) on sampled plots at Egg Island, Alaska. Simple regression lines are shown.

Table 12. Correlations between nest ratios[1] and call ratios[2] for Leach's (LCSP) and Fork-tailed Storm-Petrels (FTSP) on plots[3] where sky-counts were conducted.

		Call Ratios from 02:00-03:00 hours			
	Nest Ratios	FTSP/LCSP	r	FTSP/LCSP	r
Plot	FTSP/LCSP	(type 1)	(P)	(type 2)	(P)
Actual calls per minute					
B	0.00	3.02		5.27	
C	1.87	4.92		19.68	
D	3.40	2.75	0.47	31.13	0.39
G	14.00	1.88	(>0.1)	1.82	(>0.1)
K	1.38	2.15		25.04	
L	0.00	3.07		166.63	
Predicted calls per minute					
B	0.00	2.59		16.06	
C	1.87	2.18		8.64	
D	3.40	2.18	0.61	8.64	0.43
G	14.00	1.88	(>0.1)	9.90	(>0.1)
K	1.38	3.64		76.71	
L	0.00	3.69		77.76	
Residual calls per minute					
B	0.00	2.25		-13.89	
C	1.87	-0.81		-3.19	
D	3.40	0.23	0.32	0.29	0.47
G	14.00	1.88	(>0.1)	-0.77	(>0.1)
K	1.38	0.19		1.39	
L	0.00	0.91		-11.11	

[1] Plots A and I were not considered. No nests of either species were found and the resulting nest ratio (0:0) is undefined.

[2] Nest data from Table 6.

[3] Call-count data were obtained on the following nights: plots B and G, 16 July; all other plots, 3 July.

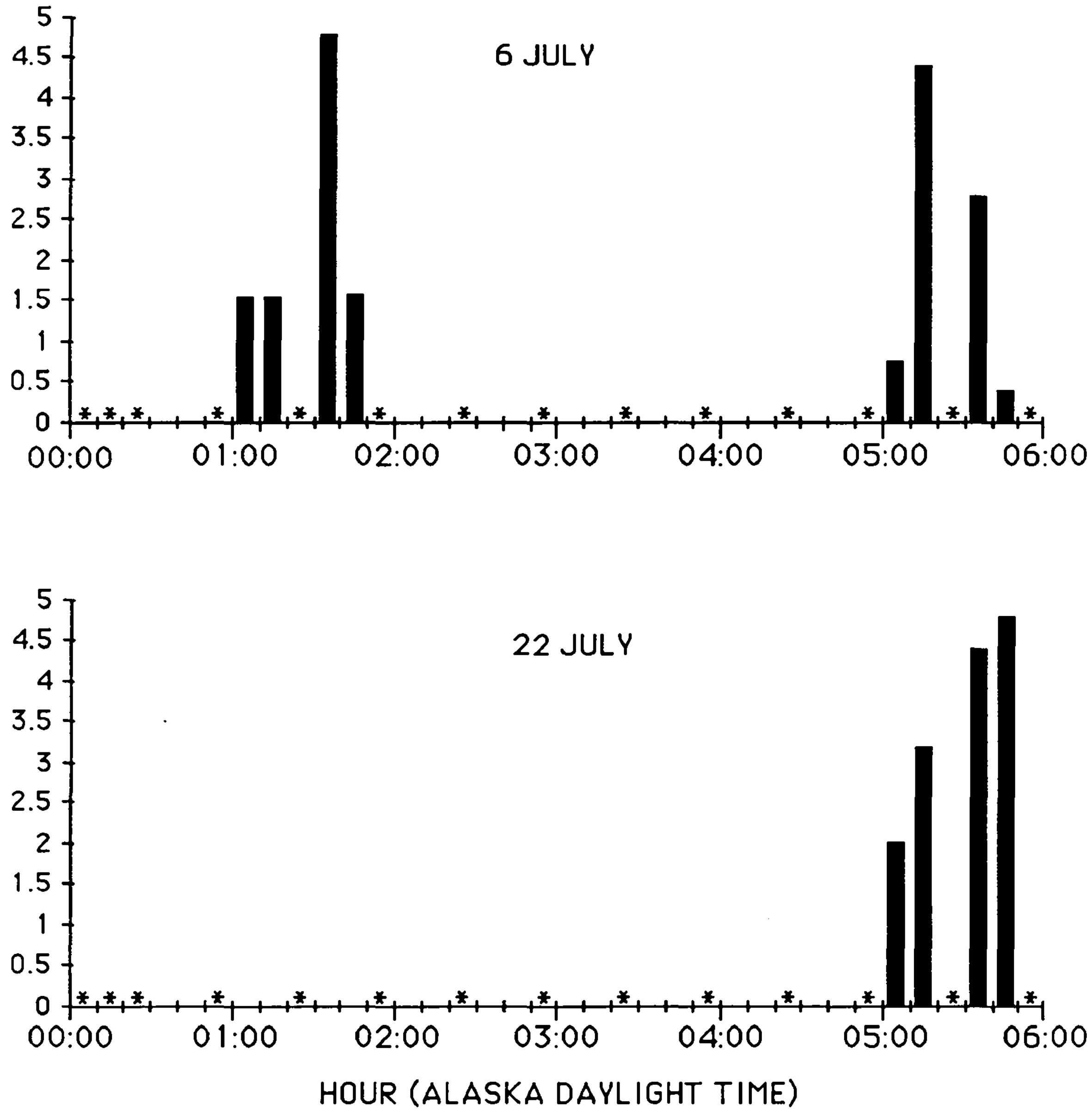


Figure 9. Nocturnal calling rate of Whiskered Auklets at Plot M, Egg Island, Alaska, on two nights. Both counts were made by the same recorder. Asterisks (*) indicate ten-minute periods for which no counts were taken.

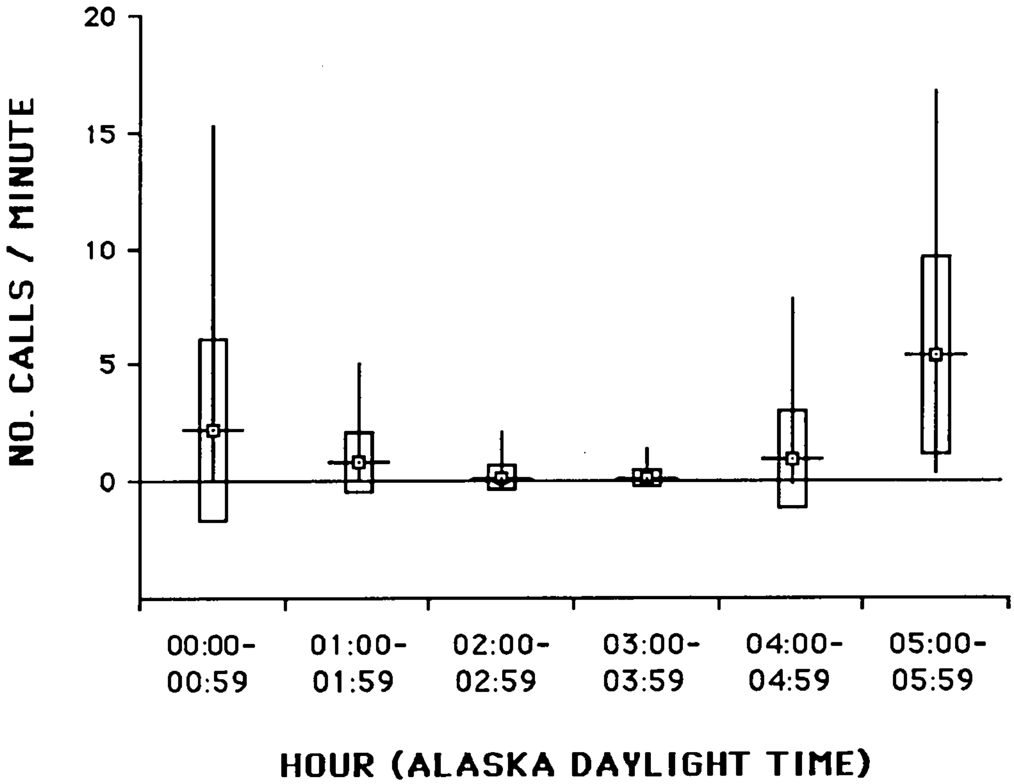


Figure 10. Nocturnal calling rate of Whiskered Auklets on six study plots at Egg Island, Alaska. Data were recorded from 26 June through 1 August 1989. Center point = mean, vertical bar = range, and box = standard deviation.

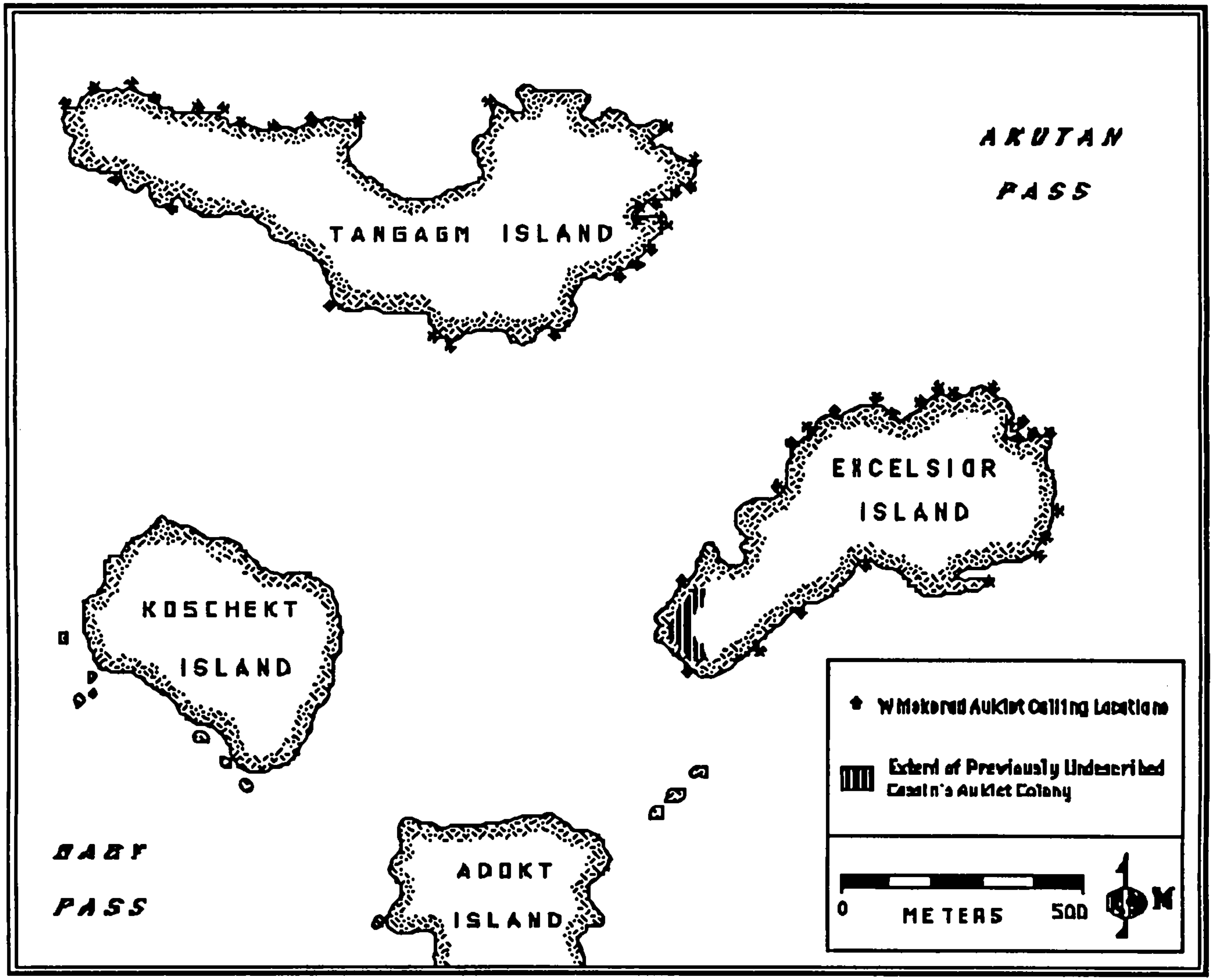


Figure 11. Locations of calling sites of Whiskered Auklets on Tangagm and Excelsior islands and in the Baby Islands, Unimak Pass, Alaska. A previously unreported Cassin's Auklet colony is also shown. (see Fig. 1 for location of Baby Islands.)

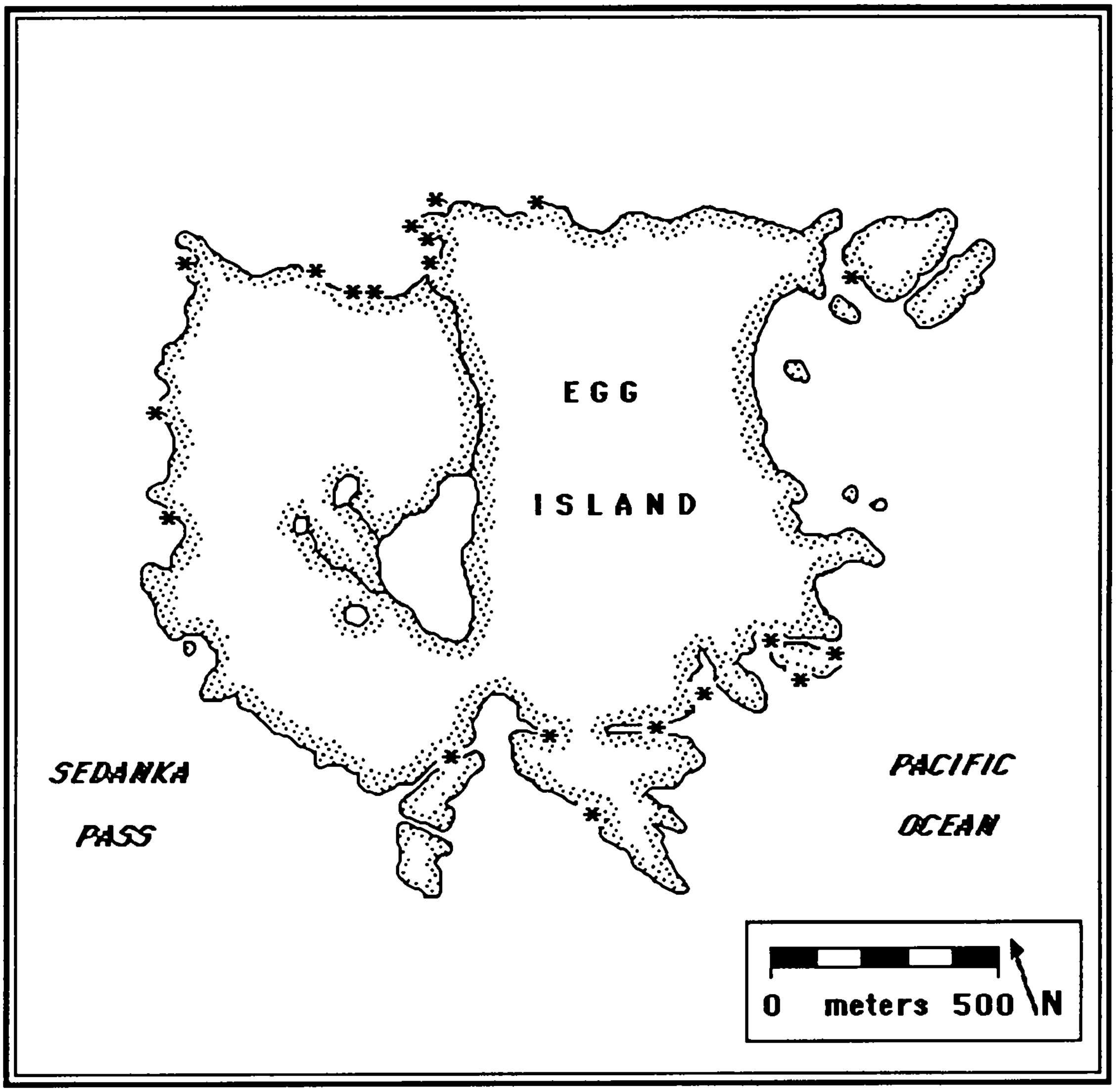


Figure 12. Locations of calling Whiskered Auklets at Egg Island, Alaska on 27 and 29 June 1987. (see Fig. 1 for location of Egg Island.)

probably a low estimate, however, because these counts took place throughout the night and we were unable to repeat the census exclusively during the pre-dawn period.

Tufted Puffin Studies

Shore-based observations of Tufted Puffins on the waters surrounding Egg Island on 7 July yielded an estimate of from 180,000 to 200,000 birds present. The counts were made during the laying/early incubation phase of the nesting cycle, and there were relatively few birds standing at the entrances to burrows on the island at the time. Birds from nearby colonies (e.g., the Baby Islands), however, may have also been present in this large aggregation of puffins. Nysewander et al. (1982) estimated that 163,316 breeding Tufted Puffins used Egg Island.

Puffin burrows varied in number among the four study plots that overlapped puffin colonies (see Table 6). But burrow densities were remarkably similar within colony boundaries, especially if terrain slope was similar. On plots E and F, puffin habitat occurred on very steep slopes and occupied approximately 597 and 346 m^2 of these plots, respectively, yielding densities of 0.81 and 0.82 burrows/m^2. In the more gentle terrain found at plots S and T, puffin nesting burrows occupied approximately 513 and 381 m^2 of the plots, respectively, and yielded densities of 0.62 and 0.67 burrows/m^2. On the 75 m^2 plot near the base camp where we excavated puffin burrow entrances, the 52 burrows found yielded a density of 0.69 burrows/m^2.

All burrows excavated had well-defined nest chambers at the distal end. Mean burrow depth was 1.16 (±0.53) m and ranged from 0.2 to 3.0 m. Of the 52 active-appearing nest burrows found on the survey strip, 17 contained an egg and one contained a small chick (both usually contained an attending adult as well), yielding a breeding occupancy of 34.6 percent. An additional 13 burrows contained nest chambers lined with grass but no egg or chick.

Of 167 burrows monitored on the regular plots, all but two burrows were used at some time by seabirds (probably puffins). Toothpicks at burrow entrances were regularly knocked over or more frequently missing when observers rechecked the burrows. On this basis, we calculated an occupancy of 98.8 percent for all burrows monitored on the four plots. This does not mean that the burrows were occupied by breeders because, as noted above, a much lower percent of the the 52 sample burrows excavated contained adults with eggs or chicks.

General Observations

Approximate distribution of nesting seabirds on Egg Island in 1987 is presented in Figure 13. Our estimates of seabird numbers in comparison with

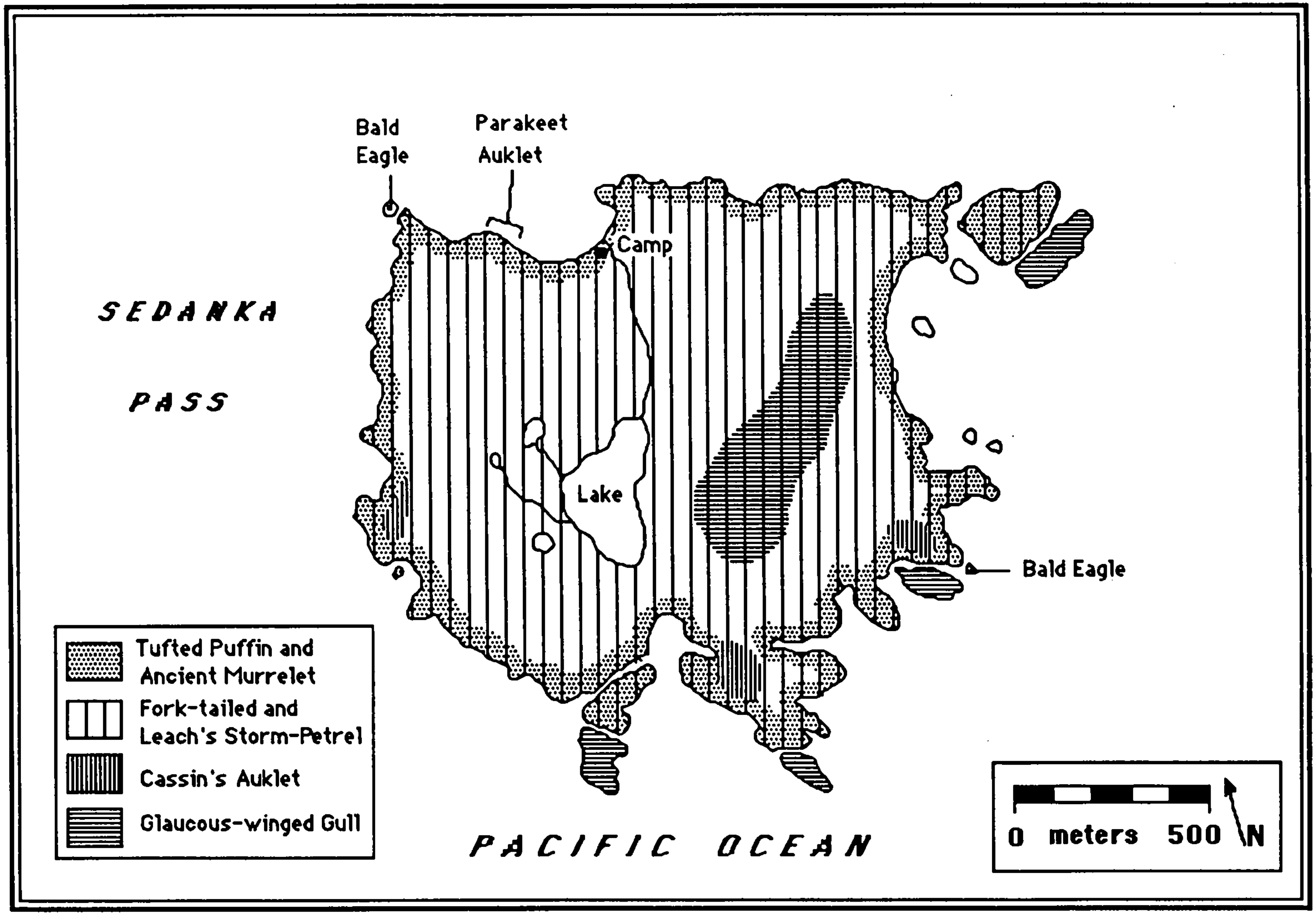


Figure 13. Approximate distribution of nesting seabirds at Egg Island, Alaska.

estimates made by Nysewander et al. (1982) based on 1980-81 studies appear in Table 13. How our estimates relate to breeding populations for most species is unknown. For example, we observed Horned Puffins daily on the waters near the island but never recorded them on the cliffs in potential nesting habitat. Similarly, we observed Pigeon Guillemots swimming near the island daily, but we also saw them flying into nest sites carrying fish to calling young so we are confident that they nested on the island.

Major differences in seabird numbers we observed in 1987 compared with those reported by Nysewander et al. (1982) include:

(1) We found no cormorants in 1987; Nysewander reported several hundred in 1980-81.

(2) Glaucous-winged Gulls apparently failed to produce any young in 1987. Similar numbers of adults were present as in 1980-81, but very few eggs were found, and we never observed a chick during our stay, although nest sites were occupied by pairs. We also noted use of small islets around Egg Island for additional limited nesting by this species.

(3) Based on counts of birds on the water, we found similar or higher numbers of Tufted Puffins than did Nysewander based on burrow counts.

(4) We found a small colony of approximately 30 Parakeet Auklets among beach boulders on the northwest corner of Egg Island. Adults were observed landing on beach boulders and disappearing into crevices.

(5) We found no definite Horned Puffin nest sites on Egg Island; Nysewander reported them "present". We observed them resting on the water daily within 100 m of the island, and during a circumnavigation of Egg Island by boat on 9 July, we observed approximately 150 of them resting on the water within 100 m of the island. Crevice nest sites could have occurred on some inaccessible cliffs.

In addition to the seabirds seen on Egg Island, we observed two other Tufted Puffin colonies on nearby islets along the coastline of Sedanka Island (Fig. 14). We travelled along the north shore of Sedanka Island, and in the area of Old Man Rocks, but noted no puffin concentrations nor other potential seabird colony sites (except for small numbers of Pigeon Guillemots) in these areas. During Whiskered Auklet censuses on the Baby Islands, we also noted the presence of a previously unreported colony of Cassin's Auklets on the west end of Excelsior Island (see Fig. 11).

Table 13. Estimated numbers of seabirds seen on or near Egg Island, Alaska in 1980-81 (Nysewander et al. 1982) and in 1987.

Species	1980-81	Method	1987	Method
Fork-tailed Storm-Petrel	200,000	Extrapolation from burrow counts		No estimate made
Leach's Storm-Petrel	70,000	Extrapolation from burrow counts		No estimate made
Double-crested Cormorant	82	Actual count of birds or nests	0	Count by boat along shoreline
Pelagic Cormorant	20	Estimate probably within 25%	0	Count by boat along shoreline
Red-Faced Cormorant	598	Actual count of birds or nests	0	Count by boat along shoreline
Glaucous-winged Gull	1508	Adjusted from counts of adults and/or nests	~2000	Estimates of adults at nesting colonies
Pigeon Guillemot	350	Adjusted from counts of adults on the water	~200	Estimates of adults on the water*
Ancient Murrelet	5000	Estimate probably within 50%		No estimate made
Cassin's Auklet	2000	Estimate probably within 50%		No estimate made
Whiskered Auklet	10+	Present in this plus unknown number more	20+	Counts of calling adults on cliffs
Horned Puffin	+	Present in unknown numbers	~150	Estimates of adults on the water*
Tufted Puffin	163,316	Extrapolated from counts of burrows	180,000 to 200,000	Estimates of adults on the water*
TOTAL	**442,906**			

* Includes birds seen resting on the water within 200 m of the island.

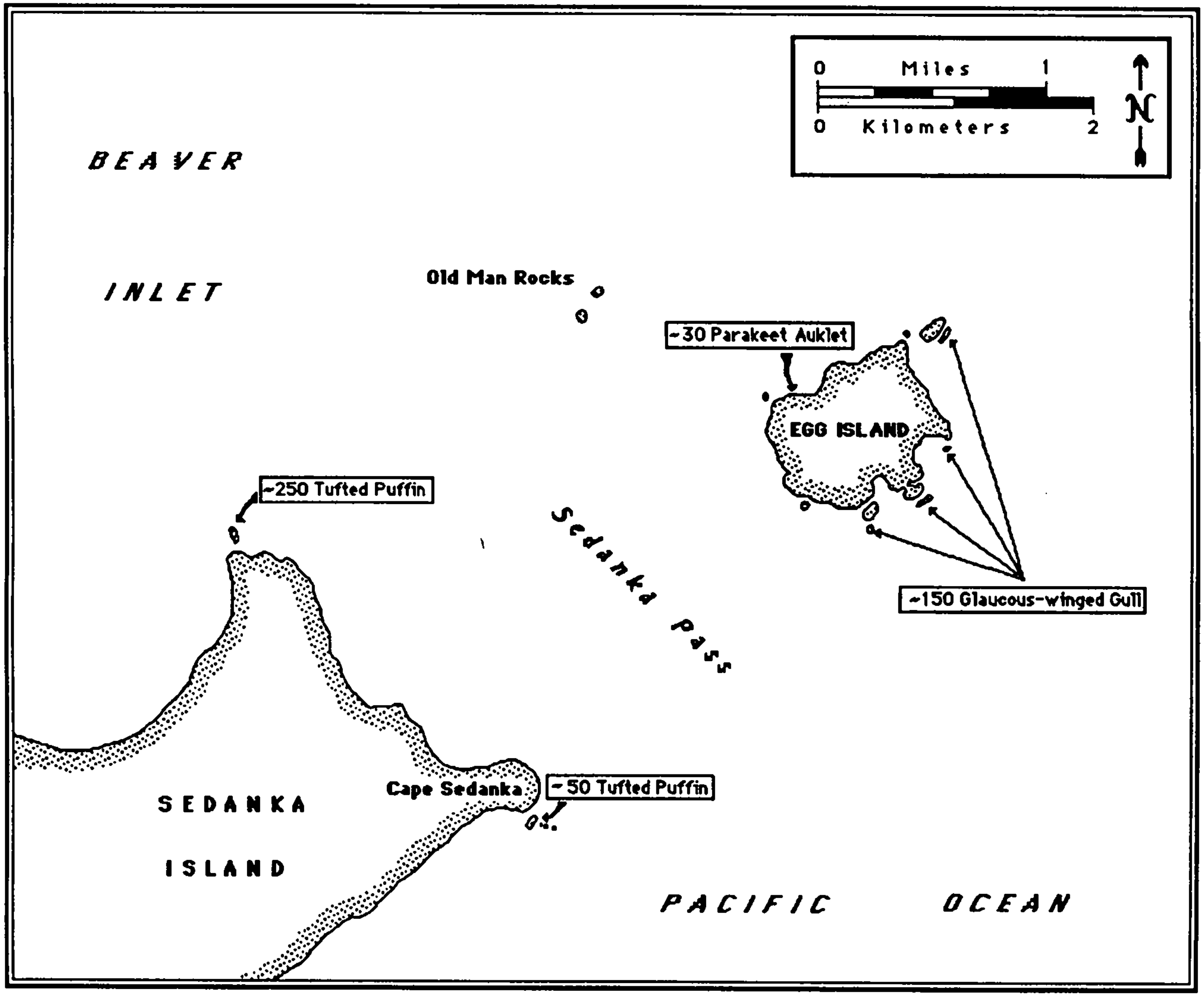


Figure 14. Locations of seabird colonies found in summer 1987 but not previously reported by Nysewander et al. (1982).

Feeding flocks of Whiskered Auklets were observed near Egg Island, the Baby Islands, and surrounding straits and passes in summer. Smaller flocks of up to 200 birds each were commonly seen in Sedanka Pass, Unalga Pass, at the mouth of Beaver Inlet, and in the straits between Egg Island and Unalga Island throughout the summer field period. During trips to the Baby Islands, we noted several flocks of over 1000 Whiskered Auklets approximately 1 km south of these islands and off Unalga Island in mid-July. Groups of auklets were most often associated with tide rips and other areas of strong currents, as previously noted by Byrd and Gibson (1980). On 14 July we counted approximately 11,400 Whiskered Auklets as they passed from west to east, flying from feeding sites in Unalga Pass eastward along the south side of Unalga Island. These flocks streamed past the island continually for almost an hour in late afternoon.

Other aggregations of seabirds in the area were usually associated with colony sites. As mentioned previously, concentrations of close to 200,000 Tufted Puffins were seen daily around Egg Island. We observed smaller groups on the waters at nearby small colonies around Sedanka Island. Flocks of Tufted Puffins numbering in the low 10,000's were also present on waters around the Baby Islands, where they nested on every island in the group. Other species of seabirds were present in small flocks or as isolated pairs and individuals throughout the inter-island area, but no notable concentrations were seen. Flocks of dark shearwaters (Short-tailed or Sooty) were frequently seen flying between islands toward either the Bering Sea or Pacific Ocean, but these birds rarely rested on waters near the islands.

DISCUSSION AND RECOMMENDATIONS

Population Monitoring of Nocturnal Seabirds

A prime objective of this study was to evaluate the call-count technique as a method for monitoring population trends of nocturnal seabirds. Ideally, any monitoring technique should; a) provide an accurate index of population trends, b) be easy to carry out, c) be readily transferable among different workers, and d) cause negligible disturbance to breeding birds (Gaston et al. 1988). Call-counts are an attractive technique because they offer the potential for standard, repeatable surveys that would cause considerably less disturbance to nesting birds than more traditional burrow-inspection techniques. Below, we discuss the usefulness of various techniques in monitoring the population levels of Fork-tailed and Leach's Storm-Petrels, Ancient Murrelets, and Cassin's Auklets.

Fork-tailed and Leach's Storm-Petrels

The call-count technique, as employed in this study, was found to be an inappropriate method for estimating the population levels of nesting storm-petrels. Our poor success in correlating call frequency and nest density probably resulted from several basic problems. Often a single problem would be exacerbated when present in combination with other problems.

(1) Scale of Measurement—Call-counts were conducted from near the centers of 25 X 25 m sample plots. It was usually impossible to accurately determine whether a given call occurred on or above a sample plot, near it, or farther away. The ability to hear calls and to estimate their distance varied with the observer, weather conditions, volume of calls, and distance from the observer of each call. The overwhelming cacophony of calls at several plot locations meant that it was impractical to accurately estimate the distance at which a bird was calling without losing track of a number of other calls. As a result, we recorded all calls for which we could determine a distinct beginning and end. Therefore, the call-count plots were of an undefined and probably temporally-varying size, whereas the plots from which we determined nesting density were of fixed size. Call-count plots probably were not representative of nesting densities that we found nearby in other plots.

(2) Recorder Abilities—Prior to undertaking formal call-counts, recorders listened to calls as a group, compared their approaches in accepting vs. rejecting questionable storm-petrel calls and their methods of recording data, and agreed upon a set of standard procedures. Near the end of the study period, we conducted paired comparisons of recorder abilities. We found that one recorder consistently counted fewer calls than other recorders. In spite of our efforts to standardize measurement techniques, plus a season's experience at counting calls, the significant differences found in recorder abilities suggest that the call-count techniques we employed are not generally transferable among workers. Furthermore, the recorder was also a significant predictor in estimating mean calling rates for storm-petrels. This indicates that variable recorder capabilities existed among all recorders throughout the study period.

(3) Operational Considerations—The call-counts made during this study were usually conducted during calm weather periods with little or no precipitation. It was clearly evident that high winds, pounding surf, or driving rain severely compromised a recorder's ability to hear storm-petrel calls. On some nights, counting had to be discontinued due to deteriorating weather conditions, and on many more nights, sampling was not even attempted. Multivariate analyses showed that weather disturbance affected the rate of calling in both storm-petrel species--calling rates were high with little weather disturbance and generally decreased with increasing disturbance. The windy and rainy summer weather typical of the Aleutians suggests that call-count techniques cannot necessarily be undertaken easily on a given study site.

(4) Biological Considerations—Several biological considerations affect the usefulness of call-count techniques for monitoring population levels of storm-petrels. First, the numbers, activities, and extent of vocalization of non-breeding storm-petrels visiting nesting islands are largely unknown. British Storm-Petrels (*Hydrobates pelagicus*) first return to colonies at two or three years of age, flying over the colonies at night but not occupying burrows. They take ownership of a burrow a year or two later, and first breed when four or five years old. Failed breeders apparently behave like nonbreeders. Furness and Baillie (1981) noted considerable variation in the relative numbers of breeders vs. non-breeders on St. Kilda Island. Harris (1974) also noted that suspected non-breeding Leach's Storm-Petrels visited colonies in California, and the same is presumably true of Fork-tailed Storm-Petrels. If non-breeders call at sampling sites, considerable bias is thus introduced to the use of call-counts as a measure of breeding populations. Second, breeding storm-petrels do not necessarily visit their nesting islands every night (Boersma and Wheelwright 1979; Quinlan 1979), and breeding activities can extend over several months (e.g. Byrd and Trapp, in prep.). Third, we noted that there appeared to be general approaches to interior portions of the island that were used by large numbers of calling birds; such areas (e.g. plots A and B) had virtually no nesting birds. Finally, storm-petrel behavior is affected by ambient light conditions (Quinlan 1979, Watanuki 1986), with fewer birds visiting nesting

islands on moonlit nights. It would have been difficult to control our sampling procedures for any of the biological considerations except ambient light conditions.

Given all of these problems, it is perhaps not too surprising that call-counts of the two storm-petrel species were not correlated with nest density on the 25 X 25 m sample plots. Call-counts were not useful measures of the abundance of either Fork-tailed or Leach's Storm-Petrels nesting on Egg Island.

In contrast, sky-counts correlated well with the numbers of nesting storm-petrels on eight plots sampled in July and August. This technique is reasonably quick, and causes very little disturbance to nesting birds. The technique is somewhat constrained by driving rain, but it could probably be successfully implemented in stronger winds than could call-counts. The strong correlation between counts of birds in overflights and nest densities suggests that the presence of non-breeders may not invalidate this technique.

The main problem with sky-counts is our present inability to distinguish between the two species of storm-petrel while looking upward at the night sky. Until this problem can be solved, species-specific information from sky-counts will not be obtainable in multi-species colonies of storm-petrels. Future workers should also investigate possible inter-observer variation in the ability to observe night-flying birds.

Ancient Murrelets

The results of this study suggest that call-counts may offer potential for monitoring Ancient Murrelet populations. Gaston et al. (1988), however, found the frequency of vocalizations of Ancient Murrelets to vary enormously on plots established at Reef Island in the Queen Charlotte Islands, British Columbia. On some nights, no calls were heard, while on others, more than 200 were recorded in the first 100 min. These authors concluded that vocalization rates were not very useful in monitoring the numbers of birds using a single plot.

It is possible that many of the calls recorded by us were given by prospecting non-breeders, since many of our call-count surveys were conducted after unknown numbers of adult Ancient Murrelets and their chicks had left Egg Island. However, unlike storm-petrels, Ancient Murrelets seem to have more direct flight routes from the sea to their nesting areas, so we were probably less influenced by calls emanating from birds not associated with the sampled study plot.

The use of knock-down tags, placed at the burrow entrances and checked daily, provided less variable estimates of the numbers of Ancient Murrelets using a study area on the Queen Charlotte Islands than did call-counts, but caused more disturbance to birds (Gaston et al. 1988). Further, use of the tag technique requires a large level of effort to detect even a 20% difference in the proportion of burrows occupied. Thus it is probably worthwhile to further investigate the use of call-counts as a potential technique for estimating numbers of nesting Ancient Murrelets.

In future work, call-counts should begin earlier in the season than was possible in this study, knock-down tags should be monitored on all sample plots, and burrow examination should be conducted as late in the study period as is practical. It would also be valuable to measure more environmental and habitat variables as potential reasons for call-count variance.

Cassin's Auklets

It appears that call-count techniques offer good potential for monitoring numbers of Cassin's Auklets. Similar to Ancient Murrelets, their behavior of flying directly to and from nesting areas and the sea, and their tendency to call mostly from the top of or below ground surface probably reduces the variation in calling rates introduced by individuals not associated with the site under investigation.

Because Cassin's Auklet burrows are easily distinguishable (e.g., DeGange et al. 1977, Nysewander et al. 1982, Gaston et al. 1988), call-counts combined with burrow-counts should enable future workers to establish relationships between these variables for other colonies. Further information on nesting success at Egg Island would be difficult to obtain easily, due to the extreme lengths of the majority of Cassin's Auklet burrows. Relatively new developments in fiber-optic equipment may be useful for inspecting burrows.

Whiskered Auklet Studies

Monitoring breeding populations of Whiskered Auklets by any technique is difficult. Characteristics of the breeding biology which complicate population monitoring include:

(1) Nest site selection is variable across the nesting range; sites include rock crevices in cliffs in the eastern Aleutians (Nysewander et al. 1982) and talus slopes and beneath beach boulders at Buldir Island (Knudtson and Byrd 1982). Nest sites are invariably difficult to access by human researchers.

(2) Nesting densities are low, with pairs probably scattered along all suitable nesting cliffs in the eastern Aleutians, including many larger islands (e.g., Tigalda and Akun--Nysewander et al. 1982).

(3) Activity patterns at colonies are also variable. In the western Aleutians, birds on Buldir Island visited land during the day (although near dusk and dawn) (Byrd et al. 1983), but in the eastern Aleutians they visited land at night (Nysewander et al. 1982, this study).

(4) Activity on land at night is bimodal. Instead of calling at the colonies throughout the night as do many other nocturnal seabirds, Whiskered Auklets call for approximately an hour immediately after dark, call sporadically at night, and are most active for approximately an hour just prior to daylight.

It would be possible, but difficult, to monitor the Whiskered Auklet population in the eastern Aleutians by call-counts. Because of the inaccessibility of nests on Egg Island, we could not compare call-counts with breeding effort. But the loudness of the calls of this species made it relatively easy to pinpoint presumed nest locations on maps, and the restricted nesting habitat (crevices in coastal cliffs) helped to narrow the area to be censused. If all or at least a large and consistent majority of nesting pairs call from the nest site just prior to sunrise, counts at this time in appropriate habitat could be useful in monitoring populations. The restricted period of calling, however, will limit the amount of habitat that can be censused by an individual or team of workers. During counts on Tangagm and Excelsior islands, four team members were able to census each island thoroughly from 0415 to 0545. Islands larger than these would be difficult to census during the peak calling period using the same number of persons.

Tufted Puffin Studies

Tufted Puffins present several problems to researchers attempting to monitor population levels. This species is known to be particularly sensitive to disturbance at the nest site, frequently abandoning breeding efforts after even a single visitation by field researchers (Pierce and Simons 1986, Baird and Jones 1986). Destruction of burrows by persons walking though colonies is also a potential hazard. In addition, preferred nesting habitat at most colonies is on very steep slopes, and is frequently inaccessible without appropriate climbing equipment. Tufted Puffins also vocalize only infrequently at the colonies, and the low-pitched quality of the call does not carry far. Further, the tendency for adults to appear at the entrance of burrows also seems to be highly variable between colony sites. At some locations, adults may stand near burrow entrances for considerable portions of the day (pers. obs.; D.G. Roseneau, pers. comm.), but on Egg Island puffins seldom stood near burrows, usually entering and exiting as rapidly as possible. The abundance of Bald Eagles (*Haliaeetus leucocephalus*), a known predator, may have contributed to this behavior.

Techniques for population monitoring of Tufted Puffins may be most practical through use of burrow-inspection techniques. Monitoring by burrow-counts should not require use of the same sample area from year to year if the sampling is carried out appropriately. This would allow use of plot or transect techniques even if disturbance is a problem. However, at least on Egg Island, burrows are very deep and in some years appear to contain far fewer breeding birds than the inter-colony average. Obtaining information on breeding occupancy would require sacrificing the breeding effort of most of the birds sampled, because of the extent of excavation required to obtain these data. Repeated monitoring in this fashion could lead to major alteration of nesting habitat. Puffins on Egg Island also appear to at least periodically inspect almost every available burrow, and monitoring of activity at burrows would not in itself be highly useful. Clearly a technique that involves remote observations of samples of burrows, or methods of inspecting burrows that require minimal disturbance to the birds, would be most useful for monitoring puffins. Use of flexible glass fiber-optical equipment for inspecting nest burrows may prove valuable for monitoring purposes, although this technique has not proven very useful for Ancient Murrelets, another burrow-nesting species (Gaston et al. 1988).

Monitoring of breeding Tufted Puffins would best occur during the early chick-rearing period. At this time, puffins are less prone to desert nests, no new nests would likely be initiated afterward, and chicks would not yet have fledged. Timing of monitoring activities would require careful planning, because breeding chronology differs among colonies and can be quite prolonged within a colony. Our studies indicated the breeding chronology of Tufted Puffins on Egg Island was later than at colonies in the western Gulf of Alaska. Most puffins were on eggs and only one newly-hatched chick was found on 6 August, about the time most hatching is completed at colonies farther east (Baird and Jones 1986).

General Observations

We found the species compositions of the colonies we visited to be generally similar to those reported by Nysewander et al. (1982). The absence of nesting cormorants on Egg Island in 1987 was not considered alarming because cormorants are known to use different nest sites from year to year, abandoning entire colonies in the process (Palmer 1962, Sowls et al. 1978).

The nesting failure of Glaucous-winged Gulls on Egg Island could have been caused by poor body condition of breeding adults, poor weather, predation, or other factors, but may also have been human-related. Local natives used the gull colony on nearby Koschekt Island (Baby Islands) for subsistence egging in June 1980 (Nysewander et al. 1982), and they may have used Egg Island in 1987 for this purpose before our arrival. We found no evidence of recent human presence on Egg Island; however, if egging similarly took place in early June, grass growth would have likely covered human sign by the time of our arrival in late June. The fact that this, and many other islands throughout Alaska, are called "Egg Island" often reflects the use of these islands by natives to gather eggs. Colonies of large gulls are frequently used as egg sources because of the relatively easy access to nests (which are often on level terrain) and the large size of the eggs.

Similar to the findings of Byrd and Gibson (1980), Whiskered Auklets congregated in flocks within tide rips and other areas of strong current convergence during the summer as well as at other seasons. Summer concentrations of this species at times were large; we found over 1000 birds per flock in several flocks south of Unalga Island and the Baby Islands in mid-July. Nysewander et al. (1982) also reported large flocks of this species, primarily in Avatanak Strait, but they also found smaller numbers near the Baby Islands. Flocks of auklets during the breeding period, however, would disperse in the evening, with at least breeding adults moving to nest sites scattered throughout the nearby islands.

Tufted Puffins were also concentrated in large, dense flocks during the breeding period, primarily in areas immediately adjacent to the nesting islands. These flocks dispersed and reformed throughout the day during the breeding season.

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Chapter 9

ABUNDANCE, DISTRIBUTION, AND VULNERABILITY TO IMPACT OF BIRDS AND MAMMALS: A SYNTHESIS

by

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SUMMARY

The Unimak Pass area supports large numbers of marine birds and lesser numbers of marine mammals. The various species studied exhibited marked differences in temporal and spatial distribution.

Both birds and mammals peaked in abundance in fall. Of the birds, short-tailed Shearwater was the most numerous species in fall and spring, and Crested Auklets were numerically dominant in winter. Dall's porpoises were in all seasons the most numerous mammals, northern fur seals were the second most numerous in fall, and sea otters were the only other relatively abundant marine mammals.

Euphausiids predominated as potential food for birds and mammals in the water column. Forage fishes were relatively uncommon and probably had less value as forage than did the euphausiids.

Prey availability appeared to play a major role in determining bird distribution. Virtually all key species studied—shearwaters, auklets, and murres—preyed predominantly on euphausiids and distributed themselves so as to benefit from euphausiid distribution. Some of these species, e.g. Common Murre, reportedly feed on fish in other areas.

In the fall, birds and their euphausiid prey were most common north of the Krenitzin Islands and northwest of Unimak Pass in areas considered to be Shelf Break Water (SBW) and Gulf of Alaska Water north (GAWn). Spectacular concentrations occurred in the northwest corner of Unimak Pass off Akun Island in an area of relatively high salinity that may have been caused by local upwelling.

During winter the euphausiid concentrations were farther east, to the north of Unimak Island within the Alaska Coastal Water north (ACWn). The major bird concentrations, composed mostly of Crested Auklets and Common Murres, were also present in this area. In spring there were no major concentrations of birds and prey but the highest densities of both were in the ACW.

Some species, including the Whiskered Auklet, did not clearly follow the prey concentrations on a seasonal basis. This species was always associated with the Krenitzin Islands and the Tidally Mixed Water (TMW), where sampling showed euphausiids to be present but not extremely abundant. It may be that zooplankton availability increased during periods of high tidal flux when the birds appeared to be most active in the passes but when sampling was impossible. Birds collected in the passes were found to have been successful in procuring euphausiids.

We found that Whiskered Auklets ventured much further from the passes than previously believed. Relatively large numbers were found at sea (5-10 nm) both north and south of the islands, especially in fall and spring, but even at sea they were most concentrated opposite passes.

Our results tend to support the hypothesis that very little upwelling or influx of nutrients or prey occurred due to water movement from the south through Unimak or other nearby passes. Rather, upwelling seemed to occur to the west of our study area through deeper passes, and the nutrients (or subsequent trophic products) were apparently transported east along the north side of the eastern Aleutians and into the North Aleutian Shelf area. Some evidence of local upwelling north of Akun Island was found during fall.

Not only did areas where birds concentrated generally correspond to areas of high euphausiid abundance, food habits analyses confirmed that euphausiids were the predominant prey of most birds. Seasonal shifts in bird distribution followed shifts in prey availability. The extent to which marine mammals were distributed in accordance with the distribution of their prey was not clear, because no food habits analyses were conducted for mammals. However, there were clear associations between most mammal species and certain water masses. High numbers of several species were found in fall in an upwelling area northeast of Akun Island.

The bird species judged to be the most vulnerable to adverse effects of oil should it be spilled in the study area were Tufted Puffin, Short-tailed Shearwater, Common Murre, Whiskered Auklet, and Crested Auklet. Major concentrations of these species were found in Akutan Pass, Derbin Strait, western parts of Unimak Pass (off Akun Island), and north of Unimak Island.

Tufted Puffin concentrations were largely of locally-breeding birds, thus mortality of large numbers could severely reduce local colonies. In contrast, concentrations of other species seemed to be primarily of wintering and other nonbreeding birds, potentially from several breeding populations, and local mortalities probably would have less drastic effects on any one breeding population.

Of the birds present mostly as non-breeders, the two auklets are probably the species at greatest risk because of their restricted distributions and large concentrations in the study area. Given prevailing currents in the study area, the auklet concentration area north of Unimak Island would probably be at greatest risk from a spill. This area supports very few Whiskered Auklets but hundreds of thousands of Crested Auklets may be present for much of the winter.

Among the mammals, northern fur seals and sea otters are more sensitive to contact with oil than are the other species because they are insulated with fur, which loses its insulative value when heavily oiled. Fur seals are judged to be highly vulnerable also because a large proportion of the Bering Sea population migrates twice annually through the Unimak Pass region; regional sea otter populations are less vulnerable because only a small proportion occupies the Unimak Pass area. Steller seal lions may be more vulnerable than at first suspected because large numbers congregate at haul-outs in the area and the population is already declining for other reasons, which could exacerbate adverse reactions to oil. Populations of other mammals are probably relatively invulnerable.

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INTRODUCTION

Unimak Pass is the major shipping passage linking the northeastern Pacific Ocean to the eastern Bering Sea. Commercial cargo vessels, fishing boats, warships, and oil industry vessels supporting activities in western and northern Alaska transit the pass. Portions of the Bering Sea—St. George Basin, North Aleutian Shelf, Navarin Basin, Norton Sound—could be eventually subject to petroleum exploration. In the event of a major oil discovery off western Alaska, tanker and support vessel use of the passage is expected to intensify, increasing the probability of accidents that could result in oil spillage and damage to regional biota.

The Unimak Pass area receives intensive use by seabirds and marine mammals. In summer, well over one million seabirds nest on islands in the area (Sowls et al. 1978). During spring and fall millions of birds and thousands of marine mammals migrate through the pass. The large numbers of these apex predators that feed in the area throughout the year suggest that the area has high and sustained productivity. Although spatially removed from the actual lease areas, the Unimak Pass area has a fauna of sufficient biological importance to be considered "at risk" from OCS activities. A lack of quantitative information on the nature and extent of use of the Unimak Pass area by marine birds and mammals prompted NOAA and MMS to obtain additional data. To this end they funded the research reported in preceding chapters. Following is a synthesis of findings related to the abundances and distributions of key species of birds and mammals and their prey, and an assessment of the vulnerability to oil spills of birds and mammals in the Unimak Pass area.

Study Area

The study area encompassed Unimak Pass and adjacent waters within a distance of approximately 50 km, including the Krenitzin Islands group. The area of interest was bounded by latitudes 53°30'N and 55°00'N and longitudes 164°00'W and 166°30'W (Fig. 1).

Resources of Concern

The species of interest fell into three groups—those that were numerous in the area, those that were very rare, and those of uncertain status. Several species were known prior to our investigations to be abundant; these included Short-tailed Shearwaters, Tufted Puffins, and Crested Auklets. Several endangered species were known to occur (or to have formerly occurred) in the Unimak Pass area; these included several of the great whales (right, gray, blue, humpback, and fin) and the Short-tailed Albatross. Species of uncertain status included northern fur seal, Whiskered Auklet, and

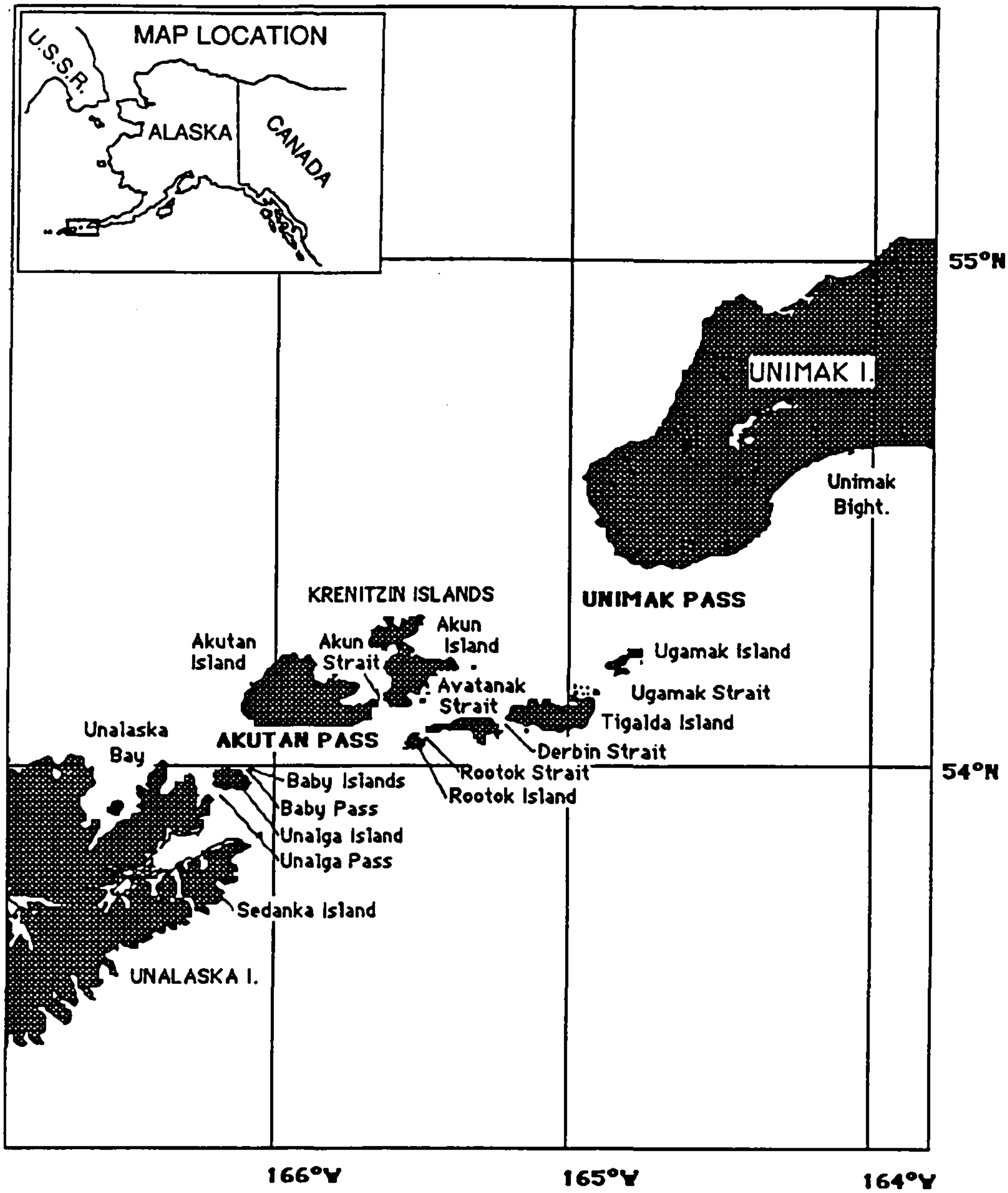


Figure 1. The Unimak Pass study area, Alaska.

seaducks; their distribution in and actual use of the pass area needed additional quantification.

METHODS

Three cruises, all using the NOAA ship R/V *Miller Freeman* (MF), were taken during this study. These cruises were as follows:

MF-86-10	18 Sept. – 7 Oct. 1986	fall
MF-87-02	14 Feb. – 9 March 1987	winter
MF-87-05	21 April – 14 May 1987	spring

Marine Birds and Mammals

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

Oceanographic Features and Prey Resources

Sampling to characterize oceanographic conditions and prey availability were undertaken, usually at night, along transects just censused. This sampling included bongo net deployment for zooplankton, CTD casts for temperature and salinity, and Marinovich mid-water trawls for forage fish. Most sample stations were reoccupied on each cruise.

RESULTS

Abundances and Distributions of Birds and Mammals

Fall

Most bird species peaked in abundance during fall (Table 1). This was particularly true of procellariids, larids, and puffins. Although many species were relatively common during this season, the total density of marine birds was not as high in fall as was observed during the winter, but was considerably higher than during spring.

Short-tailed Shearwater was overwhelmingly the most numerous species, accounting for almost two-thirds of all birds. Next in abundance was Black-legged Kittiwake, which accounted for an additional 15% of all sightings. Three additional species were common (occurring at densities ≥ 10

Table 1. Densities (#/km²) of marine birds by cruise, Unimak Pass area, Alaska, 1986-87.

SPECIES	Fall	Winter	Spring
Northern Fulmar	**9.9**	5.3	5.1
Short-tailed Shearwater	**186.3**	0.0	39.1
Black-legged Kittiwake	**42.1**	2.4	1.7
Murre	0.1	**14.2**	4.7
Whiskered Auklet	16.3	11.0	15.3
Crested Auklet	0.1	**317.8**	4.8
Auklet	3.9	**58.5**	0.3
Tufted Puffin	**9.9**	0.1	0.5
Total	281.0	424.6	79.8

Table 2. Densities (#/km²) of marine mammals by cruise, Unimak Pass area, Alaska, 1986-87.

SPECIES	Fall	Winter	Spring
Sea Otter	**0.029**	0.007	0.009
Steller Sea Lion	0.003	0.002	0.000
Northern Fur Seal	**0.039**	0.000	0.000
Harbor Seal	0.004	0.000	0.000
Killer Whale	0.005	0.000	0.009
Dall's Porpoise	**0.139**	0.074	0.051
Gray Whale	0.000	0.000	0.003
Minke Whale	0.004	0.003	0.001
Fin Whale	0.000	0.000	0.003
Total	0.22	0.10	0.08

birds/km^2)—Whiskered Auklet, Northern Fulmar, and Tufted Puffin. These five species accounted for 94% of the birds seen.

Several species, including most of the common ones—Northern Fulmar, Short-tailed Shearwater, Black-legged Kittiwake, and Tufted Puffin—had a concentration area in the northwest portion of Unimak Pass, off Akun Island (Fig. 2).

As expected, many Whiskered Auklets were encountered within the passes of the Krenitzin Islands, especially Akutan Pass. However, this species was also numerous in the Gulf of Alaska south of the islands with peak numbers occurring off passes.

Most marine mammals also were found at their peak abundances during fall (Table 2). Dall's porpoise, sea otter, and northern fur seal were most striking in this regard.

In general there were too few observations of marine mammals to make any broad generalizations regarding distribution. Northern fur seals were not as common as expected, and were essentially confined to the Bering Sea west of Unimak Pass. Most Dall's porpoises were in the Bering Sea, peaking in abundance north of Unimak Pass, but also occurred in the deeper waters of the Gulf of Alaska. Humpback whales were observed in the area of seabird concentration north of Akun Island.

Winter

The highest overall density of marine birds was recorded on the winter cruise. Three species accounted for 97% of the total. At least three-quarters of all birds were Crested Auklets. Murres, predominantly Common Murres, were the second most numerous group, but they were an order of magnitude less numerous than the auklets. The only other common species was Whiskered Auklet.

The centers of bird abundance occurred in two areas—north of Unimak Island and within the passes and straits of the Krenitzin Islands (Fig. 2). Murres were numerous in both areas, being most common in western Unimak Pass, Avatanak Strait, and off Cape Sarichef. Crested Auklets were concentrated north of Unimak Island between capes Sarichef and Mordvinof and within Akutan Pass (including Baby Pass). Whiskered Auklets were restricted to the Krenitzins, sharing the Akutan Pass area with the Crested Auklets and also concentrated in Derbin Strait.

Marine mammals were encountered very infrequently during the winter cruise. The most numerous species recorded at sea was Dall's porpoise, which was largely restricted to the deepest portions of the study area in the

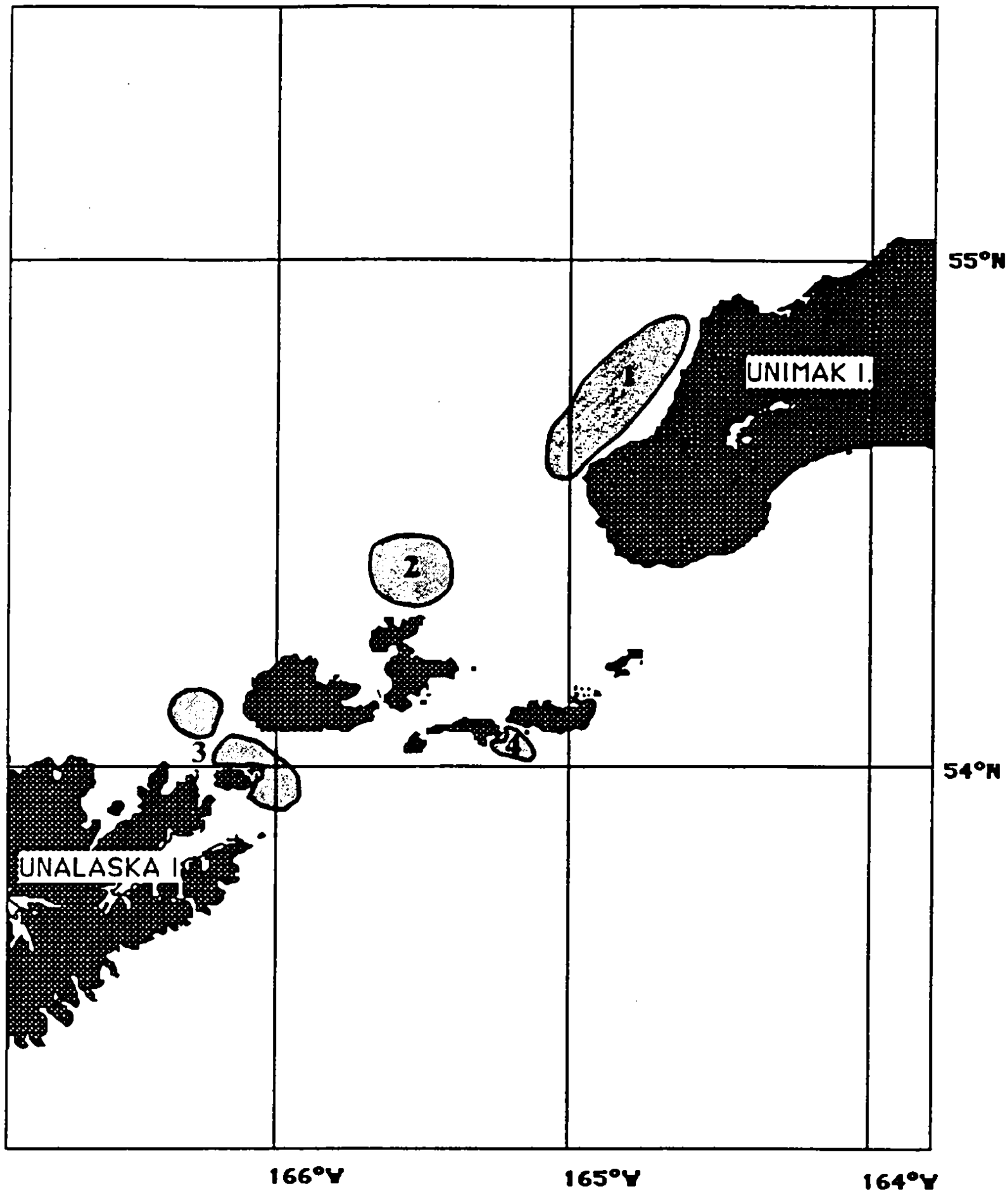


Figure 2. Areas with the highest densities of birds, Unimak Pass area, Alaska. (1=high densities of Crested Auklets and Common Murres during winter; 2=high densities of all species, especially Short-tailed Shearwaters, during fall; 3=high densities of Short-tailed Shearwaters during fall, Crested Auklets during winter, and Whiskered Auklets during all seasons.)

North Pacific. The only species of baleen whale recorded during winter was minke whale, which occurred within the passes and straits of the Krenitzins.

Spring

Overall bird densities in spring were only one-fifth of those recorded during the winter cruise, which ended not much more than a month prior to the start of the spring cruise. This illustrates the dynamic nature of bird populations during times of migration. During the spring cruise most winter birds had left for breeding areas and few of the summer birds were yet present. The most numerous species during the spring cruise—Short-tailed Shearwater—was abundant only near the end of the cruise. The only other common species observed during this cruise was Whiskered Auklet. The above two species comprised 68% of all sightings. It should be noted that Whiskered Auklet was the only species that was considered common during all cruises. Shearwaters in spring were most numerous in the eastern part of Unimak Pass, close to Unimak Island. Whiskered Auklets were more frequent north of the Krenitzins (opposite passes) than during the other cruises.

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

Oceanographic Features

Distributional analyses of water quality variables were based on shipboard CTD casts and nitrate/nitrite samples taken on transects through the area, and on inspection of remote-sensing analyses of sea surface temperatures. Findings with important implications for the vertebrate food webs in the area include the following:

(1) Low-salinity Alaska Coastal Current water was confined to the eastern parts of Unimak Pass in all seasons . Its farthest westward extension occurred in spring.

(2) Water quality distributional characteristics indicated that upwelling of deep Gulf of Alaska water south of Unimak Pass, and its subsequent transport through the pass, was probably an uncommon occurrence. Rather, it seemed that upwelling probably occurred a few to several hundred km farther west in the Aleutian chain, and that the upwelled water moved eastward along the north side of the chain, eventually reaching the Unimak Pass area. This

is consistent with recent theory by other workers (e.g., Takenouti and Ohtani 1974, Kinder and Schumacher 1981).

(3) Four different water masses probably occurred in the study area as a whole, based on surface salinities and mixing regimes. These were Alaska Coastal Current water (ACW) (adjacent to Unimak Island), Shelf Break Water (SBW) (north and west of the pass), Tidally-Mixed Water (TMW) (in shallow areas), and what we called Gulf of Alaska Water (GAW) (widely distributed in deeper, western parts of the study area). The spatial extent of the water masses, especially that of SBW and ACW, varied considerably among seasons (Fig. 3).

We subdivided two of the water masses, the GAW and the ACW, into northern (Bering) and southern (Pacific) masses. In the case of the GAW, these two regions were frequently discontinuous and so were analyzed separately. As discussed earlier the ACW retained its integrity as it passed through Unimak Pass; however, based on prior studies and on the nitrate content of the water, we anticipated that indications of upwelling would be manifest on the Bering Sea component of this water mass but not the Pacific side.

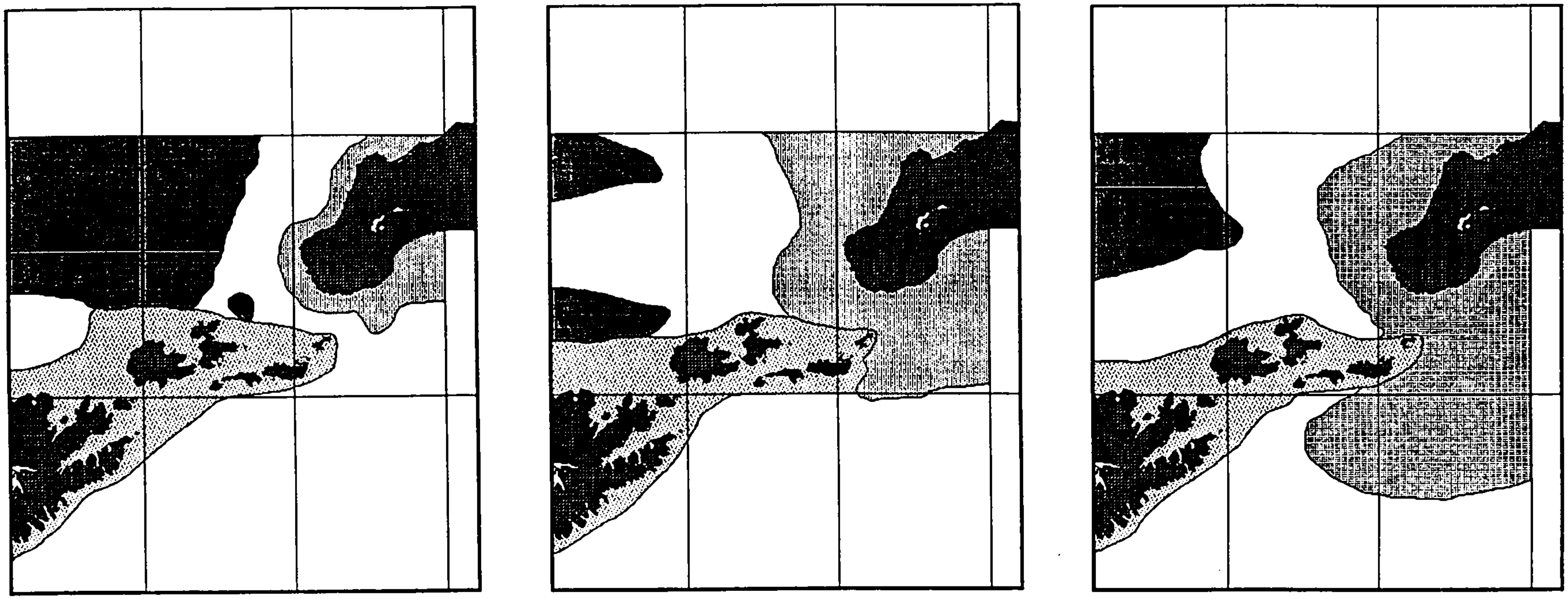
Prey Resources

Fish

The spatial and temporal distributions of forage fishes in the Unimak Pass area were assessed as a basis for explaining the distributions of marine birds and mammals of the region. These analyses were based on mid-water trawl samples taken in association with marine bird and mammal surveys.

In most portions of the study area and during most cruises, forage fishes were relatively uncommon and probably did not attract marine birds and mammals to the area. The food habits analyses of common birds (Short-tailed Shearwaters, Common Murres, Whiskered and Crested Auklets) confirmed that fish were a minor component of their diets.

During fall, however, young-of-the-year pollock were extremely abundant within the Tidally Mixed Waters around the Krenitzin Islands. Tufted Puffins were commonly seen carrying small pollock back to their nesting colonies. Lanternfish (myctophids) were present in intermediate abundance during all cruises in the deep (> 1000 m) portions of the GAWs. It is uncertain if large numbers of lanternfish were ever within the foraging range of most seabirds, but they are known to be a frequent prey of Dall's



FALL WINTER SPRING

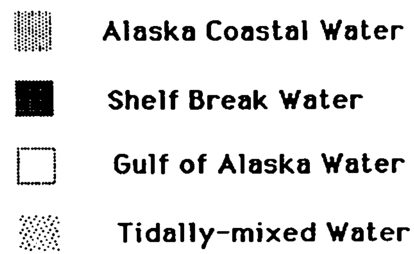


Figure 3. Distribution of major water masses during the fall, winter, and spring cruises, Unimak Pass, Alaska.

porpoises and were abundant in the same water masses during the winter and spring cruises as were the porpoises.

Invertebrates

Euphausiids and copepods, the zooplankton groups expected to dominate pelagic environments and vertebrate diets, were sampled in the water column and at the surface. Invertebrate wet-weight biomass and composition by major taxa (e.g., copepods, euphausiids) were estimated. Major findings and their implications include the following:

(1) Proportions of the total invertebrate biomass that the major zooplankton groups contributed varied seasonally. Gelatinous zooplankton (jellyfish) dominated spring catches northeast of Unimak Pass in the vicinity of the well-known "slime bank" on the North Aleutian Shelf, but were inconsequential in other seasons and places. Euphausiids formed the overwhelming majority of non-gelatinous zooplankton biomass in fall and winter, and a slight majority in spring. Copepods were scarce in fall and winter but nearly equalled the abundance of euphausiids in spring.

(2) During fall, euphausiids were virtually absent from the ACW but were present in all other water types; they peaked in abundance in the Bering Sea, especially in the SBW and GAWn (Fig. 4). During winter, euphausiid distribution changed markedly—large concentrations were found in the ACWn. By spring, abundance had dropped in most areas and the highest densities were found in the ACW and TMW.

(3) Euphasiids were the predominant zooplankton found in the samples and in the diets of marine birds.

(4) Food habits studies indicated that euphausiids found in bird stomachs from the study area were largely oceanic species; shelf species were uncommon. This finding supports other evidence that water upwelled from off the shelf dominates the Unimak Pass area.

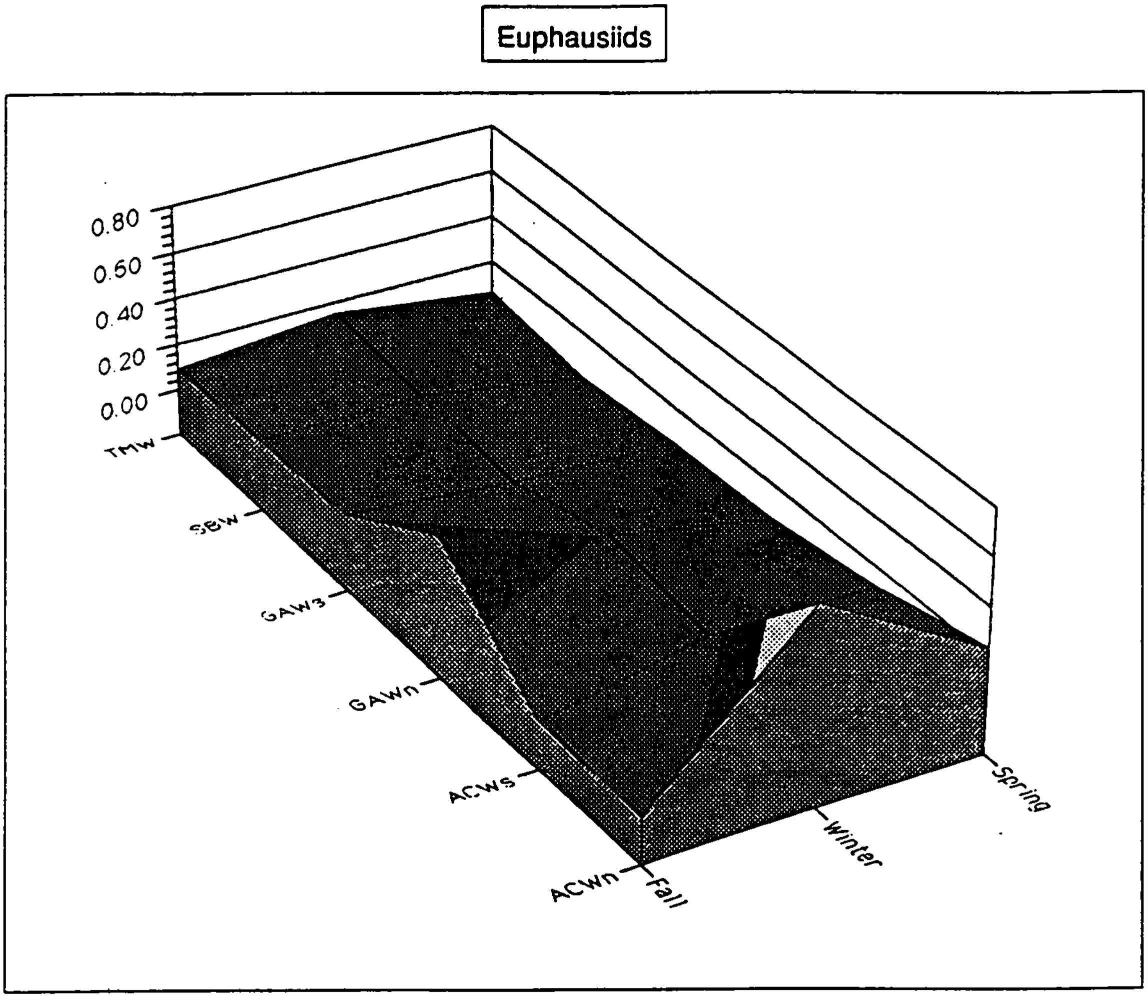


Figure 4. Density (#/km2) of euphausiids by water mass and cruise, Unimak Pass area, Alaska, 1986-87.

DISCUSSION

Water Mass Associations

Birds and mammals often exhibited striking differences in abundances among the various water masses. These distributional patterns frequently varied seasonally.

Fall

In fall, the highest densities occurred in the Shelf Break Water (SBW) because of the extreme abundance there of Short-tailed Shearwaters and Black-legged Kittiwakes. The spatial extent of this water mass was more than was observed during other seasons, occupying much of the northwest corner of the study area. Shearwaters were also abundant in the adjacent GAWn; however, Black-legged Kittiwakes were abundant only in the SBW. The abundance of these birds in the SBW and GAWn was paralleled by the highest densities of euphausiids, their principal prey, in these areas.

Birds were never abundant in the Alaska Coastal Water (ACW) in fall. Horned Puffins reached their peak abundance in the south portion of this water mass; however, they were still quite rare. These areas were also lacking in abundant prey sources for seabirds. Oceanic areas in the Gulf of Alaska likewise had very low bird and prey densities though one species, the Black-footed Albatross, was restricted to this area.

Although absolute bird densities in the TMW in fall were substantially lower than in the more structured water masses to the north, several species were largely restricted to this water mass. Most striking in this regard were Whiskered Auklet and Tufted Puffin. Cormorants, murrelets, and Common Murres also ocurred most frequently in the TMW. Some species, especially Tufted Puffins, were preying heavily on the large numbers of young pollock abundant in this area. The presence of many of these birds in the TMW is probably due to its proximity to breeding areas, because the same species nest abundantly in colonies in the Krenitzin Islands, surrounded by TMW.

In general, the ACW was little used by birds in fall. Outside of this water mass, bird use of the Bering Sea side of the chain was high relative to that of the Gulf of Alaska side. Intermediate bird densities, of a distinctive species composition, occurred in the Tidally Mixed Water.

Among the mammals, the northern fur seal (present only in fall) was most common in SBW. Dall's porpoise and minke whale were most commonly associated with GAW. Harbor seal and sea otter were found primarily in ACW and TMW, respectively.

Winter Cruise

Use of the various water masses by birds during winter differed markedly from that observed during the fall cruise. The highest densities by a large margin occurred in the ACW. Very striking was the contrast between the southern and northern components of ACW; almost all the birds were found in the latter. Crested Auklets made up the greatest proportion of birds encountered in the ACWn; however, many other species also reached their peak abundances here. Other common species in the ACWn were Northern Fulmar and Common Murre. Several species of seaducks and gulls also reached peak abundance in this area. Euphausiid prey was also markedly more abundant in the ACWn than elsewhere during the winter.

The TMW also seemed important to birds in winter. As in fall, Whiskered Auklets were still largely confined to this water mass, but even higher densities of Crested Auklets were seen using these areas. Common Murres were also numerous in this water mass, although densities were not as high as in the ACW. Although not common in the areas surveyed by the ship, most of the encounters with Emperor Geese and cormorants were in TMW.

Gulf of Alaska water had few birds in winter. The northern portion had more birds than the south; however, neither area had many. Both Tufted and Horned puffins peaked in abundance in the GAWn, but puffins were rare everywhere during the winter. Marine mammals, in particular Dall's porpoise, were most numerous in the GAWs, having a distribution similar to myctophids, a probable prey item.

The areal extent of SBW was much smaller in winter than in fall. This water mass was identified in two areas, one north of Unalaska Island and the other at the northern extreme of the study area. A more complete picture might reveal this area to be connected west of our study area. Moderate densities of birds, including many auklets (thought to be mainly Crested Auklets), were found in this water mass.

Thus the winter results showed that the Gulf of Alaska side of Unimak Pass continued to have only a few birds as in fall, and that bird use of the western segment of the Bering Sea side was greatly reduced from that of fall. Alaska Coastal Current waters north of Unimak Pass were heavily used by marine birds. Tidally Mixed Waters were of greater importance to birds during winter than during fall.

Few mammals were abundant anywhere in winter, and fur and harbor seals and several whales seen during other seasons were absent. Minke whale and Steller sea lion were most common in TMW; Dall's porpoise was most abundant in GAW. Sea otters were observed only in ACW.

Spring

Bird abundance was more equitable among water masses in spring than in fall or winter, although overall densities were relatively low. The highest bird densities occurred in the Alaska Coastal Current water (ACW). Among all the water masses, ACW continued to have the greatest abundance of euphausiids, although lower than it had in winter. The northern portion was again the most important, but the portion south of Unimak Island had more birds than were observed during any other cruise. In both ACWn and ACWs, Short-tailed Shearwaters predominated.

Gulf of Alaska Water had similar overall bird densities in northern as in southern sectors, but the species composition was different. In the south, where bird densities were highest of all cruises, Common Murres were the most frequently encountered birds. In the north, Whiskered Auklets predominated, although this species was more numerous in the Tidally Mixed Water.

As mentioned above, the TMW continued to be the major habitat for Whiskered Auklets. Although several species peaked in abundance here—i.e., murrelets, Pigeon Guillemot, and cormorants—only Whiskered Auklets occurred in appreciable abundance.

In marked contrast to the results of the fall cruise, the SBW was the least used by birds of any of the area habitats during this cruise. No species peaked in abundance in this habitat.

Several mammals reached their peak abundance in the Unimak Pass area in spring. Among these, fin whales were restricted to GAW, killer whales to TMW, and gray whales to ACW; sea otters were most abundant by far in ACW. Dall's porpoise, less abundant than in fall, was most common in GAW. Harbor seals, Steller sea lions and minke whale were absent in spring.

Geographic Areas of Importance

Birds and marine mammals are frequently opportunistic feeders. Many search for prey directly while some rely on watching for other feeding birds (e.g., Sealy 1973). Aggregations can quickly develop, but also quickly dissipate. The occurrence of these ephemeral concentrations requires that caution be made in characterizing an area as important based on aggregations of birds or mammals seen during brief visits such as our surveys. Nonetheless, we believe that some areas of concentration identified during these investigations are probably of regular importance to marine birds, either because of past evidence of concentrations in the same area (e.g., auklet concentrations observed during the North Aleutian Shelf Studies) or the apparent close associations between water masses, prey abundance, and bird/mammal presence.

The most significant bird and mammal concentration areas are as follows (see also Fig. 2):

- **Northwest of Unimak Island** within the Alaska Coastal Water. This nearshore area supported many (perhaps hundreds of thousands) Crested Auklets and Common Murres in winter.

- **Western Unimak Pass, northeast of Akun Island**. Huge concentrations of several seabirds, especially Short-tailed Shearwaters, occurred in this area during fall. Humpback whales were also observed here, but the regularity of their presence is unknown. Based on local measurements of high-salinity water in this vicinity, it appears that this is an area of upwelling.

- **Akutan Pass**. Concentrations of some marine birds occurred in Akutan Pass during all visits. During fall, Short-tailed Shearwaters were present in very large numbers in the northern portion of the pass. Whiskered Auklets were present during all cruises, augmented by large numbers of Crested Auklets during winter.

- **Derbin Strait**. Whiskered Auklets were associated with passes between the islands, although in many cases they were present offshore but opposite the passes. The major concentration areas within passes were in Akutan (including Baby) Pass and, during winter, Derbin Strait.

Vulnerability to Oil Spills

Birds

Oil spills, including the recent spill from the Exxon Valdez in Prince William Sound, have frequently resulted in high incidences of seabird deaths. Mortality is not random; the behavior of individual species, especially their mode of foraging and the degree to which they move between terrestrial and marine environments, influences their susceptibility to oiling. In general, diving birds such as loons, grebes, seaducks, and alcids are the most likely to be coated by spilled oil (Clark 1969, Vermeer 1976). Species that obtain most of their food on the wing or by wading in shallow water (i.e., tubenoses, gulls, terns, and shorebirds) are infrequently affected by oil spills (Clark 1969, Smail et al. 1972, Vermeer 1976).

Susceptibility to oiling varies among the species using Unimak Pass. Most of the major bird aggregations documented by this study, e.g., alcids and shearwaters, were of species that have a history of being susceptible to oiling. Seaducks (Oldsquaws, eiders, scoters) are also regular victims of oiling, but no major aggregations of these were identified in our study area. Storm-Petrels nest in very large numbers in the Unimak Pass area, yet they made very little use of the study area for foraging and thus would be at little risk from an oil spill should one occur in the Krenitzin Islands. The following paragraphs detail the vulnerabilities of the groups considered most at risk—the alcids and shearwaters.

The alcid species of concern with respect to oil spills in the Unimak Pass area are Common Murre, Whiskered Auklet, Crested Auklet, and Tufted Puffin. These species all occur in large numbers and frequently in large aggregations. Whiskered Auklets are of special concern because of their restricted worldwide distribution.

Murres, usually Common Murres, have topped the mortality lists of many northern oil spills (e.g., Baillie and Mead 1982, Stowe 1982, Stowe and Underwood 1984). This reflects both their widespread distribution and abundance and their susceptibility to oil. In the Unimak Pass area they are present primarily as winter visitors; there are no large breeding colonies in the area. Concentrations are most regular in the eastern part of Unimak Pass itself, especially off Cape Sarichef, and very large numbers of birds were encountered in Avatanak Strait during our winter cruise. Many swimming and foraging murres have been encountered at the south end of Akutan Pass.

Any extensive spill near land would almost certainly come in contact with murres, but the population-level consequences of heavy mortality on murres in this area are not obvious. The origins of these birds are unknown, but the major nearby colonies are Cape Peirce/Newenham to the north and the Semedi Islands to the east. If murres are essentially in mixed flocks while at sea, then oiling in a local area would presumably not be a major blow to any particular population. A major die-off of an estimated 100,000 Common Murres occurred in this area in 1970 (Unimak Island and Alaska Peninsula) (Bailey and Davenport 1972). This phenomena was believed to be weather related. No population decreases at any colonies have been linked to this event, although few studies were in existence that could have documented declines in any case.

Auklets have not figured prominently in any major oil spill, probably by virtue of their restricted distribution. Most auklets are found in the Bering Sea where no oil spills have occurred. They are probably susceptible to oiling, as most alcids have proved to be; although Vermeer and Vermeer (1975) suggest that these smaller alcids are less vulnerable to oil pollution because of their more aerial habits. In the Unimak Pass area, both Whiskered and

Crested auklets are frequently found in dense aggregations; thus if contact were made with an oil spill large numbers of birds would be involved.

Whiskered Auklets are confined primarily to the Aleutian Island chain, but relatively little is known about their breeding areas and population size. Attempts to census breeding birds on cliffs of the Krenitzin Islands (largely by call-counts) by us and others (Nysewander et al. 1982) have failed to locate large numbers. Considerable numbers of Whiskered Auklets were found during shipboard counts during all of our cruises; whether many of these leave during the summer or whether they are breeding birds is unknown. The most recent population estimate of Whiskered Auklets is "at least" 25,000 birds (Byrd and Gibson 1980). Our absolute counts in the Krenitzin Islands approached this value (e.g., 15,000 on transects during the fall cruise); hence the Unimak study area may support a substantial portion of the known Whiskered Auklets. The major concentration areas for Whiskered Auklets in our area of interest are Akutan Pass and Derbin Strait but aggregations can be found off or in almost any pass in the area. Given that an unknown but certainly high proportion of the world's Whiskered Auklets occur in the Unimak Pass area, that they are probably quite susceptible to oil, and that they occur in areas of high currents where movements of oil would be uncontrollable, this species is one of the most important with respect to potential impacts from oil.

Crested Auklets occur in the study area in much larger numbers than Whiskered Auklets. No breeding areas are known near the study area and the auklets appear to be present only during the nonbreeding season. The eastern Bering Sea (encompassing most of the worldwide distribution of this species) supports some 2 million Crested Auklets (Sowls et al. 1978). The numbers in the Unimak Pass study area in winter appear to be on the order of 200,000 to 400,000, or 10-20% of the Bering Sea population. These auklets presumably come from the major Bering Sea colonies; i.e., St. Lawrence, St. Matthew, or the Pribilof Islands. In the Unimak Pass area these birds are very concentrated; aggregations are found in Akutan Pass (especially near the Baby Islands) and north of Unimak Island. Like Whiskered Auklets, this species appears to be one of greatest concern with respect to the potential damage that an oil spill in this area could inflict. Crested Auklets occur in very large numbers in the area, a large proportion of the world's population occurs in the area, they appear to be susceptable to contact with oil, and they occur in areas of considerable currents.

Tufted Puffins differ from other alcids in the area in that they would be most susceptible to oil spills during the breeding season, which extends into October or later. The Krenitzin Islands have some of Alaska's largest colonies of Tufted Puffins, which use nearby waters intensively. After nesting, these puffins move from land into the offshore areas of the North Pacific, and are probably not concentrated such that an individual spill would be a particular threat to them.

Shearwaters occur in very large numbers in the study area during fall. They also occur in spring, although this was not documented during the present study because their migration occurred after our cruise. Large numbers fly through the Unimak Pass area in immense flocks; however, birds in flight are not necessarily at risk from oil spills. In the Unimak Pass area (including Akutan Pass) the fall aggregations of shearwaters involve birds foraging and resting on the water. These concentrations represent marine staging prior to fall migration, and are probably vulnerable to an oil spill.

Mammals

The mammals that are most sensitive to contact with oil are the most vulnerable to impact. Species that are insulated largely with fur (fur seal, sea otter) respond more adversely to oil spills than do the other species, as illustrated by the large numbers of sea otters killed by the Exxon Valdez oil spill in Prince William Sound, Alaska, in 1989. The vulnerabilities of mammals in Unimak Pass depend also on the proportions of regional populations that use the Unimak Pass area and the tendency for the animals to congregate in areas where OCS activities might occur.

The northern fur seal is judged to be highly vulnerable. Large percentages of the total population of fur seals reportedly congregate in the Unimak Pass area in spring and fall during migration passage (Kenyon and Wilke 1953, Braham et. al. 1982) (though we saw none in spring), and an oil spill in the pass at peak migration could oil a relatively large number. Further, the seals spend much of their time at the sea surface where they would come into direct contact with an oil slick.

The sea otter is obviously sensitive to being oiled as indicated by the Exxon Valdez experience. However, the proportion of the Aleutian Islands-Alaska Peninsula population that occupies the Unimak Pass area is small, indicating a regional population that is relatively invulnerable should an oil spill be restricted to the study area.

The Steller sea lion population is also relatively vulnerable because a moderately large proportion of the population hauls out and pups in the Unimak Pass area. Further, the sea lion population is currently declining for unknown reasons; possibly the individuals are responding to some environmental stress. They might thus be more sensitive than usual to additional stress imposed by OCS activities.

The majority of the 17,000 eastern Pacific gray whales move through Unimak Pass in spring and fall; the population is thus relatively exposed to

OCS activities occurring in Unimak Pass during these times. However, most information suggests that they would be far less sensitive to oil than the above three species.

The remainder of the mammals using the Unimak Pass area would probably be relatively secure as populations from appreciable impact caused by OCS development. Most appear to be not particularly sensitive to oil, and at any rate most are sufficiently dispersed that localized OCS activities would affect only small proportions of the populations.

Geographic Regions

A detailed assessment of the relative vulnerabilities among geographic areas awaits the analysis of potential spill sites and the results of oil spill trajectory models. Some preliminary comments, with respect to the concentration areas identified in this report, can be made. All of the concentration areas occurred near land but well outside of the intertidal zone. Several of the concentrations were within or near the Krenitzin Islands, often within passes. These areas probably would not be subject to tanker traffic, and any oil introduced would probably not be resident long due to the extensive flushing in these areas. However, containment attempts to protect concentration areas would probably be impossible due to the strong currents.

The ACW appears to retain its integrity as it follows the coastline of the Alaska Peninsula and Unimak Island. This suggests that a spill in this water mass may not affect birds to the west, but that a spill on the south side could be a threat to murres and auklets north of Unimak Island. We have no direct information on currents but the nutrient data from our studies suggest that north of the Krenitzin Islands there may be an eastward flow parallel to the Aleutian Chain and the Alaska Peninsula. If this is indeed the case, a spill on the Bering Sea side west of Unimak Pass could affect concentration areas east of the spill location on the north side of Unimak Pass. Current action would probably result in some effects in all the passes and straits of the Krenitzins as well.

If oil tanker traffic through Unimak Pass constituted the main threat of an oil spill, the prevailing northeastward transport in the Bering Sea and the transport characteristics of the Alaska Coastal Current suggest that the marine bird concentration area most at risk would be the area north of Unimak Island. The marine birds predominating in this area are Crested Auklets and Common Murres. Relative to other parts of our study area it is also important for seaducks, although the numbers of ducks here are small relative to those in areas farther east (e.g., Izembek Lagoon). This area is also of importance to marine mammals—gray whale migration is confined to the ACW in this area and Steller sea lions haul out on Unimak Island near Cape Mordvinof.

ACKNOWLEDGEMENTS

For their reviews of this section I thank Robert Dillinger and Jean Erwin.

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Chapter 10

APPENDICES

This chapter presents detailed data on temperature, salinity, and biological samples taken in the Unimak Pass area during the course of this study. Data are given by sampling station and season; maps showing place names and station locations (Appendix E) provide a visual reference for spatial orientation. Appendix sections are as follows:

APPENDIX A

Temperature and salinity sections based on CTD casts along transects in the Unimak Pass area, Alaska, in fall 1986 and winter and spring 1987. The transect for each section intercepted the stations indicated. Refer to station numbers in Appendix E (Figs 2-4) to determine the locations of transects.

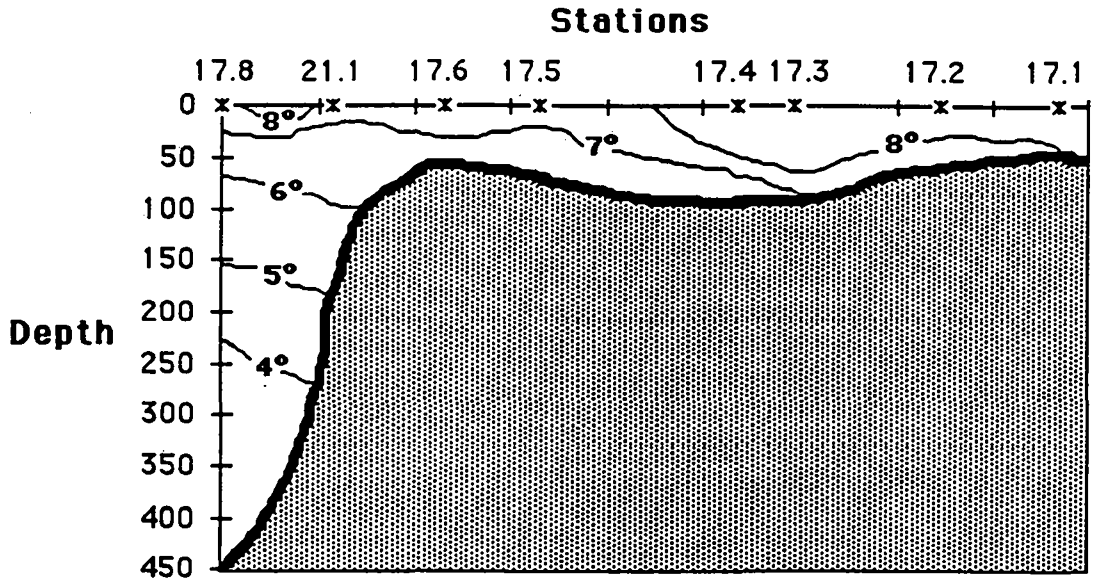


Fig. A-1. Horizontal temperature section from southwest (left) to northeast (right) on the north Aleutian shelf during fall. Transect was nearshore off Unimak, Akun, and Akutan islands. Depth is in meters.

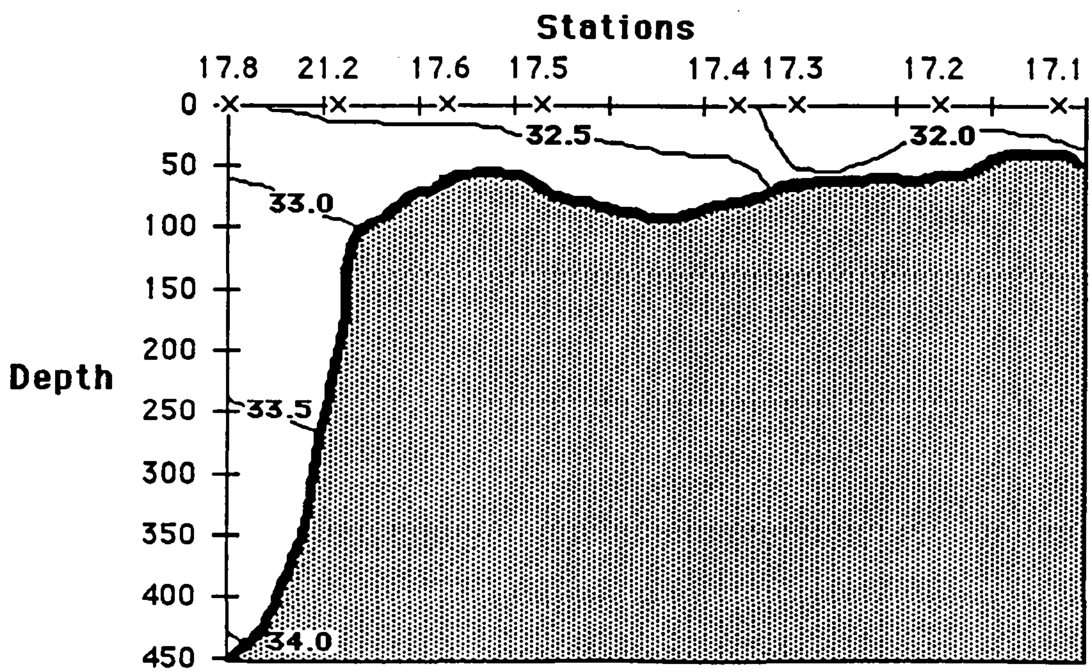


Fig. A-2. Horizontal salinity section from southwest (left) to northeast (right) on the north Aleutian shelf during fall. Transect was nearshore off Unimak, Akun, and Akutan islands. Depth is in meters.

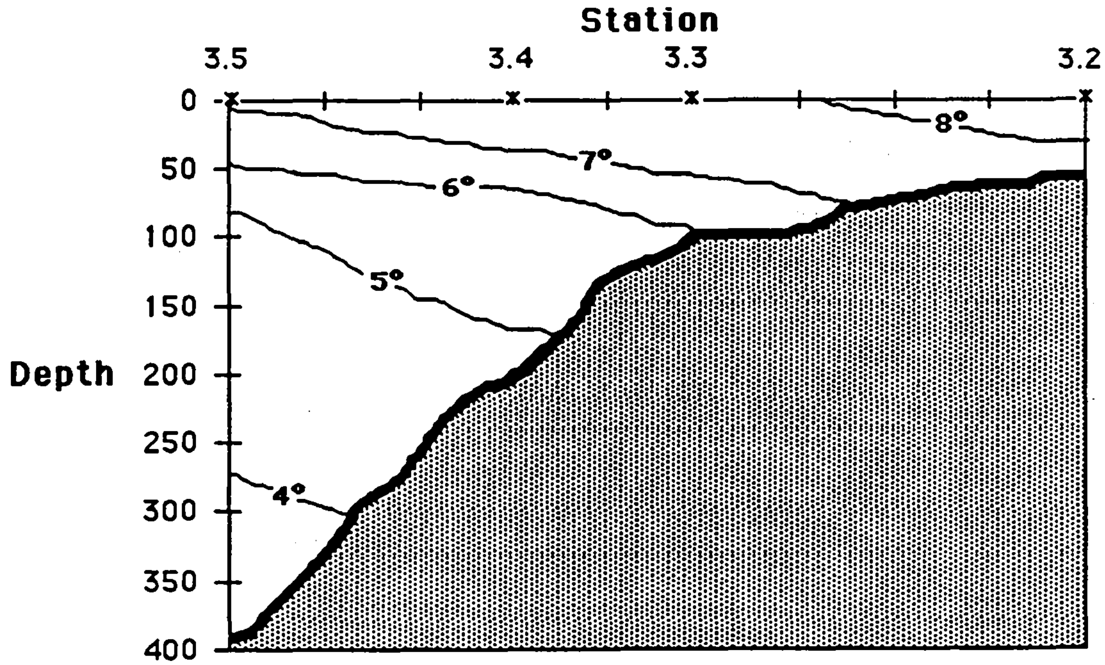


Fig. A-3. Horizontal temperature section from southwest (left) to northeast (right) on the north Aleutian shelf during fall. Depth is in meters.

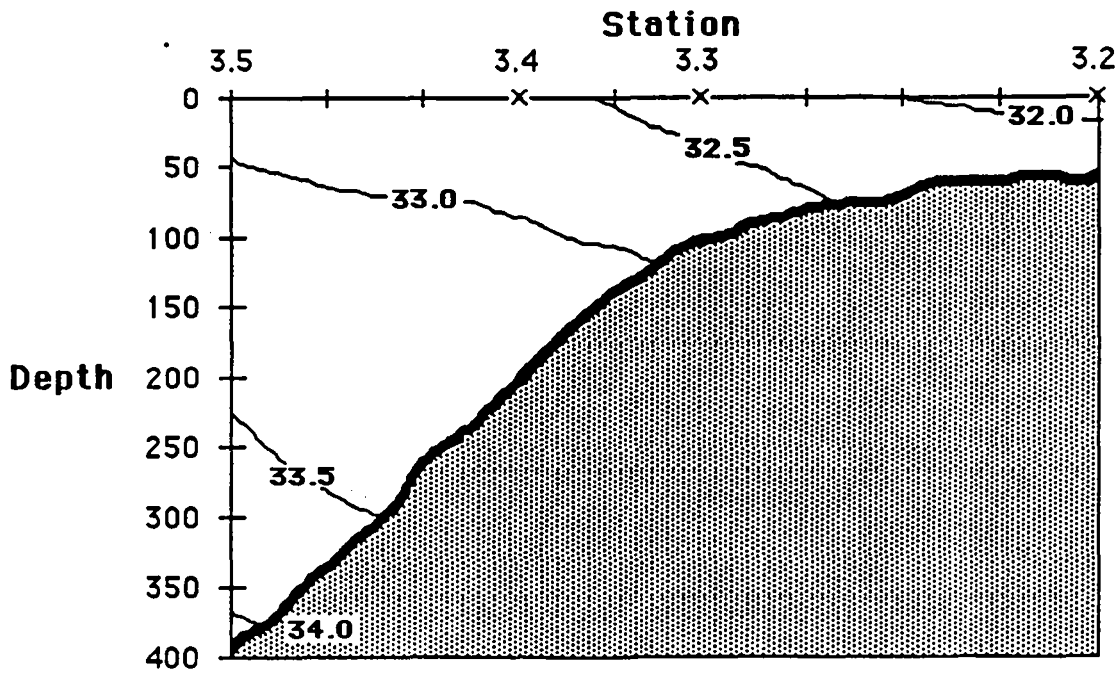


Fig. A-4. Horizontal salinity section from southwest (left) to northeast (right) on the north Aleutian shelf during fall. Depth is in meters.

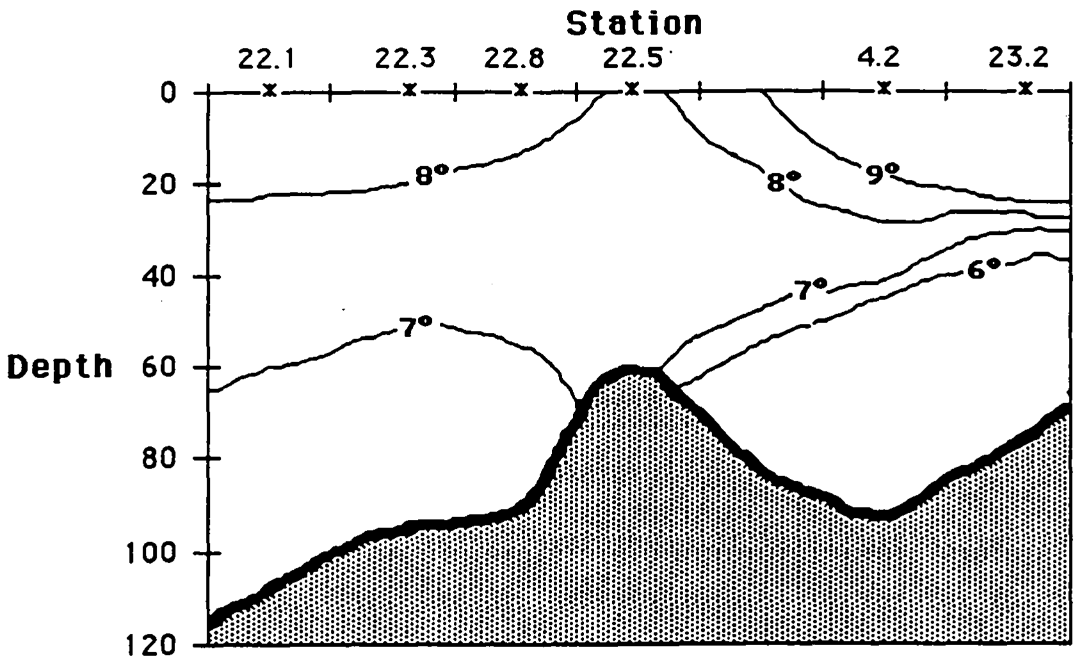


Fig. A-5. Horizontal temperature section from southwest (left) to northeast (right) on the south Aleutian shelf during fall. Transect was nearshore off Unalaska, Tigalda, and Unimak islands. Depth is in meters.

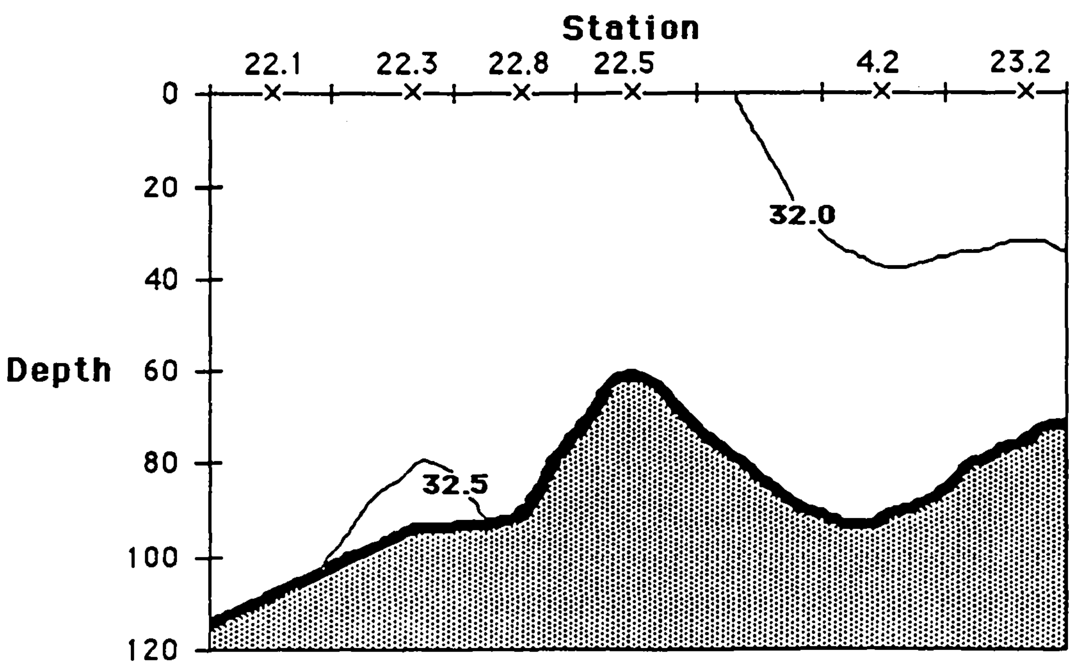


Fig. A-6. Horizontal salinity section from southwest (left) to northeast (right) on the south Aleutian shelf during fall. Depth is in meters.

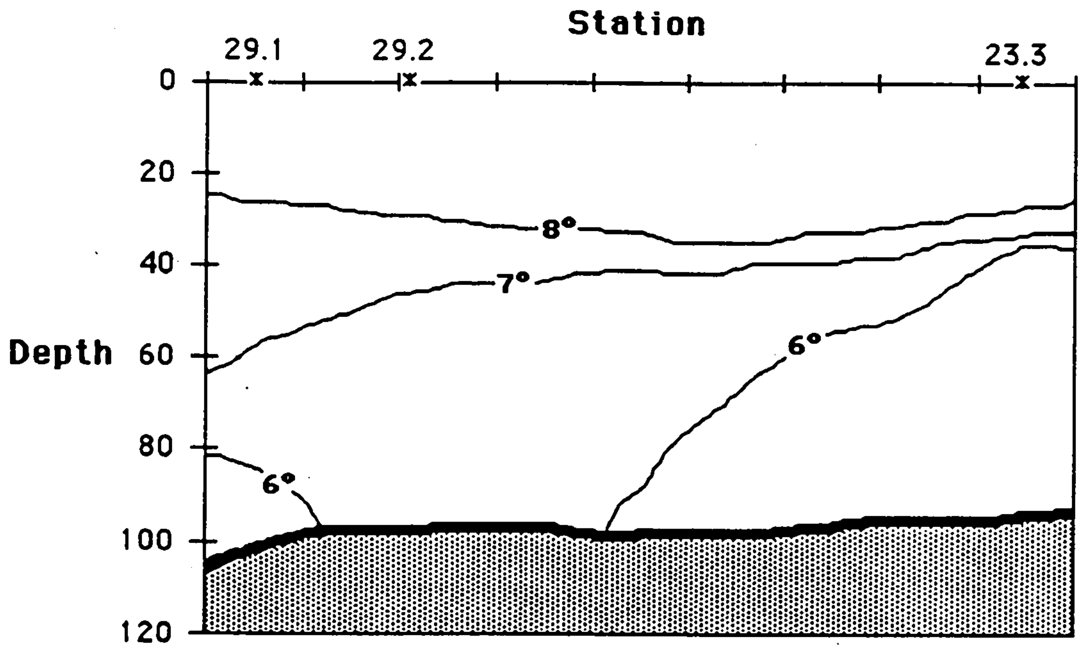


Fig. A-7. Horizontal temperature section from southwest (left) to northeast (right) on the south Aleutian shelf during fall. Transect was offshore of Unalaska, Tigalda, and Unimak islands. Depth is in meters.

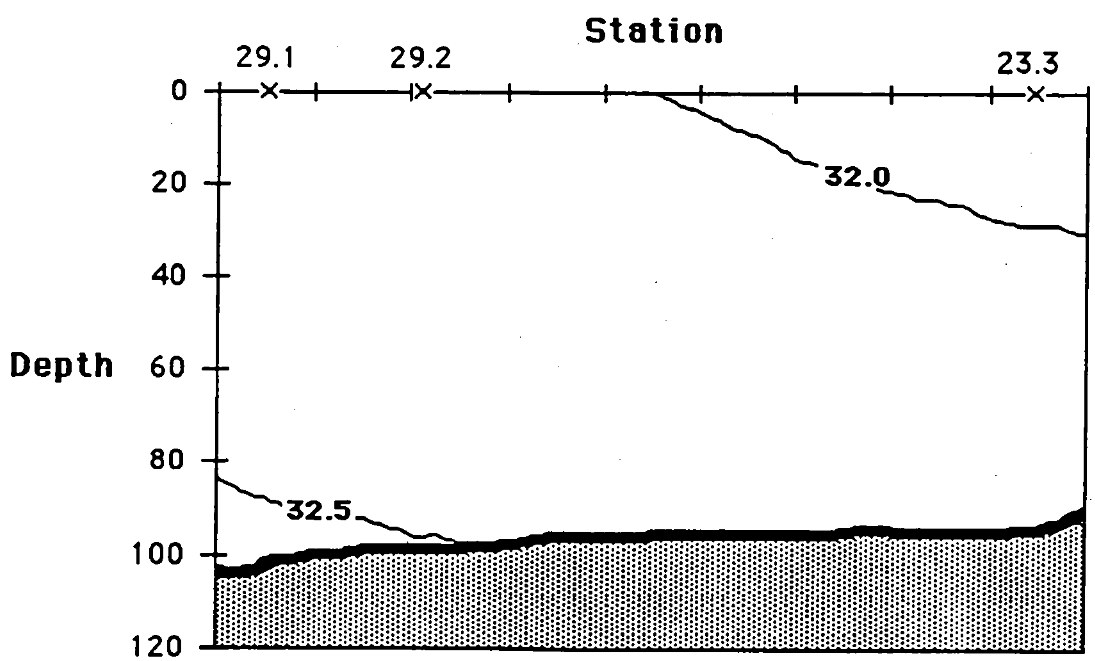


Fig. A-8. Horizontal salinity section from southwest (left) to northeast (right) on the south Aleutian shelf during fall. Depth is in meters.

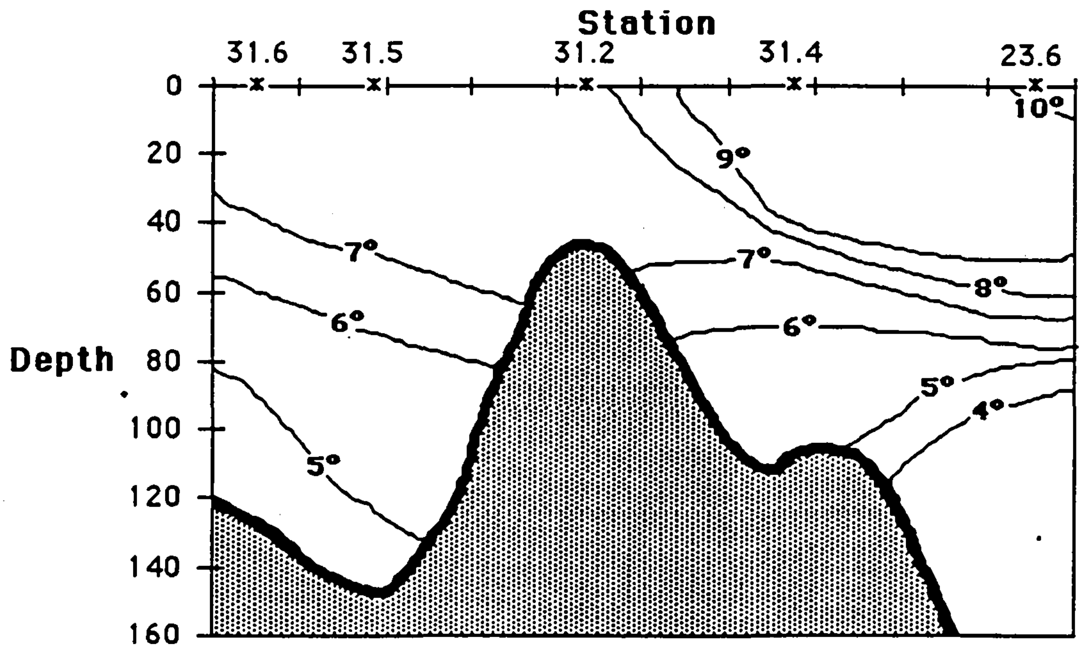


Fig. A-9. Horizontal temperature section from north (left) to south (right) through Unimak Pass during fall. Depth is in meters.

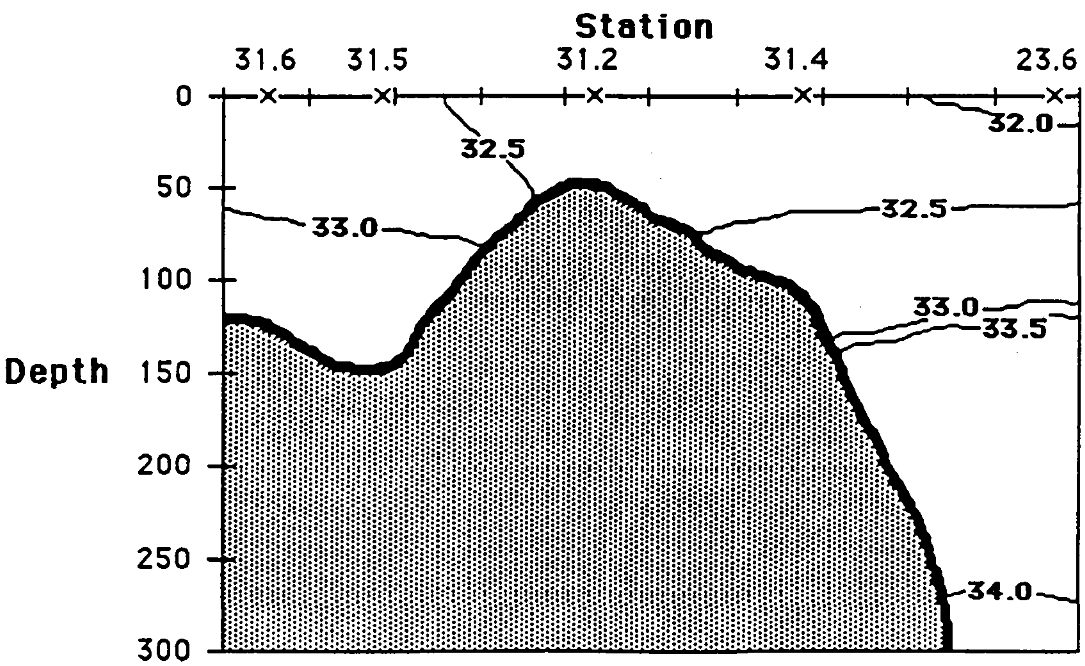


Fig. A-10. Horizontal salinity section from north (left) to south (right) through Unimak Pass during fall. Depth is in meters.

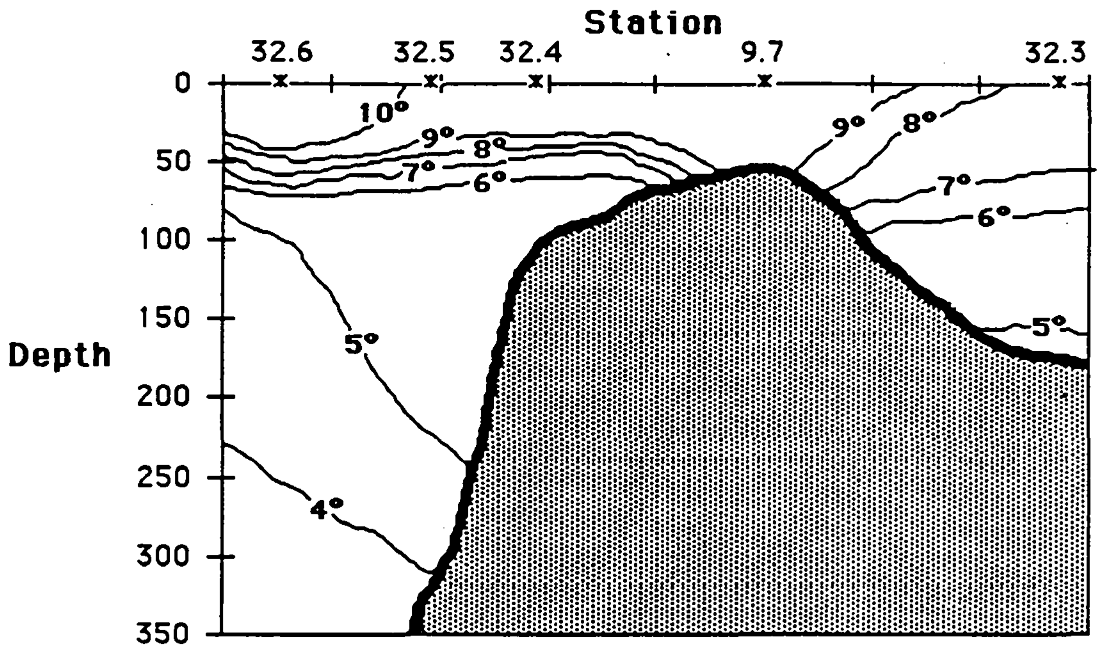


Fig. A-11. Horizontal temperature section from north (left) to south (right) through Ugamak Strait during fall. Depth is in meters.

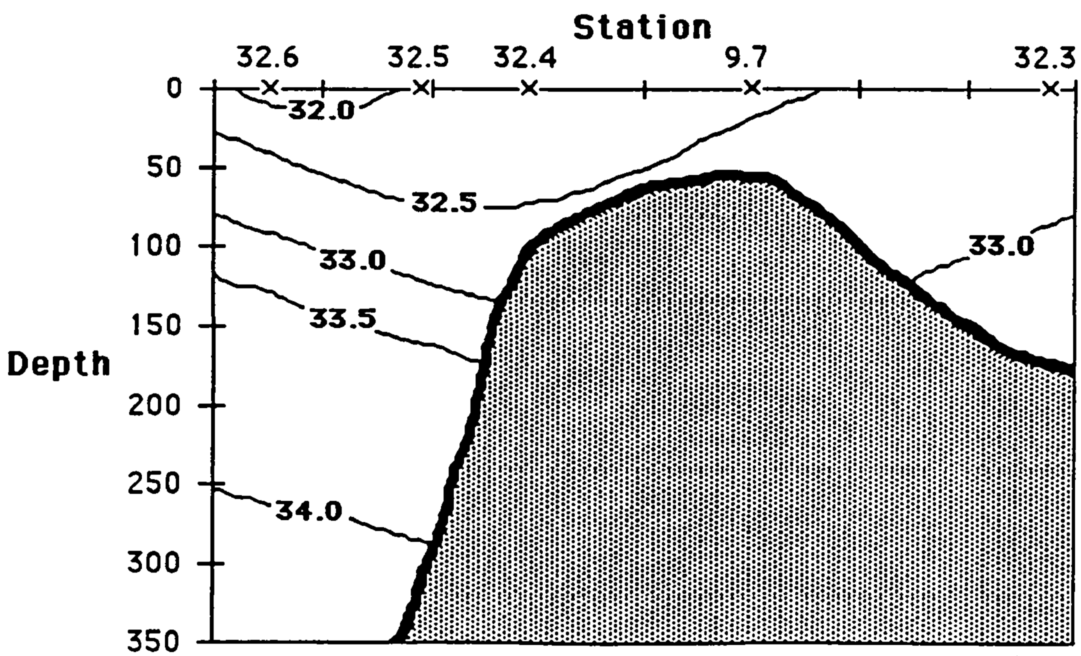


Fig. A-12. Horizontal salinity section from north (left) to south (right) through Ugamak Strait during fall. Depth is in meters.

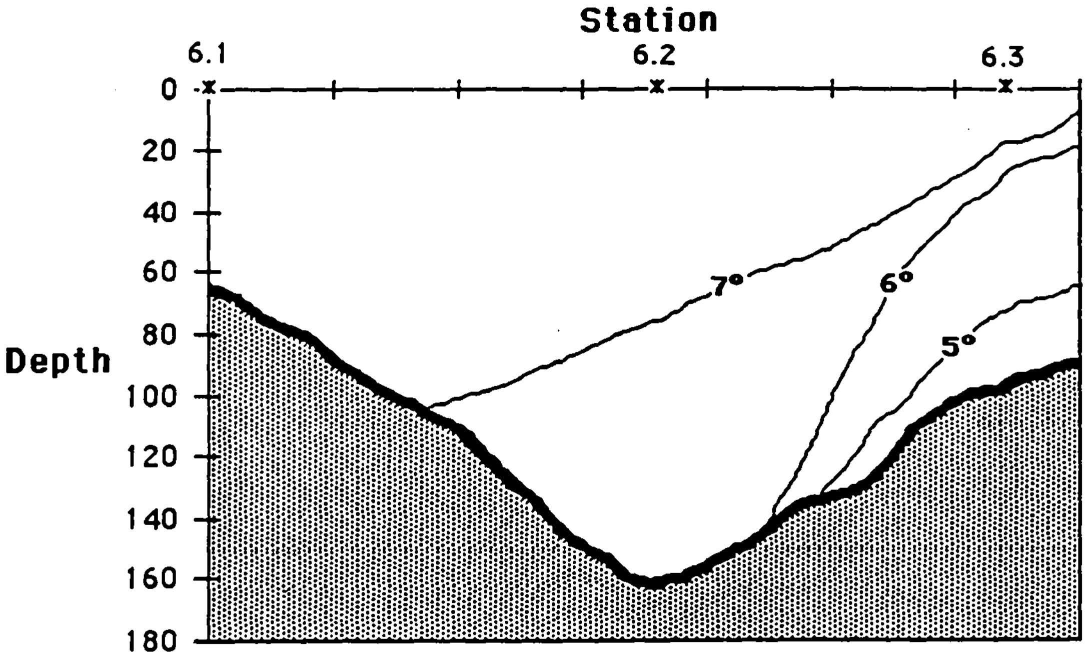


Fig. A-13. Horizontal temperature section from south (left) to north (right) on the west side of Unimak Pass north of Akun Island during fall. Depth is in m.

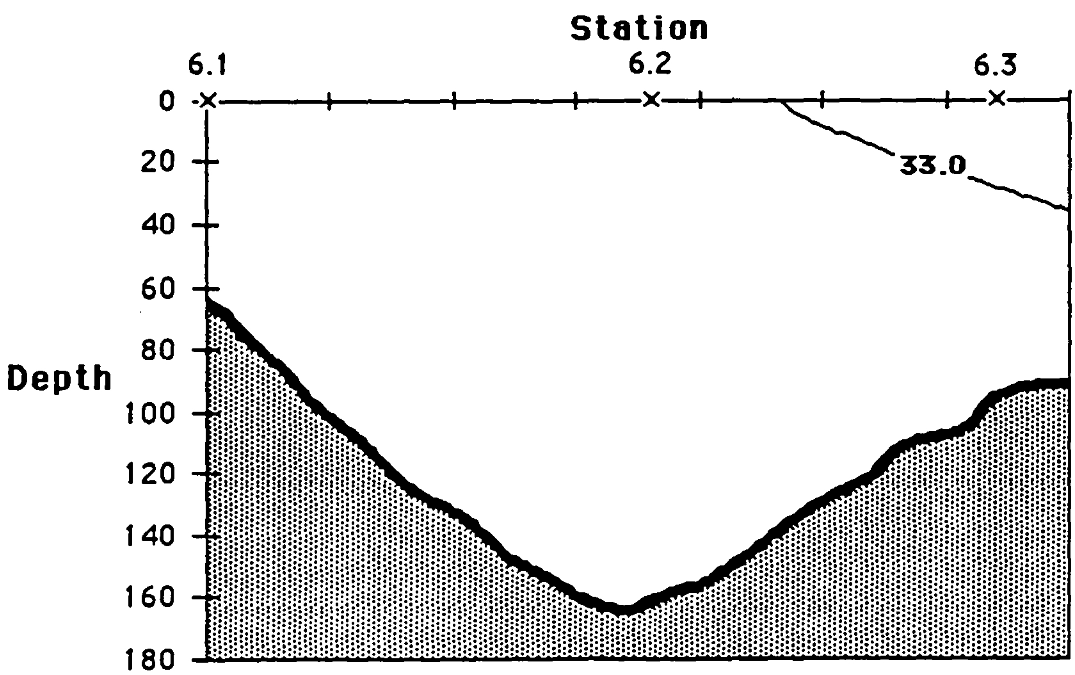


Fig. A-14. Horizontal salinity section from south (left) to north (right) on the west side of Unimak Pass north of Akun Island during fall.

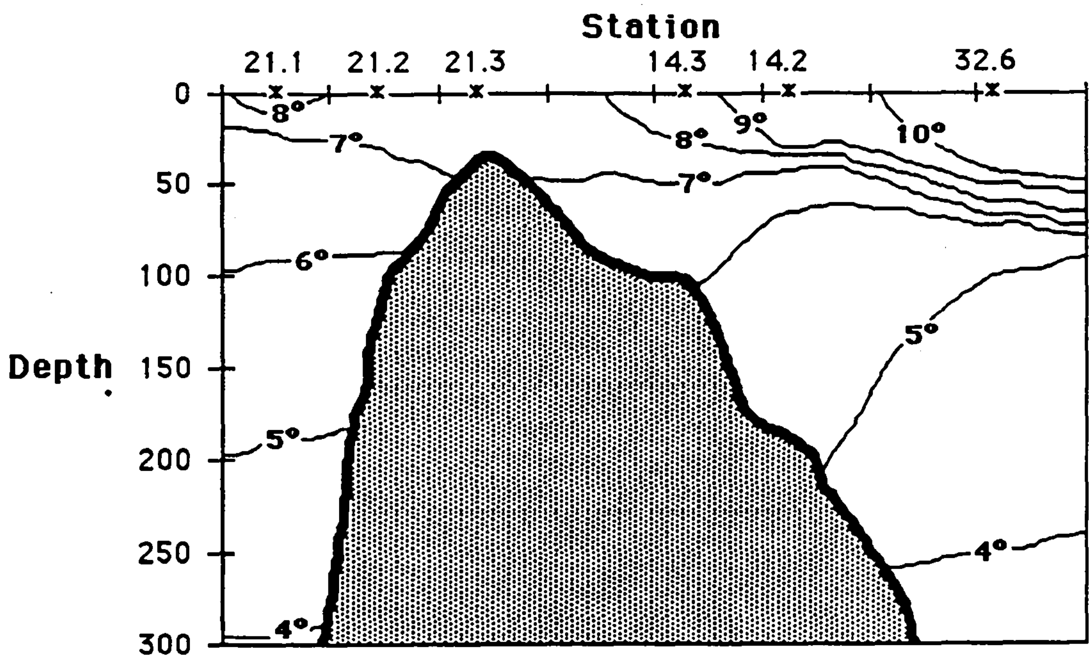


Fig. A-15. Horizontal temperature section from north (left) to south (right) through Akutan Pass during fall. Depth is in meters.

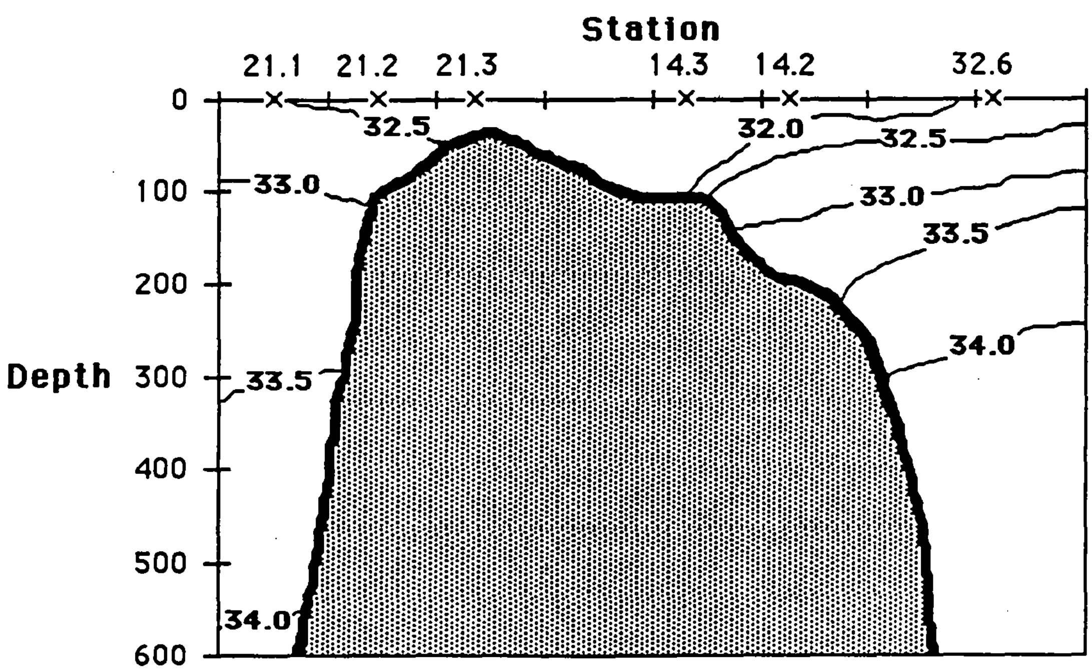


Fig. A-16. Horizontal salinity section from north (left) to south (right) through Akutan Pass during fall. Depth is in meters.

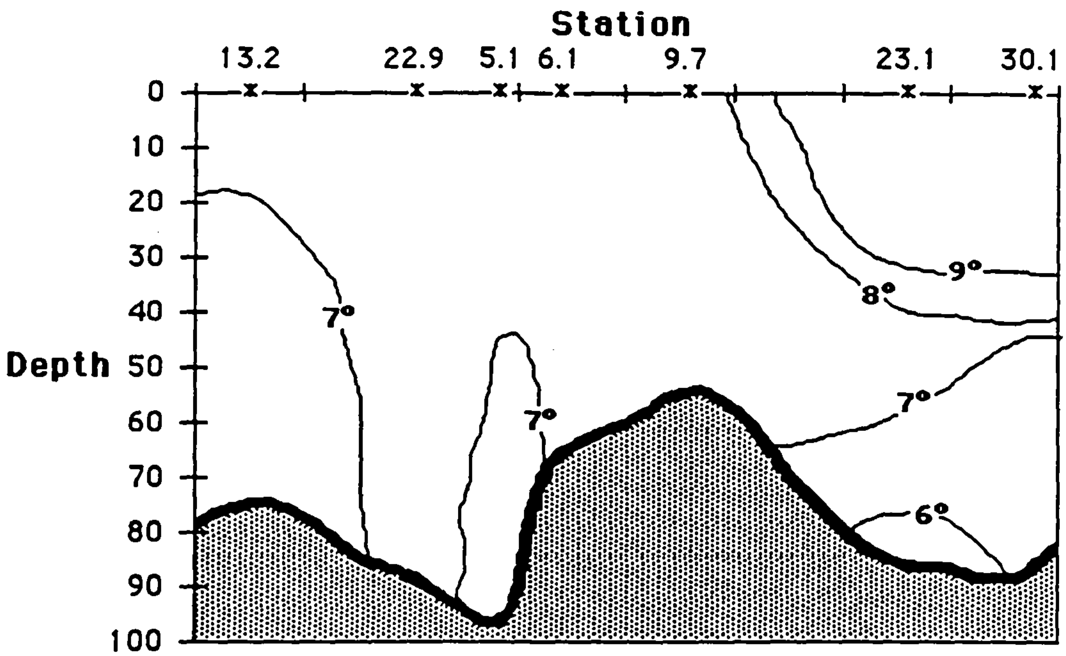


Fig. A-17. Horizontal temperature section from west (left) to east (right) through the eastern Aleutian Islands during fall.

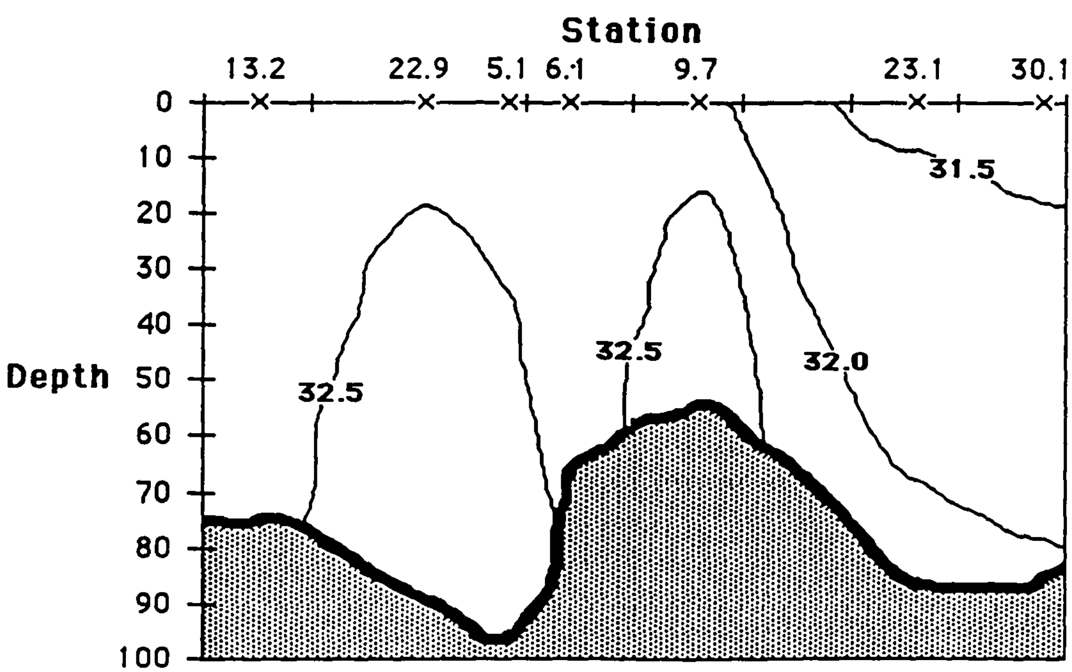


Fig. A-18. Horizontal salinity section from west (left) to east (right) through the eastern Aleutian Islands during fall.

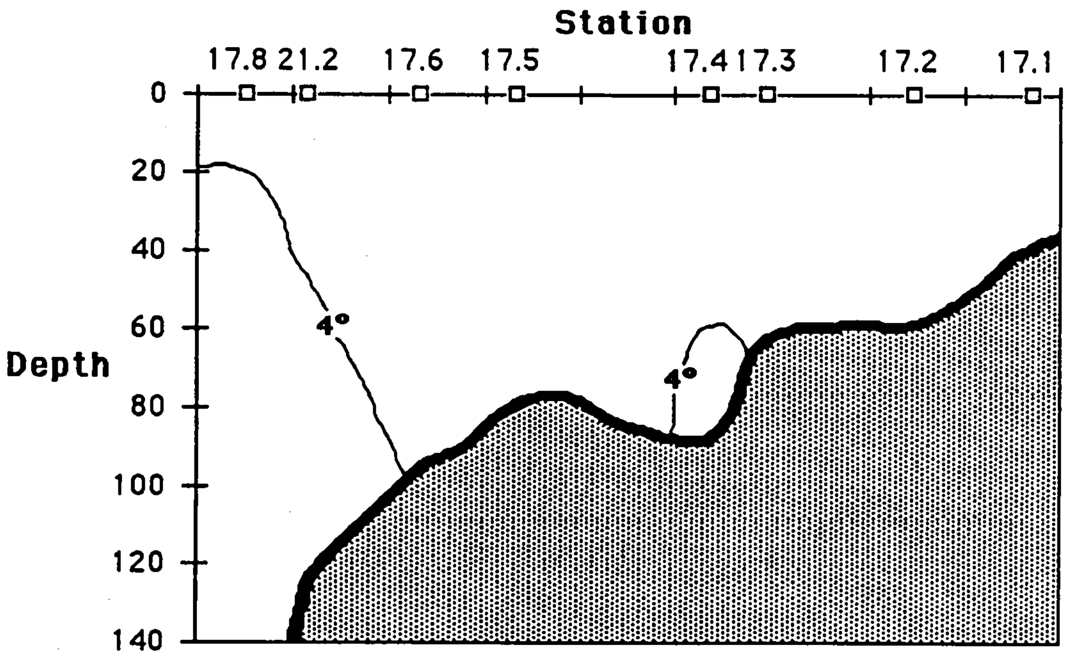


Fig. A-19. Horizontal temperature section from southwest (left) to northeast (right) on the north Aleutian shelf during winter. Transect was nearshore off Unimak, Akun, and Akutan islands. Depth is in meters.

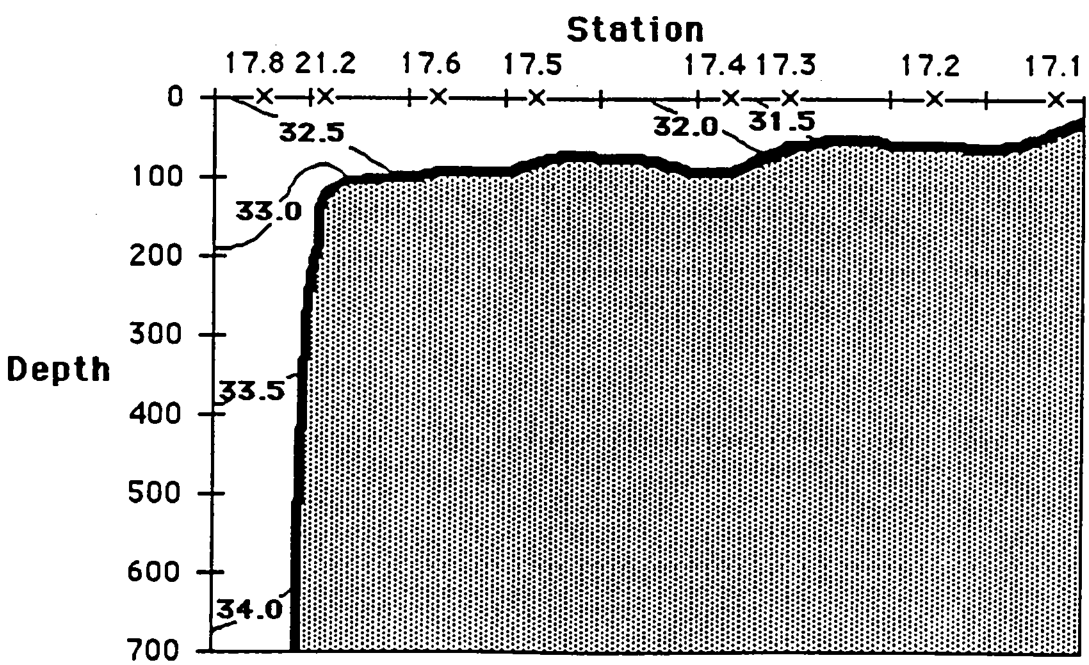


Fig. A-20. Horizontal salinity section from southwest (left) to northeast (right) on the north Aleutian shelf during winter.

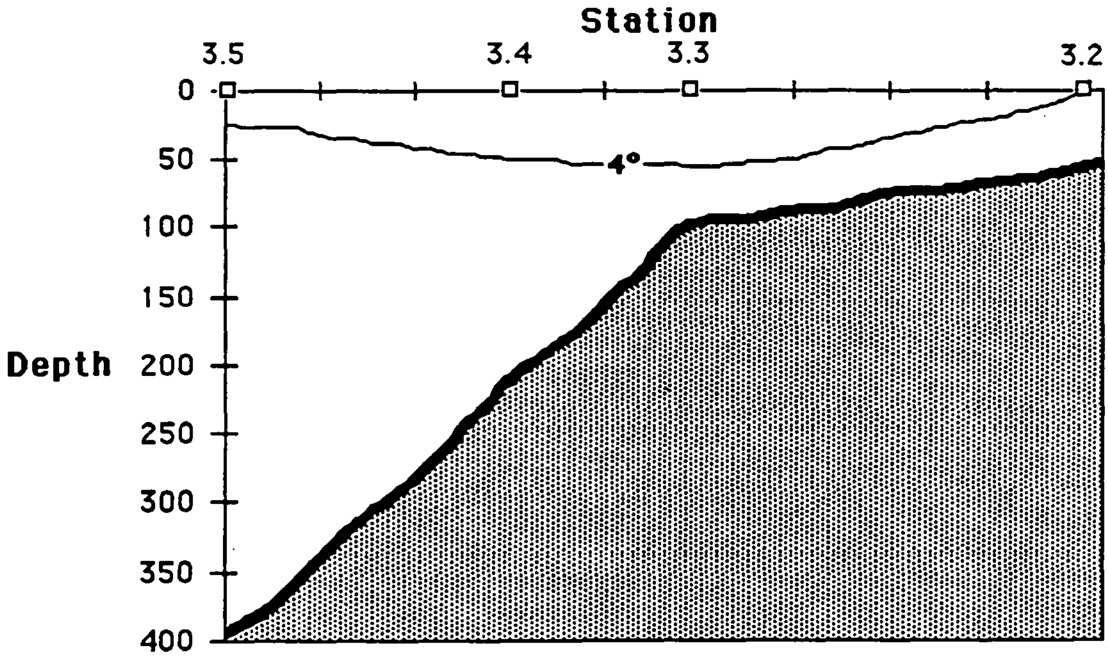


Fig. A-21. Horizontal temperature section from southwest (left) to northeast (right) on the north Aleutian shelf during winter. Depth is in meters.

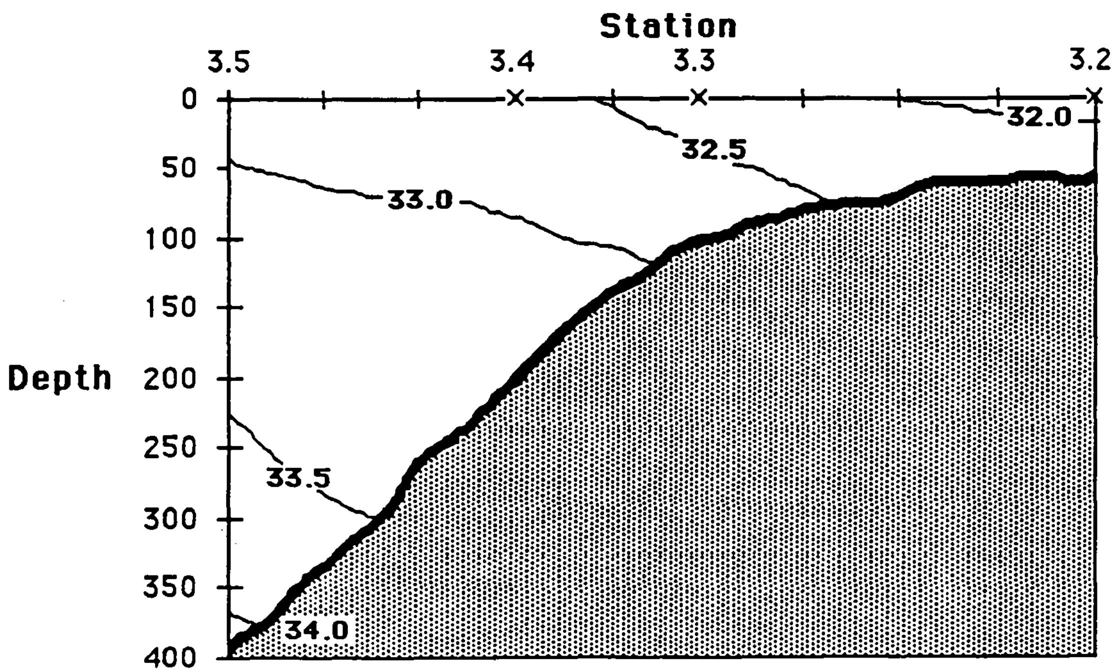


Fig. A-22. Horizontal salinity section from southwest (left)to northeast (right) on the north Aleutian shelf during winter. Depth is in meters.

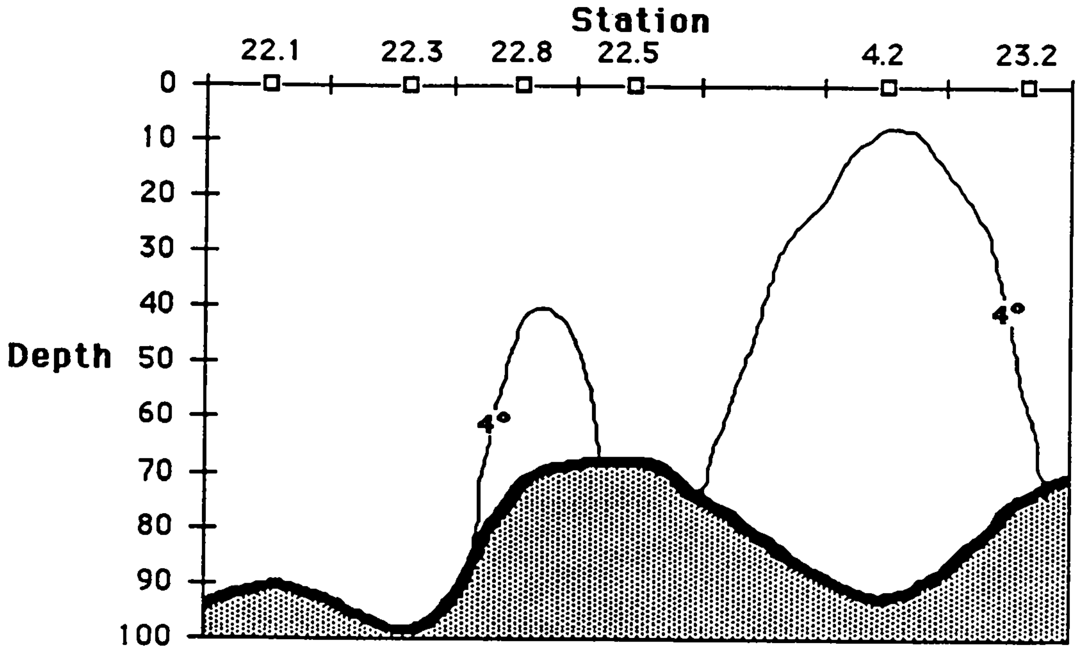


Fig. A-23. Horizontal temperature section from southwest (left) to northeast (right) on the south Aleutian shelf during winter. Depth is in meters.

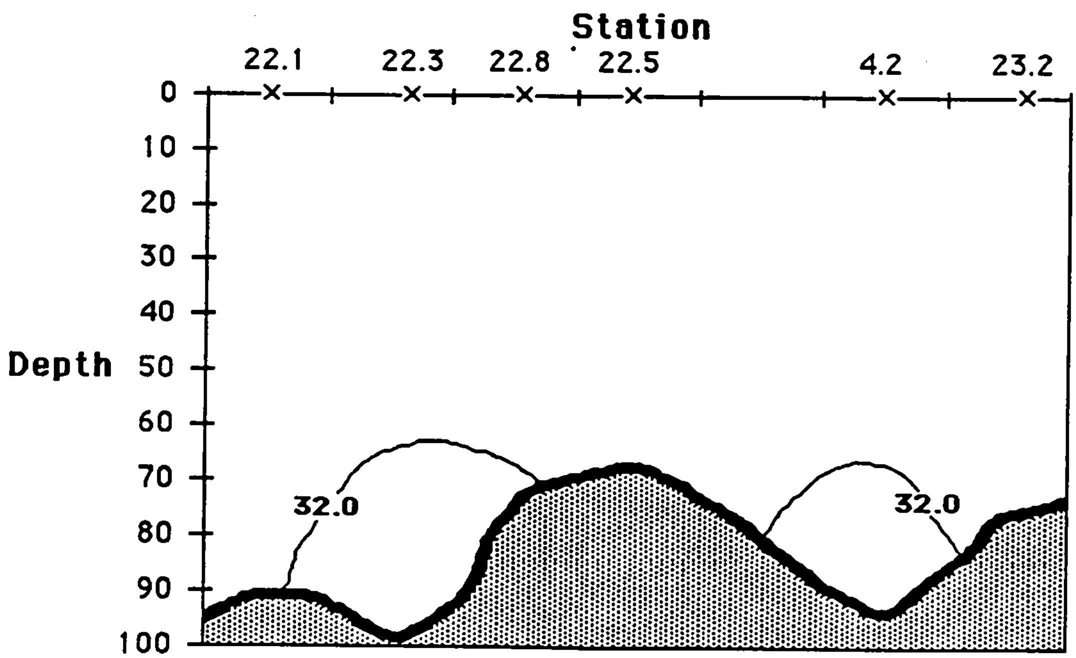


Fig. A-24. Horizontal salinity section from southwest (left) to northeast (right) on the south Aleutian shelf during winter. Depth is in meters.

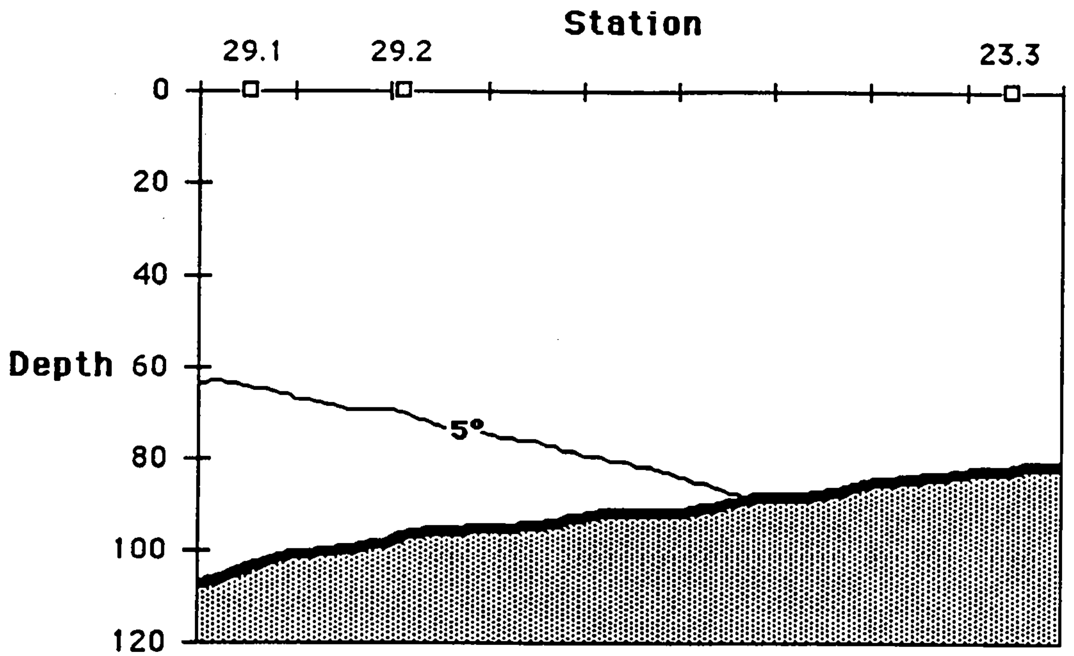


Fig. A-25. Horizontal temperature section from southwest (left) to northeast (right) on the south Aleutian shelf during winter. Transect was offshore of Unalaska, Tigalda, and Unimak islands. Depth is in meters.

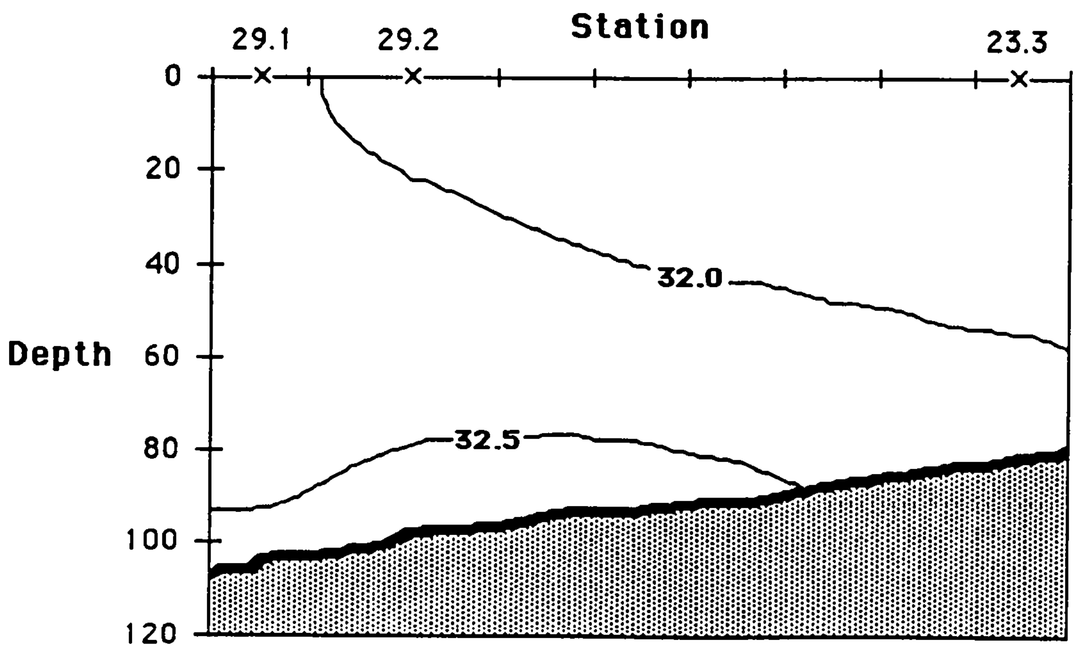


Fig. A-26. Horizontal salinity section from southwest (left)to northeast (right) on the south Aleutian shelf during winter. Depth is in meters.

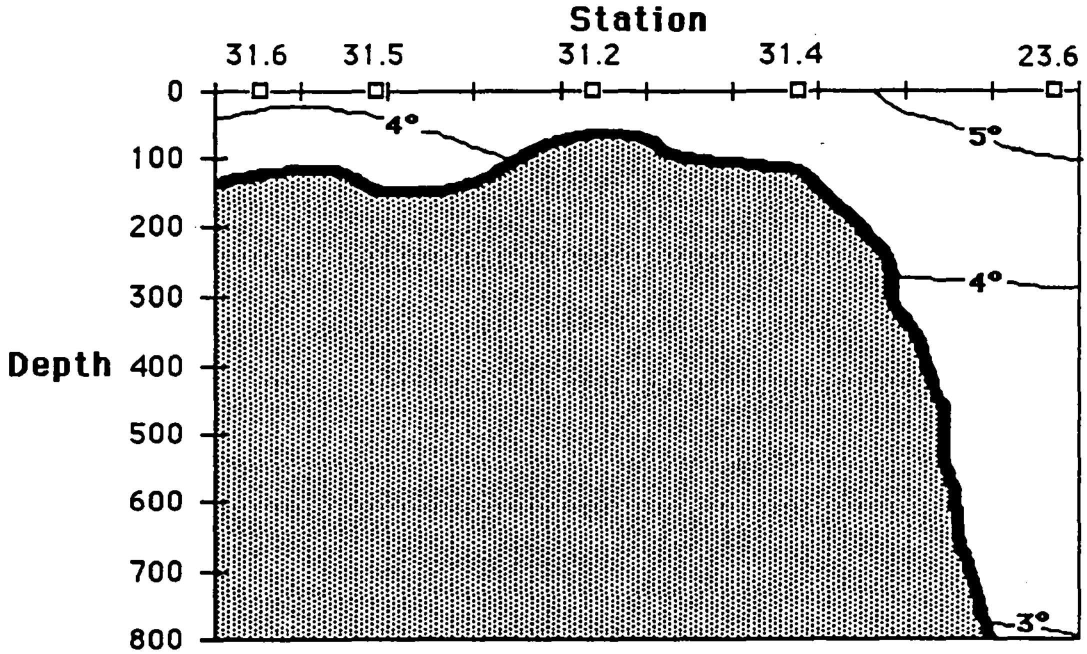


Fig. A-27. Horizontal temperature section from north (left) to south (right) through Unimak Pass during winter. Depth is in meters.

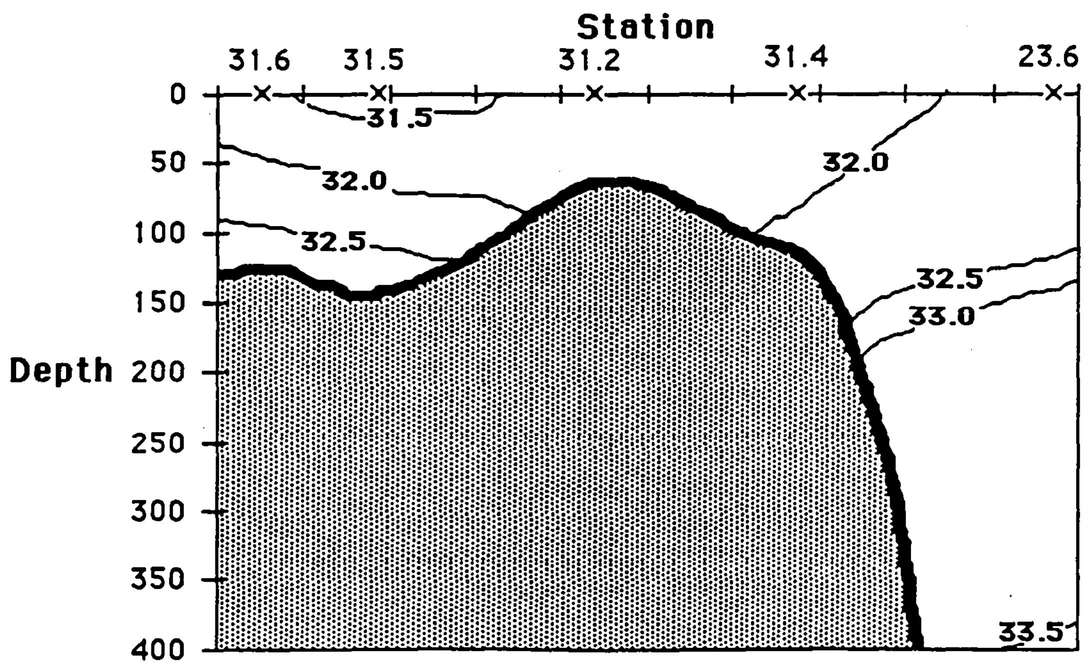


Fig. A-28. Horizontal salinity section from north (left) to south (right) through Unimak Pass during winter. Depth is in meters.

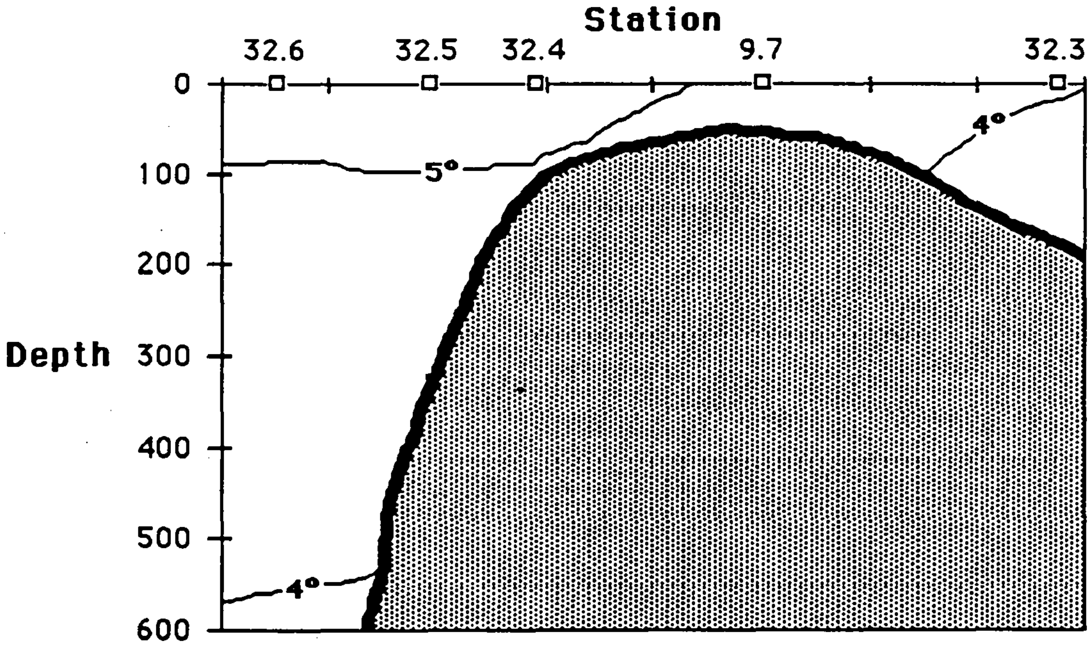


Fig. A-29. Horizontal temperature section from north (left) to south (right) through Ugamak Strait during winter. Depth is in meters.

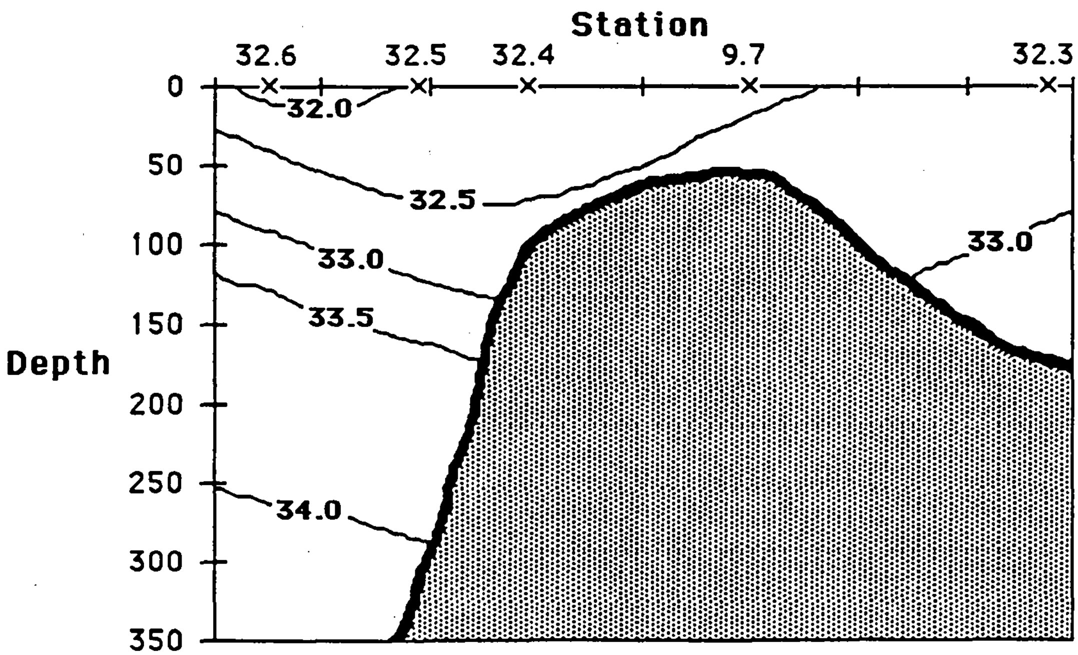


Fig. A-30. Horizontal salinity section from north (left) to south (right) through Ugamak Strait during winter. Depth is in meters.

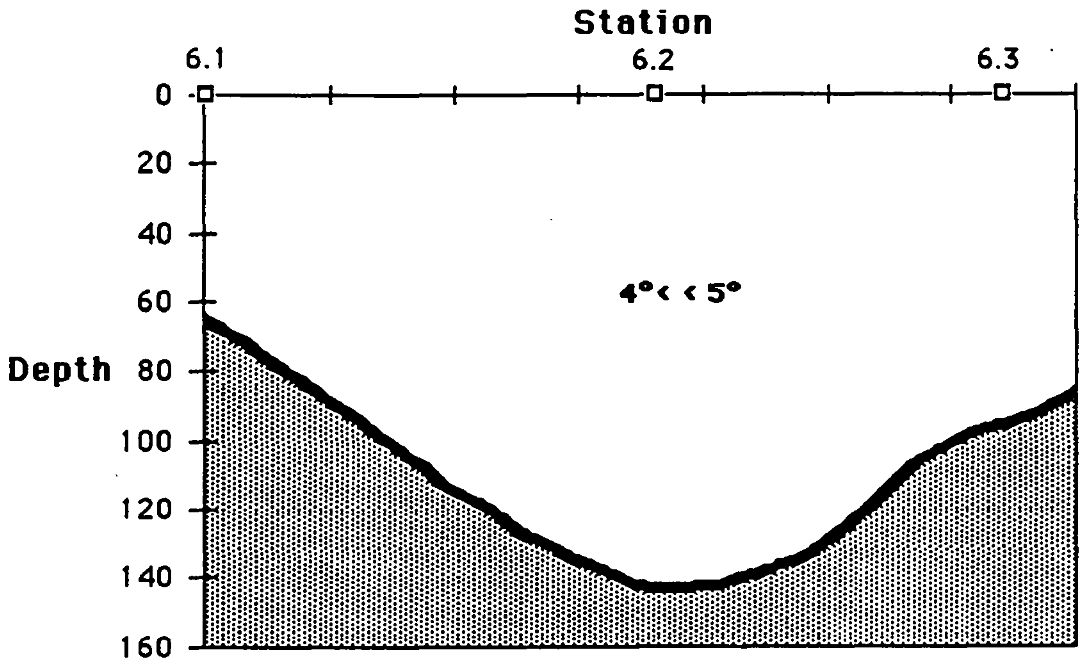


Fig. A-31. Horizontal temperature section from south (left) to north (right) on the west side of Unimak Pass north of Akun Island during winter. Depth is in meters.

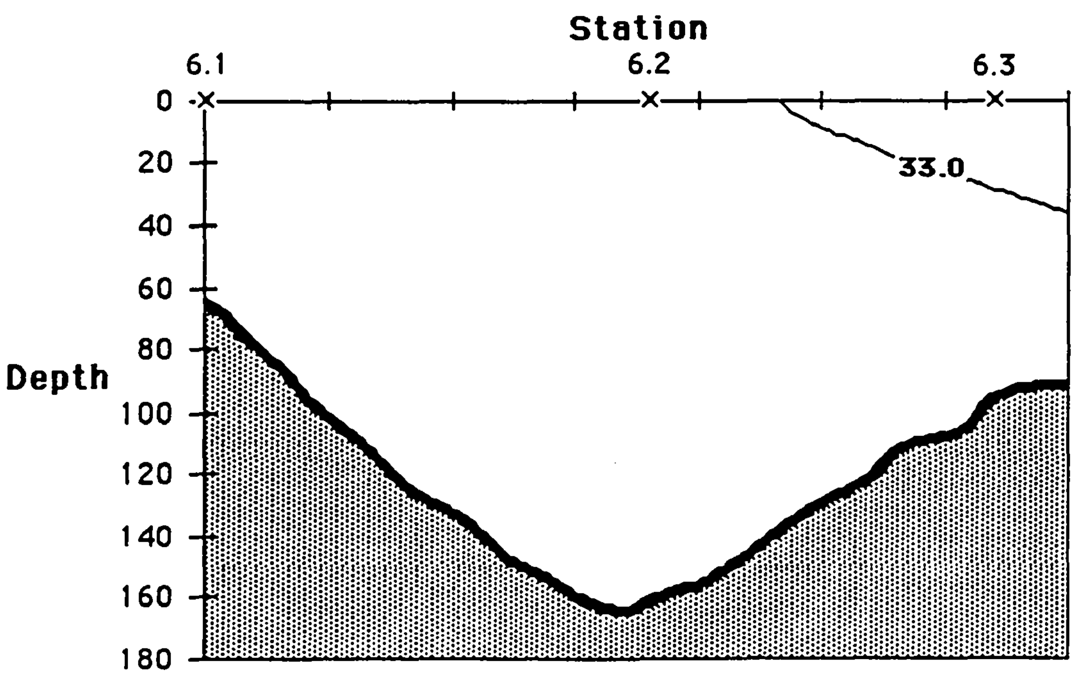


Fig. A-32. Horizontal salinity section from south (left) to north (right) on the west side of Unimak Pass north of Akun Island during winter.

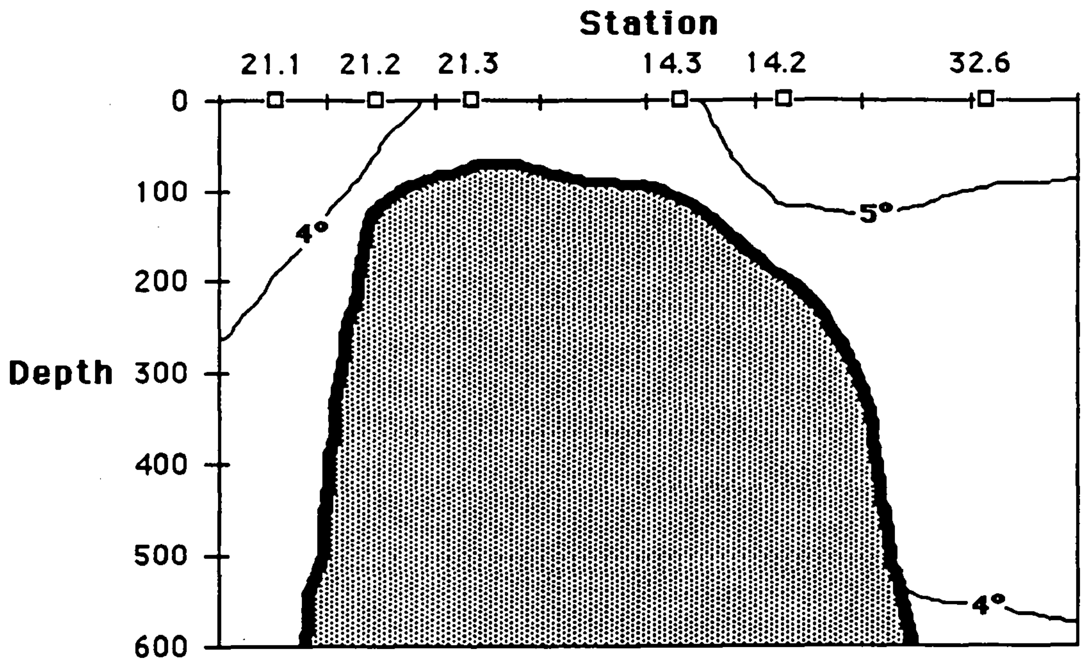


Fig. A-33. Horizontal temperature section from north (left) to south (right) through Akutan Pass during winter. Depth is in meters.

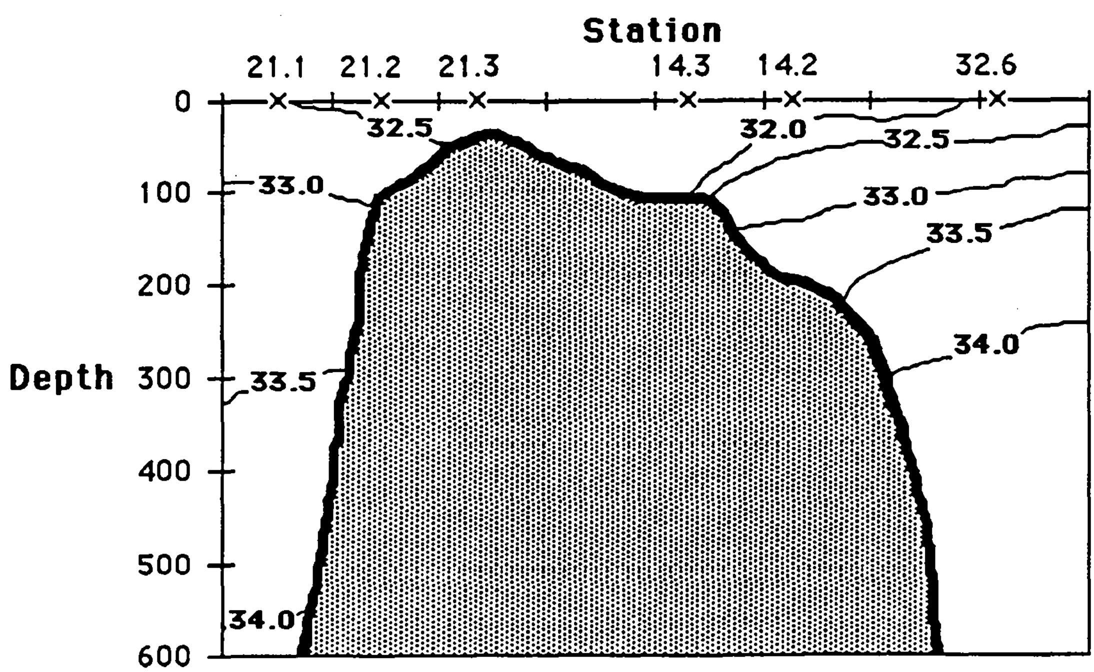


Fig. A-34. Horizontal salinity section from north (left) to south (right) through Akutan Pass during winter. Depth is in meters.

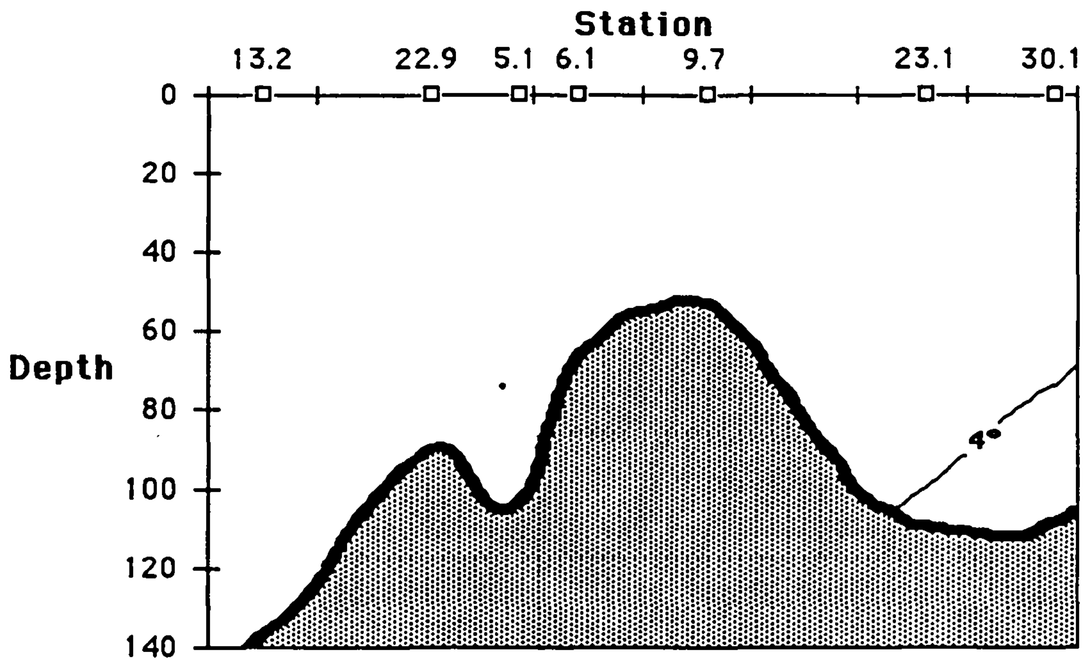


Fig. A-35. Horizontal temperature section from west (left) to east (right) through the eastern Aleutian Islands during winter.

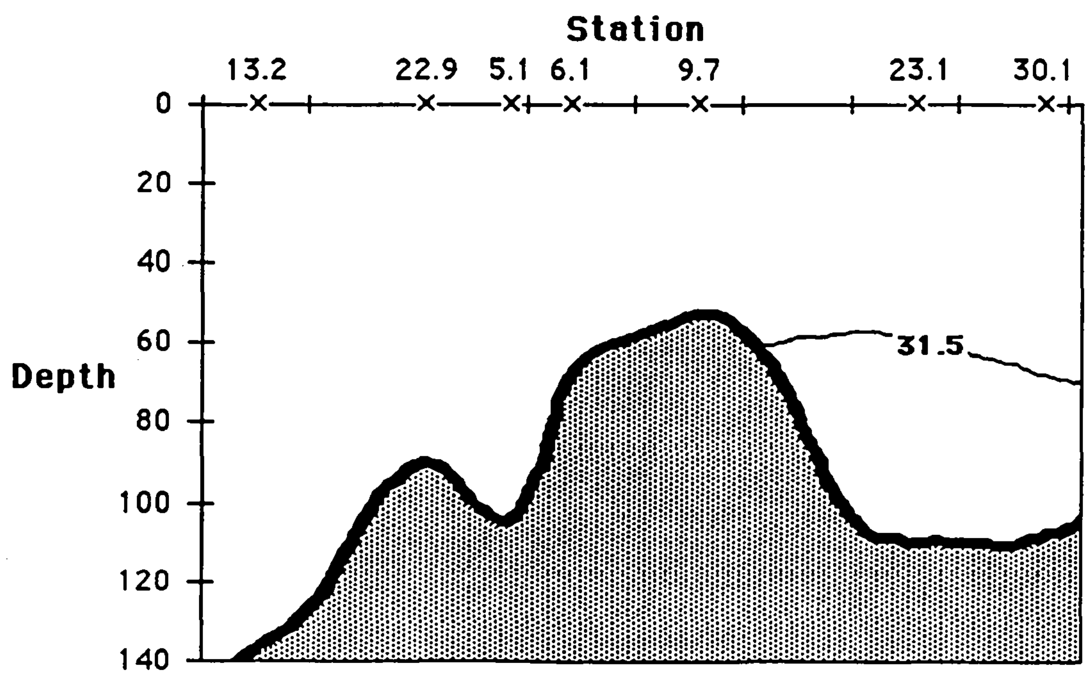


Fig. A-36. Horizontal salinity section from west (left) to east (right) through the eastern Aleutian Islands during winter.

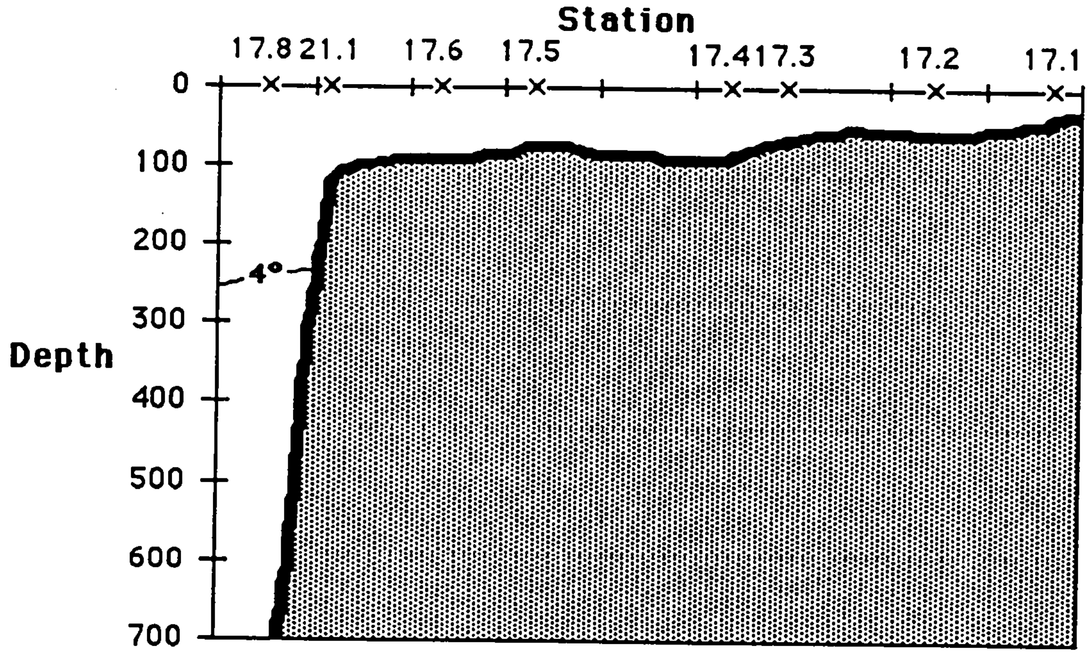


Fig. A-37. Horizontal temperature section from southwest (left) to northeast (right) on the north Aleutian shelf during spring. Transect was nearshore off Unimak, Akun, and Akutan islands. Depth is in meters.

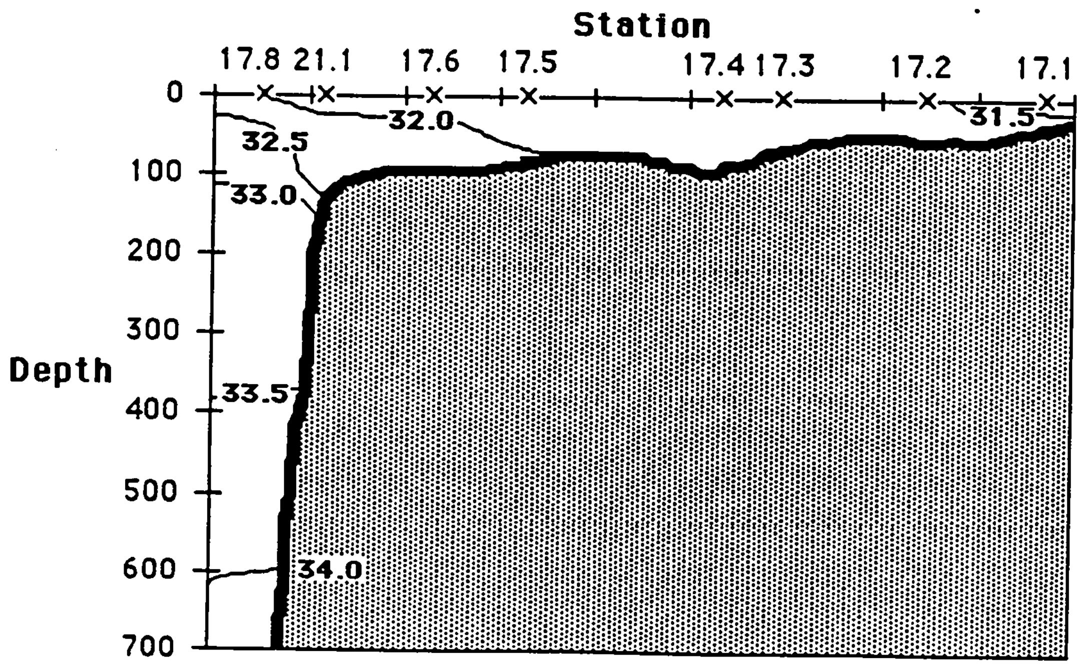


Fig. A-38. Horizontal salinity section from southwest (left) to northeast (right) on the north Aleutian shelf during spring.

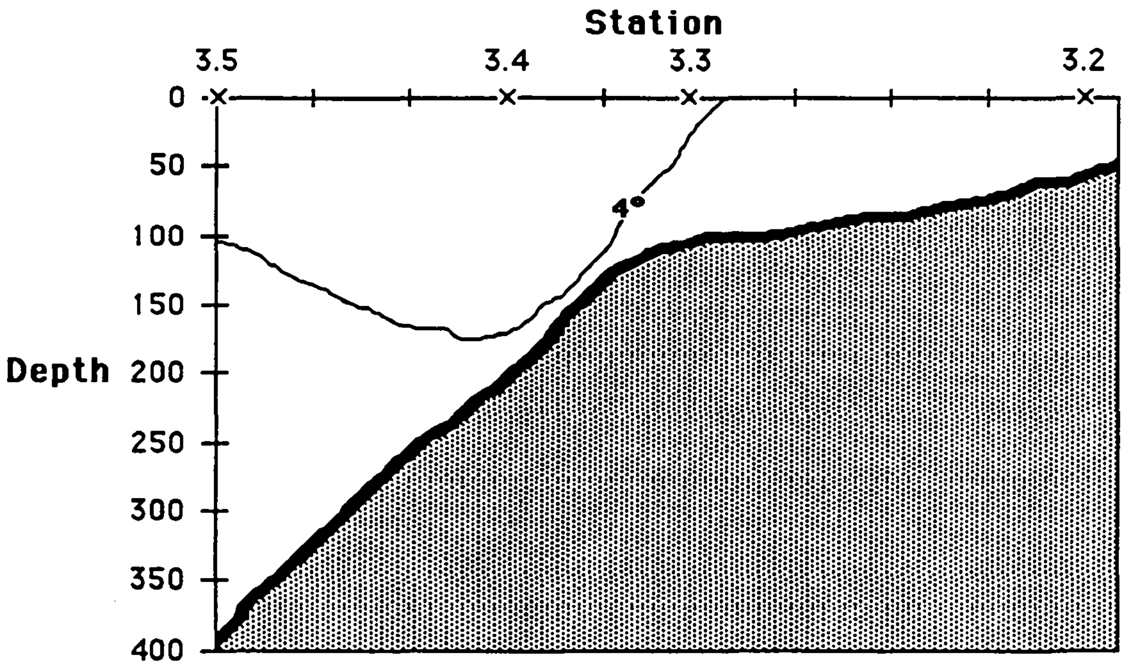


Fig. A-39. Horizontal temperature section from southwest (left) to northeast (right) on the north Aleutian shelf during spring. Depth is in meters.

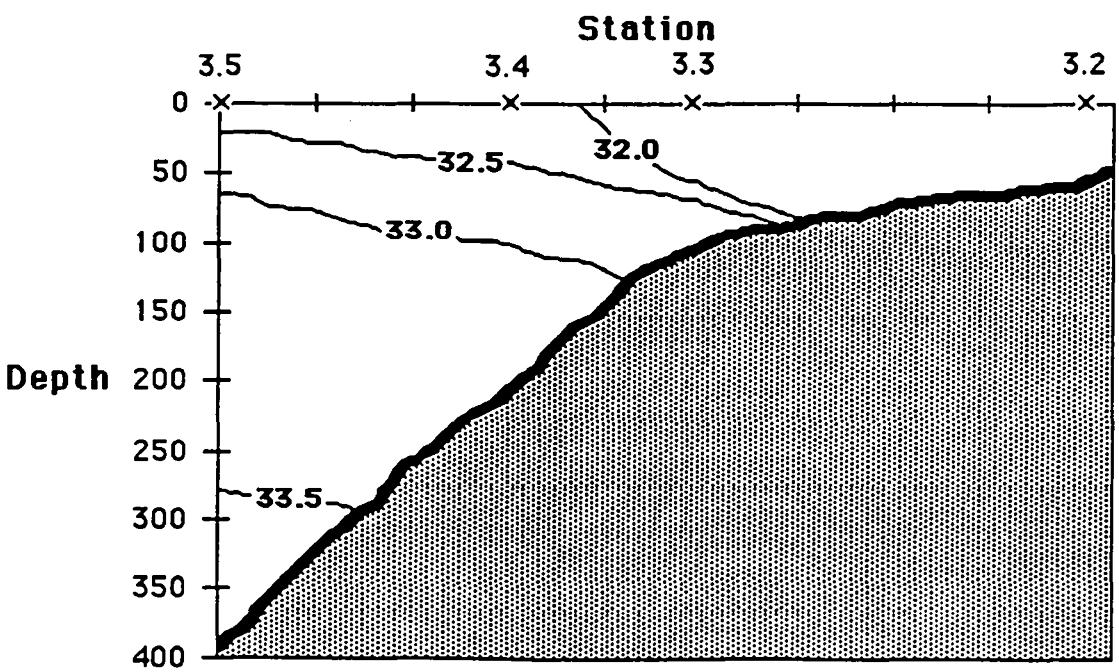


Fig. A-40. Horizontal salinity section from southwest (left) to northeast (right) on the north Aleutian shelf during spring. Depth is in meters.

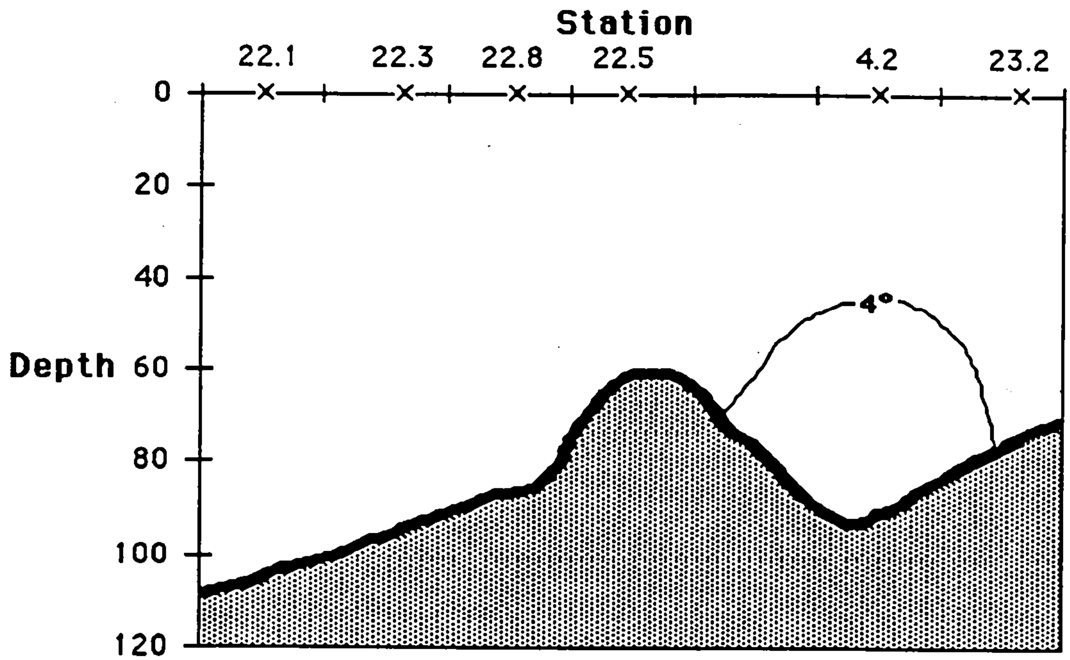


Fig. A-41. Horizontal temperature section from southwest (left) to northeast (right) on the south Aleutian shelf during spring. Transect was nearshore off Unalaska and Unimak islands. Depth is in meters.

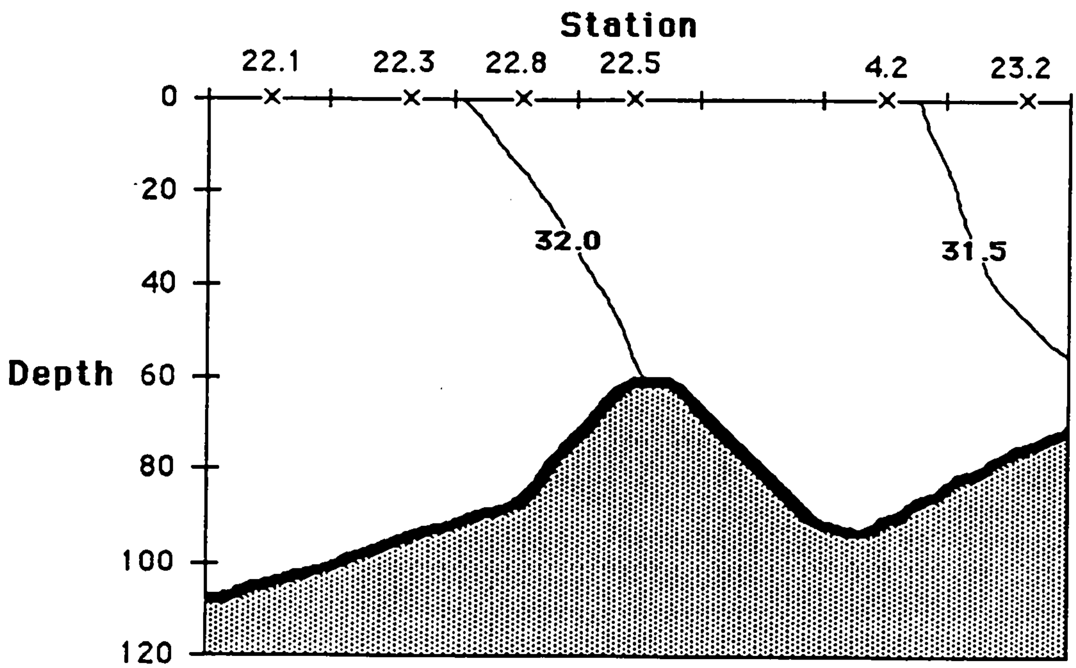


Fig. A-42. Horizontal salinity section from southwest (left) to northeast (right) on the south Aleutian shelf during fall. Depth is in meters.

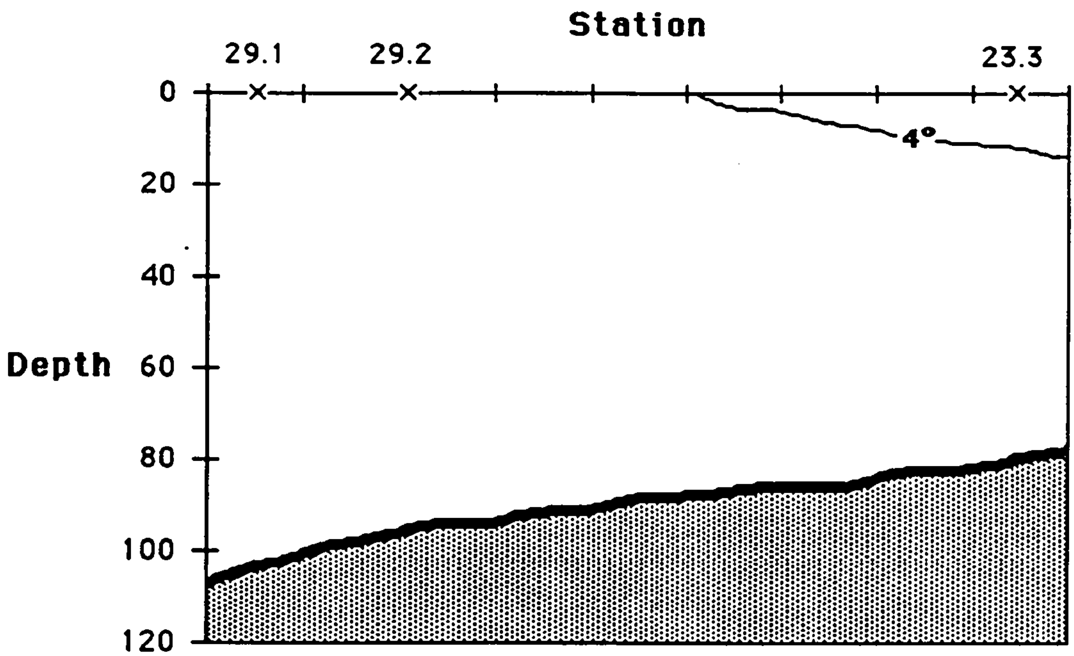


Fig. A-43. Horizontal temperature section from southwest (left) to northeast (right) on the south Aleutian shelf during spring. Transect was offshore of Unalaska, Tigalda, and Unimak islands. Depth is in meters.

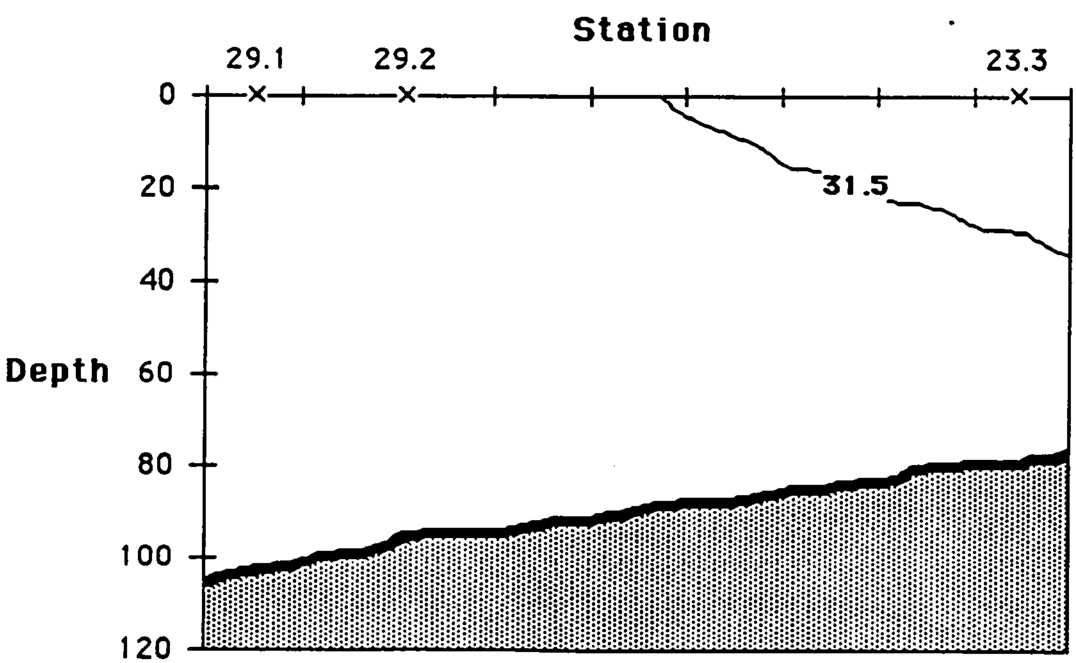


Fig. A-44. Horizontal salinity section from southwest (left) to northeast (right) on the south Aleutian shelf during spring. Depth is in meters.

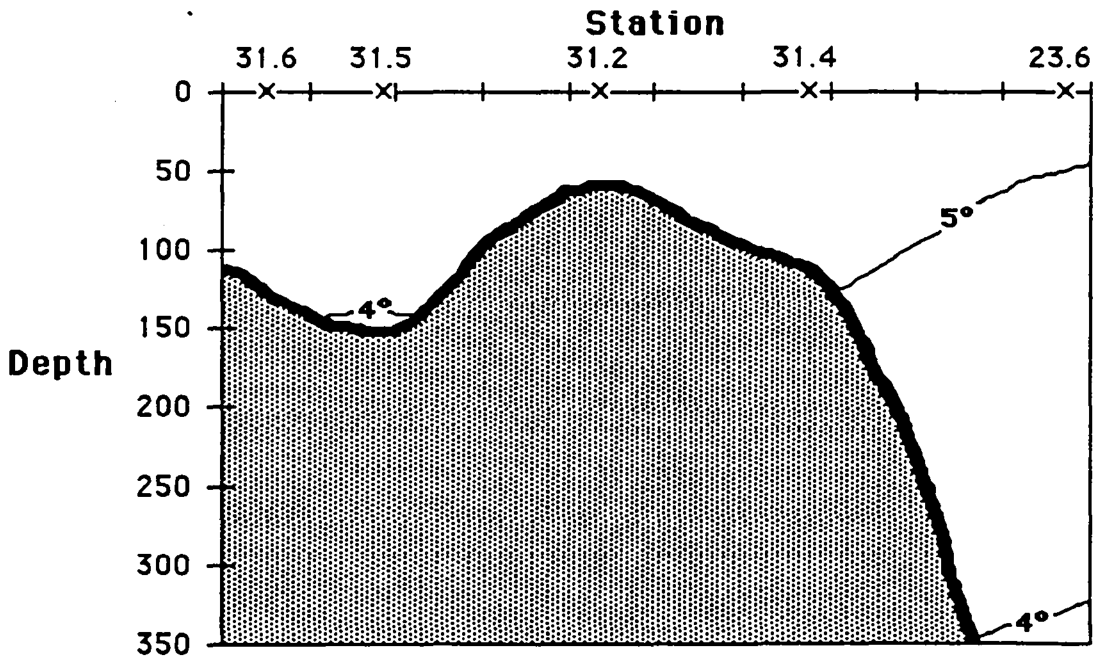


Fig. A-45. Horizontal temperature section from north (left) to south (right) through Unimak Pass during spring. Depth is in meters.

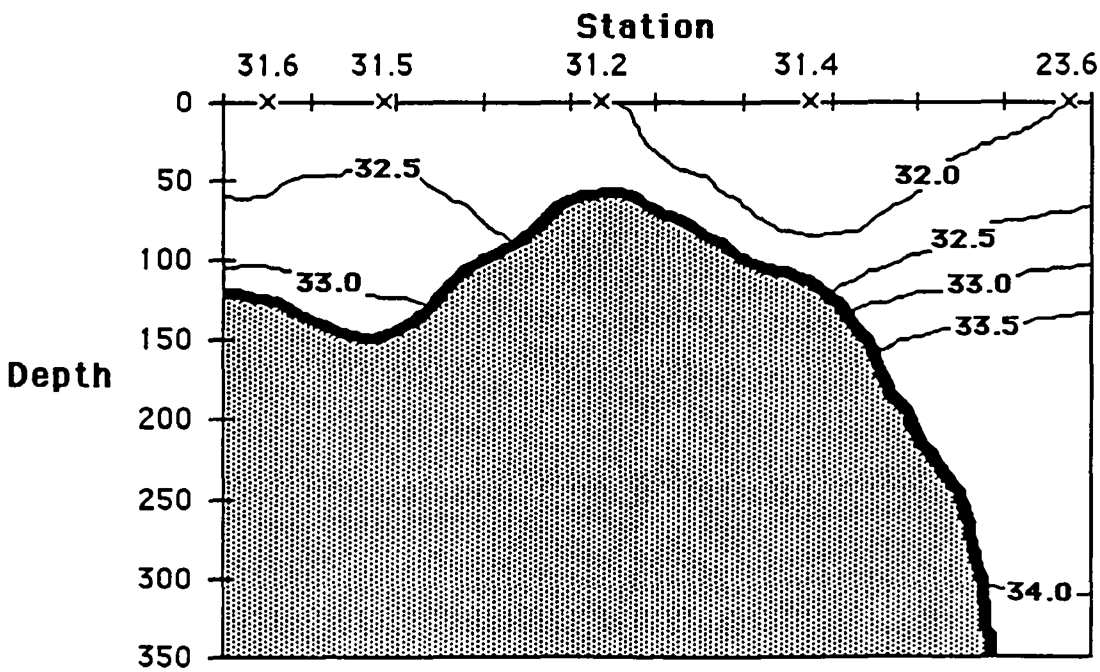


Fig. A-46. Horizontal salinity section from north (left) to south (right) through Unimak Pass during spring. Depth is in meters.

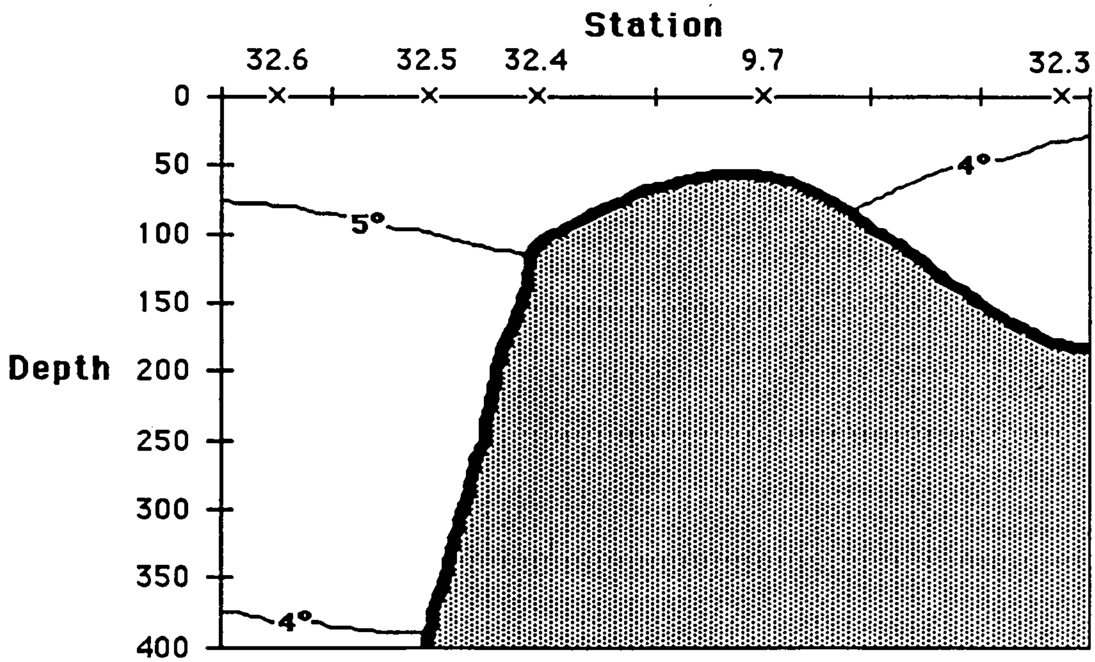


Fig. A-47. Horizontal temperature section from north (left) to south (right) through Ugamak Strait during spring. Depth is in meters.

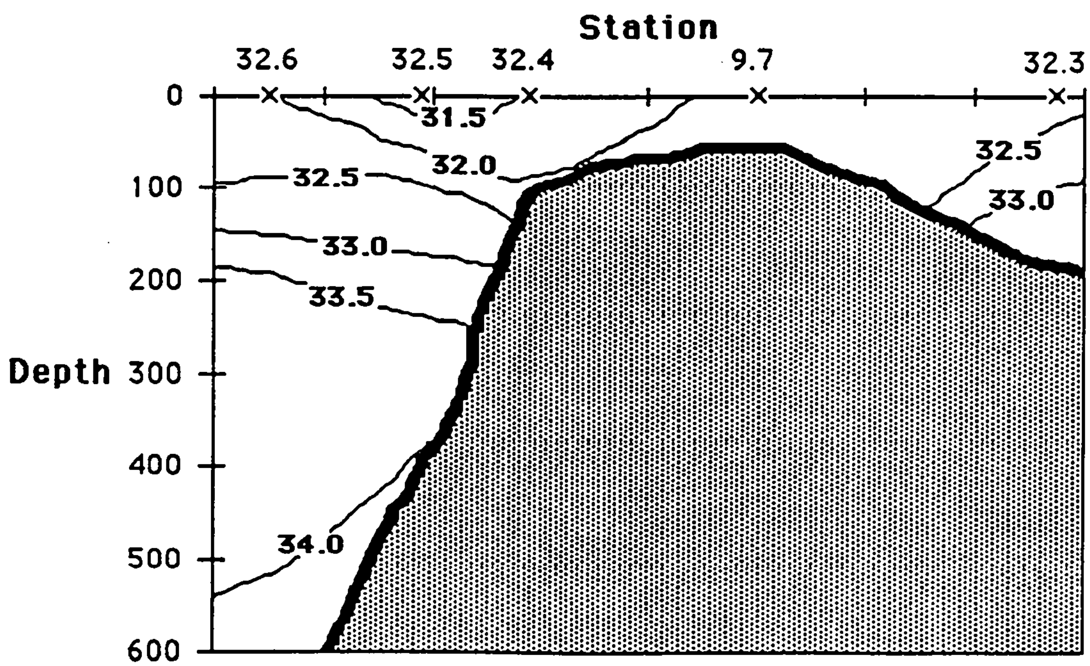


Fig. A-48. Horizontal salinity section from north (left) to south (right) through Ugamak Strait during spring. Depth is in meters.

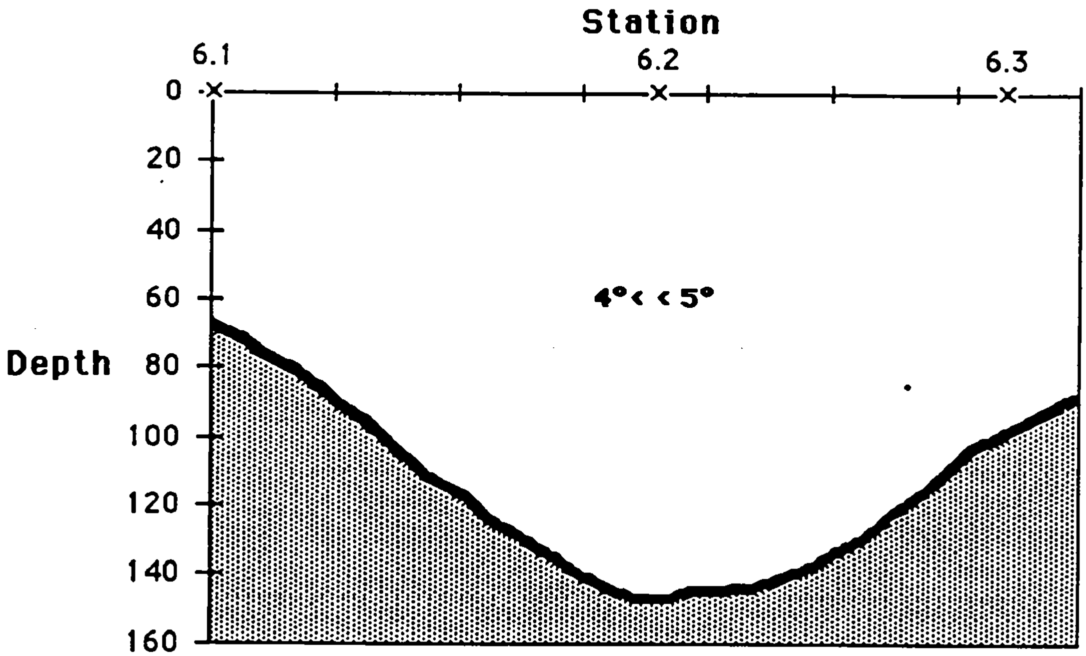


Fig. A-49. Horizontal temperature section from south (left) to north (right) on the west side of Unimak Pass during spring. Depth is in meters.

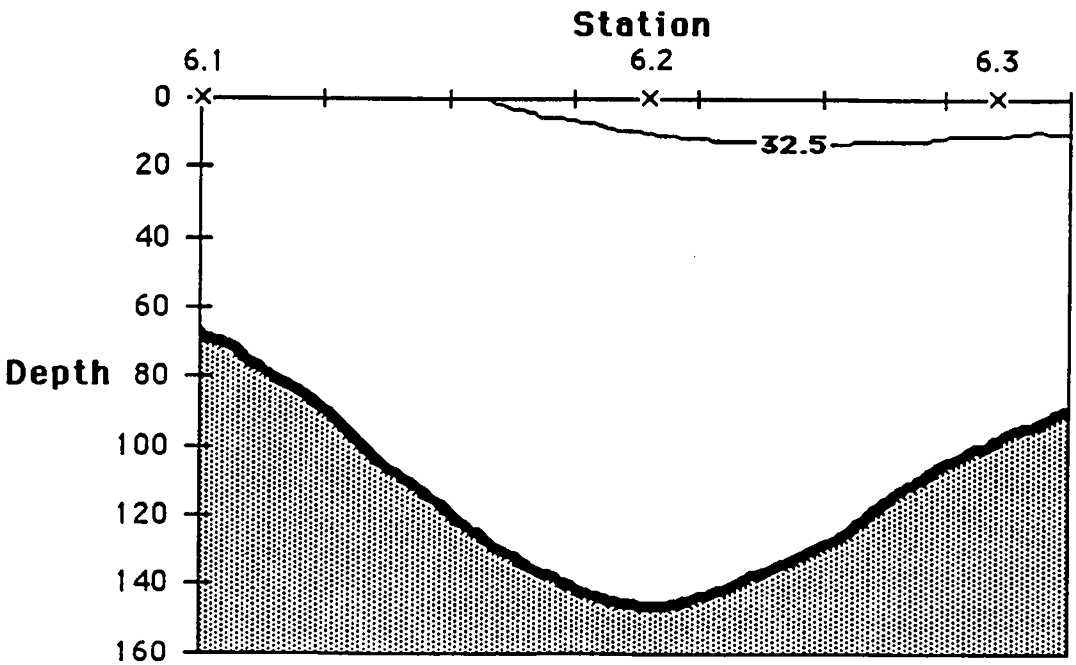


Fig. A-50. Horizontal salinity section from south (left) to north (right) on the west side of Unimak Pass during spring. Depth is in meters.

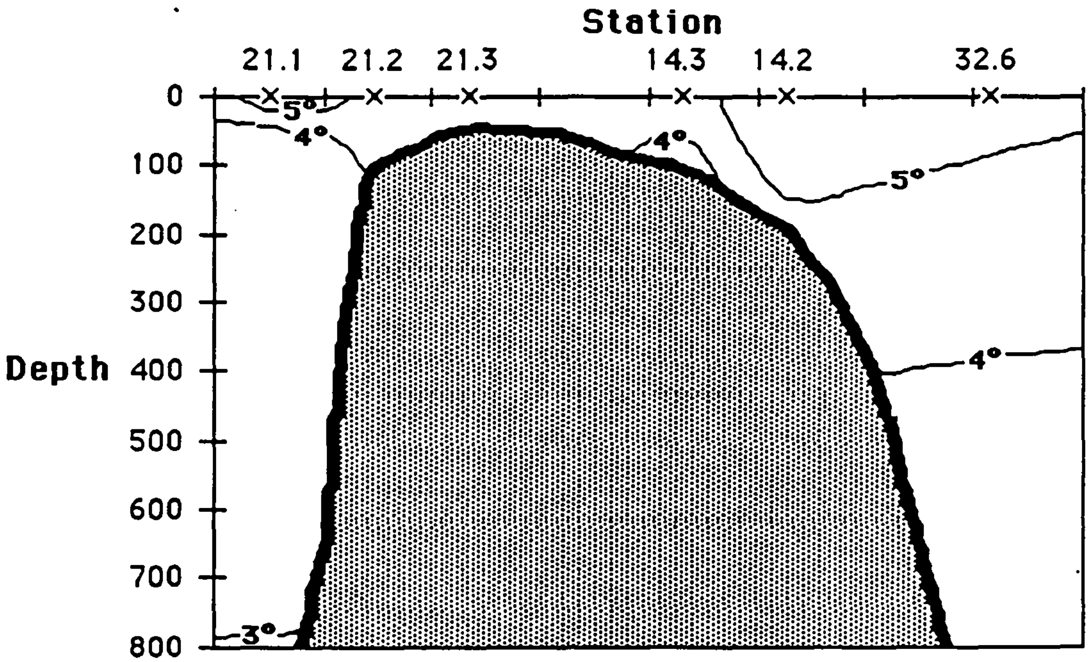


Fig. A-51. Horizontal temperature section from north (left) to south (right) through Akutan Pass during spring. Depth is in meters.

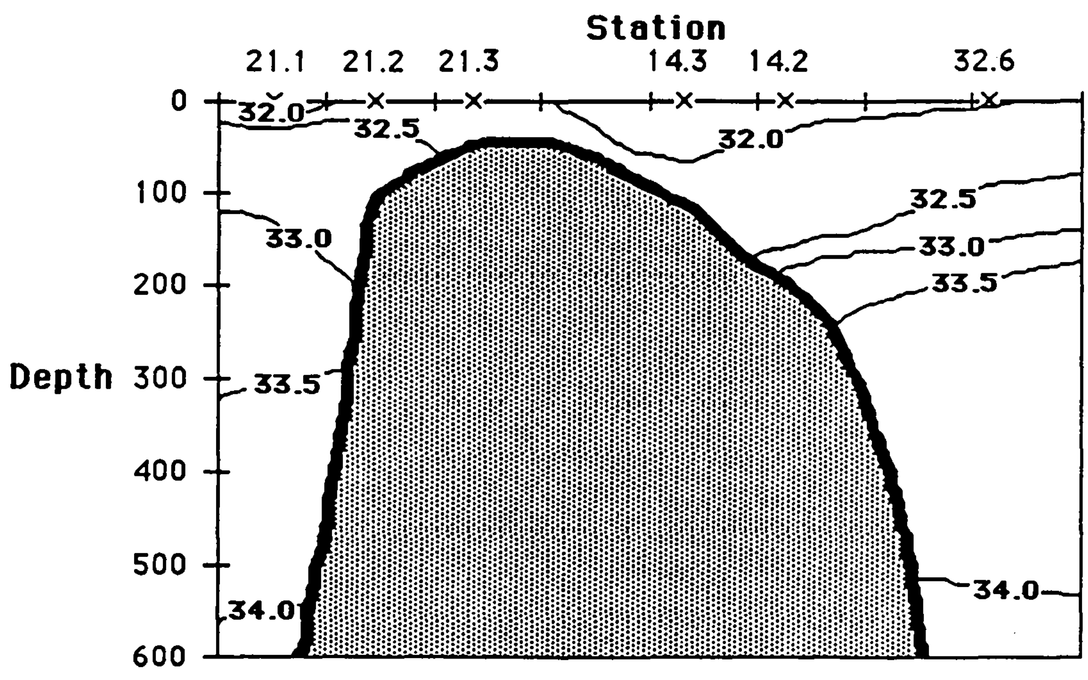


Fig. A-52. Horizontal salinity section from north (left) to south (right) through Akutan Pass during spring. Depth is in meters.

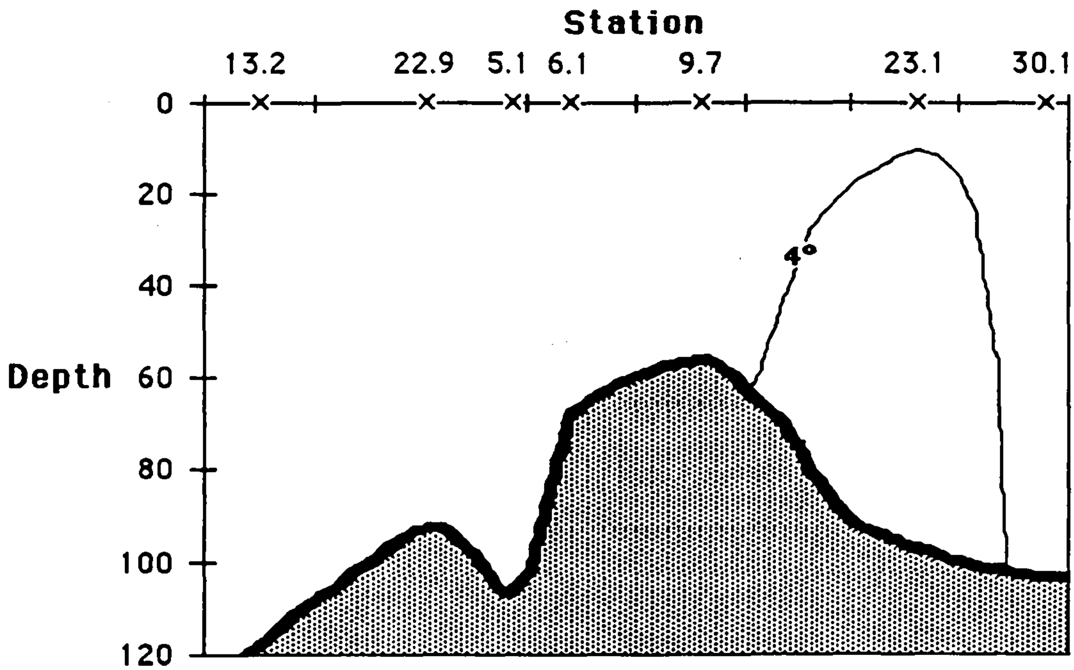


Fig. A-53. Horizontal temperature section from west (left) to east (right) through the eastern Aleutian Islands.

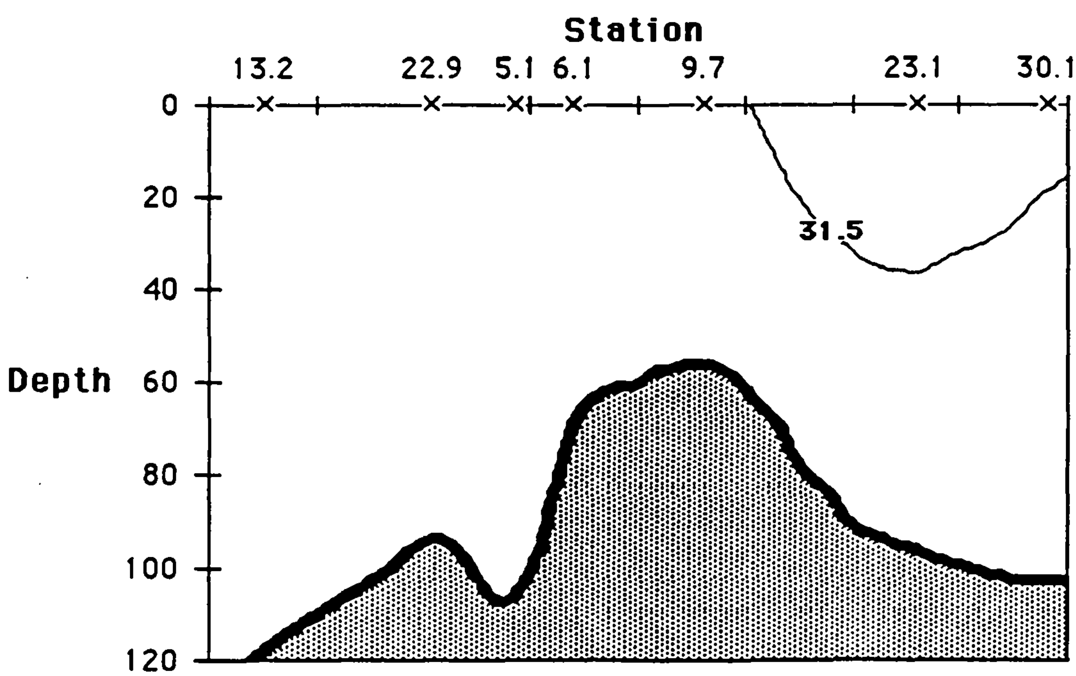
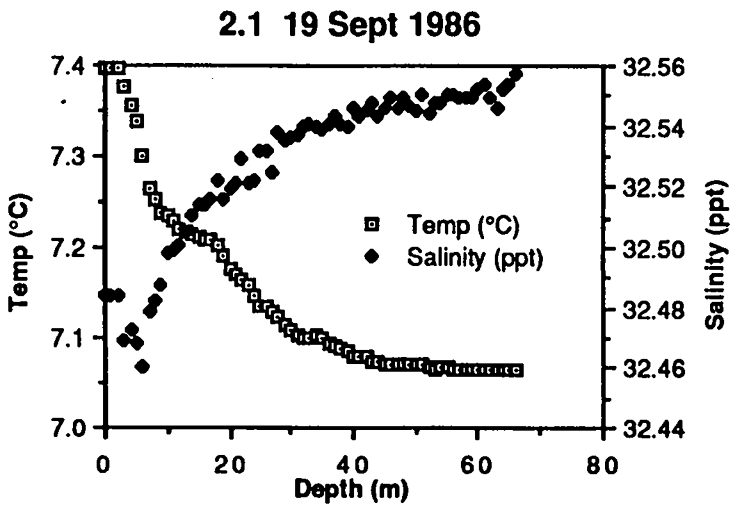
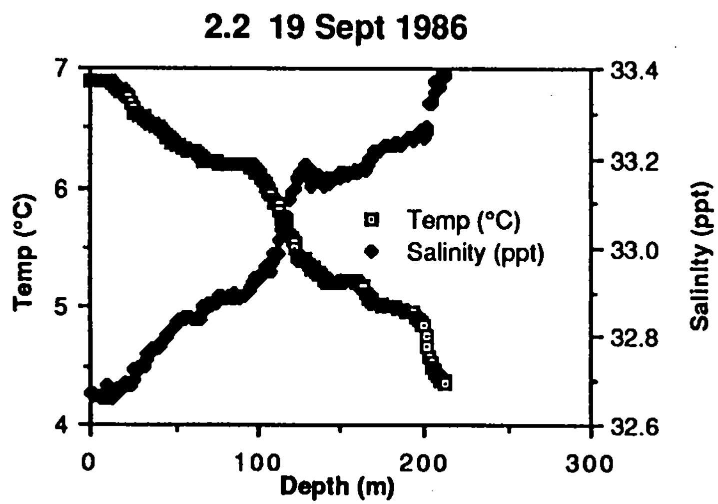


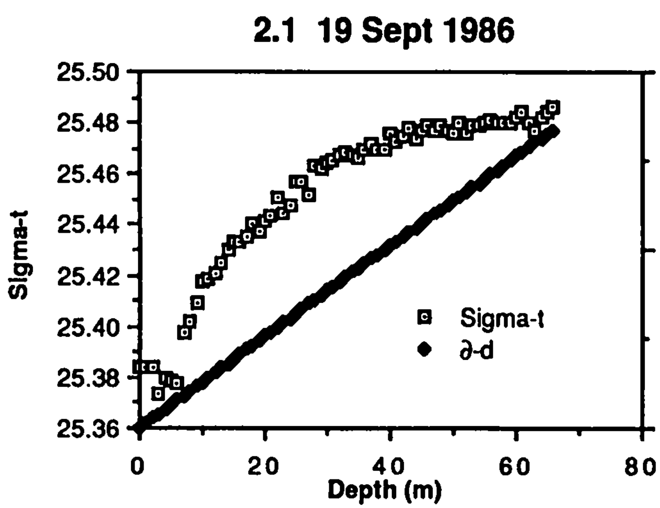
Fig. A-54. Horizontal salinity section from west (left) to east (right) through the eastern Aleutian Islands.

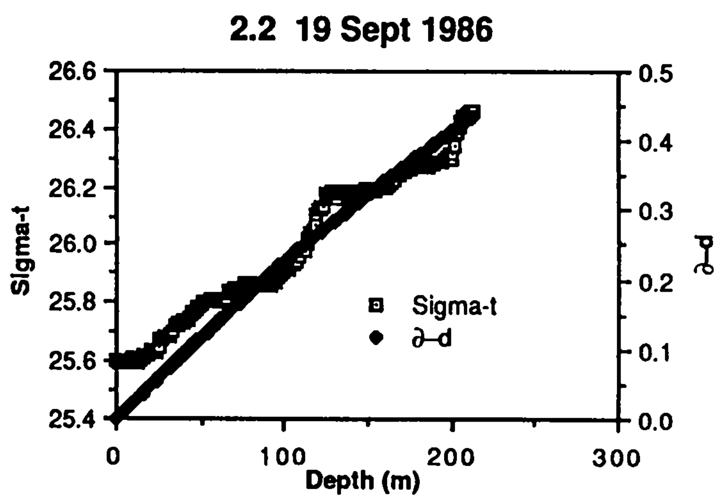
APPENDIX B-1

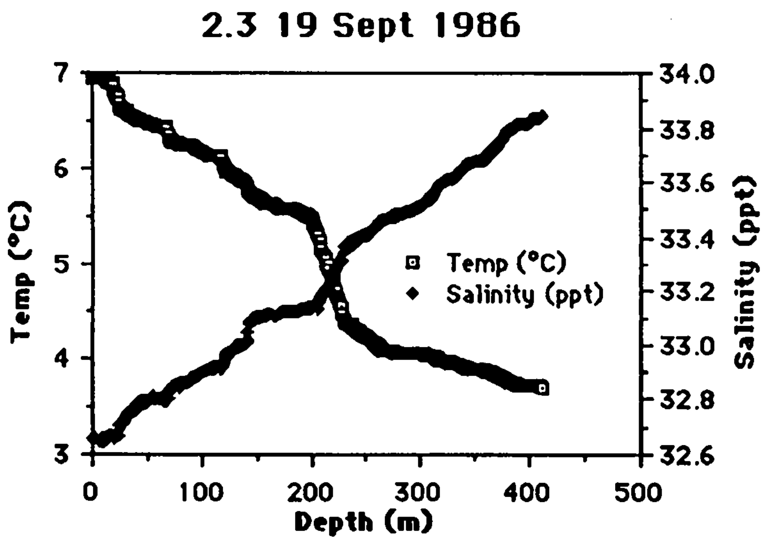
Temperature and salinity vertical profiles as determined by CTD casts at sampling stations in fall 1986 in the Unimak Pass area, Alaska. Sampling station numbers (tops of graphs) can be matched with their locations in Fig. 2 of Appendix E.

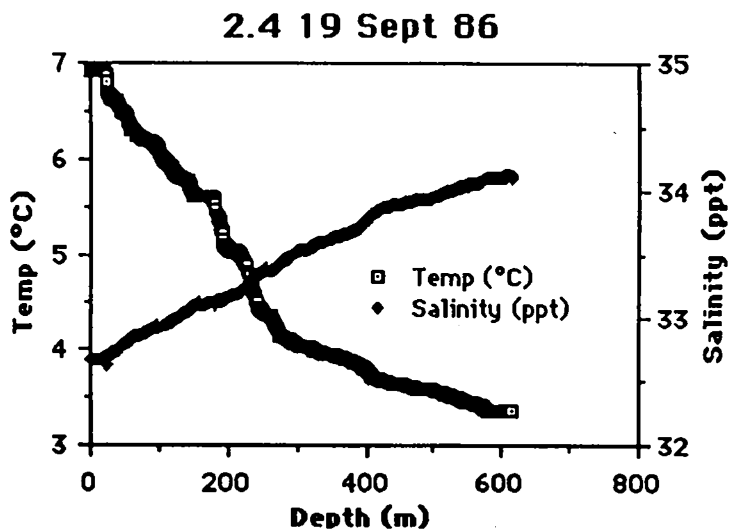

2.1 19 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

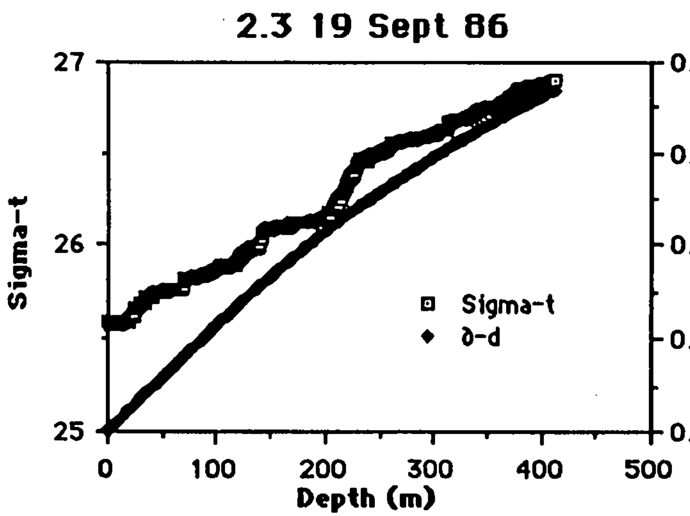

2.2 19 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

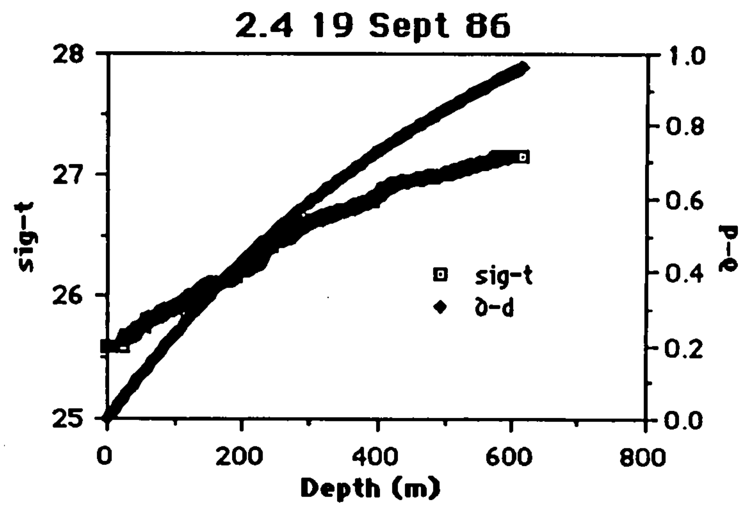

2.1 19 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

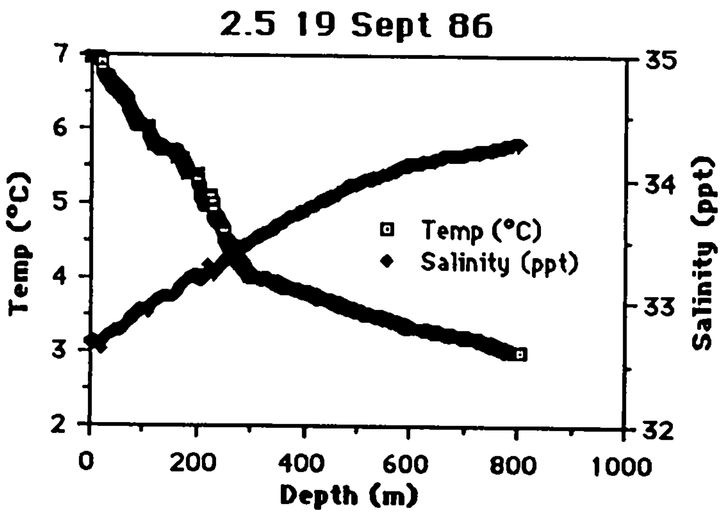

2.2 19 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

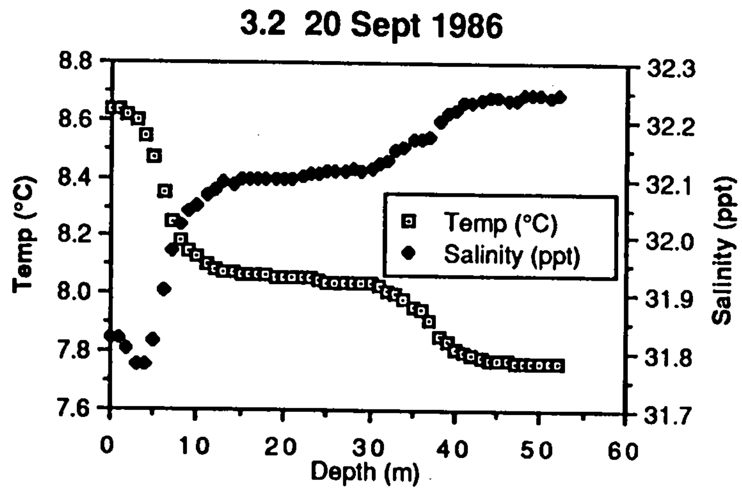

2.3 19 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

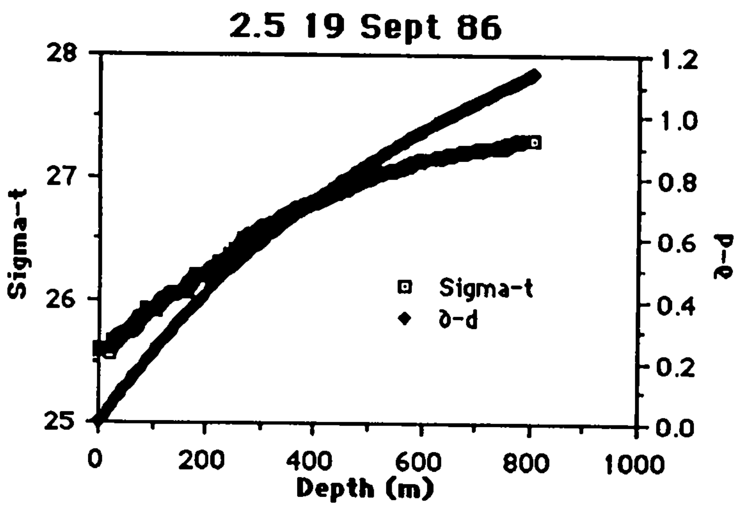

2.4 19 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

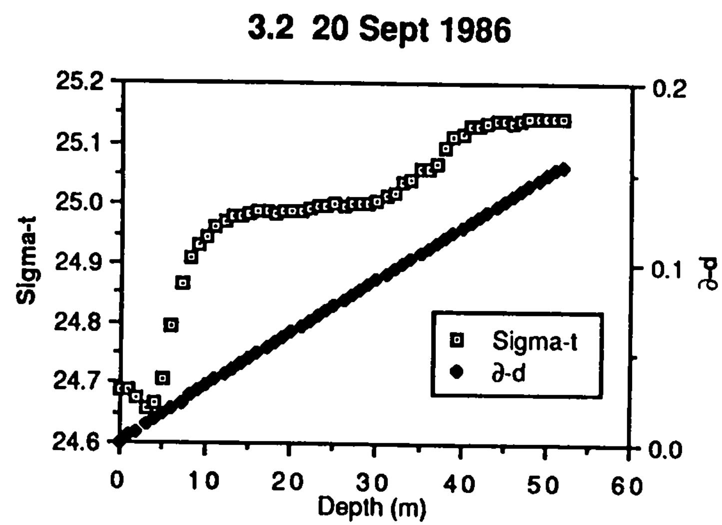

2.3 19 Sept 86
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d


2.4 19 Sept 86
sig-t
∂-d
Depth (m)
sig-t
∂-d

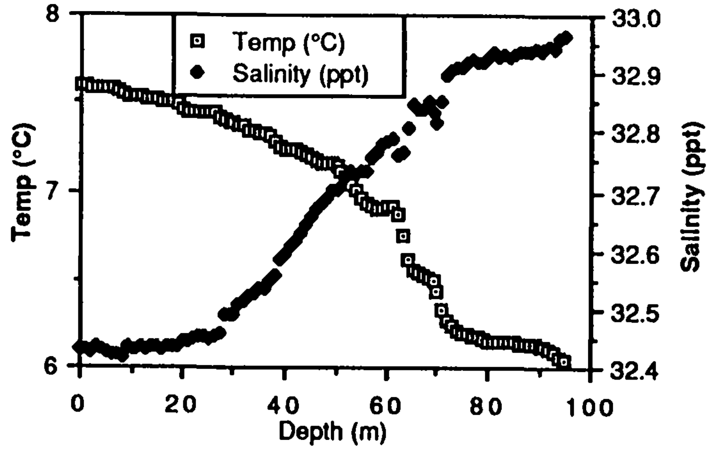

2.5 19 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
7
6
5
4
3
2
35
34
33
32
0
200
400
600
800
1000


3.2 20 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
8.8
8.6
8.4
8.2
8.0
7.8
7.6
32.3
32.2
32.1
32.0
31.9
31.8
31.7
0
10
20
30
40
50
60

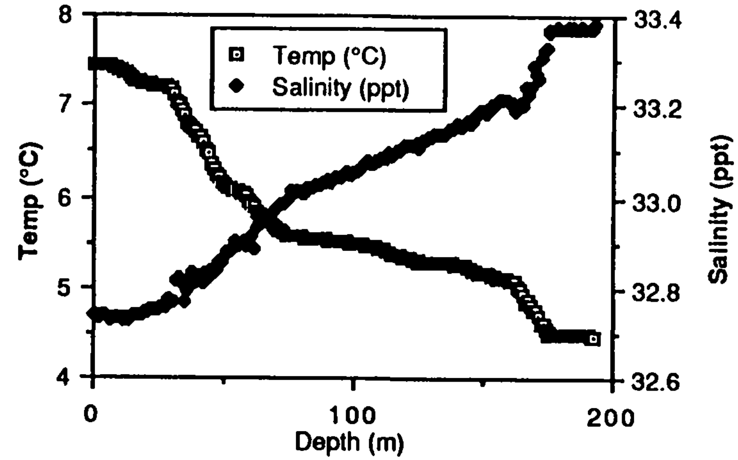

2.5 19 Sept 86
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
28
27
26
25
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000


3.2 20 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
25.2
25.1
25.0
24.9
24.8
24.7
24.6
0.2
0.1
0.0
0
10
20
30
40
50
60

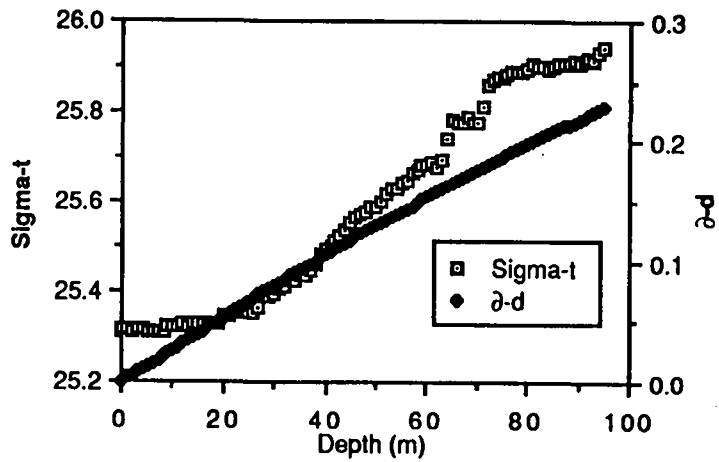
3.3 20 Sept 1986



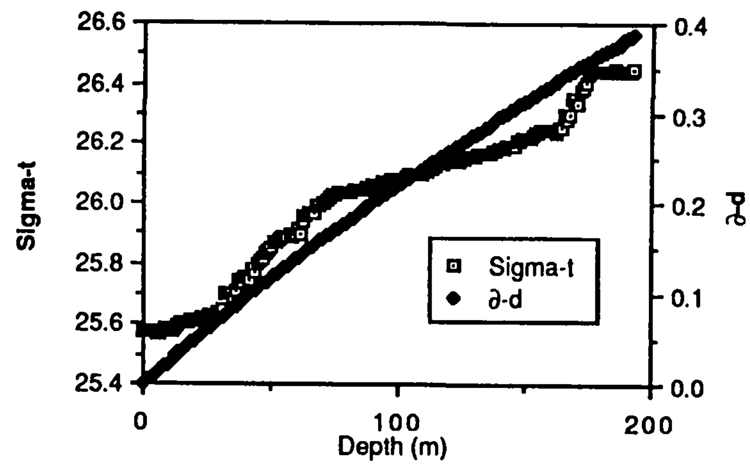
3.4 20 Sept 1986

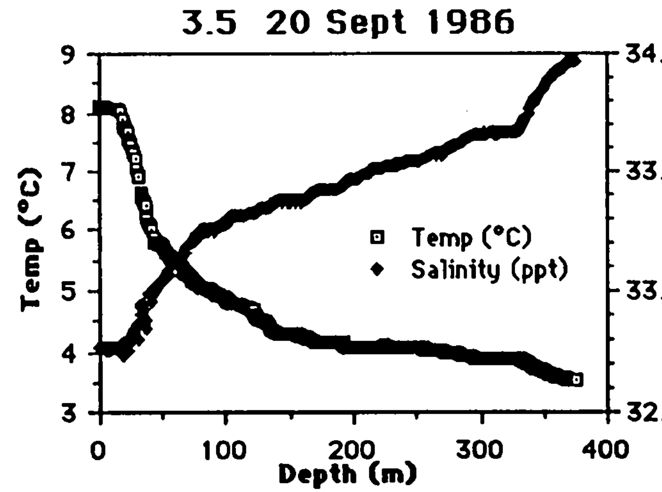


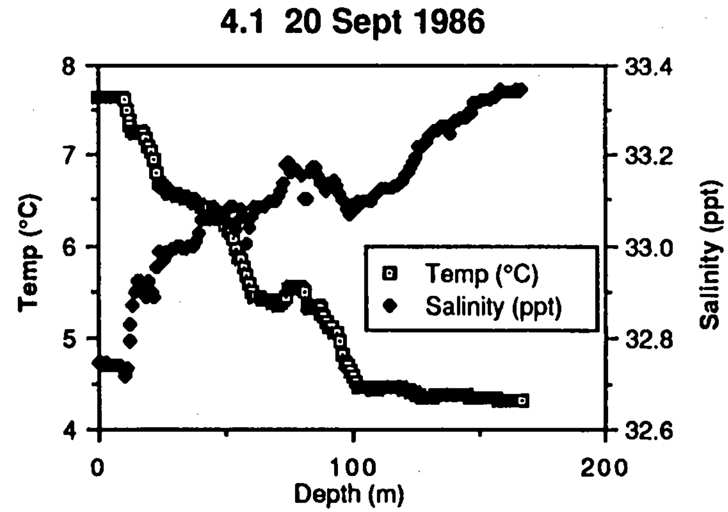
3.3 20 Sept 1986

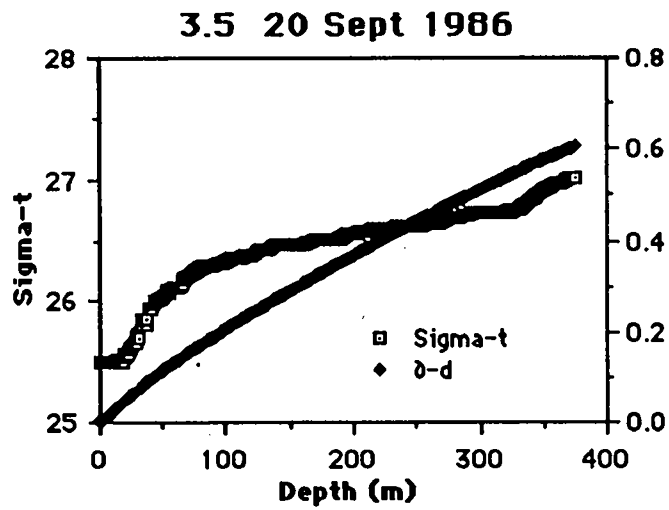


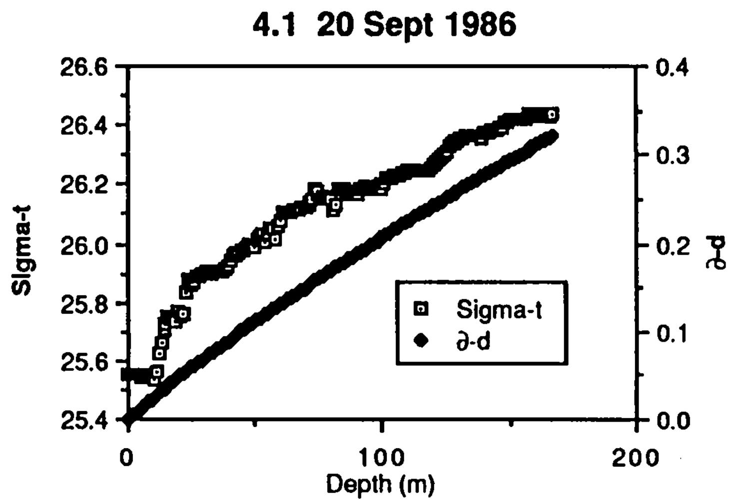
3.4 20 Sept 1986



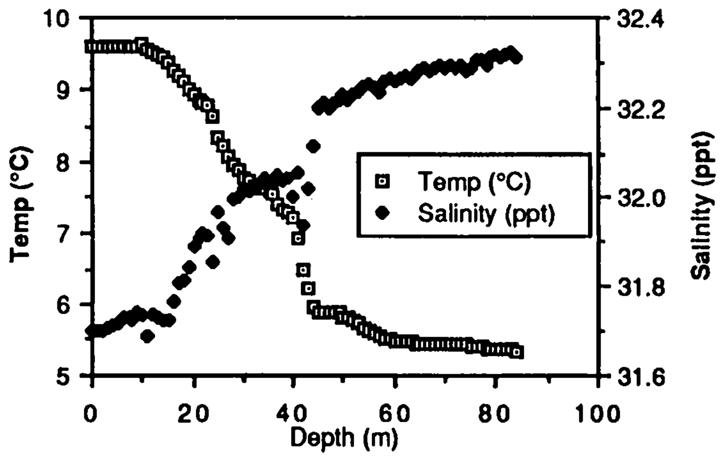

3.5 20 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)


4.1 20 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

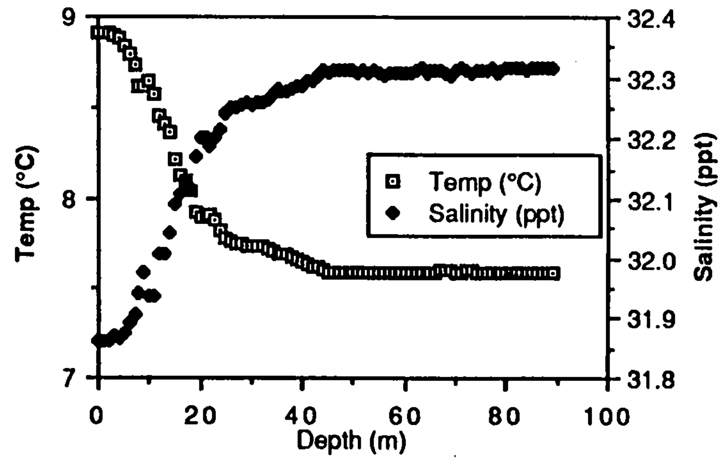

3.5 20 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d


4.1 20 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

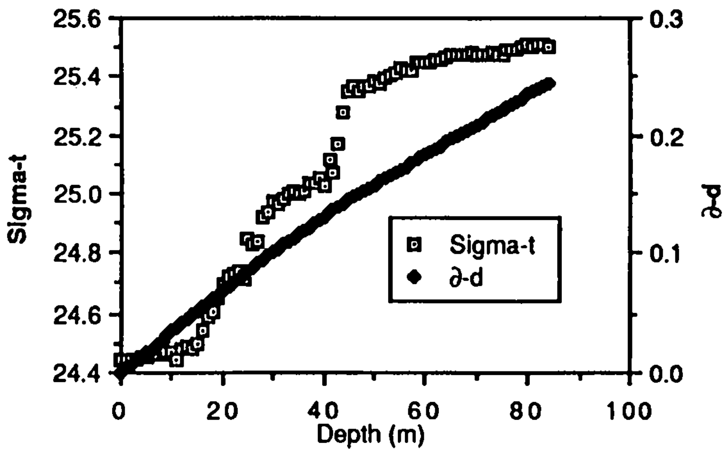
4.2 21 Sept 1986



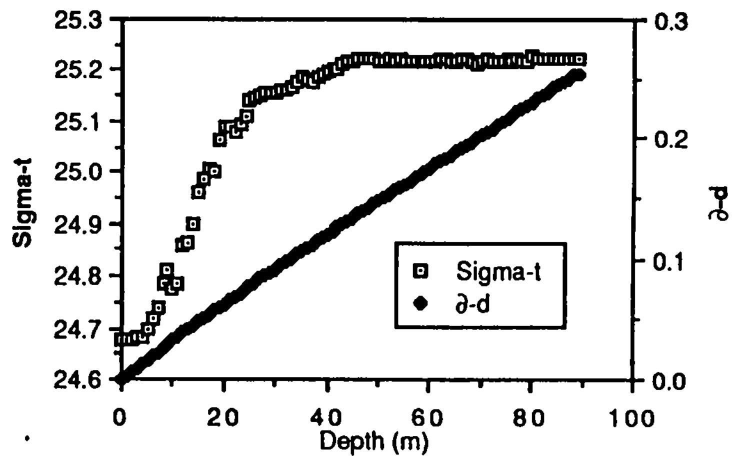
4.3 21 Sept 1986



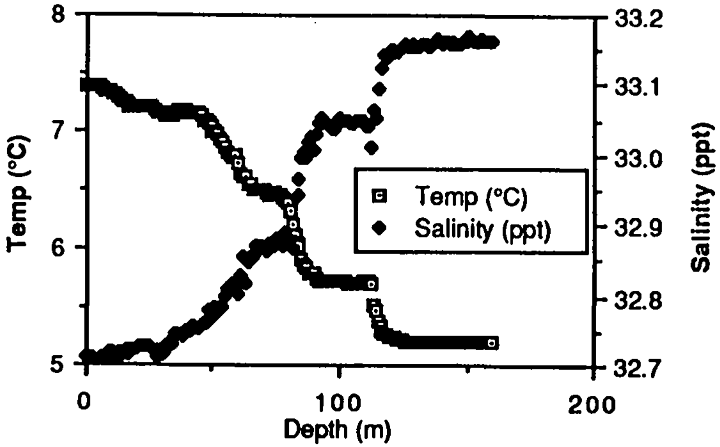
4.2 21 Sept 1986



4.3 21 Sept 1986



4.4 21 Sept 1986



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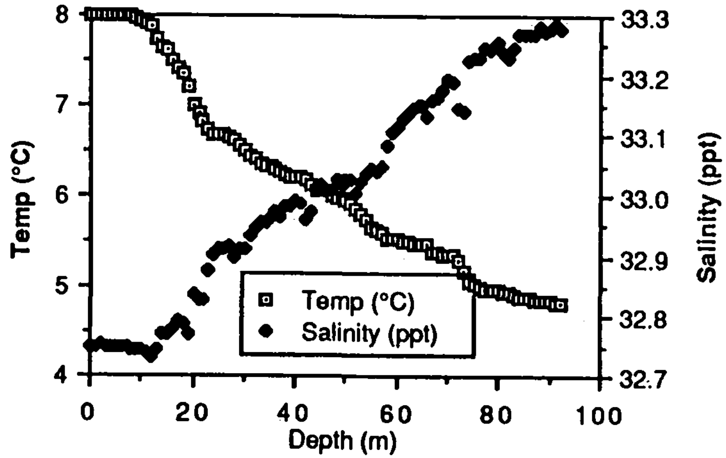
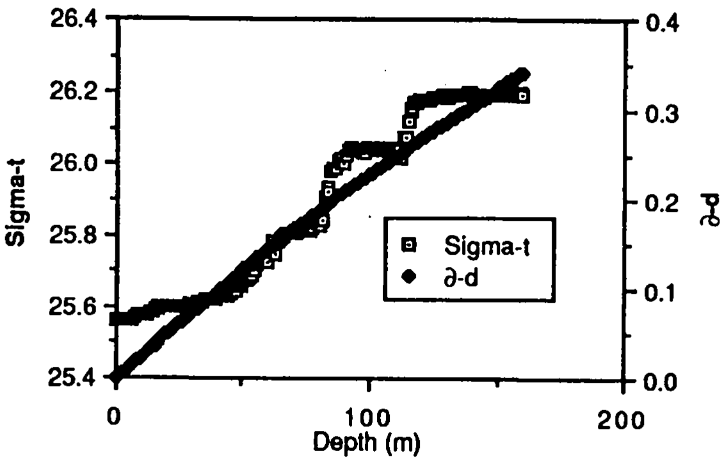


4.4 21 Sept 1986



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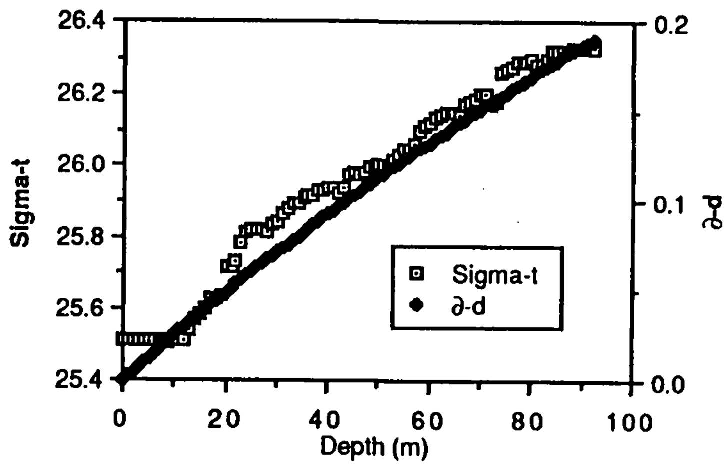
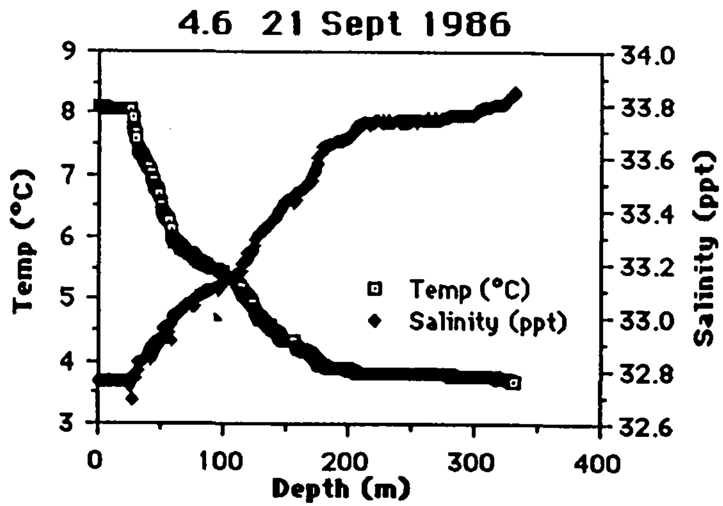
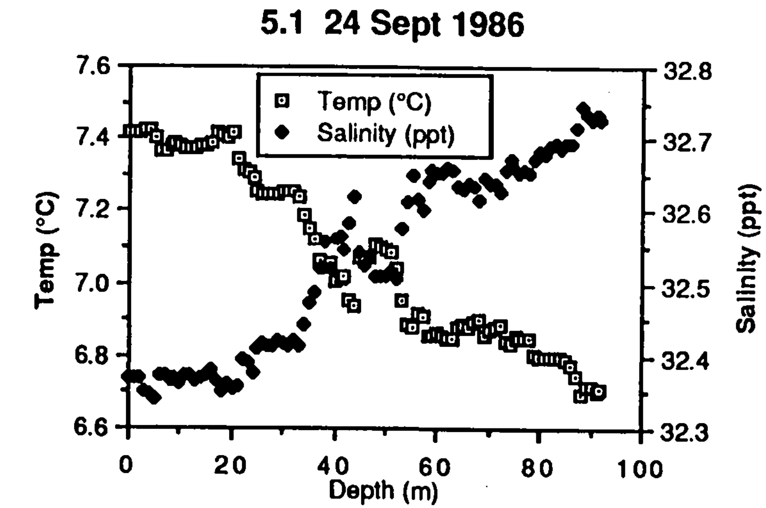
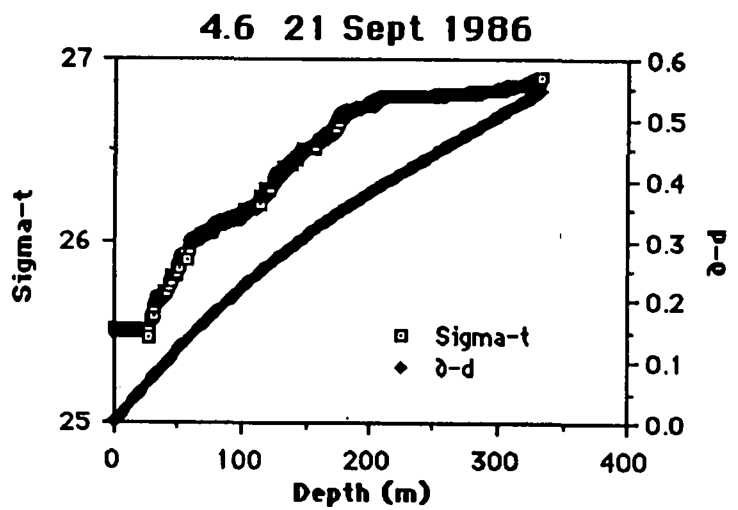
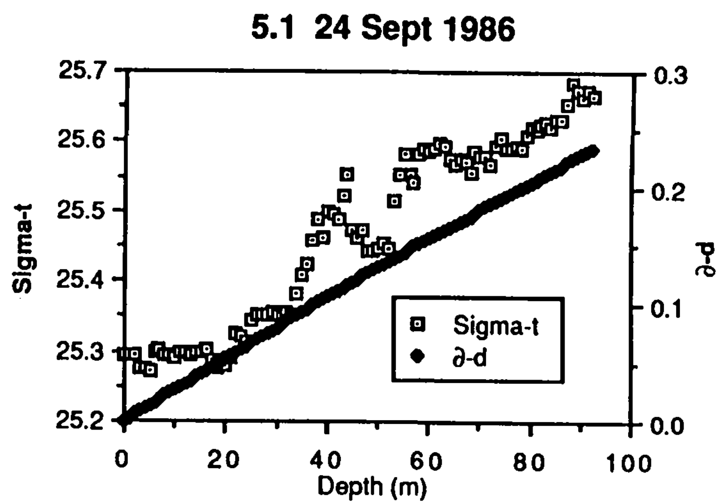


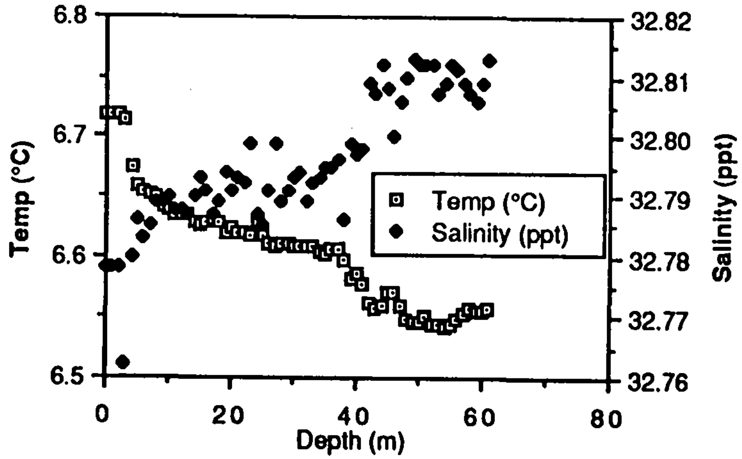

4.6 21 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)


5.1 24 Sept 1986
Temp (°C)
Salinity (ppt)
Temp (°C)
Salinity (ppt)
Depth (m)

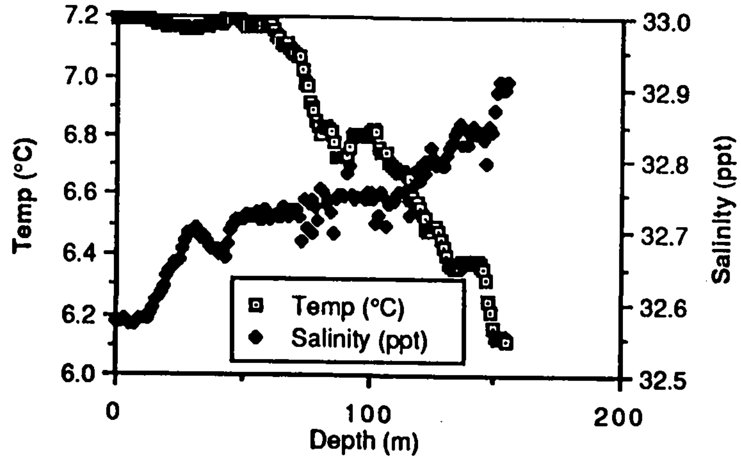

4.6 21 Sept 1986
Sigma-t
∂-d
Sigma-t
∂-d
Depth (m)


5.1 24 Sept 1986
Sigma-t
∂-d
Sigma-t
∂-d
Depth (m)

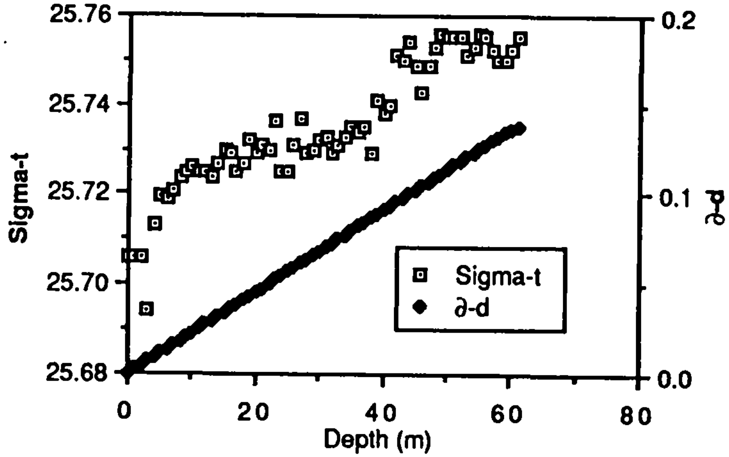
6.1 22 Sept 1986



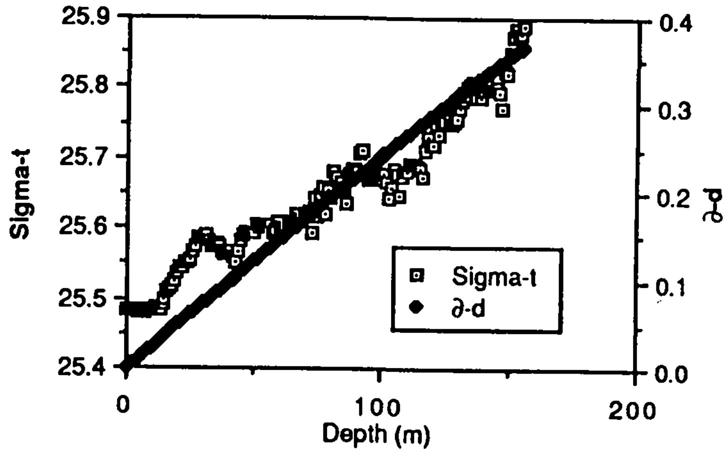
6.2 22 Sept 1986



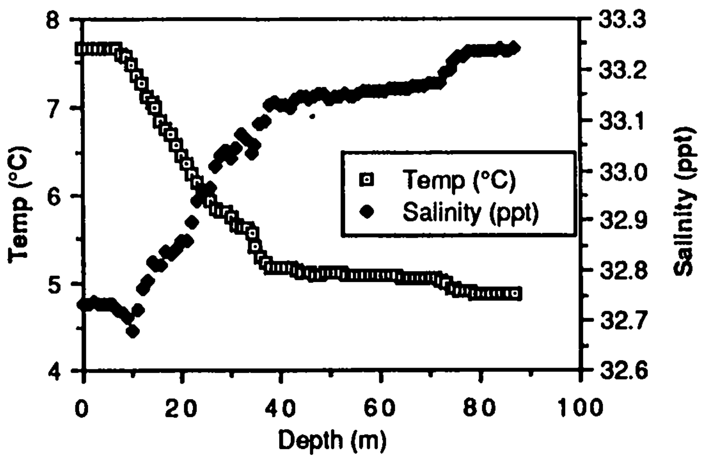
6.1 22 Sept 1986



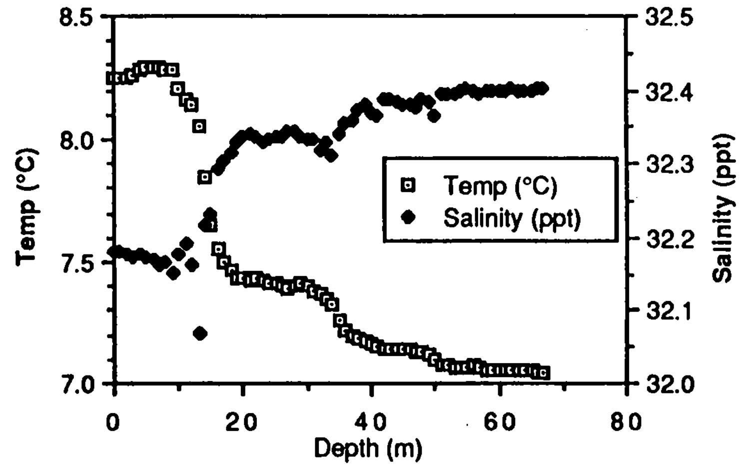
6.2 22 Sept 1986



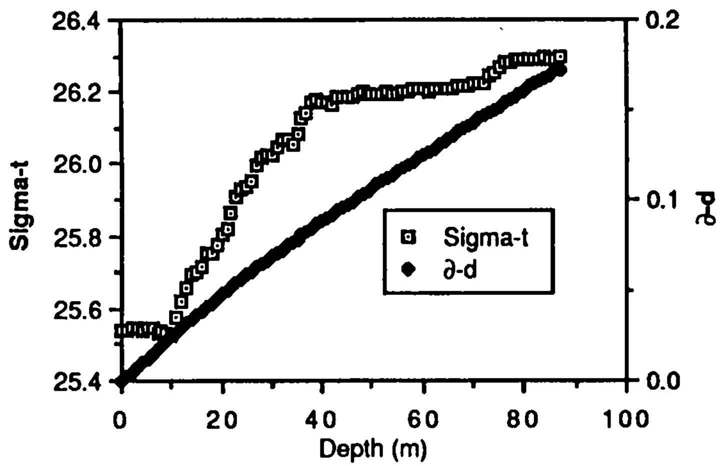
6.3 22 Sept 1986



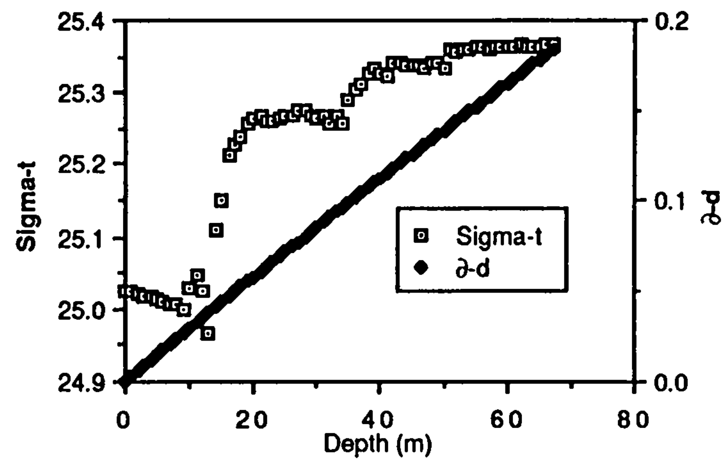
8.1 24 Sept 1986



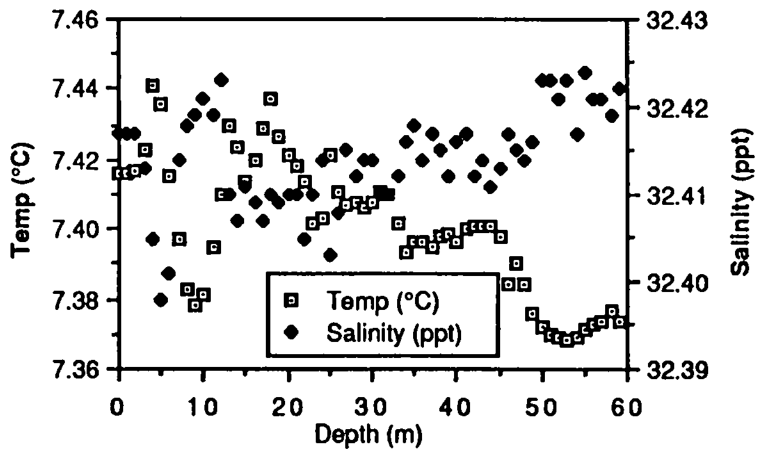
6.3 22 Sept 1986



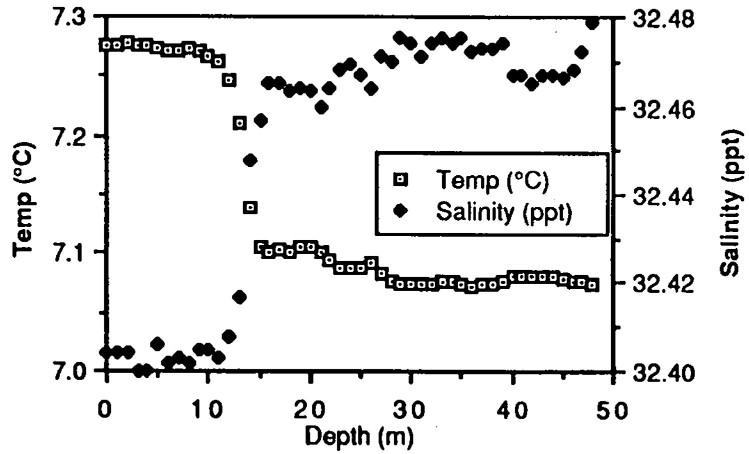
8.1 24 Sept 1986



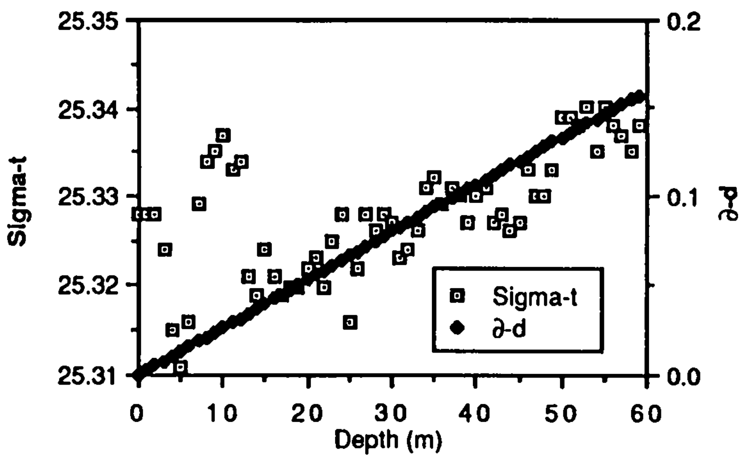
9.1 22 Sept 1986



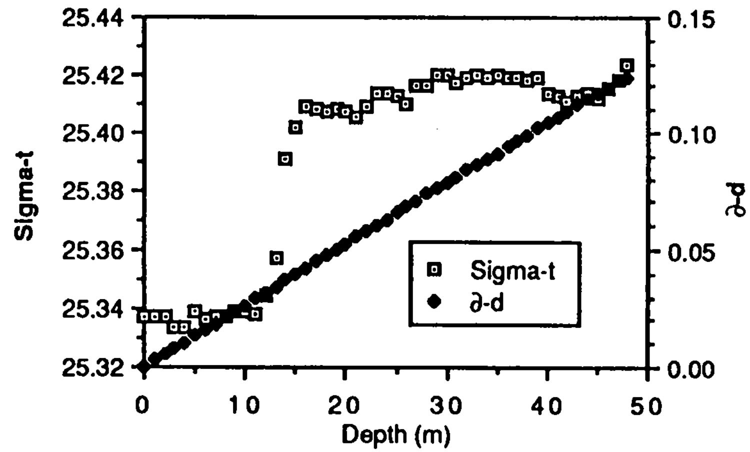
9.2 22 Sept 1986



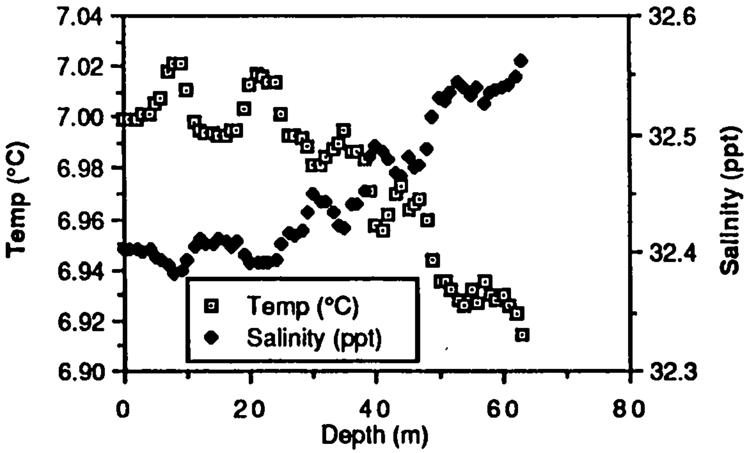
9.1 22 Sept 1986



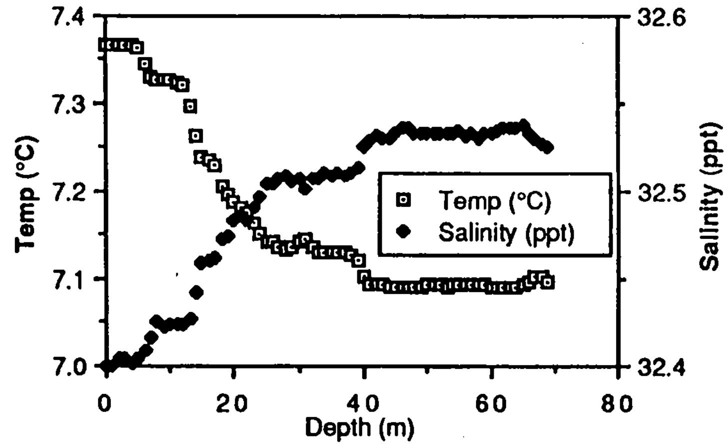
9.2 22 Sept 1986



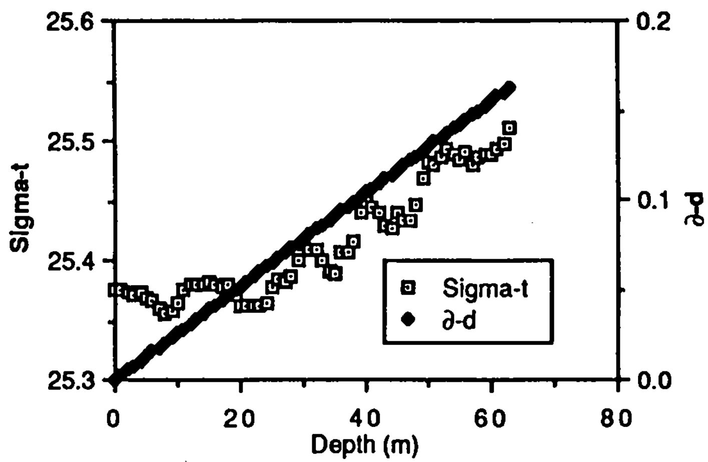
9.3 22 Sept 1986



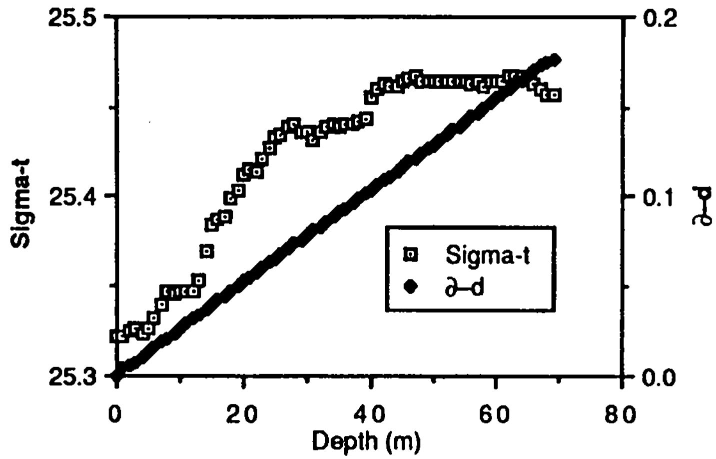
9.4 30 Sept 1986



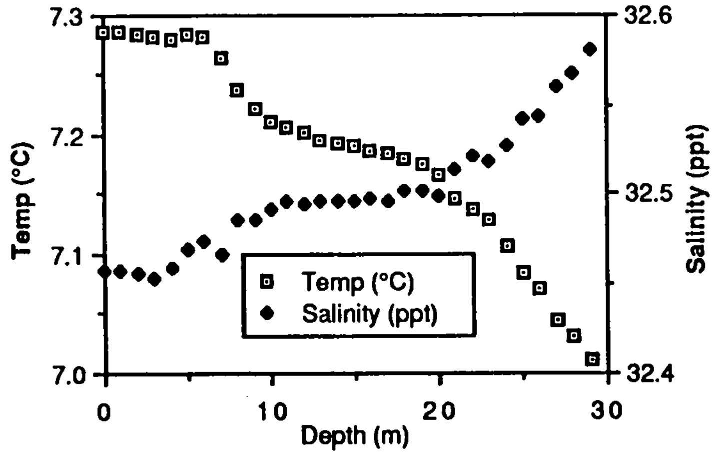
9.3 22 Sept 1986



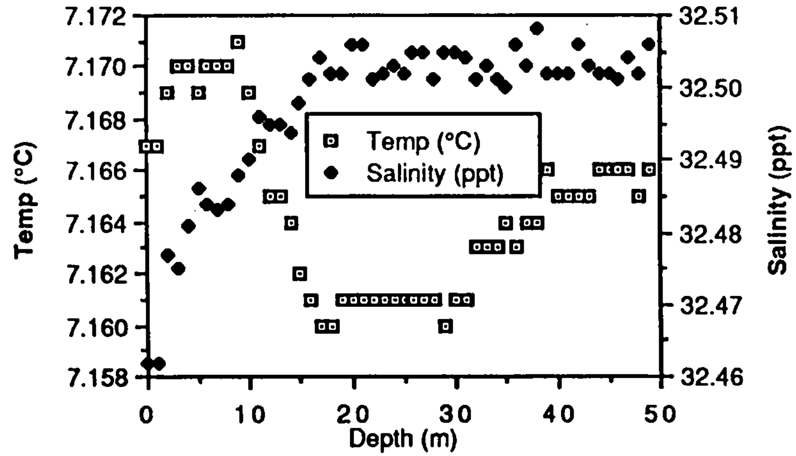
9.4 30 Sept 1986



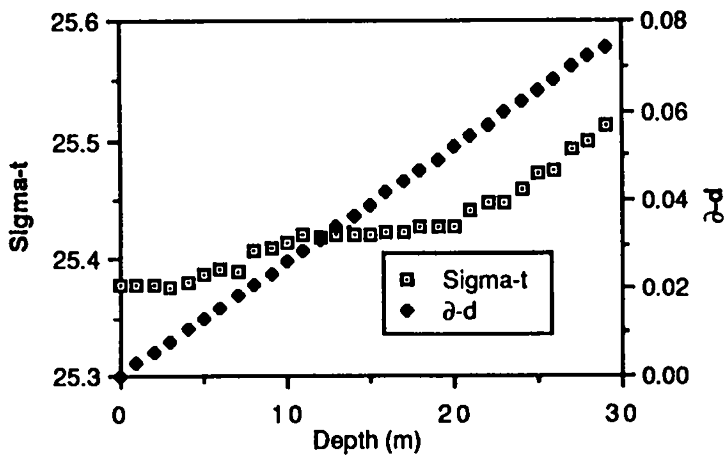
9.6 1 Oct 1986



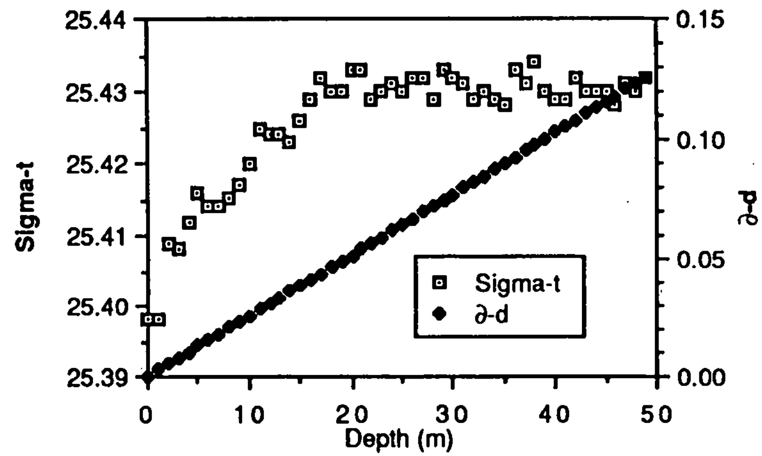
9.7 1 Oct 1986

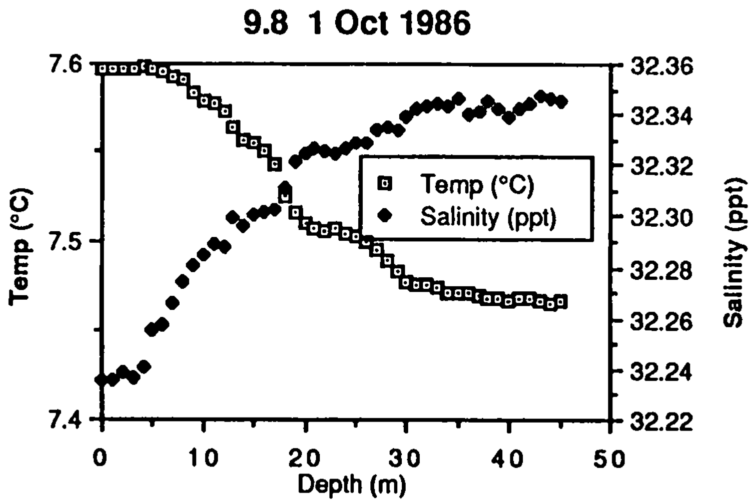


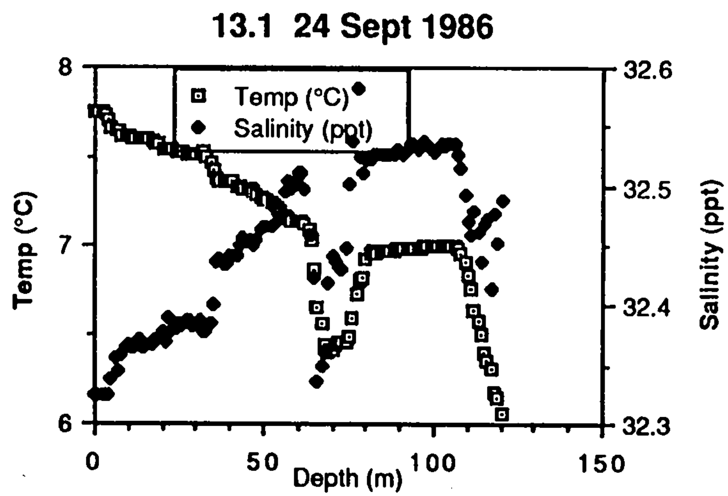
9.6 1 Oct 1986

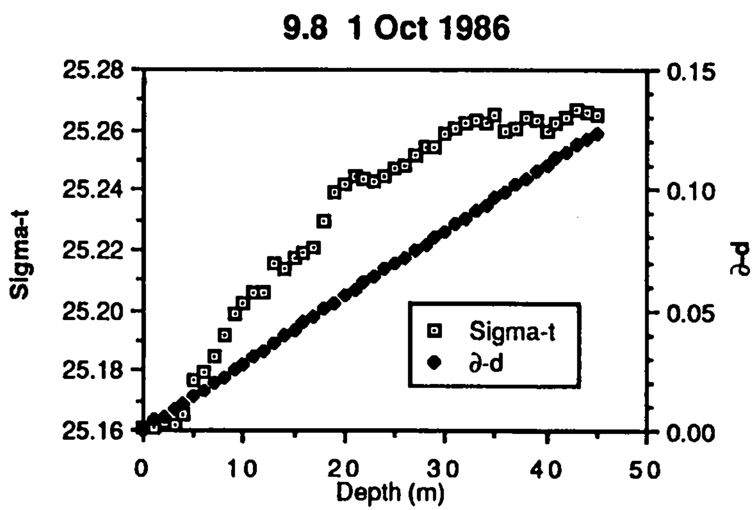


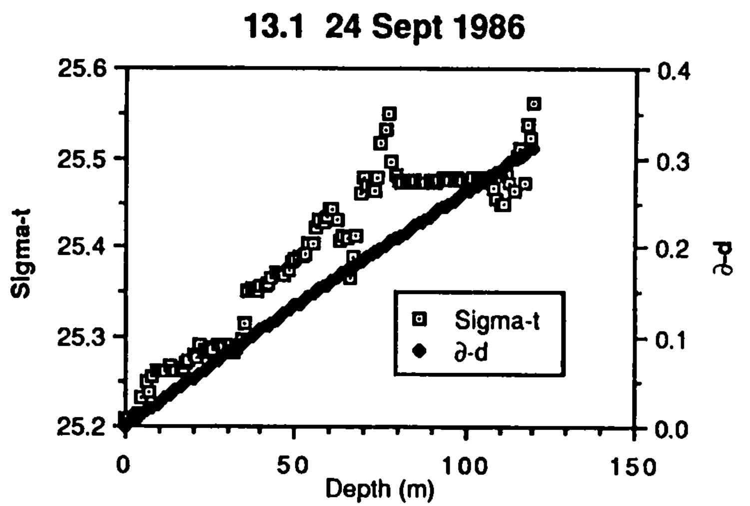
9.7 1 Oct 1986



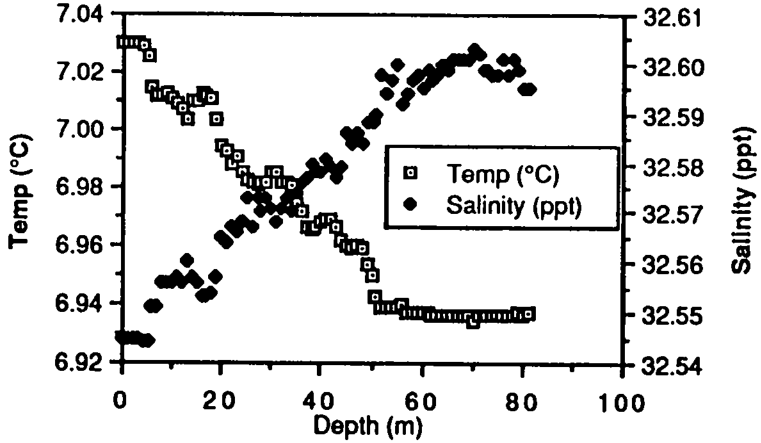

9.8 1 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.6
7.5
7.4
32.36
32.34
32.32
32.30
32.28
32.26
32.24
32.22
0
10
20
30
40
50


13.1 24 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
8
7
6
32.6
32.5
32.4
32.3
0
50
100
150

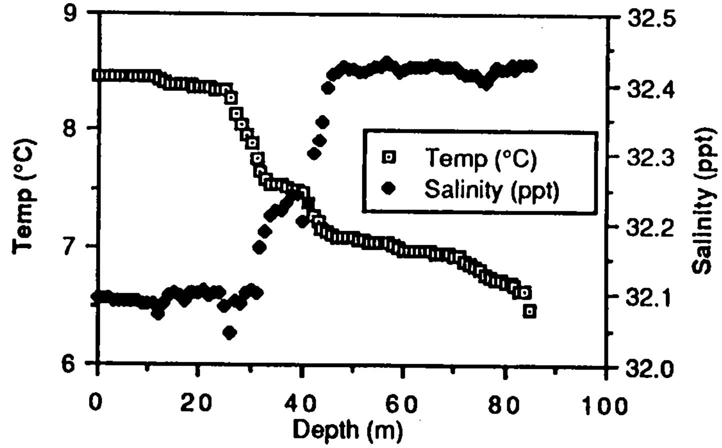

9.8 1 Oct 1986
Sigma-t
∂-d
Depth (m)
25.28
25.26
25.24
25.22
25.20
25.18
25.16
0.15
0.10
0.05
0.00
0
10
20
30
40
50


13.1 24 Sept 1986
Sigma-t
∂-d
Depth (m)
25.6
25.5
25.4
25.3
25.2
0.4
0.3
0.2
0.1
0.0
0
50
100
150

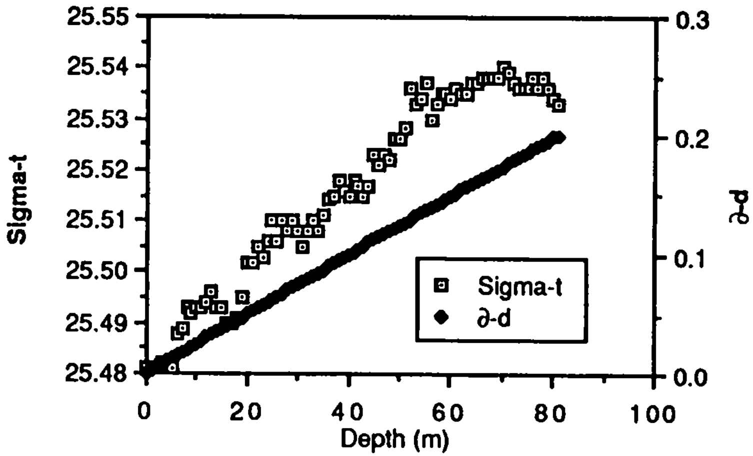
13.2 24 Sept 1986



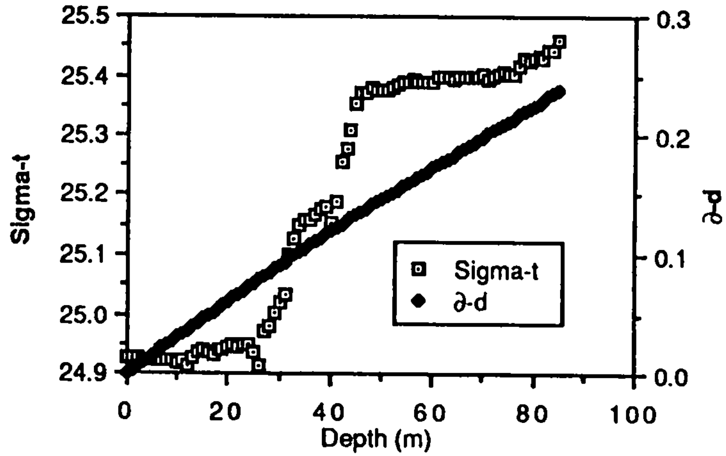
14.1 23 Sept 1986



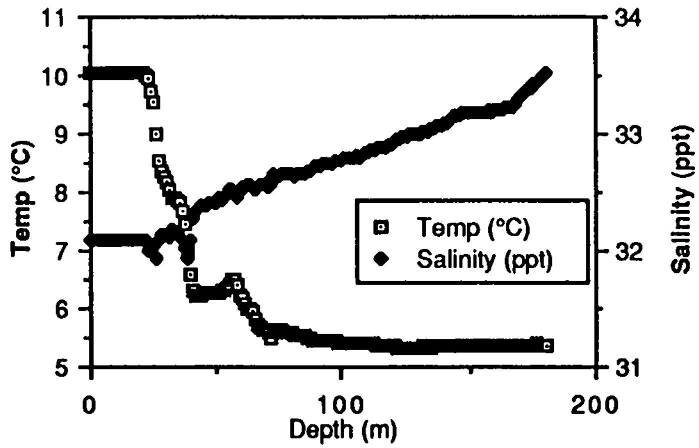
13.2 24 Sept 1986



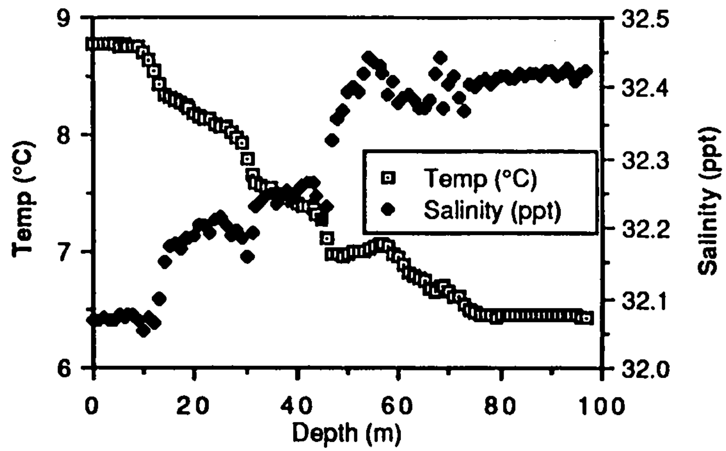
14.1 23 Sept 1986



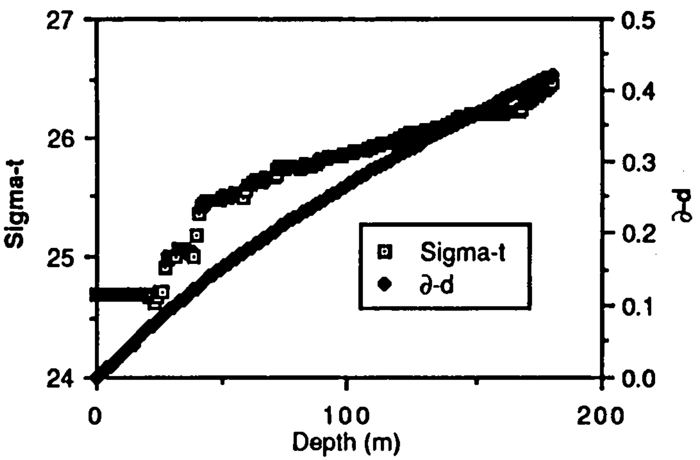
14.2 23 Sept 1986



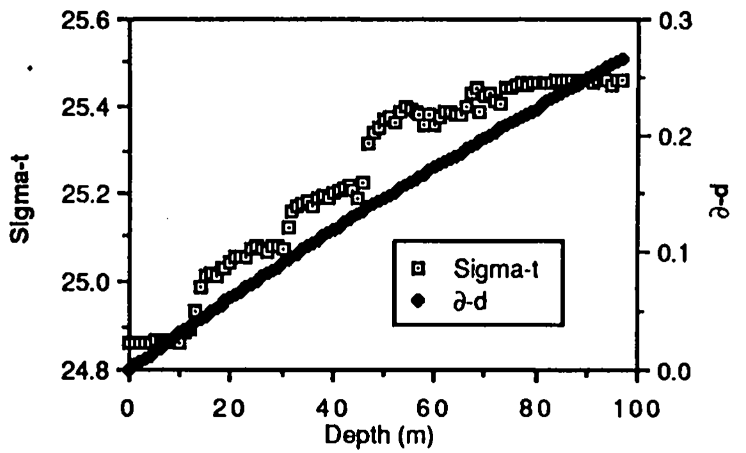
14.3 24 Sept 1986

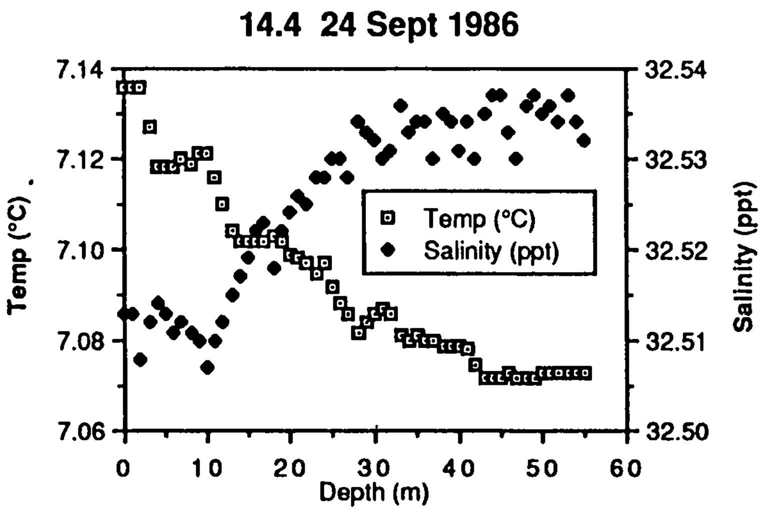


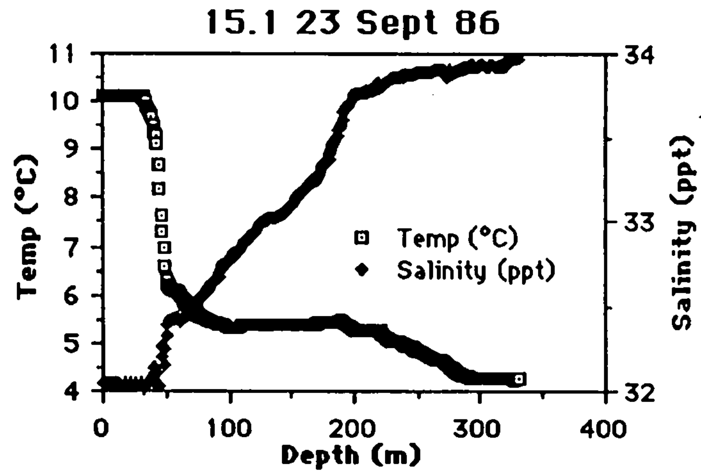
14.2 23 Sept 1986

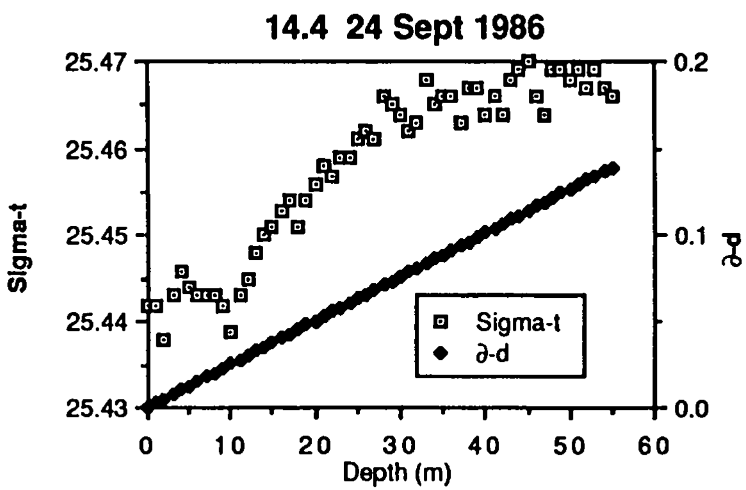


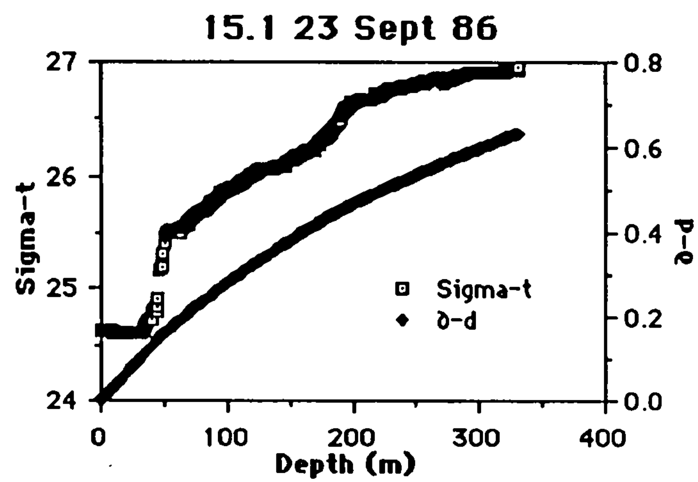
14.3 24 Sept 1986



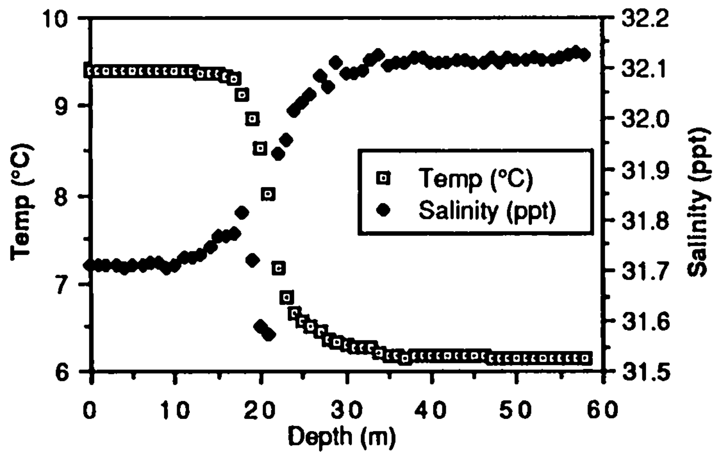

14.4 24 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.14
7.12
7.10
7.08
7.06
32.54
32.53
32.52
32.51
32.50
0 10 20 30 40 50 60


15.1 23 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
11
10
9
8
7
6
5
4
34
33
32
0 100 200 300 400

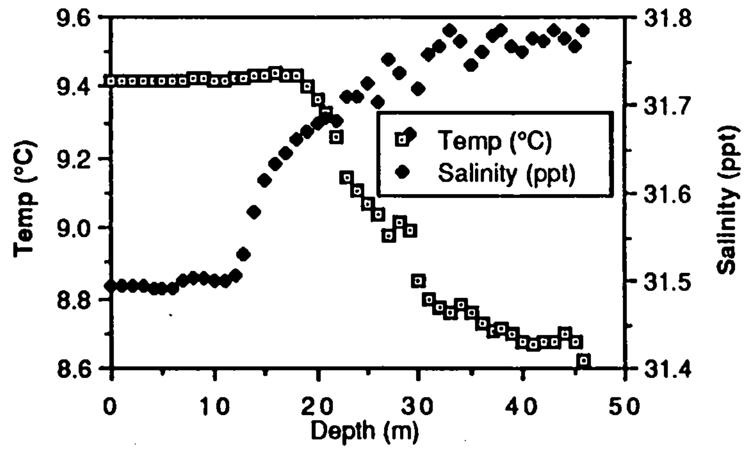

14.4 24 Sept 1986
Sigma-t
∂-d
Depth (m)
25.47
25.46
25.45
25.44
25.43
0.2
0.1
0.0
0 10 20 30 40 50 60


15.1 23 Sept 86
Sigma-t
∂-d
Depth (m)
27
26
25
24
0.8
0.6
0.4
0.2
0.0
0 100 200 300 400

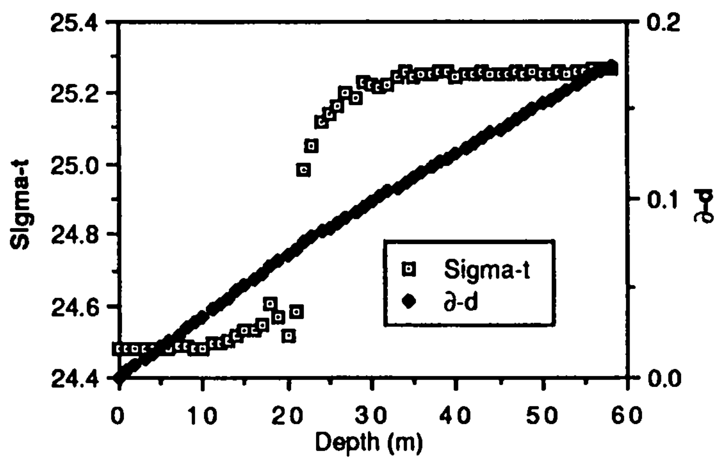
16.1 25 Sept 1986



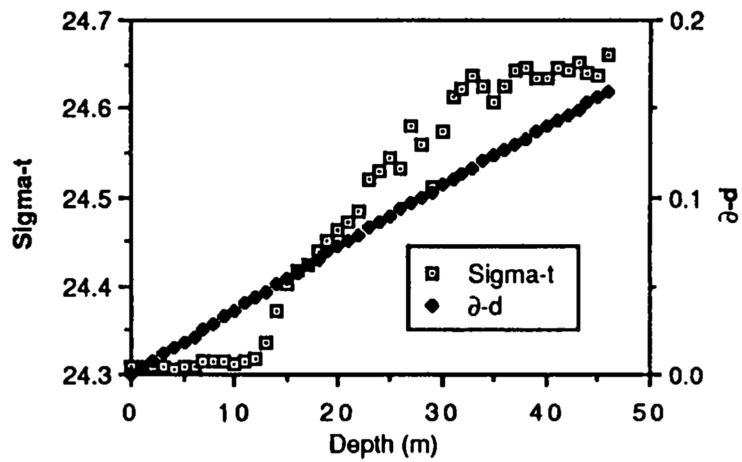
16.2 25 Sept 1986

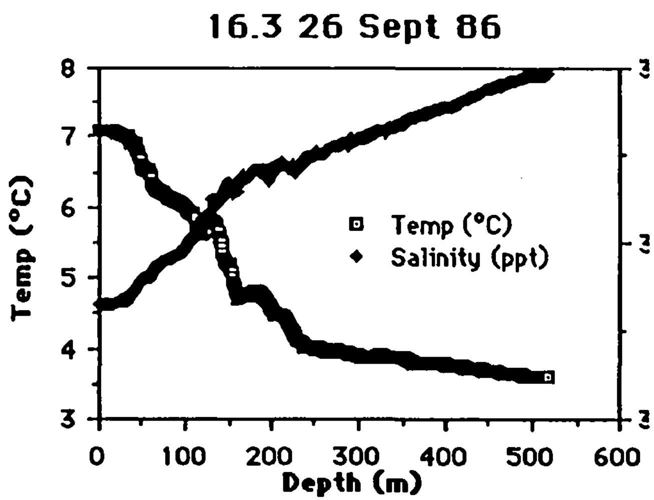


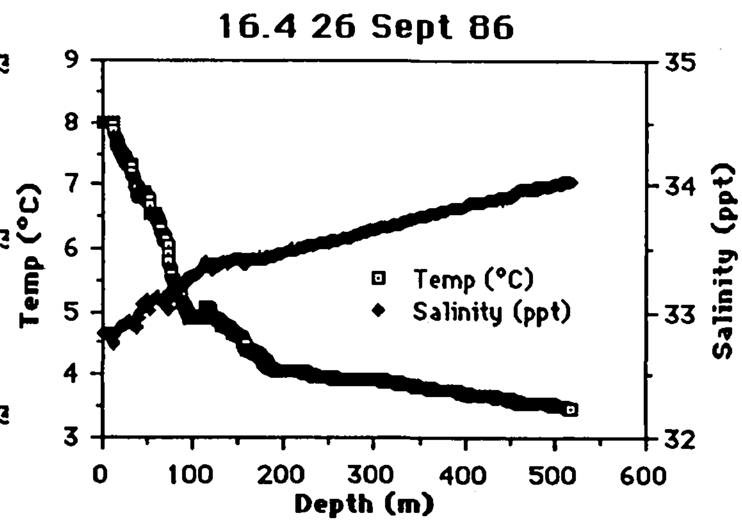
16.1 25 Sept 1986

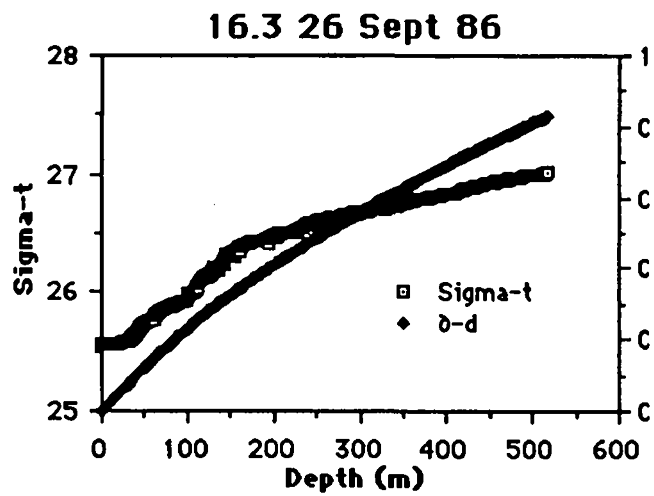


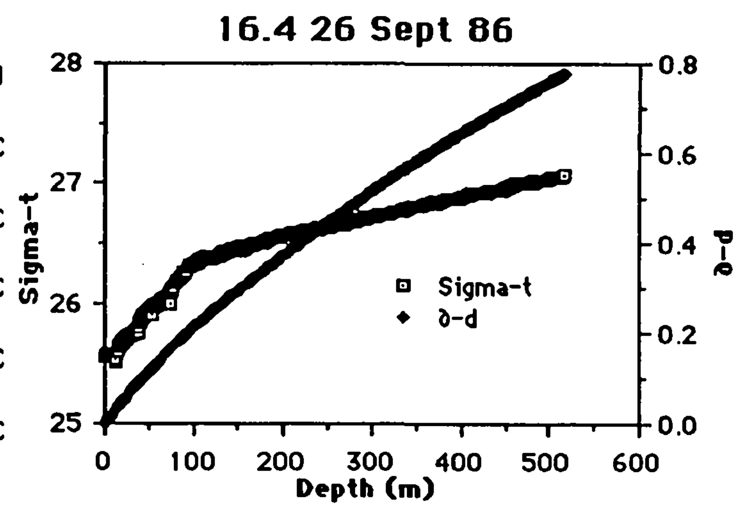
16.2 25 Sept 1986

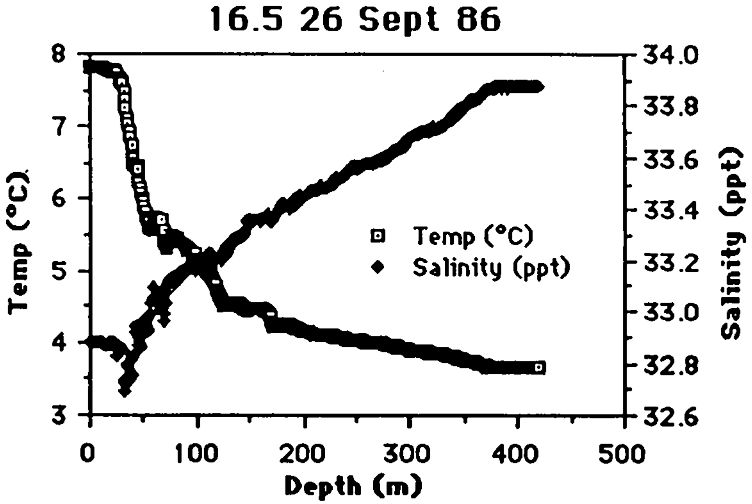


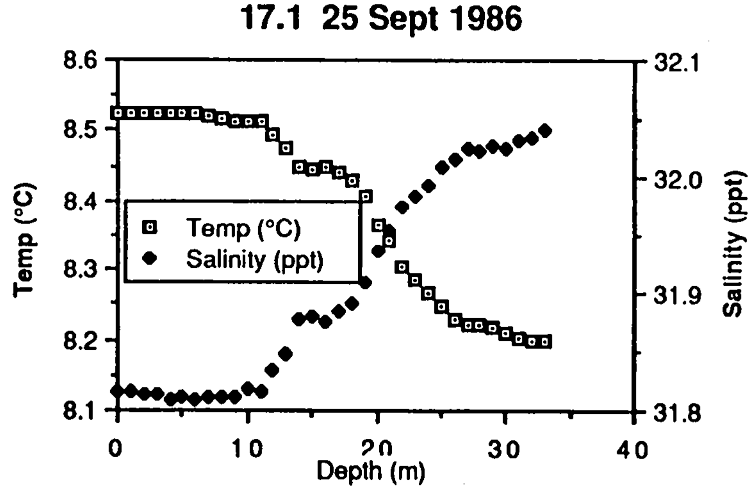

16.3 26 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
8
7
6
5
4
3
0
100
200
300
400
500
600

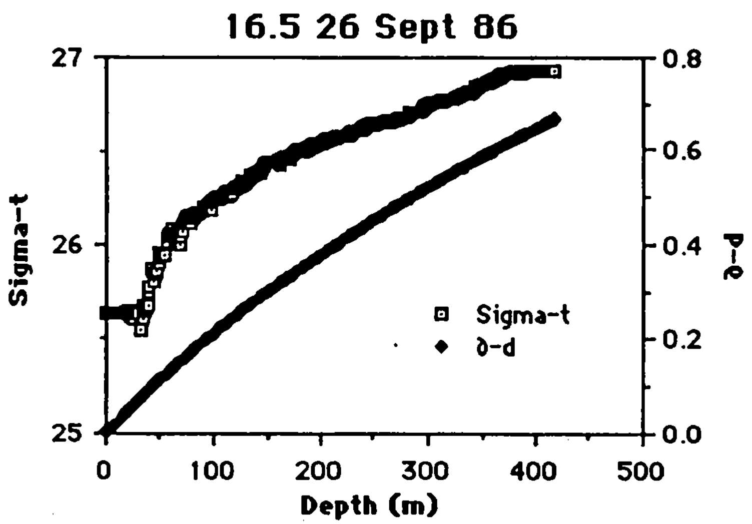

16.4 26 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
9
8
7
6
5
4
3
35
34
33
32
0
100
200
300
400
500
600

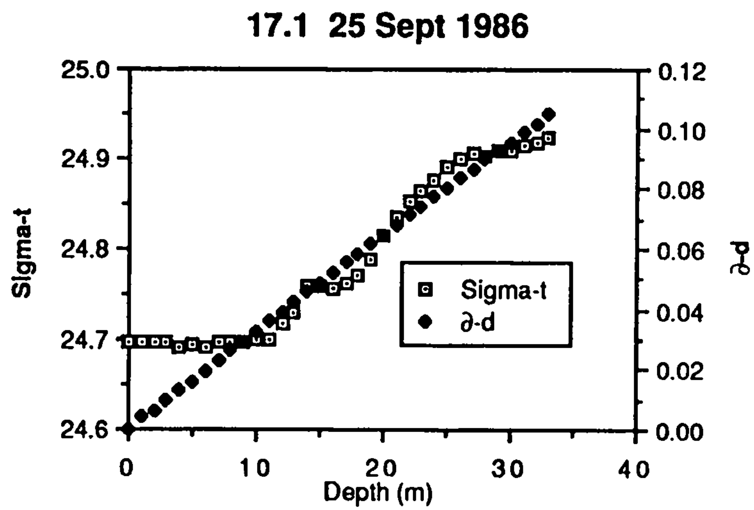

16.3 26 Sept 86
Sigma-t
ծ-d
Depth (m)
28
27
26
25
0
100
200
300
400
500
600


16.4 26 Sept 86
Sigma-t
ծ-d
Depth (m)
28
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600

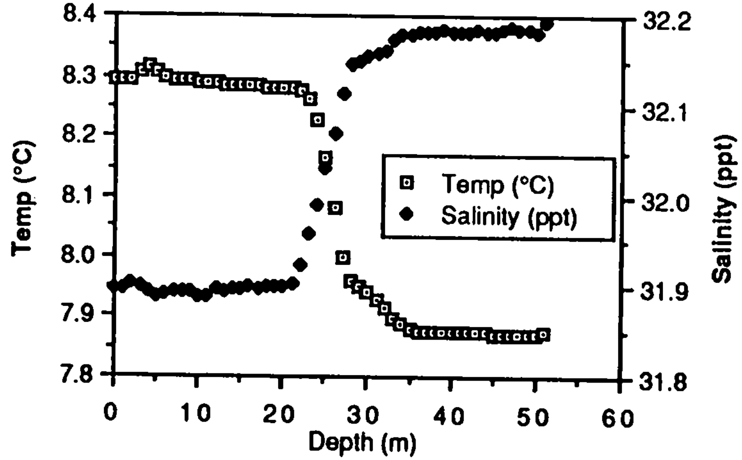

16.5 26 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)


17.1 25 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

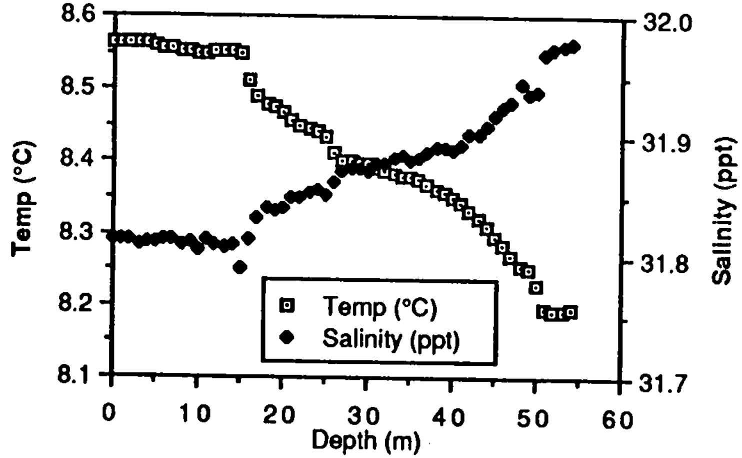

16.5 26 Sept 86
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d


17.1 25 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

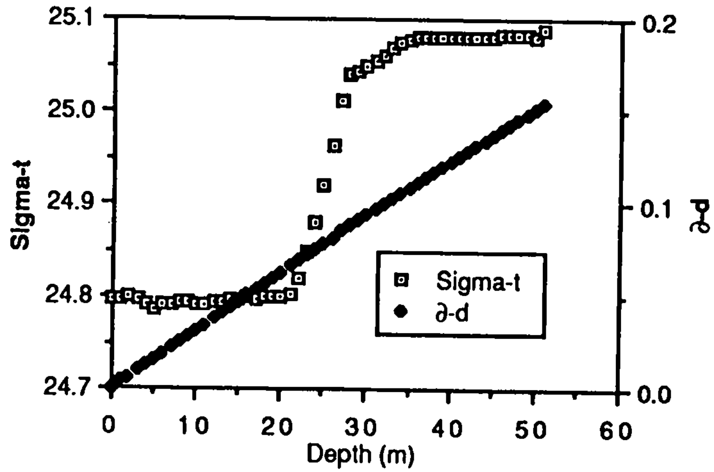
17.2 25 Sept 1986



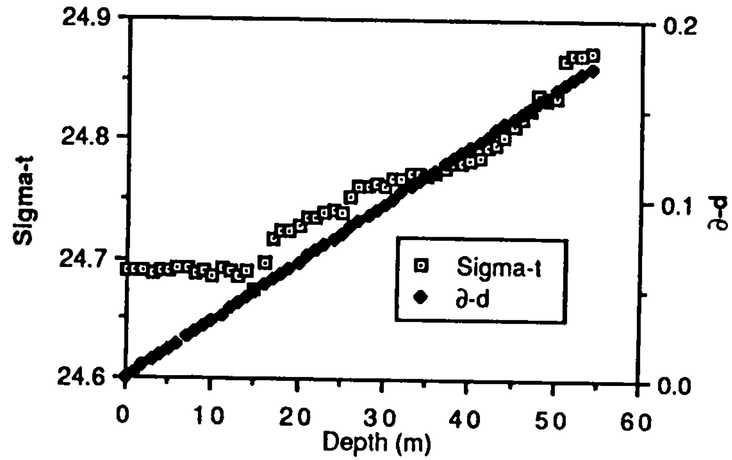
17.3 25 Sept 1986

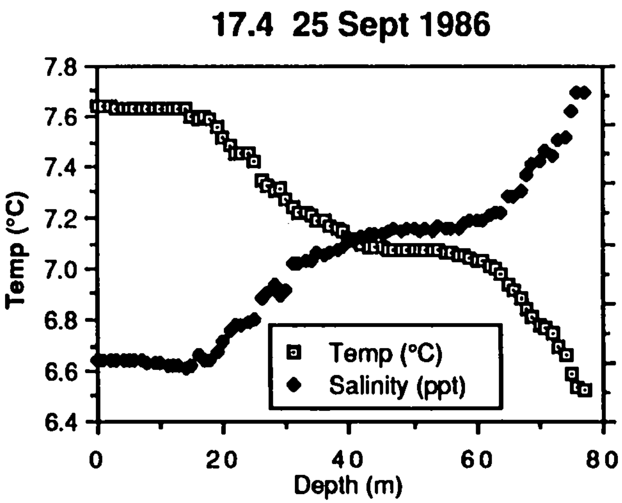


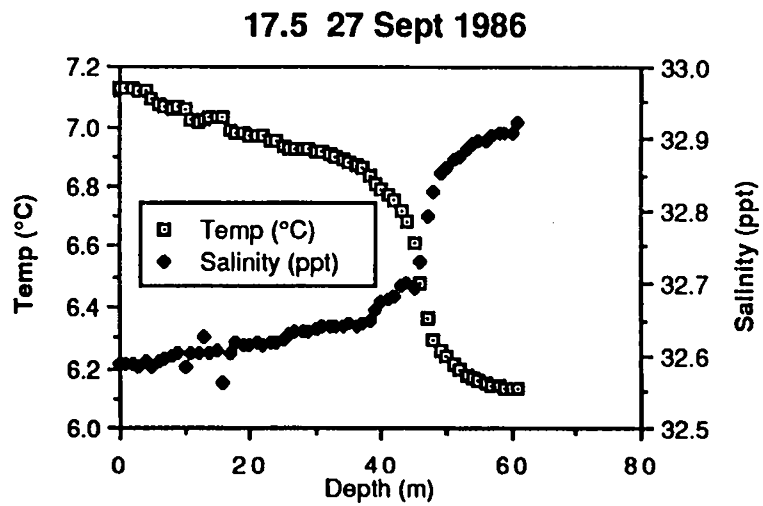
17.2 25 Sept 1986

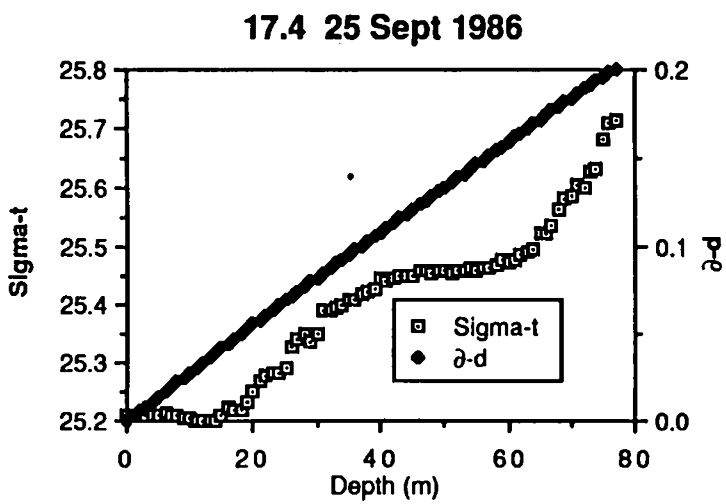


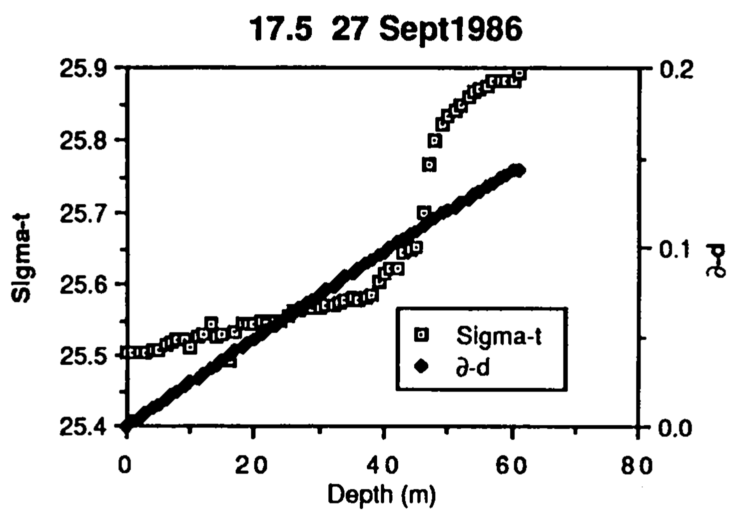
17.3 25 Sept 1986

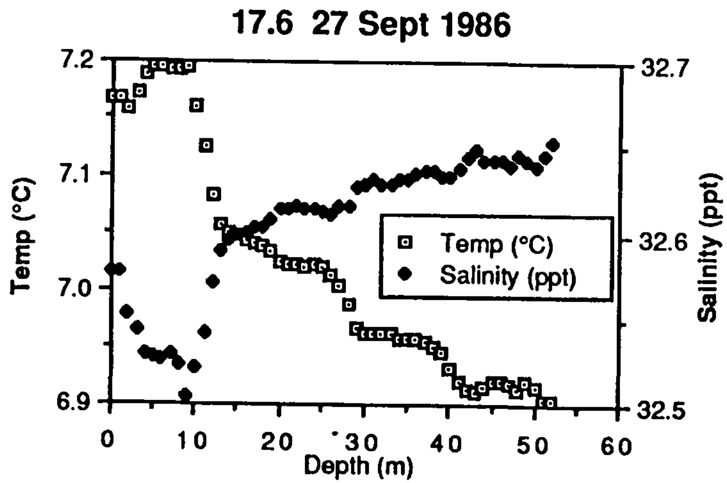


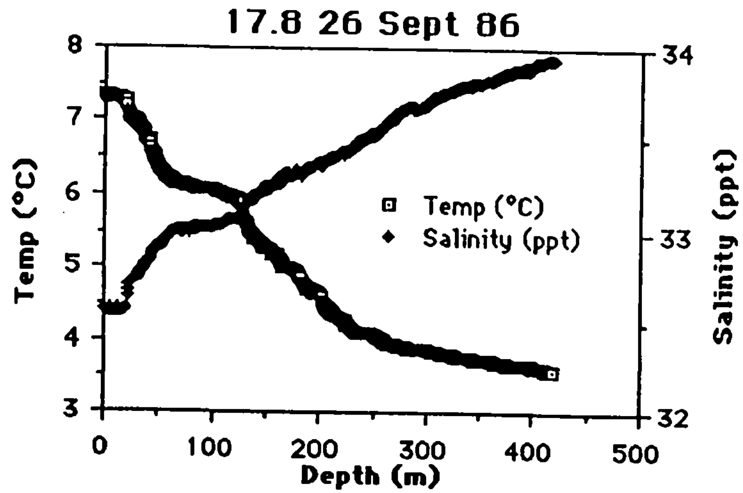

17.4 25 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
32.8
32.7
32.6
32.5
32.4
32.3
32.2
0
20
40
60
80

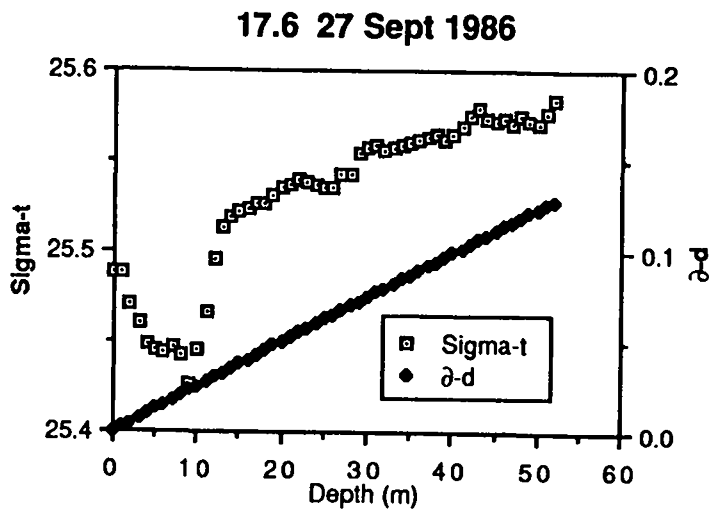

17.5 27 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.2
7.0
6.8
6.6
6.4
6.2
6.0
33.0
32.9
32.8
32.7
32.6
32.5
0
20
40
60
80

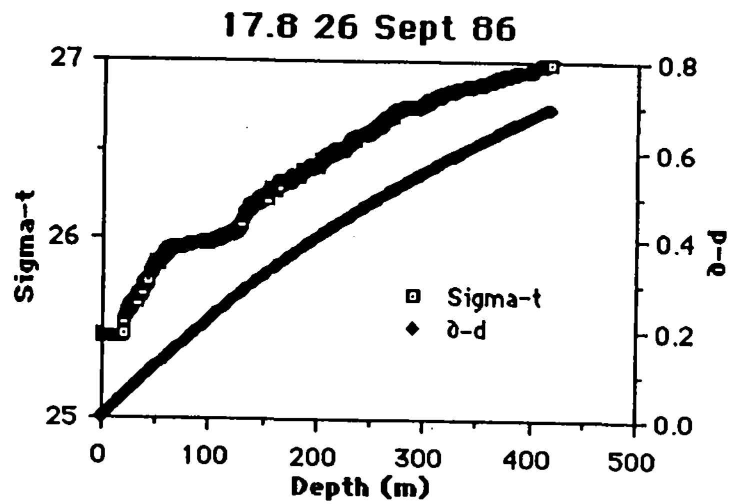

17.4 25 Sept 1986
Sigma-t
∂-d
Depth (m)
25.8
25.7
25.6
25.5
25.4
25.3
25.2
0.2
0.1
0.0
0
20
40
60
80


17.5 27 Sept1986
Sigma-t
∂-d
Depth (m)
25.9
25.8
25.7
25.6
25.5
25.4
0.2
0.1
0.0
0
20
40
60
80

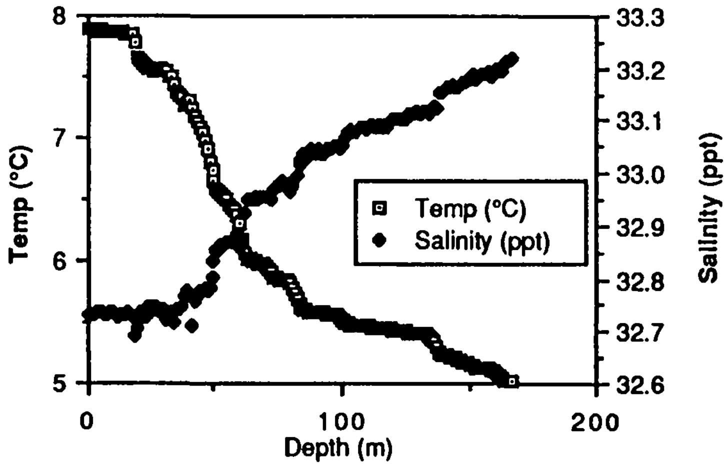

17.6 27 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)


17.8 26 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

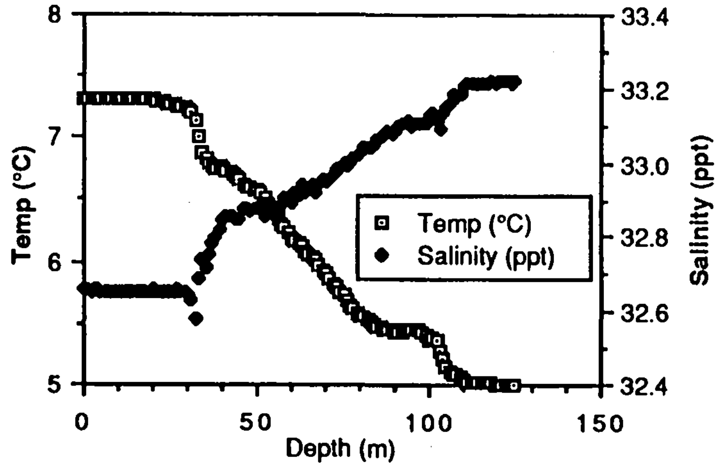

17.6 27 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d


17.8 26 Sept 86
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

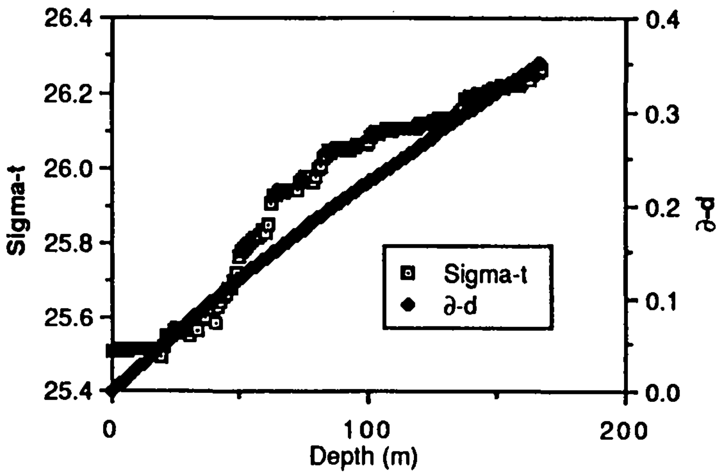
19.1 27 Sept 1986



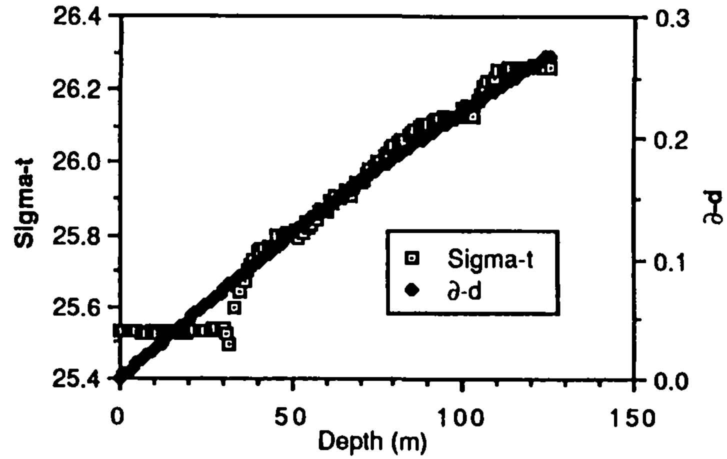
19.2 27 Sept 1986

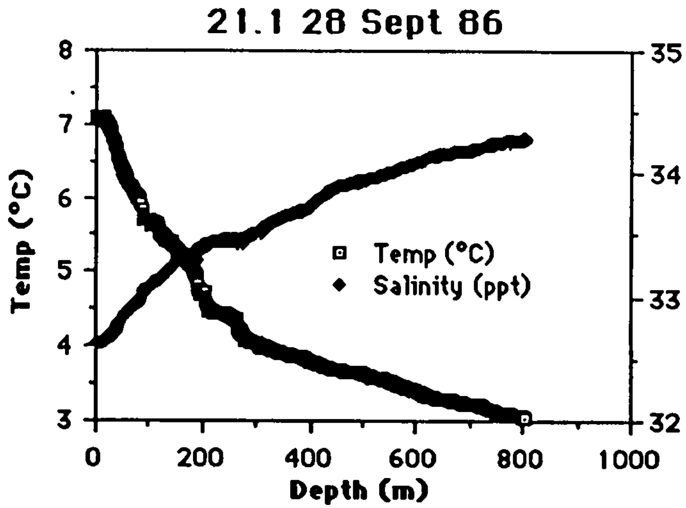


19.1 27 Sept 1986

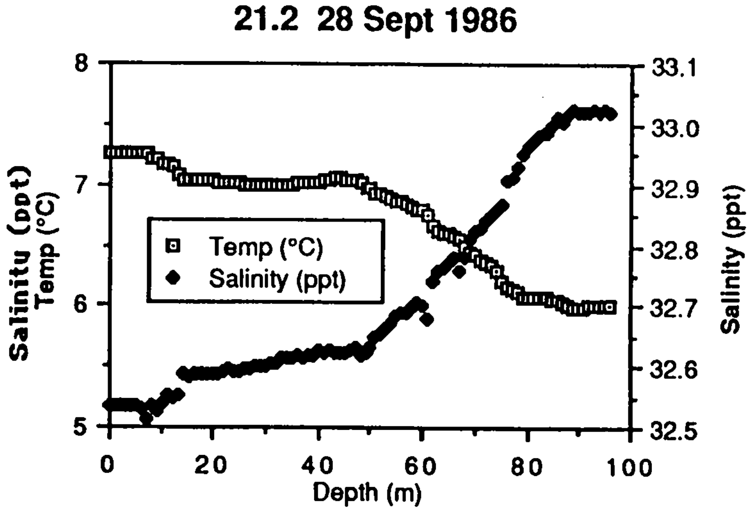


19.2 27 Sept 1986

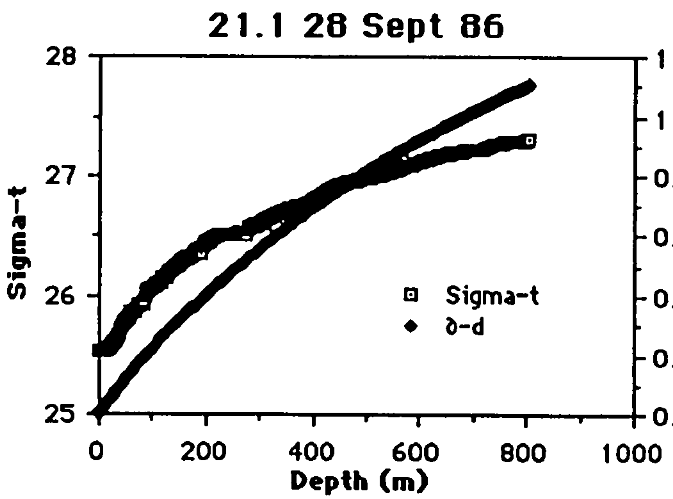




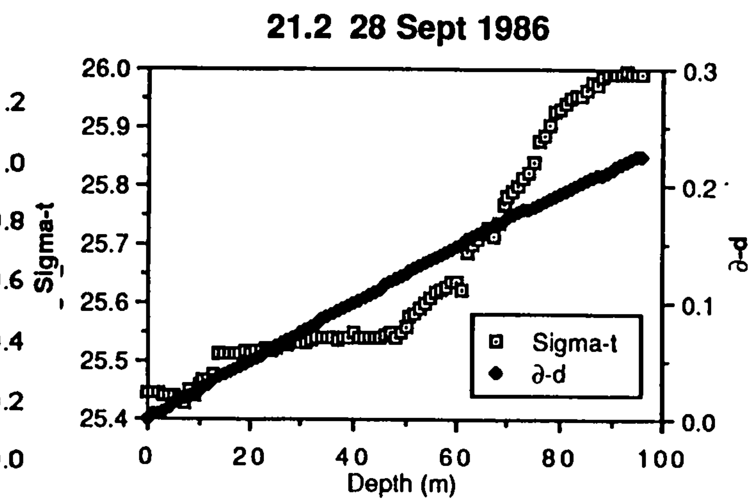
21.1 28 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)



21.2 28 Sept 1986
Temp (°C)
Salinity (ppt)
Salinitu (ppt)
Depth (m)

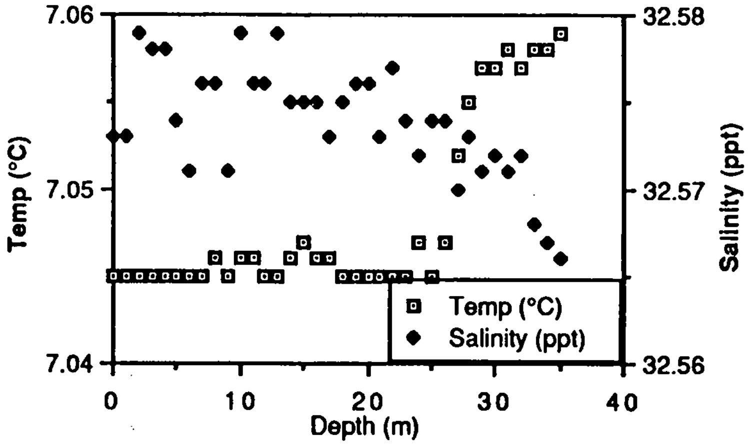


21.1 28 Sept 86
Sigma-t
∂-d
Depth (m)

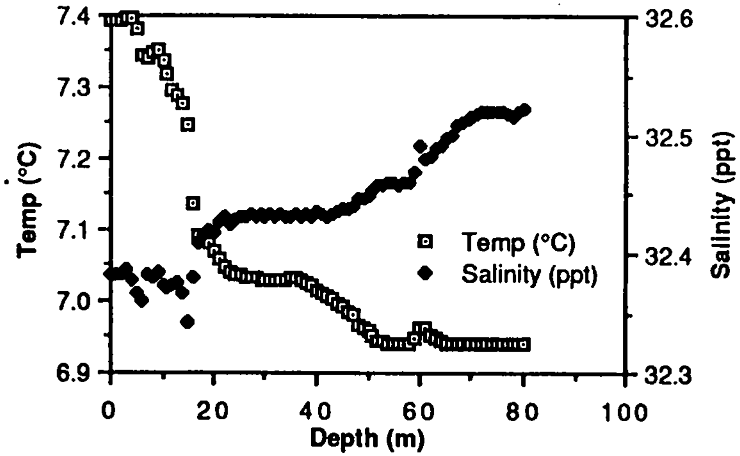


21.2 28 Sept 1986
Sigma-t
∂-d
Depth (m)

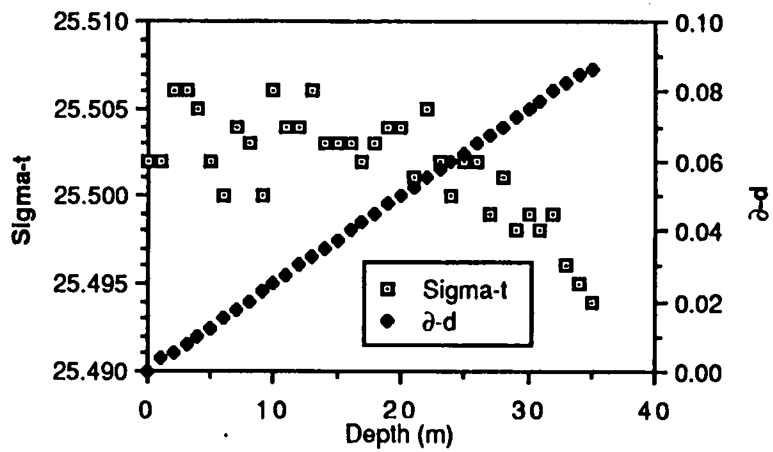
21.3 28 Sept 1986



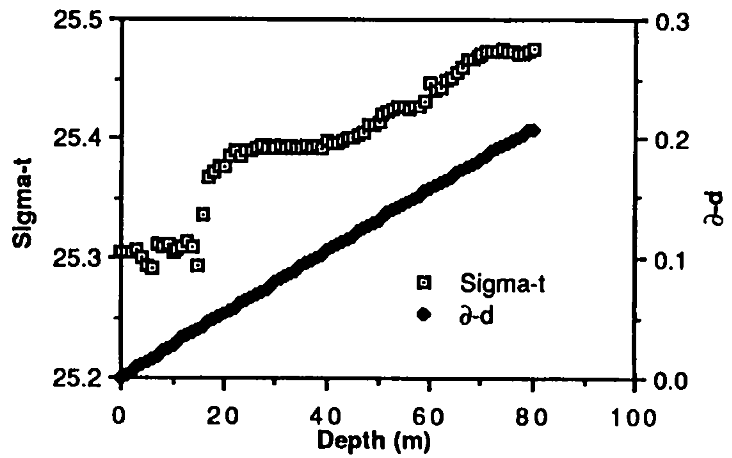
21.4 28 Sept 1986



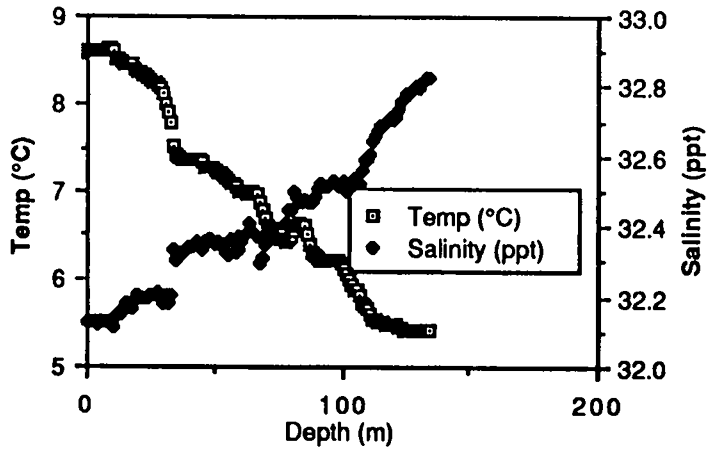
21.3 28 Sept 1986



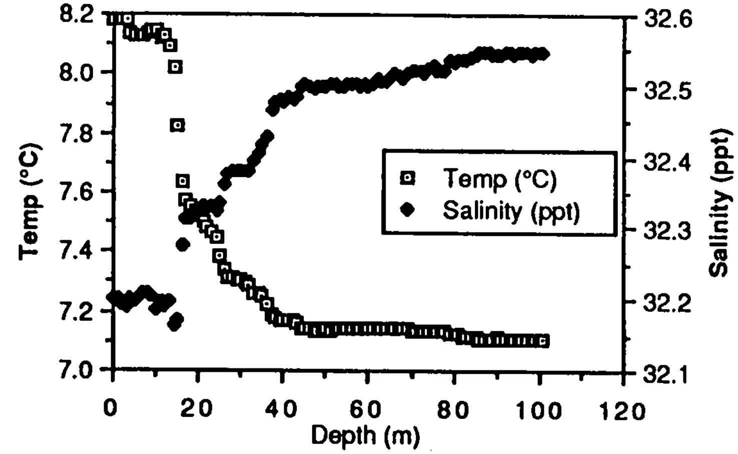
21.4 28 Sept 1986



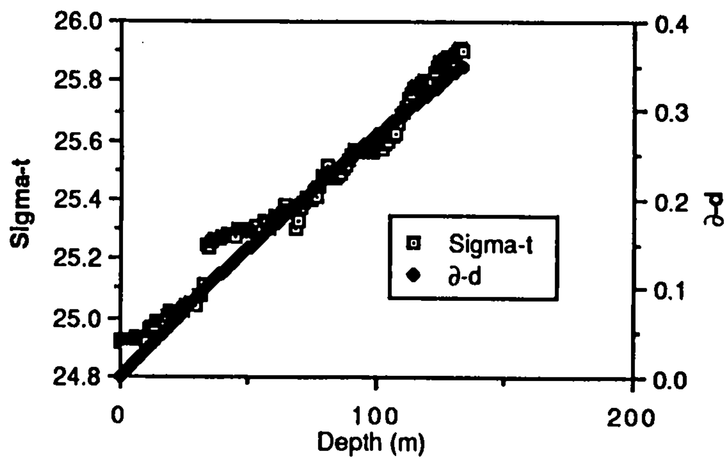
21.5 28 Sept 1986



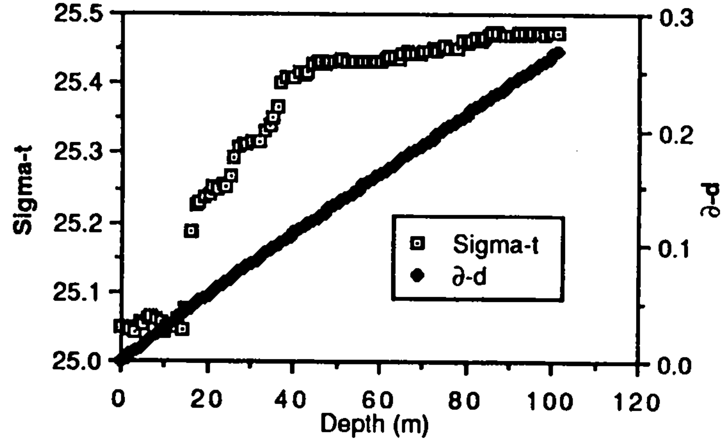
22.1 30 Sept 1986



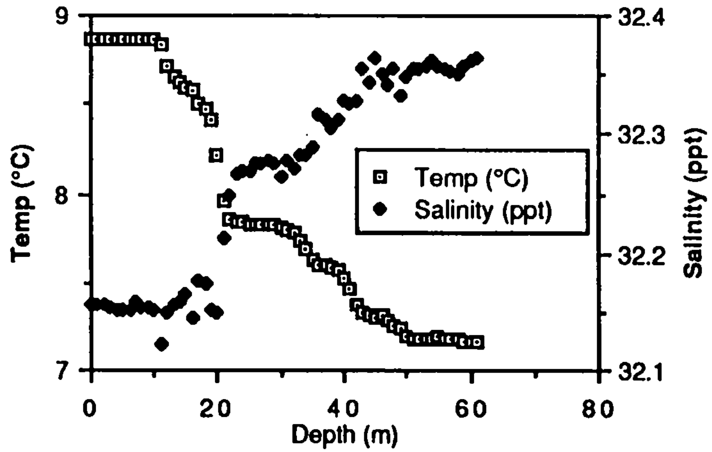
21.5 28 Sept 1986



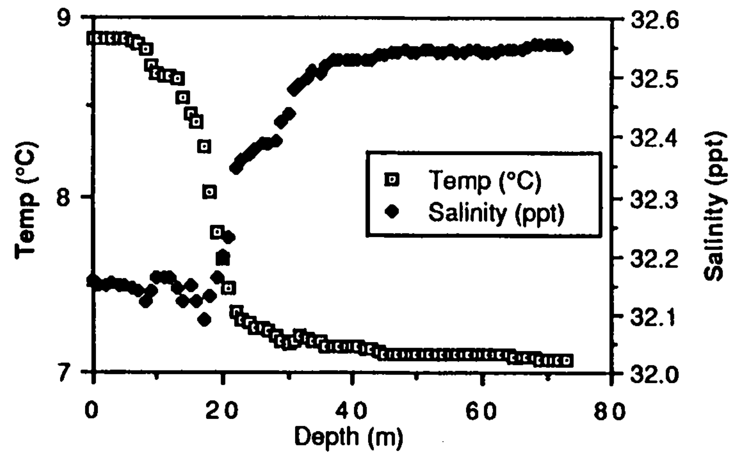
22.1 30 Sept 1986



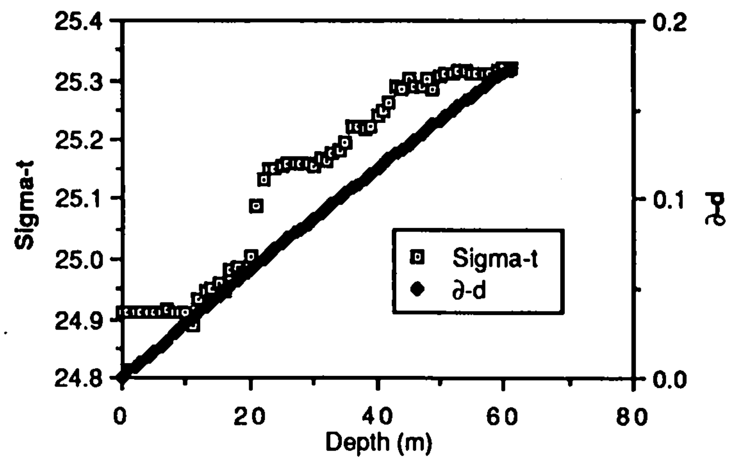
22.1 2 Oct 1986



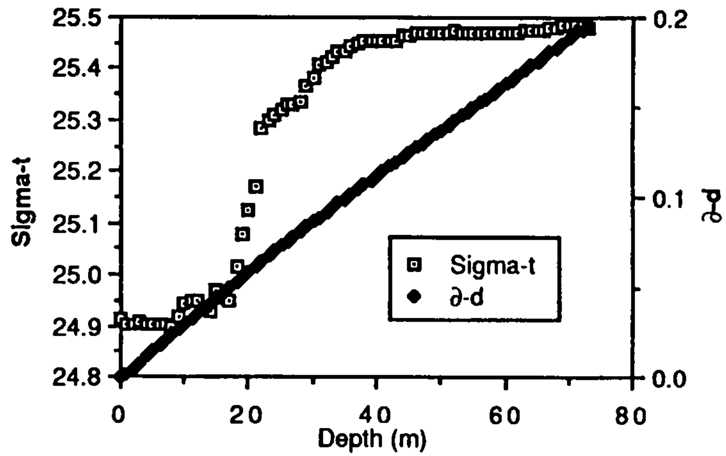
22.2 30 Sept 1986



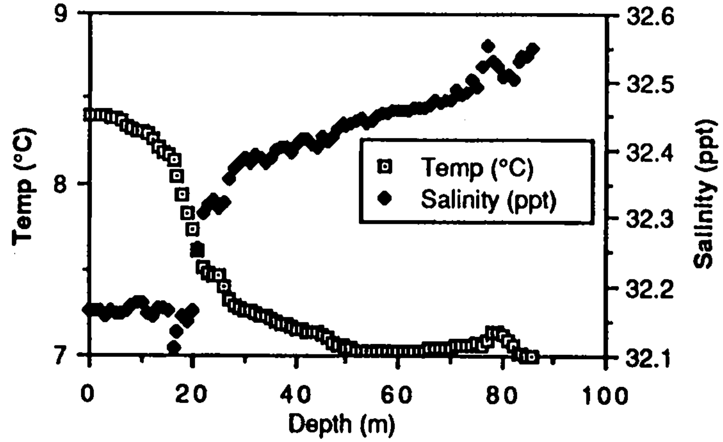
22.1 2 Oct 1986



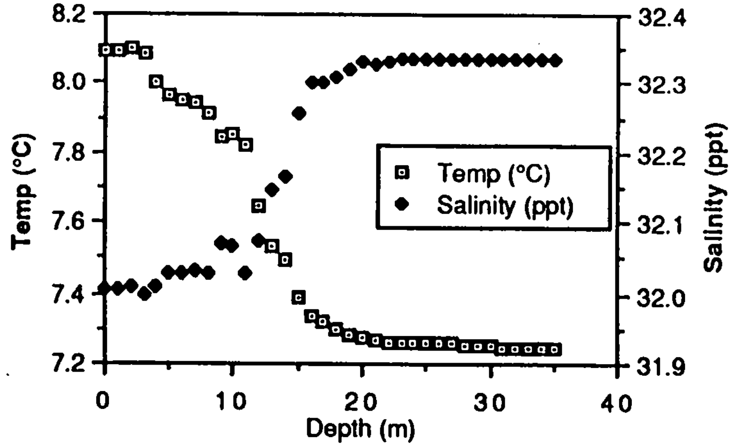
22.2 30 Sept 1986



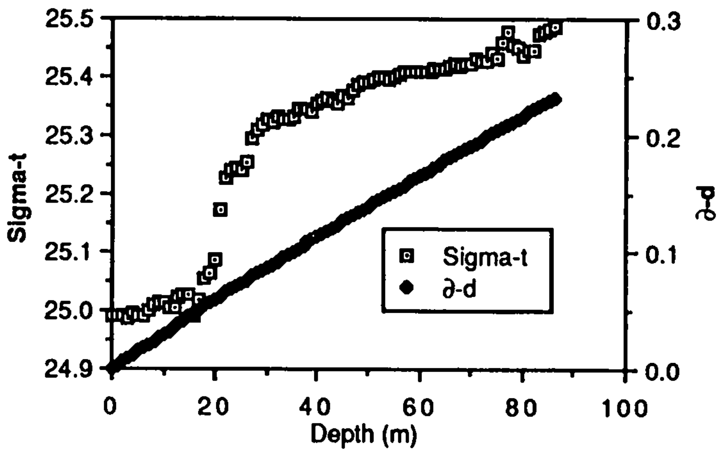
22.3 30 Sept 1986



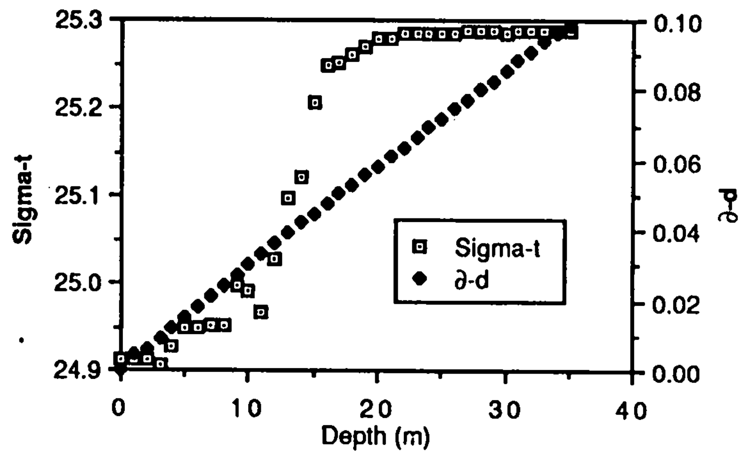
22.4 1 Oct 1986

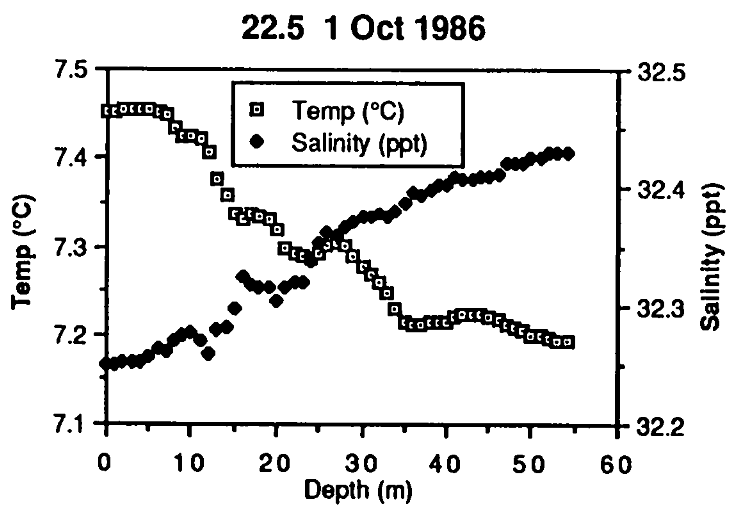


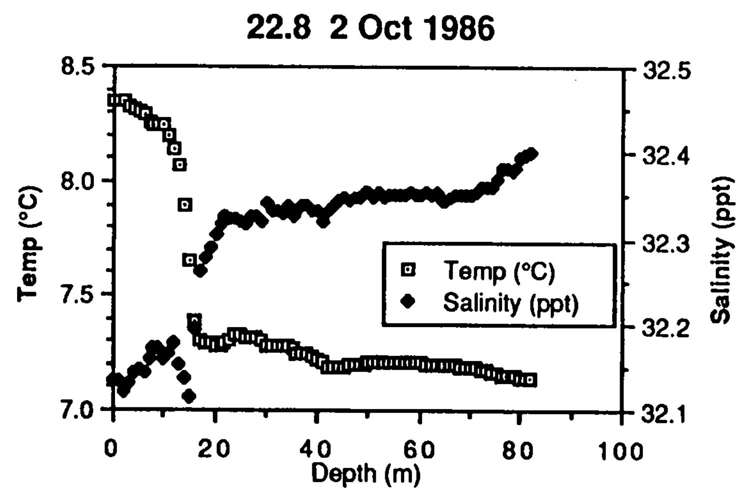
22.3 30 Sept 1986

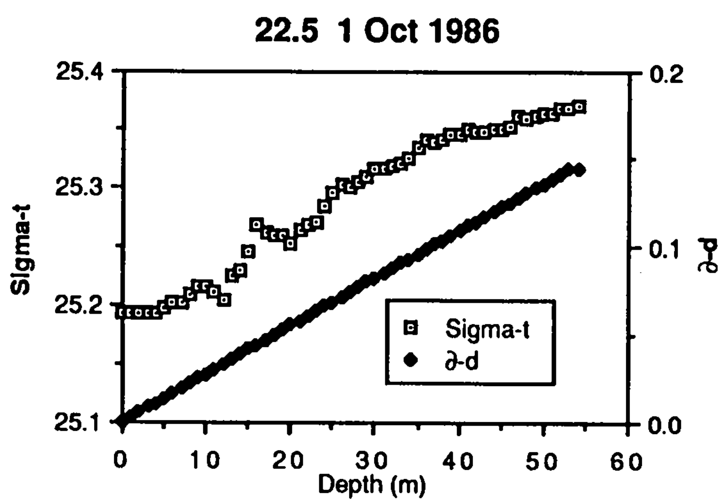


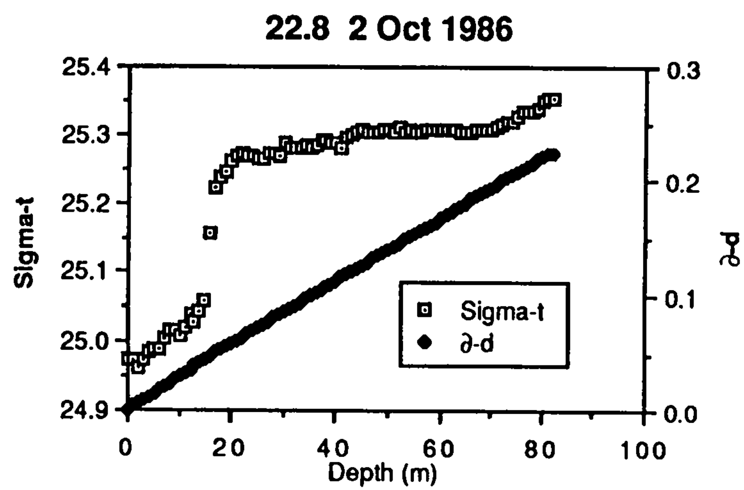
22.4 1 Oct 1986



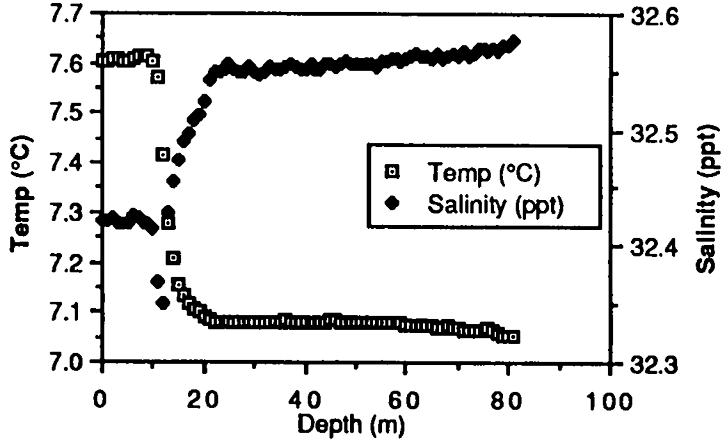

22.5 1 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.1
7.2
7.3
7.4
7.5
32.2
32.3
32.4
32.5
0
10
20
30
40
50
60


22.8 2 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.0
7.5
8.0
8.5
32.1
32.2
32.3
32.4
32.5
0
20
40
60
80
100

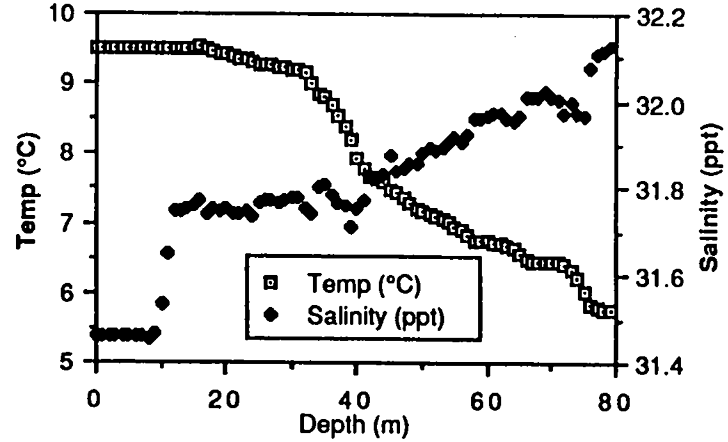

22.5 1 Oct 1986
Sigma-t
∂-d
Depth (m)
25.1
25.2
25.3
25.4
0.0
0.1
0.2
0
10
20
30
40
50
60


22.8 2 Oct 1986
Sigma-t
∂-d
Depth (m)
24.9
25.0
25.1
25.2
25.3
25.4
0.0
0.1
0.2
0.3
0
20
40
60
80
100

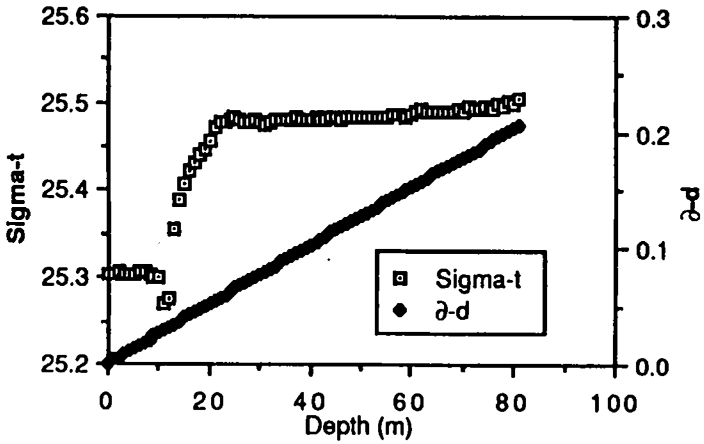
22.9 2 Oct 1986



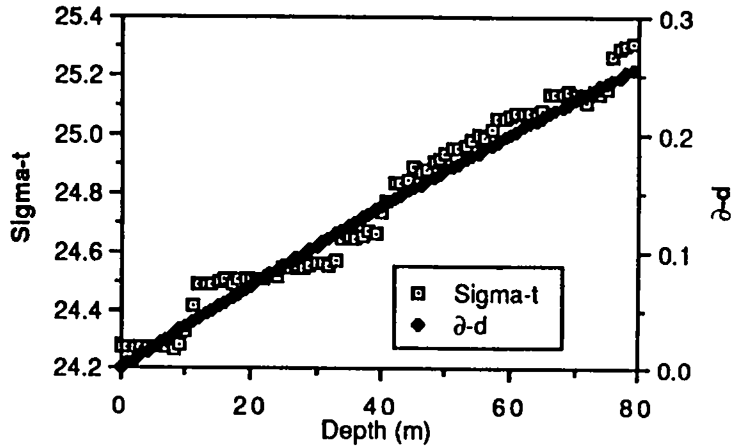
23.1 29 Sept 1986

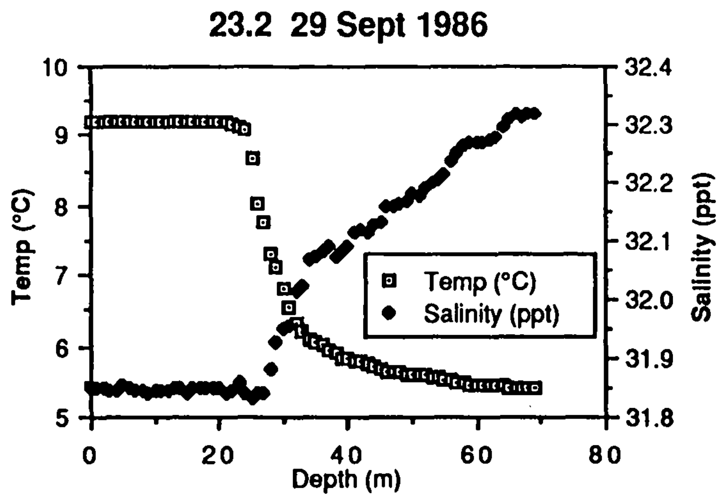


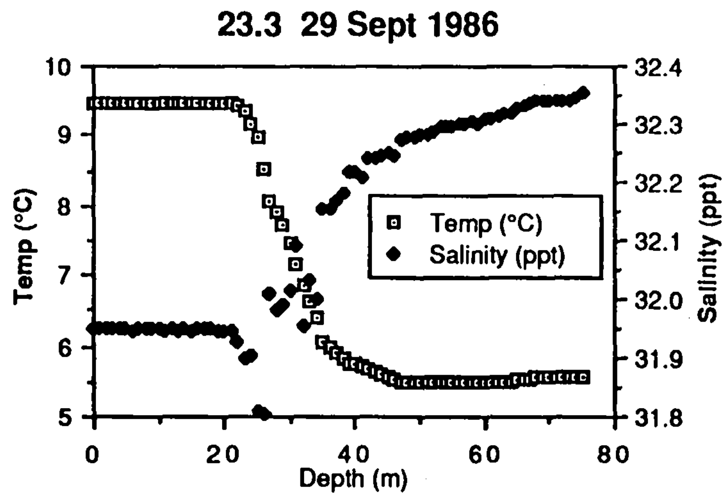
22.9 2 Oct 1986

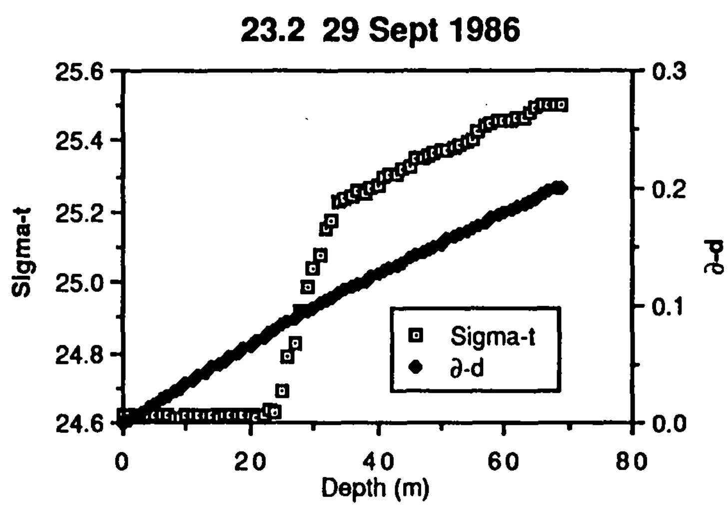


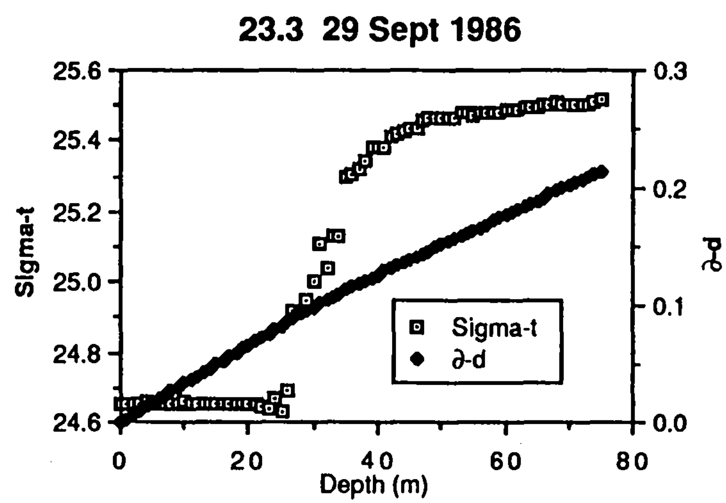
23.1 29 Sept 1986

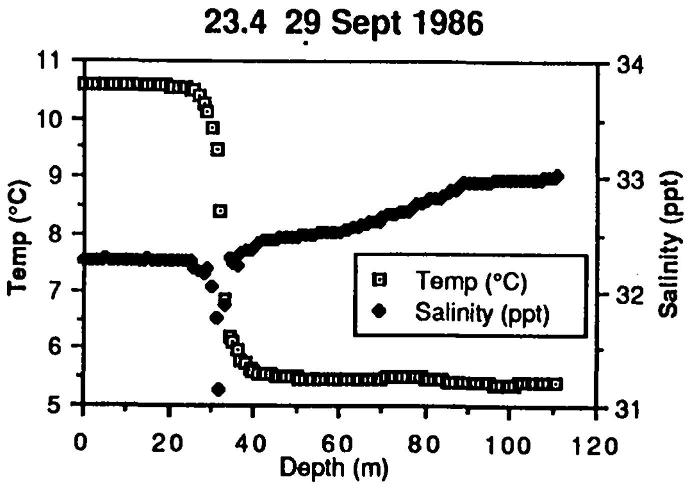


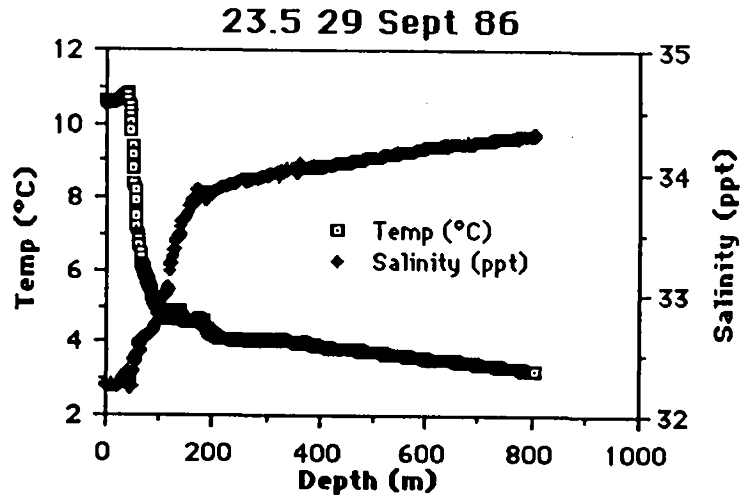

23.2 29 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

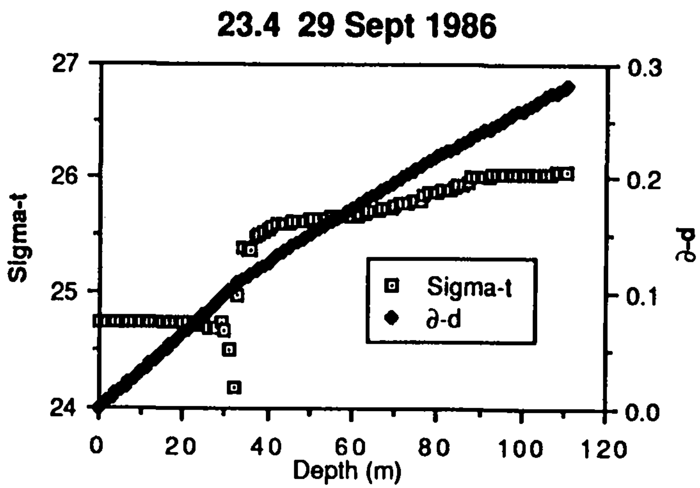

23.3 29 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

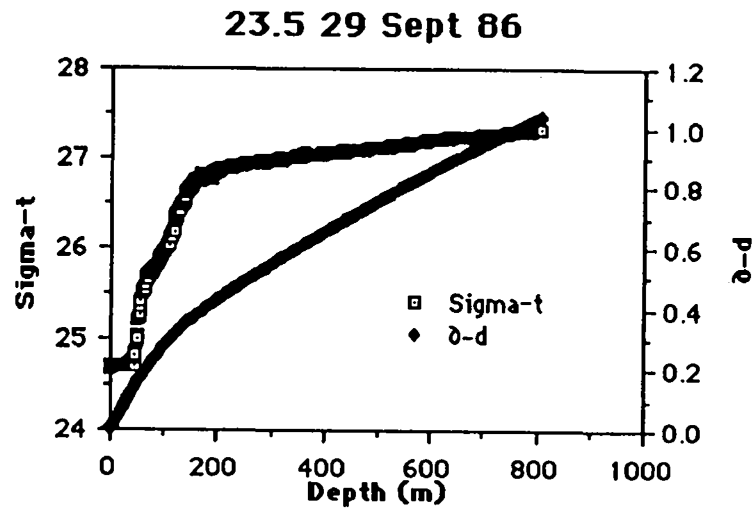

23.2 29 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

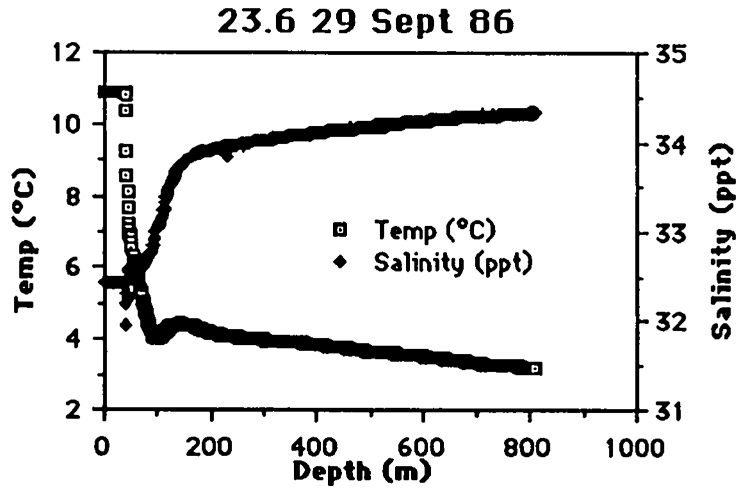

23.3 29 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

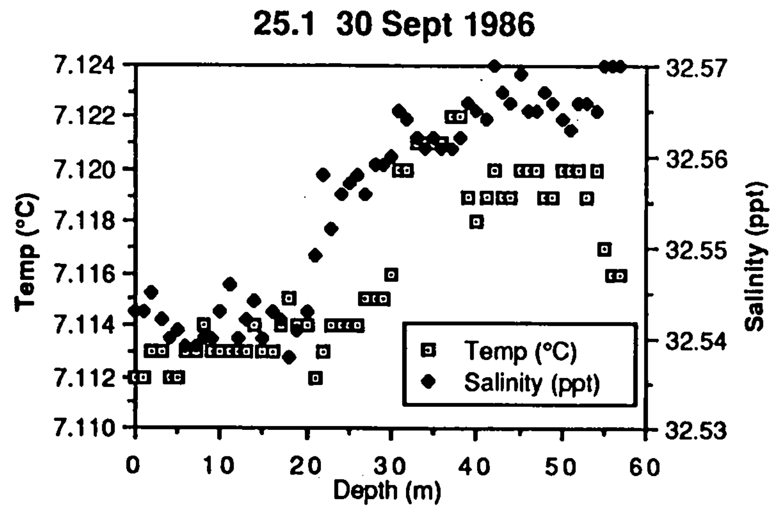

23.4 29 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

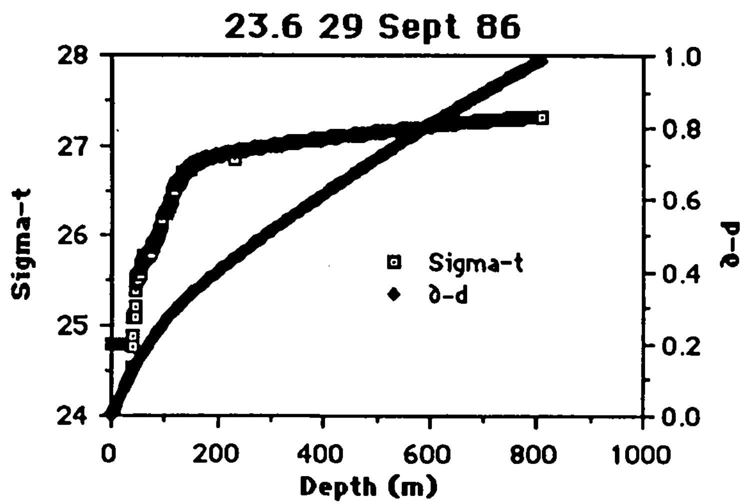

23.5 29 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

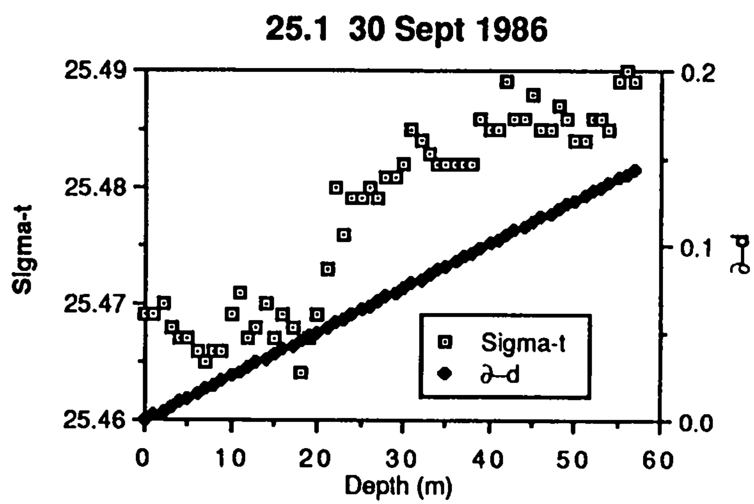

23.4 29 Sept 1986
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

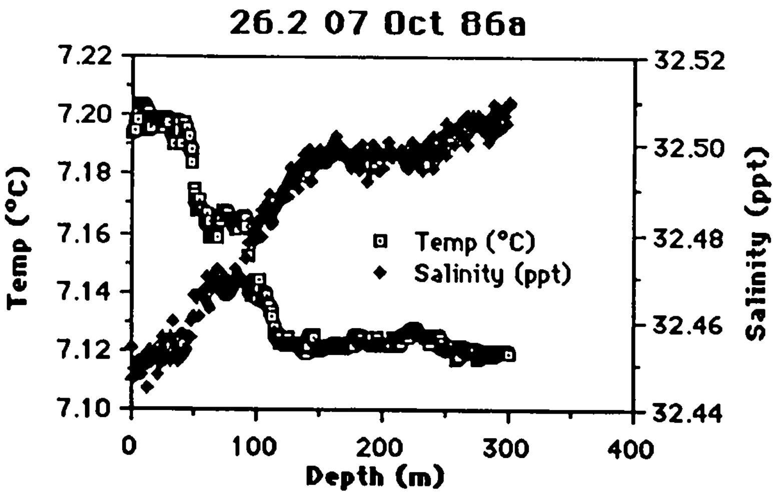

23.5 29 Sept 86
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

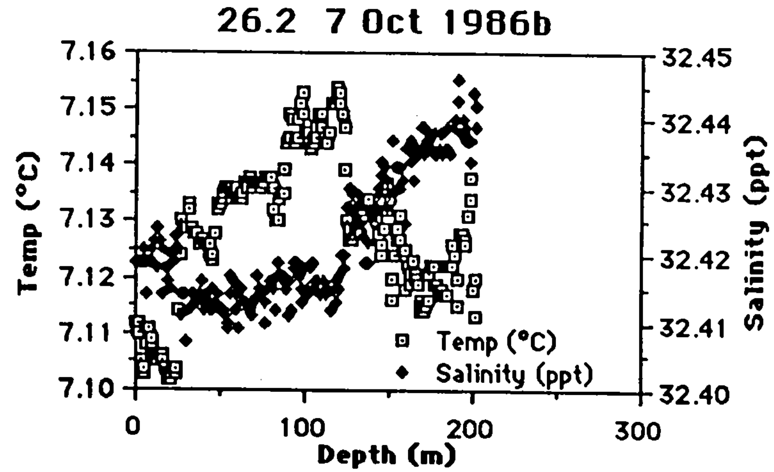

23.6 29 Sept 86
Temp (°C)
Salinity (ppt)
Depth (m)
12
10
8
6
4
2
35
34
33
32
31
0
200
400
600
800
1000

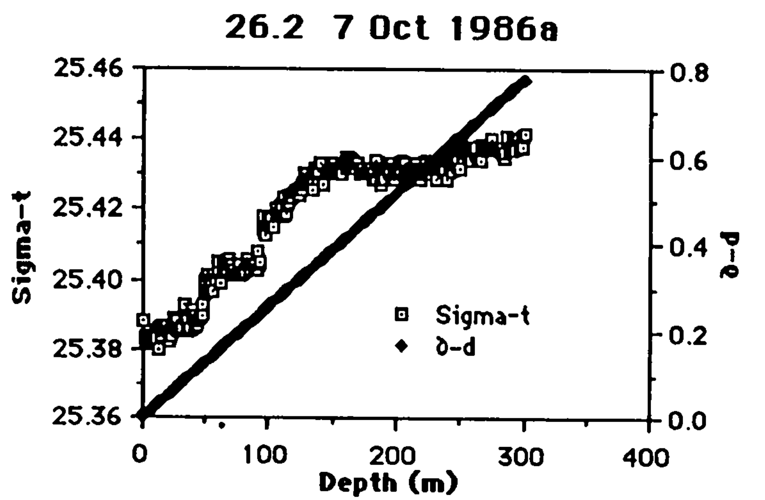

25.1 30 Sept 1986
Temp (°C)
Salinity (ppt)
Depth (m)
7.124
7.122
7.120
7.118
7.116
7.114
7.112
7.110
32.57
32.56
32.55
32.54
32.53
0
10
20
30
40
50
60

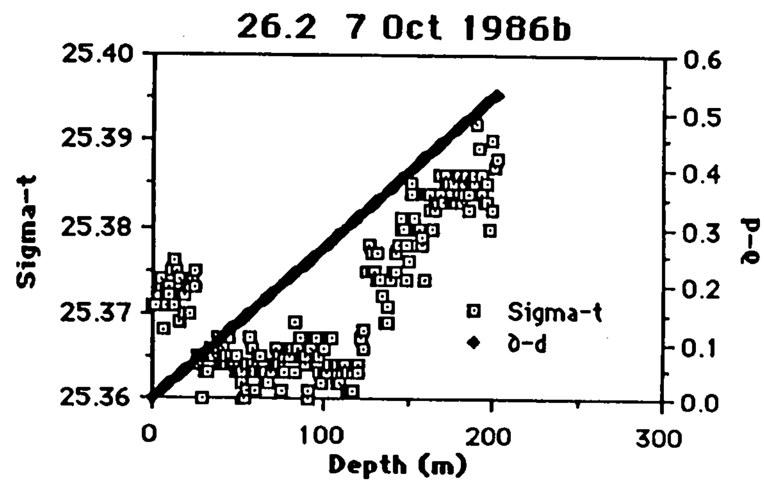

23.6 29 Sept 86
Sigma-t
∂-d
Depth (m)
28
27
26
25
24
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000

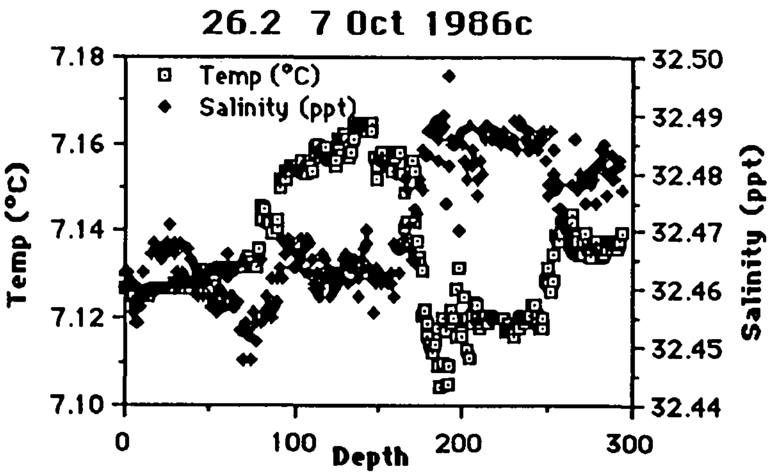

25.1 30 Sept 1986
Sigma-t
∂-d
Depth (m)
25.49
25.48
25.47
25.46
0.2
0.1
0.0
0
10
20
30
40
50
60

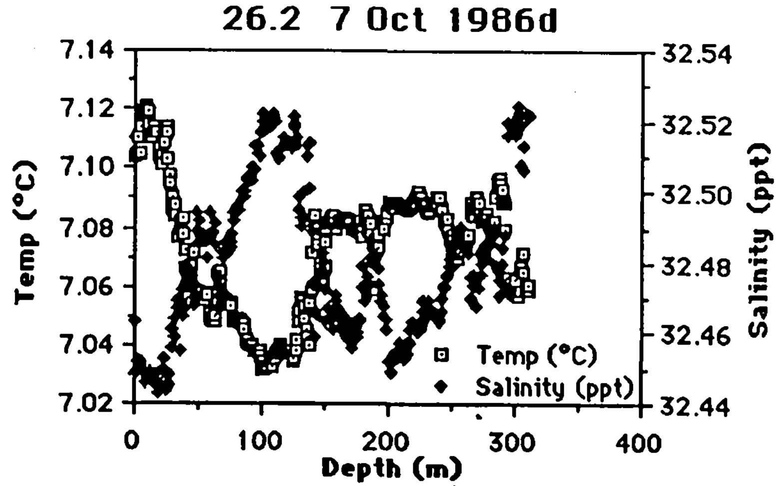

26.2 07 Oct 86a
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

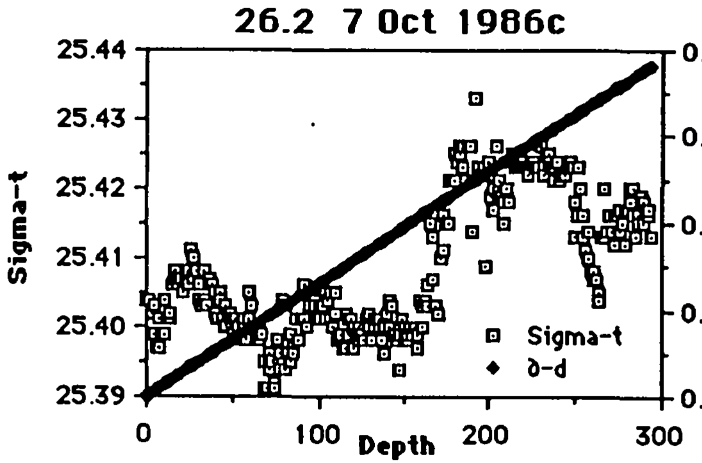

26.2 7 Oct 1986b
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

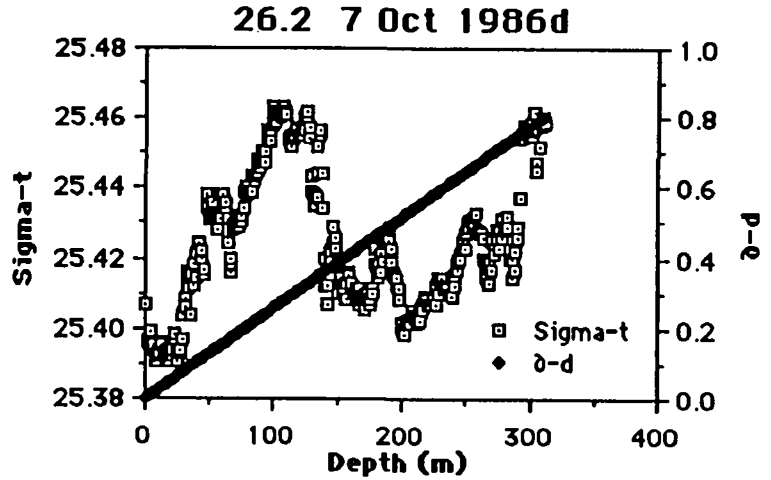

26.2 7 Oct 1986a
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

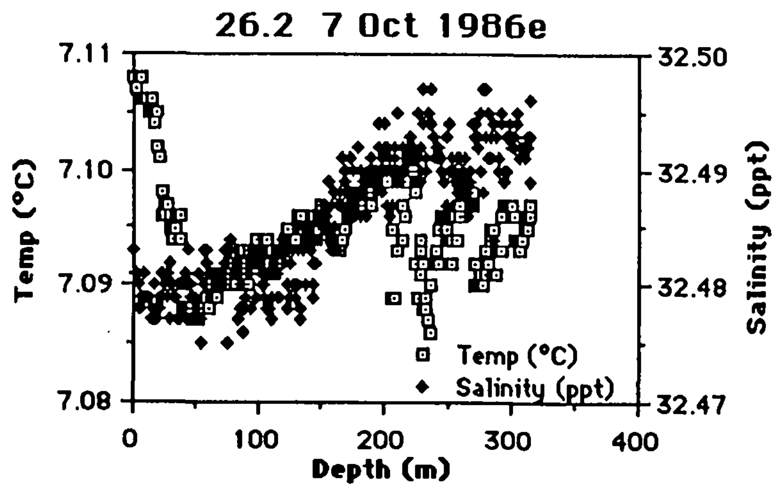

26.2 7 Oct 1986b
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

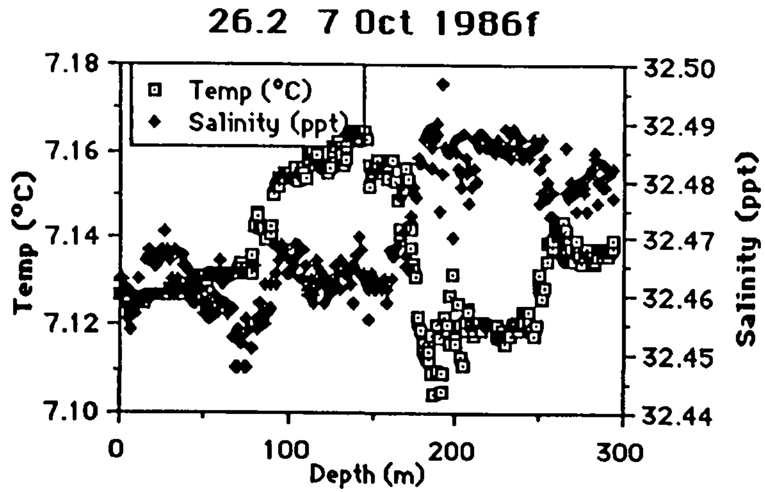

26.2 7 Oct 1986c
Temp (°C)
Salinity (ppt)
Temp (°C)
Salinity (ppt)
Depth
7.18
7.16
7.14
7.12
7.10
32.50
32.49
32.48
32.47
32.46
32.45
32.44
0
100
200
300

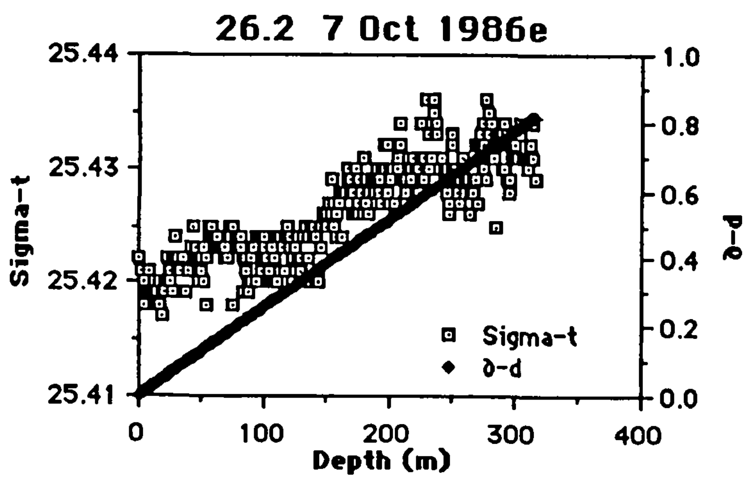

26.2 7 Oct 1986d
Temp (°C)
Salinity (ppt)
Temp (°C)
Salinity (ppt)
Depth (m)
7.14
7.12
7.10
7.08
7.06
7.04
7.02
32.54
32.52
32.50
32.48
32.46
32.44
0
100
200
300
400

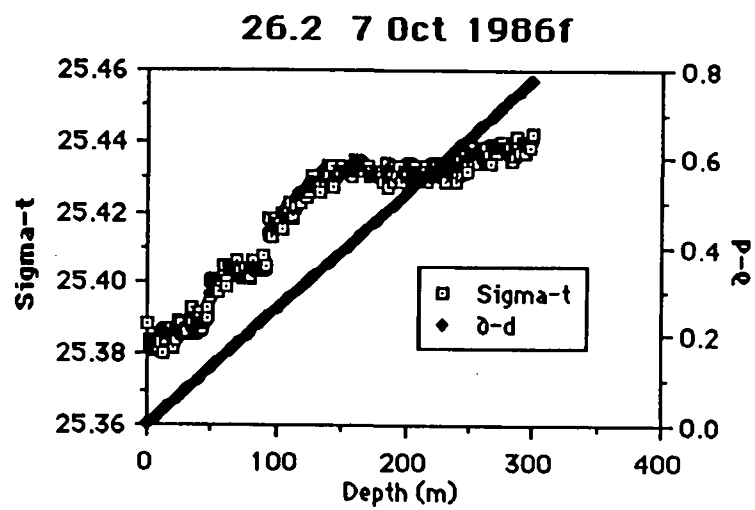

26.2 7 Oct 1986c
Sigma-t
∂-d
Sigma-t
∂-d
Depth
25.44
25.43
25.42
25.41
25.40
25.39
0.8
0.6
0.4
0.2
0.0
0
100
200
300

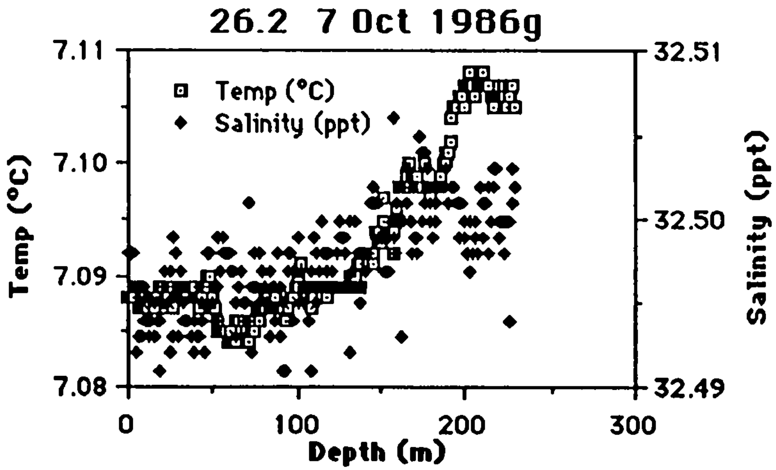

26.2 7 Oct 1986d
Sigma-t
∂-d
Sigma-t
∂-d
Depth (m)
25.48
25.46
25.44
25.42
25.40
25.38
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400

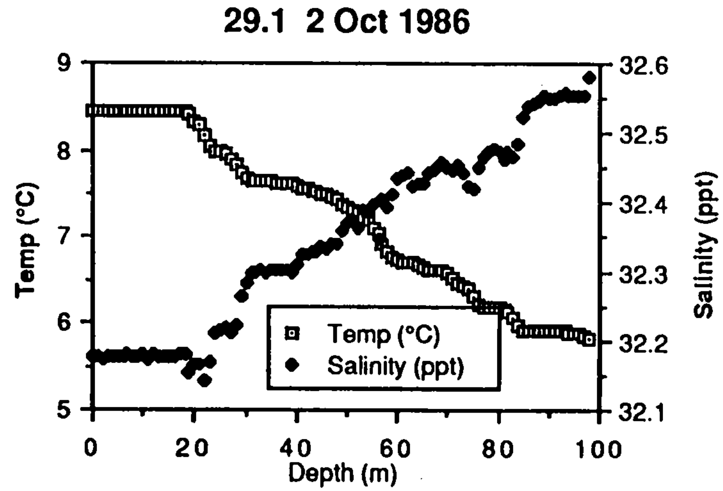

26.2 7 Oct 1986e
Temp (°C)
Salinity (ppt)
Depth (m)
7.11
7.10
7.09
7.08
32.50
32.49
32.48
32.47
0
100
200
300
400

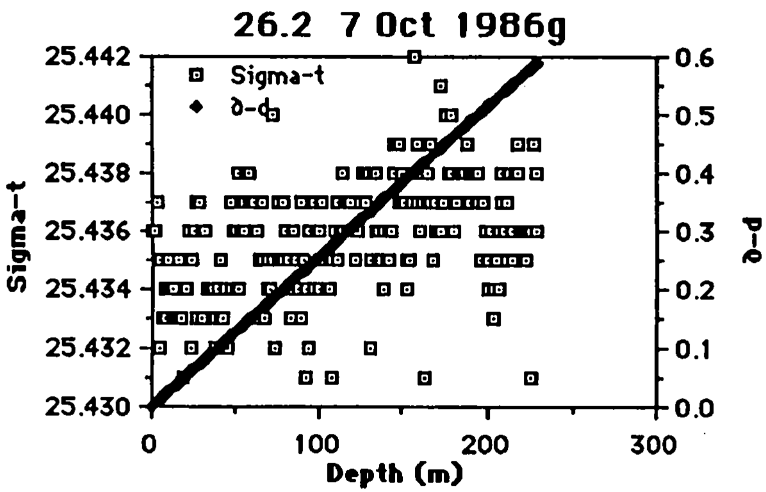

26.2 7 Oct 1986f
Temp (°C)
Salinity (ppt)
Depth (m)
7.18
7.16
7.14
7.12
7.10
32.50
32.49
32.48
32.47
32.46
32.45
32.44
0
100
200
300

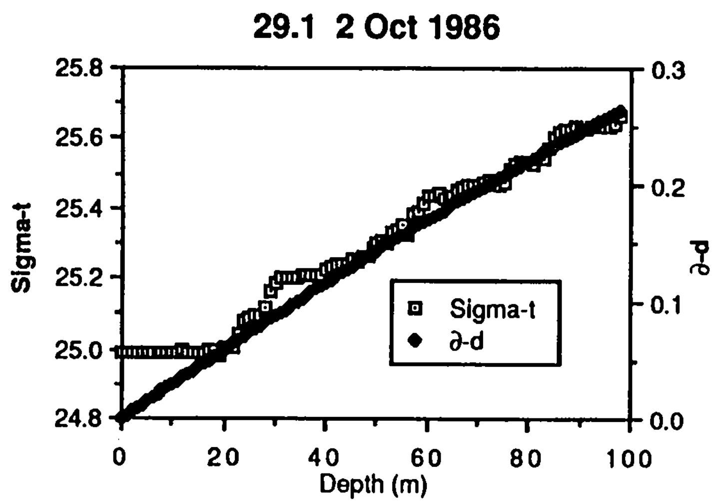

26.2 7 Oct 1986e
Sigma-t
∂-d
Depth (m)
25.44
25.43
25.42
25.41
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400


26.2 7 Oct 1986f
Sigma-t
∂-d
Depth (m)
25.46
25.44
25.42
25.40
25.38
25.36
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400

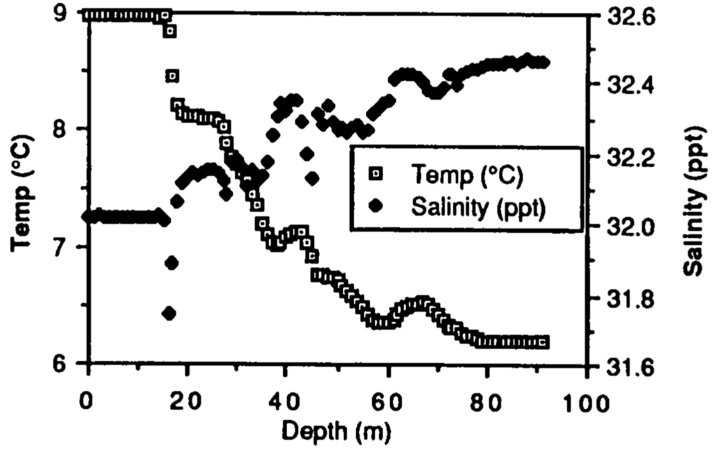

26.2 7 Oct 1986g
Temp (°C)
Salinity (ppt)
Depth (m)
7.11
7.10
7.09
7.08
32.51
32.50
32.49
0
100
200
300


29.1 2 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
9
8
7
6
5
32.6
32.5
32.4
32.3
32.2
32.1
0
20
40
60
80
100

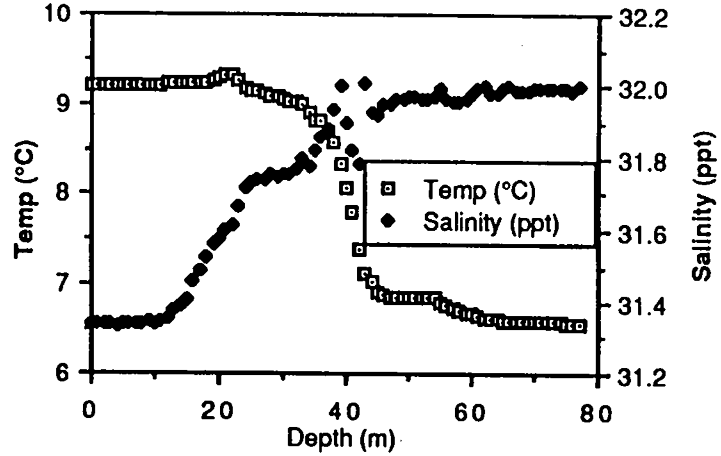

26.2 7 Oct 1986g
Sigma-t
∂-d
Depth (m)
25.442
25.440
25.438
25.436
25.434
25.432
25.430
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300


29.1 2 Oct 1986
Sigma-t
∂-d
Depth (m)
25.8
25.6
25.4
25.2
25.0
24.8
0.3
0.2
0.1
0.0
0
20
40
60
80
100

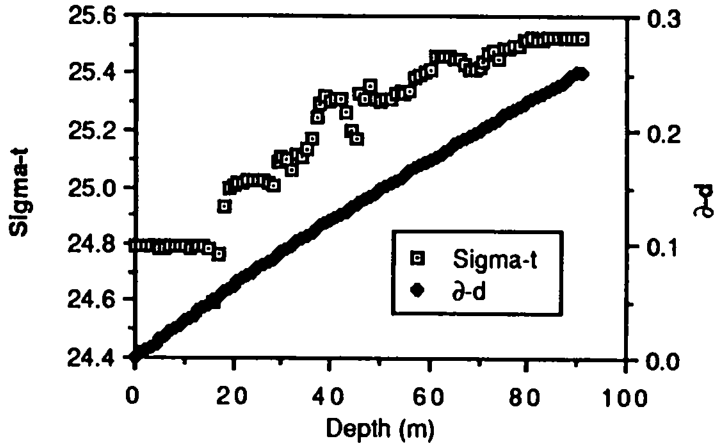
29.2 2 Oct 1986



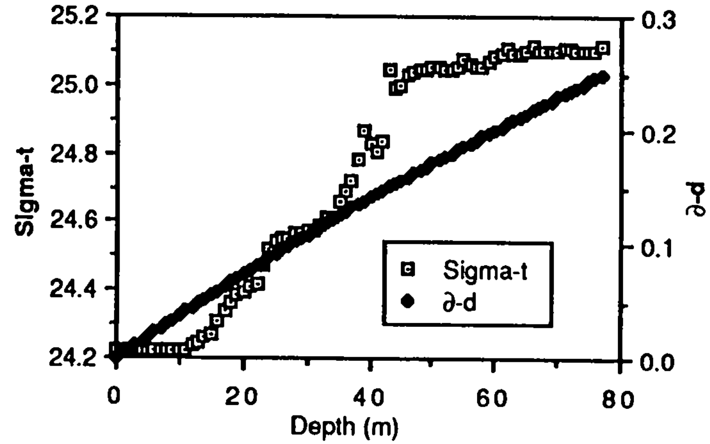
30.1 2 Oct 1986



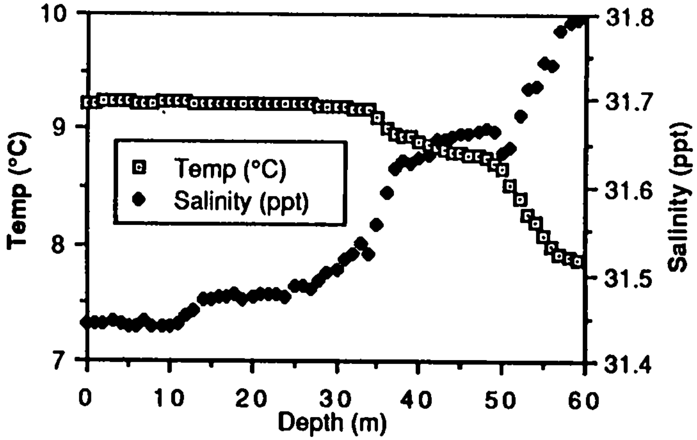
29.2 2 Oct 1986



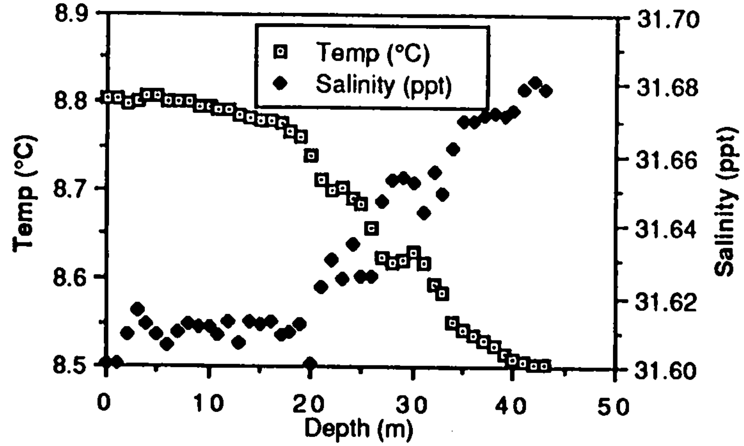
30.1 2 Oct 1986



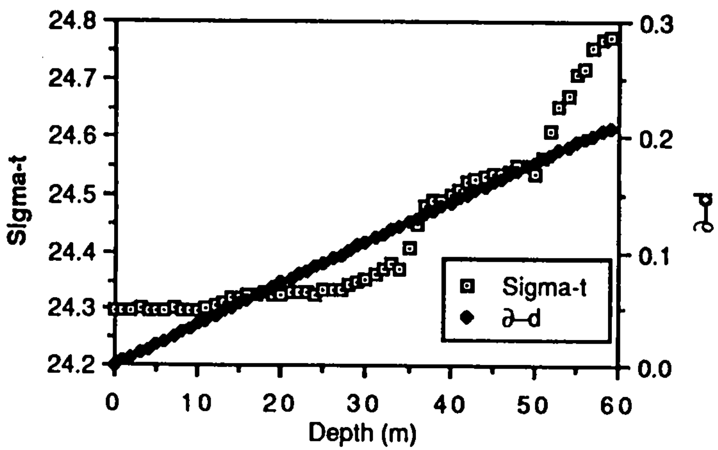
31.1 3 Oct 1986



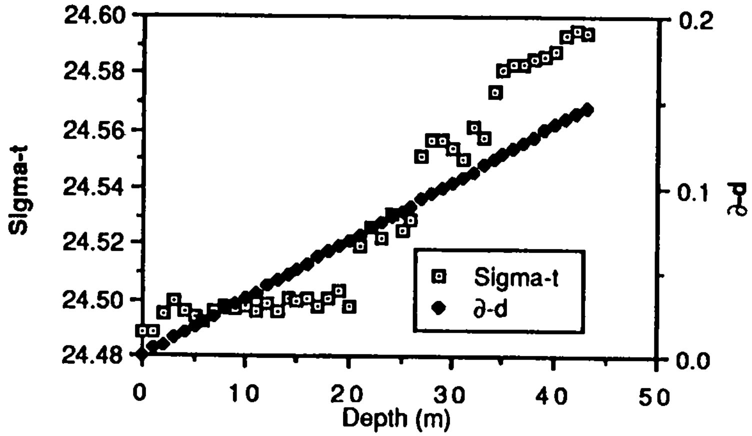
31.2 3 Oct 1986



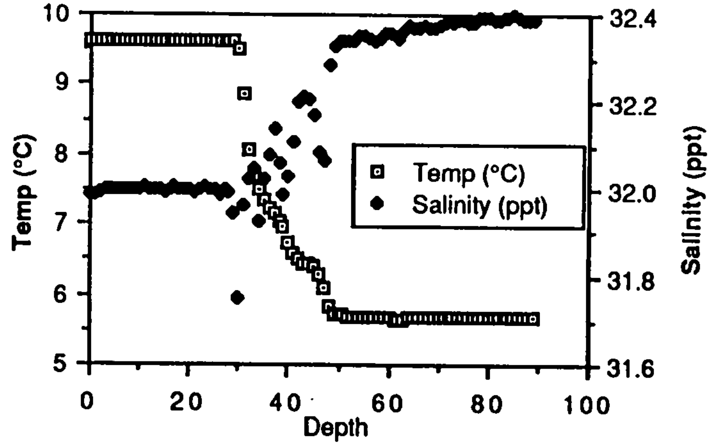
31.1 3 Oct 1986



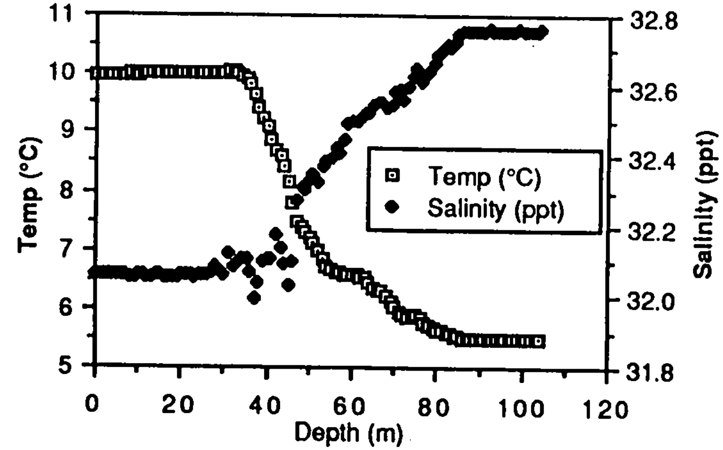
31.2 3 Oct 1986



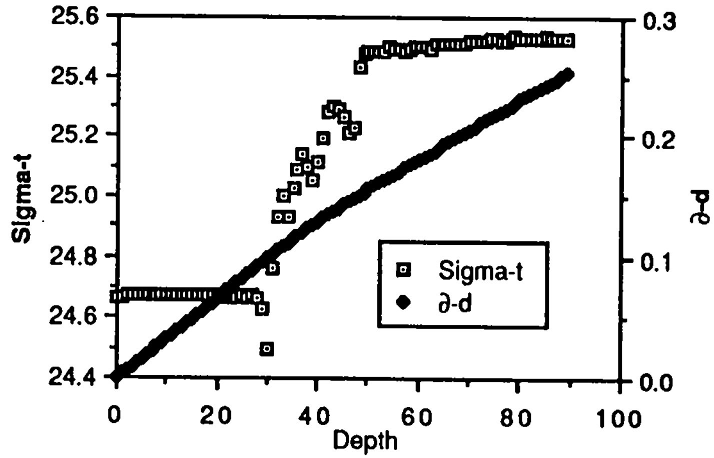
31.3 3 Oct 1986



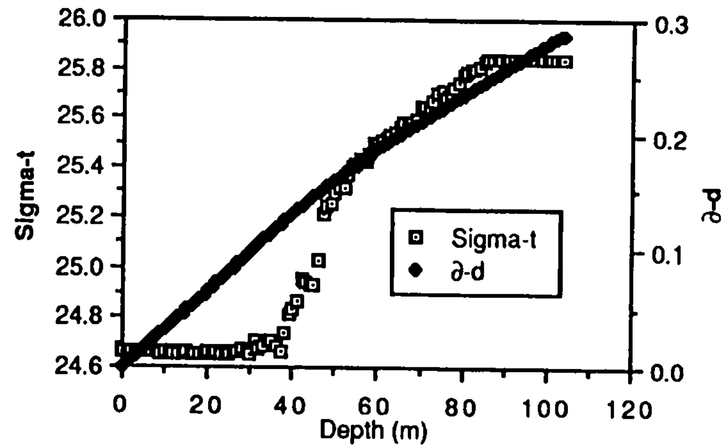
31.4 3 Oct 1986



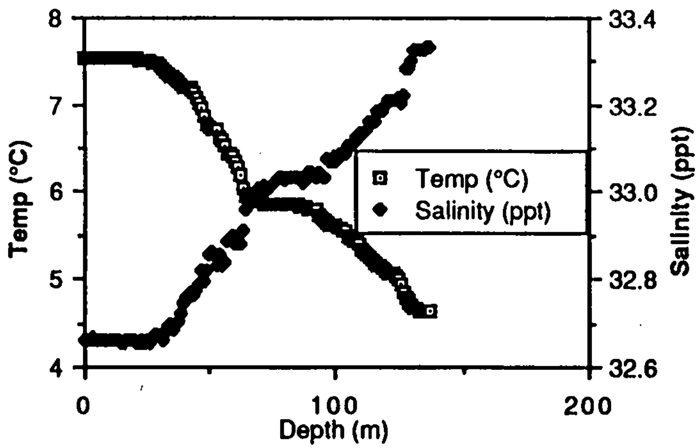
31.3 3 Oct 1986



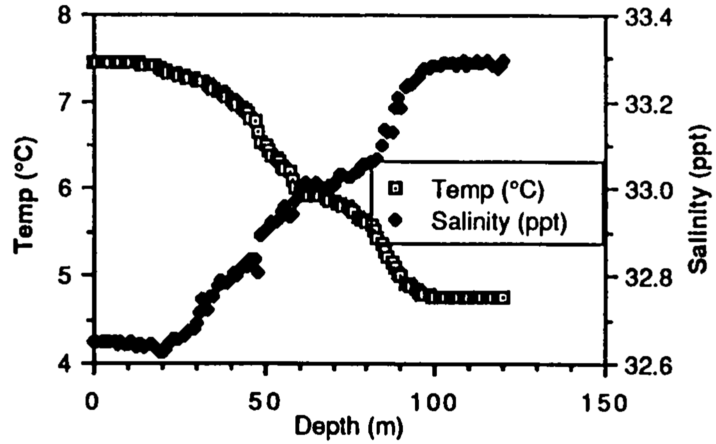
31.4 3 Oct 1986



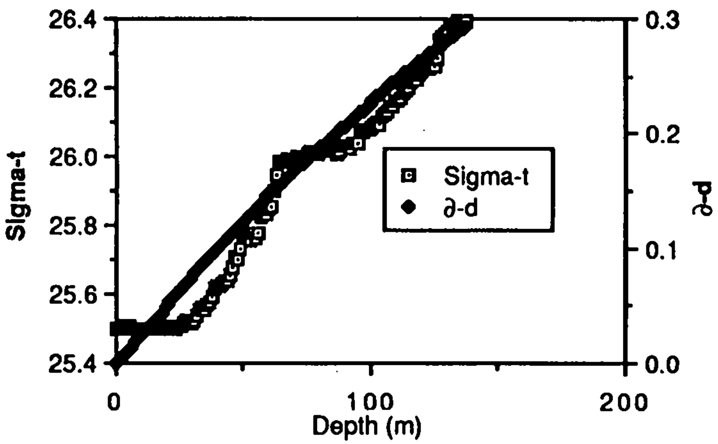
31.5 4 Oct 1986



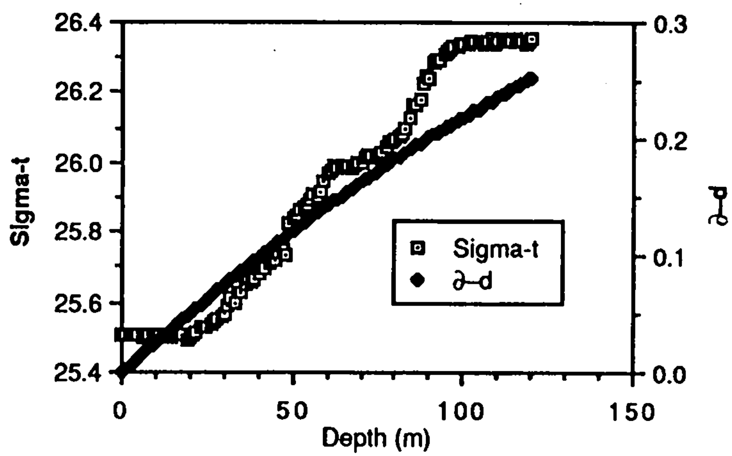
31.6 4 Oct 1986

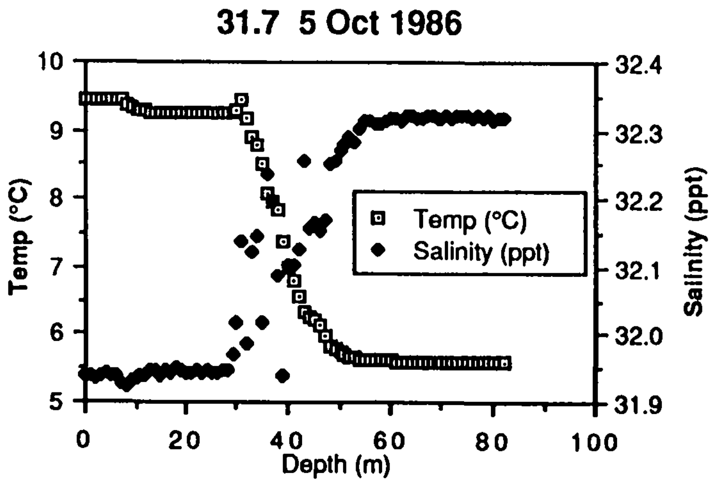


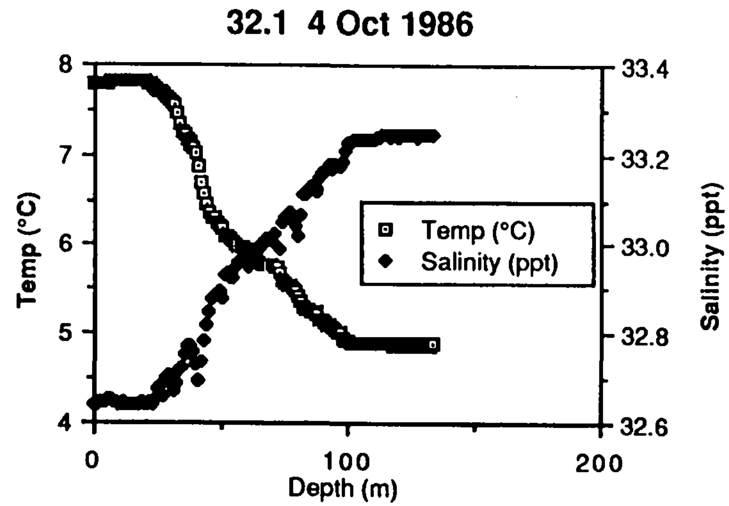
31.5 4 Oct 1986

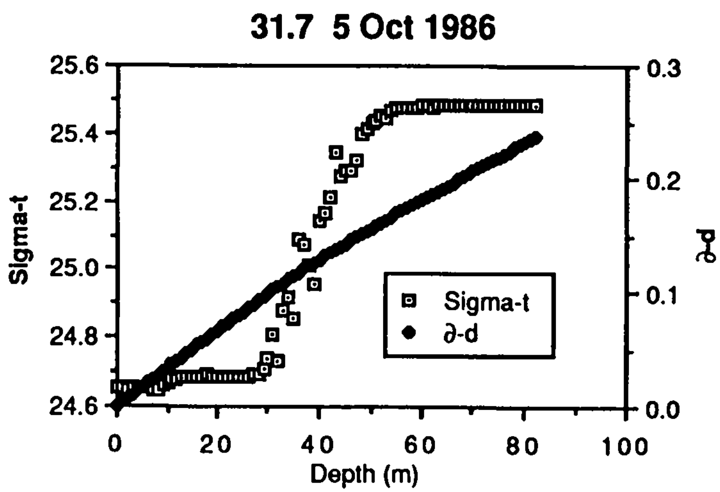


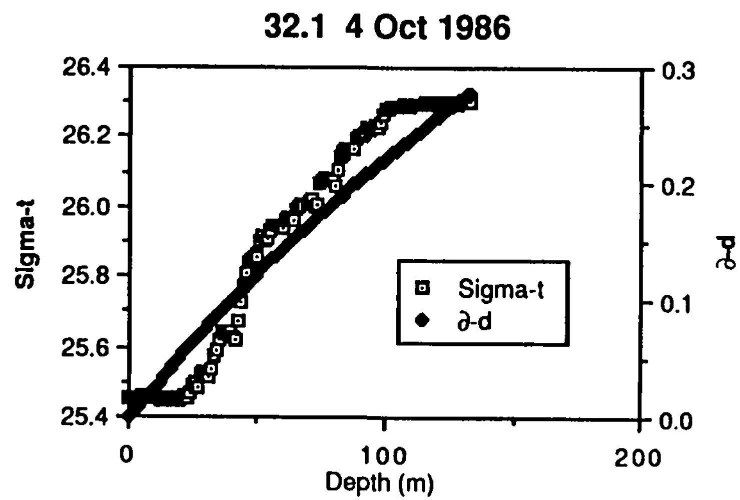
31.6 4 Oct 1986

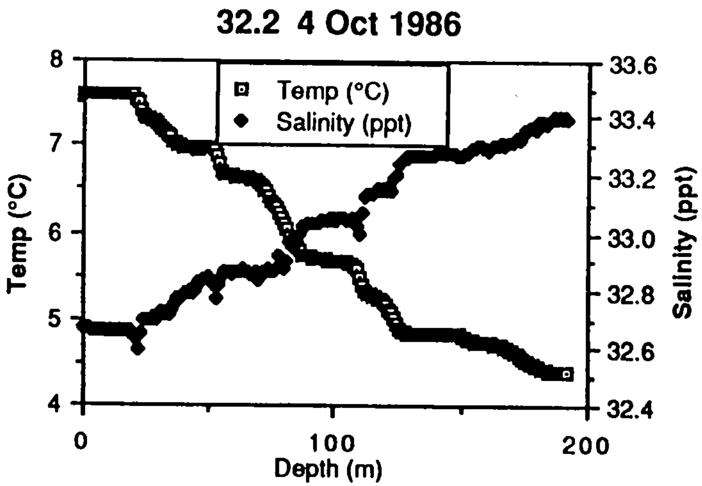


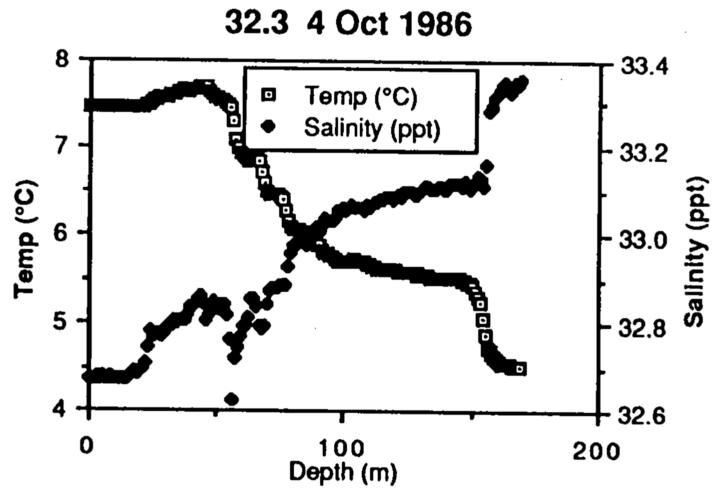

31.7 5 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
10
9
8
7
6
5
32.4
32.3
32.2
32.1
32.0
31.9
0
20
40
60
80
100

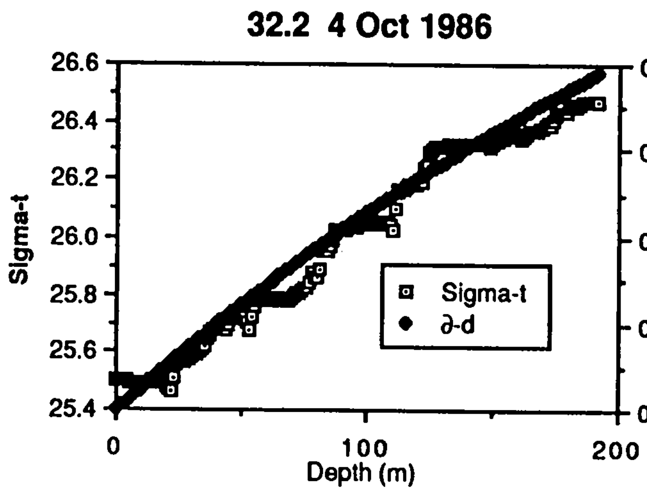

32.1 4 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
8
7
6
5
4
33.4
33.2
33.0
32.8
32.6
0
100
200

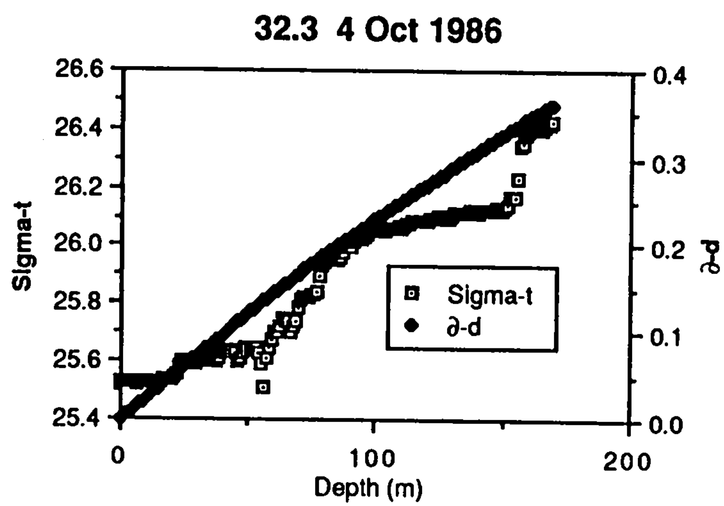

31.7 5 Oct 1986
Sigma-t
∂-d
Depth (m)
25.6
25.4
25.2
25.0
24.8
24.6
0.3
0.2
0.1
0.0
0
20
40
60
80
100

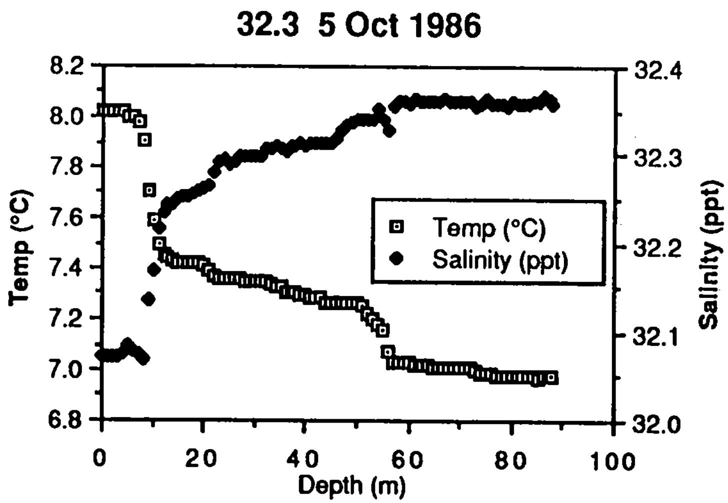

32.1 4 Oct 1986
Sigma-t
∂-d
Depth (m)
26.4
26.2
26.0
25.8
25.6
25.4
0.3
0.2
0.1
0.0
0
100
200

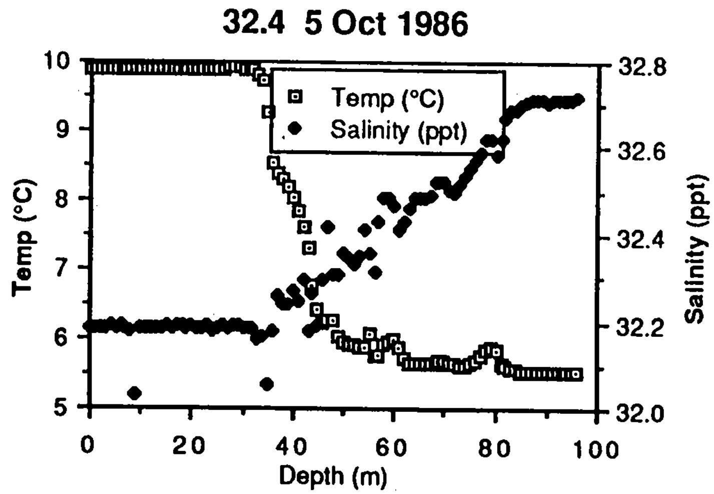

32.2 4 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)

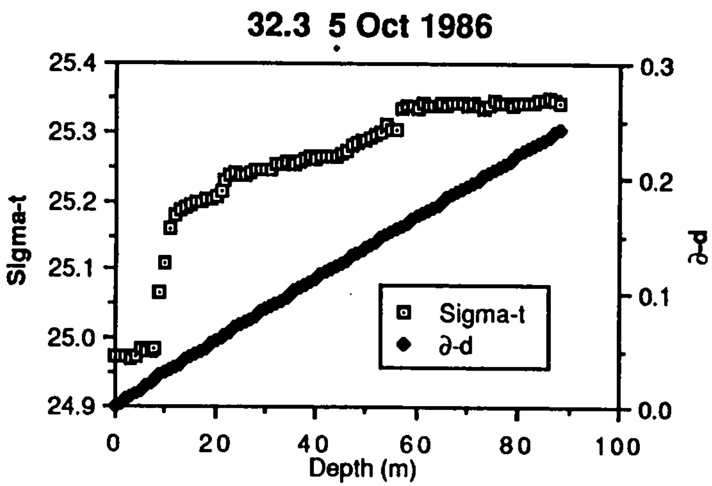

32.3 4 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)

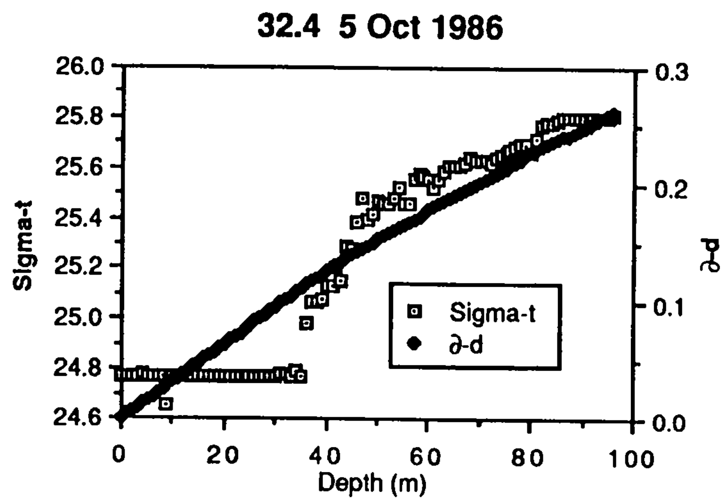

32.2 4 Oct 1986
Sigma-t
∂-d
Depth (m)

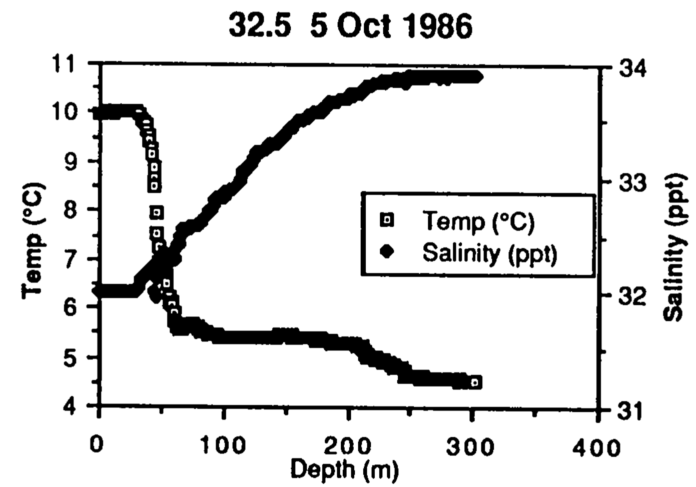

32.3 4 Oct 1986
Sigma-t
∂-d
Depth (m)

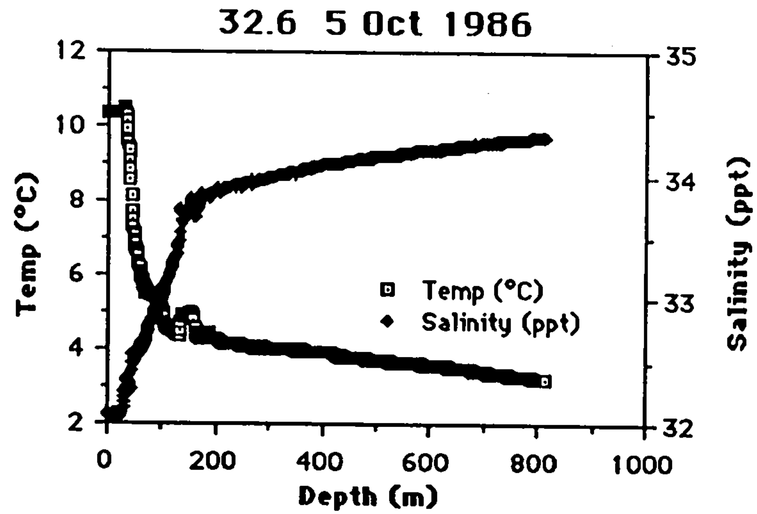

32.3 5 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
32.4
32.3
32.2
32.1
32.0
0
20
40
60
80
100

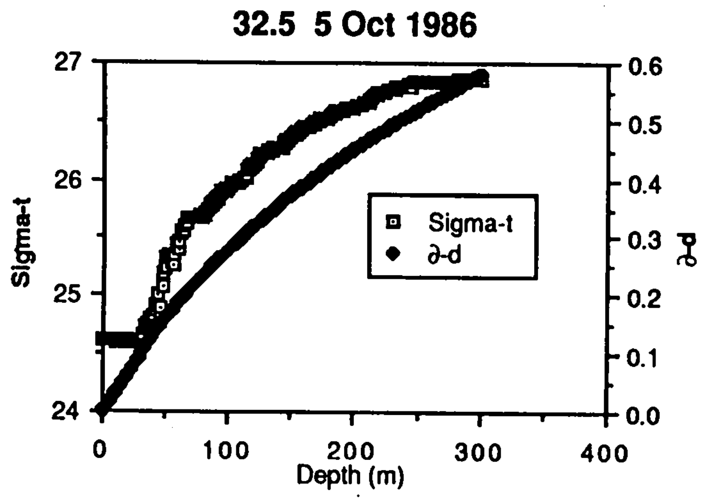

32.4 5 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)
10
9
8
7
6
5
32.8
32.6
32.4
32.2
32.0
0
20
40
60
80
100

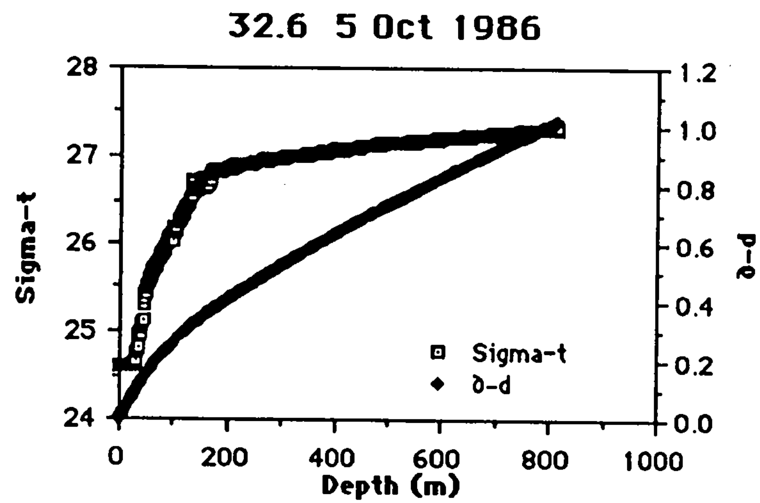

32.3 5 Oct 1986
Sigma-t
∂-d
Depth (m)
25.4
25.3
25.2
25.1
25.0
24.9
0.3
0.2
0.1
0.0
0
20
40
60
80
100


32.4 5 Oct 1986
Sigma-t
∂-d
Depth (m)
26.0
25.8
25.6
25.4
25.2
25.0
24.8
24.6
0.3
0.2
0.1
0.0
0
20
40
60
80
100


32.5 5 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)


32.6 5 Oct 1986
Temp (°C)
Salinity (ppt)
Depth (m)

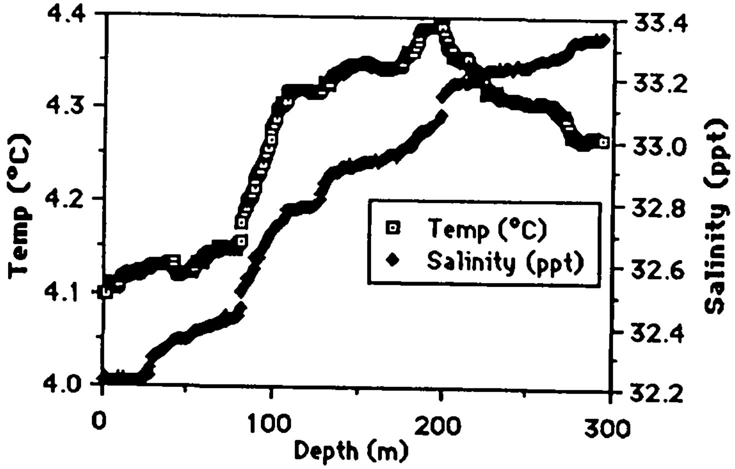

32.5 5 Oct 1986
Sigma-t
∂-d
Depth (m)


32.6 5 Oct 1986
Sigma-t
∂-d
Depth (m)

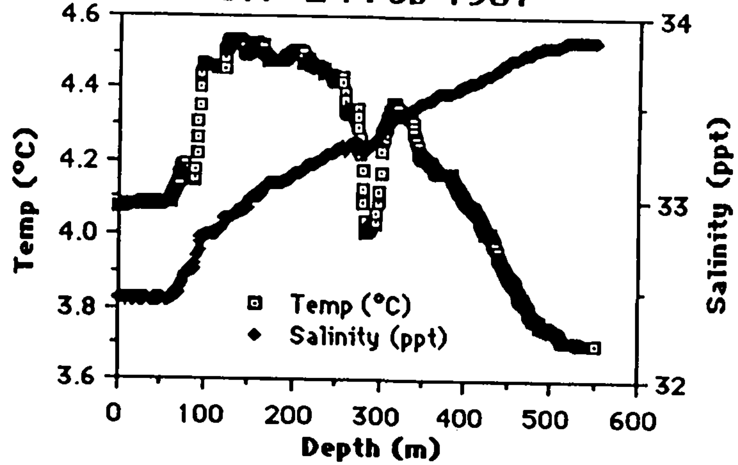
APPENDIX B-2

Temperature and salinity vertical profiles as determined by CTD casts at sampling stations in winter 1987 in the Unimak Pass area, Alaska. Sampling station numbers (tops of graphs) can be matched with their locations in Fig. 3 of Appendix E.

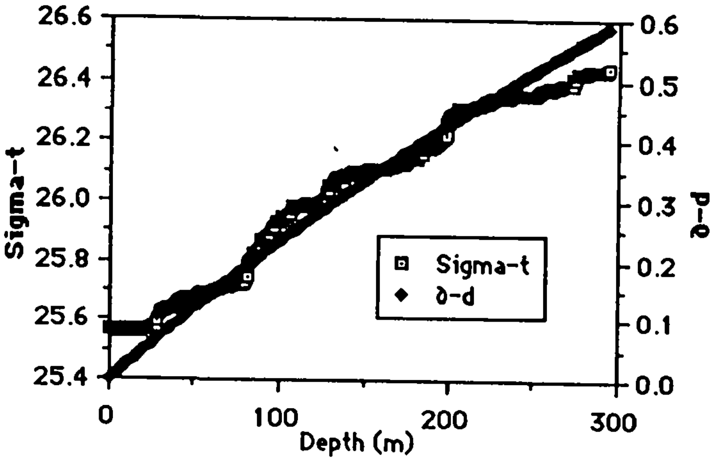
2.2 26 Feb 1987



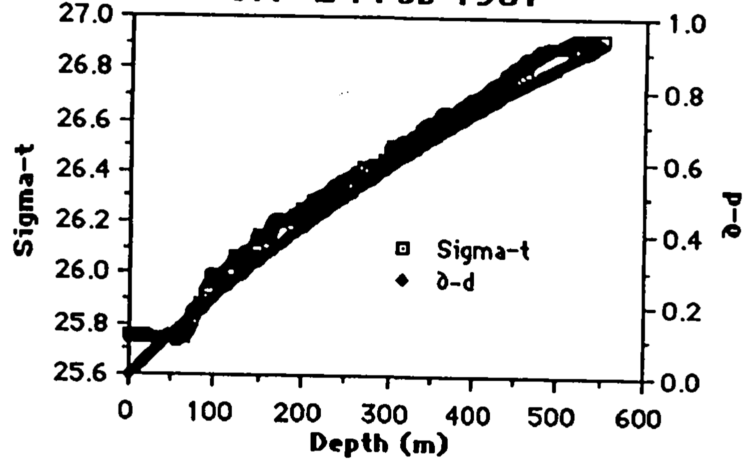
3.1 24 Feb 1987

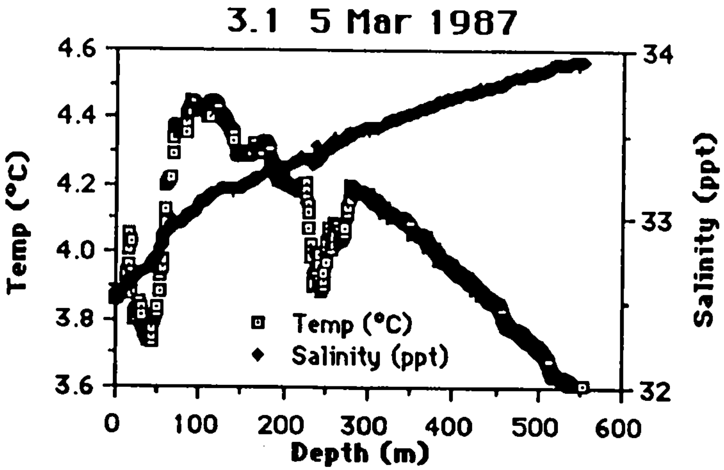


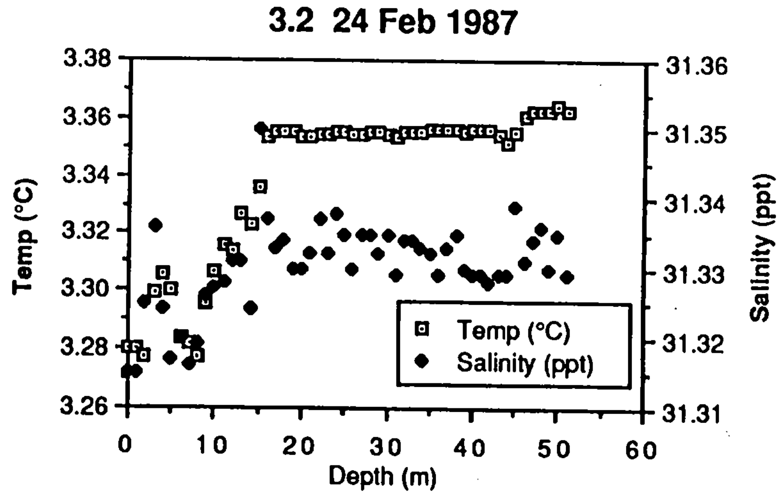
2.2 26 Feb 1987

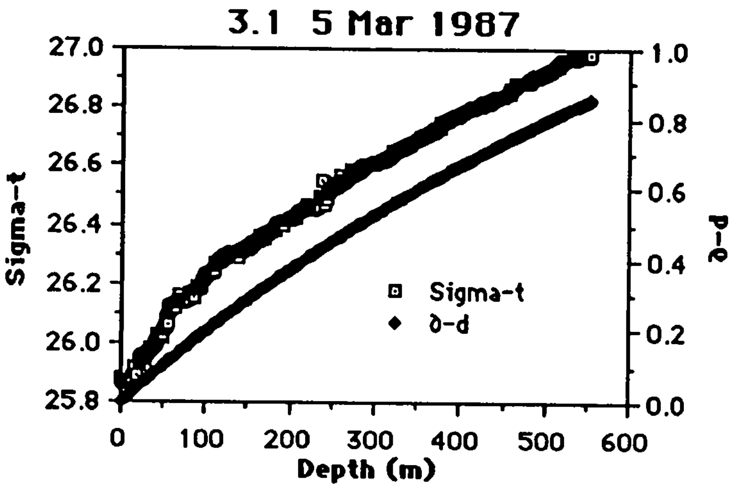


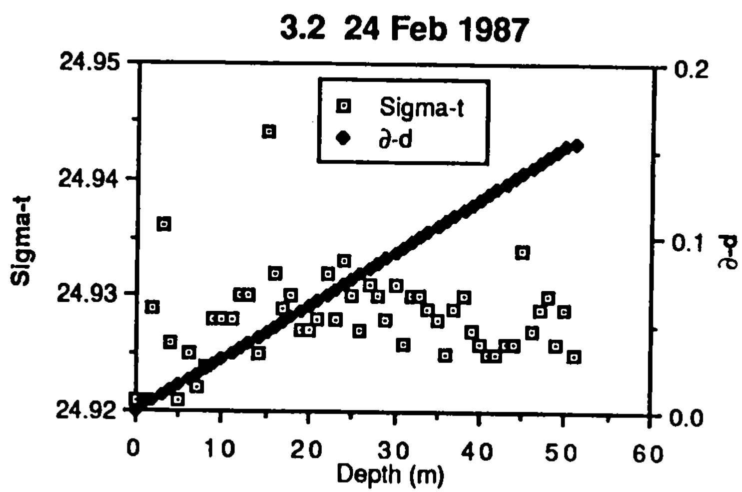
3.1 24 Feb 1987



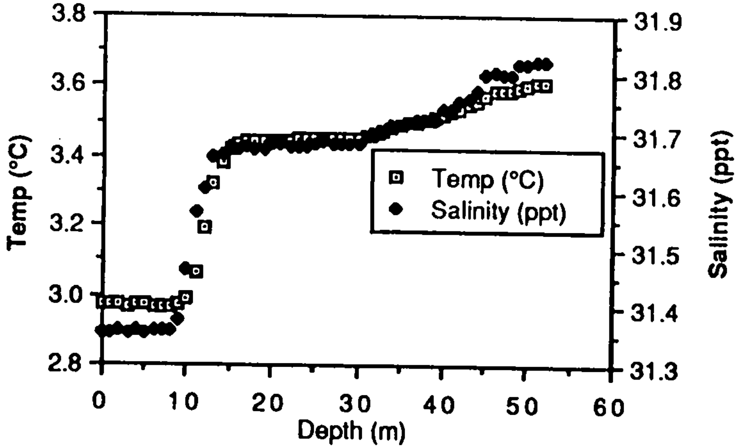

3.1 5 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.6
4.4
4.2
4.0
3.8
3.6
34
33
32
0 100 200 300 400 500 600


3.2 24 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
3.38
3.36
3.34
3.32
3.30
3.28
3.26
31.36
31.35
31.34
31.33
31.32
31.31
0 10 20 30 40 50 60

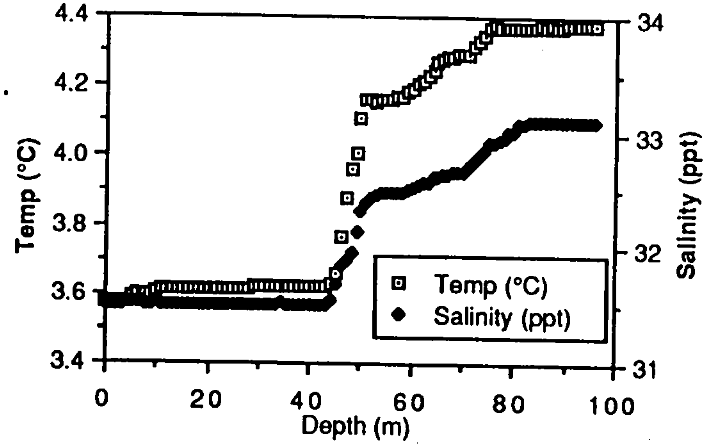

3.1 5 Mar 1987
Sigma-t
∂-d
Depth (m)
27.0
26.8
26.6
26.4
26.2
26.0
25.8
1.0
0.8
0.6
0.4
0.2
0.0
0 100 200 300 400 500 600


3.2 24 Feb 1987
Sigma-t
∂-d
Depth (m)
24.95
24.94
24.93
24.92
0.2
0.1
0.0
0 10 20 30 40 50 60

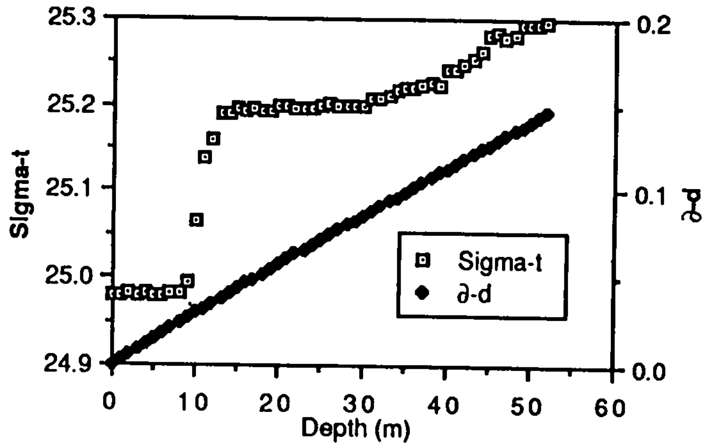
3.2 5 Mar 1987



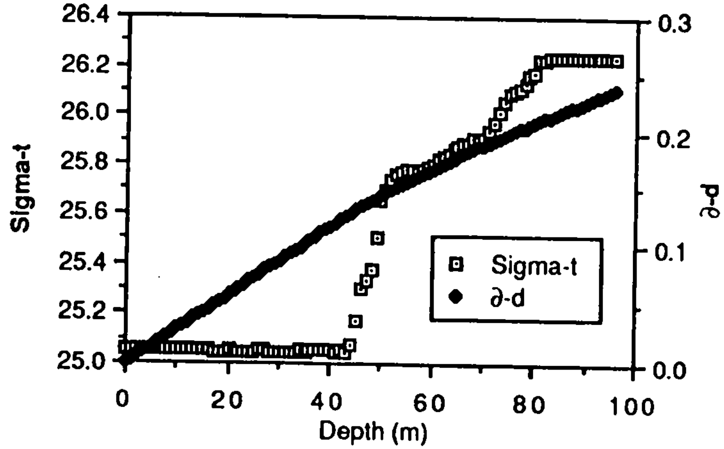
3.3 24 Feb 1987



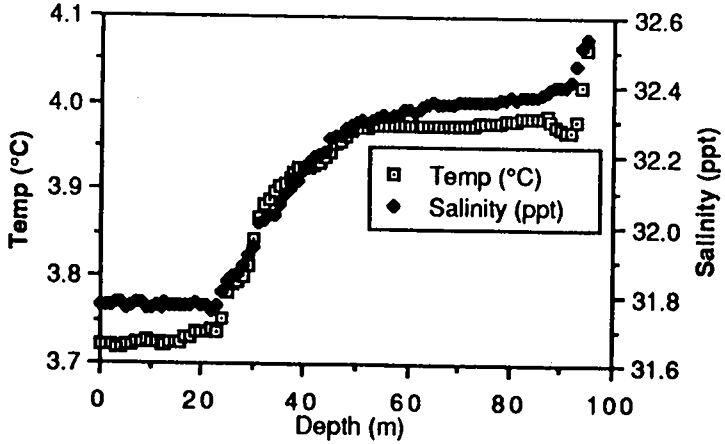
3.2 5 Mar 1987



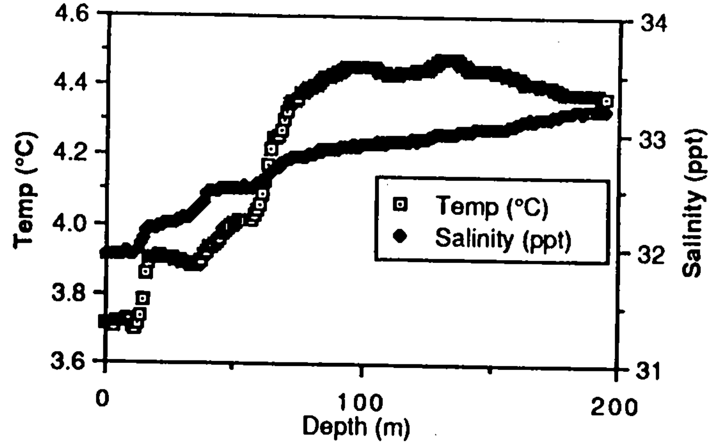
3.3 24 Feb 1987



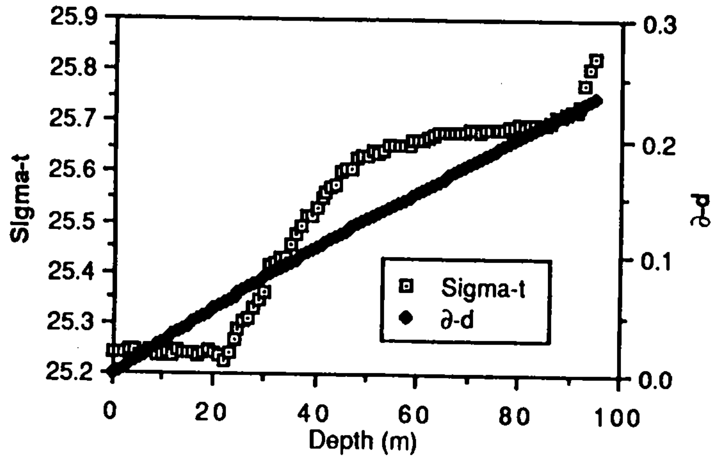
3.3 5 Mar 1987



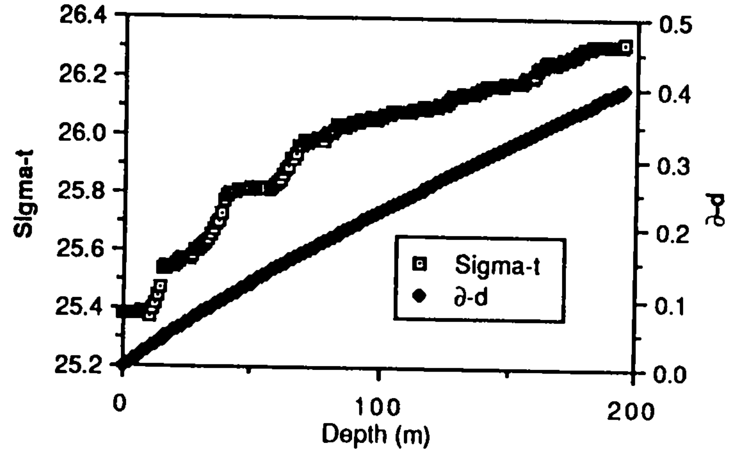
3.4 25 Feb 1987

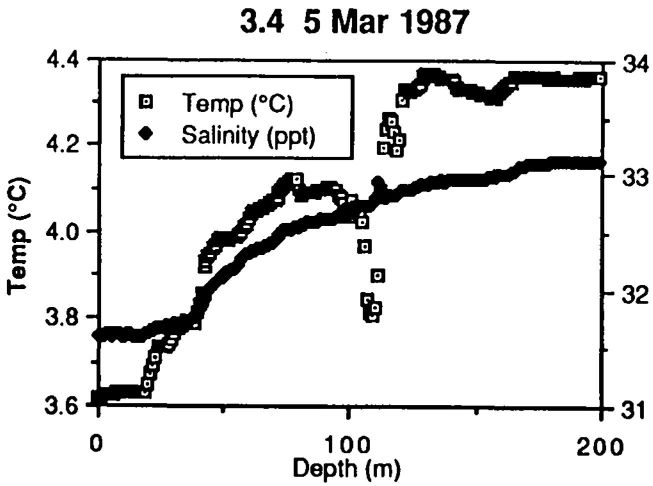


3.3 5 Mar 1987

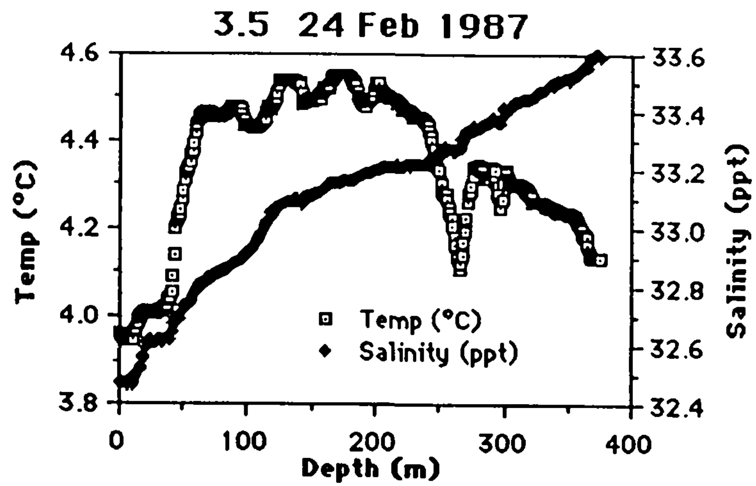


3.4 25 Feb 1987

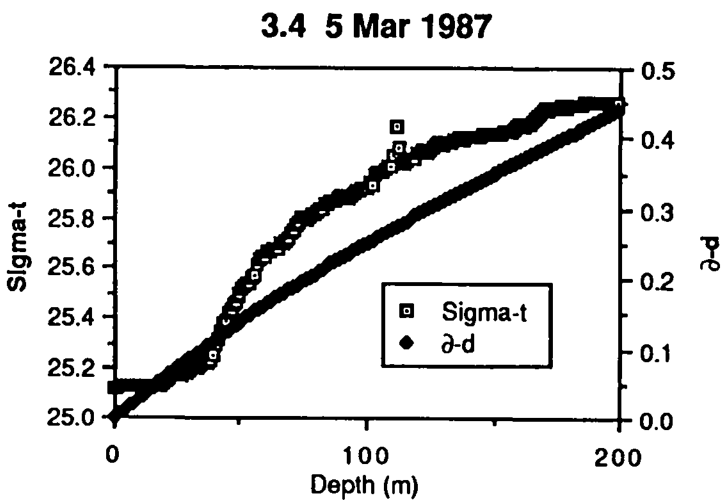




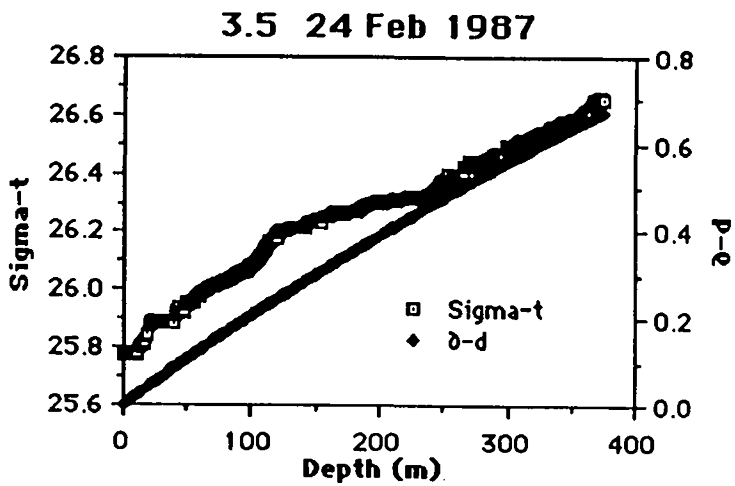
3.4 5 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)



3.5 24 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)

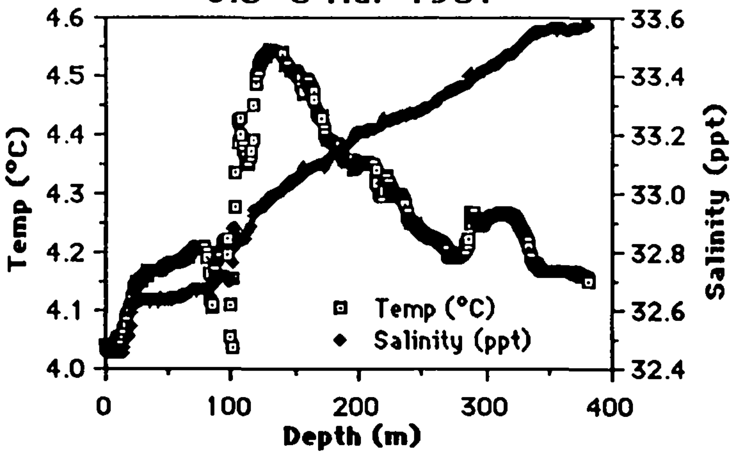


3.4 5 Mar 1987
Sigma-t
∂-d
Depth (m)

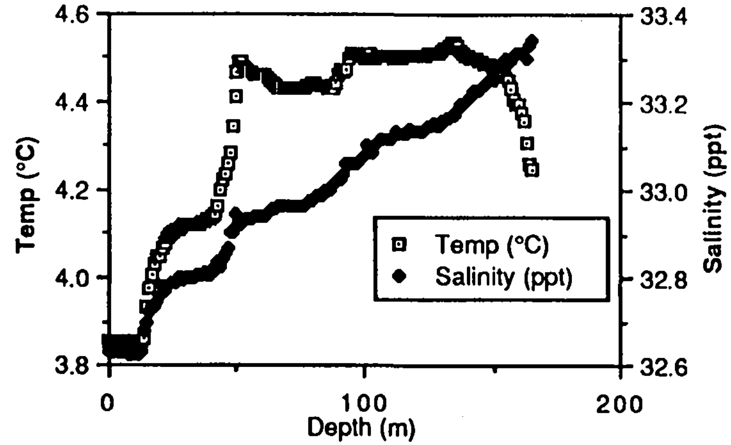


3.5 24 Feb 1987
Sigma-t
∂-d
Depth (m)

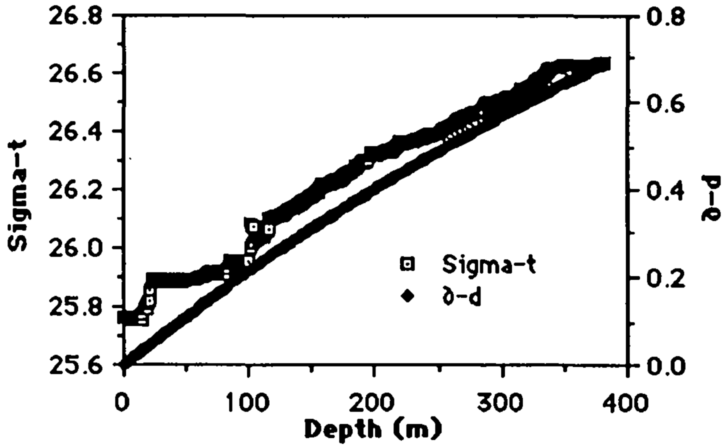
3.5 6 Mar 1987



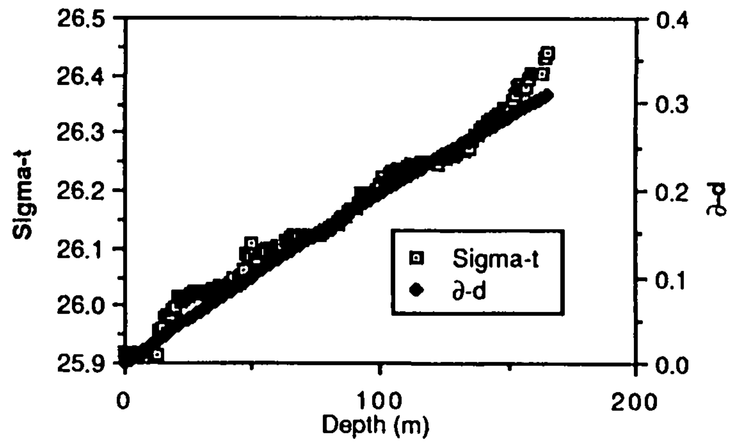
4.1 18 Feb 1987



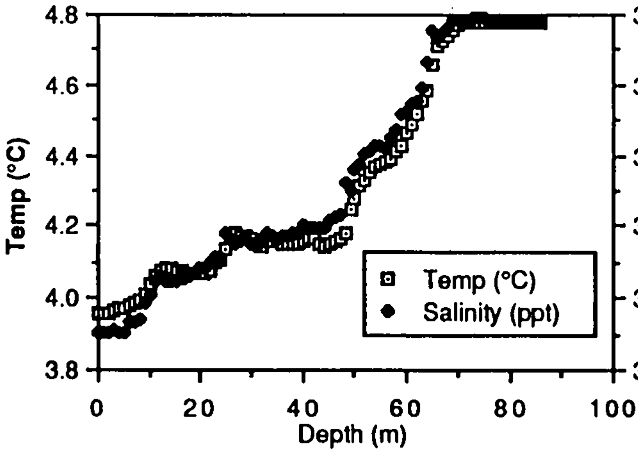
3.5 6 Mar 1987



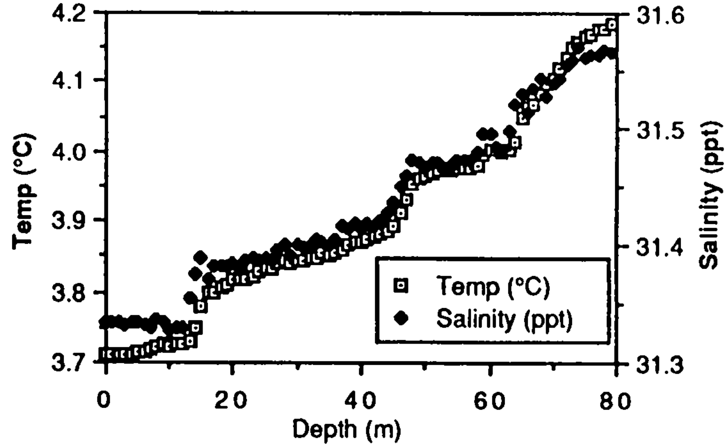
4.1 18 Feb 1987



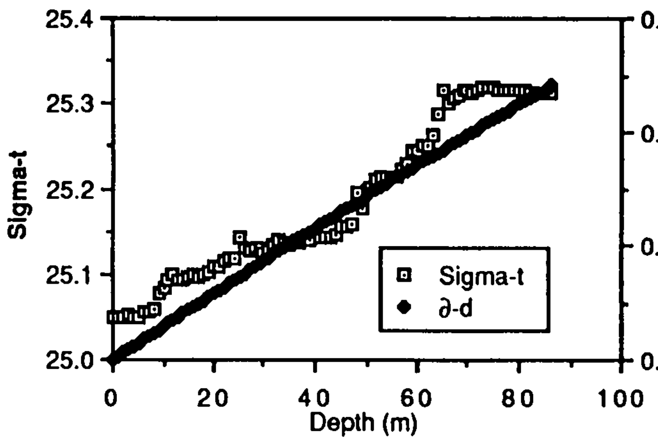
4.2 19 Feb 1987



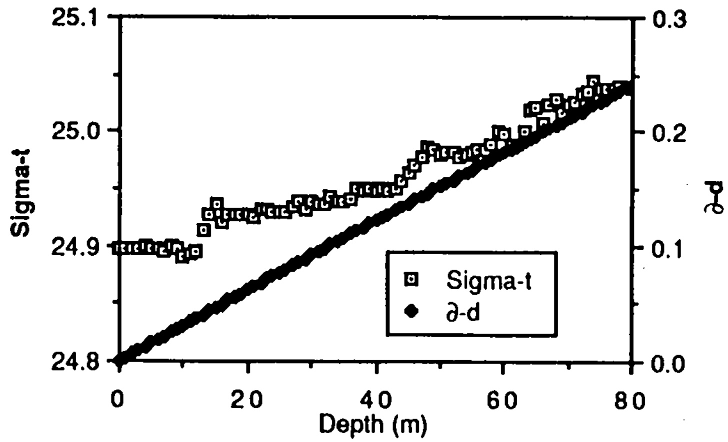
4.3 19 Feb 1987

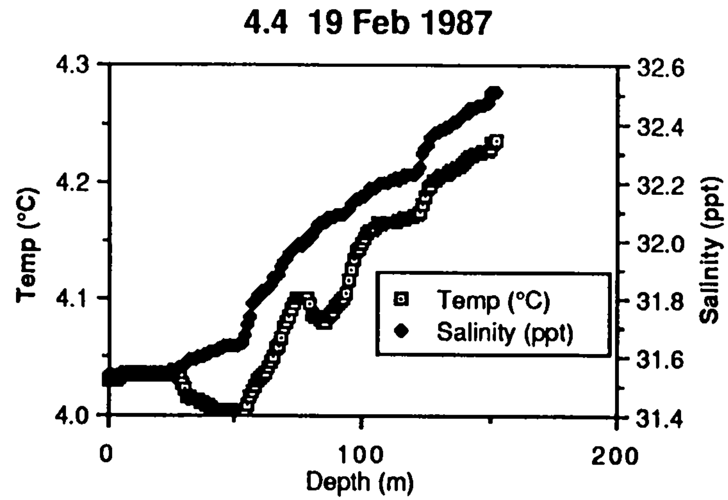


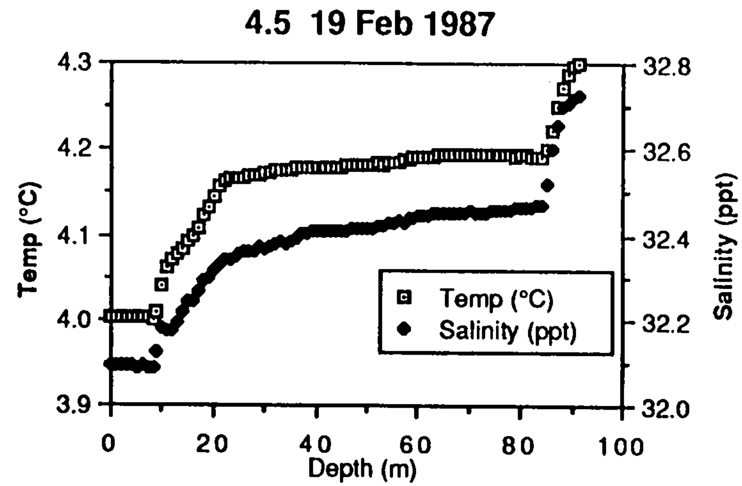
4.2 19 Feb 1987

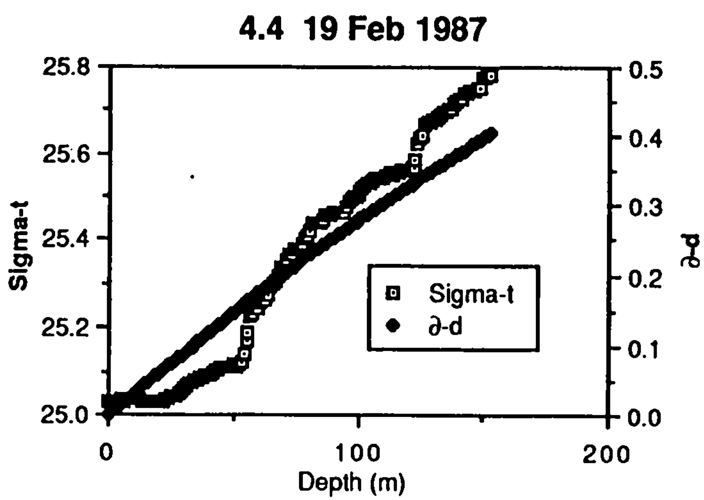


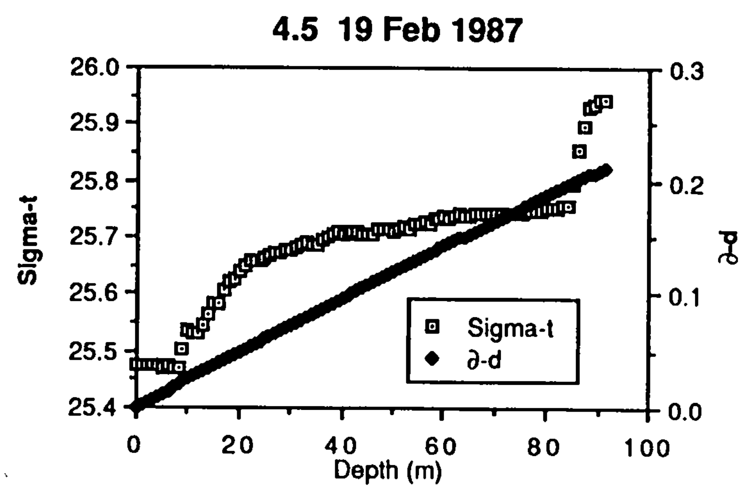
4.3 19 Feb 1987

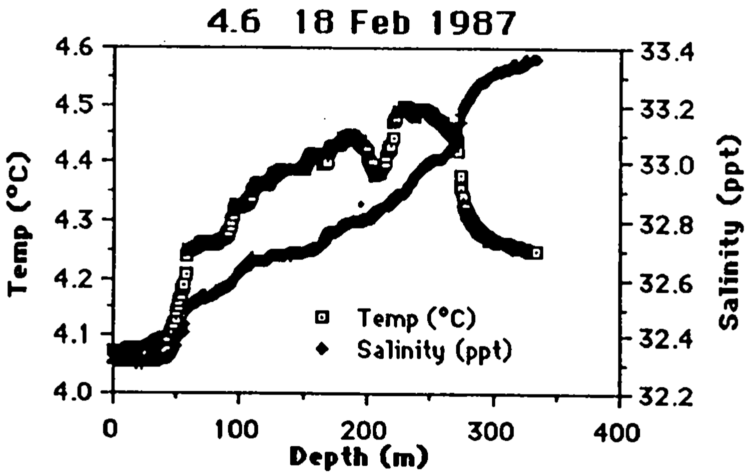


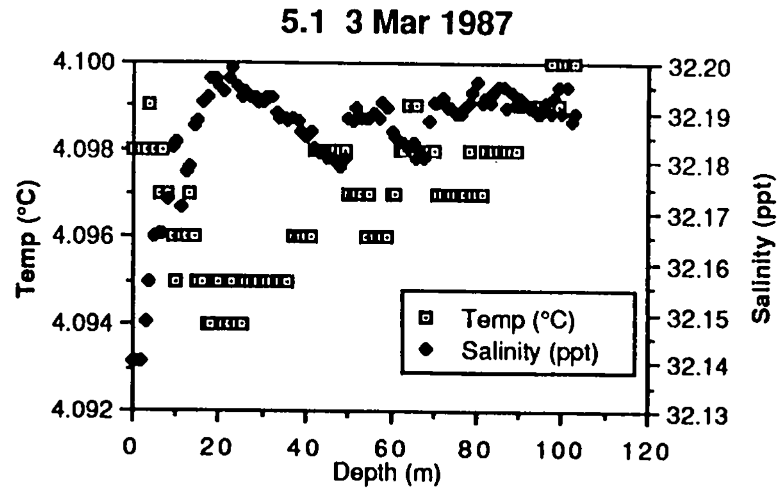

4.4 19 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

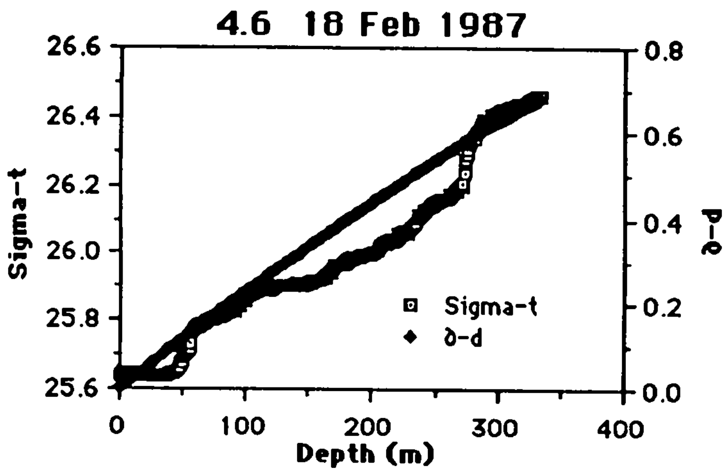

4.5 19 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

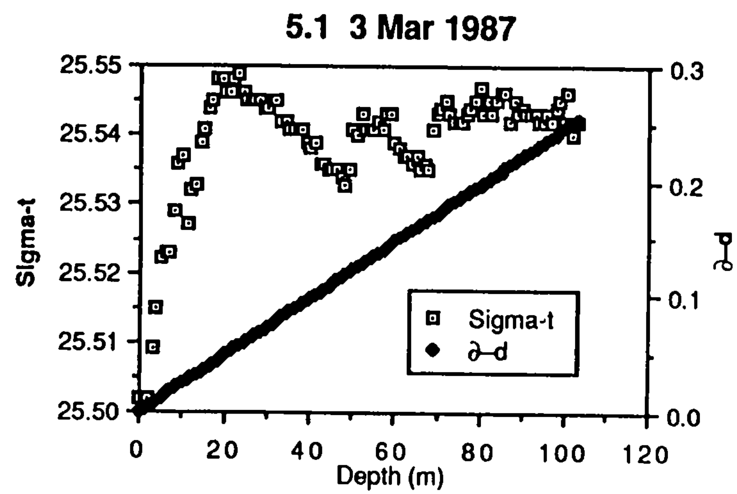

4.4 19 Feb 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d


4.5 19 Feb 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

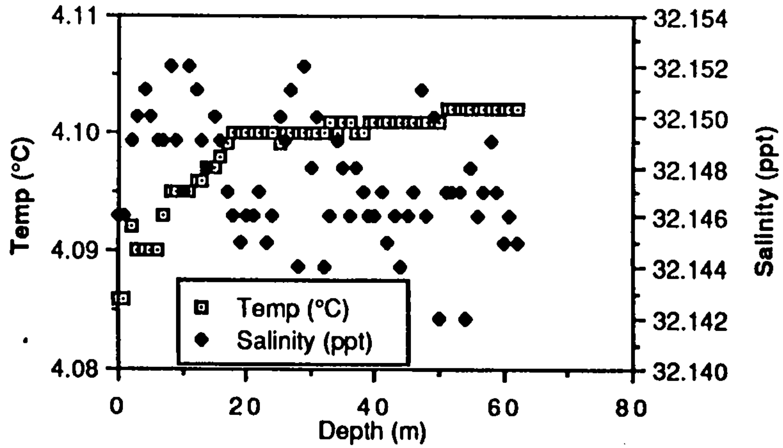

4.6 18 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)


5.1 3 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

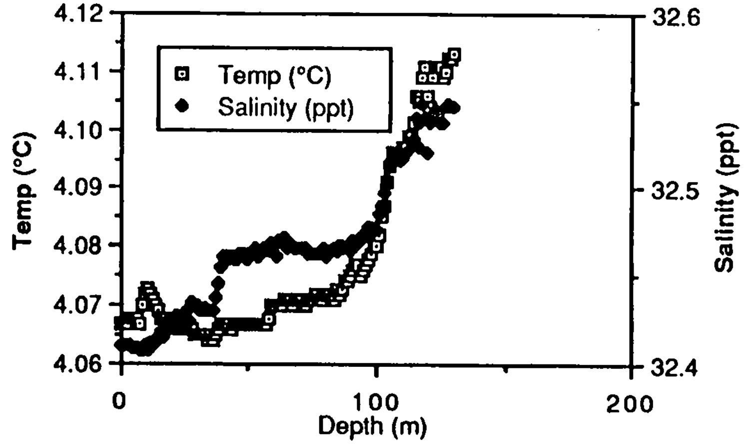

4.6 18 Feb 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d


5.1 3 Mar 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

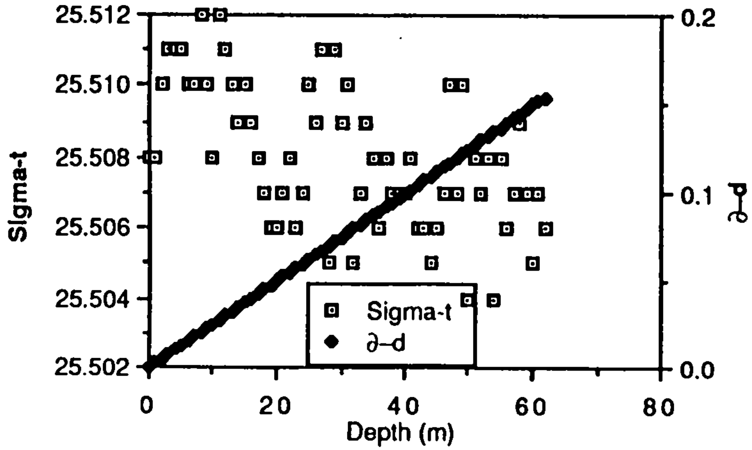
6.1 26 Feb 1987



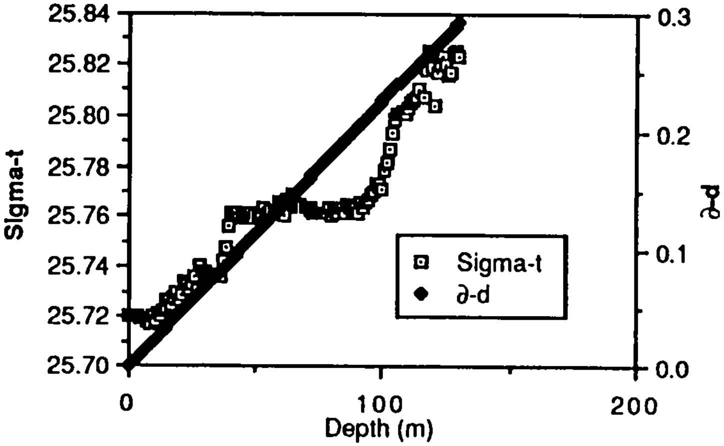
6.2 4 Mar 1987

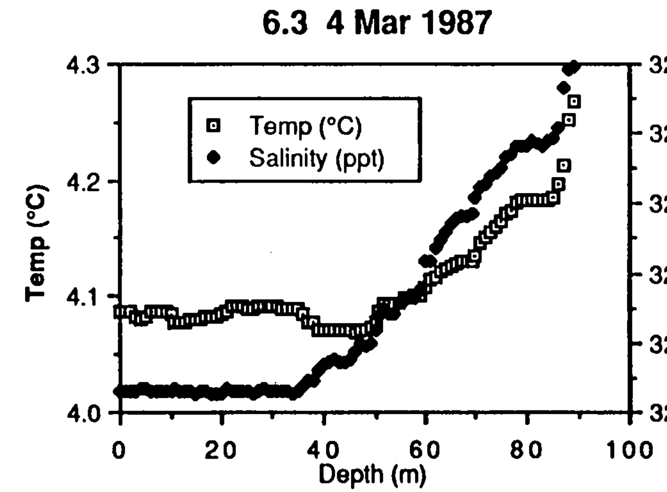


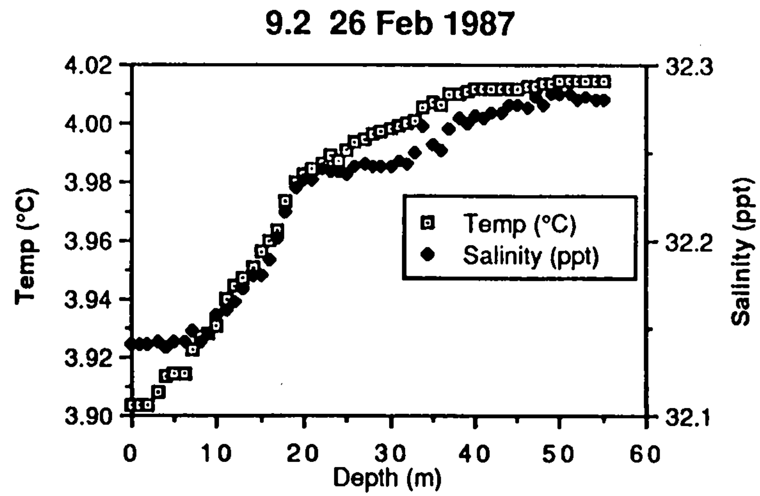
6.1 26 Feb 1987

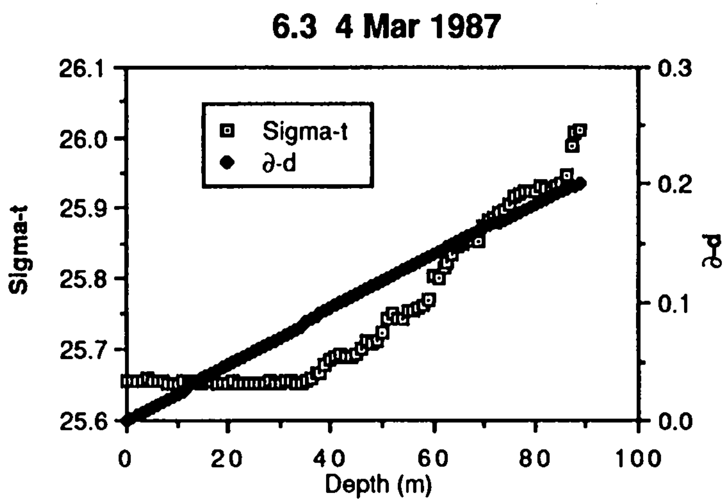


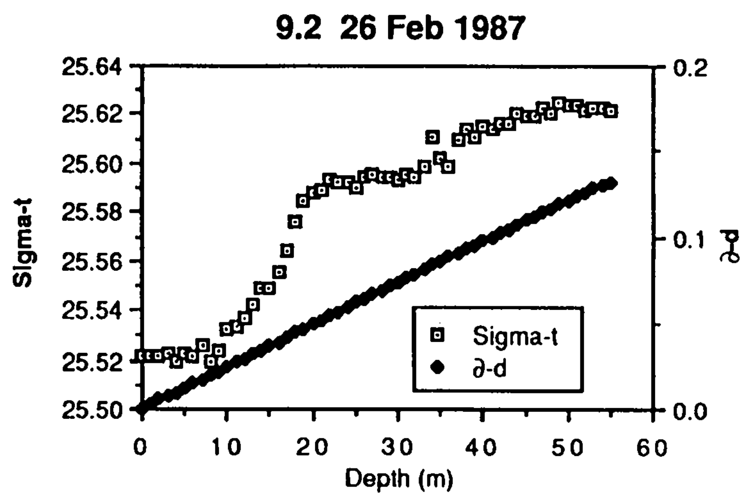
6.2 4 Mar 1987



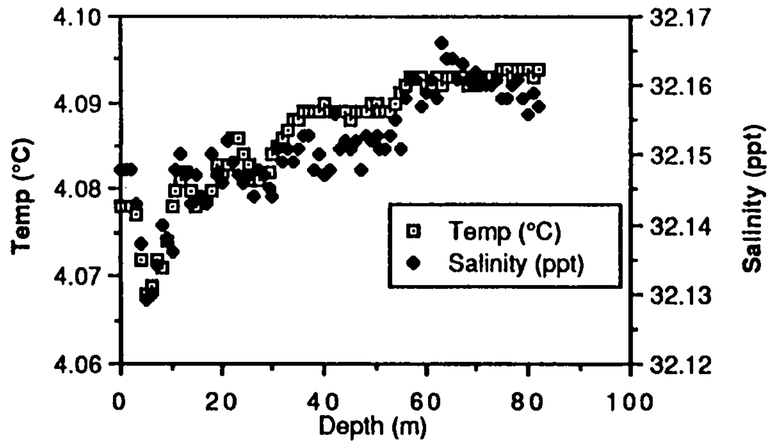

6.3 4 Mar 1987
Temp (°C)
Salinity (ppt)
4.3
4.2
4.1
4.0
32.8
32.7
32.6
32.5
32.4
32.3
0
20
40
60
80
100
Depth (m)


9.2 26 Feb 1987
Temp (°C)
Salinity (ppt)
4.02
4.00
3.98
3.96
3.94
3.92
3.90
32.3
32.2
32.1
0
10
20
30
40
50
60
Depth (m)

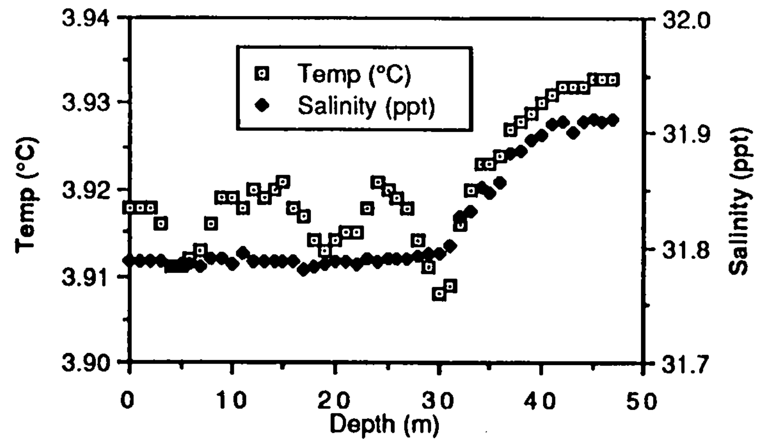

6.3 4 Mar 1987
Sigma-t
∂-d
26.1
26.0
25.9
25.8
25.7
25.6
0.3
0.2
0.1
0.0
0
20
40
60
80
100
Depth (m)


9.2 26 Feb 1987
Sigma-t
∂-d
25.64
25.62
25.60
25.58
25.56
25.54
25.52
25.50
0.2
0.1
0.0
0
10
20
30
40
50
60
Depth (m)

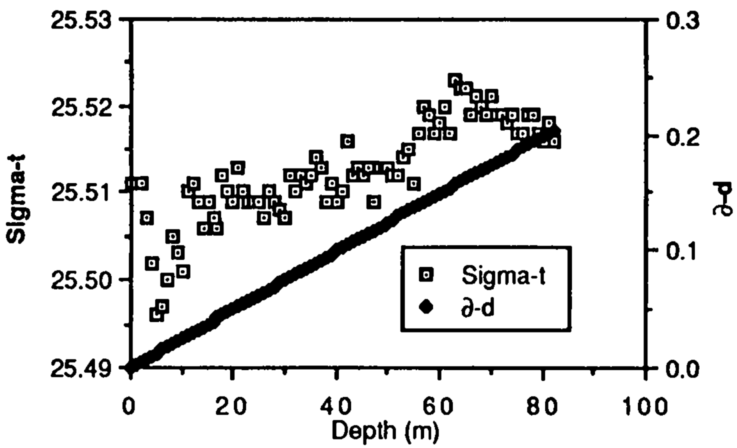
9.3 26 Feb 1987



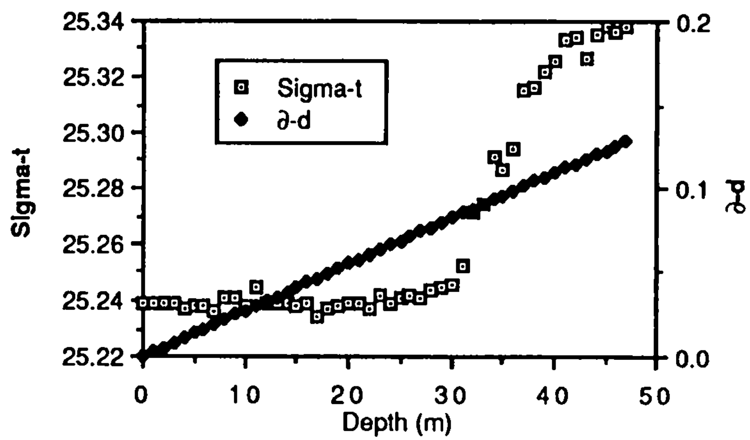
9.7 3 Mar 1987



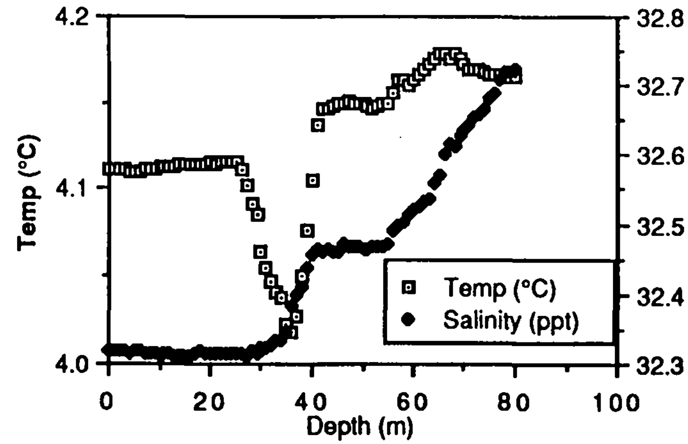
9.3 26 Feb 1987



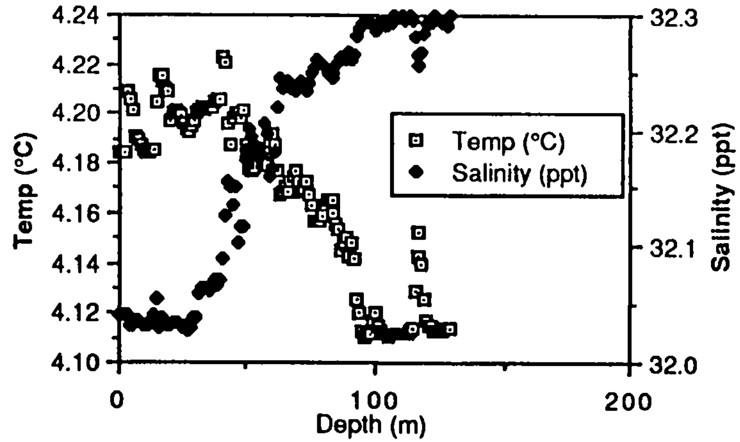
9.7 3 Mar 1987



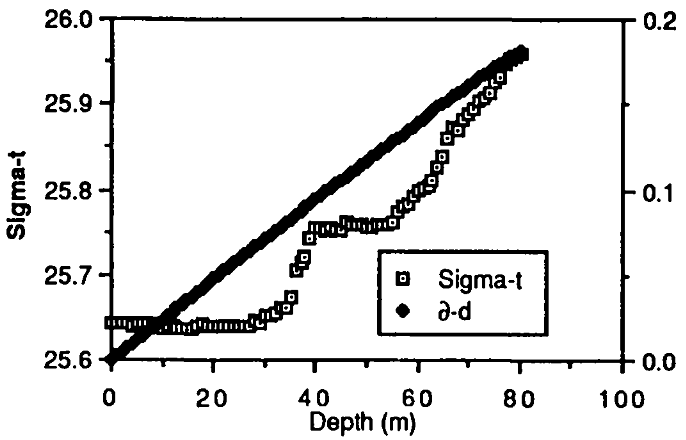
10.3 26 Feb 1987



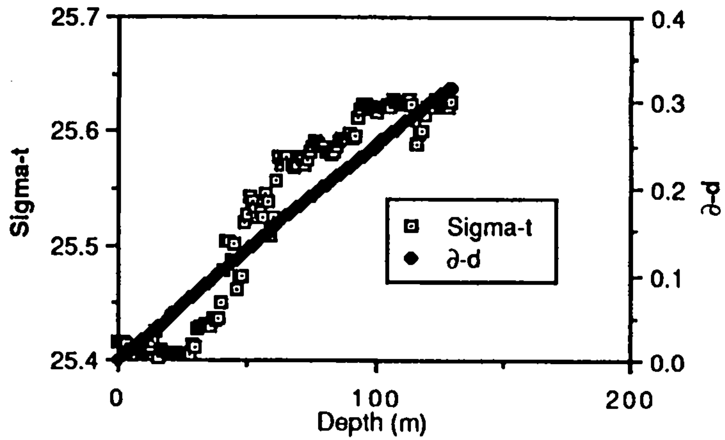
13.2 25 Feb 1987



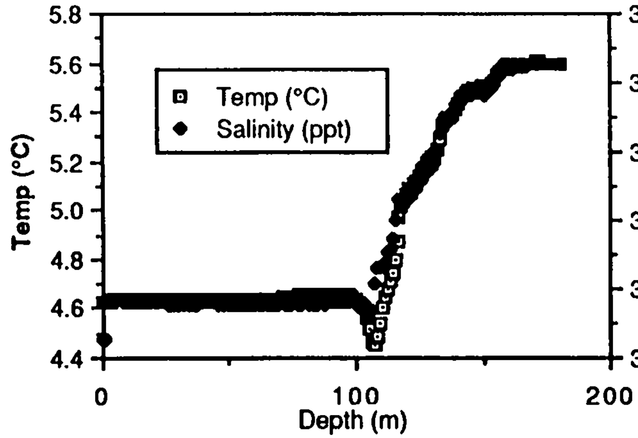
10.3 26 Feb 1987



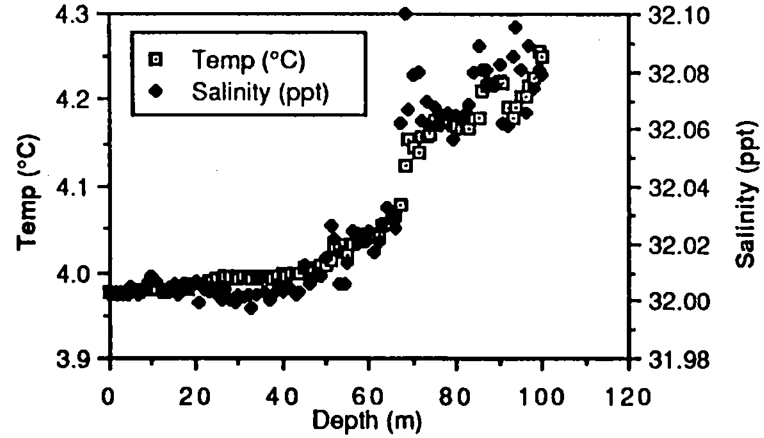
13.2 25 Feb 1987



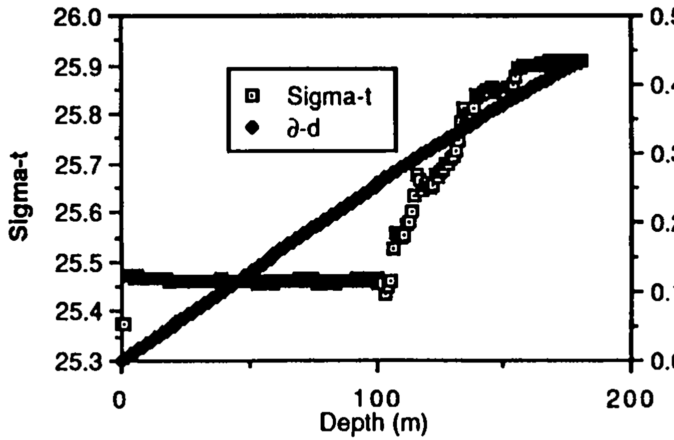
14.2 27 Feb 1987



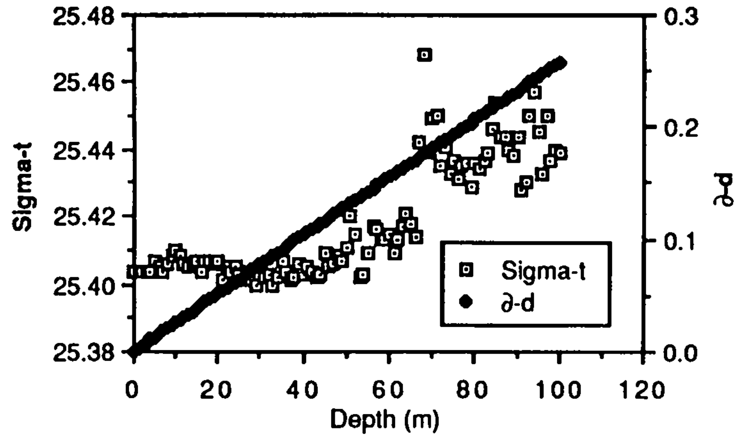
14.3 28 Feb 1987

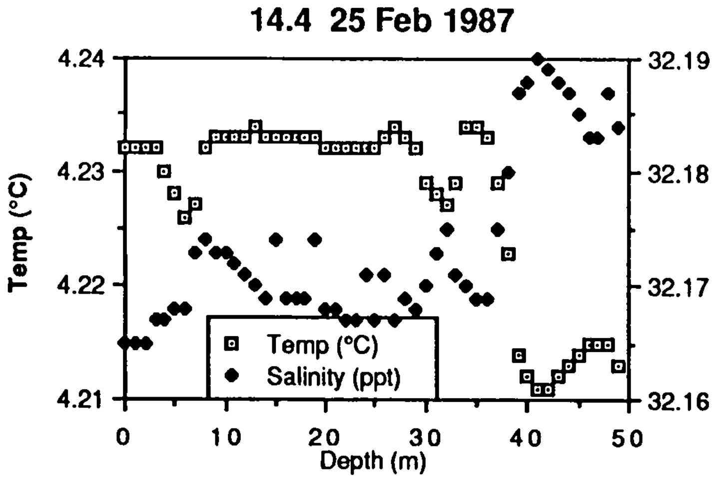


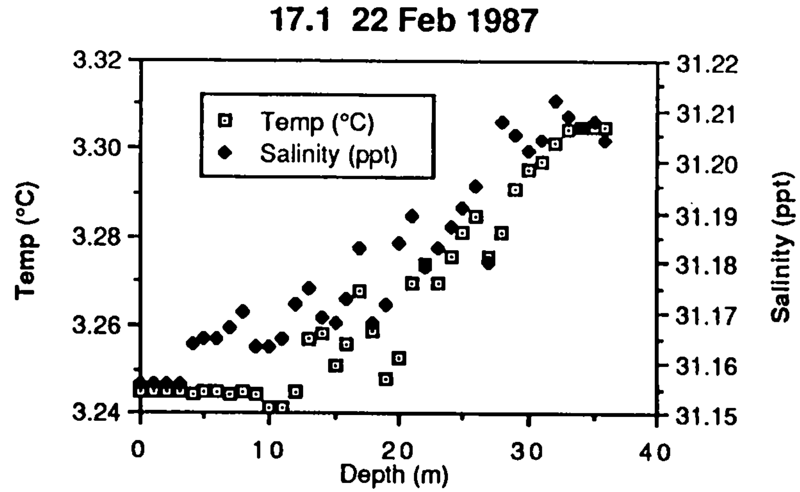
14.2 27 Feb 1987

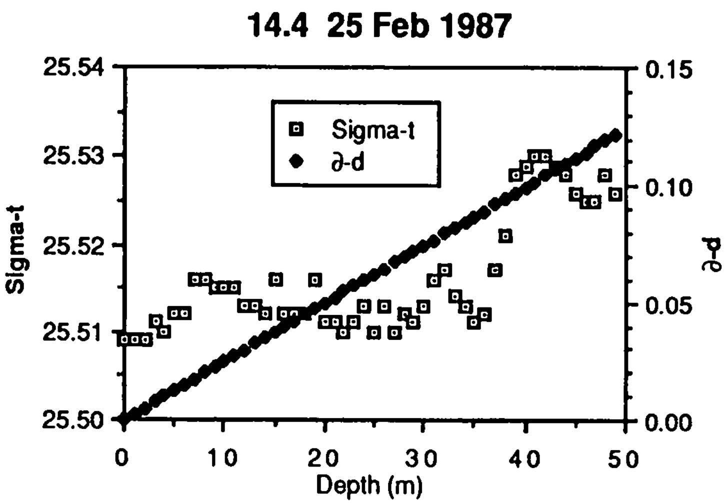


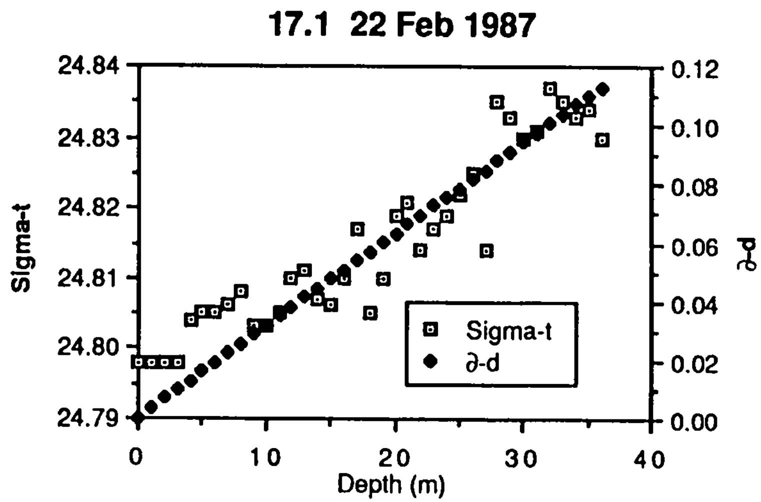
14.3 28 Feb 1987



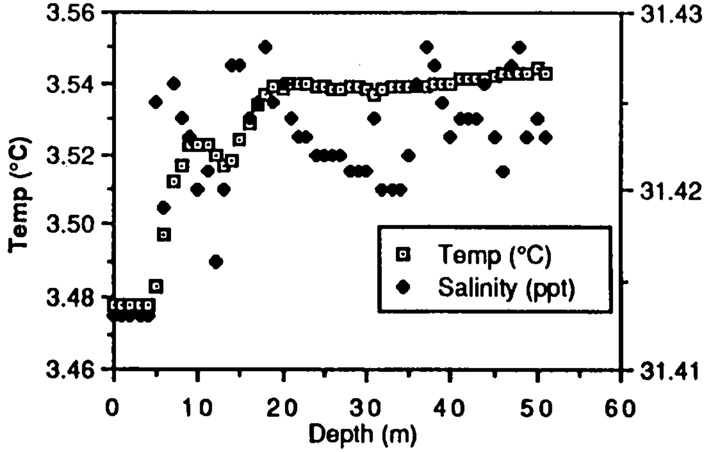

14.4 25 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.24
4.23
4.22
4.21
32.19
32.18
32.17
32.16
0
10
20
30
40
50


17.1 22 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
3.32
3.30
3.28
3.26
3.24
31.22
31.21
31.20
31.19
31.18
31.17
31.16
31.15
0
10
20
30
40

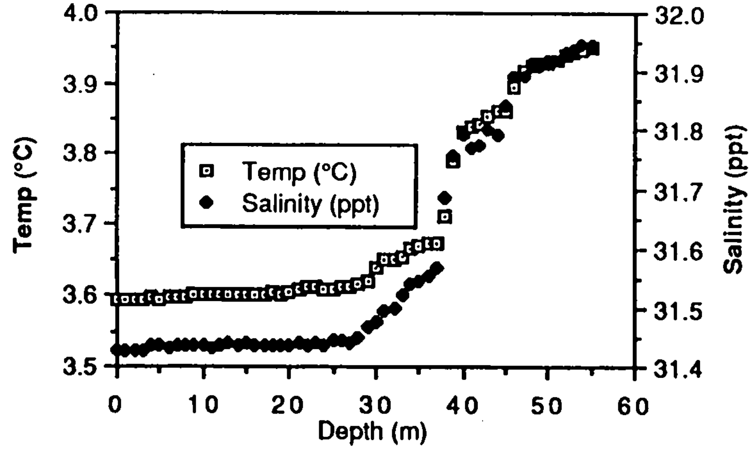

14.4 25 Feb 1987
Sigma-t
∂-d
Depth (m)
25.54
25.53
25.52
25.51
25.50
0.15
0.10
0.05
0.00
0
10
20
30
40
50


17.1 22 Feb 1987
Sigma-t
∂-d
Depth (m)
24.84
24.83
24.82
24.81
24.80
24.79
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40

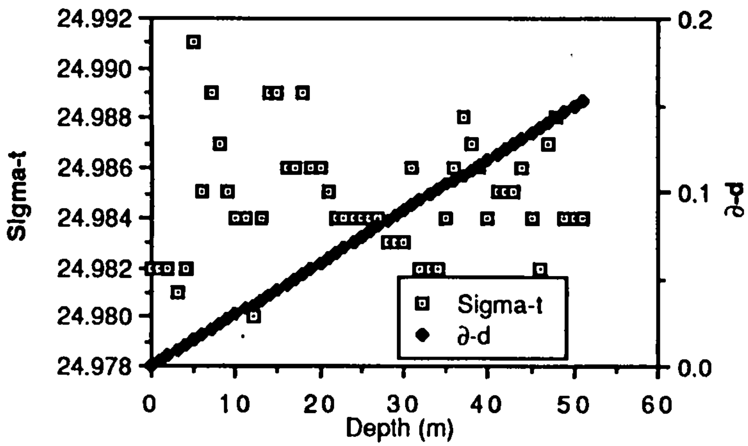
17.2 23 Feb 1987



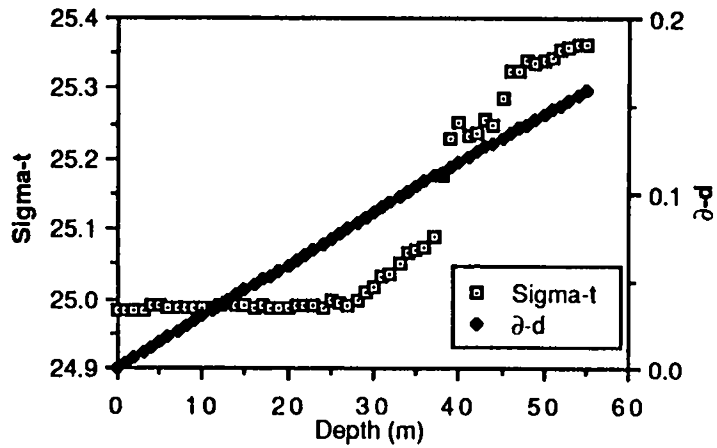
17.3 23 Feb 1987



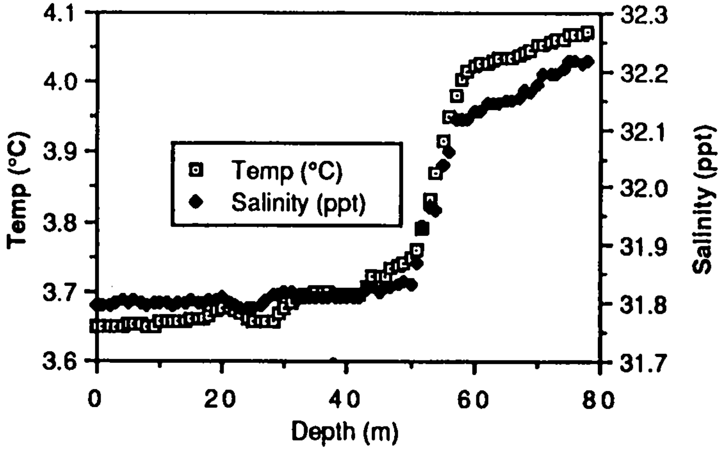
17.2 23 Feb 1987



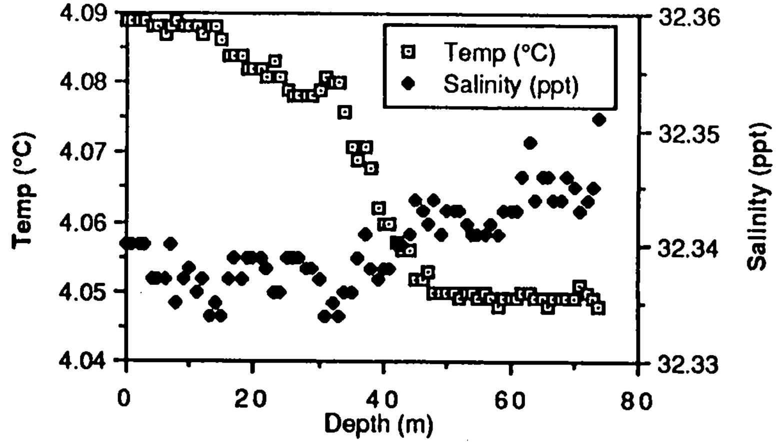
17.3 23 Feb 1987



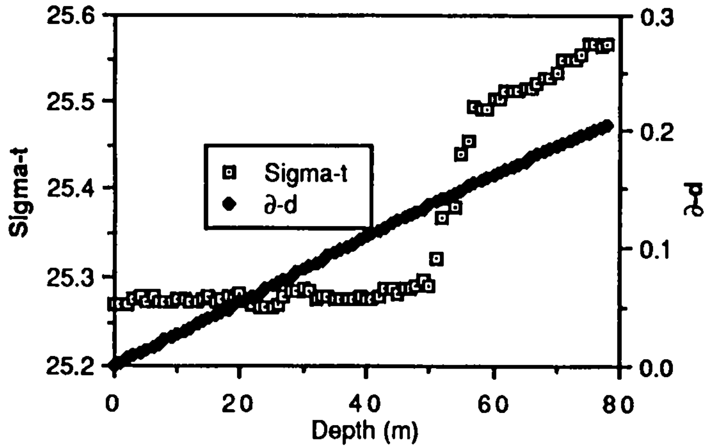
17.4 25 Feb 1987



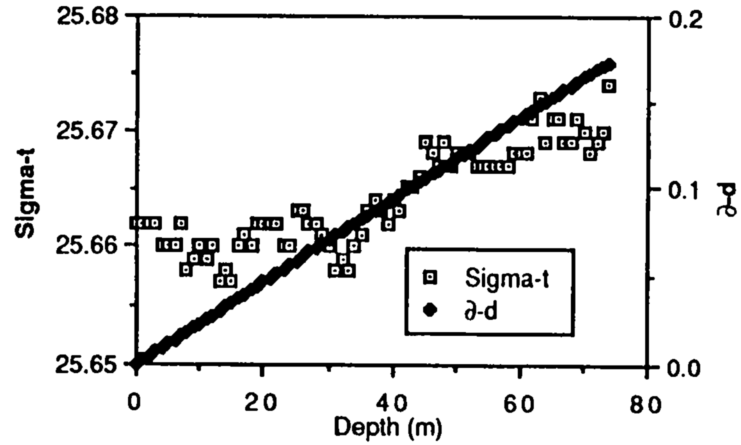
17.5 4 Mar 1987

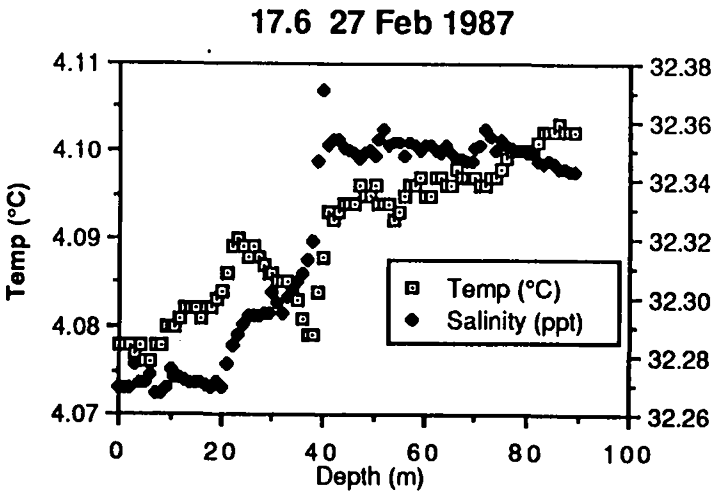


17.4 25 Feb 1987

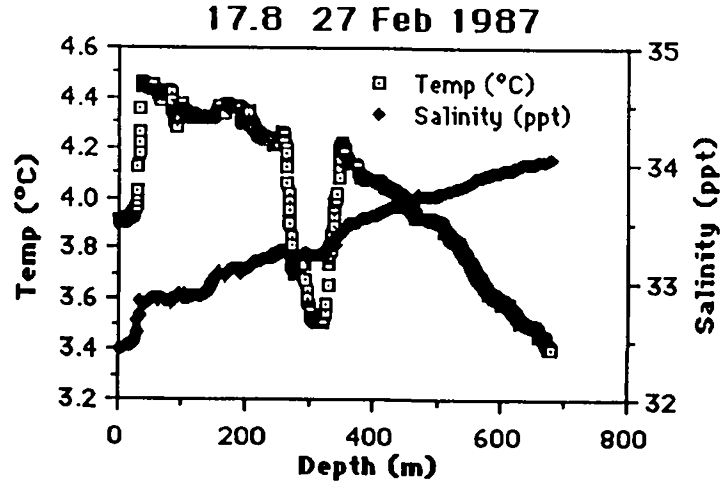


17.5 4 Mar 1987

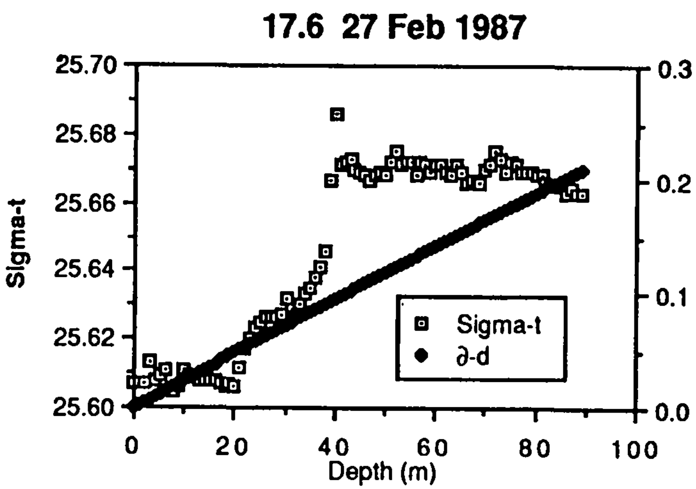




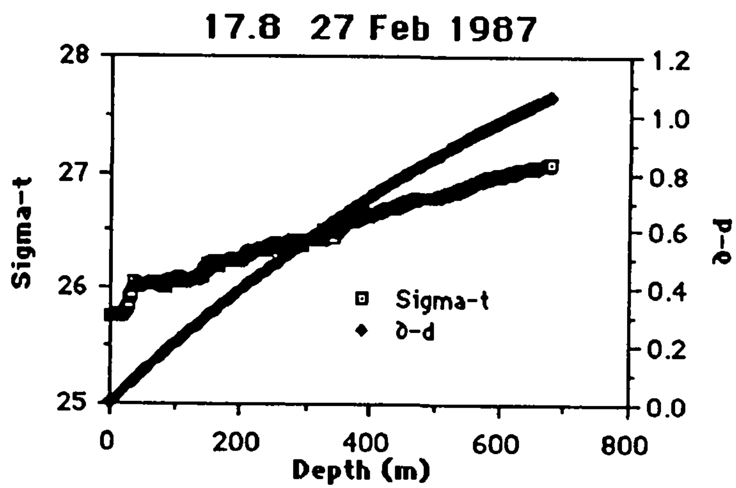
17.6 27 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.11
4.10
4.09
4.08
4.07
32.38
32.36
32.34
32.32
32.30
32.28
32.26
0
20
40
60
80
100



17.8 27 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
35
34
33
32
0
200
400
600
800

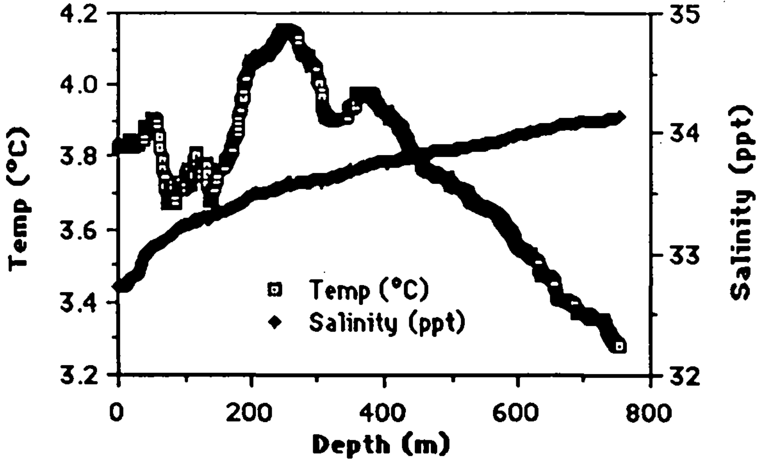


17.6 27 Feb 1987
Sigma-t
∂-d
Depth (m)
25.70
25.68
25.66
25.64
25.62
25.60
0.3
0.2
0.1
0.0
0
20
40
60
80
100

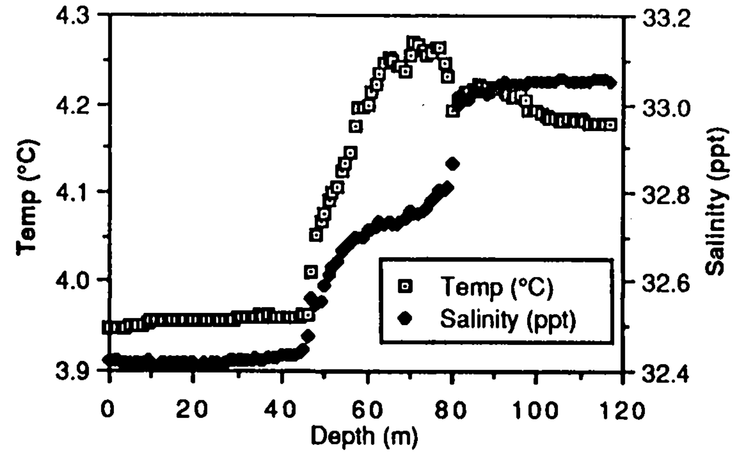


17.8 27 Feb 1987
Sigma-t
∂-d
Depth (m)
28
27
26
25
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800

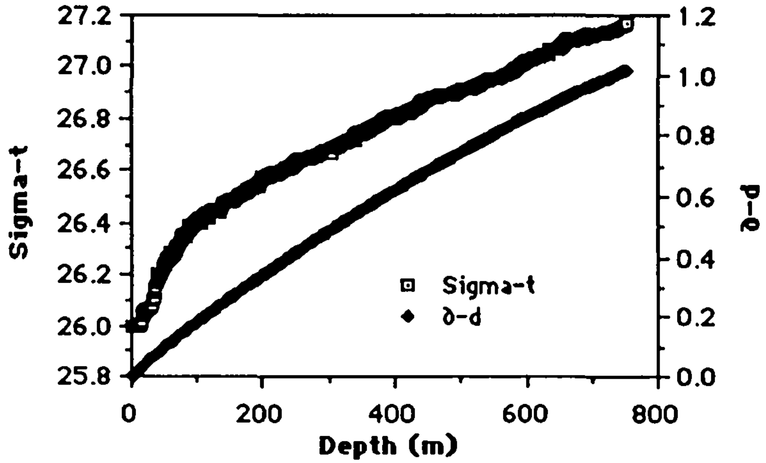
21.1 1 Mar 1987



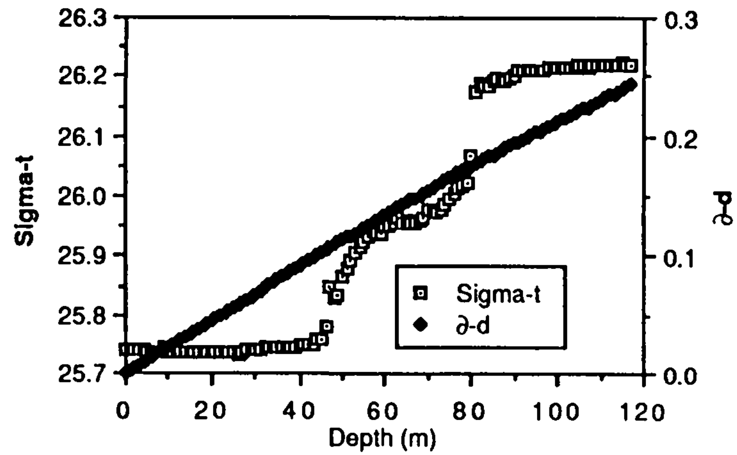
21.2 2 Mar 1987



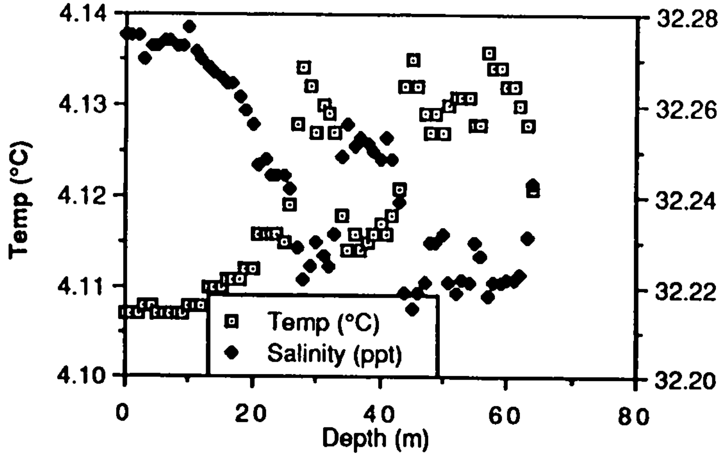
21.1 1 Mar 1987



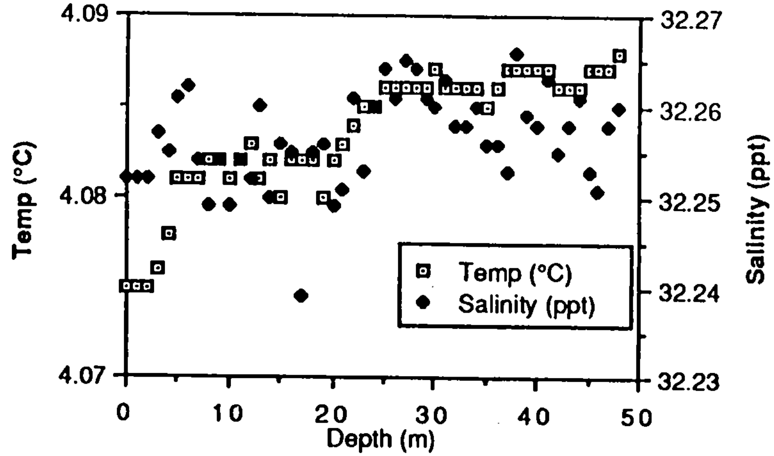
21.2 2 Mar 1987



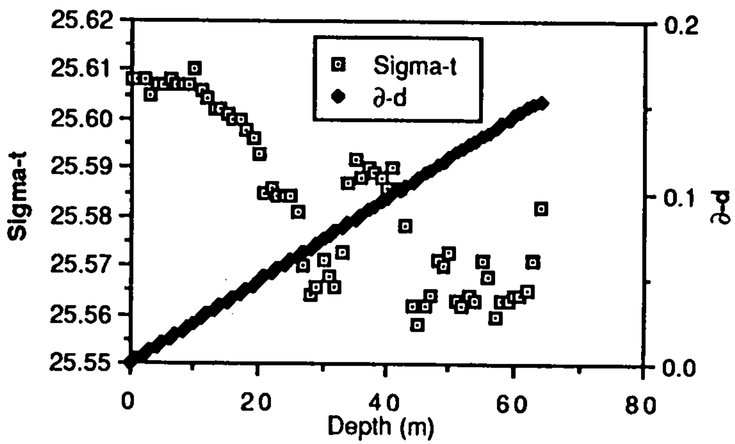
21.3 1 Mar 1987



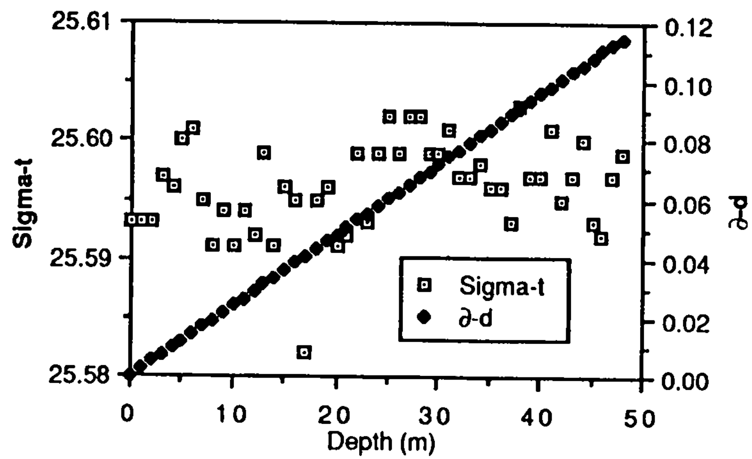
21.3 6 Mar 1987 a



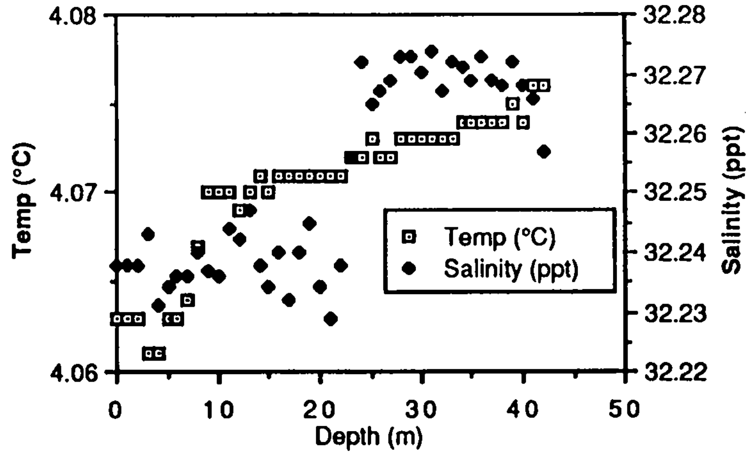
21.3 1 Mar 1987



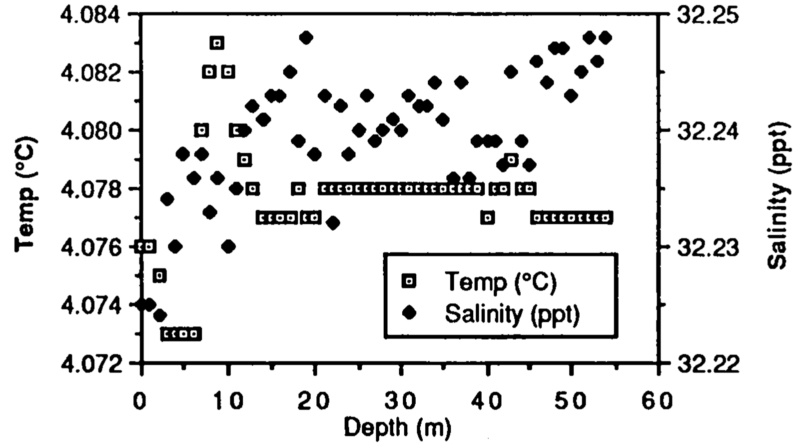
21.3 6 Mar 1987 a



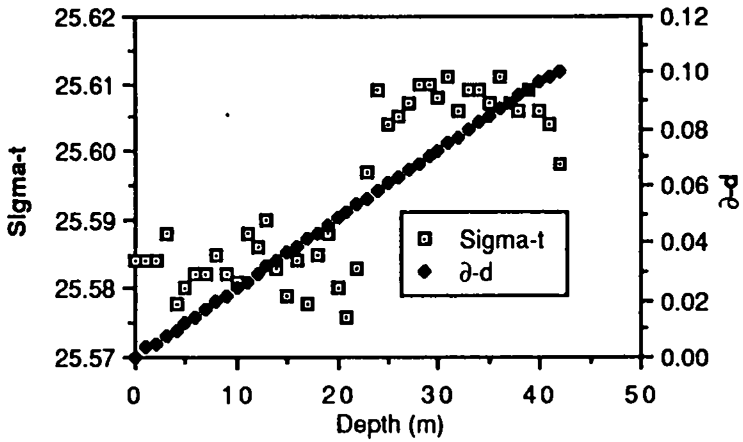
21.3 6 Mar 1987 b



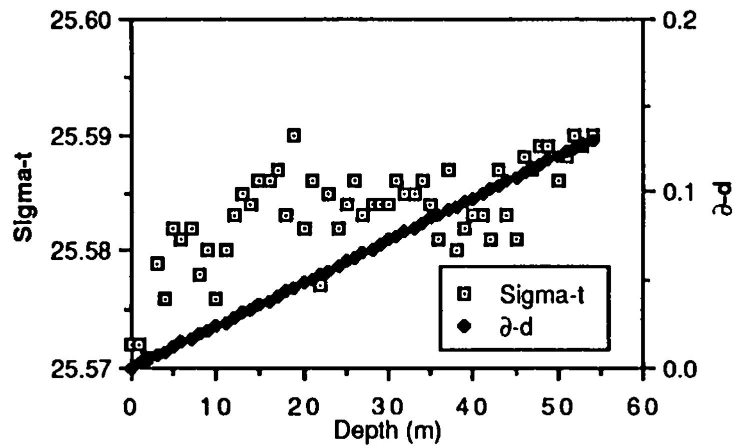
21.3 7 Mar 1987 a



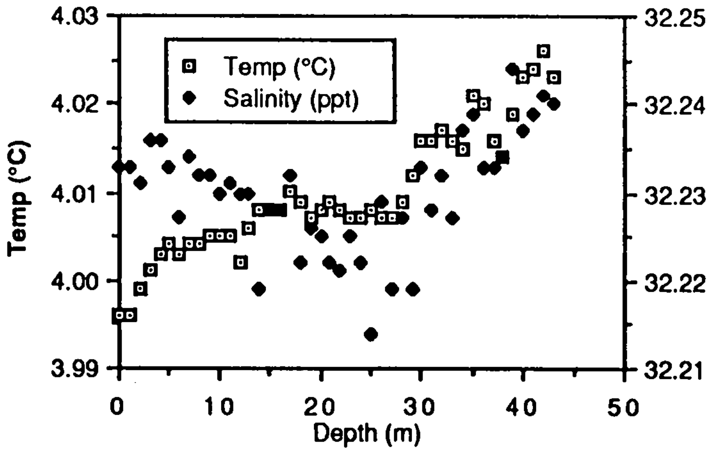
21.3 6 Mar 1987 b



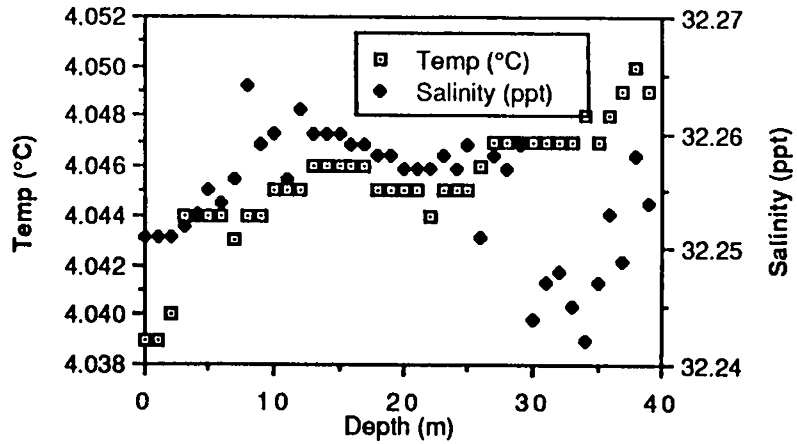
21.3 7 Mar 1987 a



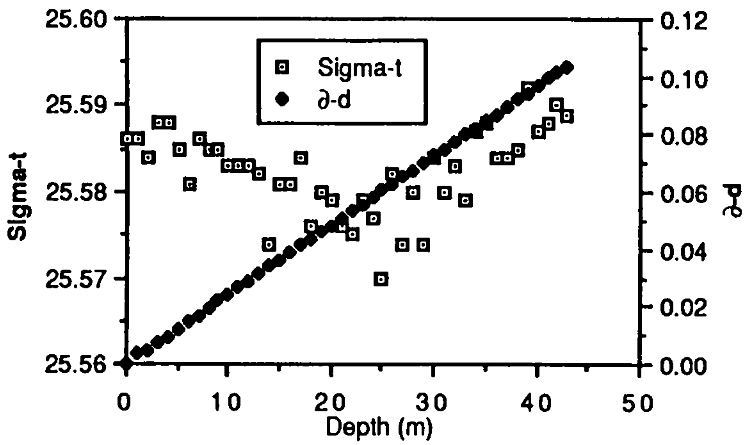
21.3 7 Mar 1987 b



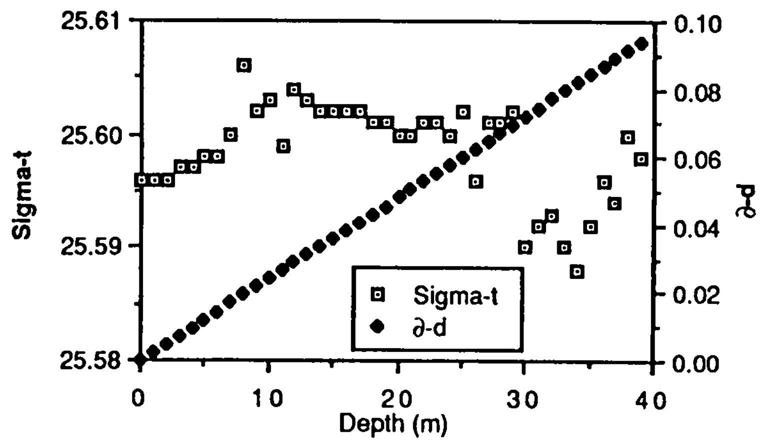
21.3 7 Mar 1987 c



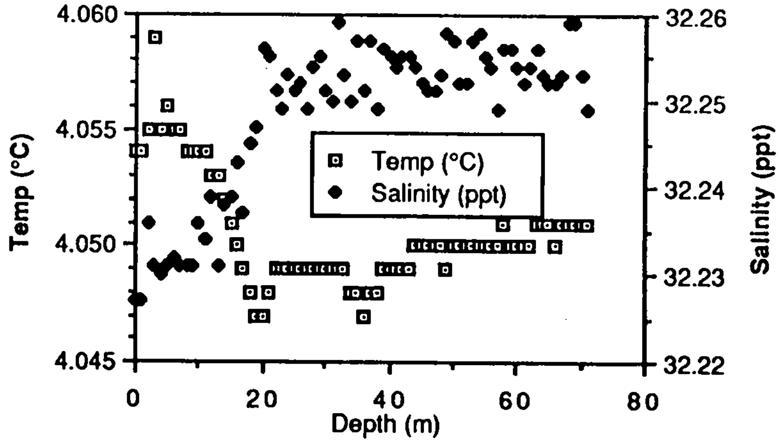
21.3 7 Mar 1987 b



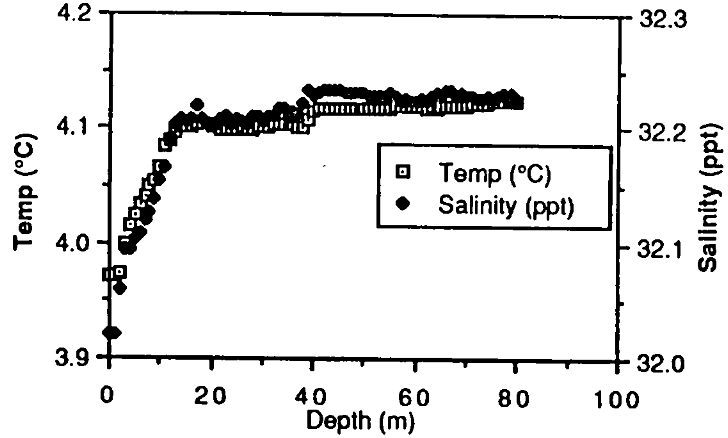
21.3 7 Mar 1987 c



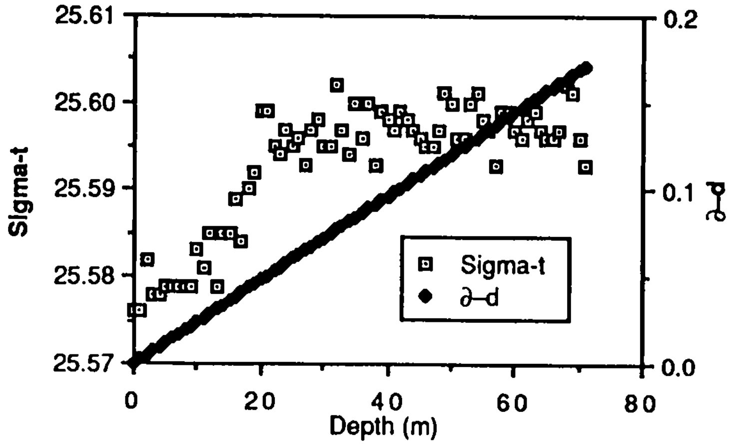
21.3 7 Mar 1987 d



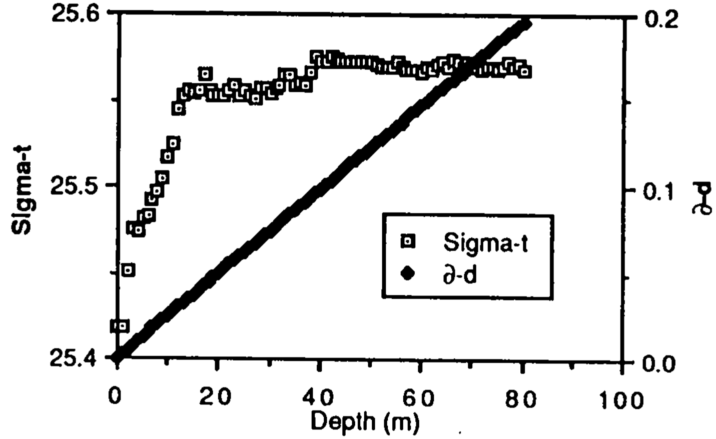
21.4 2 Mar 1987



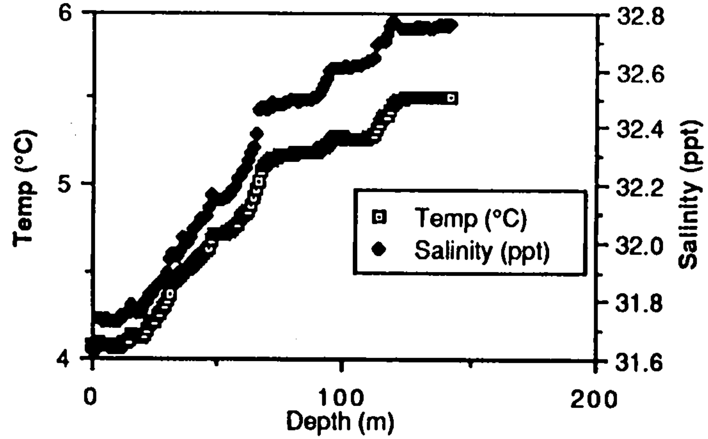
21.3 7 Mar 1987 d



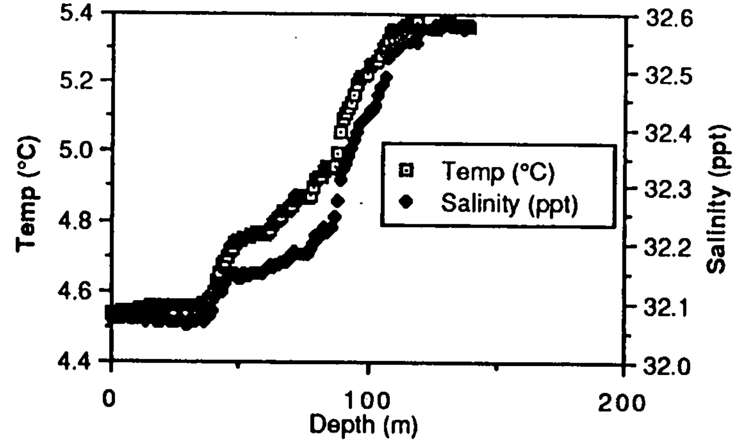
21.4 2 Mar 1987



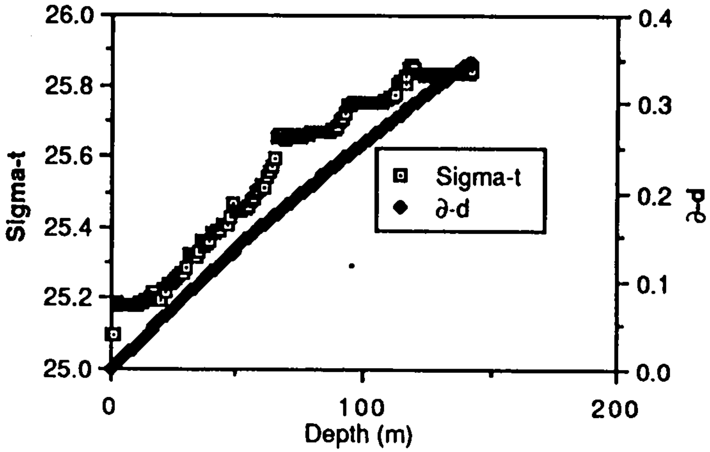
21.5 19 Feb 1987



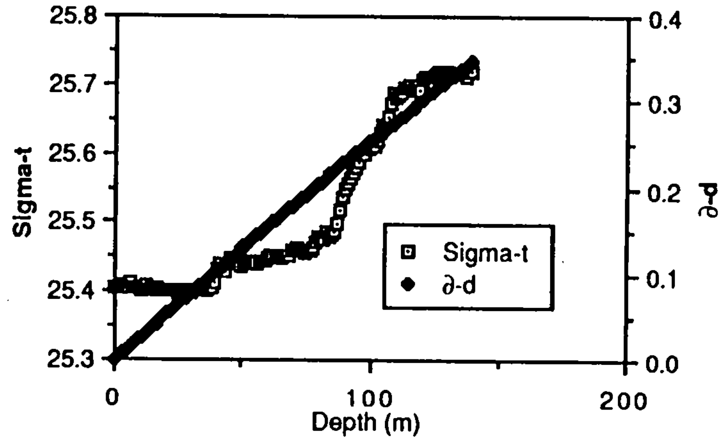
21.5 2 Mar 1987

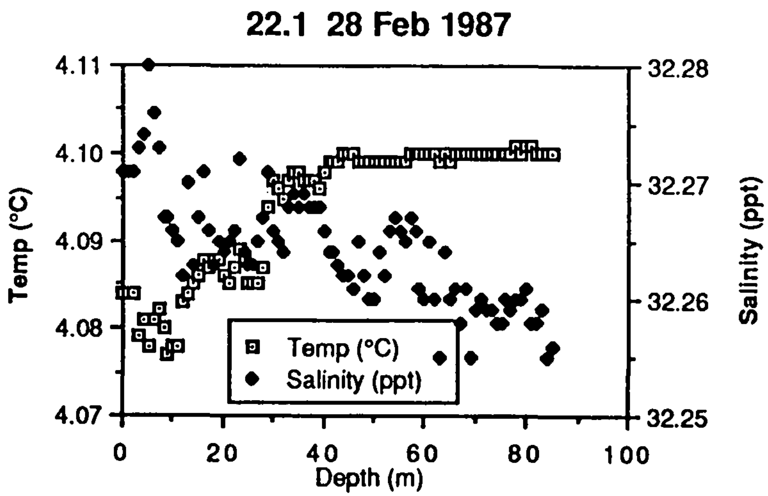


21.5 19 Feb 1987

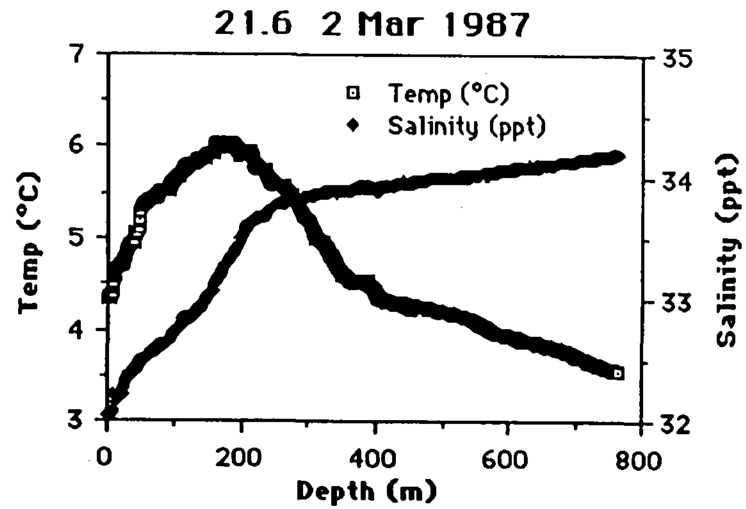


21.5 2 Mar 1987

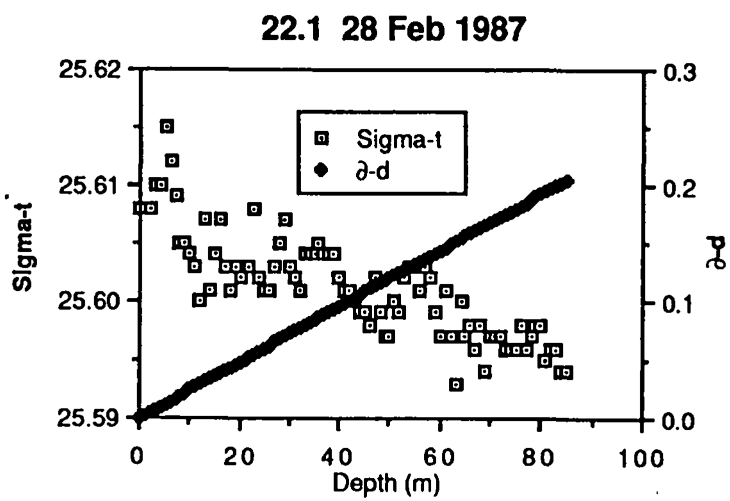




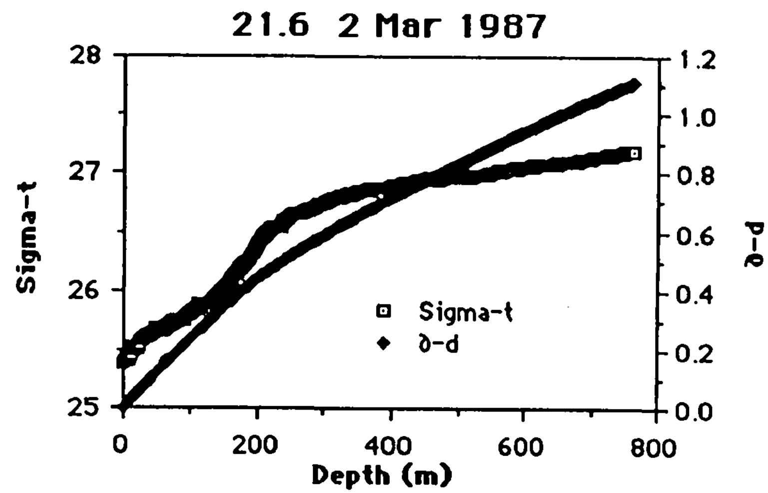
22.1 28 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.11
4.10
4.09
4.08
4.07
32.28
32.27
32.26
32.25
0
20
40
60
80
100



21.6 2 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
7
6
5
4
3
35
34
33
32
0
200
400
600
800

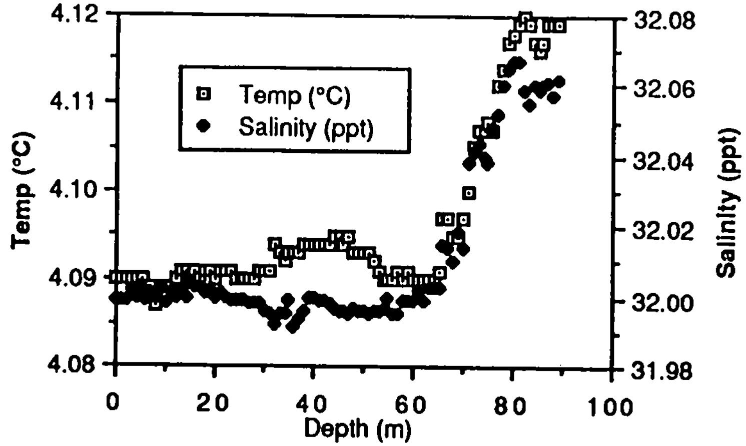


22.1 28 Feb 1987
Sigma-t
∂-d
Depth (m)
25.62
25.61
25.60
25.59
0.3
0.2
0.1
0.0
0
20
40
60
80
100

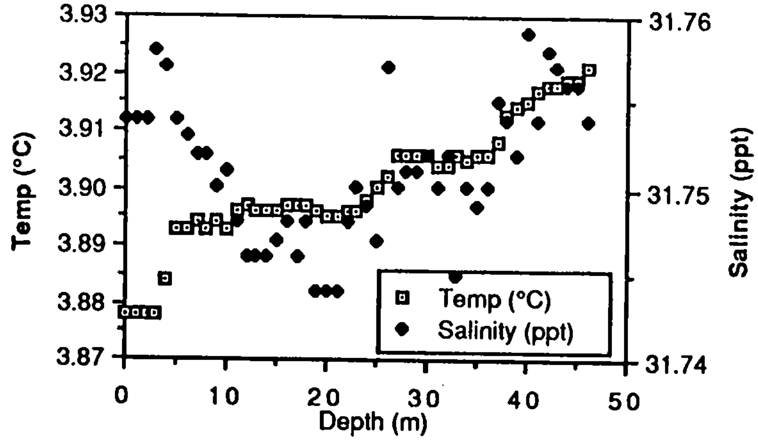


21.6 2 Mar 1987
Sigma-t
∂-d
Depth (m)
28
27
26
25
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800

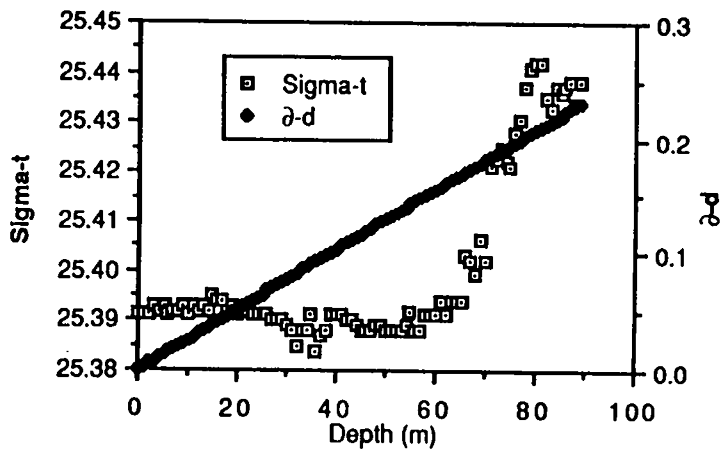
22.3 28 Feb 1987



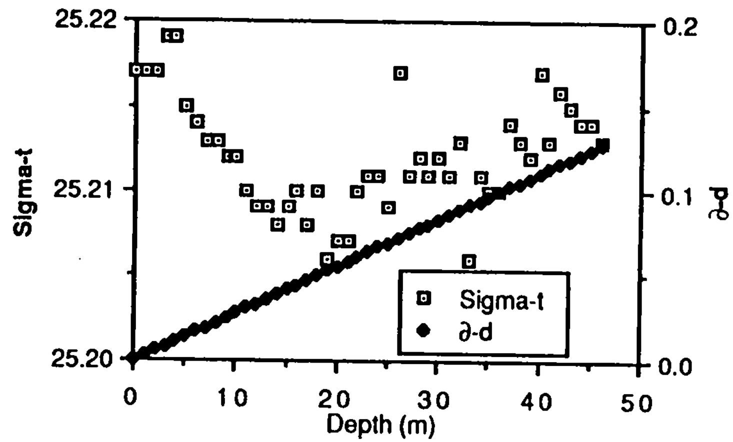
22.4 2 Mar 1987



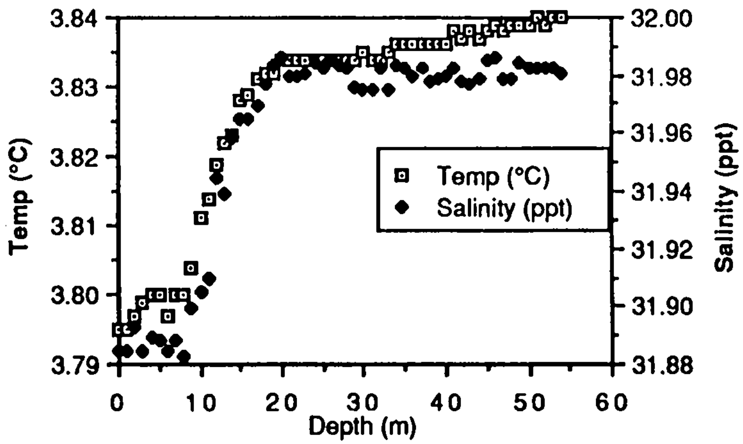
22.3 28 Feb 1987



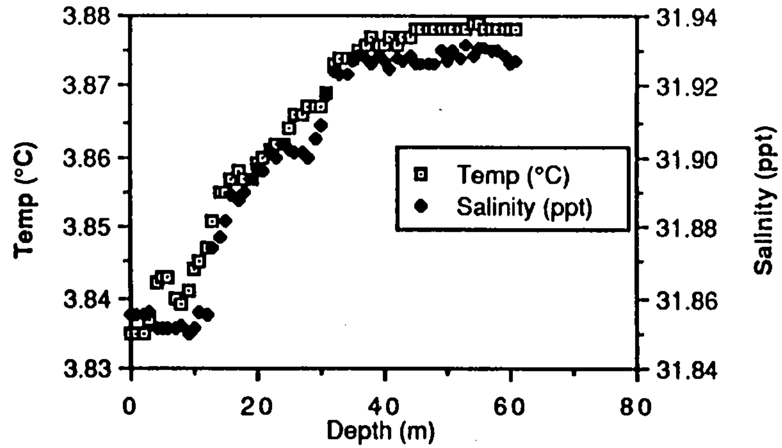
22.4 2 Mar 1987



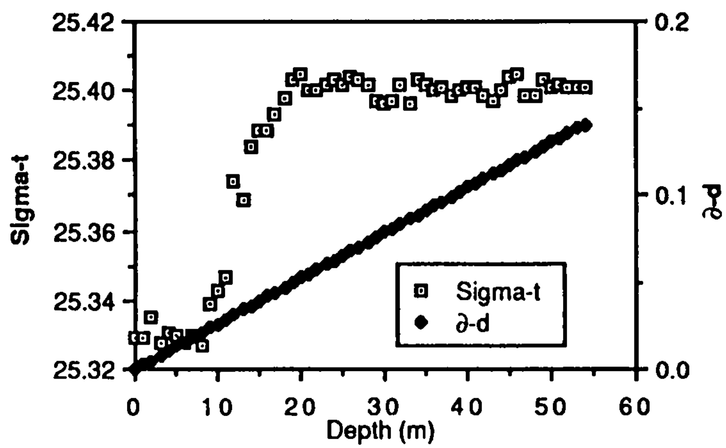
22.5 1 Mar 1987



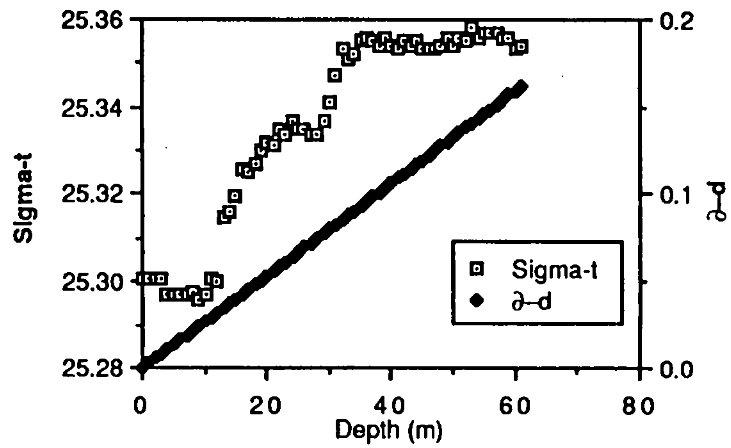
22.5 3 Mar 1987

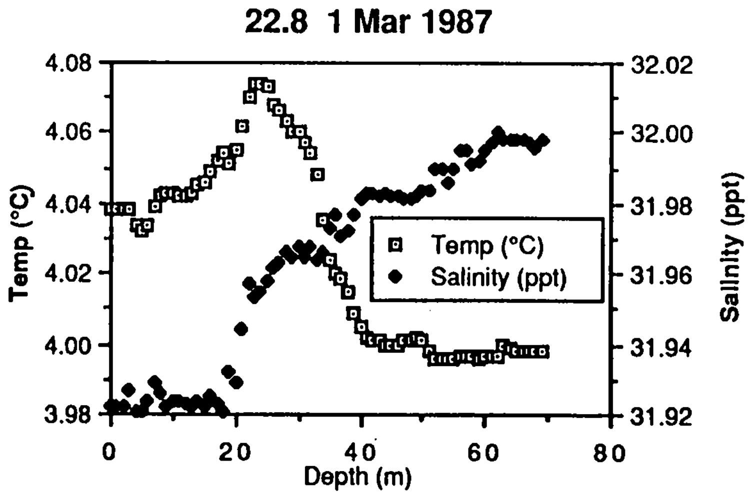


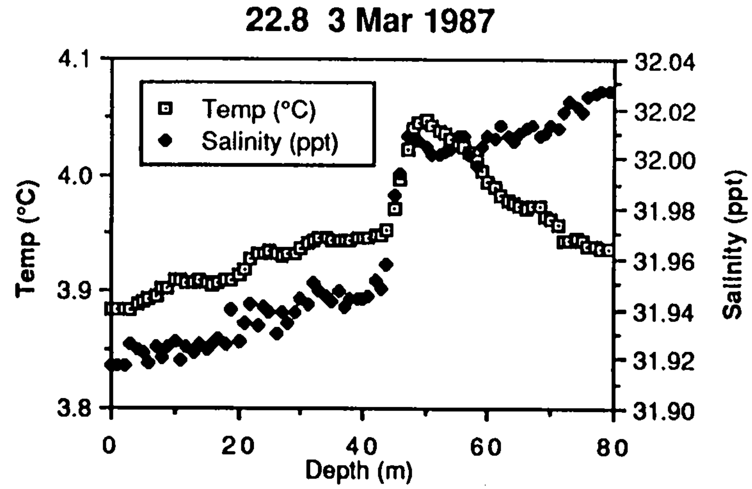
22.5 1 Mar 1987

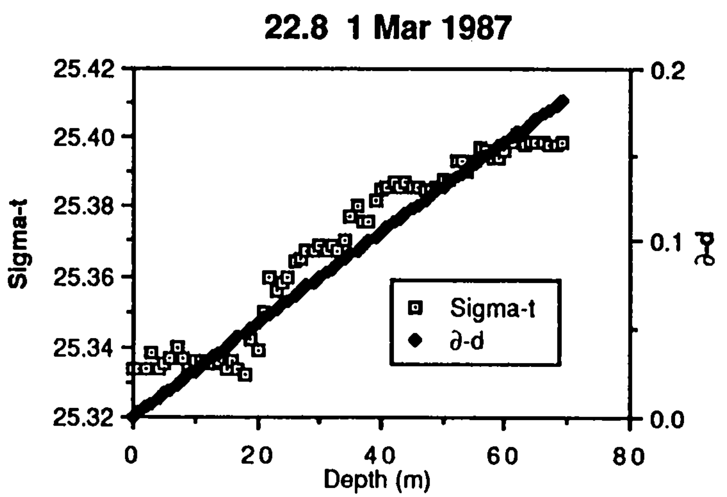


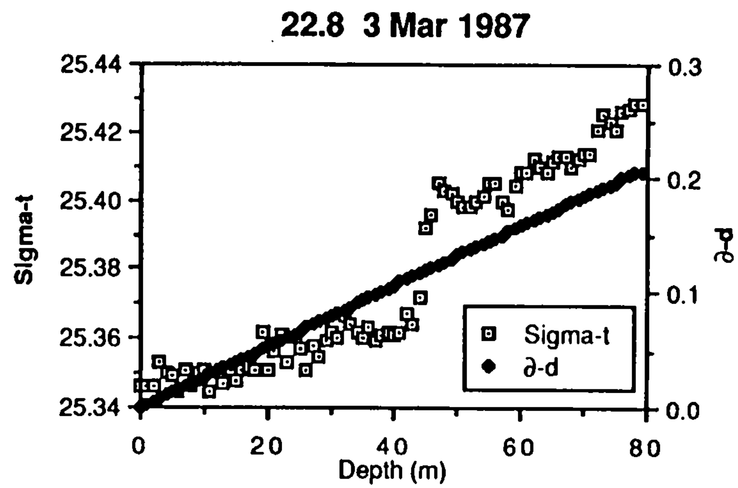
22.5 3 Mar 1987



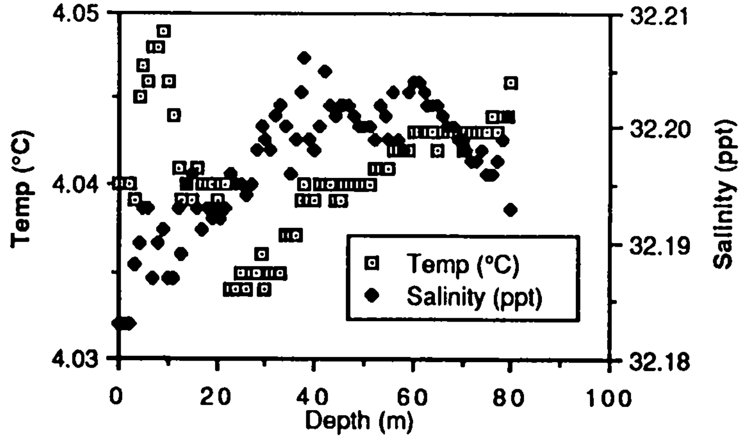

22.8 1 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.08
4.06
4.04
4.02
4.00
3.98
32.02
32.00
31.98
31.96
31.94
31.92
0
20
40
60
80


22.8 3 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.1
4.0
3.9
3.8
32.04
32.02
32.00
31.98
31.96
31.94
31.92
31.90
0
20
40
60
80

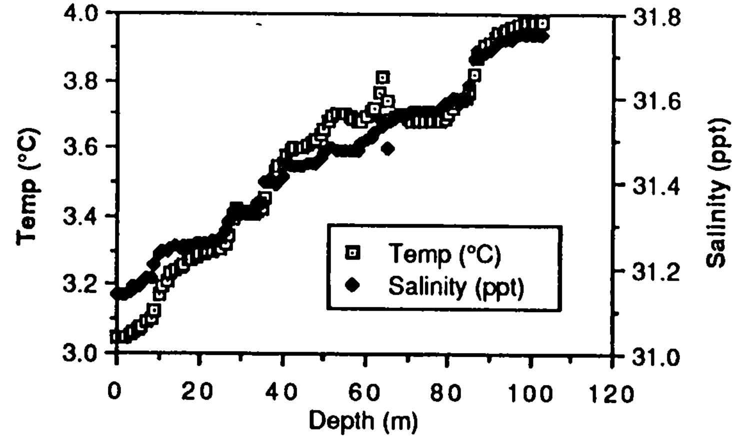

22.8 1 Mar 1987
Sigma-t
∂-d
Depth (m)
25.42
25.40
25.38
25.36
25.34
25.32
0.2
0.1
0.0
0
20
40
60
80


22.8 3 Mar 1987
Sigma-t
∂-d
Depth (m)
25.44
25.42
25.40
25.38
25.36
25.34
0.3
0.2
0.1
0.0
0
20
40
60
80

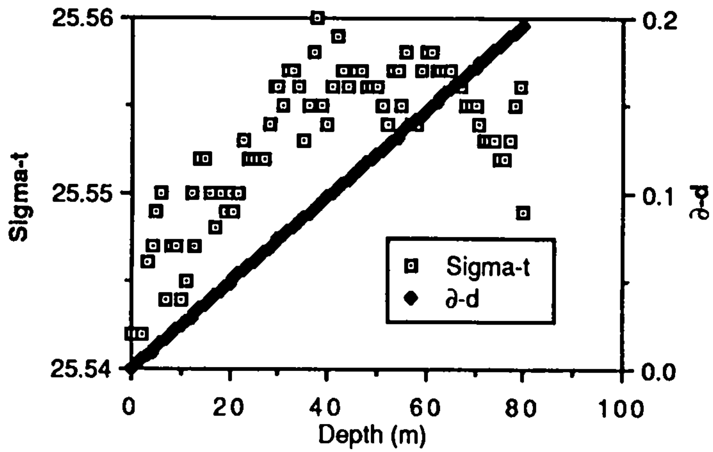
22.9 25 Feb 1987



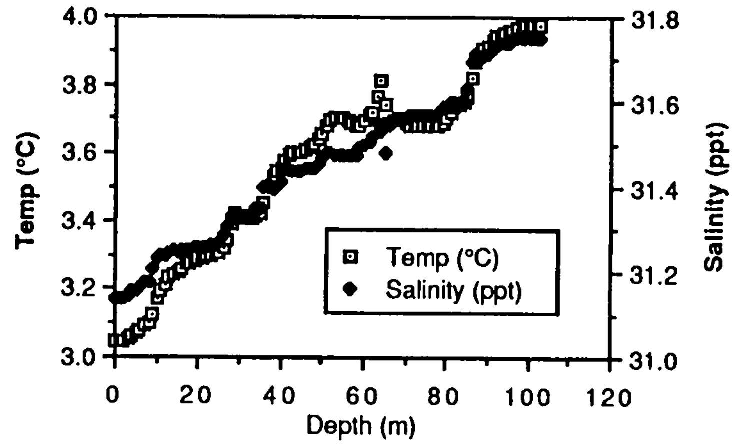
23.1 4 Mar 1987



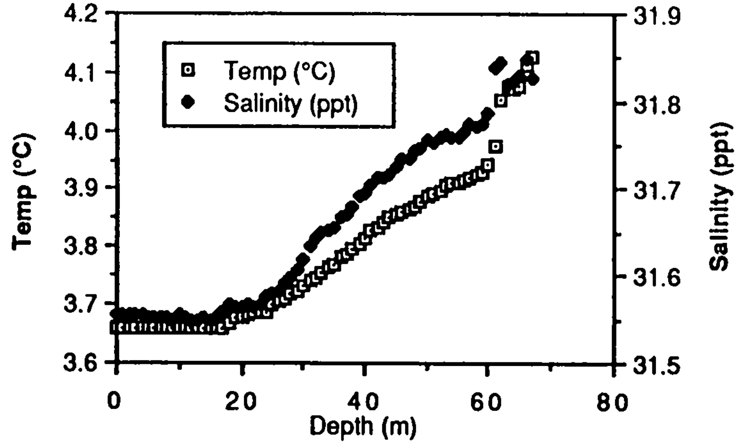
22.9 25 Feb 1987



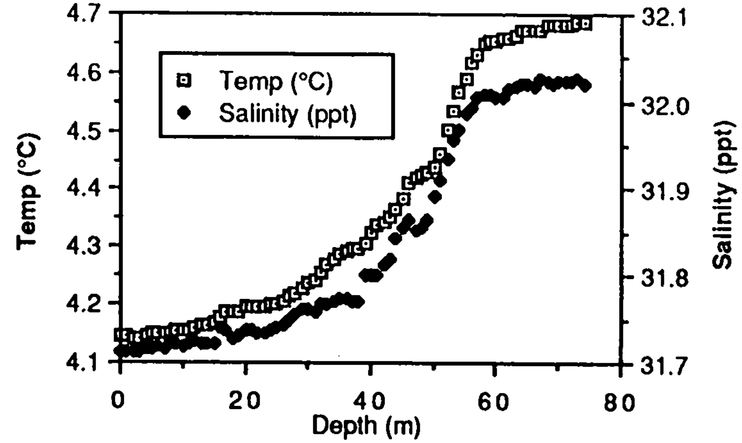
23.1 4 Mar 1987



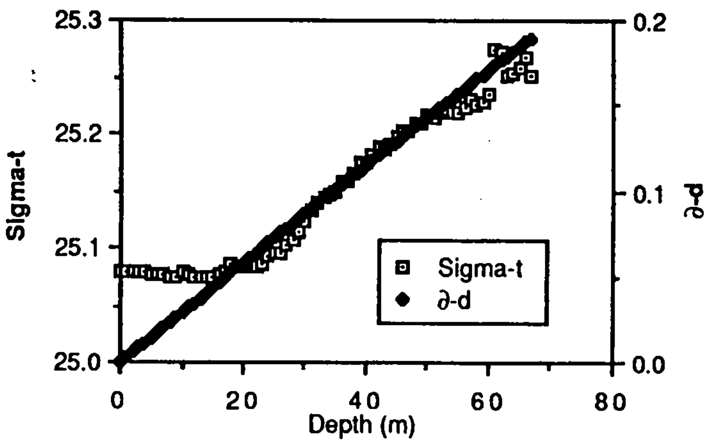
23.2 28 Feb 1987



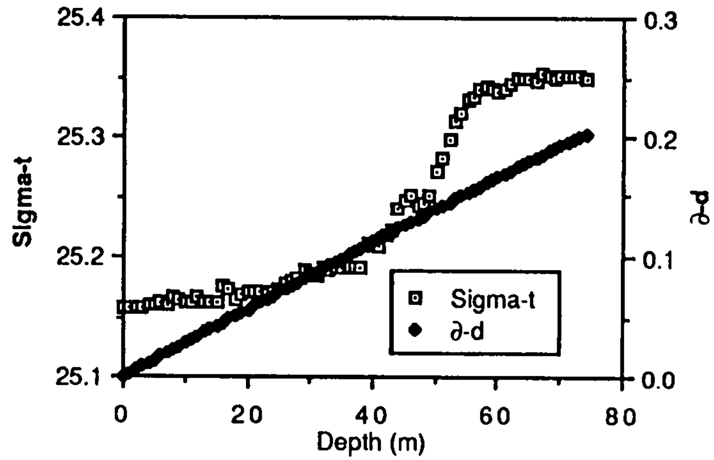
23.3 19 Feb 1987

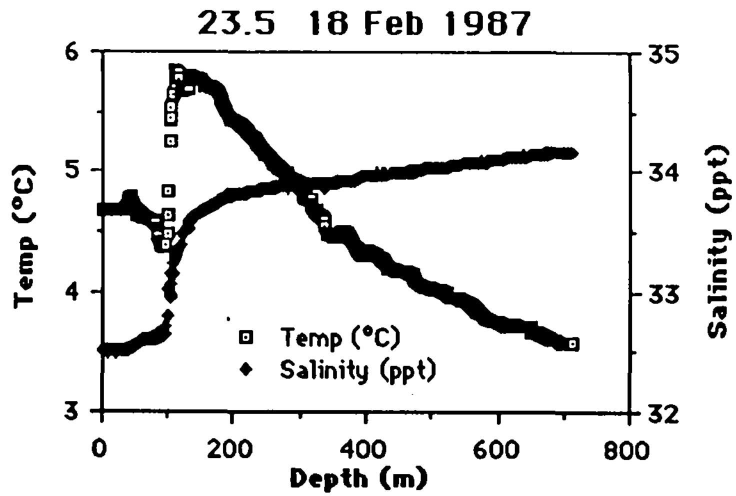


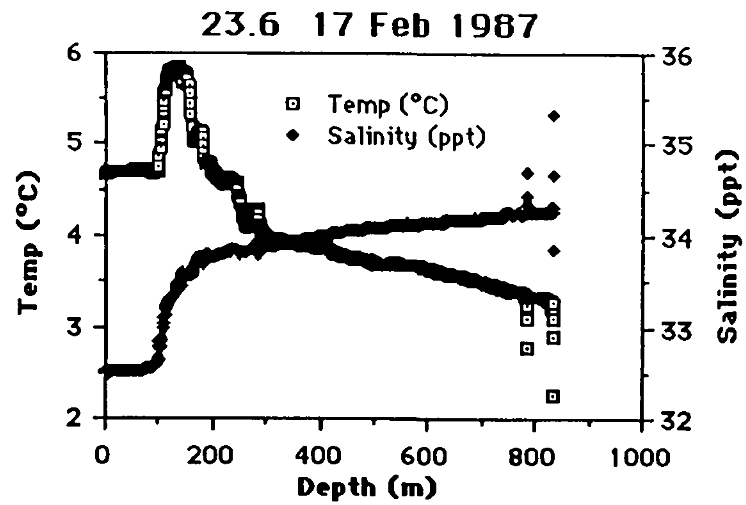
23.2 28 Feb 1987

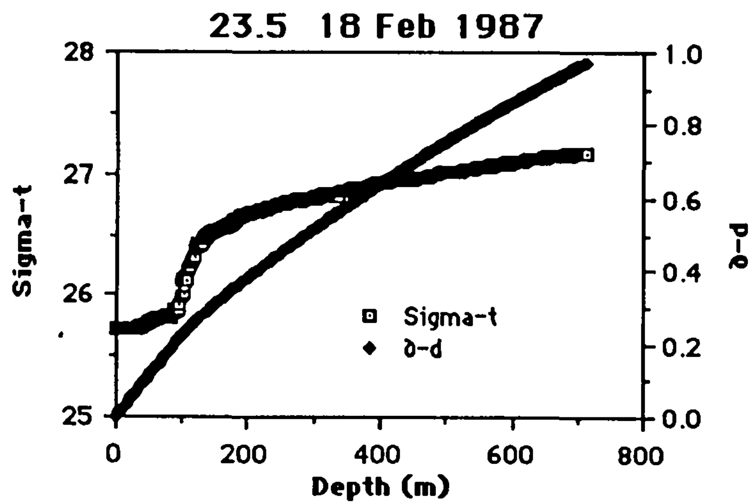


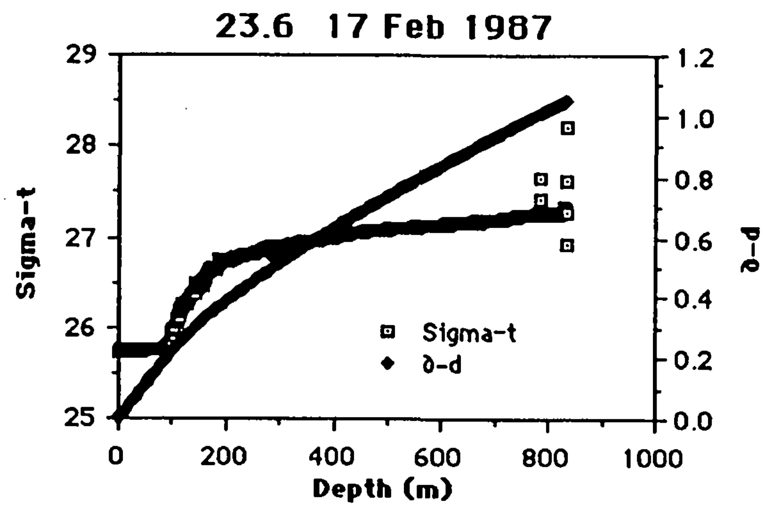
23.3 19 Feb 1987



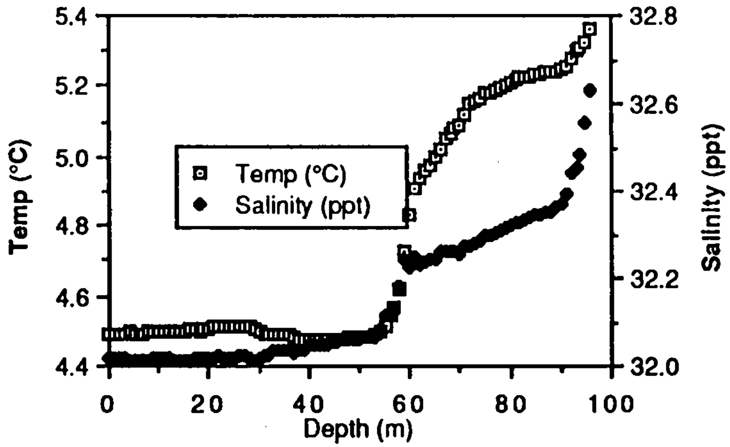

23.5 18 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
0
200
400
600
800
3
4
5
6
32
33
34
35


23.6 17 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
0
200
400
600
800
1000
2
3
4
5
6
32
33
34
35
36

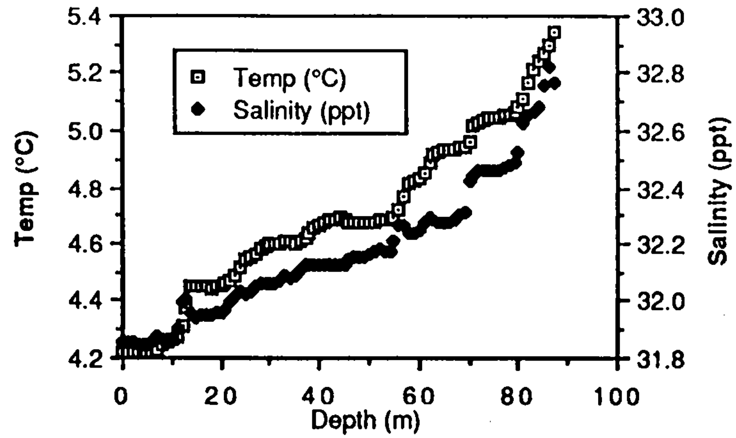

23.5 18 Feb 1987
Sigma-t
∂-d
Depth (m)
0
200
400
600
800
25
26
27
28
0.0
0.2
0.4
0.6
0.8
1.0


23.6 17 Feb 1987
Sigma-t
∂-d
Depth (m)
0
200
400
600
800
1000
25
26
27
28
29
0.0
0.2
0.4
0.6
0.8
1.0
1.2

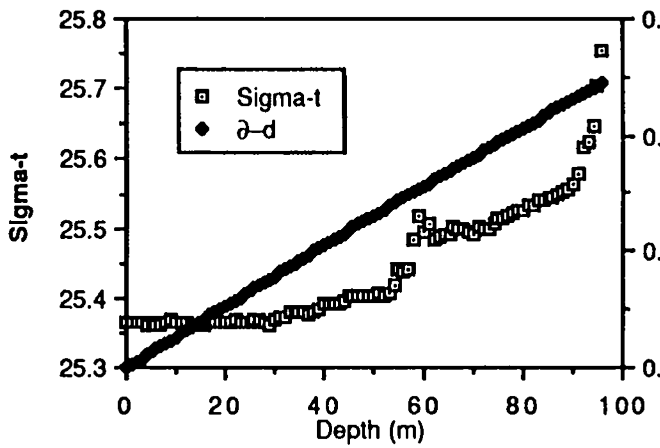
29.1 19 Feb 1987



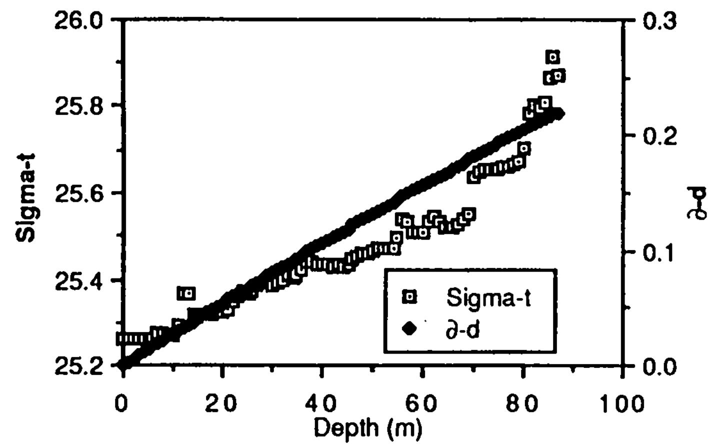
29.2 19 Feb 1987

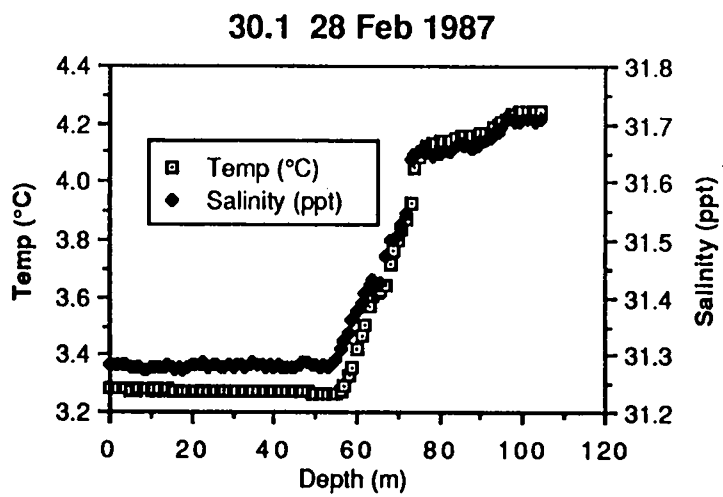


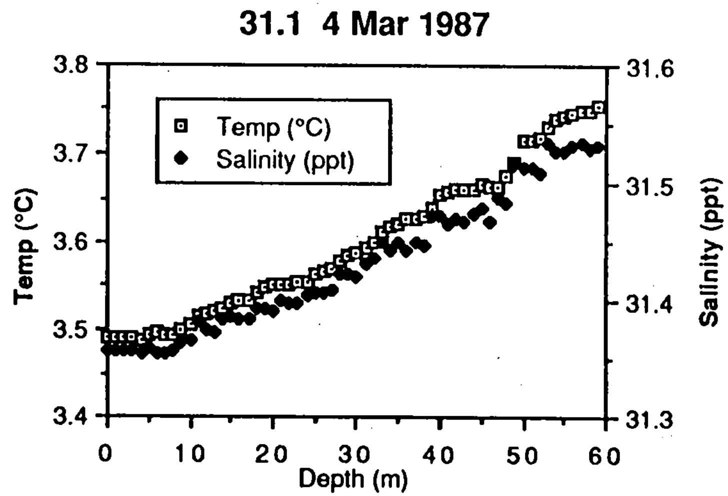
29.1 19 Feb 1987

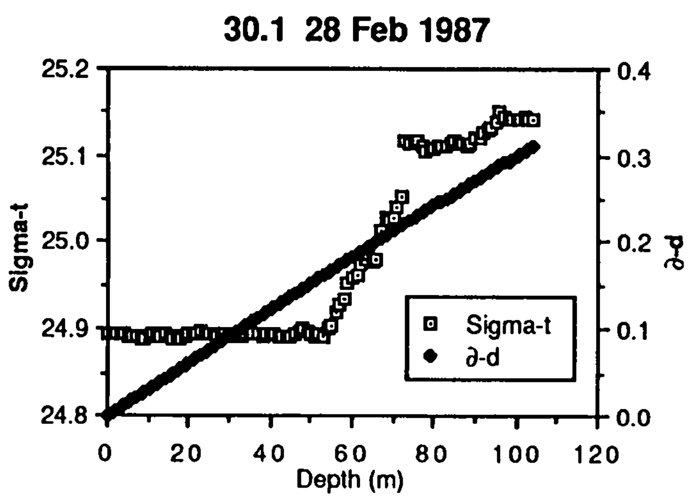


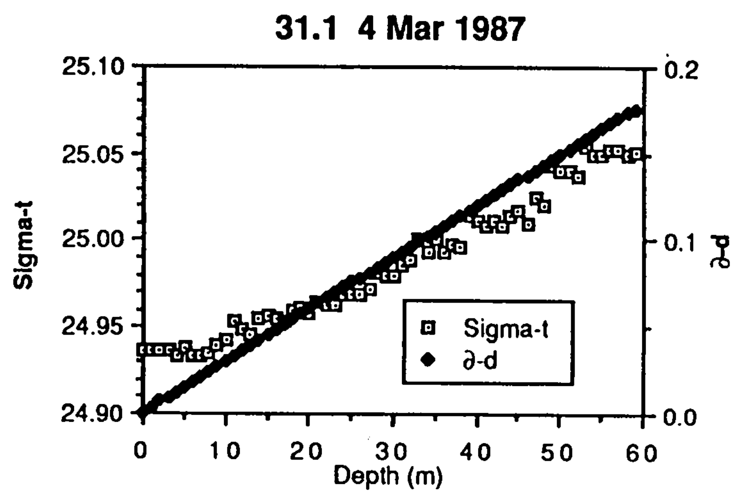
29.2 19 Feb 1987

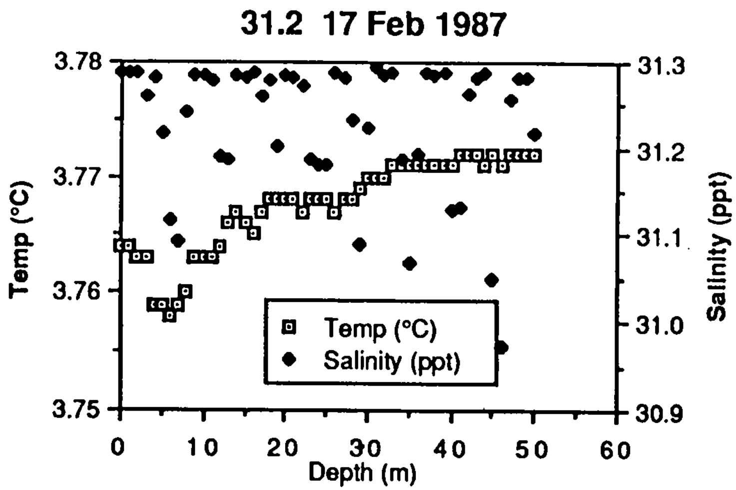


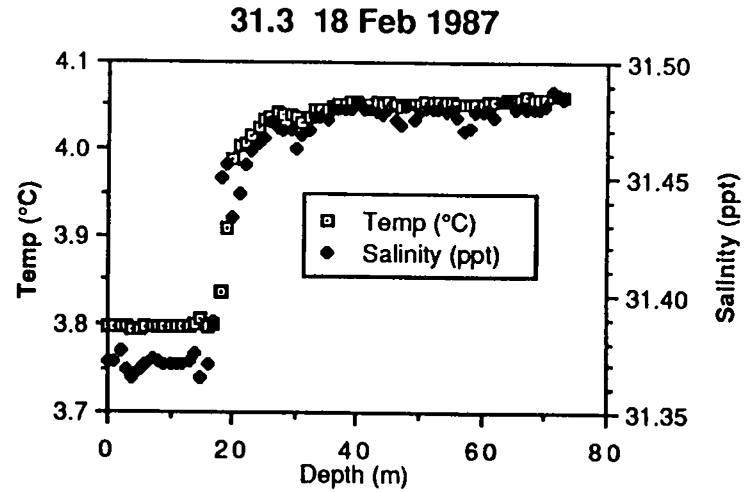

30.1 28 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.4
4.2
4.0
3.8
3.6
3.4
3.2
31.8
31.7
31.6
31.5
31.4
31.3
31.2
0
20
40
60
80
100
120

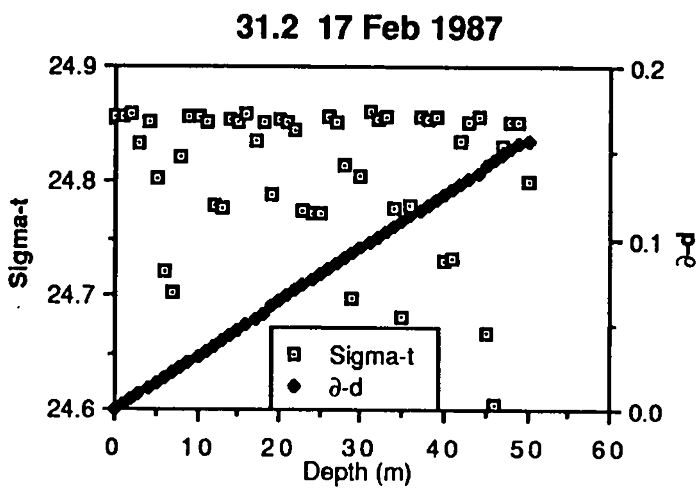

31.1 4 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
3.8
3.7
3.6
3.5
3.4
31.6
31.5
31.4
31.3
0
10
20
30
40
50
60

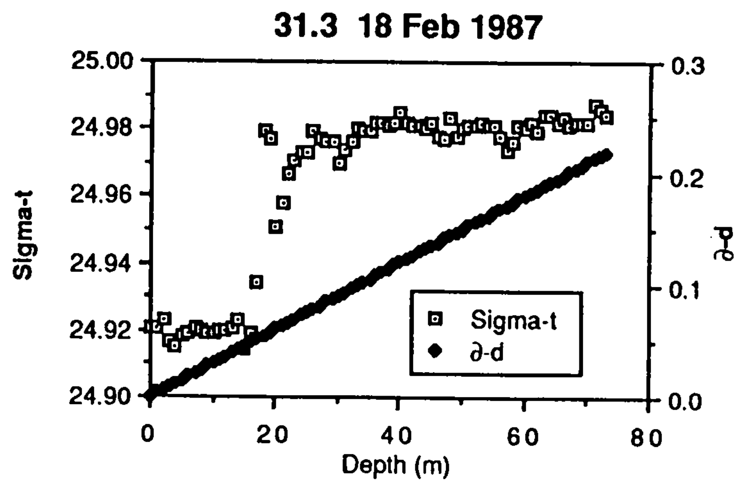

30.1 28 Feb 1987
Sigma-t
∂-d
Depth (m)
25.2
25.1
25.0
24.9
24.8
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120

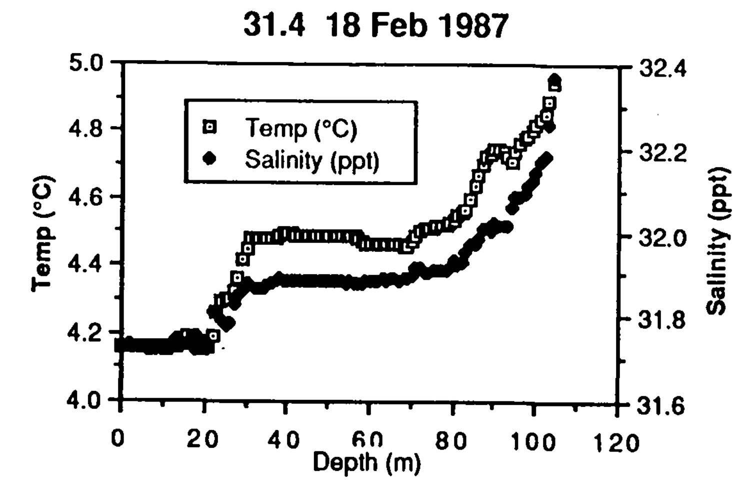

31.1 4 Mar 1987
Sigma-t
∂-d
Depth (m)
25.10
25.05
25.00
24.95
24.90
0.2
0.1
0.0
0
10
20
30
40
50
60

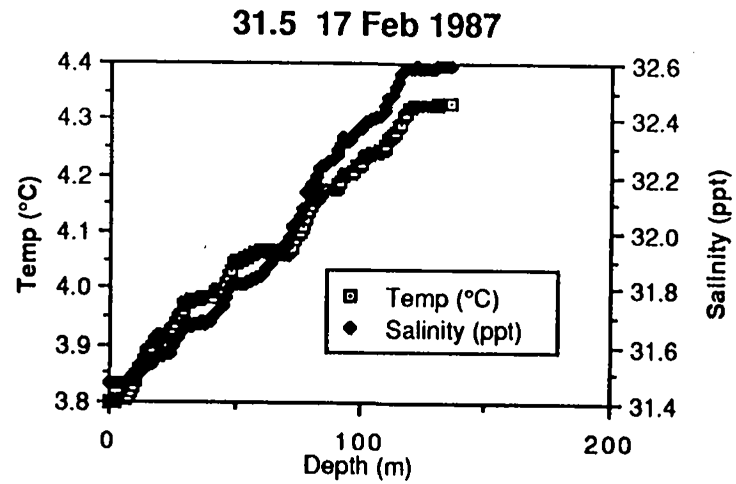

31.2 17 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
3.78
3.77
3.76
3.75
31.3
31.2
31.1
31.0
30.9
0
10
20
30
40
50
60

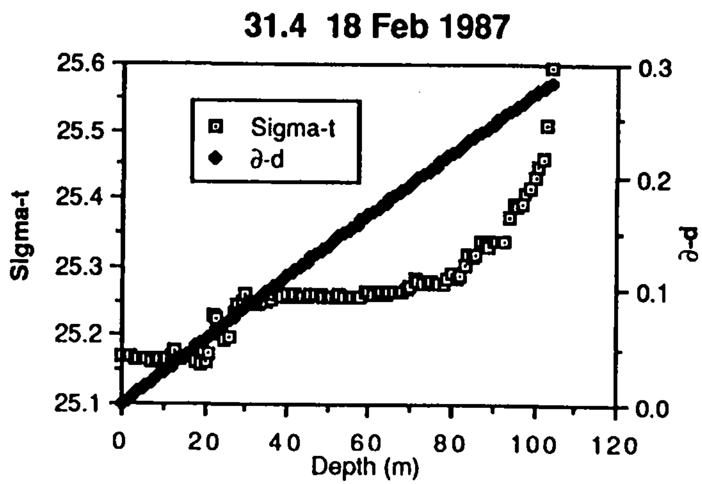

31.3 18 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.1
4.0
3.9
3.8
3.7
31.50
31.45
31.40
31.35
0
20
40
60
80

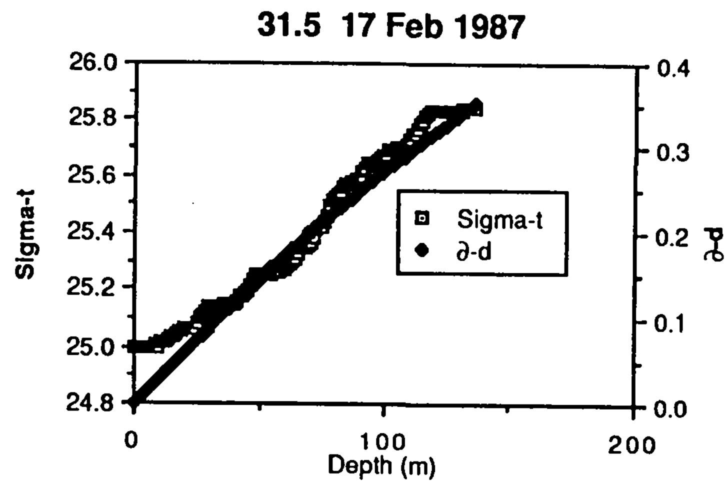

31.2 17 Feb 1987
Sigma-t
∂-d
Depth (m)
24.9
24.8
24.7
24.6
0.2
0.1
0.0
0
10
20
30
40
50
60


31.3 18 Feb 1987
Sigma-t
∂-d
Depth (m)
25.00
24.98
24.96
24.94
24.92
24.90
0.3
0.2
0.1
0.0
0
20
40
60
80

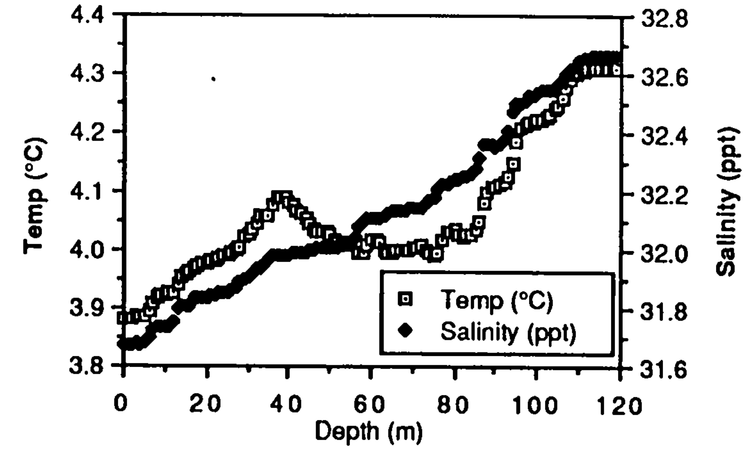

31.4 18 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
0 20 40 60 80 100 120
4.0 4.2 4.4 4.6 4.8 5.0
31.6 31.8 32.0 32.2 32.4


31.5 17 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
0 100 200
3.8 3.9 4.0 4.1 4.2 4.3 4.4
31.4 31.6 31.8 32.0 32.2 32.4 32.6

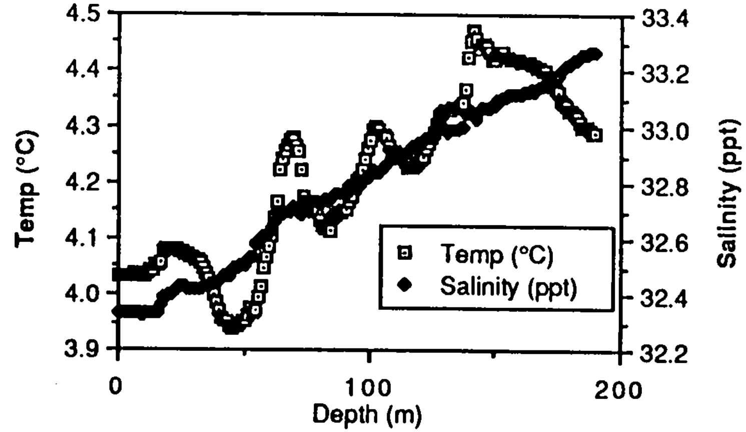

31.4 18 Feb 1987
Sigma-t
∂-d
Depth (m)
0 20 40 60 80 100 120
25.1 25.2 25.3 25.4 25.5 25.6
0.0 0.1 0.2 0.3


31.5 17 Feb 1987
Sigma-t
∂-d
Depth (m)
0 100 200
24.8 25.0 25.2 25.4 25.6 25.8 26.0
0.0 0.1 0.2 0.3 0.4

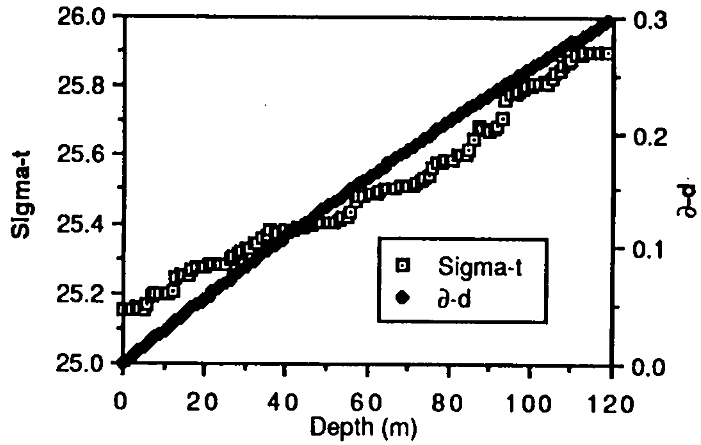
31.6 17 Feb 1987



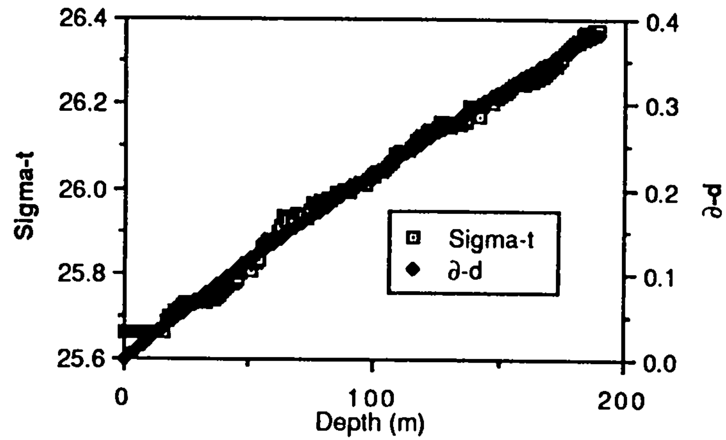
32.2 5 Mar 1987

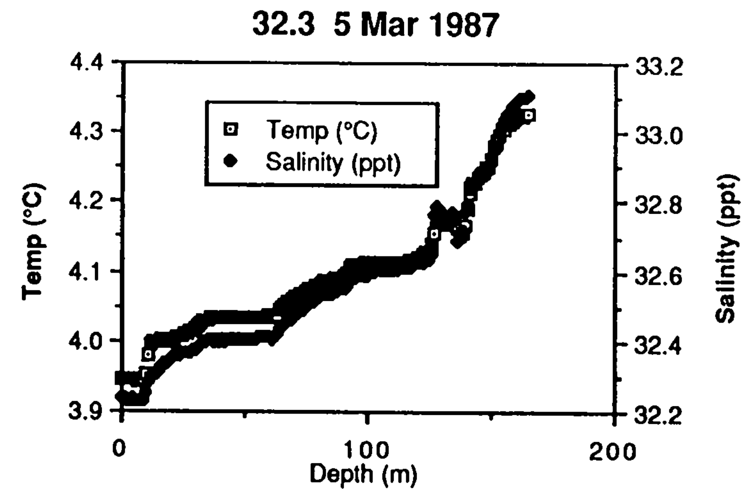


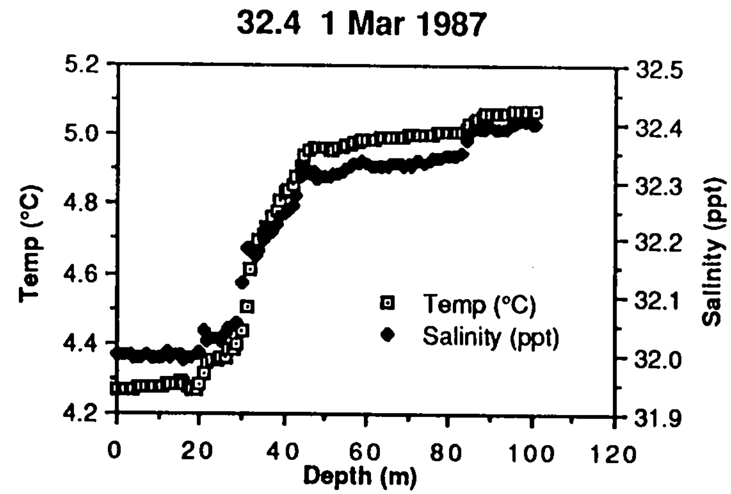
31.6 17 Feb 1987

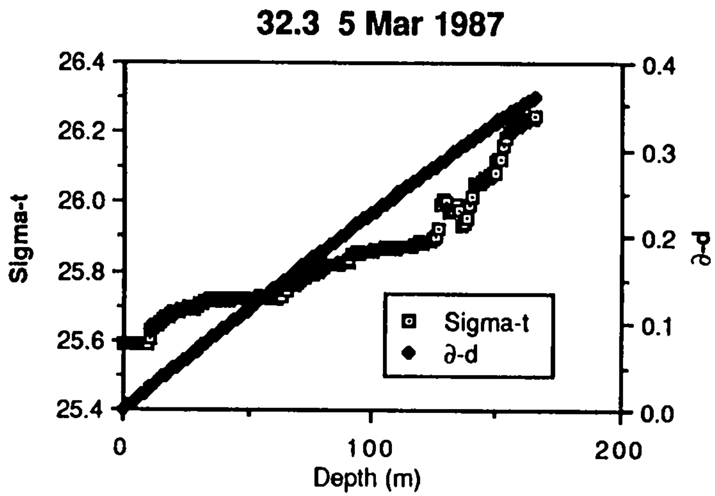


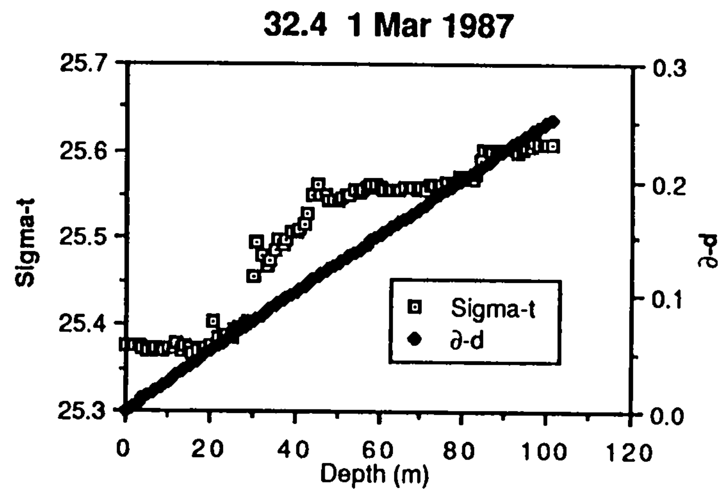
32.2 5 Mar 1987

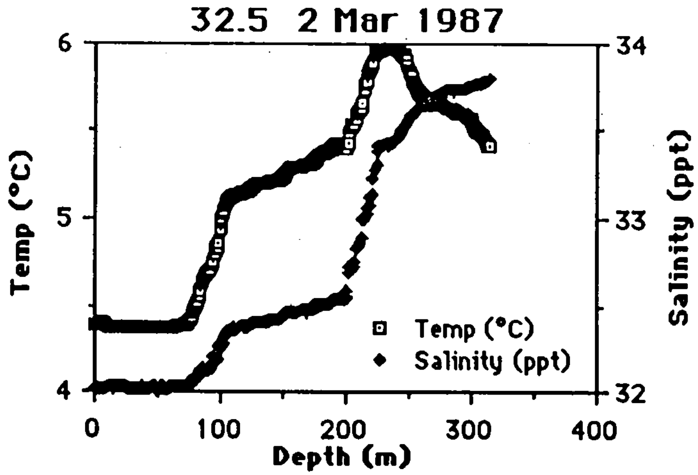


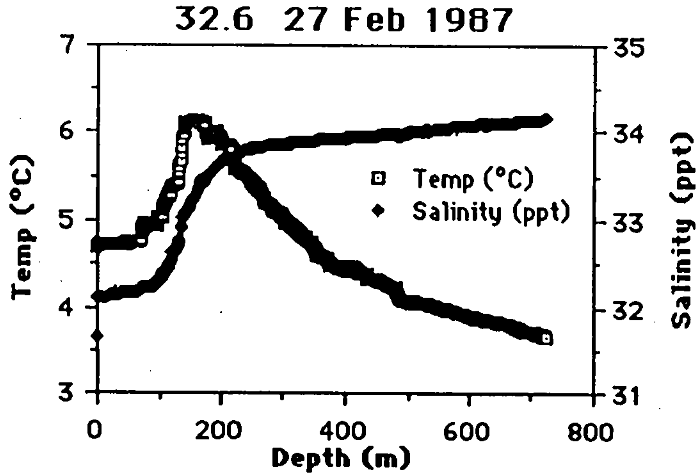

32.3 5 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.4
4.3
4.2
4.1
4.0
3.9
33.2
33.0
32.8
32.6
32.4
32.2
0
100
200

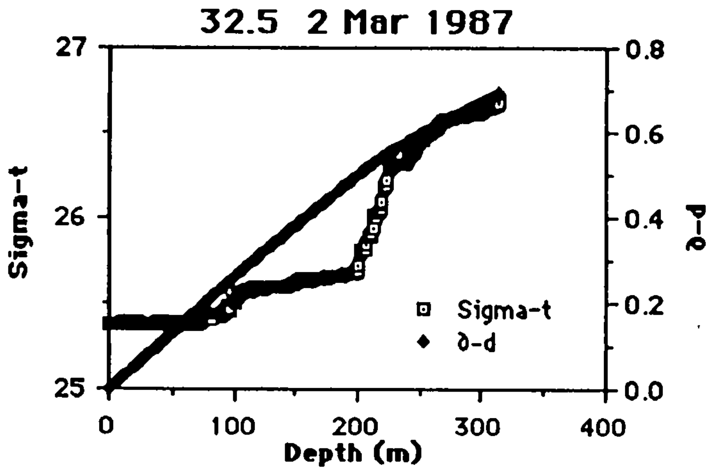

32.4 1 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
5.2
5.0
4.8
4.6
4.4
4.2
32.5
32.4
32.3
32.2
32.1
32.0
31.9
0
20
40
60
80
100
120

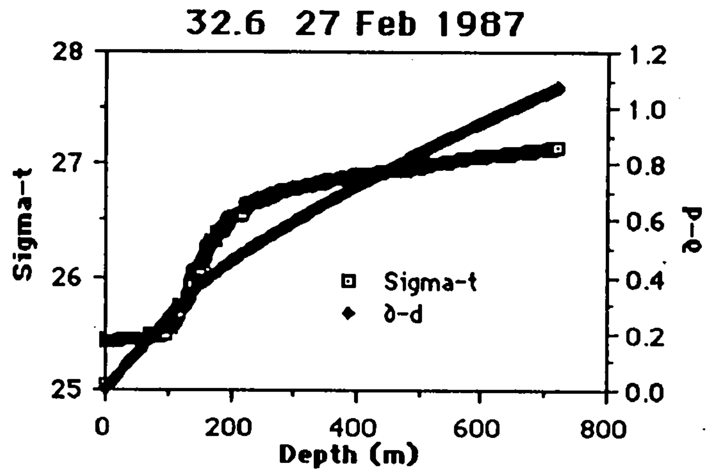

32.3 5 Mar 1987
Sigma-t
∂-d
Depth (m)
26.4
26.2
26.0
25.8
25.6
25.4
0.4
0.3
0.2
0.1
0.0
0
100
200


32.4 1 Mar 1987
Sigma-t
∂-d
Depth (m)
25.7
25.6
25.5
25.4
25.3
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120


32.5 2 Mar 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
6
5
4
34
33
32
0
100
200
300
400

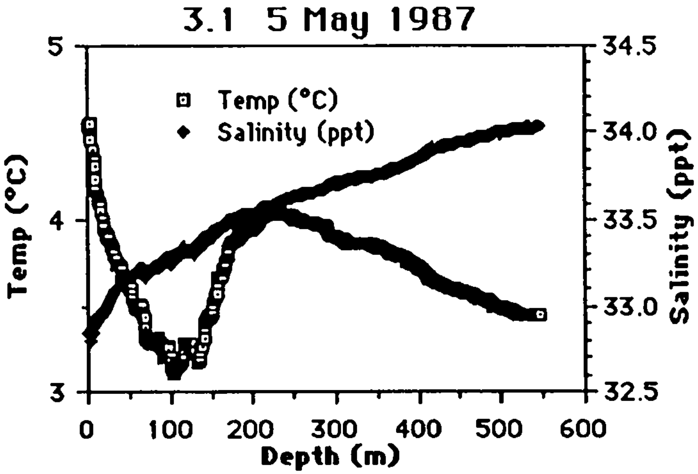

32.6 27 Feb 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
7
6
5
4
3
35
34
33
32
31
0
200
400
600
800

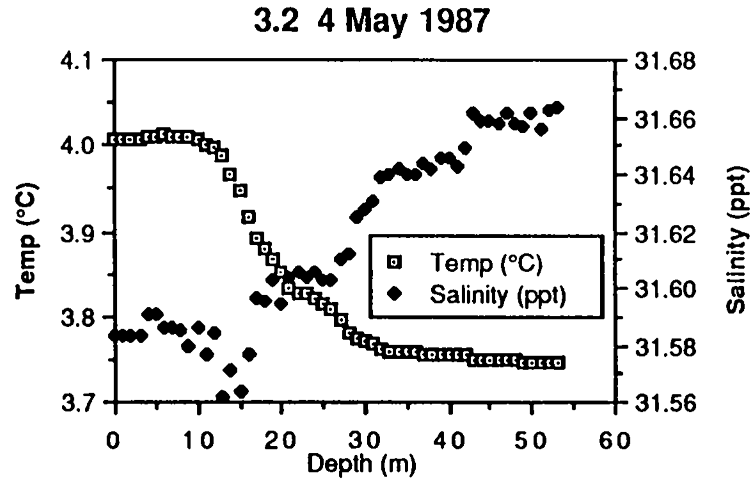

32.5 2 Mar 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400

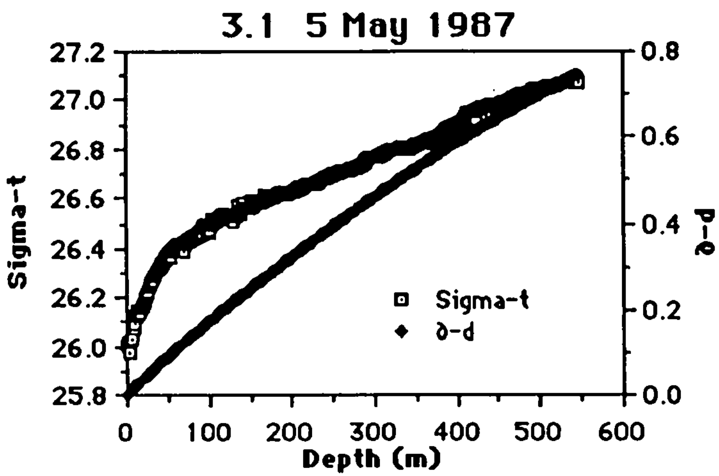

32.6 27 Feb 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
28
27
26
25
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800

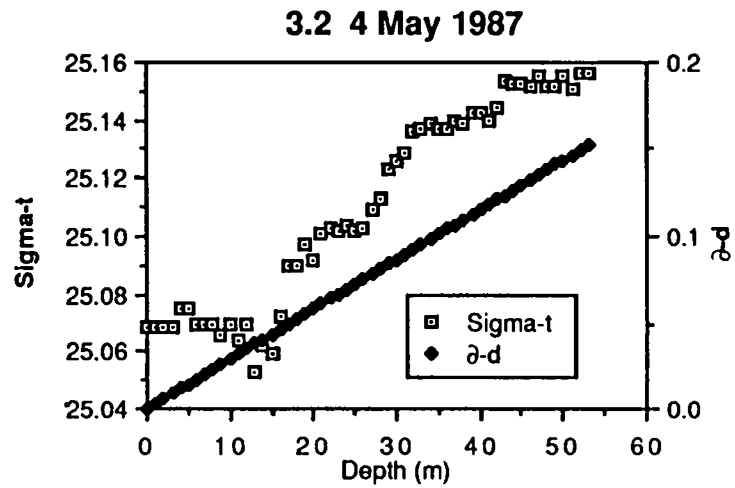
APPENDIX B-3

Temperature and salinity vertical profiles as determined by CTD casts at sampling stations in spring 1987 in the Unimak Pass area, Alaska. Sampling station numbers (tops of graphs) can be matched with their locations in Fig. 4 of Appendix E.

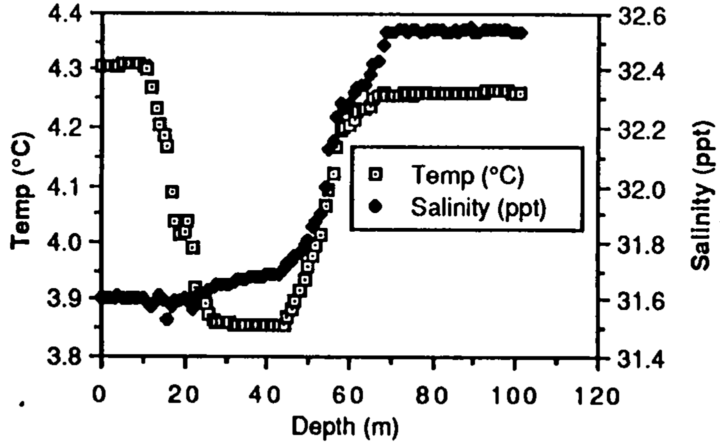

3.1 5 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
5
4
3
34.5
34.0
33.5
33.0
32.5
0
100
200
300
400
500
600


3.2 4 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.1
4.0
3.9
3.8
3.7
31.68
31.66
31.64
31.62
31.60
31.58
31.56
0
10
20
30
40
50
60

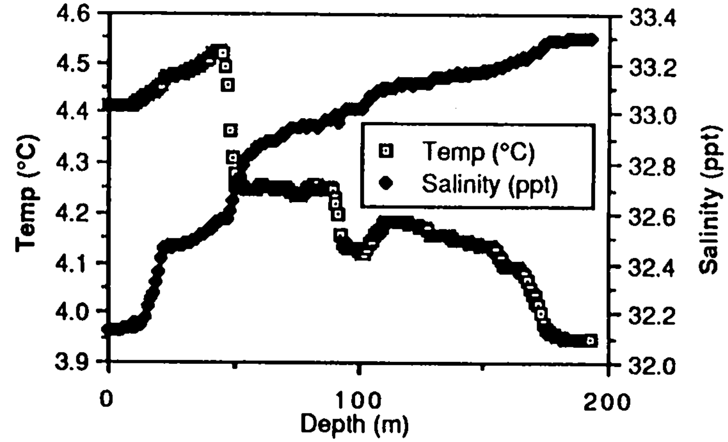

3.1 5 May 1987
Sigma-t
∂-d
Depth (m)
27.2
27.0
26.8
26.6
26.4
26.2
26.0
25.8
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600


3.2 4 May 1987
Sigma-t
∂-d
Depth (m)
25.16
25.14
25.12
25.10
25.08
25.06
25.04
0.2
0.1
0.0
0
10
20
30
40
50
60

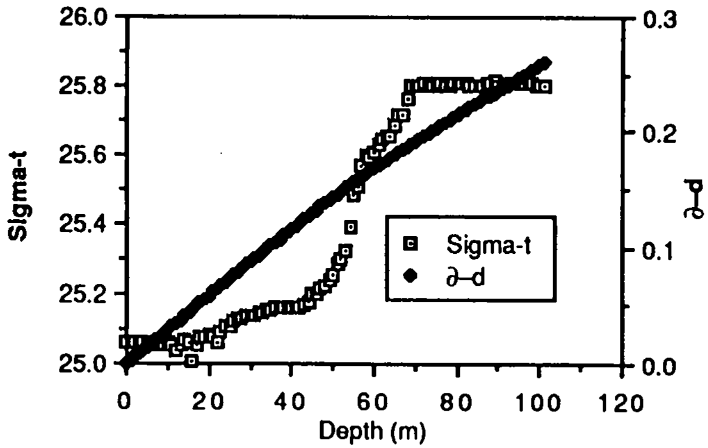
3.3 4 May 1987



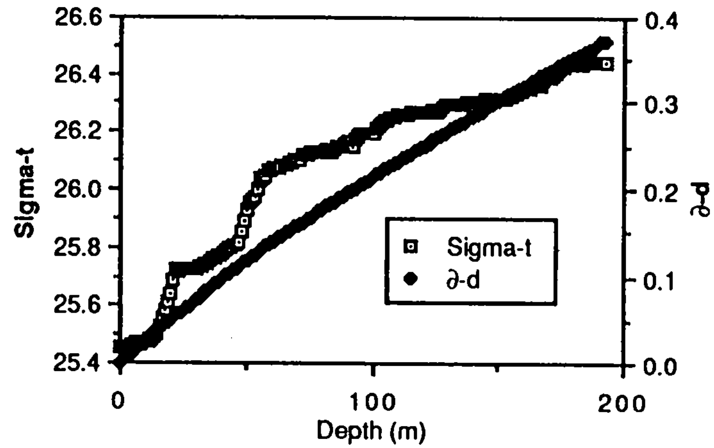
3.4 5 May 1987

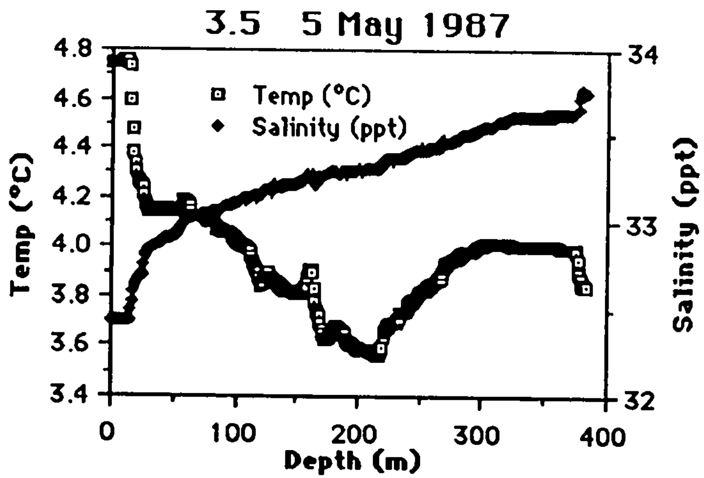


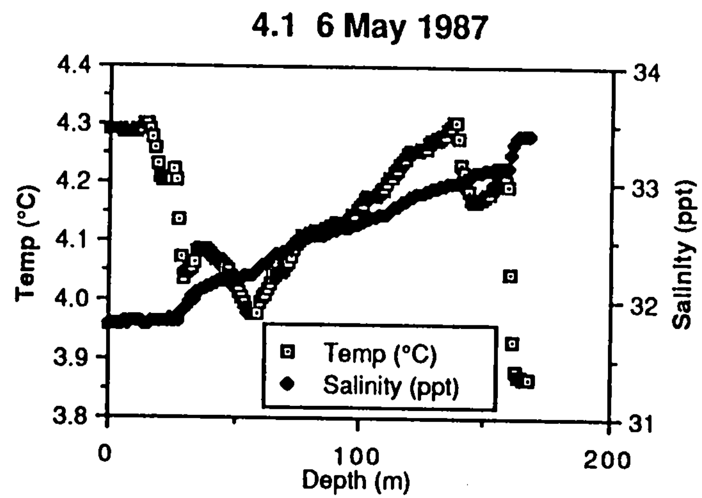
3.3 4 May 1987

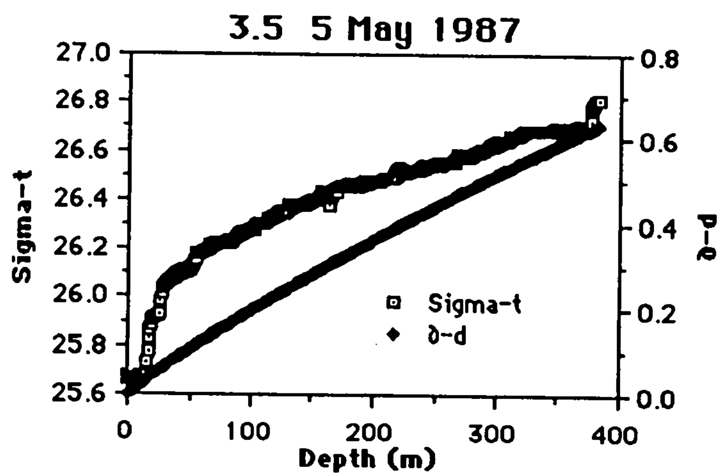


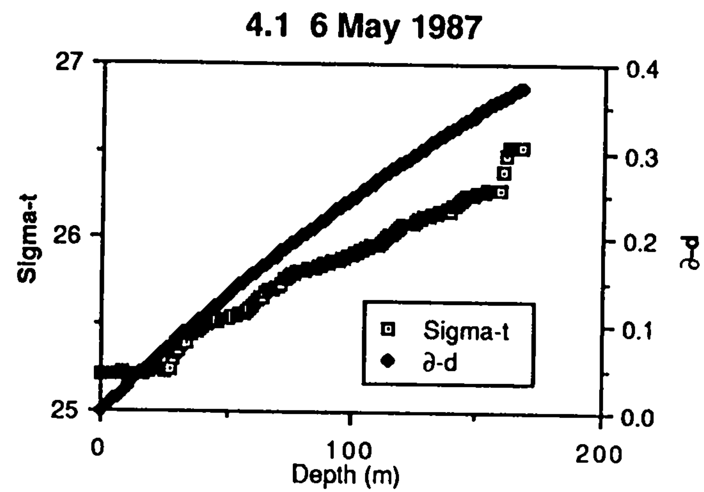
3.4 5 May 1987



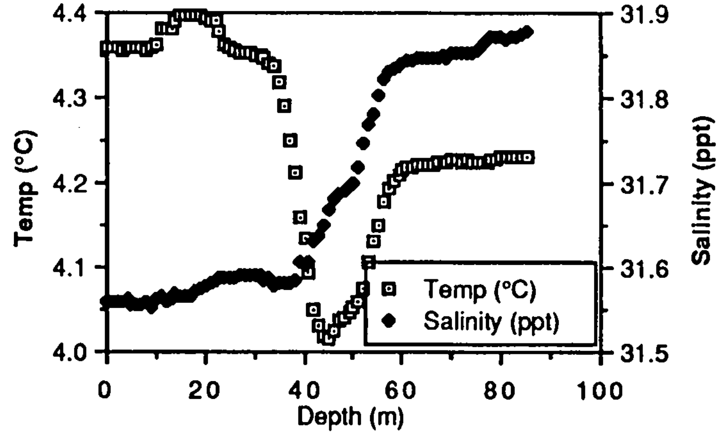

3.5 5 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
34
33
32
0
100
200
300
400


4.1 6 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
4.4
4.3
4.2
4.1
4.0
3.9
3.8
34
33
32
31
0
100
200

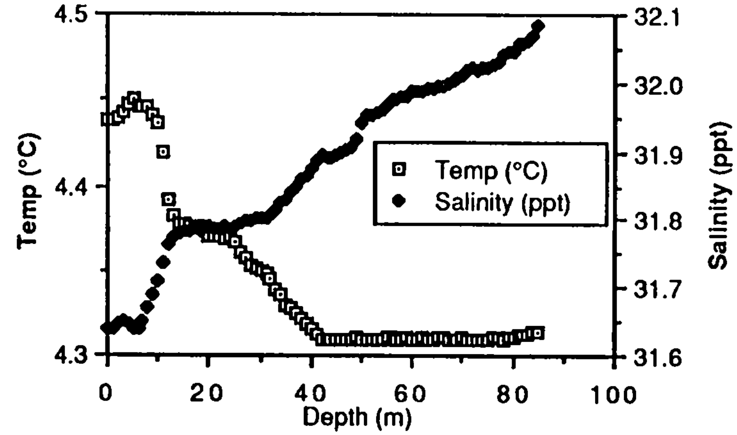

3.5 5 May 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
27.0
26.8
26.6
26.4
26.2
26.0
25.8
25.6
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400


4.1 6 May 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
27
26
25
0.4
0.3
0.2
0.1
0.0
0
100
200

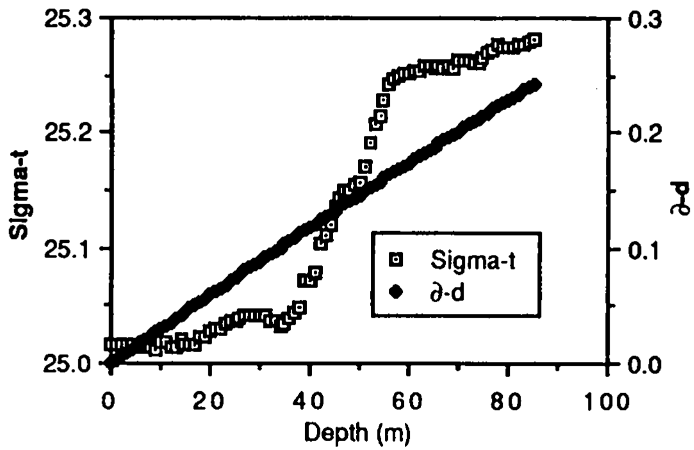
4.2 5 May 1987



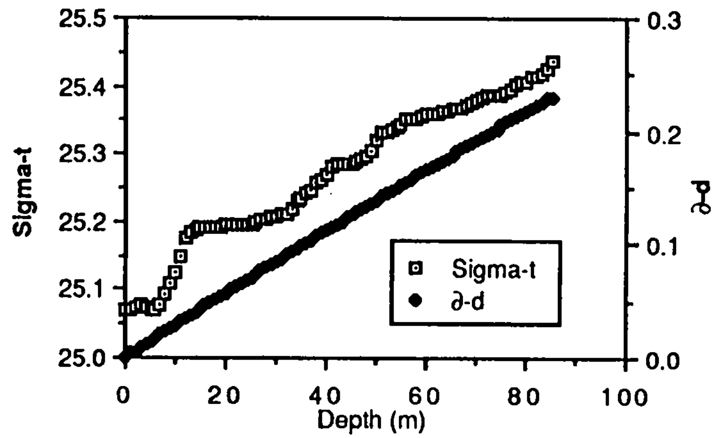
4.3 5 May 1987



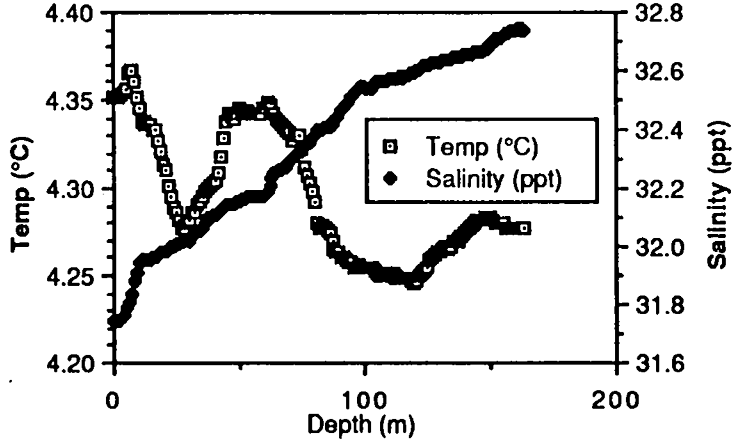
4.2 5 May 1987



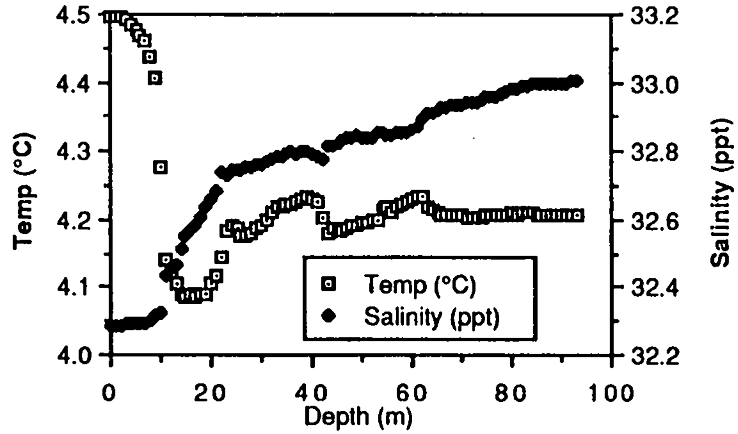
4.3 5 May 1987



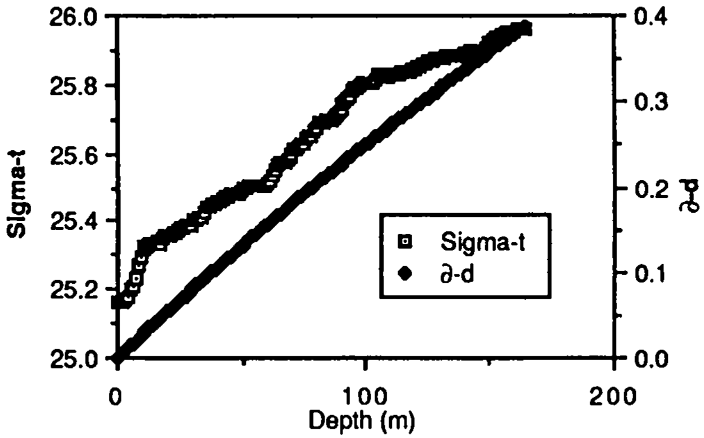
4.4 5 May 1987



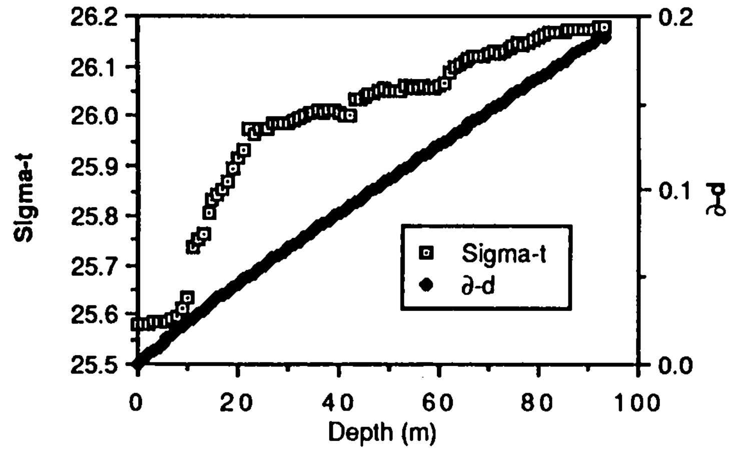
4.5 6 May 1987

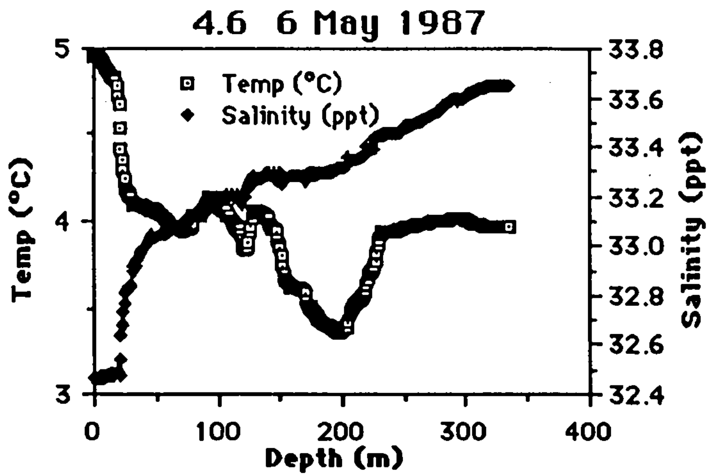


4.4 5 May 1987

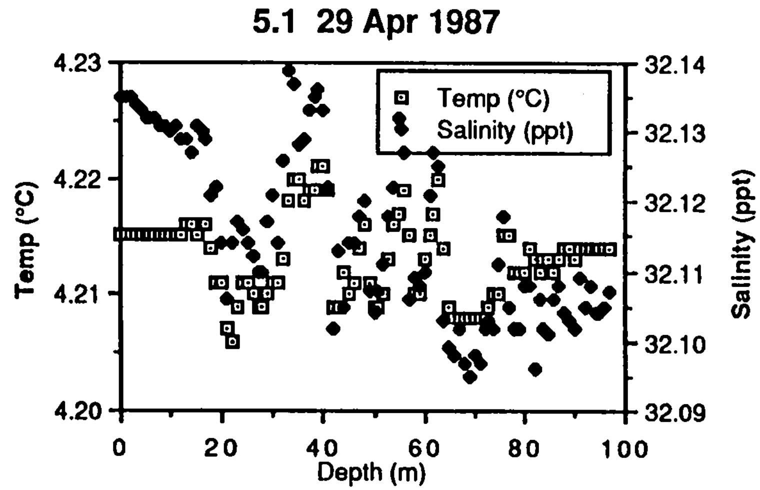


4.5 6 May 1987

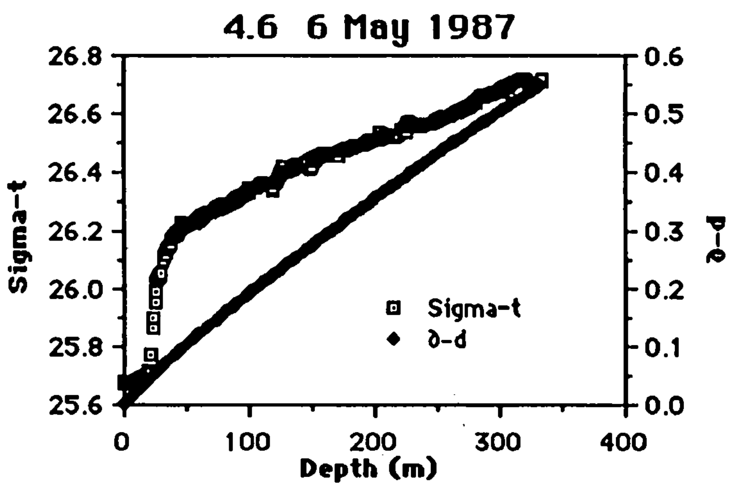




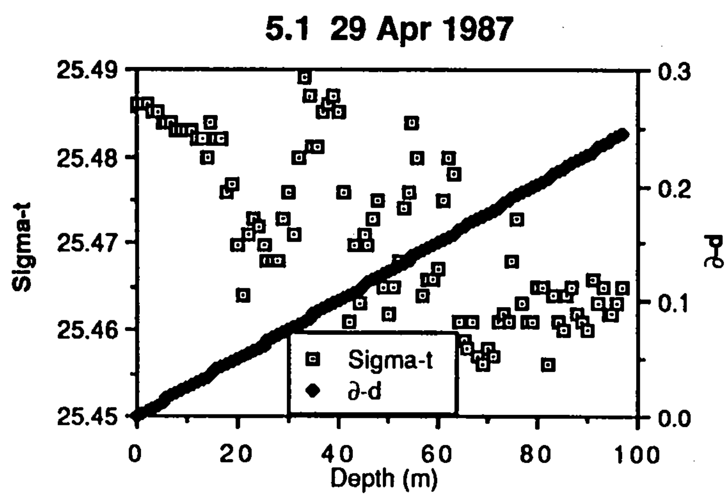
4.6 6 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
5
4
3
33.8
33.6
33.4
33.2
33.0
32.8
32.6
32.4
0
100
200
300
400



5.1 29 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.23
4.22
4.21
4.20
32.14
32.13
32.12
32.11
32.10
32.09
0
20
40
60
80
100

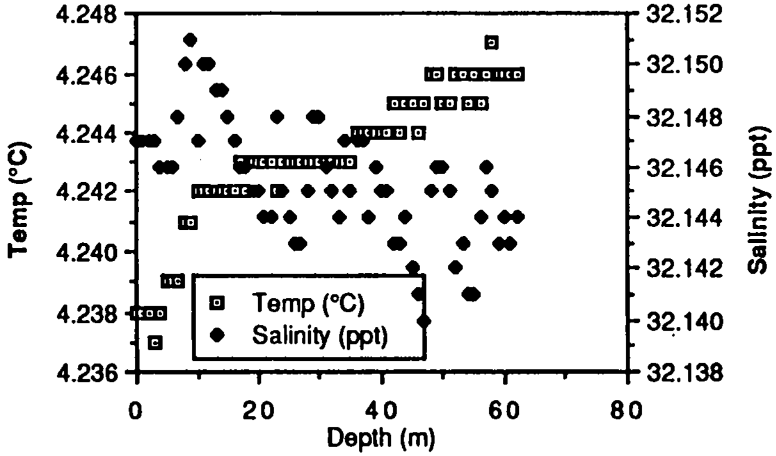


4.6 6 May 1987
Sigma-t
∂-d
Depth (m)
26.8
26.6
26.4
26.2
26.0
25.8
25.6
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
100
200
300
400

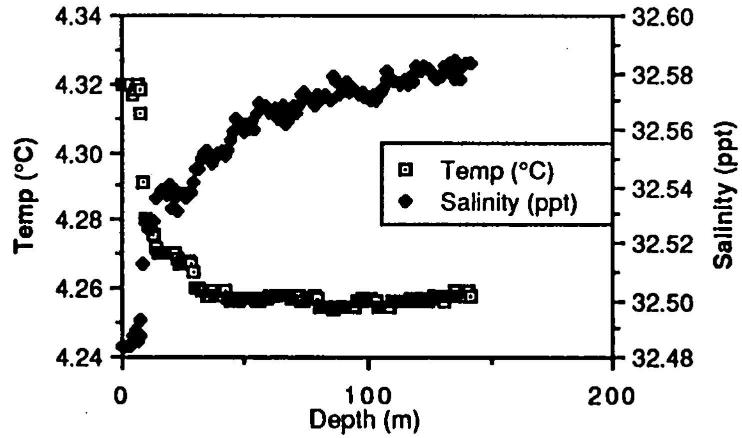


5.1 29 Apr 1987
Sigma-t
∂-d
Depth (m)
25.49
25.48
25.47
25.46
25.45
0.3
0.2
0.1
0.0
0
20
40
60
80
100

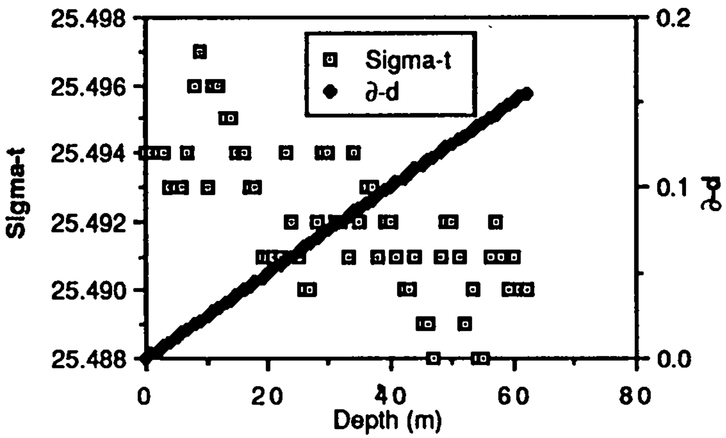
6.1 29 Apr 1987



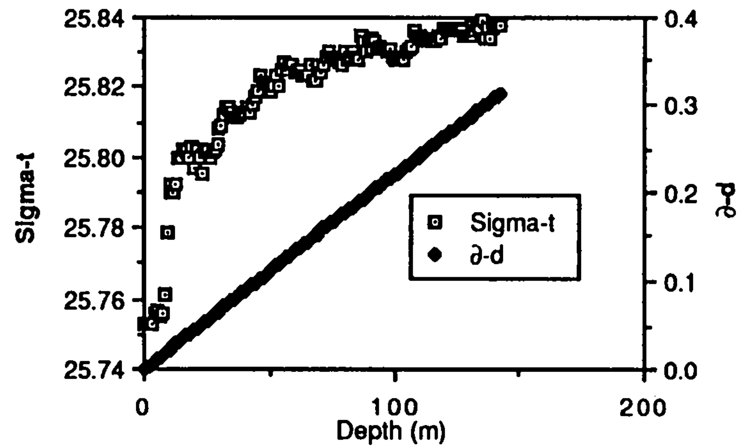
6.2 1 May 1987



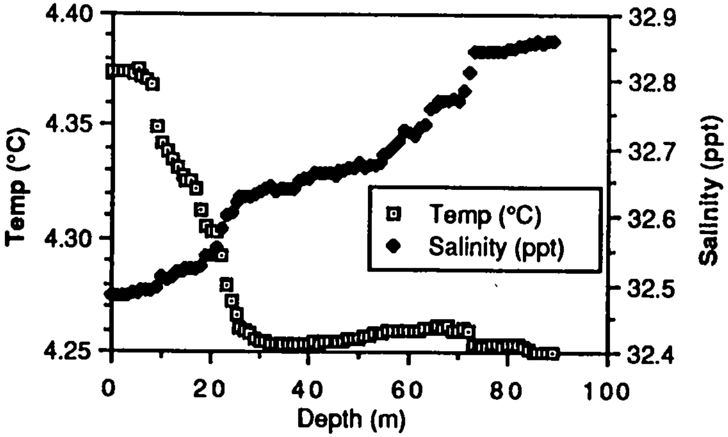
6.1 29 Apr 1987



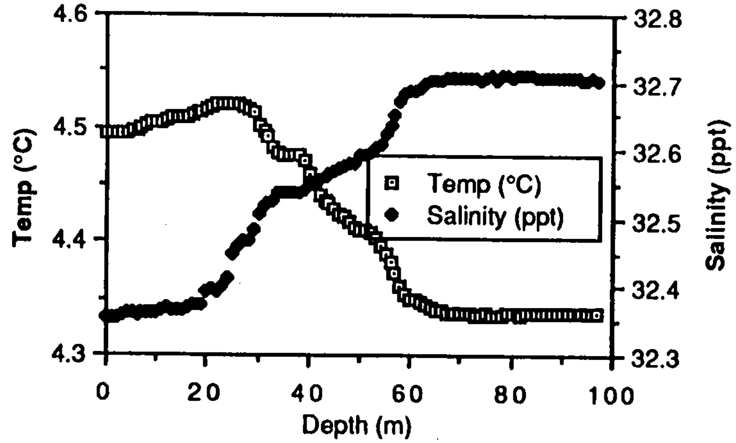
6.2 1 May 1987



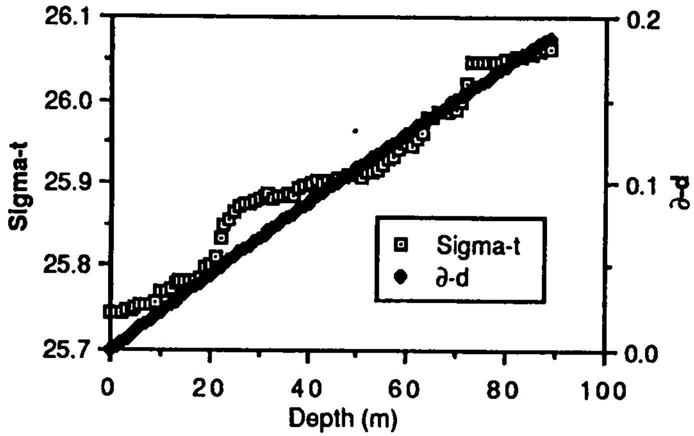
6.3 1 May 1987



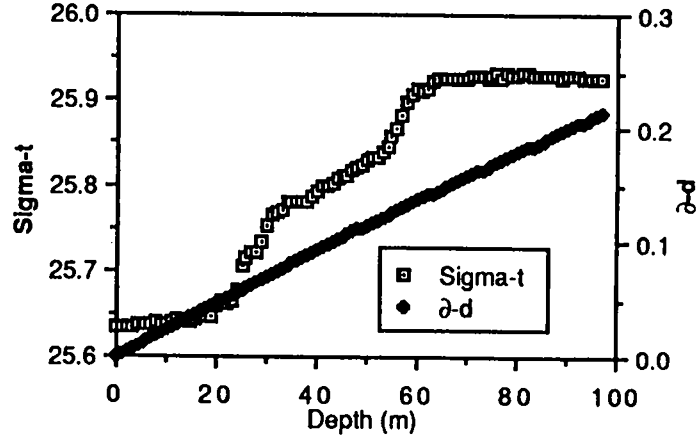
6.4 7 May 1987a



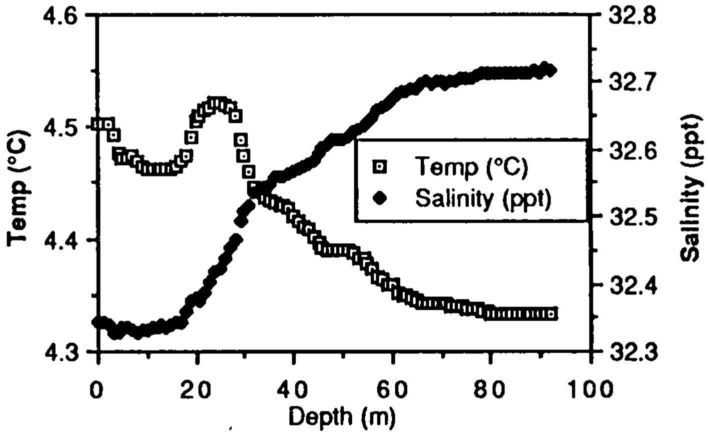
6.3 1 May 1987



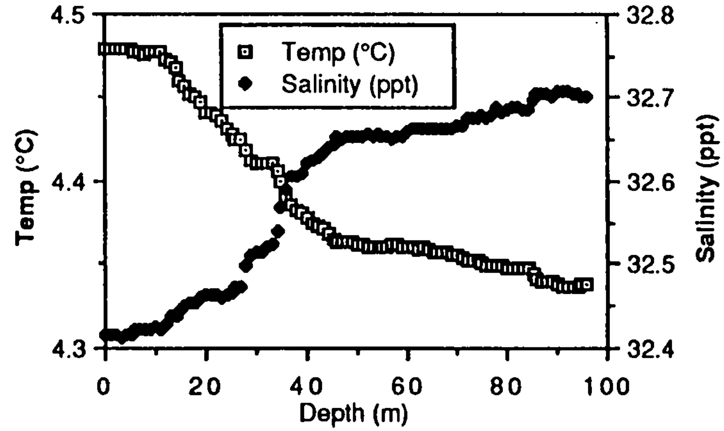
6.4 7 May 1987a



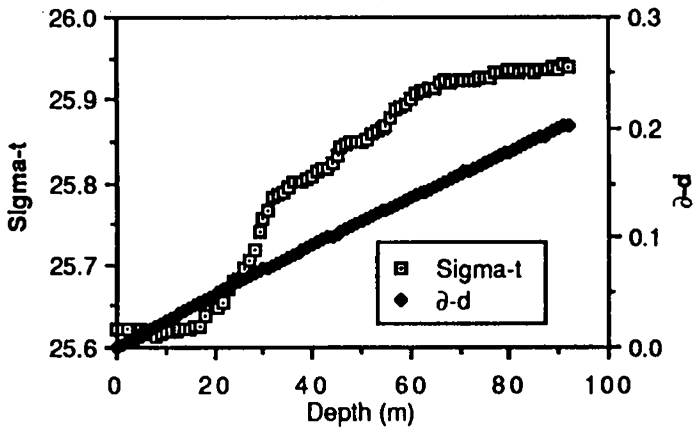
6.4 7 May 1987b



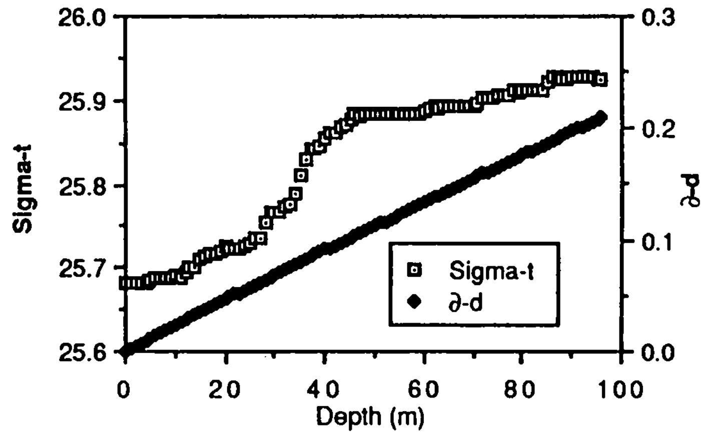
6.4 8 May 1987a



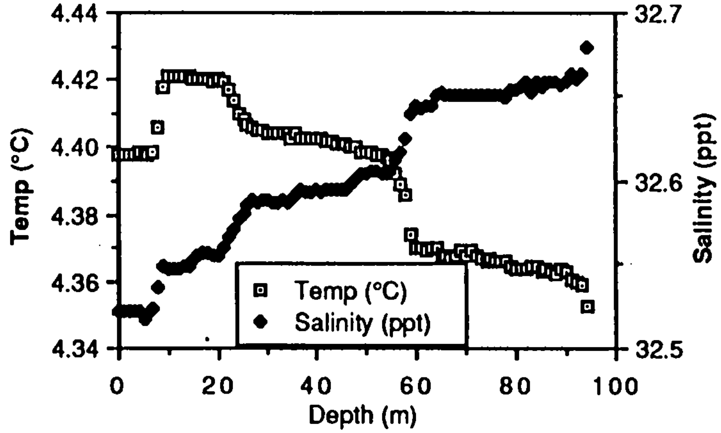
6.4 7 May 1987b



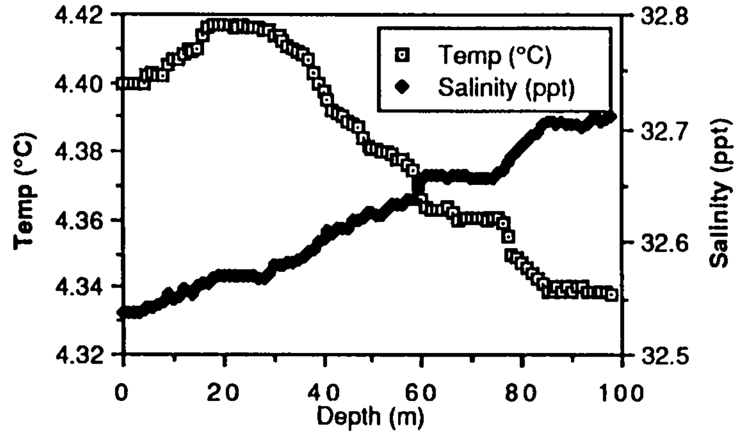
6.4 8 May 1987a



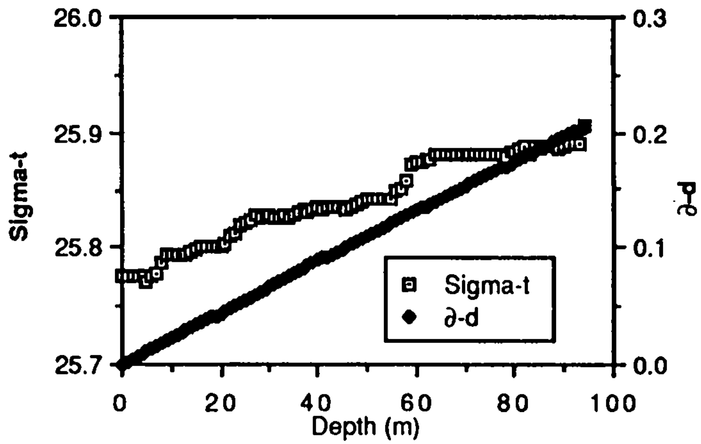
6.4 8 May 1987b



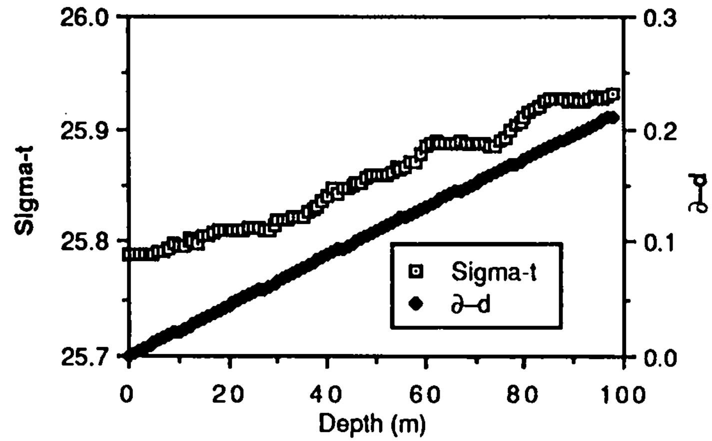
6.4 8 May 1987c



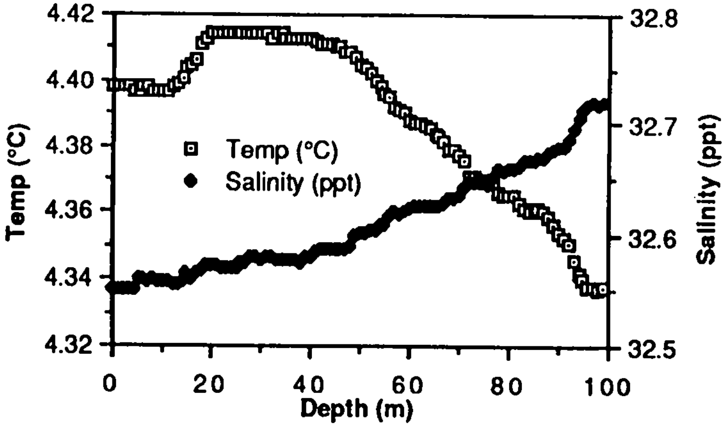
6.4 8 May 1987b



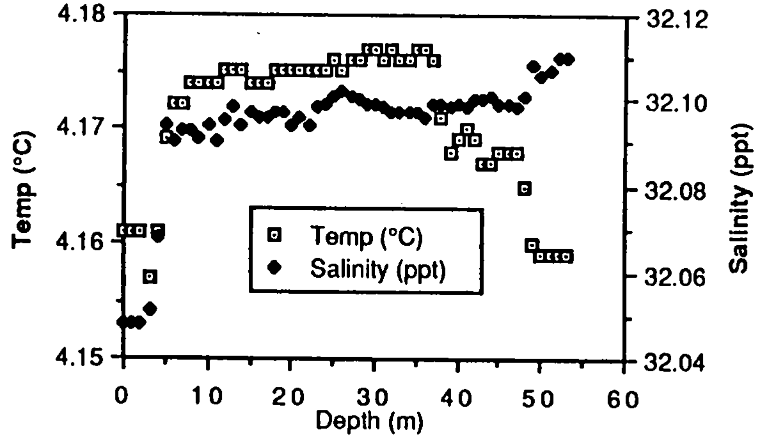
6.4 8 May 1987c



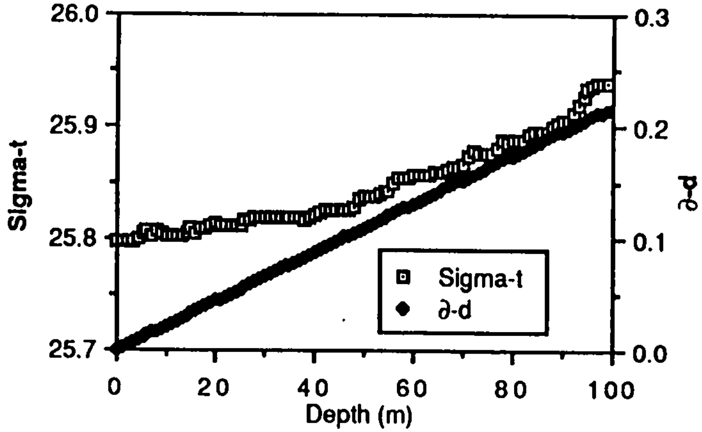
6.4 8 May 1987d



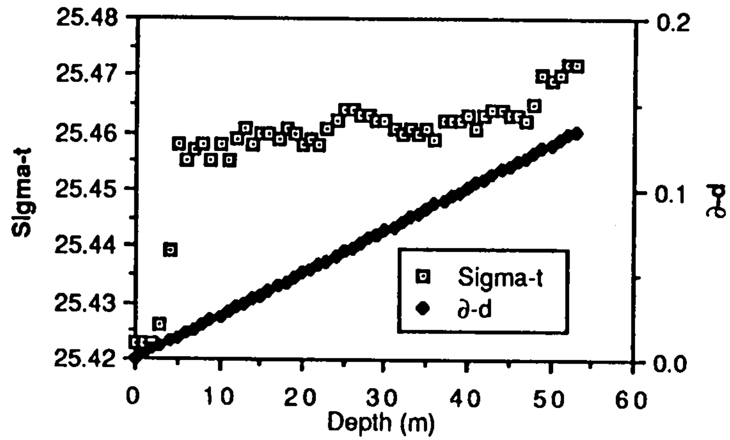
9.2 30 Apr 1987



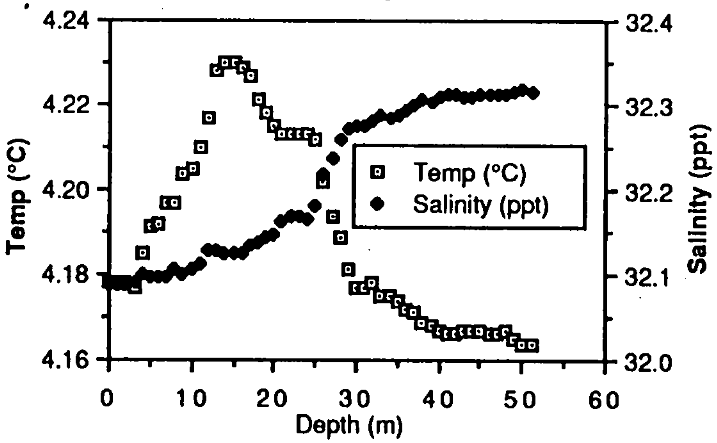
6.4 8 May 1987d



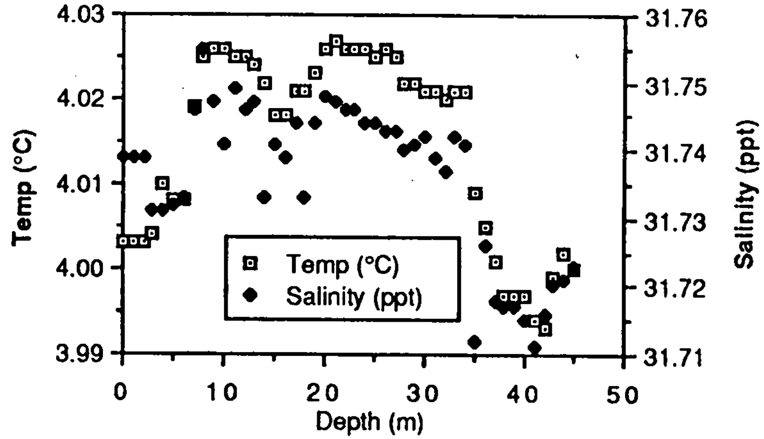
9.2 30 Apr 1987



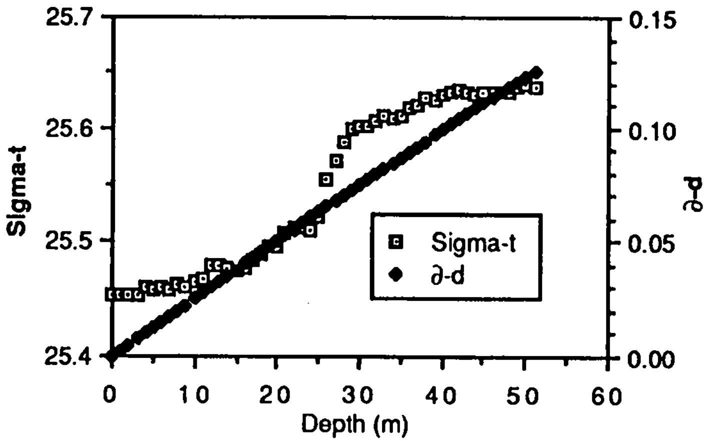
9.7 1 May 1987



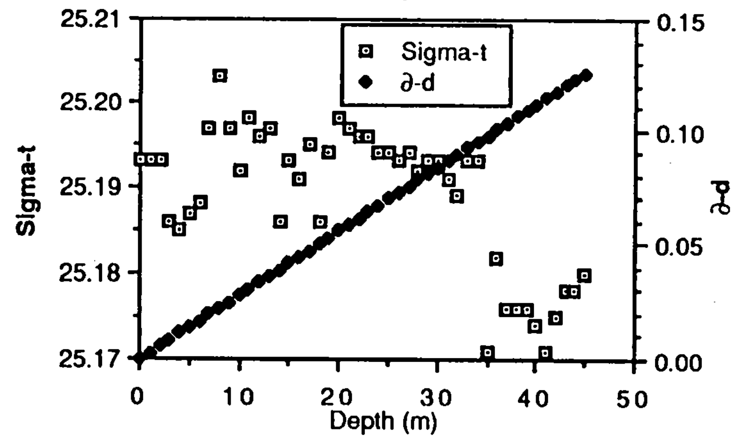
9.8 30 Apr 1987



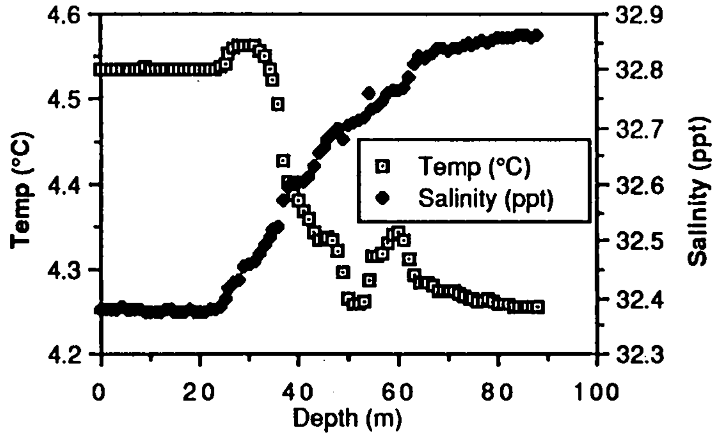
9.7 1 May 1987



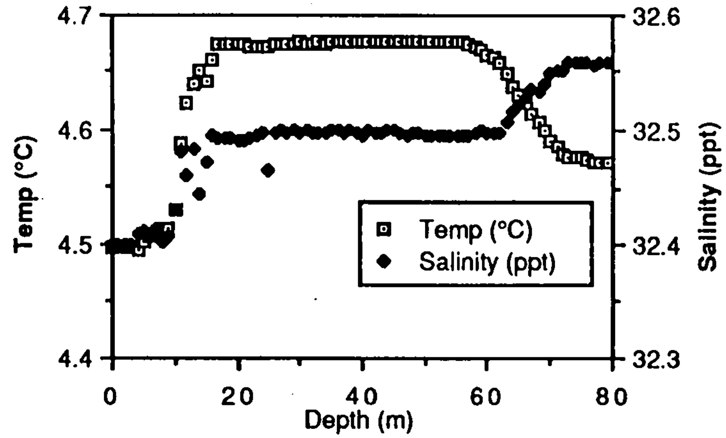
9.8 30 Apr 1987



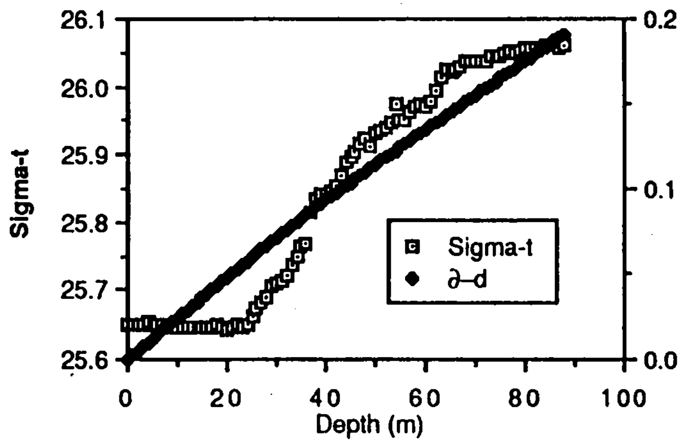
10.1 6 May 1987



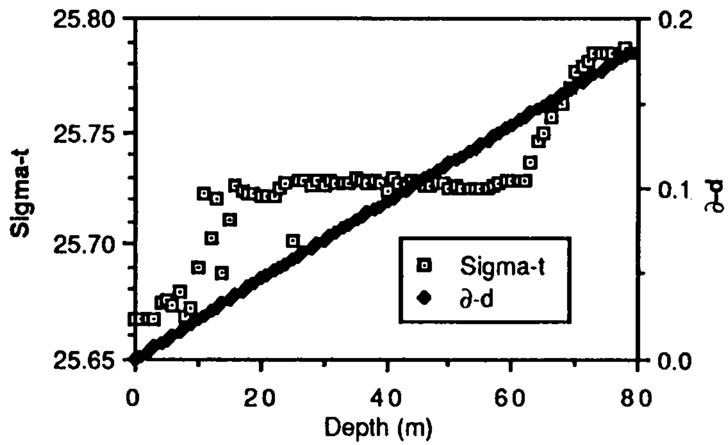
10.3 7 May 1987



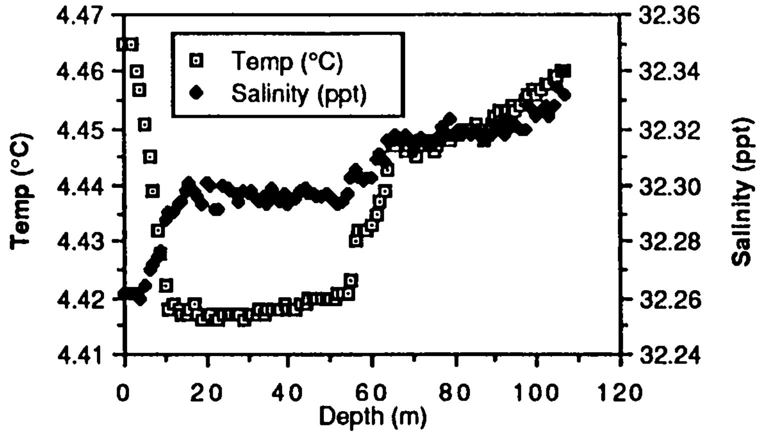
10.1 6 May 1987



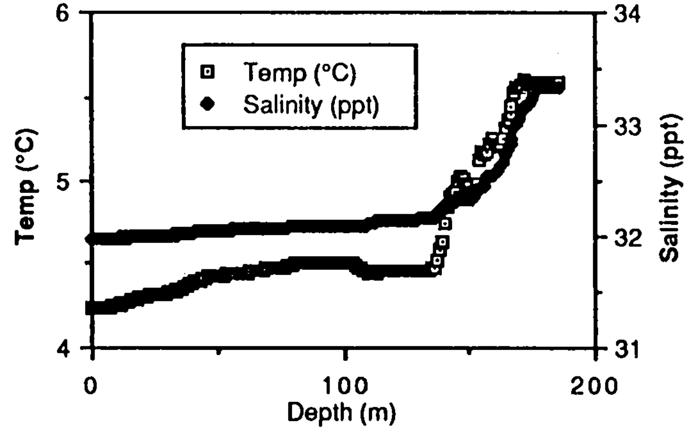
10.3 7 May 1987



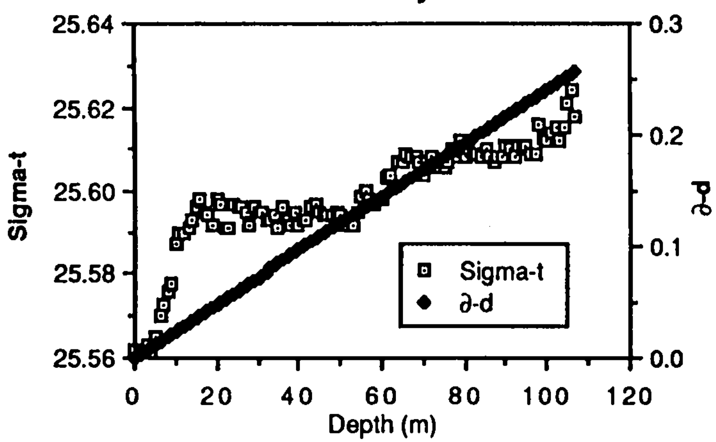
13.2 3 May 1987



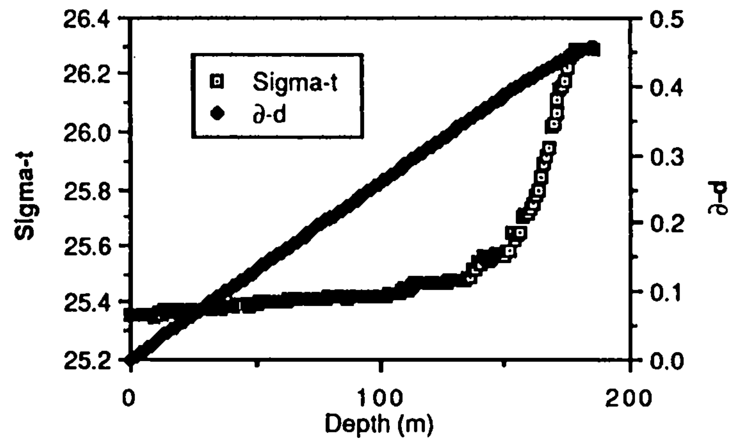
14.2 25 Apr 1987



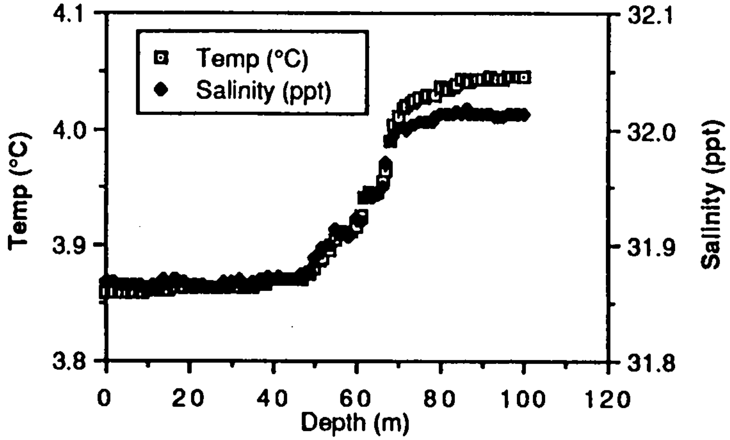
13.2 3 May 1987



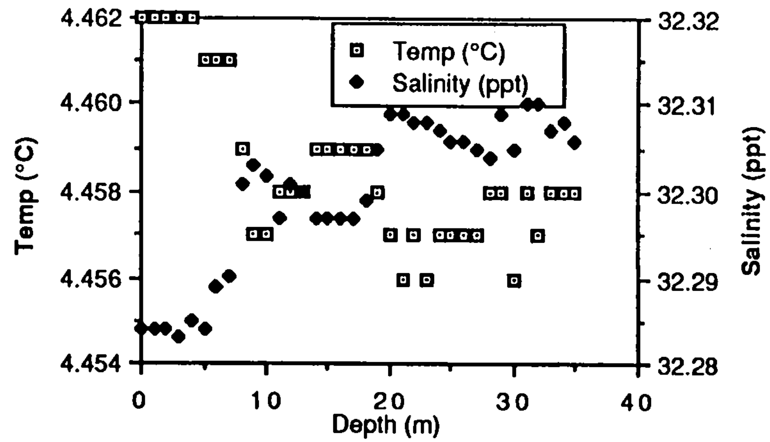
14.2 25 Apr 1987



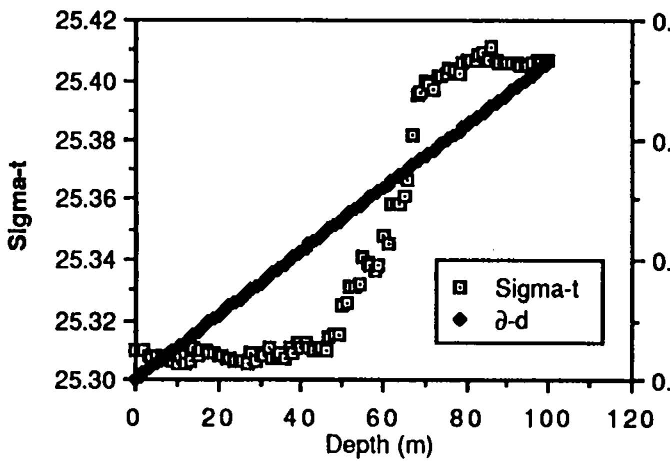
14.3 25 Apr 1987



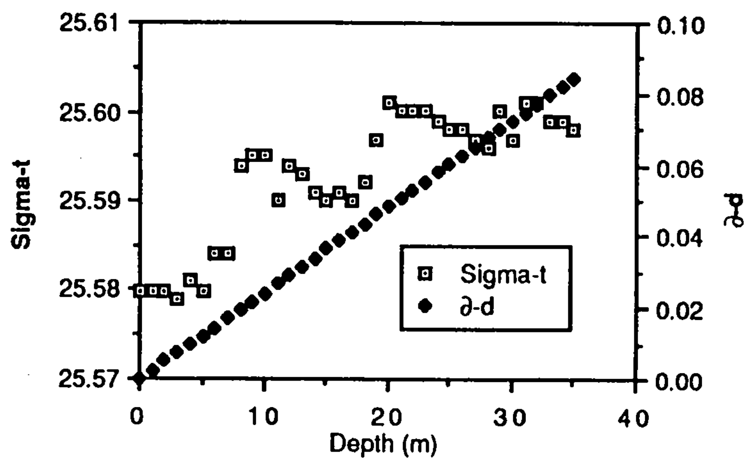
14.4 2 May 1987

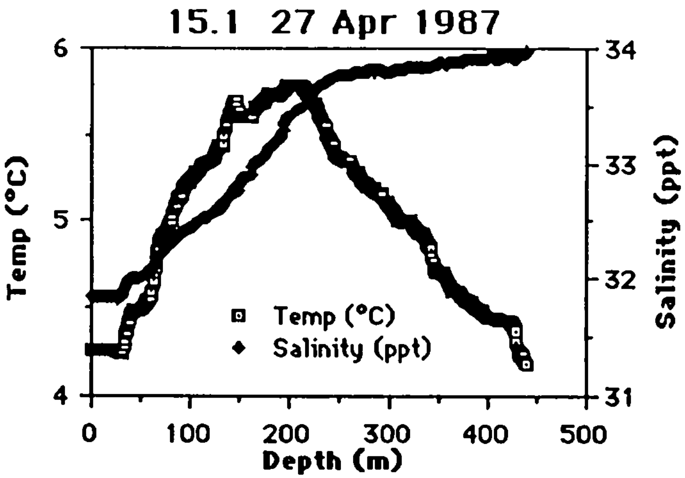


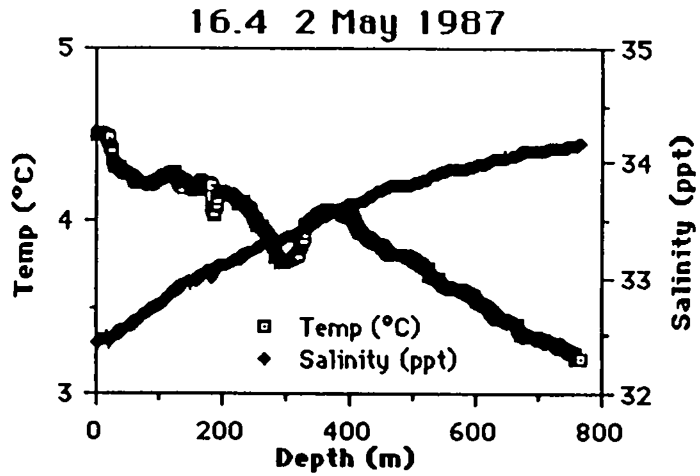
14.3 25 Apr 1987

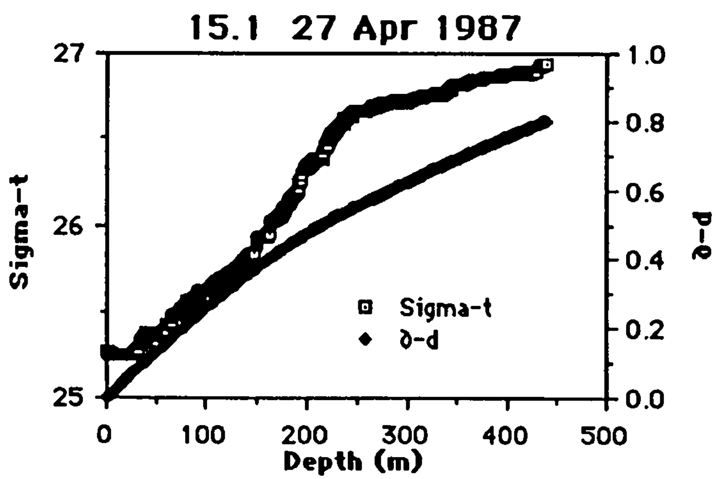


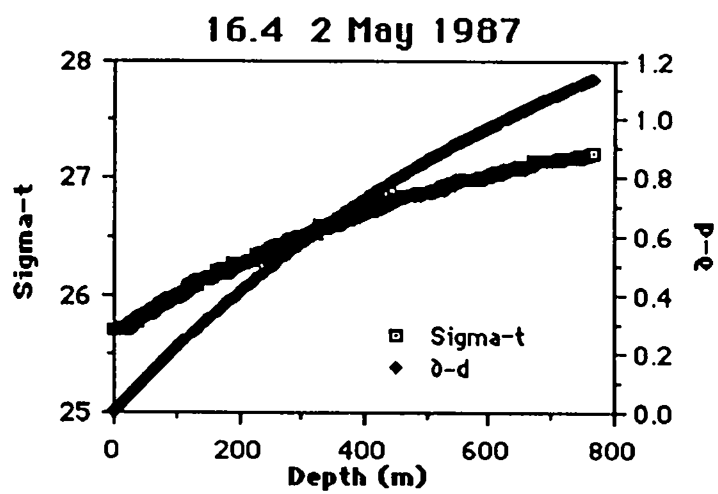
14.4 2 May 1987



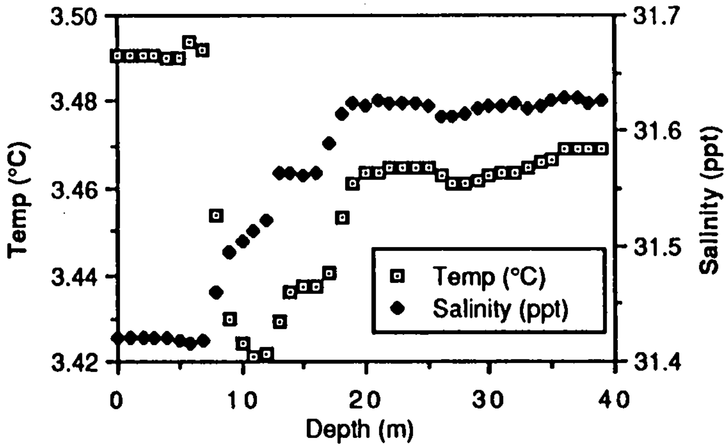

15.1 27 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
6
5
4
34
33
32
31
0
100
200
300
400
500


16.4 2 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
5
4
3
35
34
33
32
0
200
400
600
800

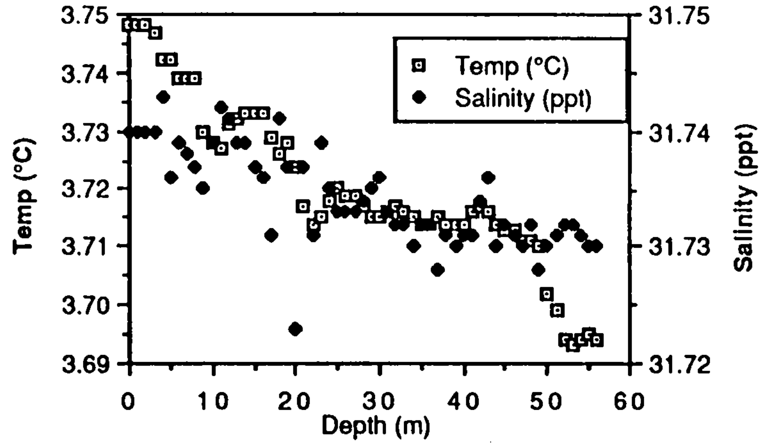

15.1 27 Apr 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
27
26
25
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500


16.4 2 May 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
28
27
26
25
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800

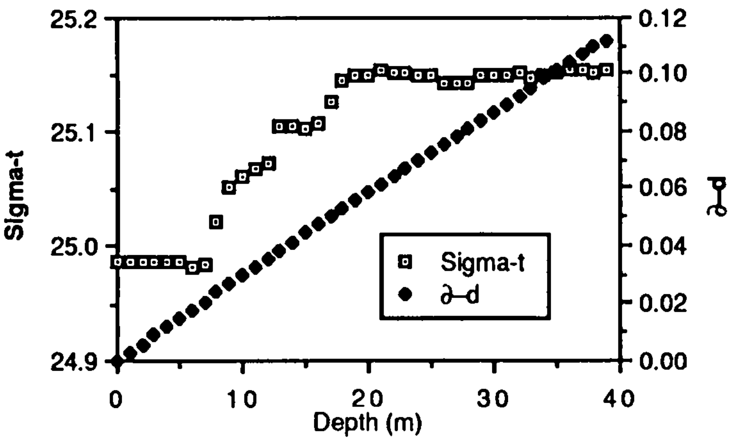
17.1 28 Apr 1987



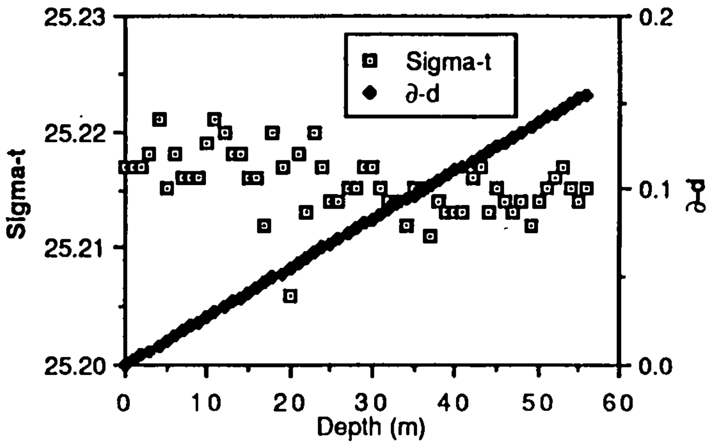
17.2 28 Apr 1987



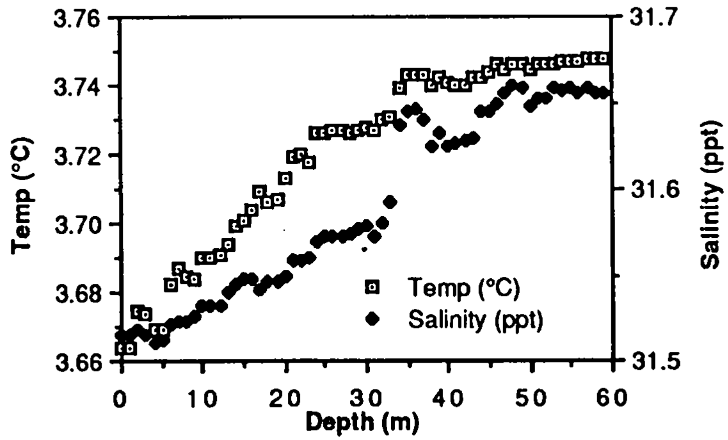
17.1 28 Apr 1987



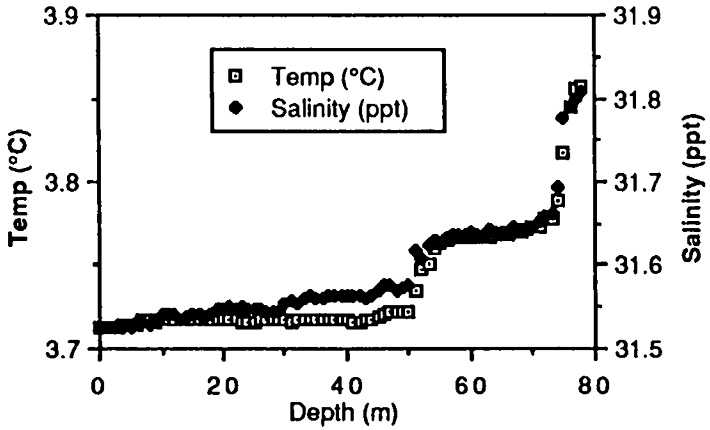
17.2 28 Apr 1987



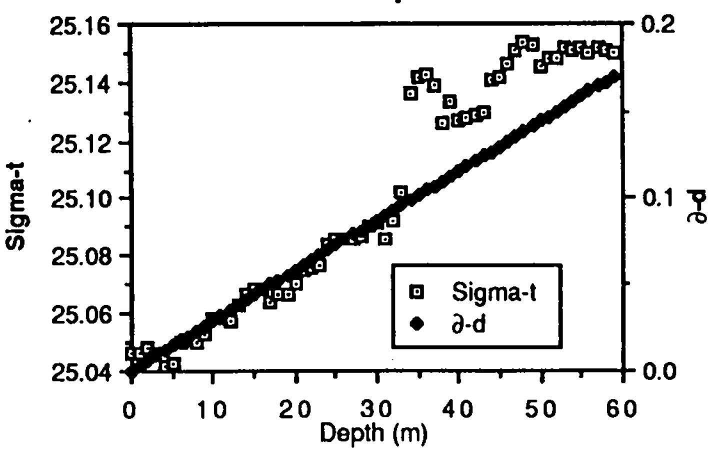
17.3 28 Apr l987



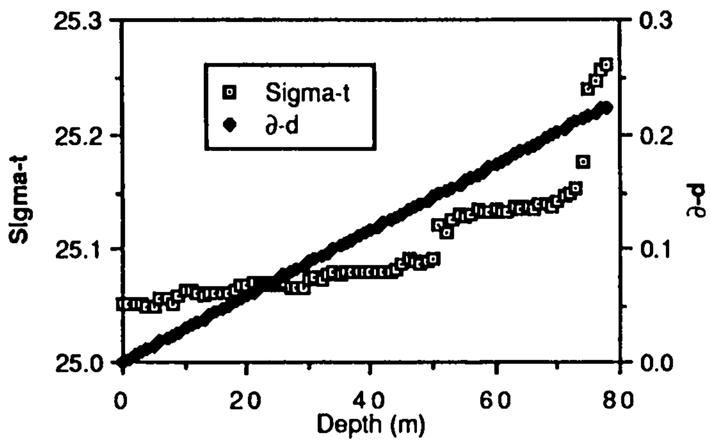
17.4 29 Apr 1987



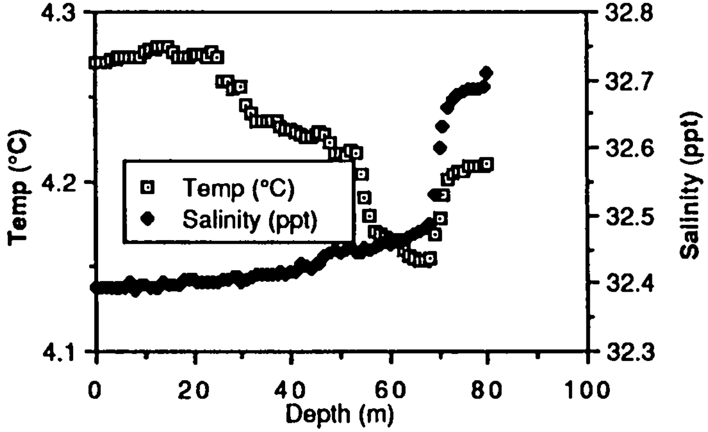
17.3 28 Apr 1987



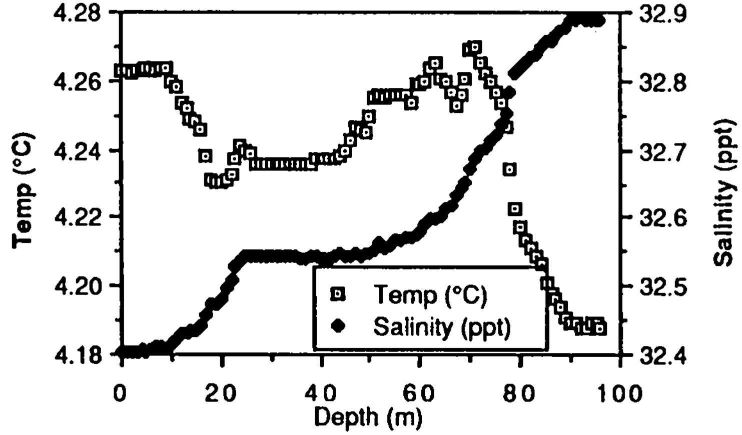
17.4 29 Apr 1987



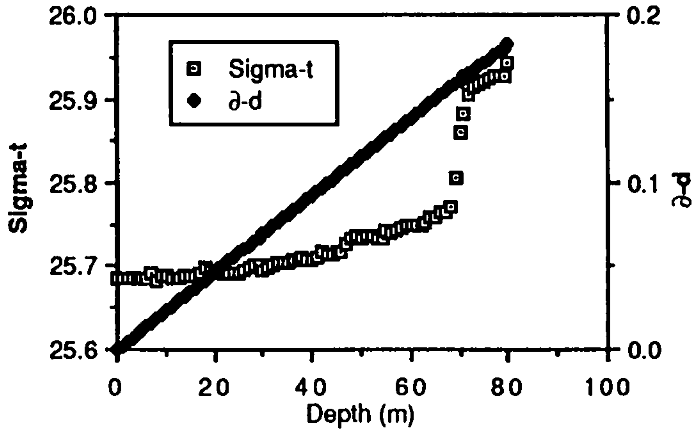
17.5 28 Apr 1987



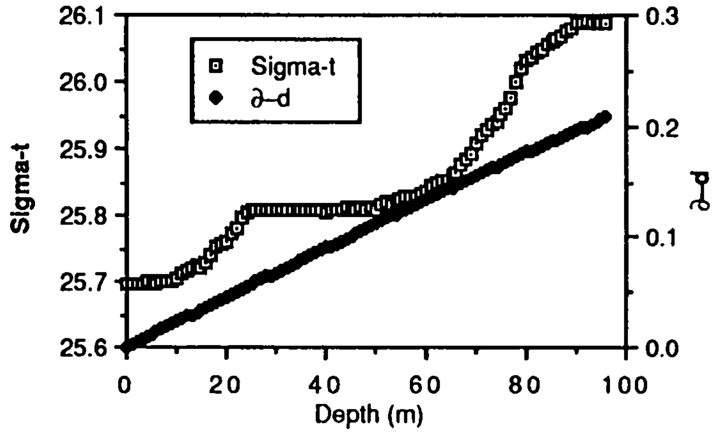
17.6 28 Apr 1987



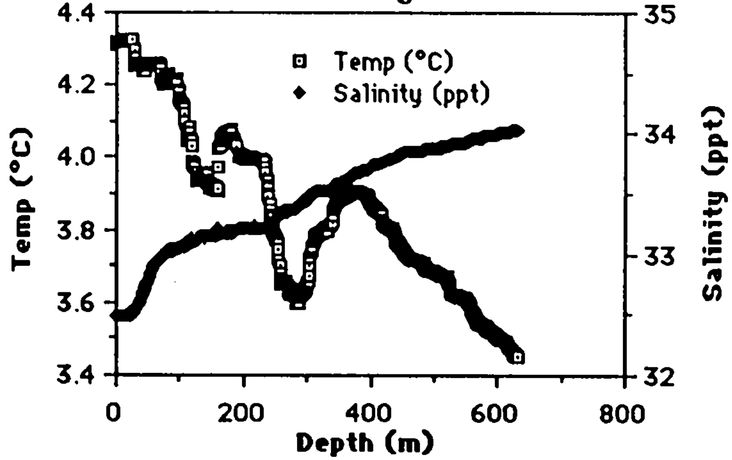
17.5 28 Apr 1987



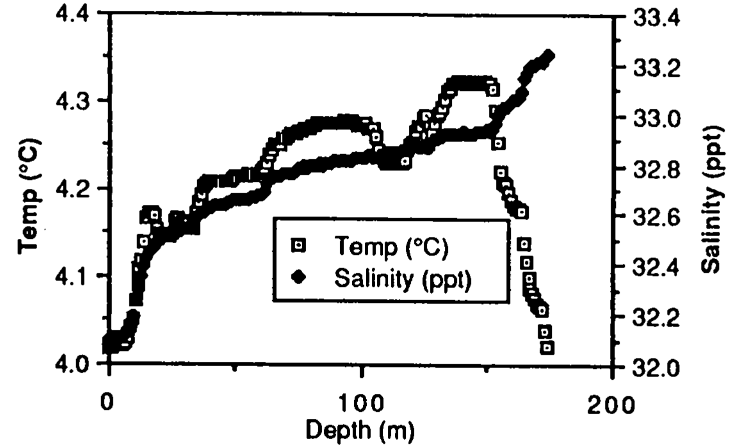
17.6 28 Apr 1987



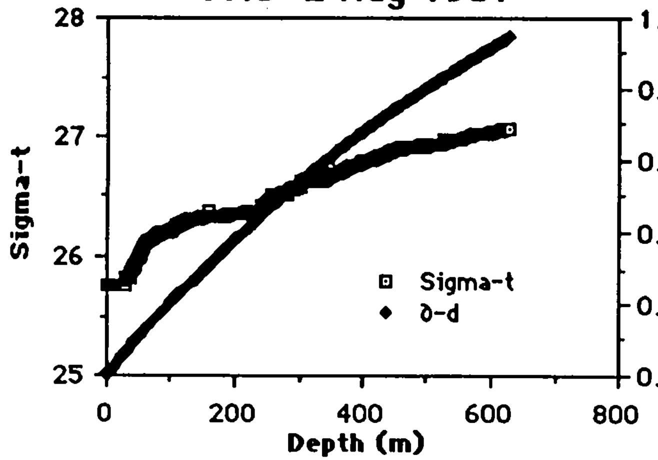
17.8 2 May 1987



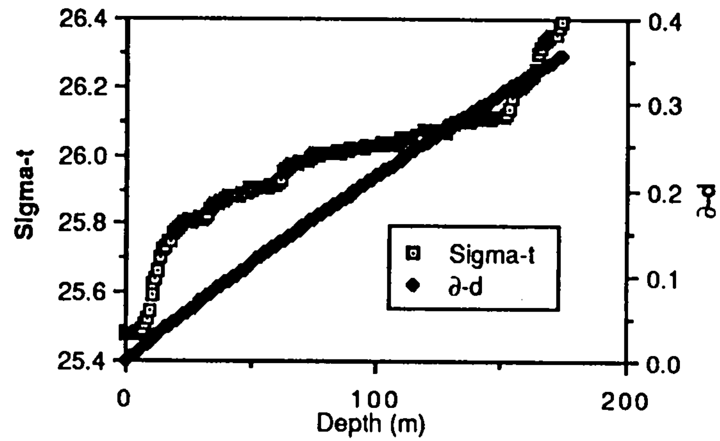
19.1 29 Apr 1987

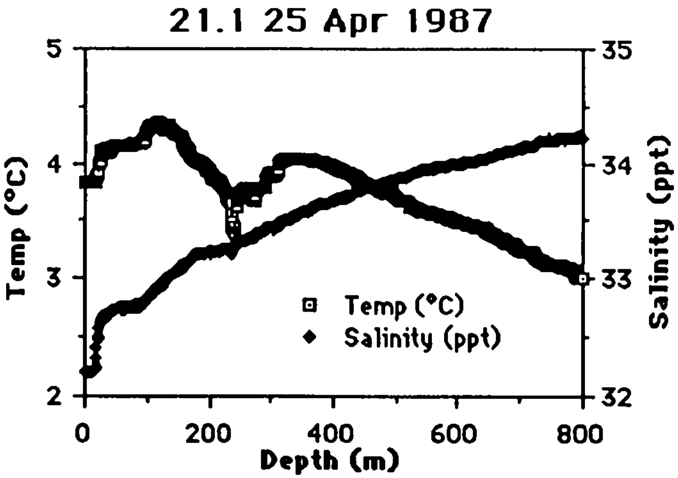


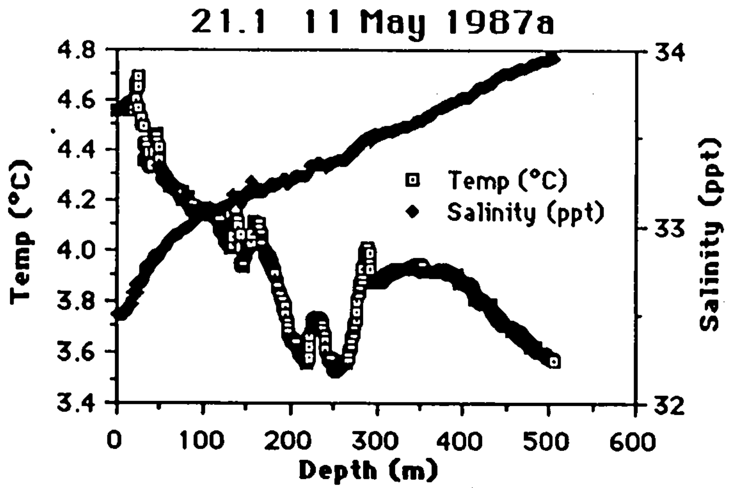
17.8 2 May 1987

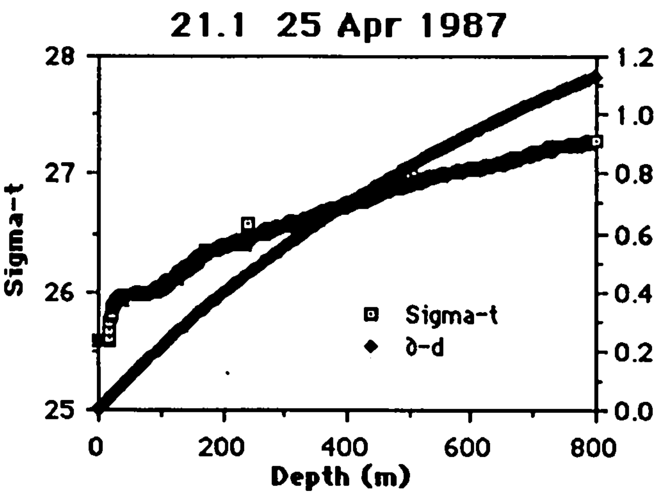


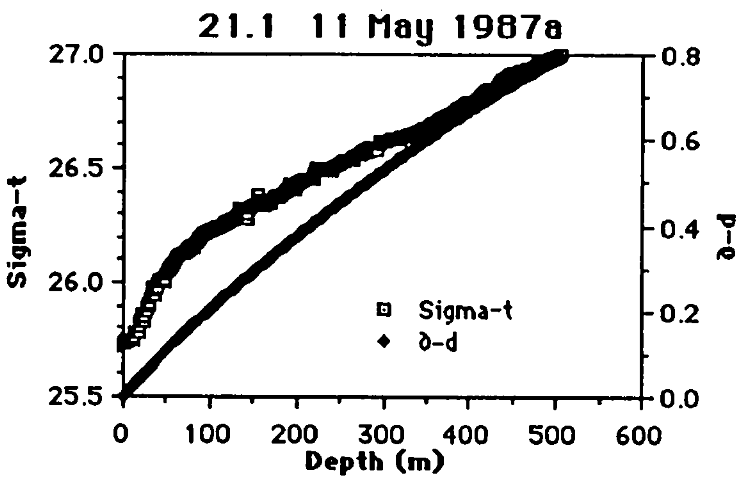
19.1 29 Apr 1987

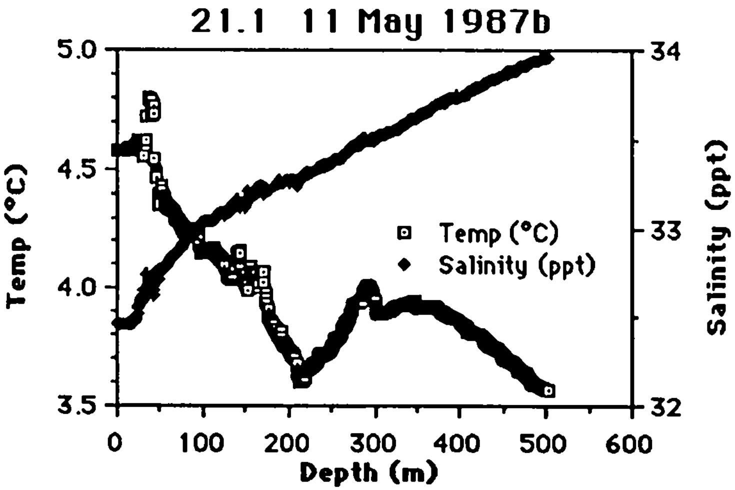


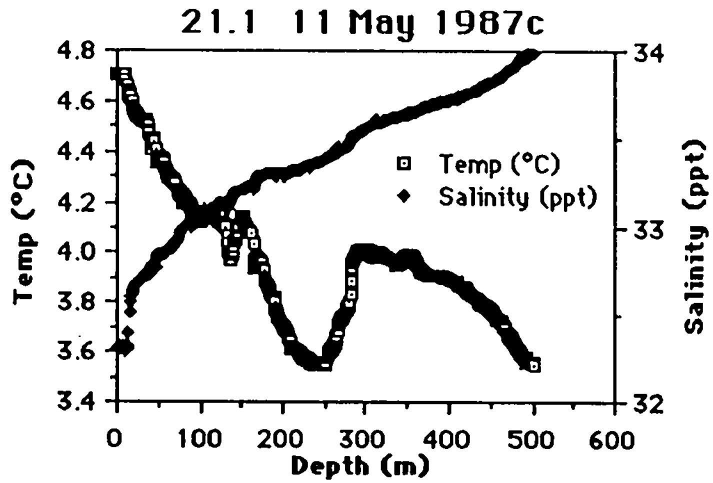

21.1 25 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

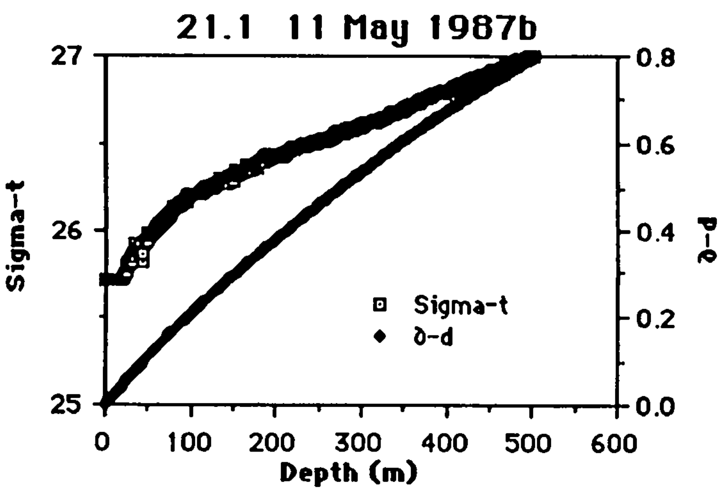

21.1 11 May 1987a
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)

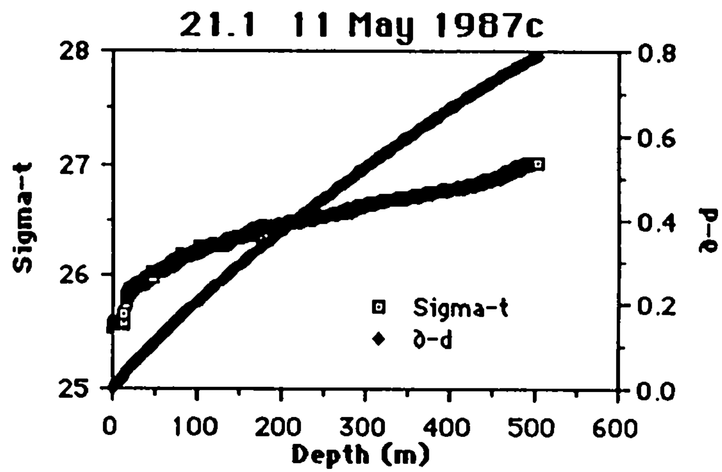

21.1 25 Apr 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

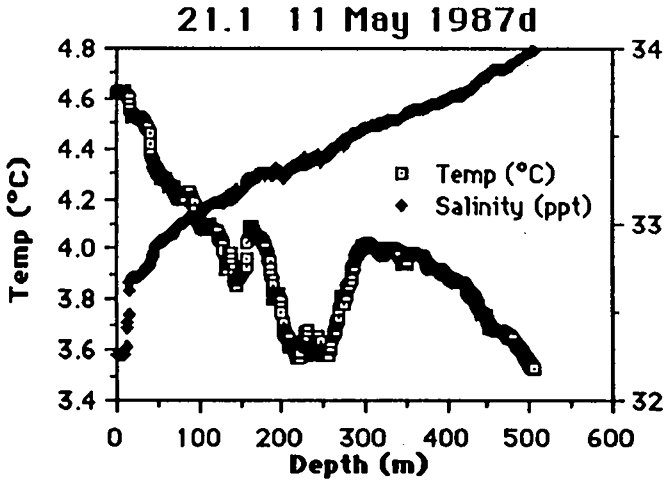

21.1 11 May 1987a
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d

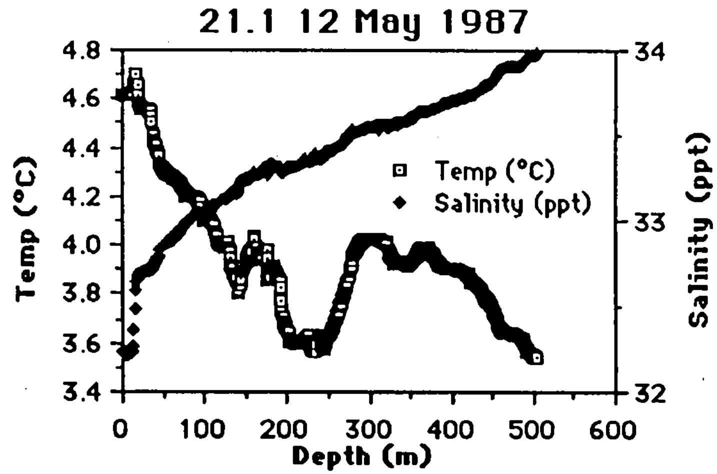

21.1 11 May 1987b
Temp (°C)
Salinity (ppt)
Depth (m)
5.0
4.5
4.0
3.5
34
33
32
0
100
200
300
400
500
600

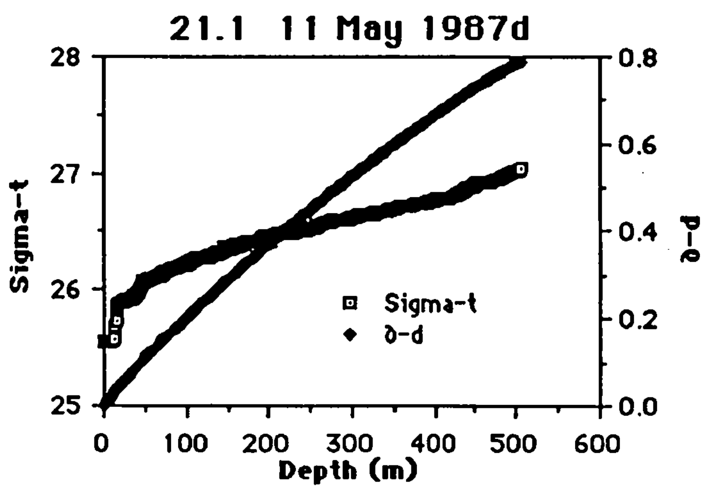

21.1 11 May 1987c
Temp (°C)
Salinity (ppt)
Depth (m)
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
34
33
32
0
100
200
300
400
500
600

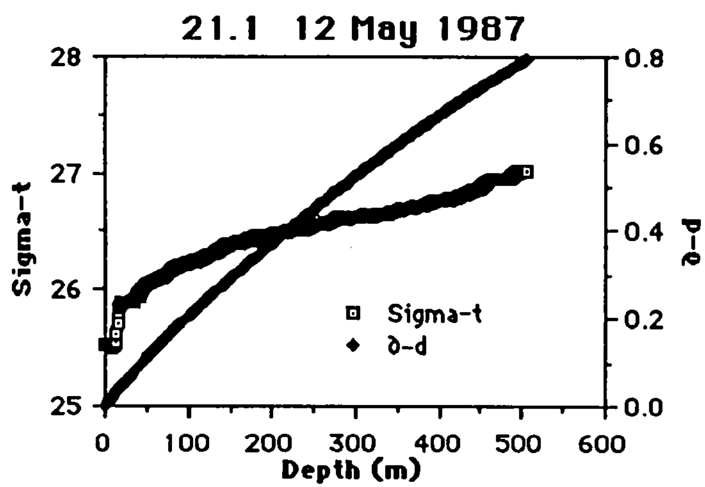

21.1 11 May 1987b
Sigma-t
∂-d
Depth (m)
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600


21.1 11 May 1987c
Sigma-t
∂-d
Depth (m)
28
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600

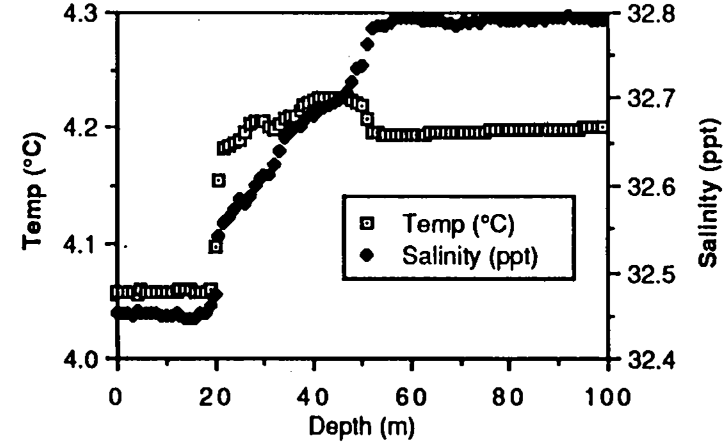

21.1 11 May 1987d
Temp (°C)
Salinity (ppt)
Depth (m)
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
34
33
32
0
100
200
300
400
500
600


21.1 12 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
34
33
32
0
100
200
300
400
500
600

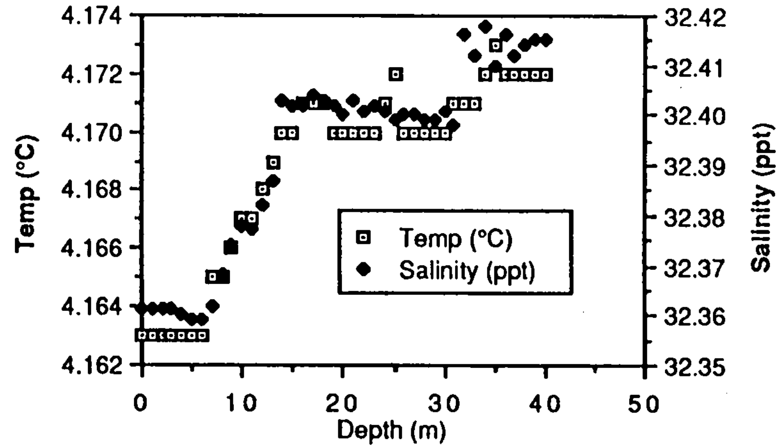

21.1 11 May 1987d
Sigma-t
∂-d
Depth (m)
28
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600


21.1 12 May 1987
Sigma-t
∂-d
Depth (m)
28
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600

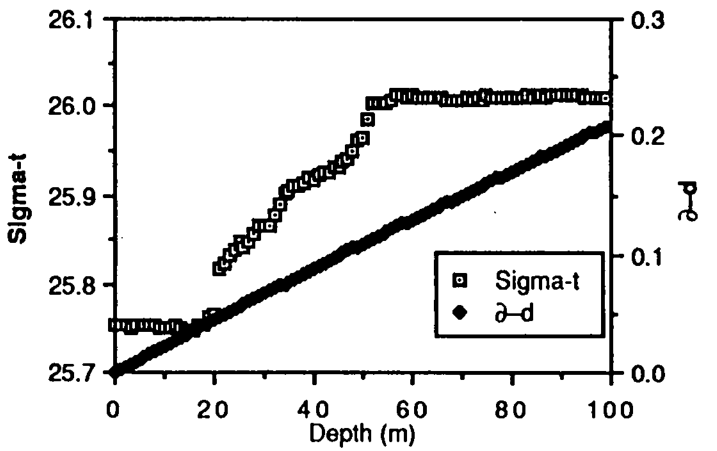
21.2 25 Apr 1987



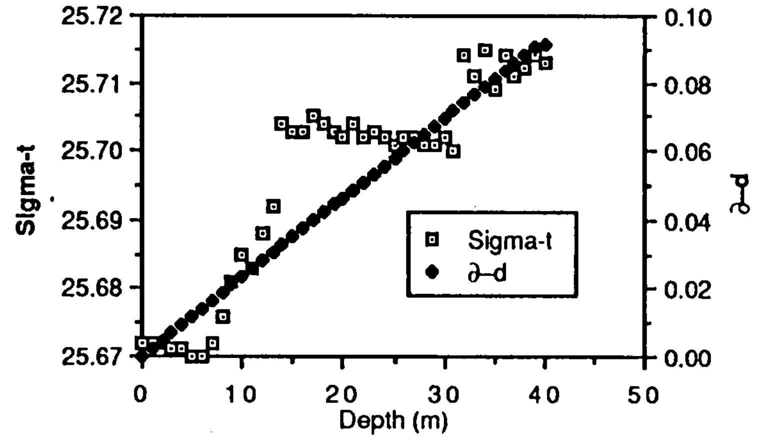
21.3 25 Apr 1987

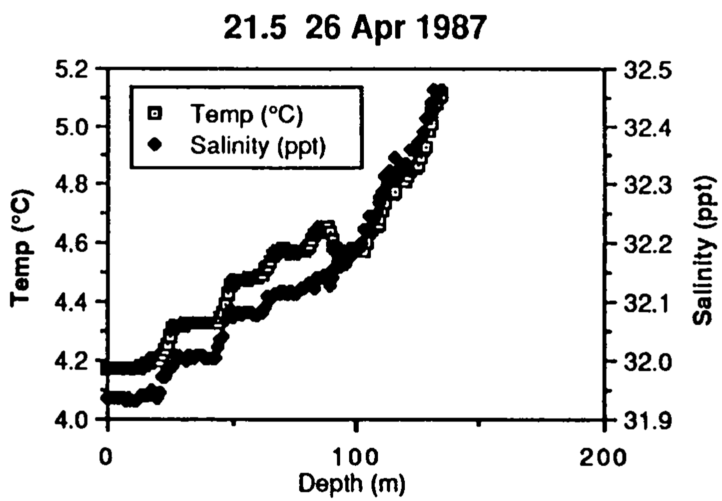


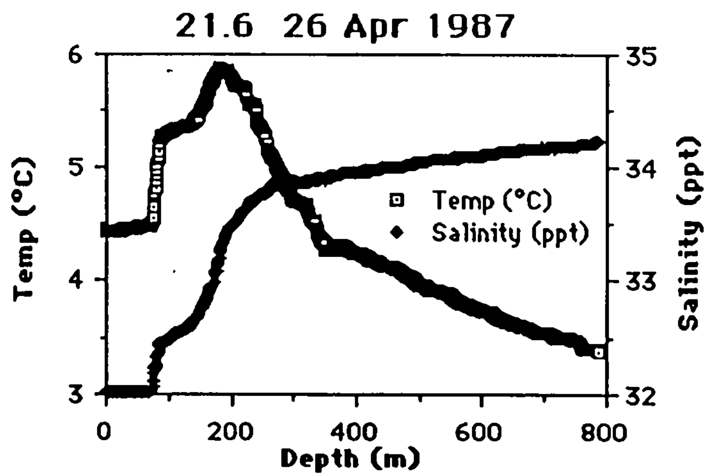
21.2 25 Apr 1987

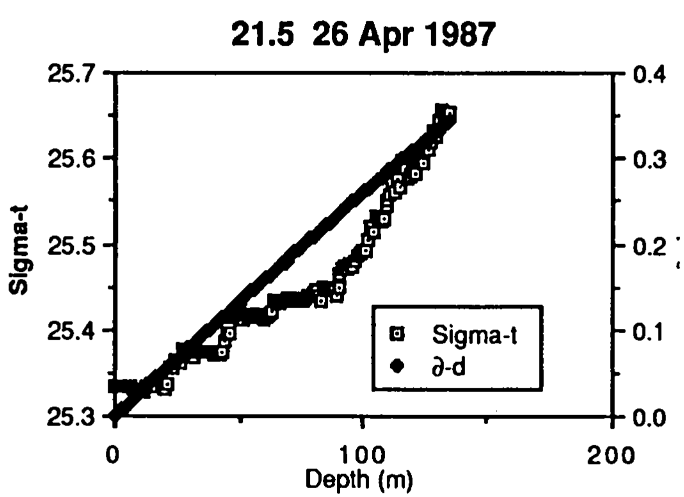


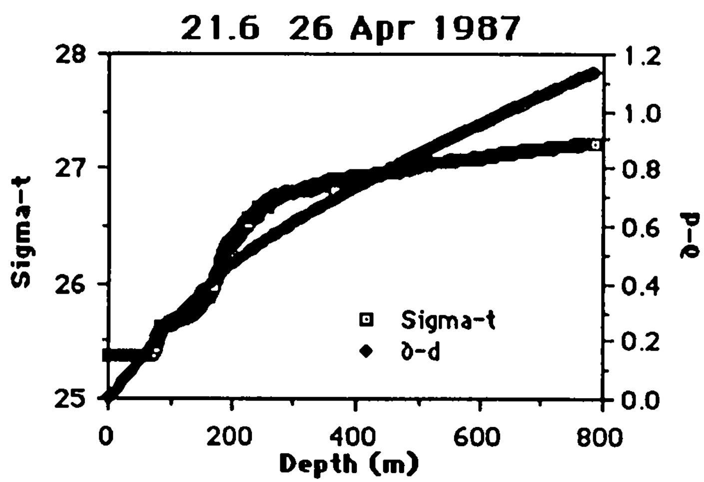
21.3 25 Apr 1987



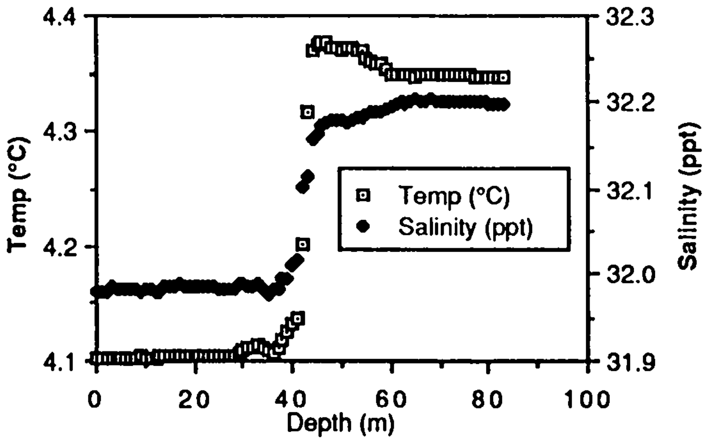

21.5 26 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)


21.6 26 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)

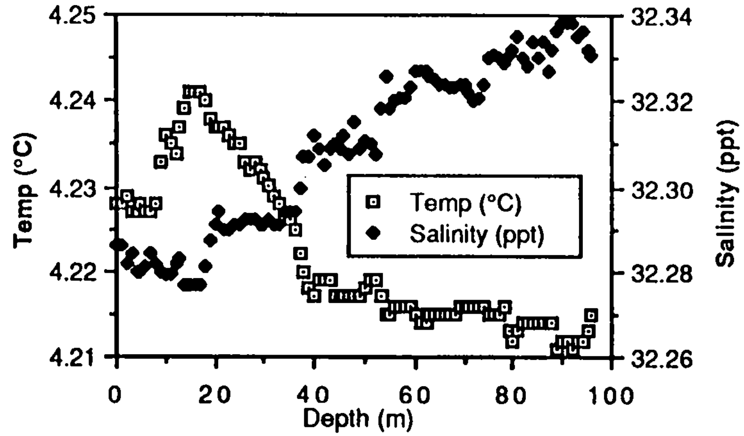

21.5 26 Apr 1987
Sigma-t
∂-d
Depth (m)


21.6 26 Apr 1987
Sigma-t
∂-d
Depth (m)

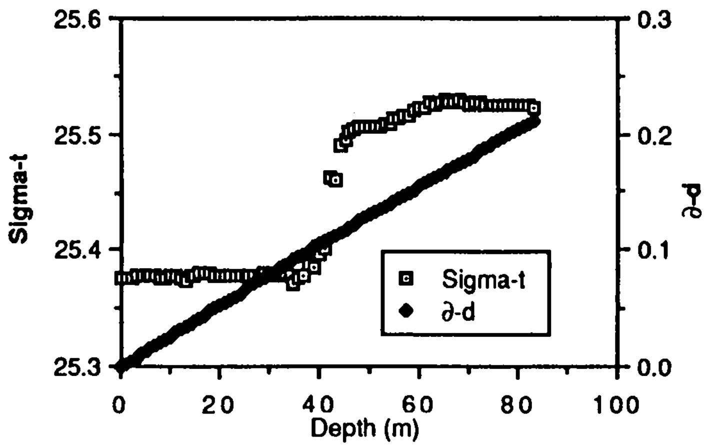
21.8 26 Apr 1987



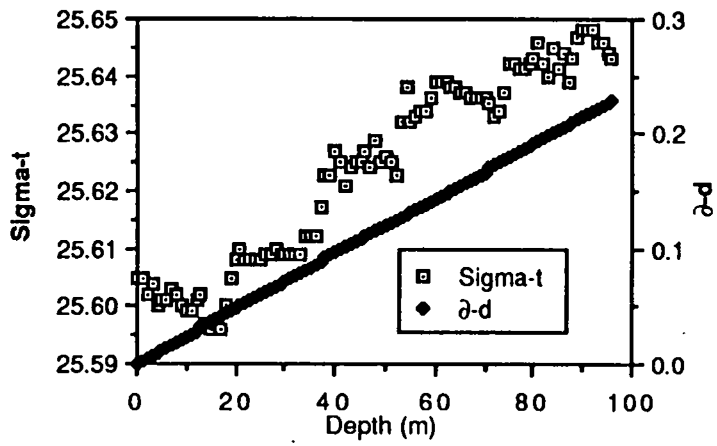
22.1 23 Apr 1987



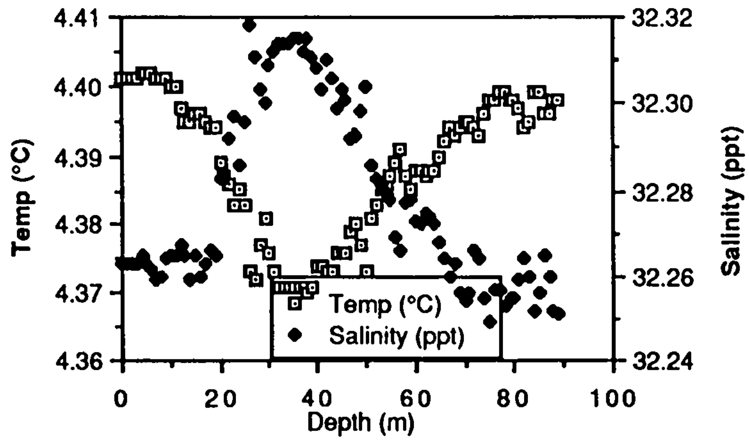
21.8 26 Apr 1987



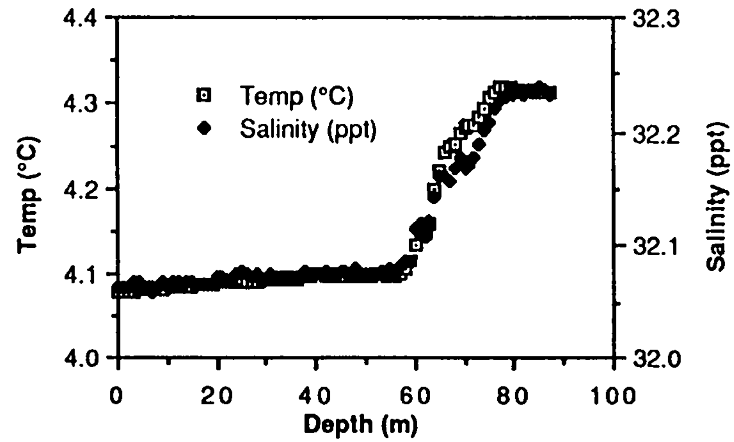
22.1 23 Apr 1987



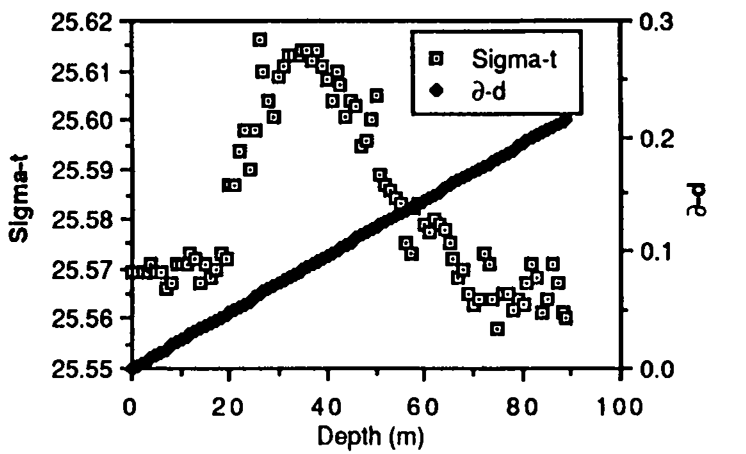
22.1 2 May 1987



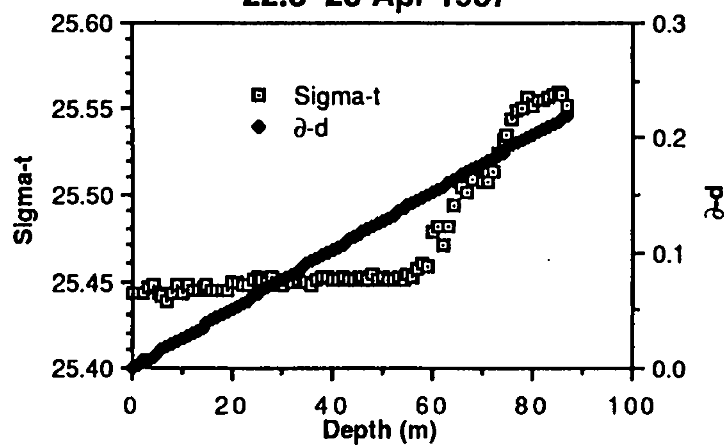
22.3 23 Apr 1987

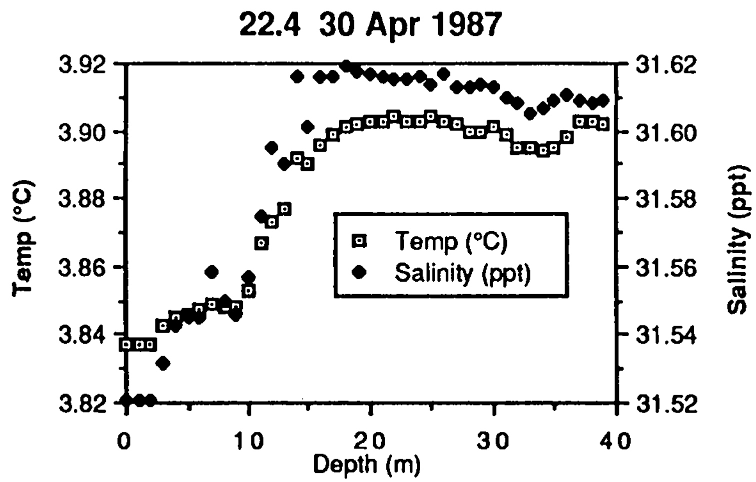


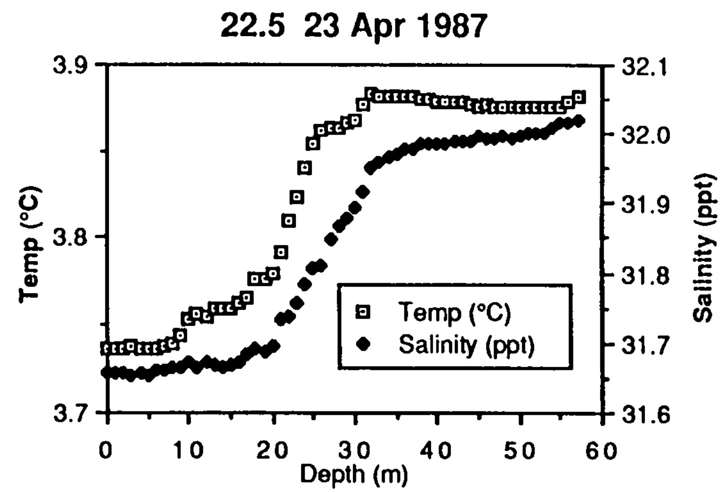
22.1 2 May 1987

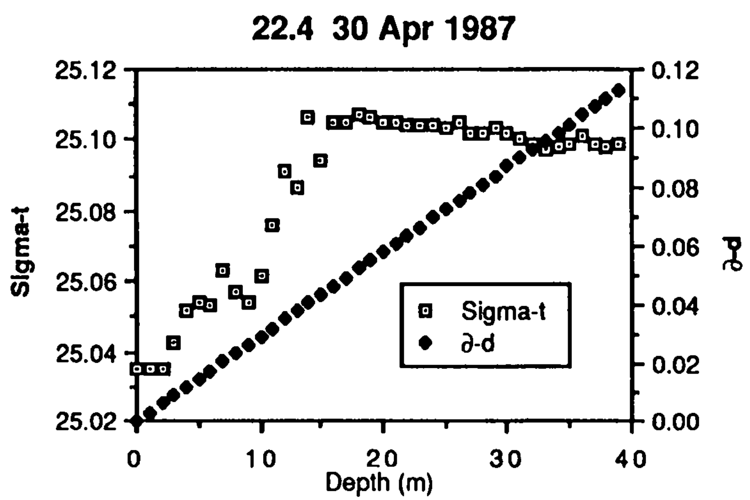


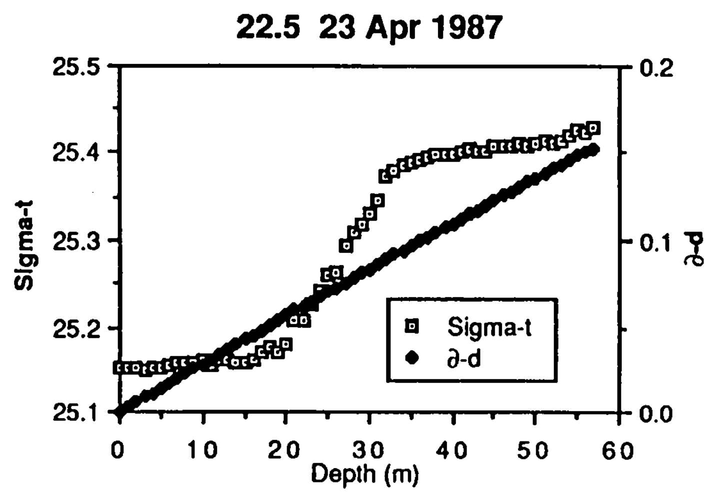
22.3 23 Apr 1987



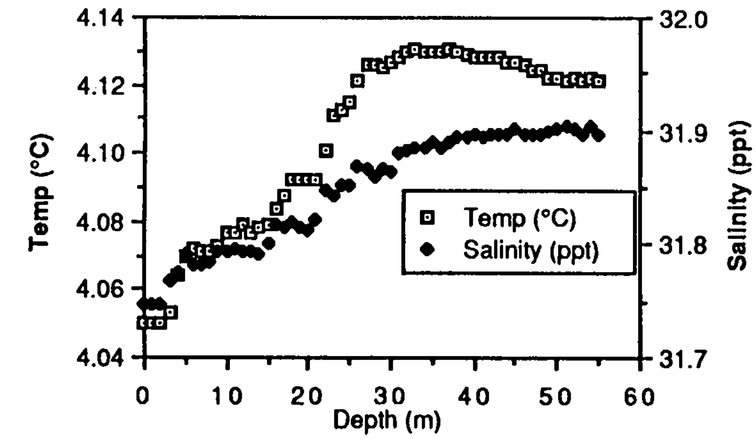

22.4 30 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
3.92
3.90
3.88
3.86
3.84
3.82
31.62
31.60
31.58
31.56
31.54
31.52
0
10
20
30
40


22.5 23 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
3.9
3.8
3.7
32.1
32.0
31.9
31.8
31.7
31.6
0
10
20
30
40
50
60

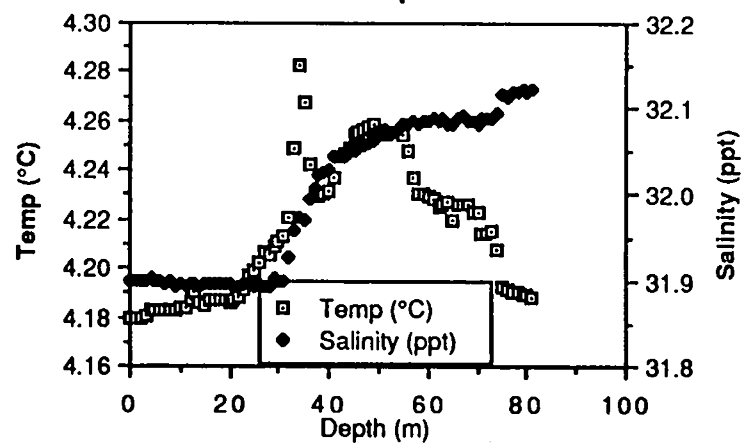

22.4 30 Apr 1987
Sigma-t
∂-d
Depth (m)
25.12
25.10
25.08
25.06
25.04
25.02
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40


22.5 23 Apr 1987
Sigma-t
∂-d
Depth (m)
25.5
25.4
25.3
25.2
25.1
0.2
0.1
0.0
0
10
20
30
40
50
60

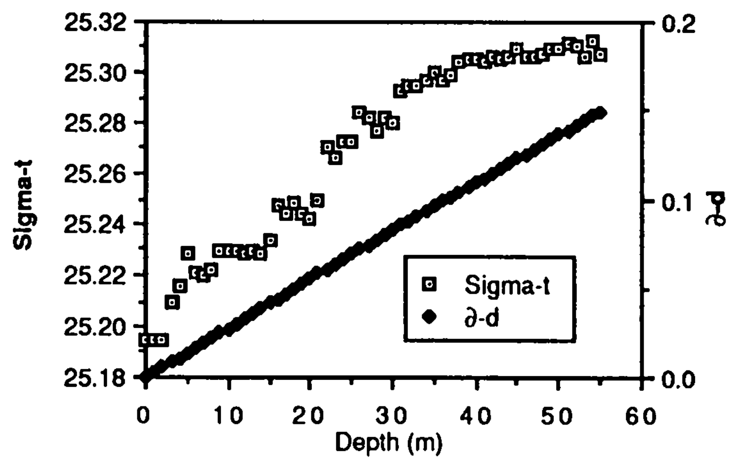
22.5 1 May 1987



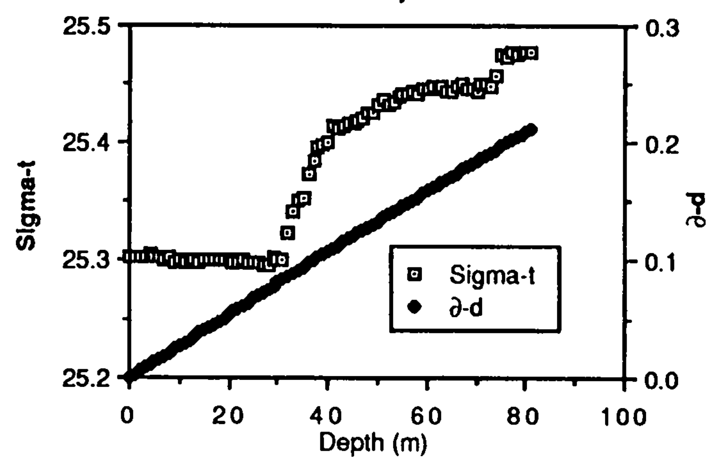
22.7 30 Apr 1987

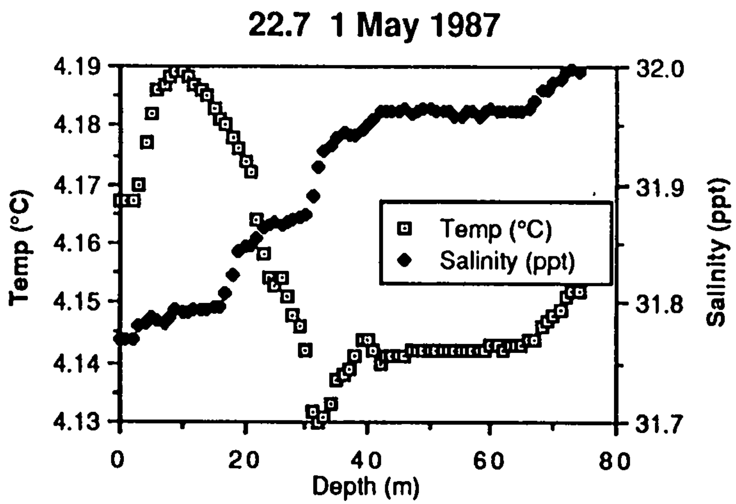


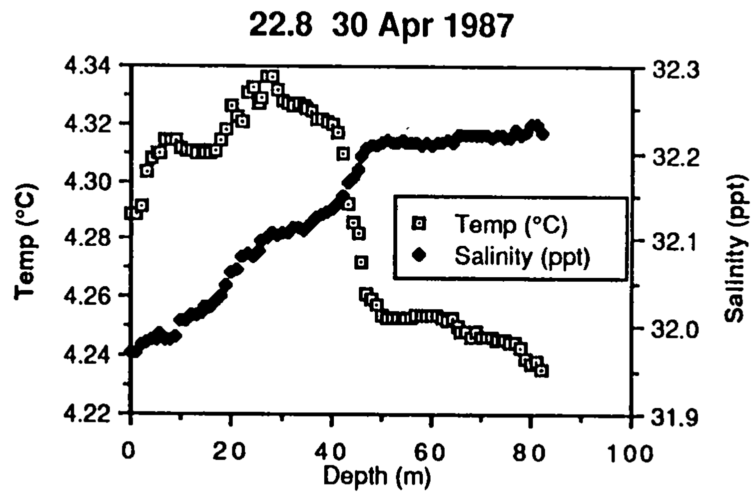
22.5 1 May 1987

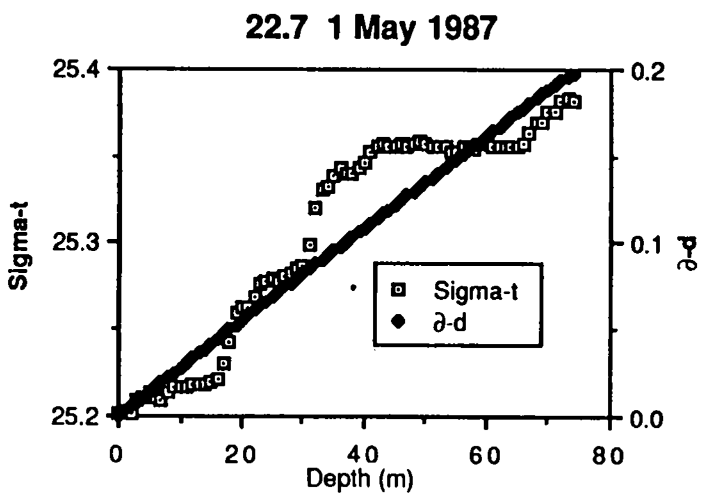


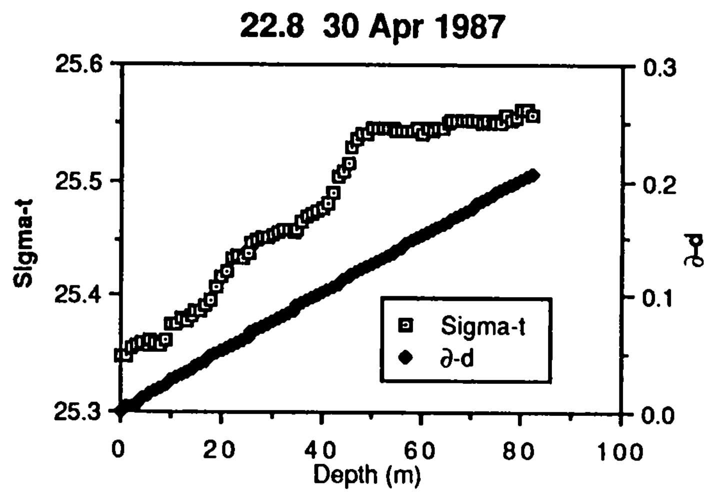
22.7 30 Apr 1987



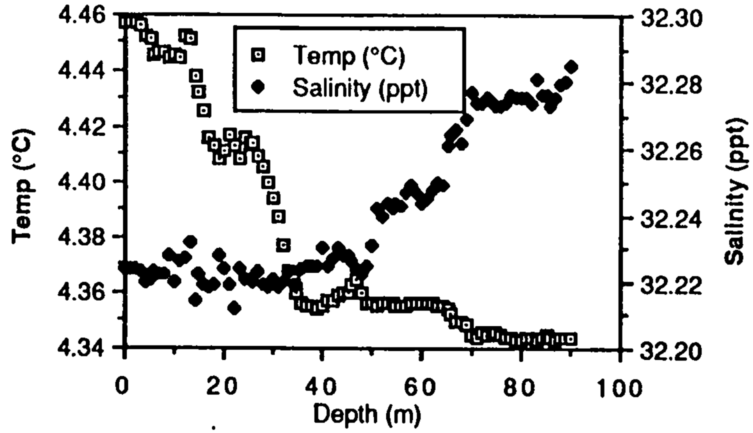

22.7 1 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.19
4.18
4.17
4.16
4.15
4.14
4.13
32.0
31.9
31.8
31.7
0
20
40
60
80


22.8 30 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.34
4.32
4.30
4.28
4.26
4.24
4.22
32.3
32.2
32.1
32.0
31.9
0
20
40
60
80
100

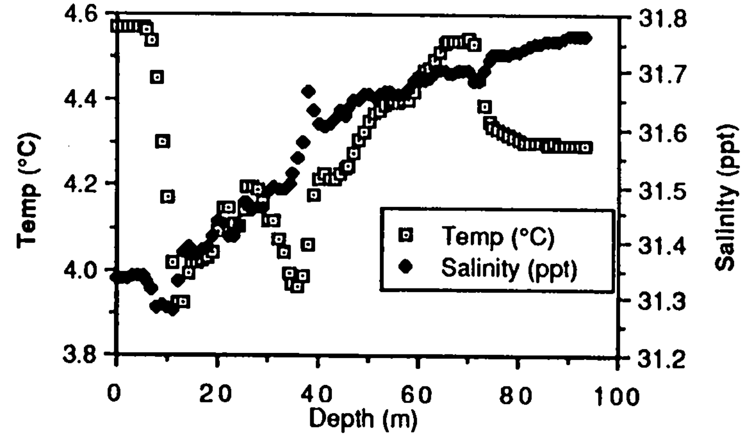

22.7 1 May 1987
Sigma-t
∂-d
Depth (m)
25.4
25.3
25.2
0.2
0.1
0.0
0
20
40
60
80


22.8 30 Apr 1987
Sigma-t
∂-d
Depth (m)
25.6
25.5
25.4
25.3
0.3
0.2
0.1
0.0
0
20
40
60
80
100

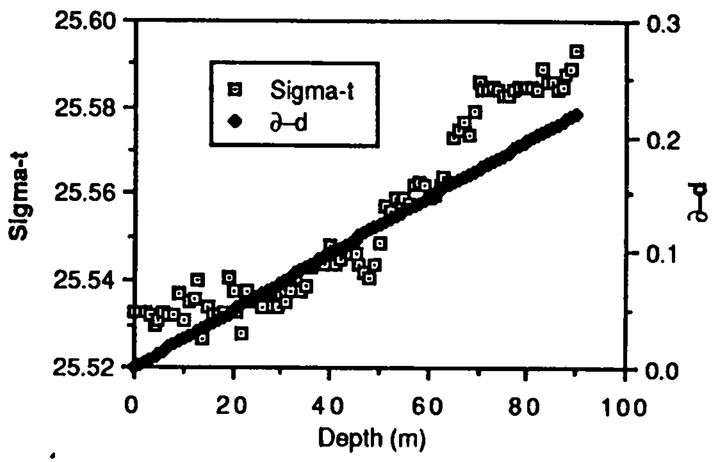
22.9 29 Apr 1987



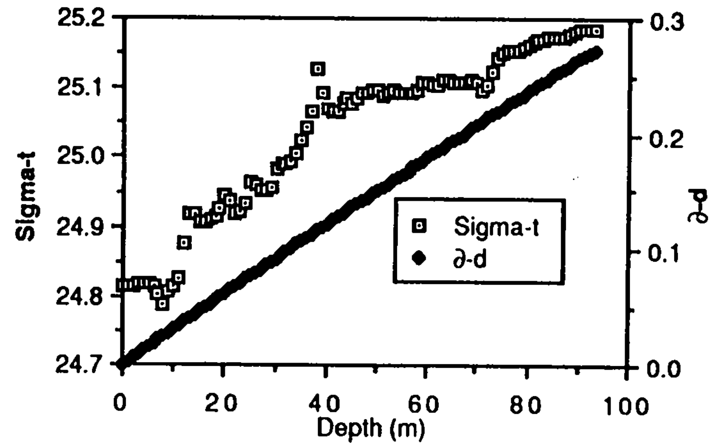
23.1 10 May 1987



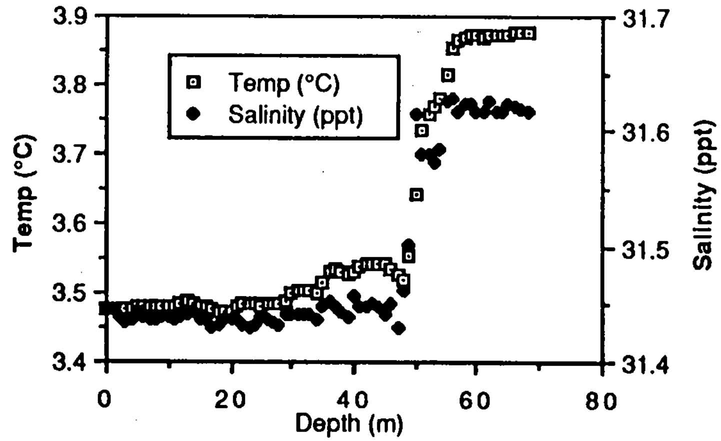
22.9 29 Apr 1987



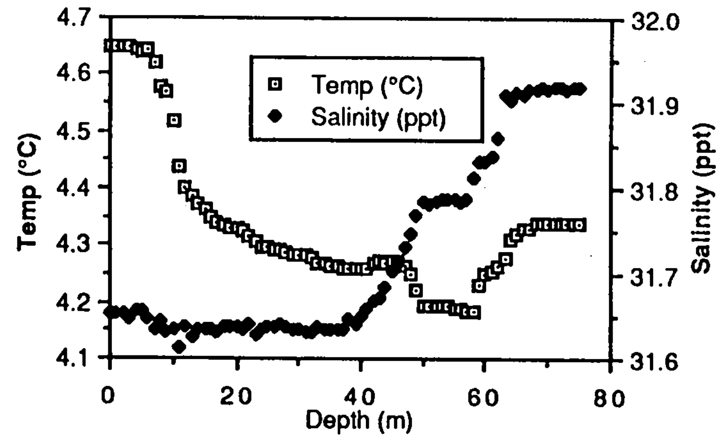
23.1 10 May 1987



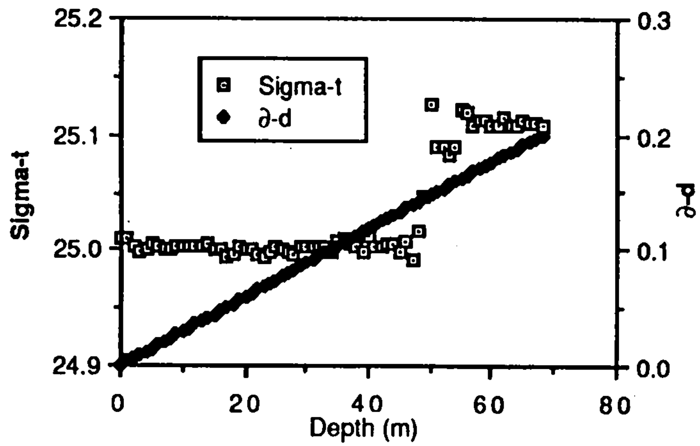
23.2 24 Apr 1987



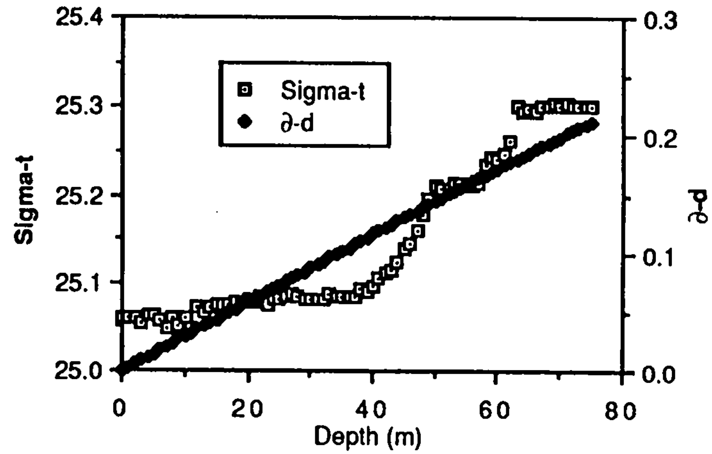
23.3 5 May 1987

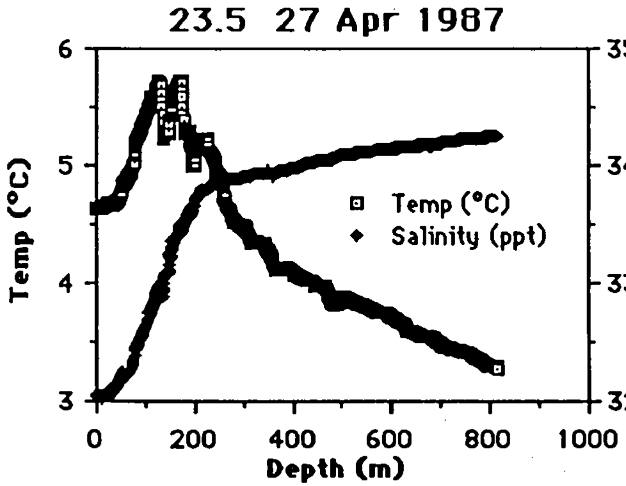


23.2 24 Apr 1987

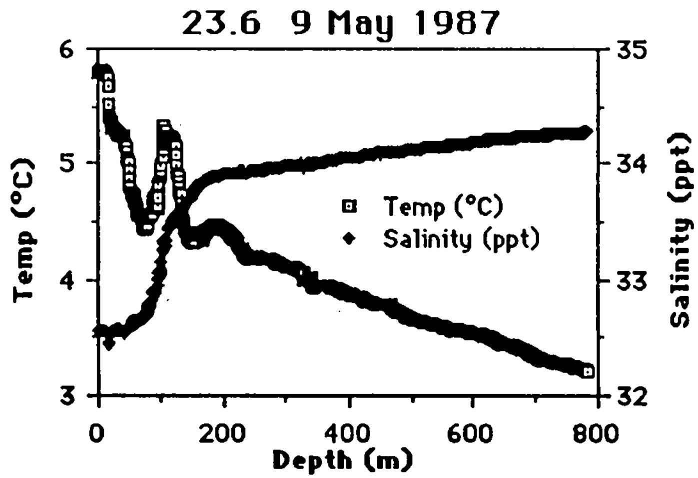


23.3 5 May 1987

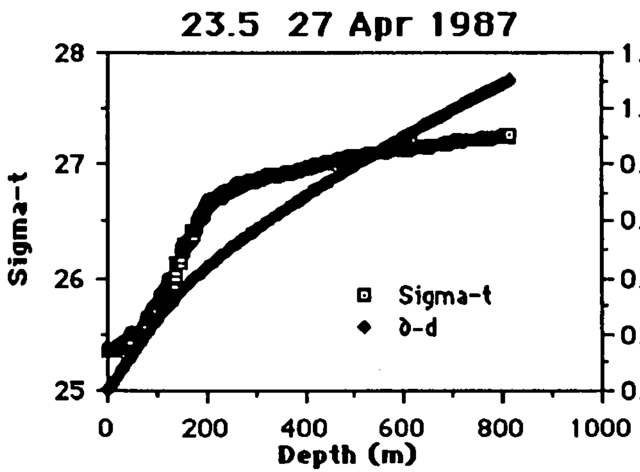




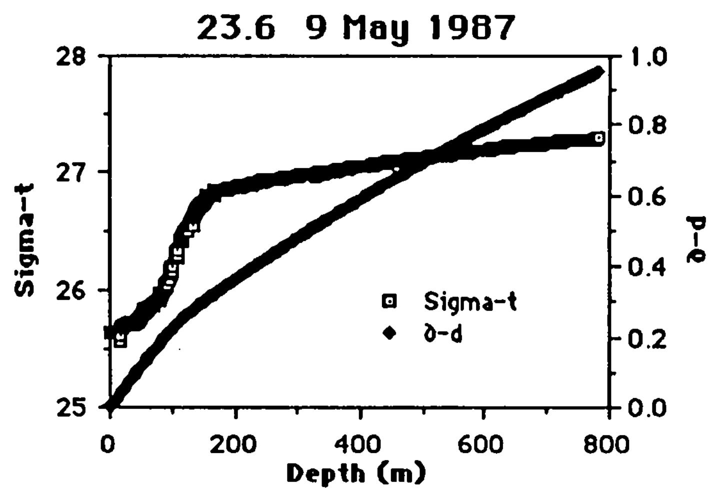
23.5 27 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
6
5
4
3
35
34
33
32
0
200
400
600
800
1000



23.6 9 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
6
5
4
3
35
34
33
32
0
200
400
600
800

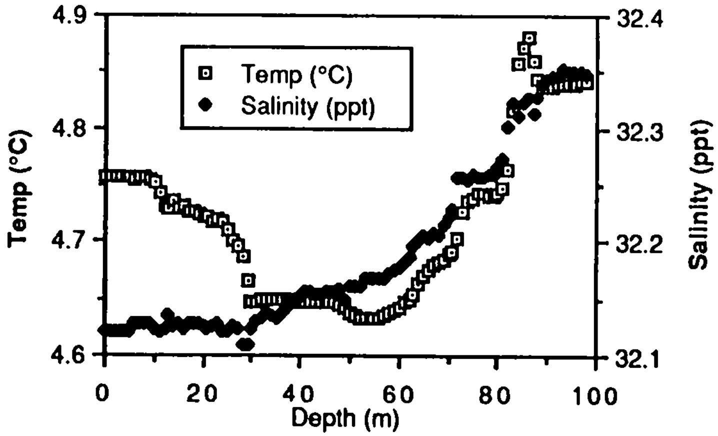


23.5 27 Apr 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
28
27
26
25
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000

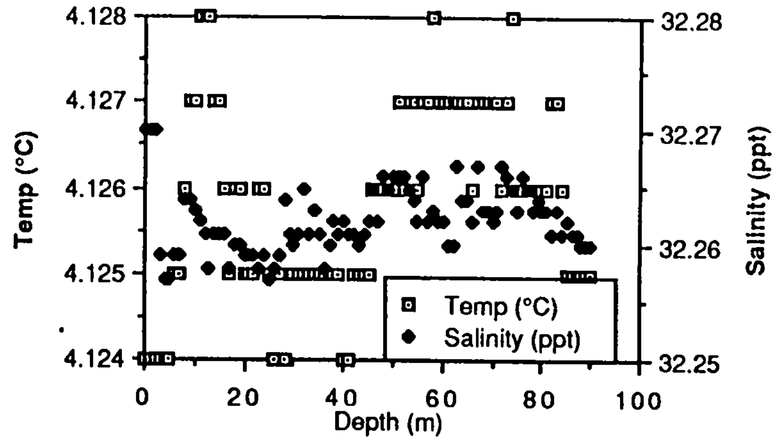


23.6 9 May 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
28
27
26
25
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800

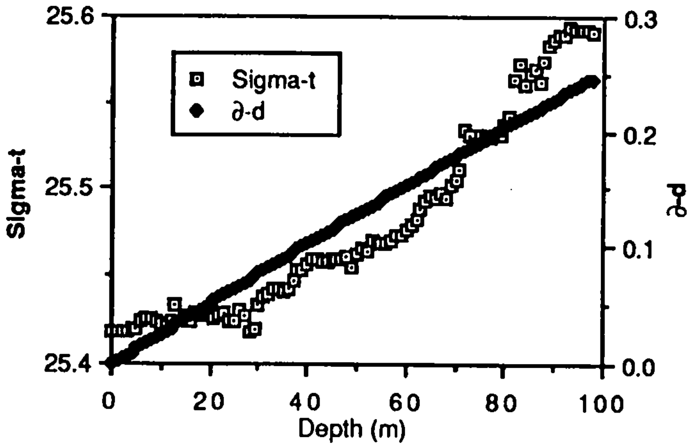
29.1 24 Apr 1987



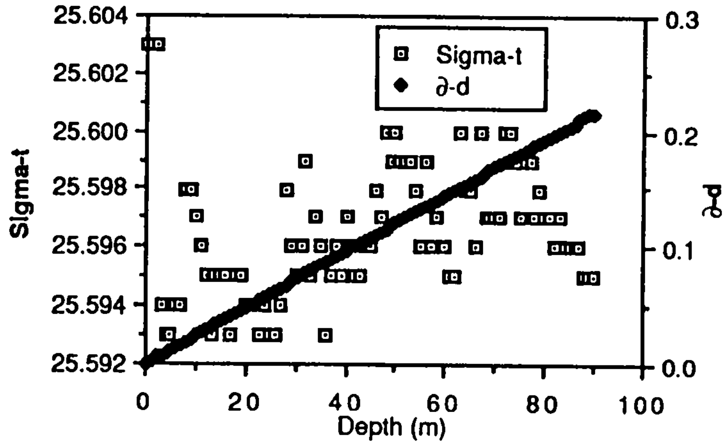
29.2 24 Apr 1987

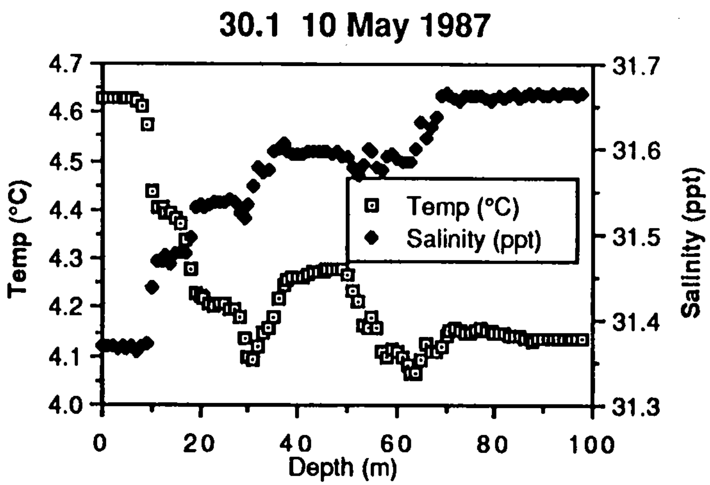


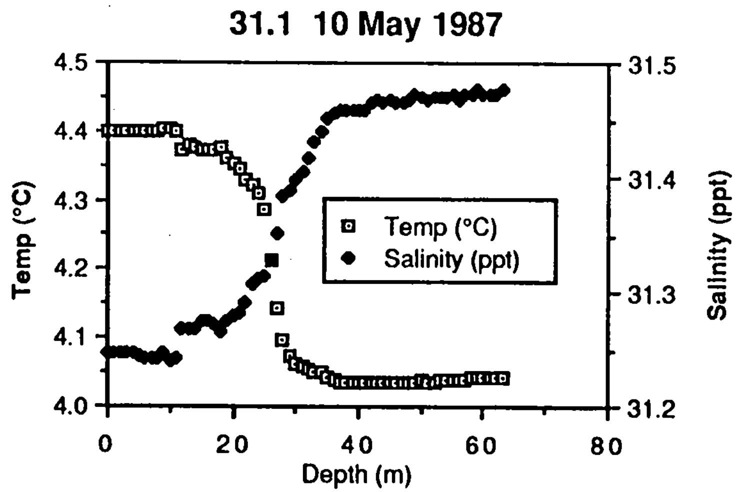
29.1 24 Apr 1987

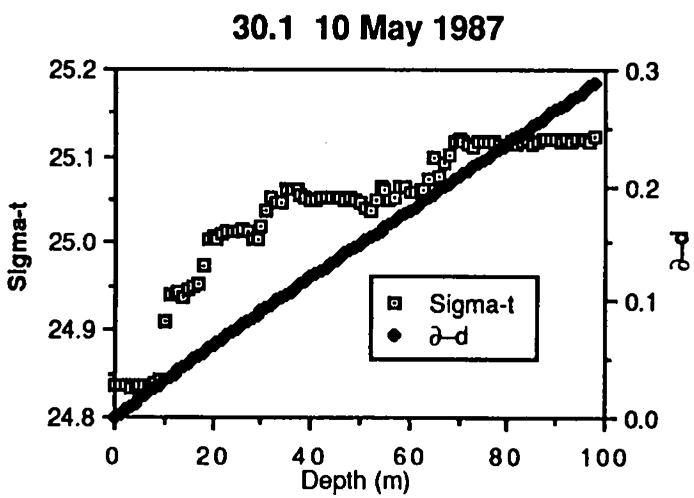


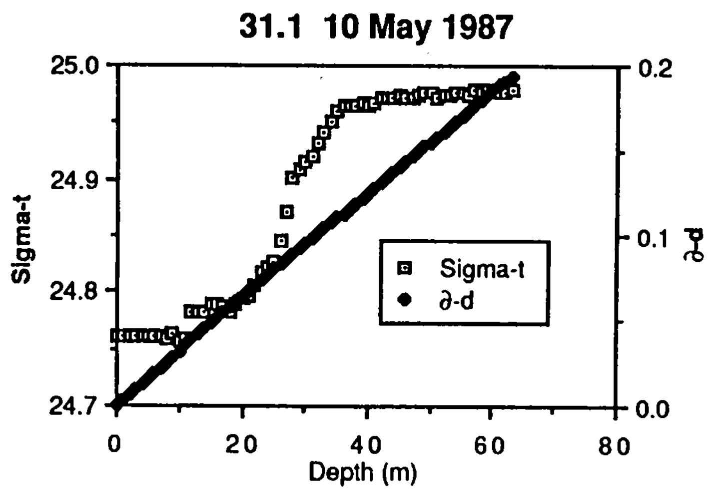
29.2 24 Apr 1987



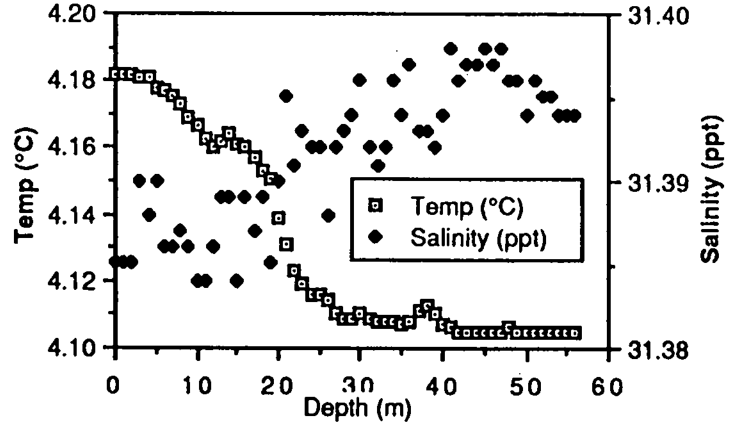

30.1 10 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
31.7
31.6
31.5
31.4
31.3
0
20
40
60
80
100


31.1 10 May 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.5
4.4
4.3
4.2
4.1
4.0
31.5
31.4
31.3
31.2
0
20
40
60
80

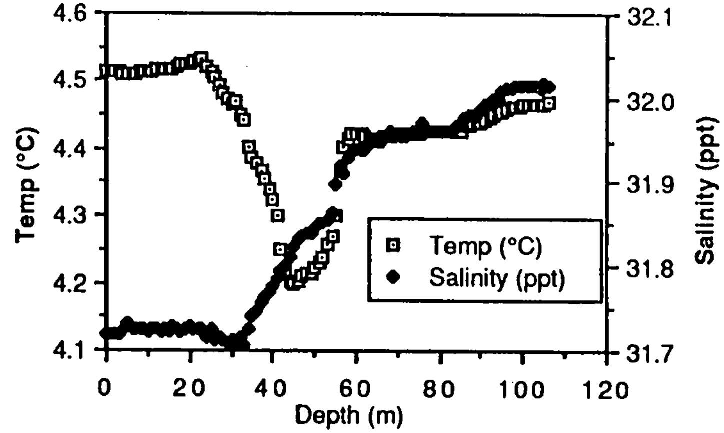

30.1 10 May 1987
Sigma-t
∂-d
Depth (m)
25.2
25.1
25.0
24.9
24.8
0.3
0.2
0.1
0.0
0
20
40
60
80
100


31.1 10 May 1987
Sigma-t
∂-d
Depth (m)
25.0
24.9
24.8
24.7
0.2
0.1
0.0
0
20
40
60
80

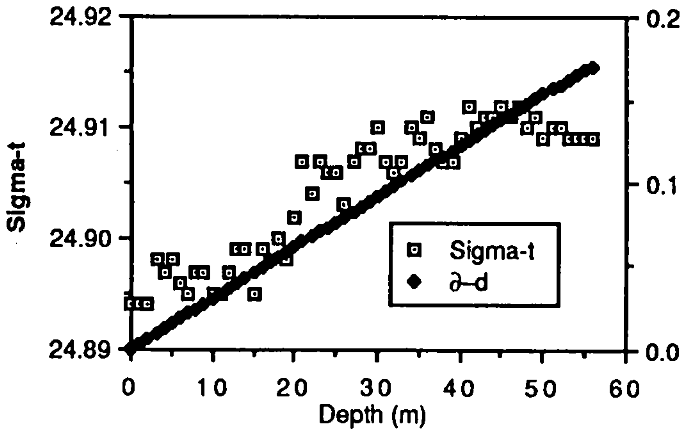
31.2 10 May 1987



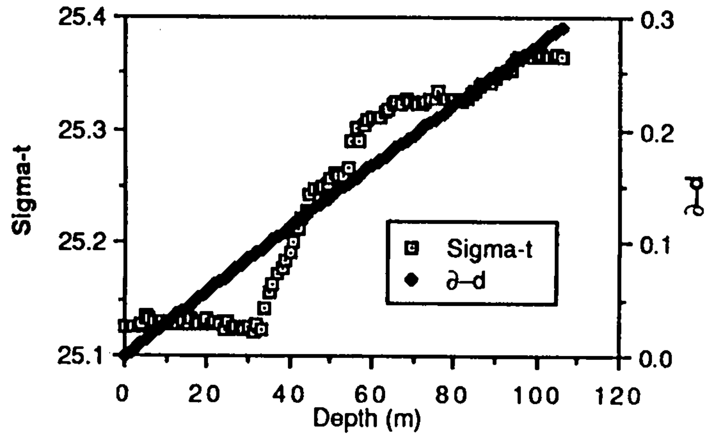
31.4 10 May 1987

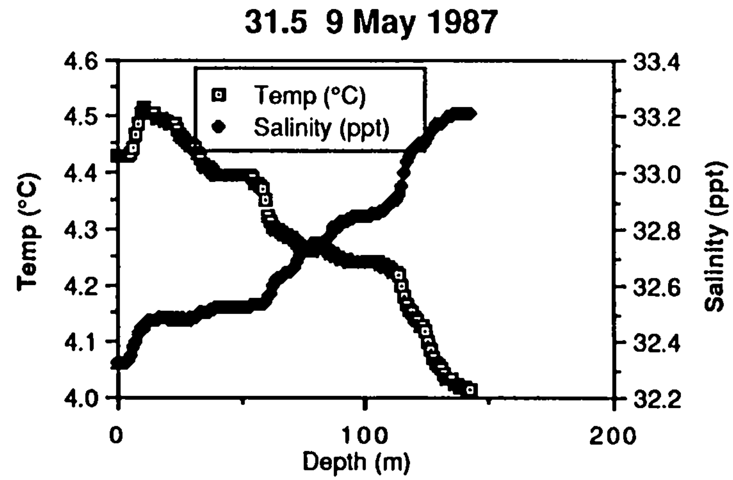


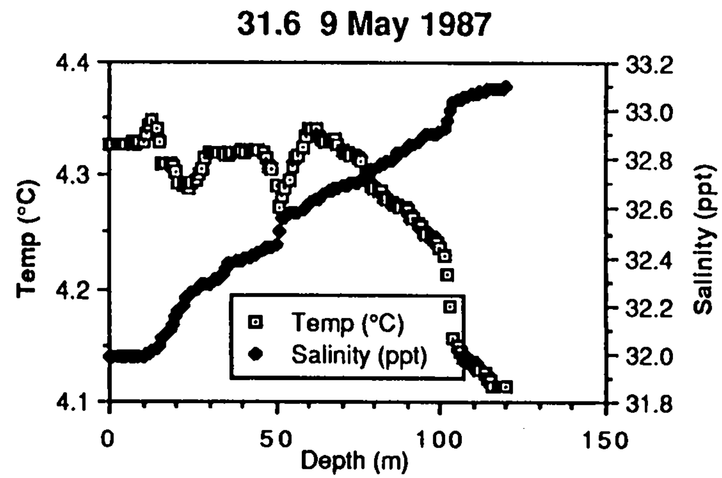
31.2 10 May 1987

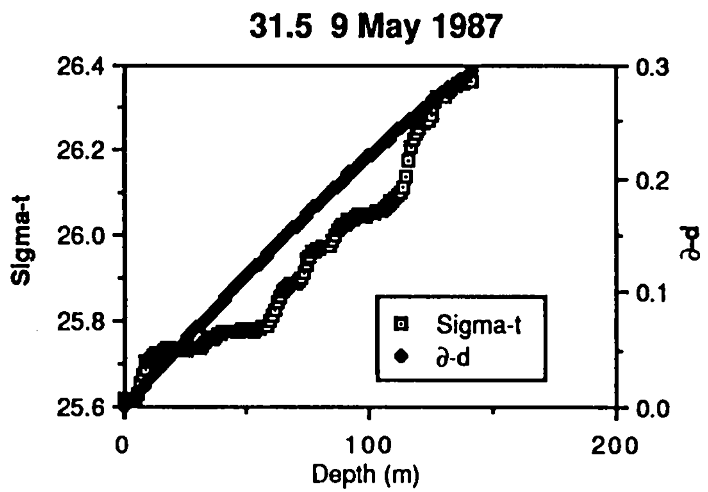


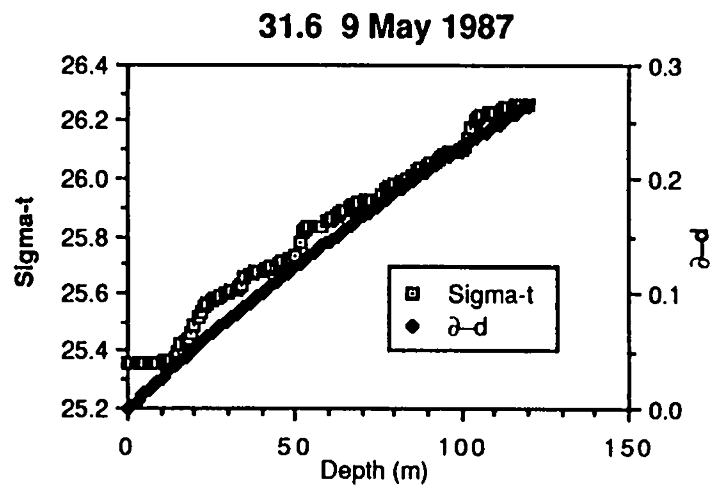
31.4 10 May 1987



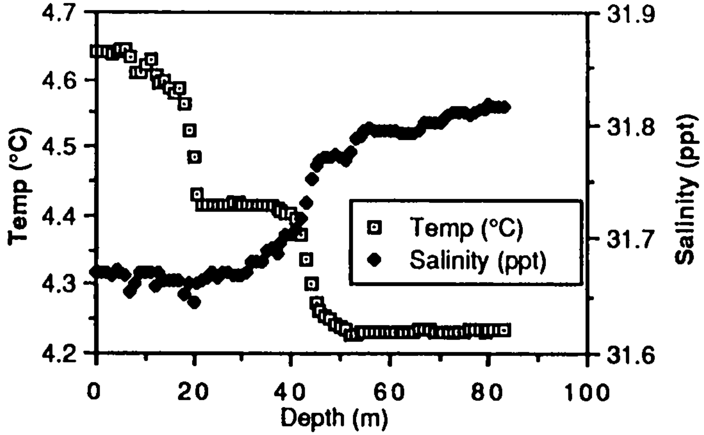

31.5 9 May 1987
Temp (°C)
Salinity (ppt)
Temp (°C)
Salinity (ppt)
Depth (m)
4.6
4.5
4.4
4.3
4.2
4.1
4.0
33.4
33.2
33.0
32.8
32.6
32.4
32.2
0
100
200


31.6 9 May 1987
Temp (°C)
Salinity (ppt)
Temp (°C)
Salinity (ppt)
Depth (m)
4.4
4.3
4.2
4.1
33.2
33.0
32.8
32.6
32.4
32.2
32.0
31.8
0
50
100
150

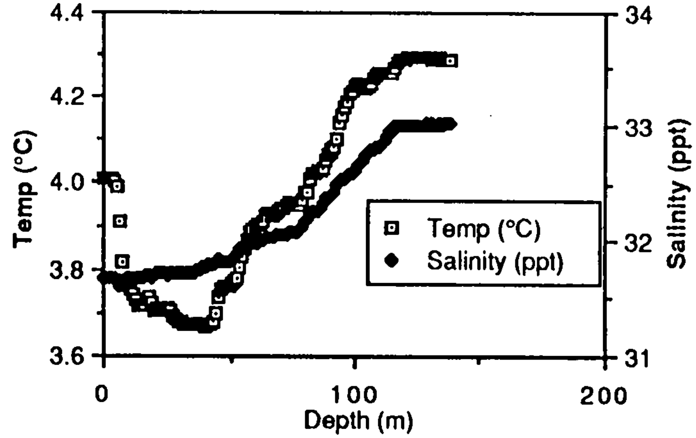

31.5 9 May 1987
Sigma-t
∂-d
Sigma-t
∂-d
Depth (m)
26.4
26.2
26.0
25.8
25.6
0.3
0.2
0.1
0.0
0
100
200


31.6 9 May 1987
Sigma-t
∂-d
Sigma-t
∂–d
Depth (m)
26.4
26.2
26.0
25.8
25.6
25.4
25.2
0.3
0.2
0.1
0.0
0
50
100
150

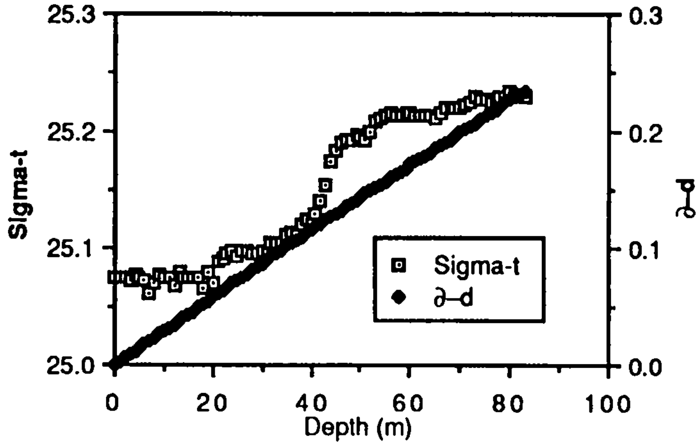
31.7 10 May 1987



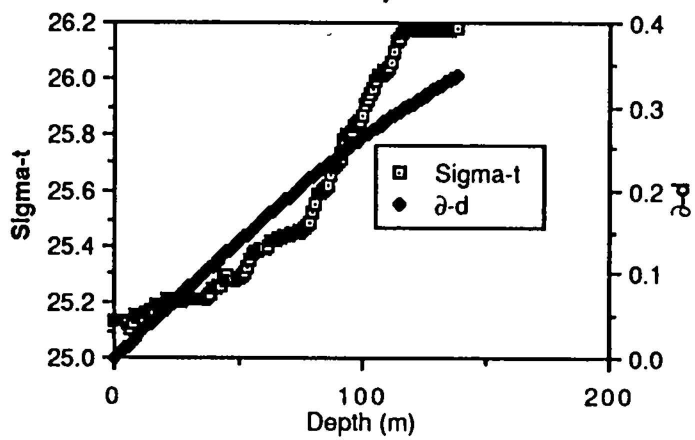
32.1 27 Apr 1987

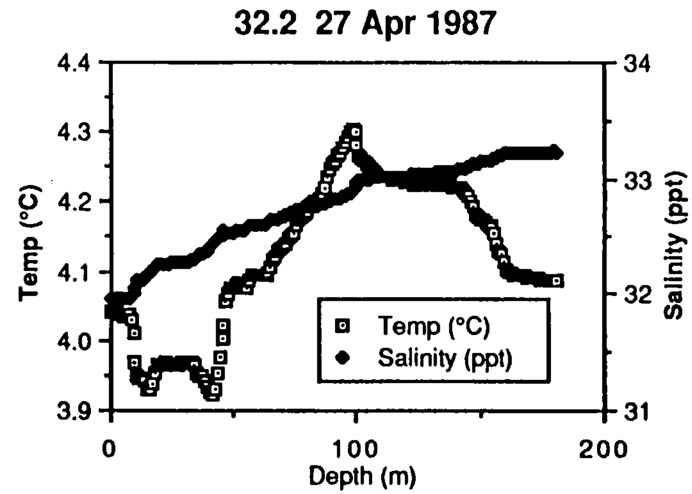


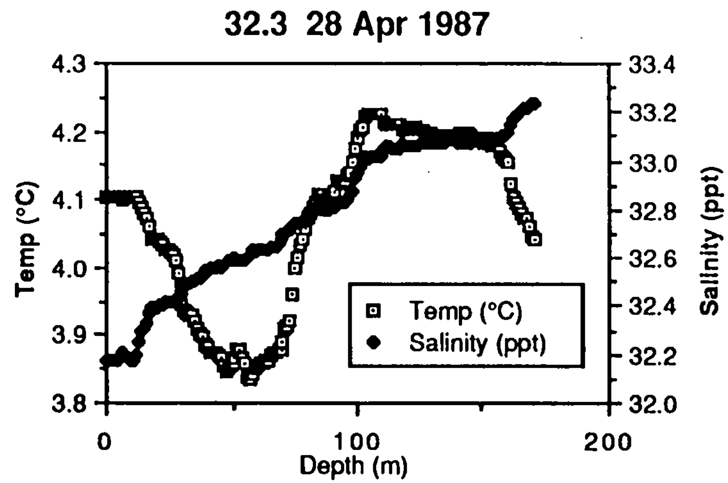
31.7 10 May 1987

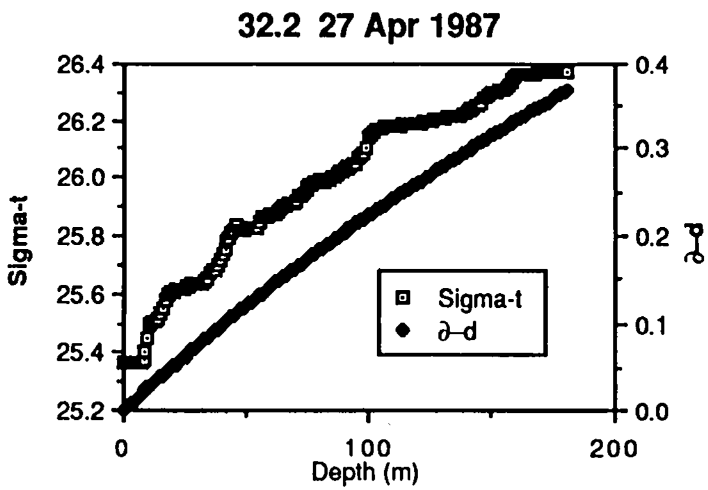


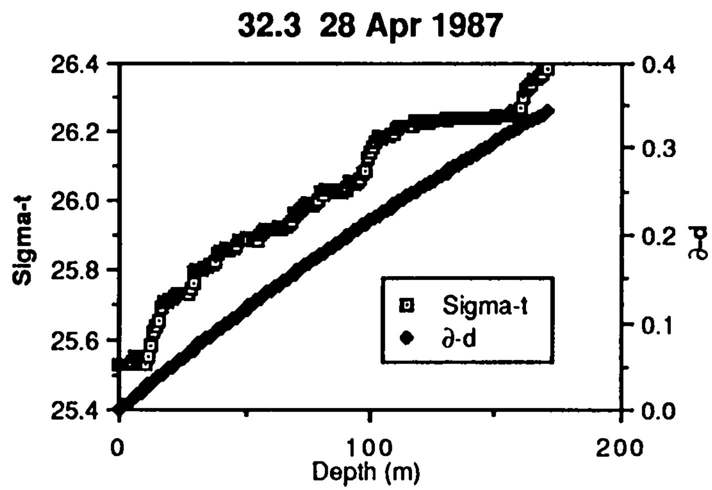
32.1 27 Apr 1987

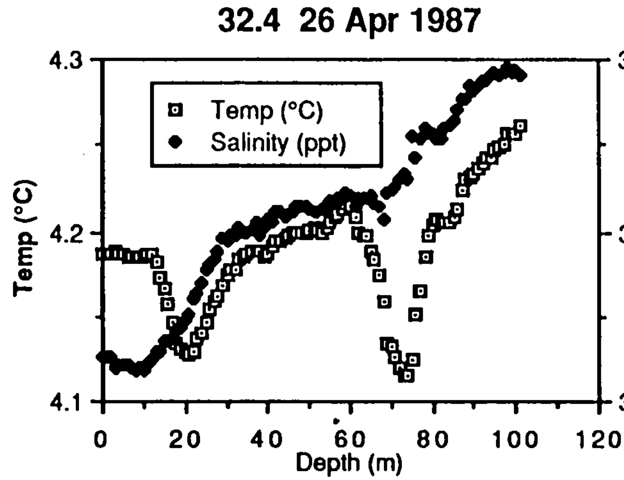


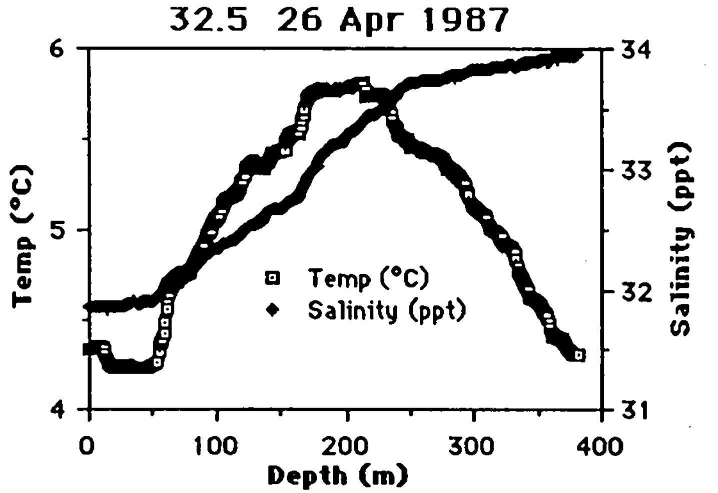

32.2 27 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.4
4.3
4.2
4.1
4.0
3.9
34
33
32
31
0
100
200
Temp (°C)
Salinity (ppt)

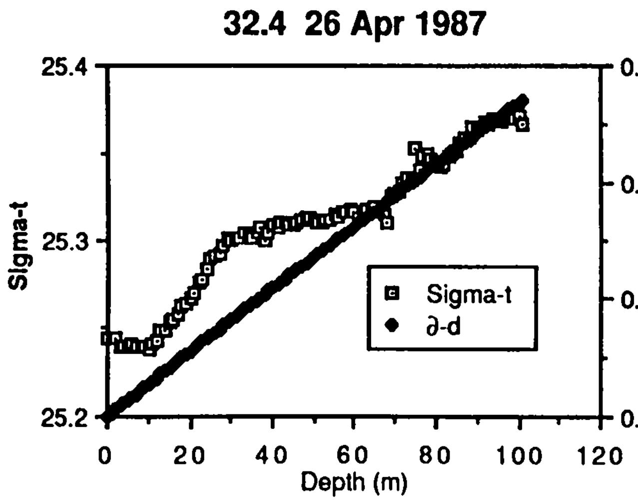

32.3 28 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.3
4.2
4.1
4.0
3.9
3.8
33.4
33.2
33.0
32.8
32.6
32.4
32.2
32.0
0
100
200
Temp (°C)
Salinity (ppt)

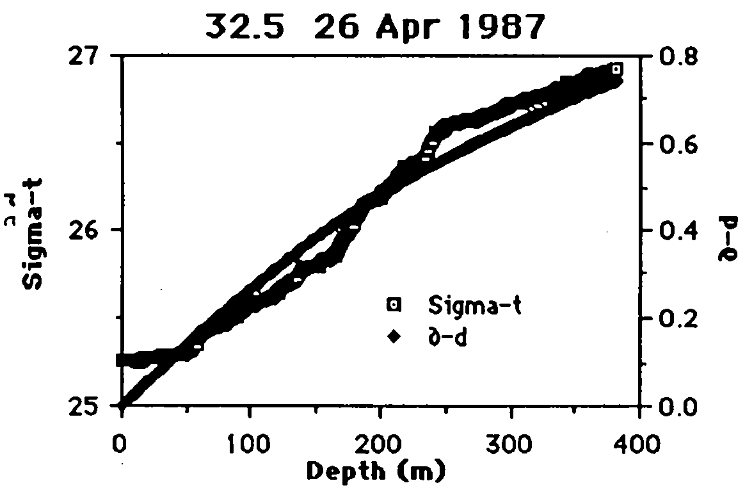

32.2 27 Apr 1987
Sigma-t
∂-d
Depth (m)
26.4
26.2
26.0
25.8
25.6
25.4
25.2
0.4
0.3
0.2
0.1
0.0
0
100
200
Sigma-t
∂-d

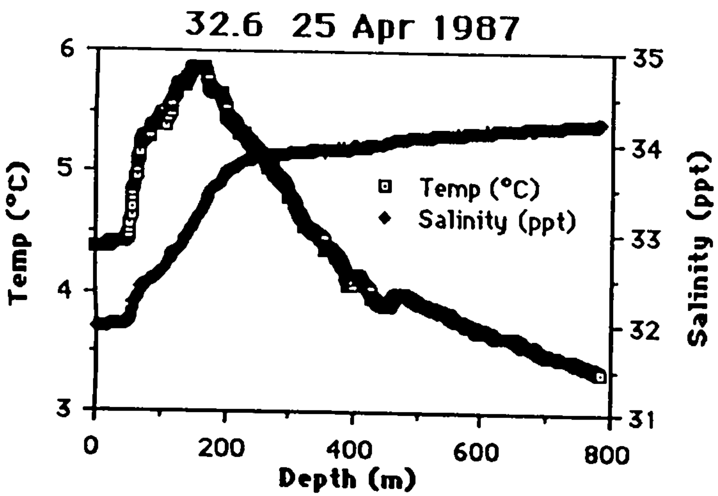

32.3 28 Apr 1987
Sigma-t
∂-d
Depth (m)
26.4
26.2
26.0
25.8
25.6
25.4
0.4
0.3
0.2
0.1
0.0
0
100
200
Sigma-t
∂-d

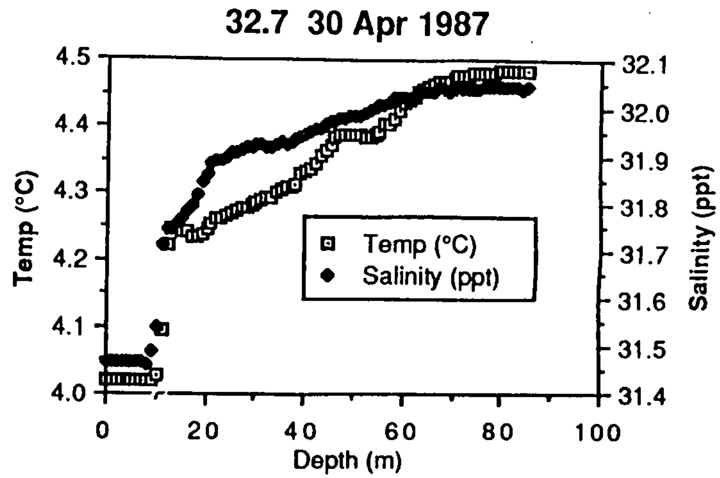

32.4 26 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
4.3
4.2
4.1
32.0
31.9
31.8
0
20
40
60
80
100
120

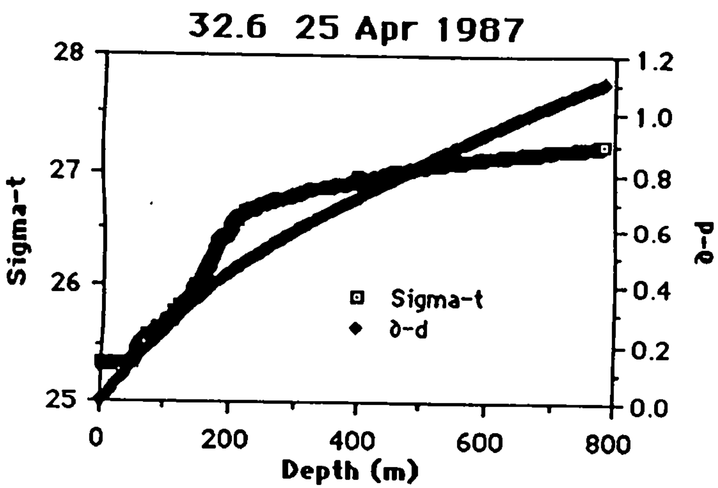

32.5 26 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
6
5
4
34
33
32
31
0
100
200
300
400

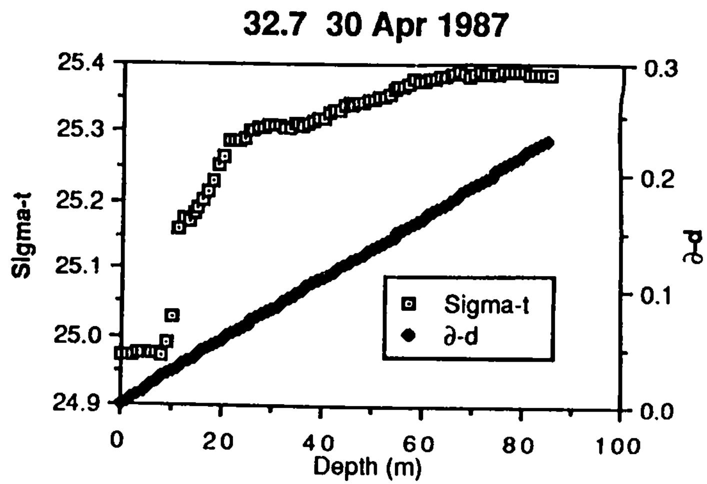

32.4 26 Apr 1987
Sigma-t
∂-d
Depth (m)
25.4
25.3
25.2
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120


32.5 26 Apr 1987
Sigma-t
∂-d
Depth (m)
27
26
25
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400

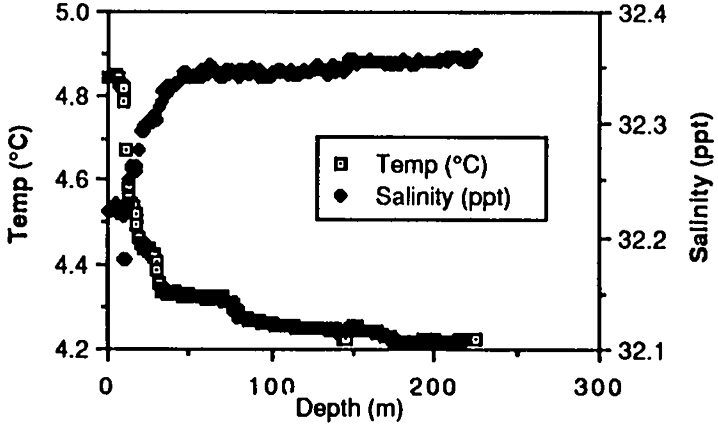

32.6 25 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
0
200
400
600
800
3
4
5
6
31
32
33
34
35


32.7 30 Apr 1987
Temp (°C)
Salinity (ppt)
Depth (m)
Temp (°C)
Salinity (ppt)
0
20
40
60
80
100
4.0
4.1
4.2
4.3
4.4
4.5
31.4
31.5
31.6
31.7
31.8
31.9
32.0
32.1

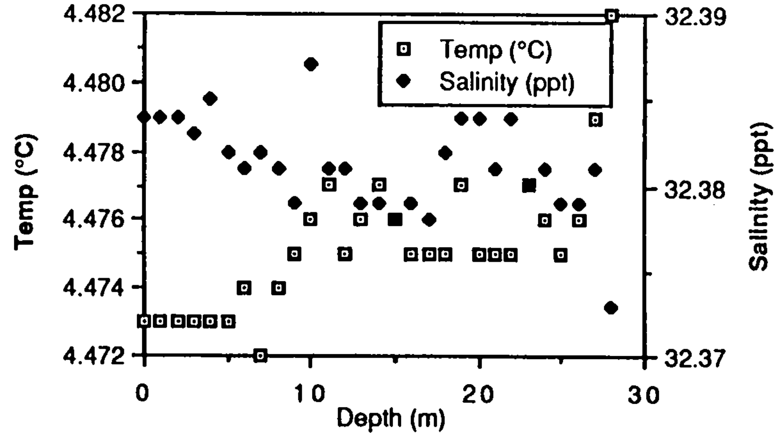

32.6 25 Apr 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
0
200
400
600
800
25
26
27
28
0.0
0.2
0.4
0.6
0.8
1.0
1.2


32.7 30 Apr 1987
Sigma-t
∂-d
Depth (m)
Sigma-t
∂-d
0
20
40
60
80
100
24.9
25.0
25.1
25.2
25.3
25.4
0.0
0.1
0.2
0.3

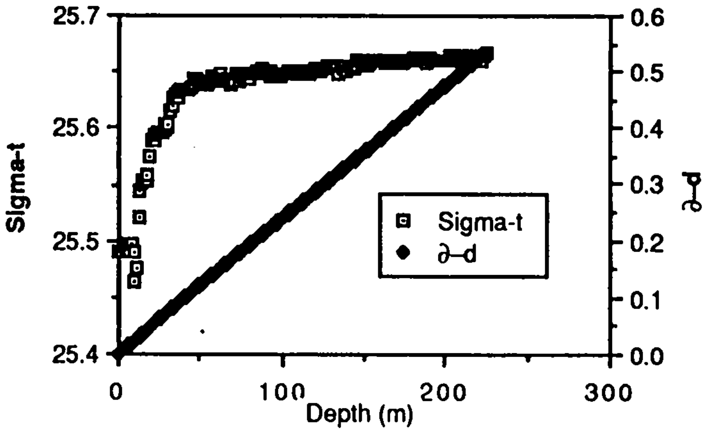
43.1 3 May 1987



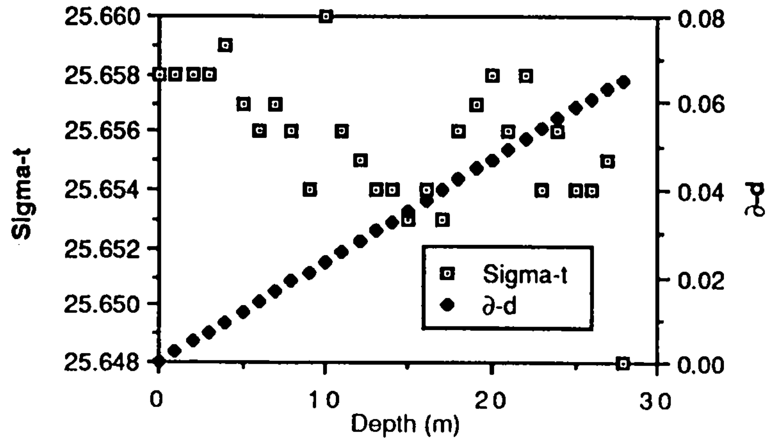
46.1 2 May 1987



43.1 3 May 1987



46.1 2 May 1987



APPENDIX C-1

Distribution of water quality measurements (CTD) and biological samples (bongo, Marinovich, trynet, Tucker, Shipeck, and dredge) taken in fall, 1986, in the Unimak Pass area, Alaska. Listings are in order by station numbers, station locations are given by degrees and minutes of North latitude and West longitude, and depths are in meters.

Table C-1. Listing of samples taken during the fall cruise.

GEAR	CAST	STATION	LATITUDE		LONGITUDE		DATE	DEPTH
CTD	1	2.1	53	56.3	165	46.7	19 Sep 86	73
HORIZONTAL BONGO	505	2.1	53	55.1	165	46.5	18 Sep 86	71
HORIZONTAL BONGO	333	2.1	53	55.1	165	46.5	18 Sep 86	71
OBLIQUE BONGO	505	2.1	53	56.0	165	46.7	18 Sep 86	71
OBLIQUE BONGO	333	2.1	53	56.0	165	46.7	18 Sep 86	71
CTD	2	2.2	54	9.7	166	21.4	19 Sep 86	219
HORIZONTAL BONGO	505	2.2	54	9.6	166	21.6	19 Sep 86	241
HORIZONTAL BONGO	333	2.2	54	9.6	166	21.6	19 Sep 86	241
OBLIQUE BONGO	505	2.2	54	9.6	166	21.6	19 Sep 86	241
OBLIQUE BONGO	333	2.2	54	9.6	166	21.6	19 Sep 86	241
CTD	3	2.3	54	9.5	166	22.5	19 Sep 86	415
CTD	4	2.4	54	10.2	166	22.7	19 Sep 86	622
CTD	5	2.5	54	11.0	166	23.9	19 Sep 86	830
HORIZONTAL BONGO	505	2.5	54	11.9	166	26.5	19 Sep 86	795
HORIZONTAL BONGO	333	2.5	54	11.9	166	26.5	19 Sep 86	795
OBLIQUE BONGO	505	2.5	54	11.4	166	23.4	19 Sep 86	840
OBLIQUE BONGO	333	2.5	54	11.4	166	23.4	19 Sep 86	840
HORIZONTAL BONGO	505	3.1	54	26.1	166	29.4	19 Sep 86	570
HORIZONTAL BONGO	333	3.1	54	26.1	166	29.4	19 Sep 86	570
MARINOVICH	1	3.1	54	24.6	166	33.2	19 Sep 86	595
CTD	6	3.2	55	0.3	164	31.2	20 Sep 86	57
HORIZONTAL BONGO	505	3.2	55	1.0	164	31.1	19 Sep 86	57
HORIZONTAL BONGO	333	3.2	55	1.0	164	31.1	19 Sep 86	57
OBLIQUE BONGO	505	3.2	55	0.7	164	30.6	19 Sep 86	57
OBLIQUE BONGO	333	3.2	55	0.7	164	30.6	19 Sep 86	57
CTD	7	3.3	54	50.0	165	6.4	20 Sep 86	101
CTD	8	3.4	54	45.1	165	24.0	20 Sep 86	201
HORIZONTAL BONGO	505	3.4	54	44.4	165	24.6	20 Sep 86	206
HORIZONTAL BONGO	333	3.4	54	44.4	165	24.6	20 Sep 86	206
OBLIQUE BONGO	505	3.4	54	44.8	165	24.1	19 Sep 86	206
OBLIQUE BONGO	333	3.4	54	44.8	165	24.1	19 Sep 86	206
CTD	9	3.5	54	37.0	165	48.0	20 Sep 86	388
CTD	10	4.1	54	51.9	166	30.3	20 Sep 86	176
HORIZONTAL BONGO	505	4.1	54	51.9	166	32.2	20 Sep 86	176
HORIZONTAL BONGO	333	4.1	54	51.9	166	32.2	20 Sep 86	176
MARINOVICH	2	4.1	54	51.2	166	29.4	20 Sep 86	179
OBLIQUE BONGO	555	4.1	54	51.8	166	31.0	20 Sep 86	176
OBLIQUE BONGO	333	4.1	54	51.8	166	31.0	20 Sep 86	176
Tucker		4.1	54	52.1	166	31.7	20 Sep 86	176
CTD	12	4.2	54	10.0	164	23.2	21 Sep 86	92
CTD	11	4.3	54	13.8	164	37.5	21 Sep 86	97
CTD	13	4.4	54	25.2	165	10.3	21 Sep 86	166
CTD	14	4.5	54	31.9	165	29.3	21 Sep 86	99
CTD	15	4.6	54	37.3	165	38.3	21 Sep 86	346
CTD	30	5.1	54	6.3	165	29.8	24 Sep 86	96
MARINOVICH	6	5.1	54	6.8	165	27.3	24 Sep 86	97
Tucker		5.1	54	6.7	165	29.8	24 Sep 86	96
CTD	19	6.1	54	9.0	165	20.1	22 Sep 86	66
CTD	20	6.2	54	18.4	165	26.5	22 Sep 86	161
CTD	21	6.3	54	25.5	165	31.2	22 Sep 86	97

Tucker		6.3	54	25.5	165	31.9	22 Sep 86	97
CTD	29	8.1	54	2.6	165	26.1	24 Sep 86	73
Tucker		8.1	54	2.8	165	25.7	24 Sep 86	73
CTD	16	9.1	54	10.4	164	53.2	22 Sep 86	69
HORIZONTAL BONGO	505	9.1	54	10.4	164	52.9	21 Sep 86	60
HORIZONTAL BONGO	333	9.1	54	10.4	164	52.9	21 Sep 86	60
OBLIQUE BONGO	505	9.1	54	10.5	164	53.2	21 Sep 86	60
OBLIQUE BONGO	333	9.1	54	10.5	164	53.2	21 Sep 86	60
CTD	17	9.2	54	7.3	165	13.9	22 Sep 86	53
HORIZONTAL BONGO	505	9.2	54	7.5	165	13.7	21 Sep 86	45
HORIZONTAL BONGO	333	9.2	54	7.5	165	13.7	21 Sep 86	45
OBLIQUE BONGO	555	9.2	54	7.4	165	13.9	21 Sep 86	53
OBLIQUE BONGO	333	9.2	54	7.4	165	13.9	21 Sep 86	53
CTD	18	9.3	54	5.1	165	30.0	22 Sep 86	63
HORIZONTAL BONGO	505	9.3	54	6.1	165	29.6	22 Sep 86	90
HORIZONTAL BONGO	333	9.3	54	6.1	165	29.6	22 Sep 86	90
OBLIQUE BONGO	505	9.3	54	5.3	165	30.9	22 Sep 86	75
OBLIQUE BONGO	333	9.3	54	5.3	165	30.9	22 Sep 86	75
CTD	60	9.4	54	5.2	165	30.1	30 Sep 86	75
HORIZONTAL BONGO	505	9.4	54	5.4	165	30.3	30 Sep 86	69
HORIZONTAL BONGO	333	9.4	54	5.4	165	30.3	30 Sep 86	69
OBLIQUE BONGO	505	9.4	54	5.4	165	29.8	30 Sep 86	79
OBLIQUE BONGO	333	9.4	54	5.4	165	29.8	30 Sep 86	79
Tucker		9.4	54	5.3	165	30.0	30 Sep 86	68
MARINOVICH	17	9.5	54	6.7	165	18.6	30 Sep 86	48
CTD	61	9.6	54	8.0	165	3.8	01 Oct 86	35
Tucker		9.6	54	8.2	165	3.7	30 Sep 86	42
CTD	62	9.7	54	12.1	164	55.3	01 Oct 86	55
HORIZONTAL BONGO	505	9.7	54	13.2	164	55.3	30 Sep 86	55
HORIZONTAL BONGO	333	9.7	54	13.2	164	55.3	30 Sep 86	55
OBLIQUE BONGO	505	9.7	54	12.3	164	55.2	30 Sep 86	55
OBLIQUE BONGO	333	9.7	54	12.3	164	55.2	30 Sep 86	55
Tucker		9.7	54	13.7	164	55.4	30 Sep 86	60
CTD	63	9.8	54	13.5	164	50.8	01 Oct 86	49
Tucker		9.8	54	13.5	164	50.7	01 Oct 86	51
HORIZONTAL BONGO	505	10.1	54	26.0	165	32.6	22 Sep 86	100
HORIZONTAL BONGO	333	10.1	54	26.0	165	32.6	22 Sep 86	100
HORIZONTAL BONGO	505	10.1	54	25.3	165	32.5	22 Sep 86	100
HORIZONTAL BONGO	333	10.1	54	25.3	165	32.5	22 Sep 86	100
OBLIQUE BONGO	505	10.1	54	25.5	165	32.9	22 Sep 86	100
OBLIQUE BONGO	333	10.1	54	25.5	165	32.9	22 Sep 86	100
Tucker		10.1	54	24.5	165	32.0	22 Sep 86	100
Tucker		10.1	54	24.5	165	32.0	22 Sep 86	100
MARINOVICH	3	10.2	54	31.1	165	22.9	22 Sep 86	146
HORIZONTAL BONGO	505	10.3	54	3.8	166	22.8	27 Sep 86	84
HORIZONTAL BONGO	333	10.3	54	3.8	166	22.8	27 Sep 86	84
MARINOVICH	4	10.3	54	29.1	165	25.1	22 Sept 86	161
MARINOVICH	12	10.3	54	4.2	166	22.2	27 Sep 86	81
OBLIQUE BONGO	505	10.3	54	3.9	166	22.2	27 Sep 86	84
OBLIQUE BONGO	333	10.3	54	3.9	166	22.2	27 Sep 86	84
CTD	25	13.1	53	46.7	165	53.8	24 Sep 86	128
Tucker		13.1					23 Sep 86	106
CTD	27	13.2	53	54.3	166	8.7	24 Sep 86	75
HORIZONTAL BONGO	505	13.2	53	54.2	166	7.9	23 Sep 86	157

HORIZONTAL BONGO	333	13.2	53	54.2	166	7.9	23 Sep 86	157
OBLIQUE BONGO	505	13.2	53	54.3	166	8.5	23 Sep 86	82
OBLIQUE BONGO	333	13.2	53	54.3	166	8.5	23 Sep 86	82
Tucker		13.2	53	55.0	166	6.7	24 Sep 86	124
CTD	22	14.1	53	48.0	165	29.2	23 Sep 86	
HORIZONTAL BONGO	505	14.1	53	48.1	165	28.9	22 Sep 86	90
HORIZONTAL BONGO	333	14.1	53	48.1	165	28.9	22 Sep 86	90
OBLIQUE BONGO	505	14.1	53	47.9	165	29.3	22 Sep 86	93
OBLIQUE BONGO	333	14.1	53	47.9	165	29.3	22 Sep 86	93
CTD	23	14.2	53	42.9	165	17.0	23 Sep 86	187
HORIZONTAL BONGO	505	14.2	53	42.6	165	16.3	23 Sep 86	195
HORIZONTAL BONGO	333	14.2	53	42.6	165	16.3	23 Sep 86	195
OBLIQUE BONGO	505	14.2	53	42.6	165	16.9	23 Sep 86	191
OBLIQUE BONGO	333	14.2	53	42.6	165	16.9	23 Sep 86	191
CTD	28	14.3	53	49.5	165	32.0	24 Sep 86	104
HORIZONTAL BONGO	505	14.3	53	49.3	165	31.4	24 Sep 86	101
HORIZONTAL BONGO	333	14.3	53	49.3	165	31.4	24 Sep 86	101
OBLIQUE BONGO	505	14.3	53	49.6	165	31.9	24 Sep 86	106
OBLIQUE BONGO	333	14.3	53	49.6	165	31.9	24 Sep 86	106
Tucker		14.3	53	49.0	165	31.1	24 Sep 86	96
CTD	26	14.4	53	58.3	166	2.9	24 Sep 86	60
HORIZONTAL BONGO	505	14.4	53	58.3	166	1.2	23 Sep 86	64
HORIZONTAL BONGO	333	14.4	53	58.3	166	1.2	23 Sep 86	64
OBLIQUE BONGO	505	14.4	53	58.4	166	1.9	23 Sep 86	64
OBLIQUE BONGO	333	14.4	53	58.4	166	1.9	23 Sep 86	64
Tucker		14.4	53	58.4	166	2.9	23 Sep 86	59
MARINOVICH	7	14.6	54	1.5	166	6.8	24 Sep 86	51
Tucker		14.6	54	0.9	166	1.4	24 Sep 86	74
CTD	24	15.1	53	44.7	164	0.4	23 Sep 86	344
HORIZONTAL BONGO	505	15.1	53	44.6	164	1.1	23 Sep 86	390
HORIZONTAL BONGO	333	15.1	53	44.6	164	1.1	23 Sep 86	390
HORIZONTAL BONGO	505	15.1	53	44.5	164	0.9	23 Sep 86	389
HORIZONTAL BONGO	333	15.1	53	44.5	164	0.9	23 Sep 86	389
MARINOVICH	5	15.1	53	43.0	164	2.0	23 Sep 86	0
Tucker		15.1	53	44.5	164	0.6	23 Sep 86	389
CTD	31	16.1	54	20.1	164	43.1	25 Sep 86	62
Tucker		16.1	54	20.2	164	43.1	24 Sep 86	66
CTD	32	16.2	54	22.8	164	43.8	25 Sep 86	47
HORIZONTAL BONGO	505	16.2	54	22.5	164	41.9	24 Sep 86	51
HORIZONTAL BONGO	333	16.2	54	22.5	164	41.9	24 Sep 86	51
HORIZONTAL BONGO	505	16.2	54	22.5	164	42.5	24 Sep 86	55
HORIZONTAL BONGO	505	16.2	54	22.5	164	42.5	24 Sep 86	55
OBLIQUE BONGO	505	16.2	54	22.6	164	42.7	24 Sep 86	51
OBLIQUE BONGO	333	16.2	54	22.6	164	42.7	24 Sep 86	51
CTD	38	16.3	54	17.3	166	28.5	26 Sep 86	1560
HORIZONTAL BONGO	505	16.3	54	13.9	166	21.3	26 Sep 86	860
HORIZONTAL BONGO	333	16.3	54	13.9	166	21.3	26 Sep 86	860
MARINOVICH	9	16.3	54	16.3	166	26.1	26 Sep 86	915
OBLIQUE BONGO	505	16.3	54	14.6	166	22.1	26 Sep 86	860
OBLIQUE BONGO	333	16.3	54	14.6	166	22.1	26 Sep 86	860
Tucker		16.3	54	13.4	166	21.4	26 Sep 86	823
CTD	39	16.4	54	19.9	166	8.6	26 Sep 86	841
Tucker		16.4	54	20.2	166	8.0	26 Sep 86	841
CTD	40	16.5	54	34.0	166	29.8	26 Sep 86	439

Tucker		16.5	54	34.2	166	29.7	26 Sep 86	439
CTD	36	17.1	54	58.1	164	26.0	25 Sep 86	40
HORIZONTAL BONGO	505	17.1	54	59.2	164	24.6	25 Sep 86	40
HORIZONTAL BONGO	333	17.1	54	59.2	164	24.6	25 Sep 86	40
HORIZONTAL BONGO	505	17.1	54	59.6	164	24.6	25 Sep 86	40
HORIZONTAL BONGO	333	17.1	54	59.6	164	24.6	25 Sep 86	40
MARINOVICH	8	17.1	54	59.0	164	19.2	25 Sep 86	38
OBLIQUE BONGO	505	17.1	54	58.9	164	25.1	25 Sep 86	40
OBLIQUE BONGO	333	17.1	54	58.9	164	25.1	25 Sep 86	40
CTD	35	17.2	54	49.0	164	42.0	25 Sep 86	57
HORIZONTAL BONGO	505	17.2	54	49.2	164	41.8	25 Sep 86	57
HORIZONTAL BONGO	333	17.2	54	49.2	164	41.8	25 Sep 86	57
CTD	34	17.3	54	38.0	164	59.0	25 Sep 86	61
HORIZONTAL BONGO	505	17.3	54	37.5	164	59.2	25 Sep 86	60
HORIZONTAL BONGO	333	17.3	54	37.5	164	59.2	25 Sep 86	60
HORIZONTAL BONGO	505	17.3	54	37.2	164	59.5	25 Sep 86	60
HORIZONTAL BONGO	333	17.3	54	37.2	164	59.5	25 Sep 86	60
OBLIQUE BONGO	505	17.3	54	37.6	164	59.4	25 Sep 86	63
OBLIQUE BONGO	333	17.3	54	37.6	164	59.4	25 Sep 86	63
CTD	33	17.4	54	33.5	165	11.6	25 Sep 86	86
HORIZONTAL BONGO	505	17.4	54	34.2	165	11.6	25 Sep 86	86
HORIZONTAL BONGO	333	17.4	54	34.2	165	11.6	25 Sep 86	86
CTD	44	17.5	54	18.6	165	39.5	27 Sep 86	66
Tucker		17.5	54	18.9	165	39.0	27 Sep 86	70
CTD	41	17.6	54	14.1	165	59.7	27 Sep 86	57
Tucker		17.6	54	14.1	165	59.6	26 Sep 86	57
CTD	37	17.8	54	6.5	166	29.6	26 Sep 86	413
HORIZONTAL BONGO	505	17.8	54	6.5	166	29.0	25 Sep 86	457
HORIZONTAL BONGO	333	17.8	54	6.5	166	29.0	25 Sep 86	457
OBLIQUE BONGO	505	17.8	54	6.9	166	29.1	25 Sep 86	444
OBLIQUE BONGO	333	17.8	54	6.9	166	29.1	25 Sep 86	444
Tucker		17.8	54	7.0	166	29.0	25 Sep 86	421
HORIZONTAL BONGO	505	17.9	54	7.3	166	34.7	25 Sep 86	717
HORIZONTAL BONGO	333	17.9	54	7.3	166	34.7	25 Sep 86	717
Tucker		17.9					25 Sep 86	
MARINOVICH	10	18.1	54	51.1	166	31.3	26 Sep 86	183
CTD	42	19.1	54	28.7	165	37.6	27 Sep 86	168
HORIZONTAL BONGO	505	19.1	54	27.5	165	37.8	26 Sep 86	161
HORIZONTAL BONGO	333	19.1	54	27.5	165	37.8	26 Sep 86	161
MARINOVICH	11	19.1	54	29.0	165	36.3	26 Sep 86	139
OBLIQUE BONGO	505	19.1	54	27.9	165	37.5	26 Sep 86	163
OBLIQUE BONGO	333	19.1	54	27.9	165	37.5	26 Sep 86	163
Tucker		19.1	54	29.2	165	37.0	26 Sep 86	168
CTD	43	19.2	54	32.4	165	33.1	27 Sep 86	129
HORIZONTAL BONGO	505	19.2	54	31.2	165	32.1	27 Sep 86	196
HORIZONTAL BONGO	333	19.2	54	31.2	165	32.1	27 Sep 86	196
OBLIQUE BONGO	505	19.2	54	32.3	165	32.7	27 Sep 86	220
OBLIQUE BONGO	333	19.2	54	32.3	165	32.7	27 Sep 86	220
Tucker		19.2	54	30.9	165	32.1	27 Sep 86	190
CTD	45	21.1	54	17.7	166	27.7	28 Sep 86	1220
CTD	46	21.2	54	8.7	166	16.4	28 Sep 86	102
CTD	47	21.3	54	1.4	166	3.3	28 Sep 86	39
CTD	48	21.4	53	51.9	165	48.3	28 Sep 86	86
CTD	49	21.5	53	40.0	165	31.1	28 Sep 86	141

CTD	56	22.1	53	54.2	165	56.2	30 Sep 86	108
HORIZONTAL BONGO	505	22.1	53	54.2	165	55.6	29 Sep 86	84
HORIZONTAL BONGO	333	22.1	53	54.2	165	55.6	29 Sep 86	84
OBLIQUE BONGO	505	22.1	53	54.6	165	55.4	29 Sep 86	79
OBLIQUE BONGO	333	22.1	53	54.6	165	55.4	29 Sep 86	79
Tucker		22.1	53	54.7	165	55.8	29 Sep 86	108
CTD	66	22.11	54	5.7	165	33.4	02 Oct 86	66
Tucker		22.11	54	5.5	165	33.4	01 Oct 86	68
CTD	57	22.2	53	54.3	165	47.2	30 Sep 86	78
Tucker		22.2	53	54.3	165	46.9	30 Sep 86	78
CTD	58	22.3	53	57.2	165	35.7	30 Sep 86	94
HORIZONTAL BONGO	505	22.3	53	57.3	165	36.9	30 Sep 86	96
HORIZONTAL BONGO	333	22.3	53	57.3	165	36.9	30 Sep 86	96
OBLIQUE BONGO	505	22.3	53	58.0	165	36.1	30 Sep 86	99
OBLIQUE BONGO	333	22.3	53	58.0	165	36.1	30 Sep 86	99
Tucker		22.3	53	58.2	165	35.6	30 Sep 86	98
CTD	64	22.4	54	12.1	164	48.1	01 Oct 86	40
HORIZONTAL BONGO	505	22.4	54	12.1	164	47.9	01 Oct 86	40
HORIZONTAL BONGO	333	22.4	54	12.1	164	47.9	01 Oct 86	40
MARINOVICH	18	22.4	54	13.9	164	48.3	01 Oct 86	57
OBLIQUE BONGO	505	22.4	54	12.1	164	47.8	01 Oct 86	40
OBLIQUE BONGO	333	22.4	54	12.1	164	47.8	01 Oct 86	40
Tucker		22.4	54	12.4	164	48.0	01 Oct 86	43
CTD	65	22.5	54	3.3	165	2.7	01 Oct 86	61
HORIZONTAL BONGO	505	22.5	54	3.1	165	3.2	01 Oct 86	64
HORIZONTAL BONGO	333	22.5	54	3.1	165	3.2	01 Oct 86	64
MARINOVICH	20	22.5	54	3.1	165	2.5	01 Oct 86	66
OBLIQUE BONGO	505	22.5	54	3.1	165	2.9	01 Oct 86	61
OBLIQUE BONGO	333	22.5	54	3.1	165	2.9	01 Oct 86	61
Tucker		22.5	54	3.0	165	3.4	01 Oct 86	64
MARINOVICH	19	22.6	54	11.2	164	52.4	01 Oct 86	73
MARINOVICH	21	22.7	54	1.8	165	10.5	01 Oct 86	75
CTD	67	22.8	53	60.0	165	17.6	02 Oct 86	90
HORIZONTAL BONGO	505	22.8	53	59.1	165	19.3	01 Oct 86	90
HORIZONTAL BONGO	333	22.8	53	59.1	165	19.3	01 Oct 86	90
MARINOVICH	22	22.8	54	2.9	165	16.9	01 Oct 86	79
OBLIQUE BONGO	505	22.8	53	59.3	165	18.6	01 Oct 86	90
OBLIQUE BONGO	333	22.8	53	59.3	165	18.6	01 Oct 86	90
Tucker		22.8	53	59.5	165	17.6	01 Oct 86	90
CTD	68	22.9	53	59.9	165	40.3	02 Oct 86	89
HORIZONTAL BONGO	505	22.9	54	0.4	165	40.9	01 Oct 86	89
HORIZONTAL BONGO	333	22.9	54	0.4	165	40.9	01 Oct 86	89
MARINOVICH	23	22.9	54	5.2	165	40.0	01 Oct 86	81
OBLIQUE BONGO	505	22.9	54	0.0	165	40.4	01 Oct 86	86
OBLIQUE BONGO	333	22.9	54	0.0	165	40.4	01 Oct 86	86
Tucker		22.9	54	1.1	165	40.2	02 Oct 86	88
CTD	50	23.1	54	25.0	164	18.5	29 Sep 86	86
Tucker		23.1	54	24.8	164	18.5	28 Sep 86	90
CTD	51	23.2	54	14.3	163	60.0	29 Sep 86	75
HORIZONTAL BONGO	505	23.2	54	13.3	164	2.5	28 Sep 86	75
HORIZONTAL BONGO	333	23.2	54	13.3	164	2.5	28 Sep 86	75
OBLIQUE BONGO	505	23.2	54	13.5	164	1.7	28 Sep 86	75
OBLIQUE BONGO	333	23.2	54	13.5	164	1.7	28 Sep 86	75
Tucker		23.2	54	13.8	164	0.5	28 Sep 86	75

CTD	52	23.3	54	3.5	164	0.1	29 Sep 86	78
Tucker		23.3	54	3.3	164	0.5	28 Sep 86	78
CTD	53	23.4	53	47.0	163	60.0	29 Sep 86	119
HORIZONTAL BONGO	505	23.4	53	47.4	164	0.9	29 Sep 86	109
HORIZONTAL BONGO	333	23.4	53	47.4	164	0.9	29 Sep 86	109
OBLIQUE BONGO	505	23.4	53	47.1	164	0.0	29 Sep 86	112
OBLIQUE BONGO	333	23.4	53	47.1	164	0.0	29 Sep 86	112
Tucker		23.4	53	47.0	164	0.1	29 Sep 86	117
CTD	55	23.5	53	35.7	164	2.0	29 Sep 86	
MARINOVICH	14	23.5	53	35.4	164	5.3	29 Sep 86	2013
Tucker		23.5					29 Sep 86	
CTD	54	23.6	53	30.7	164	2.1	29 Sep 86	
HORIZONTAL BONGO	505	23.6	53	30.8	164	0.7	29 Sep 86	XXX
HORIZONTAL BONGO	333	23.6	53	30.8	164	0.7	29 Sep 86	XXX
MARINOVICH	13	23.6	53	30.5	164	2.0	29 Sep 86	>915
OBLIQUE BONGO	505	23.6	53	30.2	164	0.6	29 Sep 86	XXX
OBLIQUE BONGO	333	23.6	53	30.2	164	0.6	29 Sep 86	XXX
Tucker		23.6	53	30.4	164	1.5	29 Sep 86	
CTD	59	25.1	54	6.1	165	38.2	30 Sep 86	59
Tucker		25.1	54	6.0	165	37.6	30 Sep 86	63
MARINOVICH	15	26.1	53	58.3	165	55.3	29 Sep 86	119
CTD	86	26.2	53	54.1	166	6.4	07 Oct 86	305
CTD	87	26.2	53	54.2	166	6.9	06 Oct 86	310
CTD	88	26.2	53	54.1	166	6.2	07 Oct 86	312
CTD	89	26.2	53	54.1	166	7.7	07 Oct 86	320
CTD	90	26.2	53	54.1	166	7.5	07 Oct 86	329
CTD	91	26.2	53	54.4	166	7.8	07 Oct 86	
CTD	92	26.2	53	53.6	166	6.4	07 Oct 86	241
OBLIQUE BONGO	505	26.2	53	54.2	166	6.9	06 Oct 86	336
OBLIQUE BONGO	333	26.2	53	54.2	166	6.9	06 Oct 86	336
OBLIQUE BONGO	505	26.2	53	54.2	166	6.6	06 Oct 86	318
OBLIQUE BONGO	333	26.2	53	54.2	166	6.6	06 Oct 86	318
OBLIQUE BONGO	505	26.2	53	54.0	166	6.6	06 Oct 86	316
OBLIQUE BONGO	333	26.2	53	54.0	166	6.6	06 Oct 86	316
OBLIQUE BONGO	505	26.2	53	54.8	166	8.3	06 Oct 86	103
OBLIQUE BONGO	333	26.2	53	54.8	166	8.3	06 Oct 86	103
OBLIQUE BONGO	505	26.2	53	54.1	166	7.2	06 Oct 86	324
OBLIQUE BONGO	333	26.2	53	54.1	166	7.2	06 Oct 86	324
OBLIQUE BONGO	505	26.2	53	54.3	166	6.6	06 Oct 86	305
OBLIQUE BONGO	333	26.2	53	54.3	166	6.6	06 Oct 86	305
OBLIQUE BONGO	505	26.2	53	54.2	166	5.9	06 Oct 86	310
OBLIQUE BONGO	333	26.2	53	54.2	166	5.9	06 Oct 86	310
OBLIQUE BONGO	505	26.2	53	54.0	166	5.9	07 Oct 86	260
OBLIQUE BONGO	333	26.2	53	54.0	166	5.9	07 Oct 86	260
OBLIQUE BONGO	505	26.2	53	53.5	166	7.7	07 Oct 86	320
OBLIQUE BONGO	333	26.2	53	53.5	166	7.7	07 Oct 86	320
OBLIQUE BONGO	505	26.2	53	53.9	166	7.2	07 Oct 86	329
OBLIQUE BONGO	333	26.2	53	53.9	166	7.2	07 Oct 86	329
OBLIQUE BONGO	505	26.2	53	54.5	166	7.7	07 Oct 86	139
OBLIQUE BONGO	333	26.2	53	54.5	166	7.7	07 Oct 86	139
OBLIQUE BONGO	505	26.2	53	53.7	166	6.2	07 Oct 86	230
OBLIQUE BONGO	333	26.2	53	53.7	166	6.2	07 Oct 86	230
MARINOVICH	16	27.1	53	54.3	166	8.8	30 Sep 86	183
CTD	70	29.1	53	30.0	166	26.1	02 Oct 86	101

HORIZONTAL BONGO	505	29.1	53	30.8	166	25.6	02 Oct 86	100
HORIZONTAL BONGO	333	29.1	53	30.8	166	25.6	02 Oct 86	100
MARINOVICH	24	29.1	53	28.7	166	25.8	02 Oct 86	115
OBLIQUE BONGO	505	29.1	53	30.4	166	25.9	02 Oct 86	100
OBLIQUE BONGO	333	29.1	53	30.4	166	25.9	02 Oct 86	100
Tucker		29.1	53	30.0	166	26.2	02 Oct 86	102
CTD	69	29.2	53	36.8	165	55.8	02 Oct 86	98
Tucker		29.2	53	37.3	165	55.8	02 Oct 86	97
CTD	71	30.1	54	29.2	164	0.5	02 Oct 86	86
HORIZONTAL BONGO	505	30.1	54	29.8	164	2.3	02 Oct 86	113
HORIZONTAL BONGO	333	30.1	54	29.8	164	2.3	02 Oct 86	113
MARINOVICH	25	30.1	54	29.3	163	59.5	02 Oct 86	82
OBLIQUE BONGO	505	30.1	54	29.3	164	1.7	02 Oct 86	106
OBLIQUE BONGO	333	30.1	54	29.3	164	1.7	02 Oct 86	106
Tucker		30.1	54	30.8	164	3.0	02 Oct 86	100
CTD	72	31.1	54	21.8	164	39.5	03 Oct 86	66
Tucker		31.1	54	21.8	164	39.6	03 Oct 86	66
CTD	73	31.2	54	22.5	164	49.5	03 Oct 86	48
OBLIQUE BONGO	505	31.2	54	22.5	164	50.1	03 Oct 86	59
OBLIQUE BONGO	333	31.2	54	22.5	164	50.1	03 Oct 86	59
Tucker		31.2	54	23.0	164	52.3	03 Oct 86	63
CTD	74	31.3	54	4.8	164	33.2	03 Oct 86	95
HORIZONTAL BONGO	505	31.3	54	22.5	164	51.1	03 Oct 86	57
HORIZONTAL BONGO	333	31.3	54	22.5	164	51.1	03 Oct 86	57
Tucker		31.3	54	4.9	164	33.7	03 Oct 86	95
CTD	75	31.4	53	57.9	164	29.7	03 Oct 86	109
HORIZONTAL BONGO	505	31.4	53	58.9	164	27.4	03 Oct 86	109
HORIZONTAL BONGO	333	31.4	53	58.9	164	27.4	03 Oct 86	109
OBLIQUE BONGO	505	31.4	53	58.5	164	27.3	03 Oct 86	109
OBLIQUE BONGO	333	31.4	53	58.5	164	27.3	03 Oct 86	109
Tucker		31.4	53	58.0	164	27.2	03 Oct 86	109
CTD	77	31.5	54	46.6	165	15.0	04 Oct 86	146
Tucker		31.5	54	46.6	165	15.1	03 Oct 86	146
CTD	76	31.6	54	59.9	165	29.6	04 Oct 86	126
HORIZONTAL BONGO	505	31.6	54	58.2	165	27.4	03 Oct 86	125
HORIZONTAL BONGO	333	31.6	54	58.2	165	27.4	03 Oct 86	125
HORIZONTAL BONGO	505	31.6	55	0.4	165	30.4	03 Oct 86	126
HORIZONTAL BONGO	333	31.6	55	0.4	165	30.4	03 Oct 86	126
MARINOVICH	26	31.6	54	59.6	165	28.3	03 Oct 86	124
OBLIQUE BONGO	505	31.6	55	0.0	165	30.1	03 Oct 86	126
OBLIQUE BONGO	333	31.6	55	0.0	165	30.1	03 Oct 86	126
Tucker		31.6	55	0.8	165	30.8	03 Oct 86	126
CTD	85	31.7	54	9.0	164	29.4	05 Oct 86	86
HORIZONTAL BONGO	505	31.7	54	8.8	164	28.2	05 Oct 86	86
HORIZONTAL BONGO	333	31.7	54	8.8	164	28.2	05 Oct 86	86
OBLIQUE BONGO	505	31.7	54	9.0	164	28.7	05 Oct 86	86
OBLIQUE BONGO	333	31.7	54	9.0	164	28.7	05 Oct 86	86
Tucker		31.7	54	9.1	164	29.0	05 Oct 86	86
MARINOVICH	29	31.8	54	35.3	163	57.7	05 Oct 86	59
CTD	80	32.1	54	60.0	165	59.9	04 Oct 86	138
HORIZONTAL BONGO	505	32.1	55	1.4	165	59.0	04 Oct 86	138
HORIZONTAL BONGO	333	32.1	55	1.4	165	59.0	04 Oct 86	138
MARINOVICH	27	32.1	54	58.6	165	59.8	04 Oct 86	143
OBLIQUE BONGO	505	32.1	55	0.9	165	59.4	04 Oct 86	138

OBLIQUE BONGO	333	32.1	55	0.9	165	59.4	04 Oct 86	138
Tucker		32.1	55	0.3	165	59.9	04 Oct 86	138
CTD	79	32.2	54	47.0	165	54.8	04 Oct 86	200
Tucker		32.2	54	46.9	165	43.6	04 Oct 86	196
CTD	78	32.3	54	36.2	165	30.9	04 Oct 86	173
CTD	84	32.3	54	0.1	164	49.9	05 Oct 86	93
HORIZONTAL BONGO	505	32.3	54	36.6	153	31.0	04 Oct 86	194
HORIZONTAL BONGO	333	32.3	54	36.6	153	31.0	04 Oct 86	194
OBLIQUE BONGO	505	32.3	54	36.1	165	31.1	04 Oct 86	171
OBLIQUE BONGO	333	32.3	54	36.1	165	31.1	04 Oct 86	171
Tucker		32.3	54	37.2	165	30.9	04 Oct 86	204
Tucker	32.7	32.3	54	0.5	164	49.8	05 Oct 86	90
CTD	83	32.4	53	50.2	164	48.0	05 Oct 86	103
HORIZONTAL BONGO	505	32.4	53	49.7	164	48.3	05 Oct 86	108
HORIZONTAL BONGO	333	32.4	53	49.7	164	48.3	05 Oct 86	108
OBLIQUE BONGO	505	32.4	53	50.2	164	48.2	05 Oct 86	103
OBLIQUE BONGO	333	32.4	53	50.2	164	48.2	05 Oct 86	103
Tucker		32.4	53	49.6	164	48.4	05 Oct 86	108
CTD	82	32.5	53	40.3	164	46.5	05 Oct 86	313
Tucker		32.5	53	40.3	164	47.2	05 Oct 86	322
CTD	81	32.6	53	29.6	164	49.5	05 Oct 86	2000
HORIZONTAL BONGO	505	32.6	53	29.4	164	49.6	04 Oct 86	2000
HORIZONTAL BONGO	333	32.6	53	29.4	164	49.6	04 Oct 86	2000
MARINOVICH	28	32.6	53	30.0	164	45.8	04 Oct 86	0
OBLIQUE BONGO	505	32.6	53	29.4	164	50.0	04 Oct 86	2000
OBLIQUE BONGO	333	32.6	53	29.4	164	50.0	04 Oct 86	2000
Tucker		32.6	53	29.3	164	49.6	04 Oct 86	2000
Shipeck	A01	A004	54	14.1	165	34.3	21 Sep 86	9
Shipeck	A02	A013	54	13.3	165	31.8	21 Sep 86	3
Shipeck	A03	A027	54	10.3	165	26.3	21 Sep 86	6
Shipeck	A04	A027	54	10.3	165	26.3	21 Sep 86	6
Shipeck	A05	A031	54	9.8	165	28.8	21 Sep 86	8
Shipeck	A06	A031	54	9.8	165	28.8	21 Sep 86	8
Shipeck	A07	A053	54	13.7	165	21.8	22 Sep 86	6
Shipeck	A08	A055	54	13.5	165	24.8	22 Sep 86	4
Shipeck	A09	A061	54	10.0	165	23.5	22 Sep 86	5
Shipeck	A10	A061	54	10.0	165	23.5	22 Sep 86	5
Shipeck	A11	A070	54	8.7	165	33.9	30 Sep 86	2
Shipeck	A12	A070	54	8.7	165	33.9	30 Sep 86	6
Shipeck	A13	A074	54	9.8	165	31.0	30 Sep 86	6
Shipeck	B04	B003	54	4.9	166	4.4	27 Sep 86	10
Shipeck	B05	B004	54	5.5	166	4.3	27 Sep 86	4
Shipeck	B06	B019	54	13.1	165	56.2	27 Sep 86	4
Shipeck	B07	B023	54	11.9	165	53.4	27 Sep 86	4
Shipeck	B08	B024	54	11.1	165	52.4	27 Sep 86	4
Shipeck	B09	B027	54	11.3	165	49.0	27 Sep 86	4
Shipeck	B01	B031	54	8.6	165	44.1	22 Sep 86	7
Shipeck	B02	B031	54	8.6	165	44.1	22 Sep 86	7
Shipeck	B03	B031	54	8.6	165	44.1	22 Sep 86	7
Shipeck	B10	B046	54	6.8	166	0.1	30 Sep 86	4
Shipeck	B11	B048	54	6.6	165	57.1	30 Sep 86	6
Shipeck	B12	B048	54	6.6	165	57.1	30 Sep 86	6
Shipeck	B13	B053	54	7.5	165	51.3	30 Sep 86	3
Shipeck	F01	F017	54	6.2	165	23.7	24 Sep 86	8

Shipeck	F02	F018	54	6.4	165	22.5	24 Sep 86	7
Shipeck	F03	F023	54	5.6	165	21.6	24 Sep 86	6
Shipeck	G06	G006	54	5.4	165	8.9	01 Oct 86	2
Shipeck	G05	G006	54	5.6	165	8.5	01 Oct 86	4
Shipeck	G04	G017	54	8.1	164	58.7	01 Oct 86	2
Shipeck	G03	G028	54	7.3	164	58.9	24 Sep 86	6
Shipeck	G02	G035	54	7.2	165	6.2	24 Sep 86	6
Shipeck	G01	G040	54	6.2	165	13.6	24 Sep 86	4

APPENDIX C-2

Distribution of water quality measurements (CTD) and biological samples (bongo, Marinovich, trynet, Tucker, Shipeck, and dredge) taken in winter, 1987, in the Unimak Pass area, Alaska. Listings are in order by station numbers, station locations are given by degrees and minutes of North latitude and West longitude, and depths are in meters.

Table C-2. Listing of samples taken during the winter cruise.

GEAR	CAST	STATION	LATITUDE	LONGITUDE	DATE	DEPTH
CTD	34	2.2	54 09.97	166 21.47	26 Feb 87	291
Hor Bongo		2.2	54 09.70	166 22.00	27 Feb 87	392
Obl Bongo		2.2	54 09.90	166 21.90	27 Feb 87	392
Surface Bongo		2.2	54 09.60	166 22.00	27 Feb 87	
CTD	23	3.1	54 25.53	166 31.26	24 Feb 87	574
CTD	72	3.1	54 25.47	166 31.65	6 Mar 87	569
Hor Bongo		3.1	54 26.70	166 31.90	24 Feb 87	549
MARINOVICH	10	3.1	54 25.83	166 31.22	24 Feb 87	580
Obl Bongo		3.1	54 25.90	166 32.20	24 Feb 87	561
Tucker		3.1	54 27.20	166 31.70	24 Feb 87	541
CTD	22	3.2	55 00.70	164 31.00	24 Feb 87	57
CTD	68	3.2	55 01.44	164 31.62	5 Mar 87	58
Hor Bongo		3.2			24 Feb 87	58
MARINOVICH	6	3.2	55 00.45	164 29.96	23 Feb 87	58
Obl Bongo		3.2			24 Feb 87	57
Tucker		3.2			24 Feb 87	57
CTD	21	3.3	54 49.98	165 06.31	24 Feb 87	103
CTD	69	3.3	54 50.01	165 06.31	5 Mar 87	104
Hor Bongo		3.3	54 49.40	165 07.20	24 Feb 87	112
MARINOVICH	9	3.3	54 50.35	165 07.86	24 Feb 87	115
Obl Bongo		3.3	54 49.50	165 06.60	24 Feb 87	104
Rock Dredge	2	3.3	54 50.23	165 06.18	24 Feb 87	104
Trynet	2	3.3	54 50.65	165 50.65	24 Feb 87	119
Tucker		3.3	54 49.30	165 08.20	24 Feb 87	115
CTD	25	3.4	54 44.83	165 24.19	25 Feb 87	206
CTD	70	3.4	54 44.91	165 24.55	5 Mar 87	210
Hor Bongo		3.4	54 46.70	165 23.90	25 Feb 87	190
Obl Bongo		3.4	54 45.90	165 24.10	25 Feb 87	189
CTD	24	3.5	54 37.20	165 48.31	24 Feb 87	393
CTD	71	3.5	54 37.13	165 48.32	6 Mar 87	393
Hor Bongo		3.5	54 37.40	165 50.90	6 Mar 87	393
Obl Bongo		3.5	54 37.30	165 50.00	6 Mar 87	393
Tucker		3.5	54 38.10	165 49.60	24 Feb 87	384
CTD	8	4.1	54 51.85	166 31.21	18 Feb 87	176
Hor Bongo		4.1	54 52.70	166 32.10	18 Feb 87	172
MARINOVICH	3	4.1	54 50.50	166 30.58	18 Feb 87	196
Obl Bongo		4.1	54 52.20	166 32.00	18 Feb 87	176
Tucker		4.1	54 53.30	166 32.10	18 Feb 87	170
CTD	13	4.2	54 09.68	164 23.33	19 Feb 87	93
CTD	12	4.3	54 13.43	164 37.29	19 Feb 87	86
CTD	11	4.4	54 25.41	165 10.17	19 Feb 87	161
CTD	10	4.5	54 31.89	165 29.30	19 Feb 87	99
CTD	9	4.6	54 37.25	165 38.29	18 Feb 87	342
CTD	59	5.1	54 06.62	165 28.43	3 Mar 87	104
Hor Bongo		5.1	54 06.50	165 29.00	3 Mar 87	97
MARINOVICH	24	5.1	54 06.04	165 29.56	3 Mar 87	110
Obl Bongo		5.1	54 06.60	165 28.90	3 Mar 87	99
Rock Dredge	3	5.1	54 06.17	165 30.19	3 Mar 87	101
Surface Bongo		5.1	54 06.40	165 29.30	3 Mar 87	102

CTD	32	6.1	54	09.35	165	19.60	26 Feb 87	66
Surface Bongo		6.1	54	09.90	165	18.60	26 Feb 87	75
CTD	64	6.2	54	18.39	165	27.28	4 Mar 87	143
Hor Bongo		6.2	54	18.40	165	26.50	4 Mar 87	155
Obl Bongo		6.2	54	18.20	165	26.10	4 Mar 87	126
Surface Bongo		6.2	54	18.30	165	26.40	4 Mar 87	170
CTD	65	6.3	54	25.30	165	31.69	4 Mar 87	95
Hor Bongo		6.3	54	25.70	165	31.20	4 Mar 87	95
Obl Bongo		6.3	54	25.50	165	31.30	4 Mar 87	95
Surface Bongo		6.3	54	26.20	165	31.10	4 Mar 87	95
CTD	31	9.2	54	07.80	165	14.08	26 Feb 87	60
Hor Bongo		9.2	54	08.10	165	13.90	26 Feb 87	58
Obl Bongo		9.2	54	08.00	165	14.10	26 Feb 87	62
Surface Bongo		9.2	54	08.20	165	12.80	26 Feb 87	57
CTD	30	9.3	54	05.71	165	29.60	26 Feb 87	88
Hor Bongo		9.3	54	05.90	165	29.50	26 Feb 87	106
Obl Bongo		9.3	54	06.00	165	29.30	26 Feb 87	106
Surface Bongo		9.3	54	06.20	165	28.10	26 Feb 87	
MARINOVICH	19	9.5	54	07.17	165	19.60	1 Mar 87	57
CTD	60	9.7	54	12.53	164	55.17	3 Mar 87	53
Hor Bongo		9.7	54	13.40	164	55.40	4 Mar 87	59
Obl Bongo		9.7	54	12.00	164	54.60	3 Mar 87	55
Surface Bongo		9.7	54	13.50	164	55.40	4 Mar 87	59
MARINOVICH	25	10.1	54	25.11	165	32.57	4 Mar 87	165
MARINOVICH	11	10.2	54	32.03	165	25.22	25 Feb 87	93
CTD	33	10.3	54	03.97	166	21.96	26 Feb 87	84
Hor Bongo		10.3	54	03.50	166	20.20	26 Feb 87	80
MARINOVICH	14	10.3	54	03.85	166	22.19	27 Feb 87	87
Obl Bongo		10.3	54	03.90	166	20.90	26 Feb 87	84
Surface Bongo		10.3	54	03.00	166	19.30	26 Feb 87	80
CTD	28	13.2	53	54.30	166	08.06	25 Feb 87	137
Hor Bongo		13.2	53	54.70	166	07.80	25 Feb 87	112
Obl Bongo		13.2	53	54.60	166	08.00	25 Feb 87	82
Surface Bongo		13.2	53	54.70	166	07.60	25 Feb 87	115
CTD	39	14.2	53	42.80	165	16.86	27 Feb 87	192
Hor Bongo		14.2	53	42.60	165	16.60	28 Feb 87	197
Obl Bongo		14.2	53	43.30	165	16.80	28 Feb 87	191
Surface Bongo		14.2	53	42.50	165	16.50	28 Feb 87	197
CTD	40	14.3	53	49.62	165	31.47	28 Feb 87	105
Hor Bongo		14.3	53	49.50	165	31.50	28 Feb 87	16
Obl Bongo		14.3	53	49.70	165	31.50	28 Feb 87	104
Surface Bongo		14.3	53	49.30	165	31.40	28 Feb 87	104
CTD	29	14.4	53	58.46	166	02.46	25 Feb 87	59
Hor Bongo		14.4	53	58.90	166	02.70	25 Feb 87	42
Obl Bongo		14.4	53	58.80	166	02.90	25 Feb 87	37
Surface Bongo		14.4	53	59.20	166	02.40	25 Feb 87	42
CTD	18	17.1	54	58.84	164	23.77	22 Feb 87	40
Hor Bongo		17.1	54	58.90	164	23.90	22 Feb 87	42
MARINOVICH	5	17.1	55	00.55	164	22.68	22 Feb 87	40
Obl Bongo		17.1	54	58.40	164	22.80	22 Feb 87	38
Rock Dredge	1	17.1	55	00.39	164	23.59	22 Feb 87	46
Trynet	1	17.1	54	59.54	164	26.12	22 Feb 87	48
Tucker		17.1	54	58.60	164	23.70	22 Feb 87	
CTD	20	17.2	54	49.34	164	41.84	23 Feb 87	60

Hor Bongo		17.2	54	50.60	164	41.70	23 Feb 87	60
MARINOVICH	7	17.2	54	48.29	164	42.87	23 Feb 87	60
Obl Bongo		17.2	54	50.20	164	41.70	23 Feb 87	60
Tucker		17.2	54	49.60	164	41.90	24 Feb 87	60
CTD	19	17.3	54	37.69	164	59.71	23 Feb 87	
Hor Bongo		17.3	54	37.30	165	01.40	23 Feb 87	70
MARINOVICH	8	17.3	54	37.32	165	00.01	23 Feb 87	64
Obl Bongo		17.3	54	37.10	165	00.70	23 Feb 87	70
Tucker		17.3	54	37.40	165	02.10	23 Feb 87	68
CTD	26	17.4	54	33.63	165	11.97	25 Feb 87	88
Hor Bongo		17.4	54	34.40	165	11.80	25 Feb 87	81
Obl Bongo		17.4	54	34.00	165	12.10	25 Feb 87	84
Tucker		17.4	54	34.70	165	11.50	25 Feb 87	81
CTD	63	17.5	54	18.98	165	40.01	4 Mar 87	80
Hor Bongo		17.5	54	18.90	165	41.40	4 Mar 87	86
Obl Bongo		17.5	54	18.90	165	40.80	4 Mar 87	84
Surface Bongo		17.5	54	19.00	165	47.00	4 Mar 87	86
CTD	37	17.6	54	14.60	165	59.53	27 Feb 87	96
Hor Bongo		17.6	54	15.10	165	57.20	27 Feb 87	96
Obl Bongo		17.6	54	15.10	165	58.50	27 Feb 87	96
Surface Bongo		17.6	54	15.10	165	56.20	27 Feb 87	91
CTD	36	17.8	54	07.00	166	28.45	27 Feb 87	706
Hor Bongo		17.8	54	07.00	166	28.50	27 Feb 83	
Obl Bongo		17.8	54	07.80	166	25.90	27 Feb 87	695
Surface Bongo		17.8	54	06.90	166	27.70	27 Feb 87	
CTD	49	21.1	54	17.73	166	27.10	1 Mar 87	1085
CTD	50	21.2	54	09.20	166	16.37	2 Mar 87	123
CTD	48	21.3	54	01.14	166	01.72	1 Mar 87	77
CTD	73	21.3	54	01.42	166	03.68	6 Mar 87	43
CTD	74	21.3	54	01.48	166	02.69	6 Mar 87	48
CTD	75	21.3	54	01.55	166	04.42	7 Mar 87	63
CTD	76	21.3	54	01.28	166	03.88	7 Mar 87	53
CTD	77	21.3	54	01.31	166	04.45	7 Mar 87	44
CTD	78	21.3	54	01.64	166	05.26	7 Mar 87	71
Obl Bongo		21.3	54	01.50	166	04.20	6 Mar 87	63
Obl Bongo		21.3	54	01.50	166	03.70	6 Mar 87	43
Obl Bongo		21.3	54	01.90	166	06.30	6 Mar 87	72
Obl Bongo		21.3	54	01.60	166	03.70	6 Mar 87	51
Obl Bongo		21.3	54	01.20	166	03.40	6 Mar 87	55
Obl Bongo		21.3	54	01.20	166	03.30	6 Mar 87	52
Obl Bongo		21.3	54	01.40	166	02.20	6 Mar 87	56
Obl Bongo		21.3	54	01.50	166	03.60	6 Mar 87	72
Obl Bongo		21.3	54	01.80	166	05.10	7 Mar 87	77
Obl Bongo		21.3	54	01.50	166	04.70	7 Mar 87	55
Obl Bongo		21.3	54	01.20	166	02.60	7 Mar 87	50
Obl Bongo		21.3	54	01.50	166	04.30	7 Mar 87	66
CTD	51	21.4	53	52.04	165	48.06	2 Mar 87	88
CTD	17	21.5	53	39.70	165	30.90	19 Feb 87	148
CTD	52	21.5	53	40.03	165	30.81	2 Mar 87	146
Tucker		21.5	53	39.30	165	29.90	20 Feb 87	201
CTD	53	21.6	53	29.76	165	16.26	2 Mar 87	1006
CTD	42	22.1	53	55.34	165	56.40	28 Feb 87	91
Hor Bongo		22.1	53	55.40	165	55.90	28 Feb 87	73
Obl Bongo		22.1	53	55.50	165	56.30	28 Feb 87	79

Surface Bongo		22.1	53	55.30	165	55.50	28 Feb 87	86
CTD	41	22.3	53	57.93	165	35.72	28 Feb 87	99
Hor Bongo		22.3	53	58.90	165	35.10	28 Feb 87	82
Obl Bongo		22.3	53	58.60	165	35.50	28 Feb 87	86
Surface Bongo		22.3	53	59.20	165	34.70	28 Feb 87	86
CTD	54	22.4	54	12.03	164	47.31	2 Mar 87	51
Hor Bongo		22.4	54	11.70	164	46.80	2 Mar 87	57
MARINOVICH	17	22.4	54	11.50	164	47.56	1 Mar 87	66
Obl Bongo		22.4	54	12.10	164	47.10	2 Mar 87	53
Surface Bongo		22.4	54	11.30	164	46.70	2 Mar 87	62
CTD	46	22.5	54	03.15	165	02.98	1 Mar 87	61
CTD	58	22.5	54	03.02	165	03.60	3 Mar 87	68
Hor Bongo		22.5	54	03.20	164	59.80	1 Mar 87	68
Hor Bongo		22.5	54	02.90	165	02.70	3 Mar 87	60
MARINOVICH	21	22.5	54	02.90	165	02.90	3 Mar 87	60
Obl Bongo		22.5	54	03.70	165	00.30	1 Mar 87	62
Obl Bongo		22.5	54	02.80	165	03.40	3 Mar 87	66
Surface Bongo		22.5	54	03.30	164	58.90	1 Mar 87	68
Surface Bongo		22.5	54	03.00	165	01.80	3 Mar 87	59
MARINOVICH	18	22.6	54	11.84	164	53.51	1 Mar 87	44
MARINOVICH	22	22.7	54	01.25	165	09.81	3 Mar 87	80
CTD	47	22.8	54	00.17	165	17.39	1 Mar 87	73
CTD	57	22.8	53	59.61	165	18.63	3 Mar 87	84
Hor Bongo		22.8	54	00.50	165	15.60	1 Mar 87	79
Hor Bongo		22.8	53	59.30	165	19.00	3 Mar 87	90
MARINOVICH	23	22.8	53	59.91	165	18.07	3 Mar 87	88
Obl Bongo		22.8	54	00.50	165	16.40	1 Mar 87	81
Obl Bongo		22.8	53	59.70	165	18.80	3 Mar 87	80
Surface Bongo		22.8	54	00.50	165	14.80	1 Mar 87	81
Surface Bongo		22.8	53	58.90	165	19.20	3 Mar 87	90
CTD	27	22.9	54	01.35	165	40.59	25 Feb 87	91
Hor Bongo		22.9	54	01.10	165	41.60	25 Feb 87	99
Obl Bongo		22.9	54	01.30	165	41.10	25 Feb 87	91
Surface Bongo		22.9	54	01.00	165	42.10	25 Feb 87	93
CTD	62	23.1	54	23.81	164	22.59	4 Mar 87	110
Hor Bongo		23.1	54	24.20	164	22.90	4 Mar 87	106
Obl Bongo		23.1	54	23.90	164	23.10	4 Mar 87	108
Surface Bongo		23.1	54	24.40	164	22.80	4 Mar 87	99
CTD	44	23.2	54	13.57	164	00.97	28 Feb 87	75
Hor Bongo		23.2	54	12.80	163	59.60	28 Feb 87	77
Obl Bongo		23.2	54	12.90	164	00.30	28 Feb 87	77
Surface Bongo		23.2	54	12.70	163	58.80	28 Feb 87	77
CTD	14	23.3	54	03.52	164	00.03	19 Feb 87	82
Tucker		23.3	54	02.70	163	59.70	19 Feb 87	81
CTD	5	23.5	53	35.52	164	03.75	18 Feb 87	1738
MARINOVICH	2	23.5	53	35.76	164	02.46	17 Feb 87	863
Tucker		23.5	53	36.10	164	06.70	18 Feb 87	1738
CTD	4	23.6	53	29.45	164	00.27	17 Feb 87	1912
Hor Bongo		23.6	53	28.90	163	03.40	17 Feb 87	1688
MARINOVICH	1	23.6	53	29.20	164	02.52	17 Feb 87	1509
Obl Bongo		23.6	53	29.30	164	01.10	17 Feb 87	1783
Tucker		23.6	53	28.80	164	04.40	17 Feb 87	1688
MARINOVICH	13	26.1	53	58.12	165	52.96	26 Feb 87	77
CTD	15	29.1	53	29.87	166	26.02	19 Feb 87	104

Hor Bongo		29.1	53	29.20	165	25.80	19 Feb 87	110
MARINOVICH	4	29.1	53	28.61	166	24.34	19 Feb 87	110
Obl Bongo		29.1	53	29.50	166	25.70	19 Feb 87	104
Tucker		29.1	53	28.80	166	25.80	19 Feb 87	113
CTD	16	29.2	53	37.00	165	55.51	19 Feb 87	97
MARINOVICH	12	29.2	54	00.71	165	42.62	25 Feb 87	91
Tucker		29.2	53	36.80	165	55.20	19 Feb 87	97
CTD	43	30.1	54	29.86	164	01.74	28 Feb 87	108
Hor Bongo		30.1	54	29.60	164	00.70	28 Feb 87	82
MARINOVICH	16	30.1	54	29.13	164	00.54	28 Feb 87	86
Obl Bongo		30.1	54	29.70	164	01.50	28 Feb 87	88
Surface Bongo		30.1	54	29.60	163	59.80	28 Feb 87	82
CTD	61	31.1	54	21.73	164	39.82	4 Mar 87	66
Hor Bongo		31.1	54	21.50	164	40.30	4 Mar 87	70
Obl Bongo		31.1	54	21.60	164	39.80	4 Mar 87	71
Surface Bongo		31.1	54	21.50	164	40.90	4 Mar 87	70
CTD	1	31.2	54	22.63	164	51.06	17 Feb 87	64
Hor Bongo		31.2	54	23.10	164	52.30	17 Feb 87	63
Obl Bongo		31.2	54	23.20	164	51.70	17 Feb 87	61
Tucker		31.2	54	22.70	164	53.10	17 Feb 87	66
CTD	7	31.3	54	14.35	164	42.82	18 Feb 87	77
Hor Bongo		31.3	54	16.20	164	44.80	18 Feb 87	99
Obl Bongo		31.3	54	15.50	164	44.30	18 Feb 87	88
Tucker		31.3	54	16.60	164	45.40	18 Feb 87	90
CTD	6	31.4	53	58.69	164	27.59	18 Feb 87	115
Hor Bongo		31.4	53	59.50	164	27.20	18 Feb 87	115
Obl Bongo		31.4	53	59.40	164	27.70	18 Feb 87	119
Tucker		31.4	53	59.10	164	27.90	18 Feb 87	112
CTD	2	31.5	54	46.86	165	14.76	17 Feb 87	144
Tucker		31.5	54	47.00	165	14.40	17 Feb 87	144
CTD	3	31.6	54	59.63	165	28.90	17 Feb 87	126
Obl Bongo		31.6	54	59.90	165	27.50	17 Feb 87	125
Tucker		31.6	55	00.20	165	27.60	17 Feb 87	125
CTD	66	32.2	54	46.94	165	49.29	5 Mar 87	196
Hor Bongo		32.2	54	47.80	165	49.70	5 Mar 87	190
Obl Bongo		32.2	54	47.00	165	49.50	5 Mar 87	193
Surface Bongo		32.2	54	48.20	165	49.90	5 Mar 87	174
CTD	67	32.3	54	36.37	165	30.86	5 Mar 87	173
Hor Bongo		32.3	54	36.40	165	30.70	5 Mar 87	183
Obl Bongo		32.3	54	35.90	165	31.10	5 Mar 87	176
Surface Bongo		32.3	54	36.70	165	30.50	5 Mar 87	185
CTD	45	32.4	53	49.65	164	48.39	1 Mar 87	107
Hor Bongo		32.4	53	50.00	164	47.70	1 Mar 87	106
Obl Bongo		32.4	53	50.00	164	48.20	1 Mar 87	106
Surface Bongo		32.4	53	50.00	164	47.30	1 Mar 87	106
CTD	55	32.5	53	40.15	164	46.48	2 Mar 87	326
Hor Bongo		32.5	53	39.10	164	45.90	2 Mar 87	389
Obl Bongo		32.5	53	39.90	164	46.10	2 Mar 87	337
Surface Bongo		32.5	53	38.70	164	46.10	2 Mar 87	
CTD	38	32.6	53	30.23	164	49.99	27 Feb 87	1673
Hor Bongo		32.6	53	29.50	164	49.90	27 Feb 87	1865
MARINOVICH	15	32.6	53	28.92	164	47.16	27 Feb 87	2124
Obl Bongo		32.6	53	29.70	164	49.80	27 Feb 87	1920
Surface Bongo		32.6	53	29.50	164	49.60	27 Feb 87	1781

CTD	56	32.7	54	01.06	164	50.83	3 Mar 87	87
Hor Bongo		32.7	54	00.10	164	50.70	3 Mar 87	92
MARINOVICH	20	32.7	53	59.54	164	50.00	3 Mar 87	91
Obl Bongo		32.7	54	00.70	164	50.70	3 Mar 87	91
Surface Bongo		32.7	54	00.20	164	50.90	3 Mar 87	96
CTD	35	46.1	54	00.91	166	07.22	26 Feb 87	29
Hor Bongo		46.1	54	00.80	166	07.20	26 Feb 87	
Surface Bongo		46.1	54	01.20	166	07.60	26 Feb 87	37
Shipeck	A24	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A25	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A26	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A27	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A28	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A29	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A30	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A31	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A32	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A33	A013	54	12.55	165	32.61	4 Mar 87	12
Shipeck	A34	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A35	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A36	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A37	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A38	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A39	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A40	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A41	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A42	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A43	A055	54	13.51	165	36.21	4 Mar 87	16
Shipeck	A14	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A15	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A16	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A17	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A18	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A19	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A20	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A21	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A22	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	A23	A074	54	09.11	165	29.05	25 Feb 87	25
Shipeck	B14	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B15	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B16	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B17	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B18	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B19	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B20	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B21	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B22	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	B23	B059	54	06.51	165	40.11	25 Feb 87	10
Shipeck	C01	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C02	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C03	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C04	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C05	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C06	C013	53	59.21	166	12.41	26 Feb 87	20

Shipeck	C07	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C08	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C09	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C10	C013	53	59.21	166	12.41	26 Feb 87	20
Shipeck	C11	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C12	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C13	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C14	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C15	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C16	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C17	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C18	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C19	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	C20	C015	53	59.31	166	10.51	26 Feb 87	15
Shipeck	E01	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E02	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E03	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E04	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E05	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E06	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E07	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E08	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E09	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	E10	E010	54	03.21	165	30.41	3 Mar 87	12
Shipeck	F04	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F05	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F06	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F07	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F08	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F09	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F10	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F11	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F12	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	F13	F016	54	05.01	165	26.51	1 Mar 87	8
Shipeck	G17	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G18	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G19	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G20	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G21	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G22	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G23	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G24	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G25	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G26	G006	54	05.01	165	08.21	3 Mar 87	9
Shipeck	G07	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G08	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G09	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G10	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G11	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G12	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G13	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G14	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G15	G026	54	07.31	164	59.21	1 Mar 87	8
Shipeck	G16	G026	54	07.31	164	59.21	1 Mar 87	8

APPENDIX C-3

Distribution of water quality measurements (CTD) and biological samples (bongo, Marinovich, trynet, Tucker, Shipeck, and dredge) taken in spring, 1987, in the Unimak Pass area, Alaska. Listings are in order by station numbers, station locations are given by degrees and minutes of North latitude and West longitude, and depths are in meters.

Table C-3. Listing of samples taken during the spring cruise.

GEAR	CAST	STATION	LATITUDE		LONGITUDE		DATE	DEPTH
CTD	55	3.1	54	26.08	166	31.69	5 May 87	556
hor bongo	52	3.1	54	26.10	166	31.10	7 May 87	554
Marinovich	20	3.1	54	26.10	166	31.66	4 May 87	567
Marinovich	25	3.1	54	26.52	166	32.93	8 May 87	540
Obl bongo	55	3.1	54	26.20	166	31.50	7 May 87	553
surf bongo	52	3.1	54	26.20	166	31.80	7 May 87	552
CTD	51	3.2	55	00.79	164	31.24	4 May 87	57
hor bongo	45	3.2	55	01.20	164	31.10	4 May 87	58
Marinovich	21	3.2	54	59.89	164	30.81	4 May 87	51
Obl bongo	47	3.2	55	00.80	164	30.80	4 May 87	58
surf bongo	45	3.2	55	00.80	164	30.90	4 May 87	58
CTD	52	3.3	54	49.81	165	06.94	4 May 87	107
hor bongo	46	3.3	54	49.90	165	06.80	4 May 87	106
Obl bongo	48	3.3	54	49.90	165	07.10	4 May 87	108
surf bongo	46	3.3	54	50.30	165	06.20	4 May 87	104
CTD	53	3.4	54	45.38	165	24.44	5 May 87	202
hor bongo	47	3.4	54	45.30	165	23.90	4 May 87	201
Obl bongo	49	3.4	54	45.40	165	24.20	5 May 87	199
surf bongo	47	3.4	54	45.70	165	23.70	5 May 87	196
CTD	54	3.5	54	37.38	165	49.58	5 May 87	392
hor bongo	55	3.5	54	36.70	165	47.70	9 May 87	396
Obl bongo	70	3.5	54	37.20	165	49.10	9 May 87	396
surf bongo	55	3.5	54	36.50	165	47.00	9 May 87	396
CTD	62	4.1	54	51.88	166	31.43	6 May 87	175
Marinovich	22	4.1	54	52.41	166	32.44	6 May 87	174
CTD	57	4.2	54	09.78	164	23.26	5 May 87	91
CTD	58	4.3	54	13.58	164	37.45	5 May 87	91
CTD	59	4.4	54	25.40	165	10.66	5 May 87	171
hor bongo	50	4.4	54	25.30	165	10.30	6 May 87	162
Obl bongo	53	4.4	54	25.40	165	10.20	6 May 87	156
surf bongo	50	4.4	54	25.30	165	10.70	6 May 87	166
CTD	60	4.5	54	31.94	165	29.50	6 May 87	98
hor bongo	51	4.5	54	32.30	165	29.70	7 May 87	97
Obl bongo	54	4.5	54	31.90	165	29.20	6 May 87	98
surf bongo	51	4.5	54	32.70	165	30.30	7 May 87	98
CTD	61	4.6	54	37.10	165	38.43	6 May 87	342
hor bongo	48	4.6	54	37.70	165	38.10	5 Jun 87	341
Obl bongo	51	4.6	54	36.90	165	37.60	6 May 87	326
surf bongo	48	4.6	54	37.30	165	38.50	6 May 87	345
CTD	31	5.1	54	06.33	165	28.17	29 Apr 87	106
hor bongo	24	5.1	54	06.80	165	29.50	29 Apr 87	
Marinovich	10	5.1	54	06.24	165	29.84	29 Apr 87	104
Obl bongo	26	5.1	54	06.70	165	29.00	29 Apr 87	90
surf bongo	25	5.1	54	06.70	165	29.30	29 Apr 87	90
CTD	32	6.1	54	09.44	165	19.48	29 Apr 87	68
hor bongo	25	6.1	54	08.90	165	19.40	29 Apr 87	67
Obl bongo	27	6.1	54	09.10	165	19.20	29 Apr 87	76
surf bongo	26	6.1	54	08.90	165	19.50	30 Apr 87	67
CTD	42	6.2	54	18.63	165	27.16	1 May 87	146

hor bongo	35	6.2	54	18.30	165	26.60	1 May 87	158
Obl bongo	37	6.2	54	17.60	165	27.10	1 May 87	151
surf bongo	35	6.2	54	18.30	165	26.40	1 May 87	158
CTD	43	6.3	54	25.65	165	31.54	1 May 87	98
hor bongo	36	6.3	54	24.90	165	31.60	1 May 87	95
Obl bongo	38	6.3	54	25.50	165	31.30	1 May 87	96
surf bongo	36	6.3	54	25.80	165	31.20	1 May 87	94
CTD	65	6.4	54	23.40	165	29.34	7 May 87	102
CTD	66	6.4	54	23.47	165	29.52	7 May 87	98
CTD	67	6.4	54	23.38	165	29.80	8 May 87	97
CTD	68	6.4	54	23.37	165	29.77	8 May 87	97
CTD	69	6.4	54	23.47	165	29.36	8 May 87	102
CTD	70	6.4	54	23.51	165	29.36	8 May 87	102
Marinovich	24	6.4	54	23.32	165	29.39	8 May 87	97
Obl bongo	57	6.4	54	23.50	165	29.50	7 May 87	97
Obl bongo	58	6.4	54	23.60	165	29.60	7 May 87	98
Obl bongo	59	6.4	54	24.10	165	29.30	7 May 87	98
Obl bongo	60	6.4	54	23.60	165	29.30	7 May 87	125
Obl bongo	61	6.4	54	23.20	165	29.30	7 May 87	88
Obl bongo	62	6.4	54	23.60	165	29.40	7 May 87	102
Obl bongo	63	6.4	54	23.50	165	29.40	7 May 87	102
Obl bongo	64	6.4	54	23.10	165	30.60	8 May 87	126
Obl bongo	65	6.4	54	23.40	165	30.50	8 May 87	113
Obl bongo	66	6.4	54	23.30	165	29.40	8 May 87	96
Obl bongo	67	6.4	54	23.40	165	29.40	8 May 87	98
Obl bongo	68	6.4	54	23.50	165	29.70	8 May 87	103
CTD	33	9.2	54	07.87	165	14.02	30 Apr 87	58
hor bongo	26	9.2	54	08.30	165	13.40	30 Apr 87	62
Obl bongo	28	9.2	54	08.00	165	13.60	30 Apr 87	62
surf bongo	27	9.2	54	08.60	165	13.10	30 Apr 87	63
CTD	39	9.7	54	12.93	164	54.95	1 May 87	56
hor bongo	32	9.7	54	13.40	164	55.00	1 May 87	57
Obl bongo	34	9.7	54	13.10	164	55.00	1 May 87	57
surf bongo	33	9.7	54	13.50	164	05.10	1 May 87	57
CTD	38	9.8	54	13.46	164	51.49	30 Apr 87	50
hor bongo	31	9.8	54	13.90	164	51.30	1 May 87	51
Obl bongo	33	9.8	54	13.70	164	51.40	1 May 87	51
surf bongo	32	9.8	54	14.30	164	50.90	1 May 87	51
CTD	63	10.1	54	25.31	165	32.58	6 May 87	93
hor bongo	49	10.1	54	25.20	165	32.70	6 May 87	94
Marinovich	23	10.1	54	24.62	165	32.94	6 May 87	95
Obl bongo	52	10.1	54	25.20	165	32.40	6 May 87	94
surf bongo	49	10.1	54	25.30	165	32.30	6 May 87	94
CTD	64	10.3	54	03.77	166	21.28	7 May 87	83
hor bongo	53	10.3	54	03.50	166	21.60	7 May 87	78
Obl bongo	56	10.3	54	03.80	166	21.10	7 May 87	83
surf bongo	53	10.3	54	03.60	166	21.10	7 May 87	81
CTD	49	13.2	53	54.65	166	07.88	3 May 87	118
hor bongo	43	13.2	53	54.50	166	08.60	3 May 87	76
Obl bongo	45	13.2	53	54.60	166	07.80	3 May 87	96
surf bongo	43	13.2	53	54.60	166	08.90	3 May 87	91
Marinovich	19	13.4	53	54.20	166	05.65	3 May 87	166
CTD	8	14.2	53	42.64	165	17.25	25 Apr 87	192
hor bongo	8	14.2	53	42.30	165	19.20	25 Apr 87	194

Obl bongo	8	14.2	53	42.30	165	18.00	25 Apr 87	195
surf bongo	8	14.2	53	42.40	165	20.10	25 Apr 87	196
CTD	7	14.3	53	49.52	165	31.61	25 Apr 87	106
hor bongo	7	14.3	53	49.50	165	33.10	25 Apr 87	106
Obl bongo	7	14.3	53	49.30	165	32.30	25 Apr 87	106
surf bongo	7	14.3	53	49.80	165	33.70	25 Apr 87	106
CTD	48	14.4	53	59.06	166	02.72	2 May 87	39
hor bongo	42	14.4	53	58.70	166	02.50	3 May 87	50
Obl bongo	44	14.4	53	58.90	166	02.70	3 May 87	40
surf bongo	42	14.4	53	58.60	166	02.40	3 May 87	61
CTD	18	15.1	53	44.13	164	01.19	27 Apr 87	450
hor bongo	12	15.1	53	43.60	164	03.60	27 Apr 87	
Marinovich	7	15.1	53	45.12	164	00.22	27 Apr 87	388
Obl bongo	14	15.1	53	43.60	164	02.00	27 Apr 87	636
surf bongo	13	15.1	53	44.40	164	01.30	27 Apr 87	440
hor bongo	54	16.3	54	14.80	166	23.20	8 May 87	910
Marinovich	5	16.3	54	15.17	166	23.99	25 Apr 87	823
Obl bongo	69	16.3	54	14.70	166	23.70	8 May 87	910
surf bongo	54	16.3	54	14.90	166	23.10	8 May 87	910
CTD	44	16.4	54	20.50	166	08.27	2 May 87	779
hor bongo	37	16.4	54	20.10	166	08.60	2 May 87	804
Obl bongo	39	16.4	54	20.00	166	09.40	2 May 87	799
surf bongo	37	16.4	54	20.00	166	09.50	2 May 87	792
CTD	25	17.1	54	59.12	164	23.58	28 Apr 87	42
hor bongo	18	17.1	54	58.70	164	24.20	28 Apr 87	41
Marinovich	9	17.1	54	59.01	164	23.45	28 Apr 87	42
Obl bongo	20	17.1	54	58.70	164	23.90	28 Apr 87	41
surf bongo	19	17.1	54	58.80	164	24.40	28 Apr 87	41
CTD	26	17.2	54	49.56	164	41.53	28 Apr 87	60
hor bongo	19	17.2	54	49.50	164	41.90	28 Apr 87	61
Obl bongo	21	17.2	54	49.80	164	41.90	28 Apr 87	61
CTD	27	17.3	54	37.45	165	00.28	28 Apr 87	66
hor bongo	20	17.3	54	37.10	165	00.50	29 Apr 87	67
Obl bongo	22	17.3	54	37.10	165	00.90	29 Apr 87	71
surf bongo	21	17.3	54	37.10	165	00.40	29 Apr 87	
CTD	28	17.4	54	34.36	165	11.84	29 Apr 87	81
hor bongo	21	17.4	54	35.50	165	11.90	29 Apr 87	89
Obl bongo	23	17.4	54	34.90	165	12.20	29 Apr 87	86
surf bongo	22	17.4	54	36.60	165	11.50	29 Apr 87	89
CTD	23	17.5	54	19.22	165	41.74	28 Apr 87	86
hor bongo	16	17.5	54	19.20	165	41.10	28 Apr 87	84
Obl bongo	18	17.5	54	19.40	165	41.30	28 Apr 87	85
surf bongo	17	17.5	54	18.90	165	40.90	28 Apr 87	84
CTD	24	17.6	54	15.23	165	59.58	28 Apr 87	102
hor bongo	17	17.6	54	14.90	165	58.90	28 Apr 87	98
Obl bongo	19	17.6	54	15.20	165	59.10	28 Apr 87	100
surf bongo	18	17.6	54	14.60	165	58.60	28 Apr 87	85
CTD	45	17.8	54	06.89	166	28.54	2 May 87	640
hor bongo	39	17.8	54	07.00	166	28.40	2 May 87	656
Obl bongo	41	17.8	54	06.80	166	28.00	2 May 87	666
surf bongo	39	17.8	54	07.10	166	28.90	2 May 87	654
CTD	29	19.1	54	28.99	165	37.84	29 Apr 87	182
hor bongo	22	19.1	54	29.00	165	38.50	29 Apr 87	230
Obl bongo	24	19.1	54	28.50	165	37.40	29 Apr 87	170

surf bongo	23	19.1	54	28.30	165	37.80	29	Apr	87	170
surf bongo	20	20.2	54	49.70	164	41.70	28	Apr	87	61
CTD	10	21.1	54	17.52	166	27.41	25	Apr	87	1050
CTD	80	21.1	54	17.91	166	27.54	11	May	87	975
CTD	81	21.1	54	17.70	166	27.29	11	May	87	1040
CTD	82	21.1	54	17.82	166	27.70	11	May	87	1017
CTD	83	21.1	54	17.79	166	27.52	11	May	87	1024
CTD	84	21.1	54	17.77	166	27.76	12	May	87	1016
hor bongo	38	21.1	54	17.60	166	27.90	2	May	87	1068
hor bongo	66	21.1	54	17.70	166	27.40	11	May	87	1005
hor bongo	67	21.1	54	17.80	166	27.50	11	May	87	1010
hor bongo	68	21.1	54	17.80	166	27.20	11	May	87	1000
hor bongo	69	21.1	54	17.80	166	27.30	11	May	87	1006
hor bongo	70	21.1	54	18.30	166	28.10	11	May	87	972
hor bongo	71	21.1	54	18.40	166	28.00	11	May	87	1962
hor bongo	72	21.1	54	17.40	166	27.50	11	May	87	1060
hor bongo	73	21.1	54	17.80	166	27.50	11	May	87	1097
hor bongo	74	21.1	54	17.60	166	27.50	11	May	87	1017
hor bongo	75	21.1	54	17.60	166	27.30	11	May	87	957
hor bongo	76	21.1	54	18.40	166	27.70	12	May	87	913
Marinovich	29	21.1	54	18.61	166	28.37	11	May	87	1006
Obl bongo	40	21.1	54	17.50	166	27.50	2	May	87	1068
Obl bongo	81	21.1	54	17.80	166	27.40	11	May	87	998
Obl bongo	82	21.1	54	18.10	166	27.40	11	May	87	1000
Obl bongo	83	21.1	54	17.60	166	27.20	11	May	87	1100
Obl bongo	84	21.1	54	17.80	166	27.30	11	May	87	1050
Obl bongo	85	21.1	54	17.90	166	27.60	11	May	87	984
Obl bongo	86	21.1	54	17.90	166	27.50	11	May	87	999
Obl bongo	87	21.1	54	17.90	166	27.20	11	May	87	1060
Obl bongo	88	21.1	54	17.60	166	27.40	11	May	87	1037
Obl bongo	89	21.1	54	17.70	166	27.10	11	May	87	1046
Obl bongo	90	21.1	54	18.00	166	27.90	11	May	87	1024
Obl bongo	91	21.1	54	18.00	166	27.60	12	May	87	1036
surf bongo	38	21.1	54	17.90	166	27.30	2	May	87	1068
surf bongo	66	21.1	54	18.30	166	27.60	11	May	87	985
surf bongo	67	21.1	54	18.20	166	27.60	11	May	87	993
surf bongo	68	21.1	54	17.90	166	27.40	11	May	87	1000
surf bongo	69	21.1	54	17.90	166	27.50	11	May	87	1006
surf bongo	70	21.1	54	17.90	166	27.30	11	May	87	1038
surf bongo	71	21.1	54	17.80	166	27.20	11	May	87	1041
surf bongo	72	21.1	54	18.10	166	27.30	11	May	87	1060
surf bongo	73	21.1	54	17.60	166	27.30	11	May	87	1020
surf bongo	74	21.1	54	17.80	166	27.20	11	May	87	1017
surf bongo	75	21.1	54	17.90	166	27.20	11	May	87	1048
surf bongo	76	21.1	54	19.10	166	27.80	12	May	87	818
CTD	11	21.2	54	08.79	166	16.22	25	Apr	87	106
Obl bongo	10	21.2	54	08.70	166	16.50	25	Apr	87	102
CTD	12	21.3	54	01.20	166	04.01	25	Apr	87	46
Obl bongo	11	21.3	54	01.60	166	04.50	26	Apr	87	75
CTD	14	21.5	53	39.55	165	31.16	26	Apr	87	144
surf bongo	10	21.5	53	40.40	165	30.80	26	Apr	87	136
CTD	15	21.6	53	29.59	165	16.57	26	Apr	87	1175
Marinovich	6	21.6	53	29.97	165	14.95	26	Apr	87	805
CTD	13	21.8	53	51.96	165	48.66	26	Apr	87	88

CTD	1	22.1	53	54.73	165	56.43	23 Apr 87	105
hor bongo	1	22.1	53	54.70	165	56.20	23 Apr 87	102
Marinovich	1	22.1	53	54.89	165	51.33	23 Apr 87	80
Obl bongo	1	22.1	53	55.00	165	55.90	23 Apr 87	81
surf bongo	1	22.1	53	55.00	165	56.10	23 Apr 87	79
CTD	46	22.11	54	05.65	165	32.93	2 May 87	94
hor bongo	40	22.11	54	05.60	165	33.20	2 May 87	99
Obl bongo	42	22.11	54	05.70	165	33.10	2 May 87	85
surf bongo	40	22.11	54	05.60	165	33.10	2 May 87	84
hor bongo	27	22.12	53	59.70	165	14.20	30 Apr 87	88
Obl bongo	29	22.12	53	59.60	165	13.70	30 Apr 87	83
CTD	2	22.3	53	58.44	165	36.29	23 Apr 87	94
hor bongo	2	22.3	53	58.60	165	36.10	23 Apr 87	86
Obl bongo	2	22.3	53	58.20	165	35.20	23 Apr 87	90
surf bongo	2	22.3	53	59.00	165	35.10	24 Apr 87	81
CTD	37	22.4	54	12.03	164	47.69	30 Apr 87	46
hor bongo	30	22.4	54	12.30	164	47.60	30 Apr 87	48
Obl bongo	32	22.4	54	12.20	164	47.60	30 Apr 87	48
surf bongo	31	22.4	54	11.80	164	47.30	30 Apr 87	48
CTD	3	22.5	54	03.18	165	01.36	23 Apr 87	61
CTD	40	22.5	54	03.13	165	02.32	1 May 87	61
hor bongo	3	22.5	54	03.10	165	01.30	24 Apr 87	61
hor bongo	33	22.5	54	02.90	165	01.90	1 May 87	59
Marinovich	16	22.5	54	02.53	165	02.90	30 Apr 87	70
Obl bongo	3	22.5	54	02.90	165	01.80	24 Apr 87	62
Obl bongo	35	22.5	54	02.90	165	02.60	1 May 87	64
surf bongo	3	22.5	54	03.30	165	01.10	24 Apr 87	60
surf bongo	34	22.5	54	03.20	165	02.30	1 May 87	56
CTD	34	22.7	53	59.76	165	13.31	30 Apr 87	86
CTD	41	22.7	54	01.67	165	10.12	1 May 87	79
hor bongo	34	22.7	54	01.50	165	10.40	1 May 87	84
Marinovich	15	22.7	54	00.67	165	09.56	30 Apr 87	86
Obl bongo	36	22.7	54	01.70	165	10.50	1 May 87	78
surf bongo	28	22.7	54	02.00	165	09.90	30 Apr 87	81
CTD	35	22.8	53	59.74	165	17.72	30 Apr 87	87
hor bongo	28	22.8	54	00.20	165	17.90	30 Apr 87	74
Marinovich	12	22.8	53	59.94	165	19.22	30 Apr 87	79
Marinovich	13	22.8	53	59.58	165	18.05	30 Apr 87	90
Marinovich	13b	22.8	53	59.52	165	17.43	30 Apr 87	90
Obl bongo	30	22.8	53	59.80	165	17.80	30 Apr 87	86
surf bongo	29	22.8	53	59.80	165	17.80	30 Apr 87	86
CTD	30	22.9	54	00.89	165	41.38	29 Apr 87	93
hor bongo	23	22.9	54	01.40	165	40.80	29 Apr 87	88
Marinovich	11	22.9	54	01.38	165	41.61	29 Apr 87	86
Obl bongo	25	22.9	54	00.80	165	40.50	29 Apr 87	94
surf bongo	24	22.9	54	00.90	165	41.10	29 Apr 87	88
CTD	76	23.1	54	24.21	164	21.72	10 May 87	97
hor bongo	61	23.1	54	24.10	164	22.00	10 May 87	93
surf bongo	61	23.1	54	24.30	164	22.00	10 May 87	92
CTD	4	23.2	54	13.32	164	00.95	24 Apr 87	75
hor bongo	4	23.2	54	13.20	164	01.70	24 Apr 87	75
Obl bongo	4	23.2	54	13.10	164	01.50	23 Apr 87	75
surf bongo	4	23.2	54	13.30	164	01.70	24 Apr 87	75
CTD	56	23.3	54	03.22	164	00.39	5 May 87	80

Marinovich	2	23.3	54	02.98	163	59.88	24 Apr 87	80
Obl bongo	50	23.3	54	03.30	163	60.00	5 May 87	79
CTD	19	23.5	53	35.72	164	04.61	27 Apr 87	1700
CTD	73	23.6	53	29.79	164	01.92	9 May 87	1990
hor bongo	58	23.6	53	29.80	164	01.70	9 May 87	1990
Marinovich	27	23.6	53	29.80	164	01.49	9 May 87	1625
Obl bongo	73	23.6	53	29.90	164	01.70	9 May 87	1990
surf bongo	58	23.6	53	29.90	164	01.80	9 May 87	1990
Marinovich	18	26.1	53	58.16	165	53.64	2 May 87	115
CTD	5	29.1	53	29.90	166	26.27	24 Apr 87	103
hor bongo	5	29.1	53	29.90	166	25.70	24 Apr 87	103
Marinovich	3	29.1	53	30.44	166	24.58	24 Apr 87	101
Obl bongo	5	29.1	53	30.00	166	26.40	24 Apr 87	102
surf bongo	5	29.1	53	29.70	166	25.20	24 Apr 87	109
CTD	6	29.2	53	37.04	165	55.70	24 Apr 87	96
hor bongo	6	29.2	53	36.80	165	55.80	24 Apr 87	96
Obl bongo	6	29.2	53	36.80	165	55.70	24 Apr 87	97
surf bongo	6	29.2	53	36.60	165	56.20	24 Apr 87	101
CTD	77	30.1	54	29.77	164	01.56	10 May 87	103
hor bongo	62	30.1	54	29.80	164	01.40	10 May 87	87
Marinovich	28	30.1	54	29.28	164	00.83	10 May 87	88
Obl bongo	77	30.1	54	29.70	164	01.90	10 May 87	113
surf bongo	62	30.1	54	29.70	164	01.60	10 May 87	
CTD	78	31.1	54	21.64	164	40.10	10 May 87	66
hor bongo	64	31.1	54	21.70	164	40.40	10 May 87	71
Obl bongo	79	31.1	54	21.60	164	40.20	10 May 87	70
surf bongo	64	31.1	54	21.80	164	39.80	10 May 87	65
CTD	79	31.2	54	22.67	164	51.45	10 May 87	60
hor bongo	65	31.2	54	22.90	164	51.20	10 May 87	71
Obl bongo	80	31.2	54	22.70	164	51.40	10 May 87	61
surf bongo	65	31.2	54	22.90	164	51.10	10 May 87	57
hor bongo	63	31.3	54	15.80	164	44.20	10 May 87	86
Obl bongo	78	31.3	54	15.60	164	44.60	10 May 87	67
surf bongo	63	31.3	54	15.60	164	44.60	10 May 87	86
CTD	74	31.4	53	59.08	164	28.19	10 May 87	112
hor bongo	59	31.4	53	59.20	164	28.50	10 May 87	112
Obl bongo	74	31.4	53	58.80	164	28.10	10 May 87	112
surf bongo	59	31.4	53	58.90	164	27.70	10 May 87	112
CTD	71	31.5	54	47.04	165	15.37	9 May 87	146
hor bongo	56	31.5	54	47.00	165	15.40	9 May 87	146
Obl bongo	71	31.5	54	46.80	165	15.00	9 May 87	145
surf bongo	56	31.5	54	47.00	165	15.80	9 May 87	148
CTD	72	31.6	54	59.82	165	29.06	9 May 87	125
hor bongo	57	31.6	54	60.00	165	29.10	9 May 87	125
Marinovich	26	31.6	54	59.96	165	28.60	9 May 87	124
Obl bongo	72	31.6	55	00.00	165	29.10	9 May 87	125
surf bongo	57	31.6	54	00.10	165	29.70	9 May 87	125
CTD	75	31.7	54	09.02	164	29.13	10 May 87	89
hor bongo	60	31.7	54	08.80	164	29.00	10 May 87	87
Obl bongo	75	31.7	54	09.20	164	29.70	10 May 87	87
surf bongo	60	31.7	54	09.50	164	29.60	10 May 87	87
CTD	20	32.1	55	00.21	165	59.85	27 Apr 87	140
hor bongo	13	32.1	55	00.20	165	59.50	27 Apr 87	142
Marinovich	8	32.1	55	00.53	166	00.48	27 Apr 87	134

Obl bongo	15	32.1	55	00.50	165	59.80	27 Apr 87	142
Obl bongo	76	32.1	54	24.30	164	21.70	10 May 87	96
surf bongo	14	32.1	55	00.40	165	59.40	27 Apr 87	
CTD	21	32.2	54	47.40	165	49.57	27 Apr 87	190
hor bongo	14	32.2	54	47.20	165	49.70	27 Apr 87	190
Obl bongo	16	32.2	54	47.60	165	49.20	27 Apr 87	188
surf bongo	15	32.2	54	47.30	165	49.30	27 Apr 87	190
CTD	22	32.3	54	36.55	165	30.80	28 Apr 87	182
hor bongo	15	32.3	54	36.90	165	28.50	28 Apr 87	159
Obl bongo	17	32.3	54	36.90	165	29.40	28 Apr 87	169
surf bongo	16	32.3	54	35.60	165	28.00	28 Apr 87	135
CTD	17	32.4	53	49.76	164	48.08	26 Apr 87	106
hor bongo	11	32.4	53	49.80	164	48.20	26 Apr 87	106
Obl bongo	13	32.4	53	49.60	164	48.00	26 Apr 87	106
surf bongo	12	32.4	53	49.90	164	48.00	26 Apr 87	106
CTD	16	32.5	53	39.42	164	46.27	26 Apr 87	392
hor bongo	10	32.5	53	39.40	164	46.00	26 Apr 87	350
Obl bongo	12	32.5	53	38.60	164	45.80	26 Apr 87	402
surf bongo	11	32.5	53	39.70	164	46.40	26 Apr 87	336
CTD	9	32.6	53	29.34	164	50.07	25 Apr 87	2195
hor bongo	9	32.6	53	29.70	164	49.90	25 Apr 87	2195
Marinovich	4	32.6	53	28.05	164	49.33	25 Apr 87	2377
Obl bongo	9	32.6	53	28.40	164	50.90	25 Apr 87	2195
surf bongo	9	32.6	53	29.90	164	50.10	25 Apr 87	2195
CTD	36	32.7	53	59.94	164	50.82	30 Apr 87	91
hor bongo	29	32.7	54	00.40	164	50.80	30 Apr 87	91
Marinovich	17	32.7	54	00.26	164	50.79	30 Apr 87	90
Obl bongo	31	32.7	54	00.50	164	50.60	30 Apr 87	91
surf bongo	30	32.7	54	00.50	164	50.40	30 Apr 87	92
CTD	50	43.1	53	49.43	166	20.54	3 May 87	253
hor bongo	44	43.1	53	49.60	166	20.50	3 May 87	281
Obl bongo	46	43.1	53	49.40	166	20.40	3 May 87	250
surf bongo	44	43.1	53	49.40	166	20.20	3 May 87	262
CTD	47	46.1	54	01.01	166	07.54	2 May 87	31
hor bongo	41	46.1	54	01.20	166	07.50	2 May 87	54
Obl bongo	43	46.1	54	01.10	166	06.70	2 May 87	36
surf bongo	41	46.1	54	01.00	166	07.40	2 May 87	49
Shipeck	A54	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A55	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A56	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A57	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A58	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A59	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A60	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A61	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A62	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A63	A030	54	10.41	165	28.21	29 Apr 87	15
Shipeck	A44	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A45	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A46	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A47	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A48	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A49	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A50	A070	54	08.21	165	33.21	29 Apr 87	15

Shipeck	A51	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A52	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	A53	A070	54	08.21	165	33.21	29 Apr 87	15
Shipeck	E11	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E12	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E13	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E14	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E15	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E16	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E17	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E18	E010	54	03.11	165	30.41	30 Apr 87	10
Shipeck	E19	E010	54	03.11	165	30.41	30 Apr 87	10

APPENDIX D

Haul characteristics for forage fish samples for fall, winter, and spring cruises, Unimak Pass, Alaska.

Table D. Haul characteristics for forage fish samples.

Fall Cruise

Gear	#	STA	Lat.		Long		Date	Bottom	Duration	Depth	Dist
Marinovich	1	3.1	54	24.57	166	33.23	19-Sep-86	325		64	
Marinovich	2	4.1	54	51.23	166	29.38	20-Sep-86	98		19	
Marinovich	3	10.2	54	31.08	165	22.92	22-Sep-86	80		70	
Marinovich	4	10.3	54	29.14	165	25.06	22-Sep-86	88		10	
Marinovich	5	15.1	53	43.04	164	02.04	23-Sep-86			100	
Marinovich	6	5.1	54	06.75	165	27.31	24-Sep-86	53		26	
Marinovich	7	14.6	54	01.45	166	06.84	24-Sep-86	28		9	
Marinovich	8	17.1	54	59.00	164	19.21	25-Sep-86	21		15	
Marinovich	9	16.3	54	16.27	166	26.07	26-Sep-86	500		75	
Marinovich	10	18.1	54	51.09	166	31.30	26-Sep-86	100		25	
Marinovich	11	19.1	54	29.01	165	36.27	26-Sep-86	76		45	
Marinovich	12	10.3	54	04.22	166	22.19	27-Sep-86	44		15	
Marinovich	13	23.6	53	30.53	164	02.01	29-Sep-86	>500		4	
Marinovich	14	23.5	53	35.35	164	05.33	29-Sep-86	1100		125	
Marinovich	15	26.1	53	58.29	165	55.26	29-Sep-86	65		18	
Marinovich	16	27.1	53	54.28	166	08.79	30-Sep-86	100		20	
Marinovich	17	9.5	54	06.65	165	18.58	30-Sep-86	26		5	
Marinovich	18	22.4	54	13.87	164	48.33	1-Oct-86	31		20	
Marinovich	19	22.6	54	11.17	164	52.39	1-Oct-86	40		20	
Marinovich	20	22.5	54	03.10	165	02.50	1-Oct-86	36		20	
Marinovich	21	22.7	54	01.80	165	10.50	1-Oct-86	41		23	
Marinovich	22	22.8	54	02.92	165	16.94	1-Oct-86	43		25	
Marinovich	23	22.9	54	05.23	165	40.02	1-Oct-86	44		20	
Marinovich	24	29.1	53	28.68	166	25.75	2-Oct-86	63		48	
Marinovich	25	30.1	54	29.34	163	59.52	2-Oct-86	45		20	
Marinovich	26	31.6	54	59.64	165	28.33	3-Oct-86	68		29	
Marinovich	27	32.1	54	58.60	165	59.82	4-Oct-86	78		35	
Marinovich	28	32.6	53	29.95	164	45.81	4-Oct-86			20	
Marinovich	29	31.8	54	35.25	163	57.65	5-Oct-86	32		20	

Winter Cruise

Gear	#	STA	Lat.		Long		Date	Bottom	Duration	Depth	Dist
Marinovich	1	23.6	53	29.20	164	02.52	17-Feb-87	1509	00.50	154	1.5
Marinovich	2	23.5	53	35.76	164	02.46	17-Feb-87	863	00.50	115	0.9
Marinovich	3	4.1	54	50.50	166	30.58	18-Feb-87	196	00.50	135	1.5
Marinovich	4	29.1	53	28.61	166	24.34	19-Feb-87	110	00.50	100	1.5
Rock Dredge	1	17.1	55	00.39	164	23.59	22-Feb-87	46	00.17	46	0.5
Trynet	1	17.1	54	59.54	164	26.12	22-Feb-87	48	00.03	48	0.08
Marinovich	5	17.1	55	00.55	164	22.68	22-Feb-87	40	00.50	18	1.5
Marinovich	6	3.2	55	00.45	164	29.96	23-Feb-87	58	00.50	18	1.25
Marinovich	7	17.2	54	48.29	164	42.87	23-Feb-87	60	00.50	42	1.5
Marinovich	8	17.3	54	37.32	165	00.01	23-Feb-87	64	00.50	55	1.5
Rock Dredge	2	3.3	54	50.23	165	06.18	24-Feb-87	104	00.05	104	0.2
Trynet	2	3.3	54	50.65	165	50.65	24-Feb-87	119	00.10	115	0.4
Marinovich	9	3.3	54	50.35	165	07.86	24-Feb-87	115	00.50	82	1.4
Marinovich	10	3.1	54	25.83	166	31.22	24-Feb-87	580	00.50	252	1.5
Marinovich	11	10.2	54	32.03	165	25.22	25-Feb-87	93	00.50	86	

Marinovich	12	29.2	54	00.71	165	42.62	25-Feb-87	91	00.50	79	1.75
Marinovich	13	26.1	53	58.12	165	52.96	26-Feb-87	77	00.50	68	1.4
Marinovich	14	10.3	54	03.85	166	22.19	27-Feb-87	87	00.50	82	1.4
Marinovich	15	32.6	53	28.92	164	47.16	27-Feb-87	2124	00.50	179	1.3
Marinovich	16	30.1	54	29.13	164	00.54	28-Feb-87	86	00.50	71	1.35
Marinovich	17	22.4	54	11.50	164	47.56	1-Mar-87	66	00.50	48	1.4
Marinovich	18	22.6	54	11.84	164	53.51	1-Mar-87	44	00.50	42	1.8
Marinovich	19	9.5	54	07.17	165	19.60	1-Mar-87	57	00.55	40	1.6
Marinovich	20	32.7	53	59.54	164	50.00	3-Mar-87	91	00.50	75	1.85
Marinovich	21	22.5	54	02.90	165	02.90	3-Mar-87	60	00.50	55	1.6
Marinovich	22	22.7	54	01.25	165	09.81	3-Mar-87	80	00.50	70	2.7
Marinovich	23	22.8	53	59.91	165	18.07	3-Mar-87	88	00.50	66	1.7
Marinovich	24	5.1	54	06.04	165	29.56	3-Mar-87	110	00.50	82	0.25
Marinovich	25	10.1	54	25.11	165	32.57	4-Mar-87	165	00.50	95	1.5
Rock Dredge	3	5.1	54	06.17	165	30.19	3-Mar-87	101	00.08	101	0.21

Spring Cruise

Gear	# STA		Lat.		Long		Date	Bottom	Duration	Depth	Dist
Marinovich	1	22.1	53	54.89	165	51.33	23-Apr-87	80	00.50	31	1.35
Marinovich	2	23.3	54	02.98	163	59.88	24-Apr-87	80	00.50	46	1.3
Marinovich	3	29.1	53	30.44	166	24.58	24-Apr-87	101	00.50	58	1.35
Marinovich	4	32.6	53	28.05	164	49.33	25-Apr-87	2377	00.50	230	0.65
Marinovich	5	16.3	54	15.17	166	23.99	25-Apr-87	823	00.50	119	1.8
Marinovich	6	21.6	53	29.97	165	14.95	26-Apr-87	805	00.50	229	1.3
Marinovich	7	15.1	53	45.12	164	00.22	27-Apr-87	388	00.50	247	1.27
Marinovich	8	32.1	55	00.53	166	00.48	27-Apr-87	134	00.50	96	1.45
Marinovich	9	17.1	54	59.01	164	23.45	28-Apr-87	42	00.50	26	1.2
Marinovich	10	5.1	54	06.24	165	29.84	29-Apr-87	104	00.50	44	1.5
Marinovich	11	22.9	54	01.38	165	41.61	29-Apr-87	86	00.50	40	1.35
Marinovich	12	22.8	53	59.94	165	19.22	30-Apr-87	79	00.50	48	1.75
Marinovich	13	22.8	53	59.58	165	18.05	30-Apr-87	90	00.25	38	1.13
Marinovich	13b	22.8	53	59.52	165	17.43	30-Apr-87	90	00.25	48	1.08
Marinovich	15	22.7	54	00.67	165	09.56	30-Apr-87	86	00.50	33	1.93
Marinovich	16	22.5	54	02.53	165	02.90	30-Apr-87	70	00.50	35	1.3
Marinovich	17	32.7	54	00.26	164	50.79	30-Apr-87	90	00.50	59	1.6
Marinovich	18	26.1	53	58.16	165	53.64	2-May-87	115	00.50	42	1.25
Marinovich	19	13.4	53	54.20	166	05.65	3-May-87	166	00.50	51	1.25
Marinovich	20	3.1	54	26.10	166	31.66	4-May-87	567	00.50	53	1.6
Marinovich	21	3.2	54	59.89	164	30.81	4-May-87	51	00.50	18	1.4
Marinovich	22	4.1	54	52.41	166	32.44	6-May-87	174	00.50	71	1.35
Marinovich	23	10.1	54	24.62	165	32.94	6-May-87	95	00.50	64	1.25
Marinovich	24	6.4	54	23.32	165	29.39	8-May-87	97	00.50	37	1.25
Marinovich	25	3.1	54	26.52	166	32.93	8-May-87	540	00.50	137	1.4
Marinovich	26	31.6	54	59.96	165	28.60	9-May-87	124	00.50	73	1.4
Marinovich	27	23.6	53	29.80	164	01.49	9-May-87	1625	00.50	110	1.4
Marinovich	28	30.1	54	29.28	164	00.83	10-May-87	88	00.50	79	1.5
Marinovich	29	21.1	54	18.61	166	28.37	11-May-87	1006	00.50	132	1.5

APPENDIX E

Place names and sampling station locations for fall, winter, and spring cruises, Unimak Pass area, Alaska.

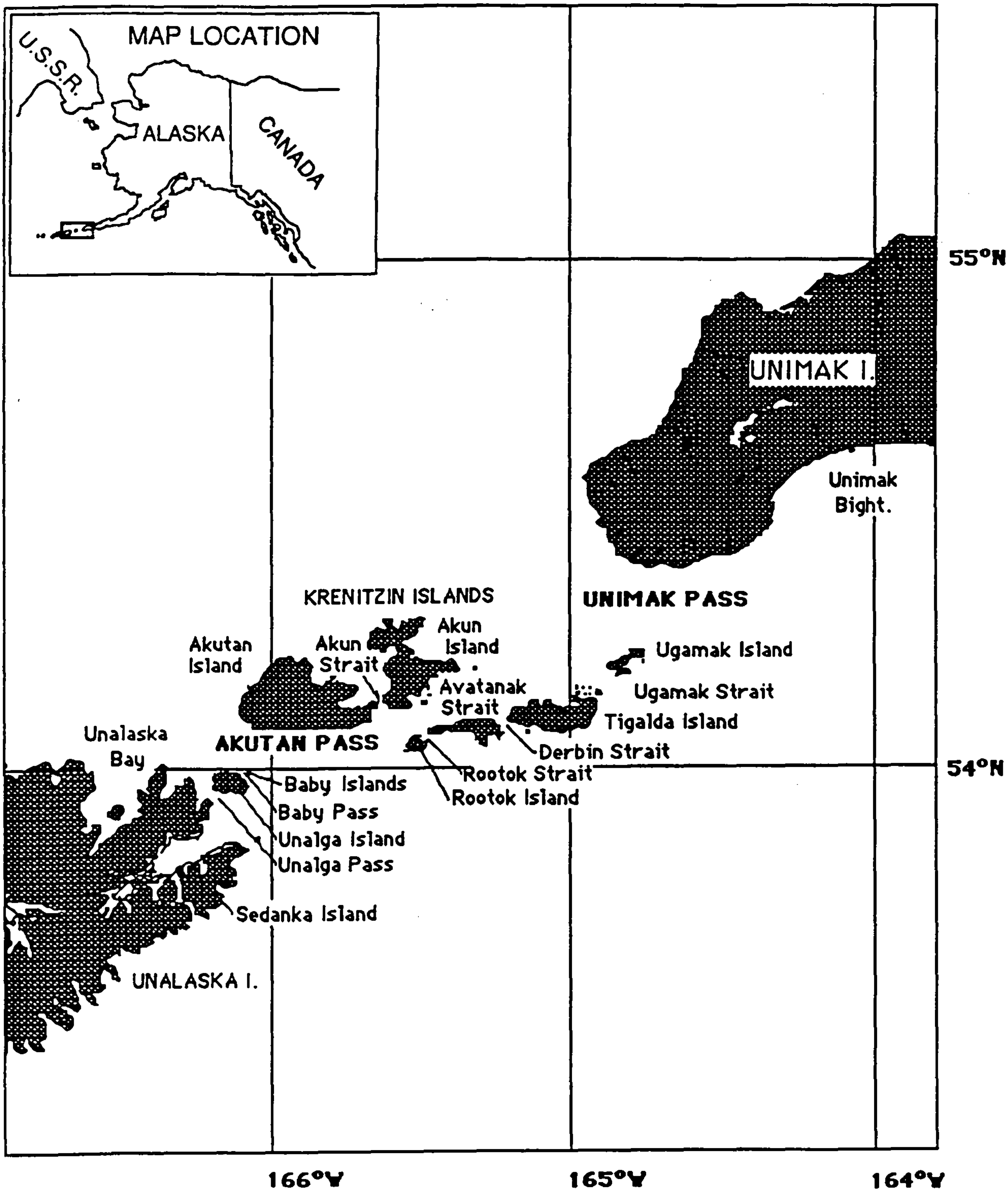


Figure 1. Place names in the Unimak Pass area, Alaska.

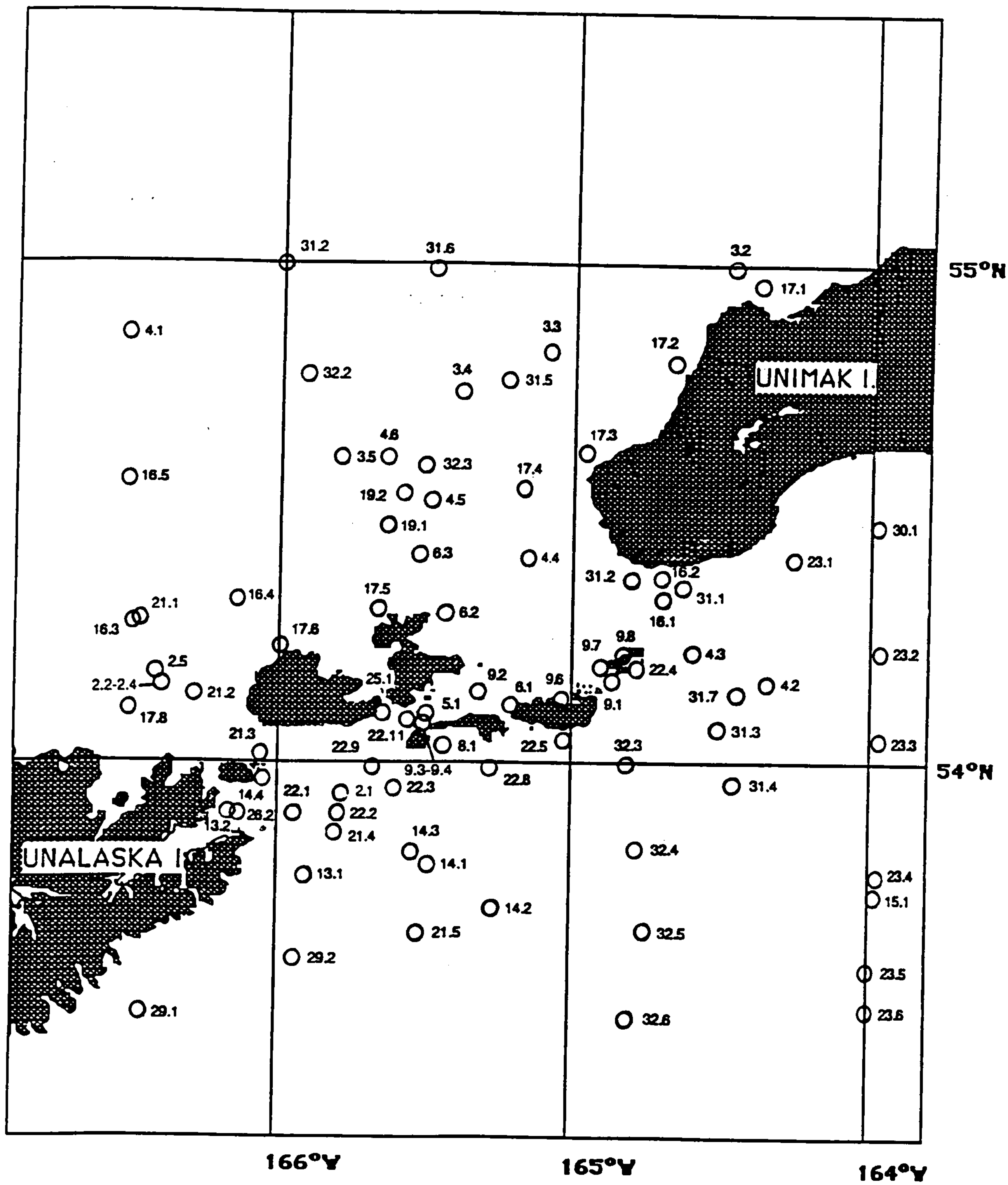


Figure 2. Locations of CTD stations sampled during the fall 1986 cruise, 18 Sept-7 Oct, Unimak Pass area, Alaska.

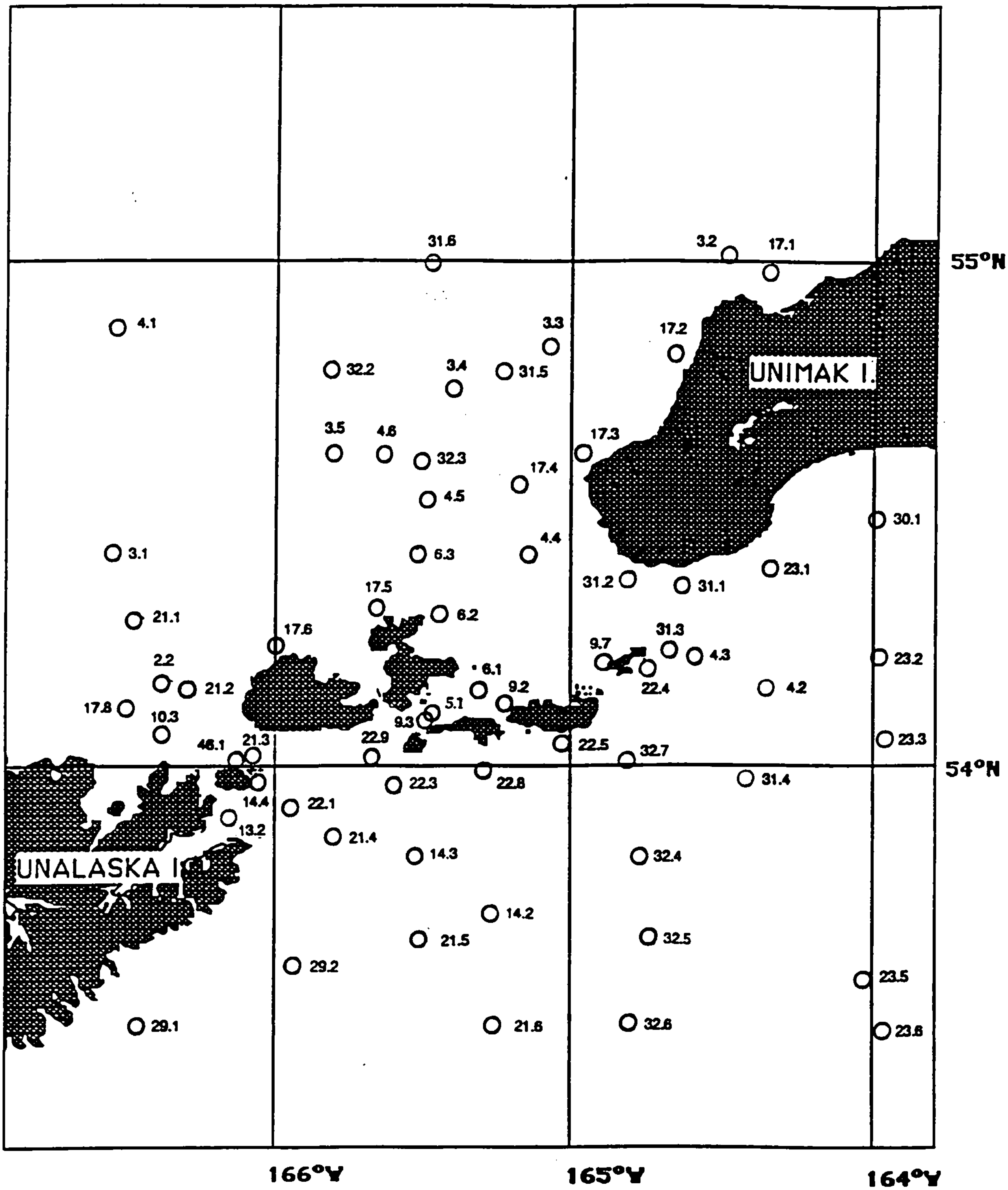


Figure 3. Locations of CTD stations sampled during the winter 1987 cruise, 14 Feb-9 March, Unimak Pass area, Alaska.

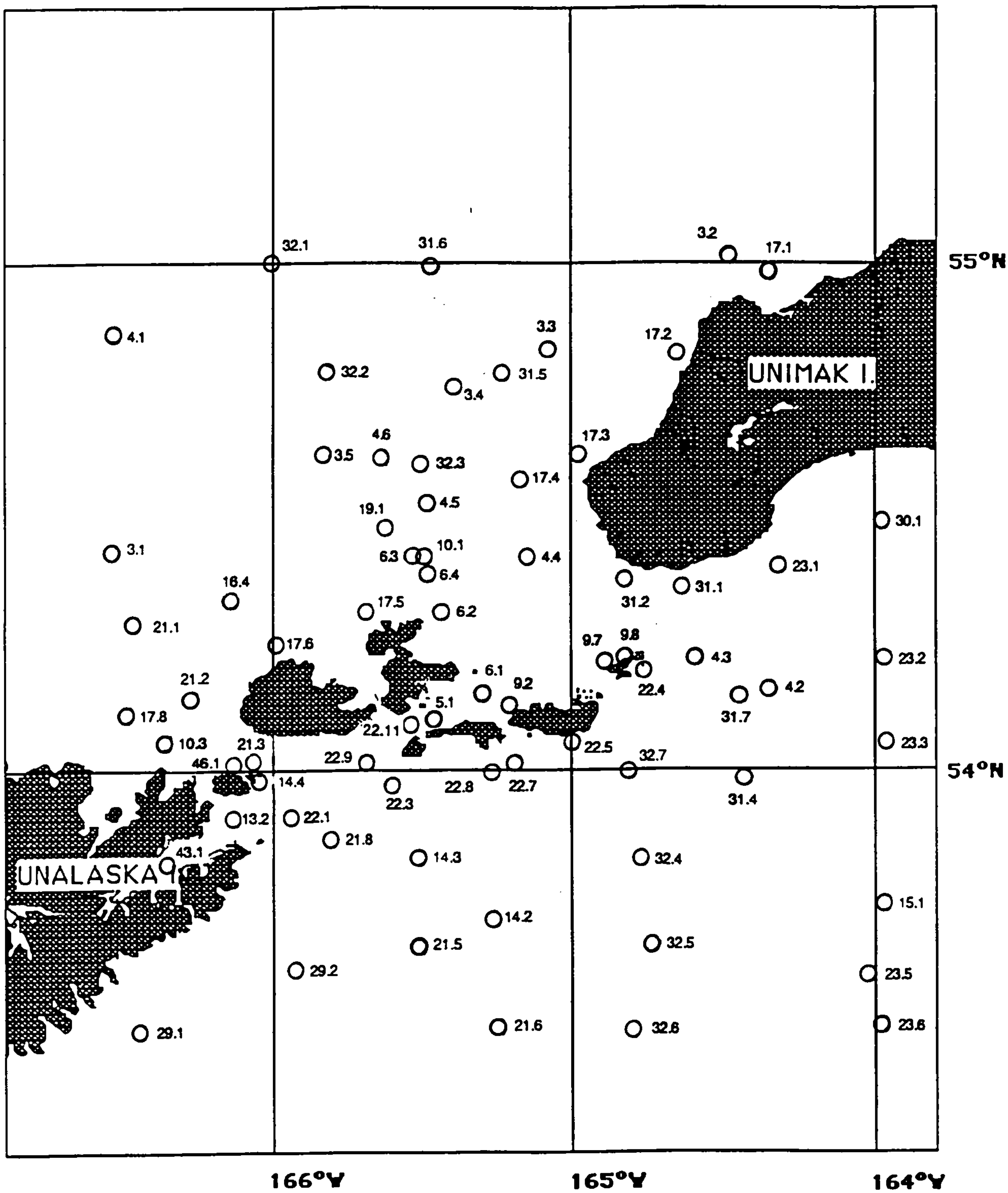


Figure 4. Locations of CTD stations sampled during the spring 1987 cruise, 21 April-14 May, Unimak Pass area, Alaska.