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I am submitting herewith a thesis written by Andrew Jay Reed entitled: "Benthic Macrofaunal Invertebrates of the East Siberian and Chukchi Seas: Benthic Biomass, Community Structure and Radionuclide Contamination." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology.

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Associate Vice Chancellor and
Dean of the Graduate School

BENTHIC MACROFAUNAL INVERTEBRATES OF THE EAST SIBERIAN AND CHUKCHI SEAS: BENTHIC BIOMASS, COMMUNITY STRUCTURE AND RADIONUCLIDE CONTAMINATION

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ABSTRACT

Benthic macrofaunal invertebrates were collected at 22 stations during an August-September 1995 cruise in the East Siberian and Chukchi Seas. The study area extended from the mouth of the Kolyma River east to Bering Strait. Benthic biomass and species composition were studied in relation to sediment characteristics and hydrographic parameters. Taxon-abundance and biomass based station groups were identified by cluster analysis and ordination techniques. Benthic macrofaunal biomass was found to be greatest in the eastern part of the study area and generally decreased from east to west and from offshore to nearshore. The highest benthic biomass, found in the Chukchi Sea, averaged 48.4 g C m^{-2} (s.d.= +/- 19.2). A diverse fauna exists at these stations with bivalves (F. Nuculanidae: *Nuculana radiata* and F. Tellinidae: *Macoma calcarea*) and amphipods (F. Ampeliscidae: *Byblis* sp. and *Ampelisca* sp.) dominating the biomass with other species of polychaetes, bivalves and amphipods also present. The lowest benthic biomass was found at stations in the East Siberian Sea, particularly near the Kolyma River mouth. These stations averaged 2.3 g C m^{-2} (s.d.= +/- 1.1), were dominated by isopods (F. Idoteidae: *Idotea ochotensis*) and small bivalves (F. Nuculidae: *Nucula belloti*) and showed low species diversity. The Kolyma River discharges freshwater onto the shallow continental shelf of the East Siberian Sea and this water is then carried to the east, during most years, by the Siberian Coastal Current. Freshwater inflow of

the Kolyma River and the relatively high biological productivity of the more productive Chukchi Sea appear to be dominant oceanographic features. Organic carbon of terrestrial origin and lower nutritional value for the marine benthic community is more prevalent in the East Siberian Sea. Indications from the $\delta^{13}C$ values and C/N ratios of the organic carbon in the sediments suggest a progressive increase, west to east, in the relative contribution of marine vs. terrestrial origin of particulate organic carbon available to the benthos. Organic $\delta^{13}C$ values reached a minimum of -25.5‰ in the East Siberian Sea and increased to a maximum of -20.3‰ in the Chukchi Sea. C/N ratios (wt./wt.) ranged from a maximum of 8.3 in the East Siberian Sea and decreased to a minimum of 5.2 in the Chukchi Sea. The results of the study indicate that higher biomass of the study area is related to the marine origin of available organic carbon and the production of the overlying water column while benthic community structure is affected by sediment characteristics and the influence of the Kolyma River plume.

In addition to the ecologically oriented investigations, twenty-eight samples representing 16 stations were analyzed to assess the activities of accumulated natural and anthropogenic radionuclides. The samples counted were chosen to best represent the various animal types, feeding strategies, and geographic locations of invertebrates. The assays of gamma-emitting radionuclides in this study indicate that benthic macrofaunal invertebrates in the

East Siberian and Chukchi Seas have not concentrated anthropogenically introduced radionuclides in detectable amounts with two exceptions. These exceptions were collected from two stations in the East Siberian Sea that contained only trace quantities of ^{137}Cs that produced a positive signal, but had large uncertainties. Activities, on a wet weight basis, of the natural radioactive isotope ^{40}K, were not concentrated in the tissues of benthic macrofaunal invertebrates above levels that can be reasonably attributed to absorption from the underlying sediment or the overlying water.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES, continued.

LIST OF FIGURES

LIST OF FIGURES, continued.

LIST OF FIGURES, continued.

FIGURE PAGE

I. INTRODUCTION

A. Benthic Macrofaunal Biomass and Community Structure

Many environmental variables influence the community structure, abundance and biomass of benthic macrofaunal invertebrates in soft-bottom marine systems. The relative importance of environmental variables in shaping the benthic community changes depending upon differences in hydrographic characteristics, sediment characteristics and biological effects.

Sediment Grain Size

Marine sediment grain size can greatly affect the distribution of benthic invertebrates (Gray, 1981). For example, Long et al. (1995) showed that the distribution of the dominant benthic invertebrates was associated with sediment grain size as well as depth in the Gulf of Carpentaria, Australia. Weston (1987) demonstrated that sediment grain size was the most important factor in differentiating benthic invertebrate assemblages on the continental shelf off Cape Hatteras, North Carolina. Brandt (1993) demonstrated on a transect taken at the Kolbeinsey Ridge, north of Iceland, that differences in benthic crustacean abundance were due to sediment characteristics, such as grain size, as well as the quality and quantity of organic carbon reaching the sea floor.

Food Supply

Piepenburg et al. (1996) showed that the total organic carbon (TOC) content, a direct reflection of the average flux of organic matter to the benthos, and depth were the main factors structuring the benthic communities in the waters around Svalbard; sediment grain size was considered to be less important. Kröncke (1994) showed that food availability is the main factor in structuring the macrofaunal communities between Svalbard and Makarov Basin in the deep Arctic Ocean. Ambrose and Renaud (1995) demonstrated that sediment pigment concentration was the most important predictor of infaunal density and polychaete biomass in the Northeast Water Polynya, partially because sediment grain size and depth were approximately equal at all sampling sites. In the northern Bering and eastern Chukchi Seas, Grebmeier et al. (1989) showed that sediment heterogeneity and water temperature most consistently affected benthic community structure, while benthic biomass and abundance were positively correlated with the primary production of the overlying water column (Grebmeier et al., 1988). In that same study, food supply and predation pressure/disturbance effects were also shown to have a more spatially variable effect (Grebmeier et al., 1989). A number of studies have shown that it is normally a combination of environmental factors that control the community structure and biomass of benthic macrofaunal assemblages.

The quality and quantity of the organic carbon supplied to the benthos by the pelagic system is a major factor influencing benthic community structure and biomass (Grebmeier, 1987; Grebmeier et al., 1989; Carey, 1991; Brandt, 1993; Feder et al., 1994b). Generally, the water column primary production on Arctic continental shelves, such as the East Siberian Sea, is low (5-80 g C m^{-2} yr^{-1}; Dayton et al., 1994), but primary production can be as high as 300 g C m^{-2} yr^{-1} in the southern Chukchi Sea (Grebmeier and McRoy, 1989; Springer and McRoy, 1993). The relative amounts of autochthonous organic carbon sinking down in the water column and reaching the benthos in shallow systems is a reflection of primary production. Portions of the Chukchi Sea show high autochthonous primary productivity due to the influx of advected nutrients from nutrient-rich Pacific waters (Grebmeier et al., 1989; Grebmeier and Barry, 1991), and the benthos in these areas has been shown to have high biomass, up to 50-60 g C m^{-2} (Grebmeier et al., 1988). Benthic abundance and biomass are low on those Arctic continental shelves where organic carbon available to the benthos is derived from only low levels of autochthonous primary productivity (Grebmeier and Barry, 1991).

Primary production in Arctic regions can be limited by the high latitude that limits sunlight in winter, the extensive seasonal ice cover that limits irradiance, the summer introduction of large amounts of freshwater inflowing from the major rivers and the melting of sea ice. This freshwater introduction can act to stratify and vertically stabilize the water column during the spring and summer (Dayton et al., 1994), further limiting the amount of organic carbon reaching the benthos. Also, the food quality of organic carbon reaching the benthos can be negatively affected by highly refractory terrestrial carbon. For example, while terrestrial peat transported in the runoff from rivers in the Arctic can contribute a significant amount of organic carbon to the benthos, few benthic invertebrates are able to digest and utilize carbon of terrestrial origin (Griffiths et al., 1984).

Food Quality

Stable carbon isotope ratios ($\delta^{13}C$) have been used as indicators of the origin of organic carbon in general (Peterson and Fry, 1987), in the western Arctic (Hobson et al., 1995) and Chukchi Sea marine sediments in particular (Grebmeier, 1987; Grebmeier et al., 1988; Naidu et al., 1993). In a study on the continental shelf of Alaska, sediment $\delta^{13}C$ values of -24‰ and greater were reported for the organic debris deposited in the Kobuk and Noatak estuaries and the Yukon Delta (Naidu et al., 1993), indicating a primarily terrigenous carbon source. In that same study, values were typically -20‰ to -23‰ in open water areas of the Chukchi Sea, where the sediments were less affected by the freshwater inflow from rivers. Less negative $\delta^{13}C$ values of carbonate-free surface sediments are indicative of primarily marine sources of carbon and more negative $\delta^{13}C$ values are indicative of sediments with primarily terrestrial sources of carbon.

Increased nutritive quality of food positively affects the growth of marine animals (Valiela, 1995). Carbon/nitrogen (weight/weight) ratios have been used as indicators of food quality in numerous Arctic benthic studies including Grebmeier (1987), Grebmeier and McRoy (1989), Feder et al. (1994b) and Grebmeier and Cooper (1995). Organic particles of terrestrial origin have relatively higher carbon/nitrogen (C/N) ratios than those derived from marine sources (Goodell, 1972). Higher quality marine food sources show relatively low C/N ratios (greater relative amounts of nitrogen to carbon) and lower quality marine food sources show high C/N ratios (lesser relative amounts of nitrogen to carbon).

In the polar regions, sediment chlorophyll-a concentrations are a measure of three types of primary productivity: carbon production from ice algae, carbon production from the water column and benthic algae. Carbon production from sinking ice algae and water column primary producers combine with benthic algae to constitute the algae available to consumers in the benthos. In the late winter and early spring when the ice-covered sea begins to melt, the large majority (up to about 99%) comes from the sinking of ice algae (Dayton, 1990). As the ice melts, water column primary production begins to play a greater role. In an investigation of the Northeast Water Polynya, Ambrose and Renaud (1995) found that sediment chlorophyll concentration was the most important predictor of infaunal density and polychaete biomass. Sediment chlorophyll-a values serve as an integrated measure of primary productivity available for consumption to the benthos (Ambrose and Renaud, 1995).

Benthic Community Structure

There have been a number of quantitative studies undertaken on the spatial distribution of benthic macrofaunal invertebrates in the eastern portion of the Chukchi Sea (e.g. Stoker, 1978, 1981; Grebmeier 1987; Grebmeier et al., 1988, 1989; Feder et al., 1994b), but there is little information on the benthos of the Chukchi Sea west of the international dateline and essentially no information on the benthic invertebrates of the East Siberian Sea. Even the classic summary of the early Soviet ecological investigations made in the 1930's - 1950's of the area, *Biology of the Seas of the U.S.S.R.* (Zenkevitch, 1963), contains very limited hydrographic information concerning the East Siberian Sea and there is only a small amount of quantitative information on the faunal distribution of the benthic invertebrates of the area.

Deposit-feeding benthic invertebrates feed by the ingestion of sediment and utilize the small particles of organic detritus accumulated within the sediment, while filter-feeding species feed by collecting food particles suspended in the water column (Barnes, 1980; Kozloff, 1990). Generally, sediments with a high percentage of silt and clay support relatively more deposit feeding invertebrates, while sediments with a high percentage of sand support relatively more filter feeding invertebrates. As the percentage of the silt and clay content in the sediment increases, the community composition can change from a majority of suspension-feeding species to a majority of deposit-feeding species (Gray, 1981).

The diversity of any community is a combination of the total number of species that it may theoretically contain, species richness, and the distribution of individuals between those species, species evenness (Shannon and Weaver, 1963). Gambi et al. (1997) demonstrated that species richness, diversity and evenness values of polychaete species increase with depth in Terra Nova Bay, Antarctica. Similarly, Long and Lewis (1987) showed that faunal diversity on the north shore of the Gulf of St. Lawrence increased with depth. Benthic diversity was higher in those regions of the Chukchi and northern Bering Seas with higher sediment silt and clay content and more heterogeneous sediment composition (Grebmeier et al., 1989). Unlike the above study, Feder et al. (1994b) found that differences in faunal diversity in the northeastern Chukchi Sea were not related to differences in sediment sorting, partially because the sediments were poorly sorted throughout the study area. They attributed differences in diversity to differences in environmental stresses (ice-gouging effects, high current flow, wave action, sediment reworking by sand dollars and benthic feeding by marine mammals; Feder et al., 1994b). Other hypothesized contributors to species diversity are competition and spatial patchiness of organic input. These studies show that the diversity of benthic macrofaunal assemblages is normally affected by a number of factors.

Objectives and Hypotheses: Benthic Macrofaunal Biomass and Community Structure

The objective of this study is to understand, by use of statistical techniques based on both species abundance and biomass, the spatial distribution and community structure of the benthic macrofaunal invertebrates of the East Siberian and western Chukchi Seas and their relationship to hydrographic, sedimentary and biological variables. The following hypotheses were tested:

1. Benthic production in the study area is most affected by factors associated with the influence of the Kolyma River and the Chukchi Sea. Benthic production will reach a maximum in those areas that demonstrate the following variable conditions: the greatest amount of organic carbon, the highest quality of organic carbon, shallow depth, warm bottom water temperatures, relatively high salinity, high bottom water macronutrient concentrations, high sediment chlorophyll-a concentration, high integrated water column chlorophyll values, low C/N ratios and less negative sediment $\delta^{13}C$ values.

2. The species diversity of the benthic macrofaunal invertebrates is at a minimum in those areas with relatively coarse, sandy sediment and low benthic production and will reach a maximum in those areas with both the greatest benthic production and the largest percentage of silt and clay in the sediments.

3. Sediment characteristics, most important among them sediment grain size, control the distribution of benthic invertebrates with differing feeding strategies in the study area. Following Gray (1981), sediments with a high

percentage of silt and clay will support relatively more deposit feeding invertebrates, while sediments with a high percentage of sand will support relatively more filter feeding invertebrates.

B. Natural and Artificially Introduced Radionuclides in Benthic Macrofaunal Invertebrates

The Bilibino Nuclear Power Station (BNPS) is a small nuclear power plant (about 1/100 of the power output of the Chernobyl Nuclear Power Station) located in Bilibino, Chukotka in the Russian Far East (Cooper et al., 1996). Four reactors were brought on-line between 1974 and 1976 to provide heat and power for local inhabitants. The BNPS is located 1300 km northwest of Nome, Alaska, and is the closest Russian nuclear power plant to the United States. It is conceivable that if significant releases of radionuclides were to occur at the BNPS, high levels of fission product radionuclides could be transported into the Kolyma River, and be transported eastward by the Siberian Coastal Current to the East Siberian and Chukchi Seas. It is possible that these radionuclides could become bioaccumulated into lower trophic levels of the marine food chain and then become concentrated in greater amounts in those species of fish and marine mammals consumed by man.

There have been no significant accidents at the BNPS. However, in the aftermath of the 1986 nuclear accident at the Chernobyl nuclear power plant and more recent discoveries of widespread dumping and radionuclide contamination in western parts of the Russian Arctic, it has become increasingly important to assess the state of radionuclide contamination of the entire Arctic, including the unassayed portions of the East Siberian and Chukchi Seas that are part of this study.

^{40}K: Background Information and Behavior in the Marine Environment

Potassium-40 (^{40}K) is the most common naturally-produced radionuclide in the earth's crust and decays by both beta emission (89.3%) to ^{40}Ca and also by electron capture (10.7%) to ^{40}Ar. The radioactive isotope ^{40}K is present as 0.012% of all potassium and has a half-life of 1.26×10^9 years (Eisenbud, 1987).

In seawater, the majority (>98%) of potassium is present as the potassium ion, K^+. The principle of constant proportion allows the determination of the amount of potassium present in seawater (Smith, 1974). Potassium is present in an almost constant ratio to the chlorinity of seawater throughout the world's oceans (Riley and Tongudai, 1967). Given the measured salinity of seawater, it is possible to determine the amount of potassium present and therefore the amount and activity of ^{40}K present in the seawater sample. On average, a liter of seawater (at a salinity of 35 parts per thousand, ppt) contains about 4.5×10^{-8} g mL^{-1} of ^{40}K with 1.1×10^{-2} Bq mL^{-1} (Horne, 1969). Therefore, each liter of seawater contains about 11 Bq of radioactivity due to ^{40}K. ^{40}K is the principal contributor to the natural radioactivity of the world's oceans, being responsible for more than 90% of the total natural radioactivity of seawater (Horne, 1969).

The world average of the ^{40}K activity in soil is 370 Bq kg^{-1} (Tykva and Sabol, 1995). ^{40}K is also present in sedimentary limestone (70 Bq kg^{-1}) sandstone (300 Bq kg^{-1}) and shale (700 Bq kg^{-1}) (Tykva and Sabol, 1995). ^{40}K activities in sediments are a reflection of sediment composition; quartz rich sandy sediments are characterized by low K values in marine environments (Zucker et al., 1984).

^{137}Cs: Background Information and Behavior in the Marine Environment

Concentrations of naturally-occurring cesium (Cs) varies widely in different environments. Various soil types contain between 0.3 and 25 µg Cs g^{-1}, while basalt rocks contain approximately 1 µg Cs g^{-1} (Avery, 1996). Naturally-occurring cesium is more dilute in aquatic systems, with concentrations ranging from 0.01 to 1.2 ng mL^{-1} in freshwater habitats and approximately 0.0005 to 2.0 ng mL^{-1} in marine habitats (Komorov and Bennet, 1983).

^{137}Cs (fission product, 30.2 year half-life) accumulates in biological food chains. There is also evidence that cesium can displace cellular potassium in humans (Bramham and Riddell, 1994). It is reasonable to assume that this preference may occur in other biota and further increase accumulated amounts and biological half-lives of radiocesium in these organisms, once introduced into the body.

The distribution of ^{137}Cs between soluble and sediment-bound phases is variable. Cesium associated with sediment binds irreversibly to clay-sized (<63 µm) particles. Higher levels of ^{137}Cs have been shown to be associated with sediments with higher percentages of clay-sized particles in the James River Estuary (Zucker et al., 1984). Given these properties of cesium in the marine environment, it can be predicted that higher amounts of ^{137}Cs would be associated with sediments in areas with higher percentages of clay-sized sediment particles. Also, in near-shore areas, sediments act as a cesium sink (Nakamura and Nagaya, 1985). The incorporation of ^{137}Cs into benthic marine sediments can be facilitated by the settling of cesium-associated solid particles (i.e. fecal pellets) down in the water column and in many cases these solids can have a higher affinity for Cs^+ than for K^+ (Komarov and Bennett, 1983).

Objectives and Hypotheses: Bioaccumulation of ^{137}Cs and ^{40}K in Marine Benthic Macrofaunal Invertebrates

The feeding strategy of a particular organism influences its ability to bioaccumulate ^{137}Cs and ^{40}K. Fecal pellets and dead plant and animal remains settle to the bottom and are mixed in the sediment. Deposit-feeding benthic invertebrates consume this deposited material and utilize the organic material as a food source. ^{137}Cs associated with clay-sized sediment particles and ^{40}K in the minerals themselves can become incorporated into the animals' body as a result of this feeding activity. Therefore, deposit-feeding benthic macrofaunal invertebrates should accumulate greater amounts of ^{137}Cs and ^{40}K in their tissues than would animals with other feeding strategies.

It is also reasonable to expect that invertebrates that can feed at higher trophic levels, i.e. carnivores and scavengers, have concentrated greater amounts of radionuclides than those that feed at lower trophic levels. Carnivorous and scavenging invertebrates have the opportunity to consume prey that have already accumulated radionuclides into their bodies, therefore increasing the radionuclide levels in their tissues.

The main goal of the radionuclide portion of the study is to determine if benthic macrofaunal invertebrates of the East Siberian Sea have accumulated radionuclides in significant amounts. Two hypotheses are posed to test the factors important in the distributions of radionuclides among geographic regions and among various invertebrates.

1. Benthic macrofaunal invertebrates in areas with higher percentages of clay-sized particles concentrate higher amounts of radiocesium.

2. Deposit-feeding, carnivorous or scavenging benthic invertebrates accumulate radionuclides in higher amounts than filter feeding invertebrates.

C. Study Area and Hydrographics

The study area extends from the mouth of the Kolyma River north of the Chukotka, Russian Federation coast and continues to the Bering Strait (Figure 1). The northernmost limit is Wrangel Island and the latitudinal line 71° N in the central and western part of the study area and 68° N in the eastern part of the study area. The westernmost limit is the mouth of the Kolyma River. The easternmost limit is bounded by the longitudinal line 168° W. The study area is situated on a broad (up to 800 km), shallow (<50 m) continental shelf (Zenkevitch, 1963). The East Siberian and Chukchi Sea shelves are normally covered with sea ice from November through June (Carey, 1991), although there is considerable variation in the mean ice limit from year to year in the Chukchi Sea (Zenkevitch, 1963). Figure 1 shows the general ice coverage of the East Siberian and Chukchi Seas between 17 August through 5 September, 1995.

The discharge of rivers emptying into the East Siberian Sea varies seasonally with more than 90% of the total discharge taking place in June, July, August and September (Naugler et al., 1974). The largest of these rivers, the Kolyma, drains an area of about 644,000 km^2, has an annual water discharge of 102 to 120 $km^3\ yr^{-1}$ and deposits a sedimentary load of 4.7×10^6 tons yr^{-1} into the East Siberian Sea (Naugler et al., 1974; Aagaard and Carmack, 1989; Pavlov et al., 1994). This freshwater inflow lowers the salinity of the East Siberian Sea to about 10‰ near the mouth of the Kolyma River, increasing to about 33‰ in the

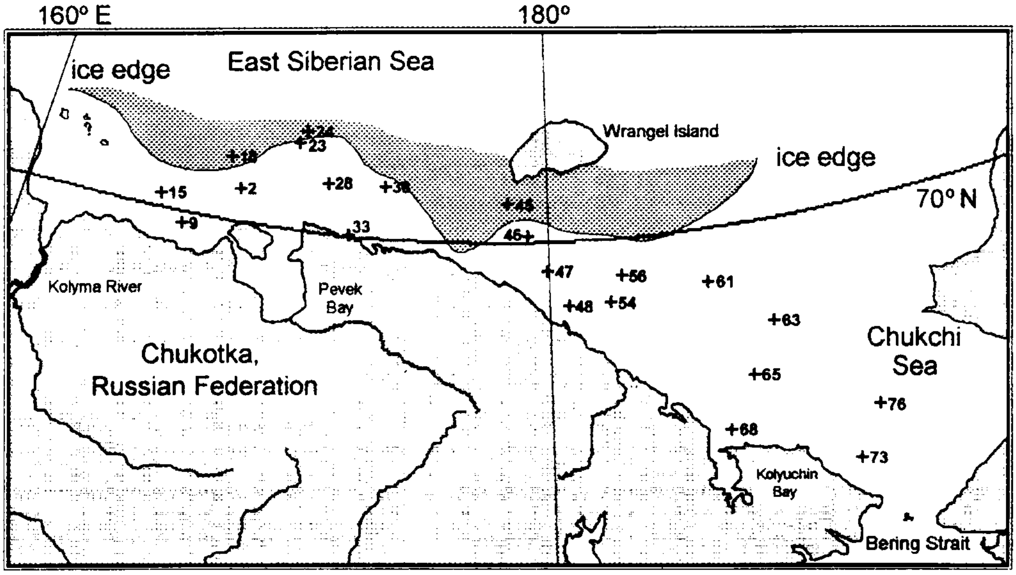


Figure 1. Station locations including the ice edge for cruise HX-189 to the East Siberian and Chukchi Seas (17 August through 5 September 1995).

bottom waters near Wrangel Island at the East Siberian/Chukchi Sea interface (Zenkevitch, 1963).

The Siberian Coastal Current (SCC) is a wind and buoyancy-forced coastal current flowing eastward along the East Siberian Sea coast into the western Chukchi Sea (Golikov et al., 1991; Weingartner et al., 1996). The main mass of the SCC turns back into the southern part of the Chukchi Sea, but a small part of it can enter Bering Strait (Zenkevitch, 1963). The SCC consists of relatively fresh water discharged from the Kolyma River and probably the Indigirka and Lena Rivers from the Laptev Sea shelf further to the west. The SCC is bounded by the Chukotkan coast to the south and by warmer, more saline Bering Sea water 120 km offshore to the north. This freshwater inflow from the Kolyma River greatly influences the hydrographics of the area, although unlike 1992 and 1993, the SCC in the summer and fall of 1995 was virtually absent from the Chukchi Sea (Weingartner et al., 1996). Fresh water from the Kolyma River is directed eastward into the East Siberian Sea by the Siberian Coastal Current where it is undercut by warmer, more saline Pacific-influenced water (Figure 2). This cold, coastal current is sluggish, with speeds generally less than 15 cm s^{-1}, is not well developed and varies seasonally as well as locally under the prevailing wind conditions (Naugler et al., 1974). Tidal current speeds generally do not exceed 20 cm s^{-1} and the tidal range is less than 20 cm along the coast (U.S. Navy Hydrographic Office, 1954). Because of the fine grain size of the input material from rivers, the low energy currents and small tidal range, the sediments of the East Siberian Sea are generally extremely fine grained, although there are localized areas of higher percentages of larger grain sizes thought to be the result of ice rafting (Naugler et al., 1974).

A relatively warm and strong current flows north into the southern Chukchi Sea through Bering Strait (Grebmeier and McRoy, 1989; Grebmeier et al., 1989) with only a small amount of Chukchi Sea water occasionally flowing southward into the northern Bering Sea (Zenkevitch, 1963). This current is divided into two distinct water masses: the low temperature, high salinity and highly productive Bering Shelf-Anadyr Water (BSAW) to the west and the warmer, low salinity and less productive Alaska Coastal Water (ACW) to the east (Grebmeier et al., 1989). BSAW water flows north through Bering Strait and is bathymetrically steered to the west into the Chukchi Sea portion of the study area about 120km north of the Chukotkan coast, while ACW water is steered to the east just north of the Seward Peninsula and skirts the Alaskan coastline (Grebmeier et al., 1989). The major current regimes of the East Siberian and Chukchi Seas are shown in Figure 2.

II. MATERIALS AND METHODS

All data for this study were collected as a part of a larger project jointly undertaken by Russian and U.S. scientists while aboard the 189th cruise of the R/V *Alpha Helix* between 18 August and 5 September, 1995. This project was funded by the Arctic Nuclear Waste Assessment Program (ANWAP), U.S. Office

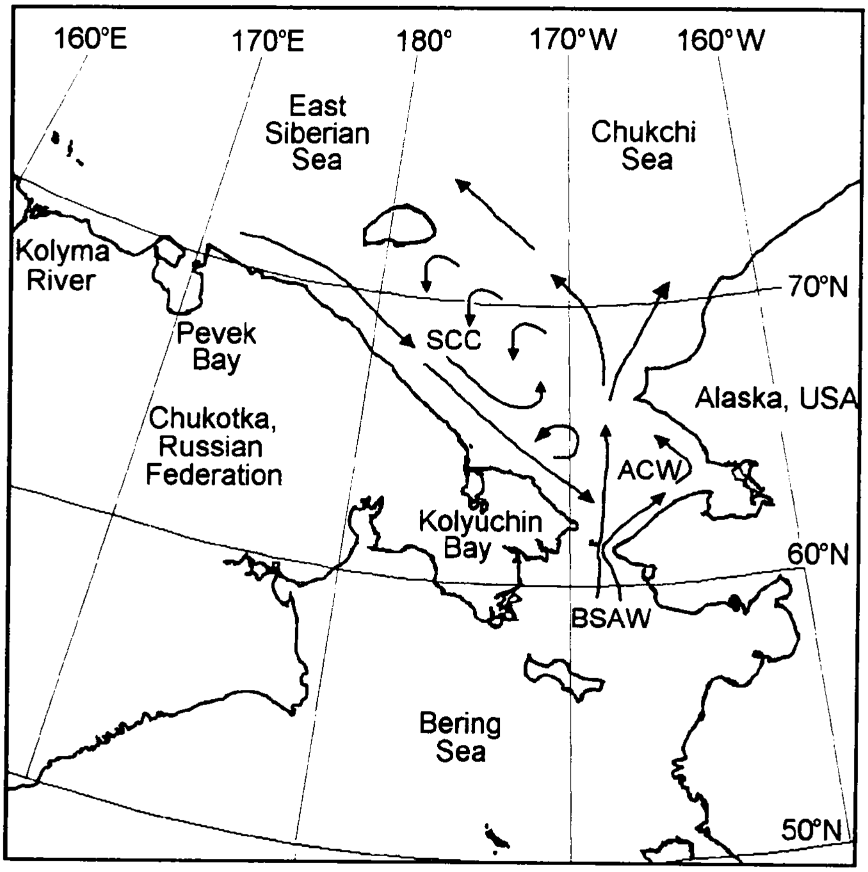


Figure 2. Major current regimes of the East Siberian and Chukchi Seas, showing the Siberian Coastal Current (SCC) and the location of Alaska Coastal Water (ACW) and Bering Shelf/Anadyr Water (BSAW). Adapted from Zenkevitch (1963); Naugler et al., (1974) and Grebmeier et al., 1989.

of Naval Research. The objective of the larger project was to collect sediment, water and biological samples to study oceanic processes and assess anthropogenic contaminant levels, both radioactive and organic, present in the regions of the East Siberian and Chukchi Sea influenced by the Kolyma River discharge. This project allowed the opportunity for the collection of samples used in this thesis.

A. Hydrographic Measurements

Seawater samples were collected using a conductivity-temperature-depth (CTD) profiler equipped with a Niskin bottle rosette for collecting water samples at 5 m increments throughout the water column. The CTD profiler was used to collect temperature and salinity measurements and water for chlorophyll-a and biological macronutrient determinations. Nutrient samples (nitrate, phosphate and silica) were collected with the CTD/rosette water sampler at approximately 5 m from the bottom. Nutrient samples were collected in acid-washed plastic vials, frozen and sent to the University of California at Santa Barbara for analysis on a Model 240XA CHN (carbon, hydrogen, nitrogen) analyzer using standard analytical methods. The hydrographic data collected from all 22 stations for bottom water temperature, salinity, sigma-t and depth, along with the three bottom water macronutrients were all included as input variables in the principal components analysis.

Water column and surface sediment samples were collected for the quantification of chlorophyll-a (Grebmeier and Cooper, 1996, unpublished data). Water column chlorophyll samples were collected in clean 250 mL plastic bottles and filtered through precombusted Gelman® glass fiber microfilters. The filters were homogenized and the chlorophyll was extracted in 90% acetone. Sample chlorophyll-a was analyzed shipboard using a calibrated Turner Designs fluorometer using the techniques described in Parsons et al. (1984). Sediment chlorophyll samples were taken by collecting a 2 cm^3 plug (diameter= 1.4 cm) of surface sediment using a modified syringe, placed in centrifuge tubes with 10 mL of 90% acetone and stored for 12 hours in a refrigerator before quantification of chlorophyll-a. Extracted sediment was returned to the laboratory for drying and weight determinations. Chlorophyll-a values for the surface sediments as well as the integrated water column chlorophyll-a values were included as input variables in the principal components analysis.

B. Sediment Parameters

Surface sediment samples were taken from each station with a single van Veen grab, placed into Whirl-pak bags, frozen and returned to Oak Ridge National Laboratory for analysis. The sediment samples were first dried and homogenized, then approximately 20 g (dry weight) were placed in containers and the organic matter was removed by the addition of 30 mL of hydrogen peroxide. Iron oxides were removed by the addition of a sodium citrate buffer solution, heat (80 °C) and repeated centrifugation for 5 minutes at 1500 rpm. After this initial processing, individual sediment grains <5 phi were separated from smaller grains (silt and clay, $\geq$5 phi) by wet-sieving using standard geological sieves. Sediment grains less than 5 phi were separated into the standard sizes of 0, 1, 2, 3 and 4 phi by dry sieving on a sieve shaker. Sediments 5 phi and greater were separated into clay and silt fractions by flocculation with magnesium chloride and centrifugation. Sediment grain size analysis was performed using techniques adapted from Krumbein and Pettijohn (1938), Royse (1970), Carver (1971), Stockham and Fochtman (1977), Buchanon (1984), Blake and Hartge (1986), Kunze and Dixon (1986) and Gee and Bauder (1996). A complete protocol for the sediment grain size analysis for this study is appended (Appendix A). The weights for individual phi sizes and individual weight percents for each station were recorded. The modal phi size was computed for each station and used as a variable for the principal components analysis.

One g subsamples were acidified with two mL of 1N HCl and dried overnight to obtain carbonate-free sediments. The carbon/nitrogen (wt./wt.) ratio of the organic portion of the sediments was measured on a Model 240XA CHN analyzer (Control Equipment Corp., Lowell, Massachusetts) at the University of California, Santa Barbara. The carbonate-free sediments were analyzed for stable carbon isotope composition following the methods of Cooper et al. (1998). The sediments were combusted in vacuo at 875 °C for two hours in 9 mm O.D. Vycor glass tubing, in the presence of 1 g cupric oxide, 1 g copper and silver foil. A programmable furnace with a slow cool-down function was used to prevent the production of oxides of nitrogen (Lajtha and Michener, 1994). Following isolation of CO_2 gas, stable carbon isotope measurements were determined using a VG SIRA Series II dual inlet stable isotope mass spectrometer at the Environmental Sciences Division, Oak Ridge National Laboratory. Precision was determined to be +/- 0.11‰ (standard deviation) based upon replicate analyses of one of the sediment samples. Calibration of the internal standard used was assured through concurrent processing of a sample of the NBS-22 oil standard. The $\delta^{13}C$ value is reported in terms of δ values, which are expressed as parts per thousand differences from the PDB standard using the equation:

$$\delta^{13}C = [(^{13}C/^{12}C_{sample}) / (^{13}C/^{12}C_{standard}) - 1] \times 10^3$$

For example, more negative $\delta^{13}C$ values are indicative of organic sediment more depleted in the heavier ^{13}C isotope. Both the C/N ratio (Grebmeier and Cooper, 1996, unpublished data) and the $\delta^{13}C$ value were calculated for each station and used as input variables in the principal components analysis.

C. Sampling and Statistical Analysis of Benthic Macrofaunal Invertebrates

Four replicate samples were collected from each of 22 stations (Figure 1). Benthic macrofaunal invertebrates were collected, processed and preserved using techniques previously used by Grebmeier and Cooper (1995), as well as Feder et al. (1994b). Faunal samples were taken with a 0.1 m^2 van Veen grab weighted with 32 kg of lead to improve sediment penetration. The van Veen grab was used with the assumption that it is unable to consistently capture deep-dwelling bivalves in the families Myidae and Matricidae (Stoker, 1978 and Grebmeier, 1987) that may have been expected in the area (Zenkevitch, 1963). After retrieval, samples were washed with seawater through 1 mm stainless steel screens. The animals were then preserved in 10% formalin in sea water buffered with hexamethyltetramine, stored in plastic containers and saved for laboratory analysis at the University of Tennessee. The animals were keyed to species level or the lowest taxon possible. The identification of samples was accomplished using the keys and guides of Zenkevitch (1963), Pavlovskii (1966), Fedyakov and Naumov (1989), Vassilenko (1989), Foster (1991) and Kozloff (1996). Additional taxonomic information was obtained from comparisons with studies from adjacent areas (Grebmeier, 1987; Grebmeier et al., 1989; Feder et al., 1994a; Feder et al., 1994b) and other Arctic benthological investigations (Kröncke, 1994). The preserved animals were blotted dry, counted and wet weighed to determine an initial wet-weight biomass. The wet-weight biomass values were converted to organic carbon biomass values using the same conversion factors used by Stoker (1981), Grebmeier (1987), and Feder et al. (1994b) to facilitate direct comparisons of biomass calculations between this study and studies of adjacent areas. The organic carbon conversions eliminate the influence of calcium carbonate found in the shells of mollusks and the tests of echinoids and foraminiferans on biomass. The organic conversion values used are in Appendix B. Biomass and abundance values were quantified as grams of C m^{-2} and individuals m^{-2}. Dominant species are defined as those with biomass or abundance values that are an order of magnitude above other species from the station. Just as in other recent benthic macrofaunal surveys in adjacent areas, such as Grebmeier (1989) and Feder et al. (1994b), most highly motile epifaunal invertebrates, including the predatory gastropod *Natica clausa*, shrimps, crabs and most sea stars, were excluded from the benthic biomass database. The epifaunal isopod *Idotea ochotensis* as well as the infaunal sea star *Ctenodicus crispatus* were, however, included in the analysis. Colonial organisms, such as the bryozoan *Alcyonidium vermiculare* and the soft coral *Eunephyta rubiformis*, were given an abundance value of 1 per colony.

The patterns of faunal distribution and community structure of macrofaunal assemblages were examined using classification techniques and measures of species dominance and diversity. Species diversity, a measure of the relationship between species richness (a function of the number of species in a community) and the distribution of individuals among species (Burd, et al., 1990) was estimated by calculating the Shannon-Weaver diversity index, H′ (Shannon and Weaver, 1963; Pielou, 1966):

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where s is the number of species, n_i is the number of individuals of the *i*th species, N is the total number of individuals and $p_i = n_i / N$, for the *i*th species.

A species evenness (J′) index was calculated after Pielou (1966) as:

$$J' = H' / \log S$$

where H′ is the Shannon-Weaver diversity index and S is the number of species. Evenness values approach zero when the species abundance for a few, dominant species is high and are 1.0 when all of the species present are represented by an equal number of individuals.

Margalef's species richness index, (SR), was calculated following Margalef (1958) using the equation:

$$SR = (S-1) / \ln N$$

where S is the number of species and N is the number of individuals in the sample.

The Bray-Curtis dissimilarity coefficient, δ, was calculated between every station combination using the formula from Bray and Curtis (1957) and Clarke (1993). The Bray-Curtis dissimilarity coefficient is also called the "index of affinity", "percentage similarity" or the Czekanowski coefficient in other studies (Burd et al., 1990). Because the Bray and Curtis dissimilarity measure on untransformed data increases the influence of taxa with high abundances (Boesch, 1973), natural log-transformed abundance values, ln(x+1), were used to increase the importance of less abundant taxa without an excessive decrease in the importance of more abundant taxa (Field et al., 1982).

The Bray-Curtis dissimilarity coefficient, d_{jk}, between any two stations j and k is defined as:

$$\delta_{jk} = \sum_{i=1}^{p} \delta_{jk}(i)$$

where

$$\delta_{jk}(i) = 100 \left| y_{ij} - y_{ik} \right| / \sum_{i=1}^{p} (y_{ij} + y_{ik})$$

and p = number of species and y_{ij} = transformed abundance or biomass of the *i*th species in the *j*th sample. Two matrices, one based on species abundance and one based on species biomass, were constructed using the Bray-Curtis similarity index. These matrices were used as the input for the hierarchial cluster analysis.

The use of combined abundance and biomass descriptions of benthic communities is becoming of increasing interest among benthic ecologists (Burd et al., 1990). A numerical cluster analysis using the program COMPAH (Gallagher, 1996) was performed to cluster the 22 stations by both faunal abundance and by faunal biomass. This program groups stations together based on faunal similarities based on the Bray-Curtis similarity coefficient (Gallagher, 1996). This similarity coefficient has been used extensively as input for cluster analysis in many other soft-bottom benthic studies (Grebmeier, 1987; Grebmeier et al., 1989; Warwick et al., 1990; Clarke and Ainsworth, 1993; Branch et al., 1993; Warwick and Clarke, 1993; Feder et al., 1994b; Kröncke, 1994; Long et al., 1995; Briggs et al., 1996; Gambi et al., 1997) and has been shown to accurately reflect actual relationships in benthic studies using both real data and simulated data (Stauffer et al., 1985). Of the preceding soft-bottom benthic studies, only Briggs et al. (1996) clusters stations by both faunal abundance and faunal biomass.

Each cluster analysis underwent an optimal rotation of the results of the hierarchical cluster linkage and was plotted as a dendrogram. An ecologically meaningful number of clusters was determined by comparing the similarity levels between clusters and examining the results plotted on a map of the study area. The dominant species, by both abundance and biomass, as well as the mean abundance and biomass for each cluster were compiled.

The objective of any principal components analysis (PCA) is to describe the variation of a set of multivariate data in terms of a set of uncorrelated variables, each called a principal component (Everitt and Dunn, 1991). Principal components analysis was used in this study to reduce the number of intercorrelated hydrographic, sedimentary and biological variables to a set of principal components (uncorrelated variables) that retain the majority of the information contained in the original variables. The PCA for this study was performed using the commercial software program STATISTICA (Statsoft Inc., 1996). The principal component axes were rotated using the Varimax technique. After the extraction of the first principal component, other principal components that maximized the remaining variability were extracted. The principal components were extracted in decreasing order of importance, that is, principal component 1 (PC1) accounts for as much as possible of the variation in the original data, PC2 accounts for a maximum amount of the remaining variation, etc. and were named in this order. The number of principal components extracted was determined following an examination of the scree plot of eigenvalues (Everitt and Dunn, 1991; Jackson, 1993; Rencher, 1995). The PCA axes were interpreted by examination of the factor loadings (correlations) between the environmental variables and the principal component axes. Both the factor loadings of the environmental variables on each principal component and the factor scores of each station on each principal component were computed and ordinated.

Fauna were categorized into feeding strategies after Fauchald and Jumars (1979), Stoker (1981), Grebmeier (1987) and Aitken and Fournier (1993). Animals were sorted into five groups according to feeding strategy:

C/S group: carnivores and carnivore/scavengers

DF group: deposit feeders (surface and subsurface)

FF group: filter feeders

SDF/FF group: deposit feeders that are also filter feeders

C/S/SDF group: deposit feeders that are also scavengers and/or carnivores

Mean percentages for individual feeding strategy groups were calculated for individual stations and clustered station groups.

D. Detection of Gamma-Ray Emitting Radionuclides

Twenty-eight samples representing sixteen stations were analyzed for the presence of natural and anthropogenically introduced gamma emitting radionuclides using a lead shielded, solid-state Intrinsic Germanium Detector (IGe) coupled to a Nuclear Data 6700 microprocessor programmed to acquire spectra in 4096 channels with gamma-ray energies ranging from 60 to 1850 KeV. These analyses were carried out at the Environmental Sciences Division of Oak Ridge National Laboratory. This detector undergoes a daily calibration check as well as a weekly calibration check using standard samples that have traceability to the U.S. National Institute of Standards and Technology (NIST) and the U.S. Environmental Protection Agency (EPA). Background corrections were performed and control samples were counted to verify detector performance.

Samples were counted in containers with various "geometries" to achieve the best balance between large sample size and the particular photon efficiencies of different container sizes. Four geometries were used in this study. A 15 cm^3 petri dish was used to try to quantify radionuclide activities in small samples because of its' very high photon efficiency (4.25%). Plastic dishes of 200 mL and 400 mL as well as 500 mL and 1000 mL Marinelli beakers were also utilized. Marinelli beakers (1.71% photon efficiency for 500 mL and 1.24% photon efficiency for 1L), 200 mL dishes (1.96% photon efficiency) and 400 mL dishes (1.02% photon efficiency) gave optimal combinations of volume and photon efficiency for these analyses. The photon efficiencies for the containers were calculated at 662 KeV. Counting times ranged from 24 to 72 or more hours. In reporting the data, a trace was defined as a positive signal with an uncertainty greater than 50%. Signals detected with an uncertainty less than 50% were quantified and reported in Becquerels (Bq), which is equal to one radioactive decay per second.

Two strategies were used to try to quantify any radionuclides present. Individual species and groups of similar types of animals were counted after they had been drained of all formalin, rinsed with water, sorted and stored in 50% propanol. Samples labeled "grab in formalin" were samples still in the original formalin with all pebbles, organic material and debris still present. These samples were counted in this unprocessed state to eliminate the possibility of not detecting radionuclides that had been leached from the bodies of the animals and were soluble in the propanol or formalin, and consequently subject to discard. It was surmised that samples counted in this unsorted state would provide the best opportunity to detect all anthropogenically introduced radionuclides present at individual stations. Sample stations were chosen to represent near-shore and offshore stations as well as both eastern and western stations.

III. RESULTS

The latitudes, longitudes, depths and the date sampled for the twenty-two stations are listed in Appendix C. The raw data for sediment parameters is in Appendix D and the raw data for hydrographic parameters is in Appendix E. Samples were collected and analyzed for all seventeen variables at all twenty-two stations, except station 36 where sediment chlorophyll-a data was unavailable and station 68, where C/N ratio data was unavailable. Temperature and salinity values identify a transition zone between ESSW and BSAW. All samples were collected during cruise 189 of the R/V *Alpha Helix* between 18 August and 5 September 1995.

A. Hydrographics

Two major water masses dominated the hydrographics of the area: East Siberian Shelf (ESS) water (bottom salinity = 29.0 ppt (parts per thousand) to 32.5 ppt; bottom temperature = -1.9 to 0 °C) and Bering Shelf/Anadyr (BSAW) water (bottom salinity > 32.5 ppt; bottom temperature = -1.0 to 3.0 °C). The BSAW water indicated in this study is the same water mass described by Grebmeier et al. (1988). The transition zone separating the two water masses was identified south of Wrangel Island in the central portion of the study area (Figure 3).

Hydrographic measurements indicate that fresh water from the Kolyma River was limited to the East Siberian Sea during this period (Grebmeier and Cooper, unpublished data). Bottom water salinity was 29.0 ppt near the Kolyma River mouth and steadily increased eastward into the Chukchi Sea (Figure 4). Maximum bottom salinity values (> 32.5 ppt) were recorded in the transition zone and into the Chukchi Sea. The coldest bottom water temperatures (-1.7 °C) were recorded in the East Siberian Sea and the transition zone, with warmer temperatures characterizing the Chukchi Sea (up to 2.2 °C) (Figure 5).

Depths were shallow throughout, with the maximum depth no greater than 50 m (Figure 6). The shallowest depth was 16 m at station 15 in the East Siberian Sea and the maximum depth, 50 m, was station 61 in the Chukchi Sea. Generally, depths are shallowest in the East Siberian Sea and increased to between 40-50 m in the Chukchi Sea. Depths were less than 30 m at nearshore stations throughout the study area.

Sigma-t (σ_t) values are a measure of the *in situ* density of seawater at a given temperature. Sigma-t is defined as: $\sigma_t = (\rho - 1)1000$ where ρ is the relative density at temperature, T (Millero, 1996). The distribution of σ_t values for the

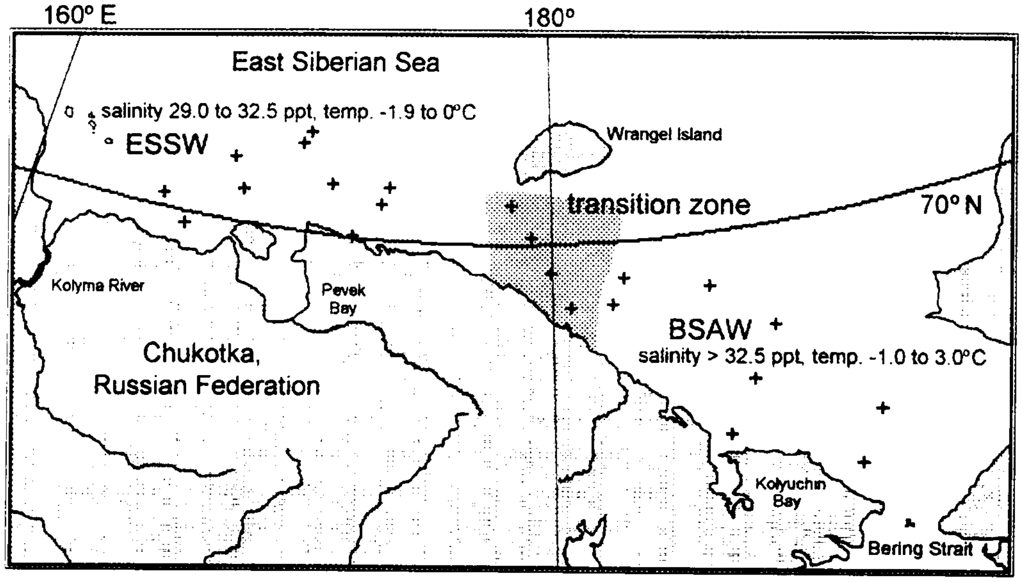


Figure 3. Relative locations of East Siberian Shelf Water (ESSW) and Bering Shelf/Anadyr Water (BSAW) during HX-189. Zones are based on bottom water salinity and temperature.

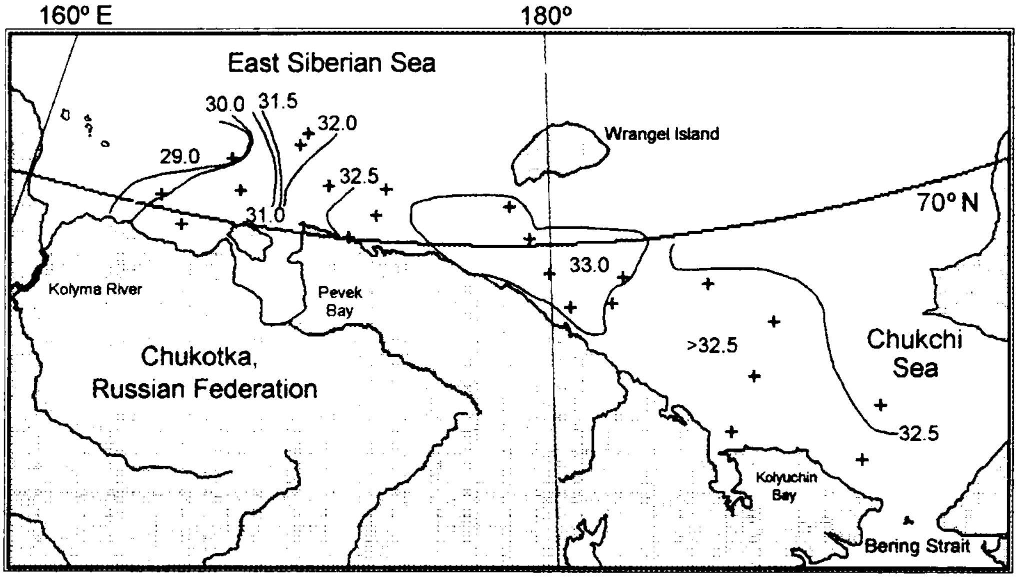


Figure 4. Distribution of bottom water salinity (ppt) for cruise HX-189 (17 August through 5 September 1995).

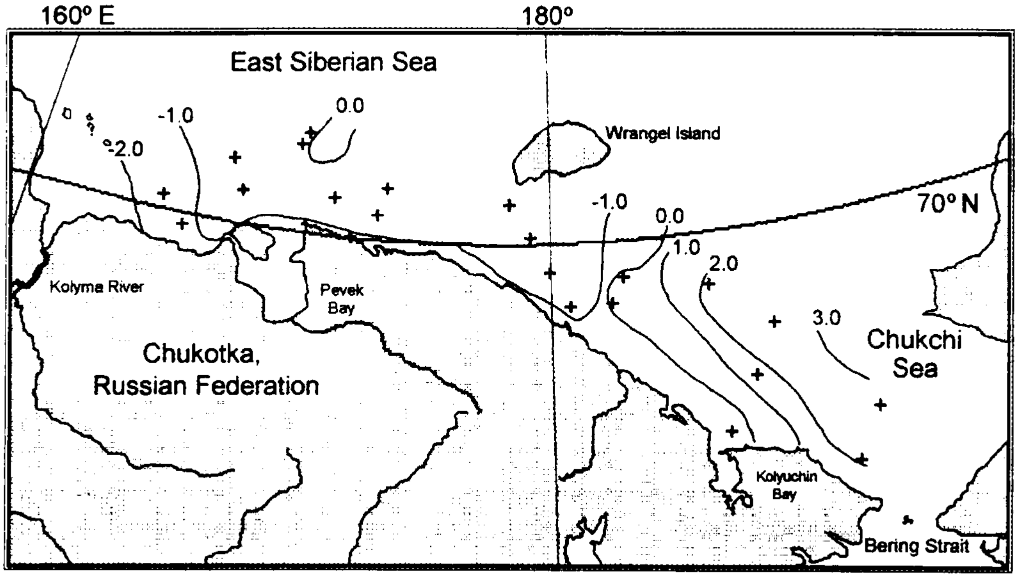


Figure 5. Distribution of bottom water temperatures for cruise HX-189 (17 August through 5 September 1995).

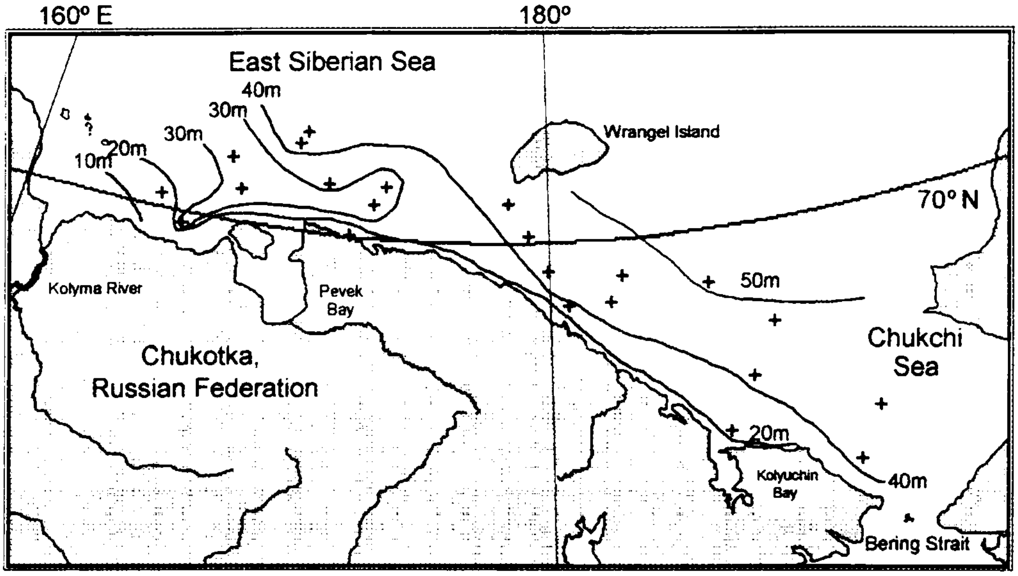


Figure 6. Bathymetry (m) for the East Siberian and Chukchi Seas, cruise HX-189 (17 August through 5 September 1995).

East Siberian and Chukchi Seas are shown in Figure 7. The minimum σ_t value was at station 15, closest to the mouth of the Kolyma River. The maximum value was at station 45, just south of Wrangel Island. Generally, σ_t values were lowest near the Kolyma River mouth (24.3 to 25.6) and increased eastward to between 26.0 and 26.5 in the Chukchi Sea.

The integrated chlorophyll values of the overlying water column (mg m^{-2}) concentrations were generally greater in the East Siberian Sea and decreased in the Chukchi Sea (Figure 8). The highest value (657 mg m^{-2}) was at station 23 in the East Siberian Sea and the lowest value (23 mg m^{-2}) was at station 46, south of Wrangel Island.

Bottom water chlorophyll-a concentrations (mg m^{-3}) were generally greater in the East Siberian Sea and decreased in the Chukchi Sea (Figure 9). Values ranged from 1.5 to 68.4 mg m^{-3} in the East Siberian Sea and 0.6 to 17.7 mg m^{-3} in the Chukchi Sea. The maximum concentration, 68.4 mg m^{-3}, was at station 15 in the East Siberian Sea near the Kolyma River mouth and the minimum concentration, 0.6 mg m^{-3}, was at station 56, offshore in the Chukchi Sea.

Bottom water macronutrient values are shown in Table 1. Nitrate concentrations ranged from 0.5 μM at station 15 in the East Siberian Sea to 18.0 μM at station 45, just south of Wrangel Island. Nitrate concentrations were relatively low in the East Siberian Sea (mean= 8.1 μM), increased at the seven stations south of Wrangel island in the central portion of the study area (mean= 12.0 μM), and decreased at the five stations closest to Bering Strait in the

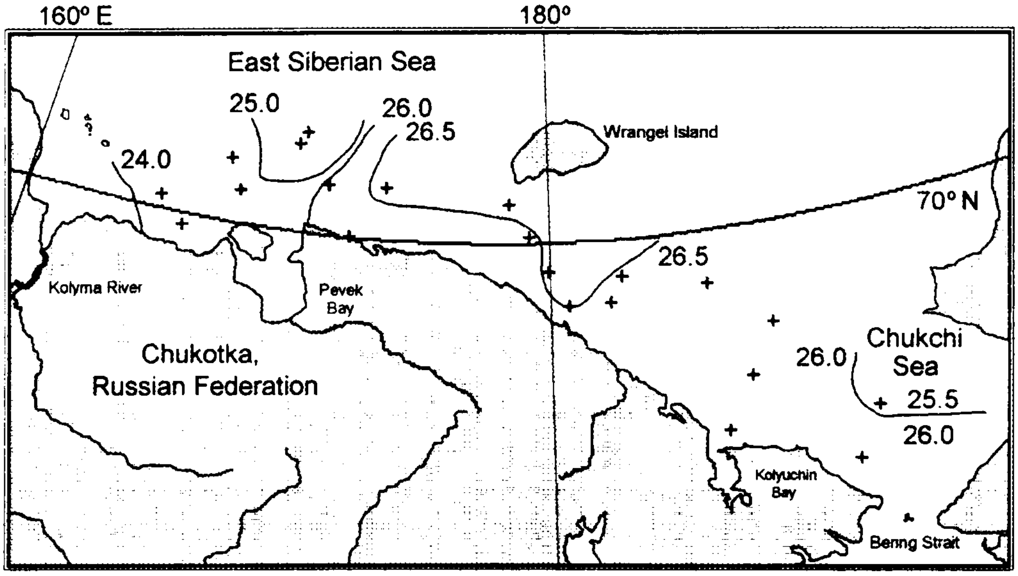


Figure 7. Distribution of bottom water sigma-t values for HX-189 (17 August through 5 September 1995).

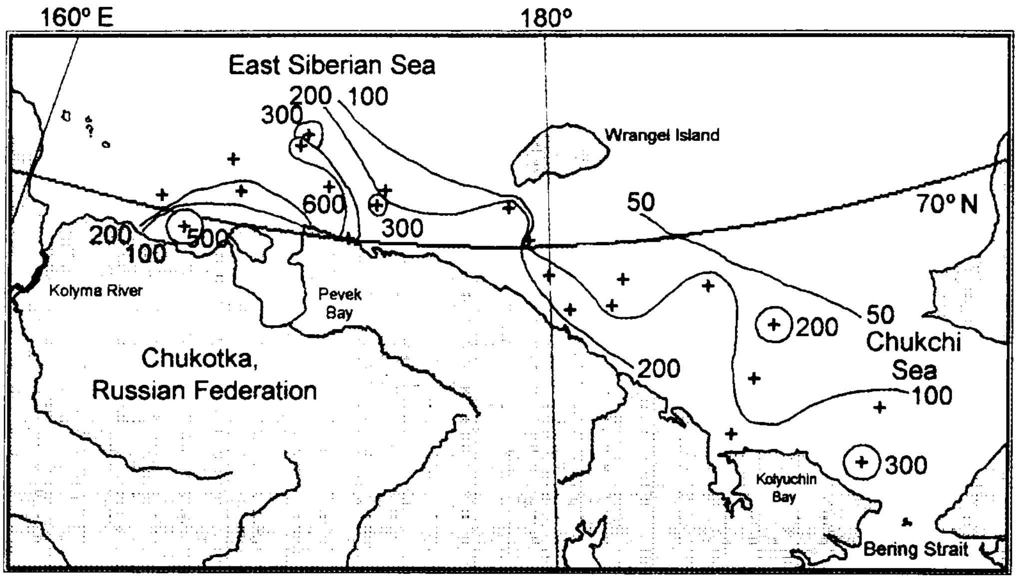


Figure 8. Distribution of integrated chlorophyll values (mg chl. m^{-2}) for HX-189 (17 August through 5 September 1995).

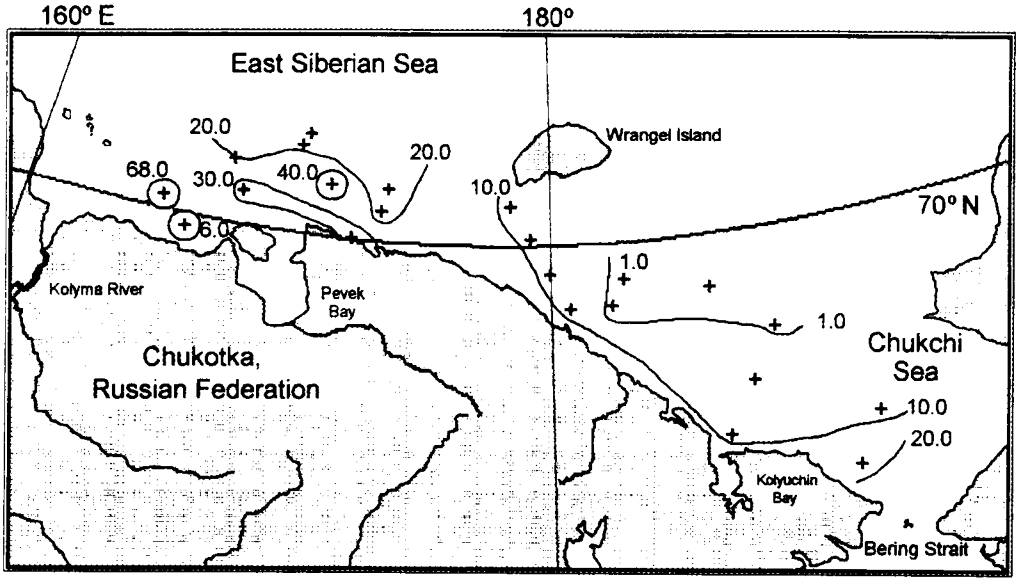


Figure 9. Distribution of bottom water chlorophyll-a concentrations ($mg\ m^{-3}$) for cruise HX-189 (17 August through 5 September 1995).

Table 1. Biological macronutrients of bottom waters for individual stations during cruise HX-189 (17 August through 5 September 1995).

HX-189 Station	Silica µM	Phosphate µM	Nitrate µM
2	36	2.9	8.2
9	44	2.5	9.5
15	19	0.8	0.5
18	28	1.6	5.6
23	45	2.7	11.6
24	41	2.6	8.6
28	15	2.1	6.0
33	36	1.8	6.4
35	23	1.4	8.6
36	43	2.3	16.0
45	48	2.4	18.0
46	50	2.9	17.6
47	5	0.1	0.5
48	50	2.6	16.4
54	0	1.5	7.5
56	11	2.3	10.7
61	18	2.5	13.2
63	19	2.0	14.4
65	12	2.7	10.0
68	14	1.7	7.4
73	24	2.1	18.0
76	16	1.7	8.5

Chukchi Sea (mean= 7.9 μM). The lowest bottom water concentration of phosphate was 0.1 μM at station 47 in the western Chukchi Sea and the highest (2.9 μM) at station 9 near the Kolyma River mouth. The distribution of bottom water phosphate was more uniform when compared to the other macronutrients. Average values were close to 2.1 μM at the eastern, central and the western portions of the study area. Silica bottom water concentrations ranged from 50 μM at stations 46 and 48 to below detection at station 54. The highest average silica concentration was in the westernmost portion of the study area (mean= 33.0 μM), decreased in the central portion (mean= 25.9 μM) and decreased again in the easternmost portion (mean= 17.0 μM).

B. Sediment Characteristics

Sediment grain size analysis was completed on all stations as part of the larger project. Sediments in the East Siberian Sea were typically dominated by silt and clay sized (>4 phi) grains while the Chukchi Sea demonstrates a majority of 3 and 4 phi sized grains at nearshore stations and stations close to Bering Strait. The percentage of silt and clay sized sediment grains in sediments increases with increasing distance from shore in both the Chukchi and East Siberian Seas (Figure 10). The majority of stations show a modal phi size of 5-9 phi (silt-sized grains) with 14 modal phi size (clay-sized grains) dominating the sediments at some of the offshore stations in the East Siberian Sea (Figure 11).

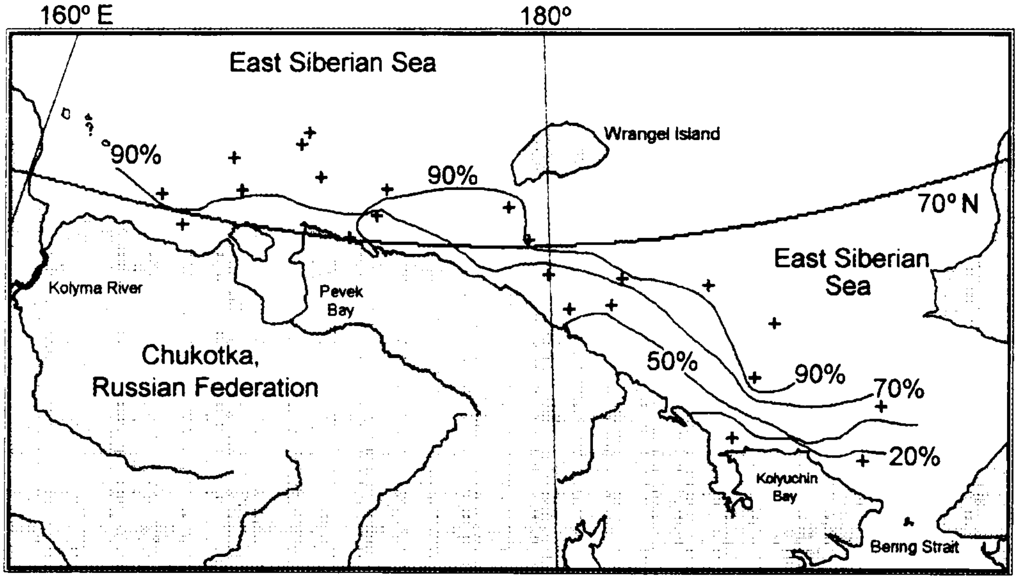


Figure 10. Percentages of silt and clay fraction (>4 phi) in sediments for cruise HX-189 (17 August through 5 September 1995).

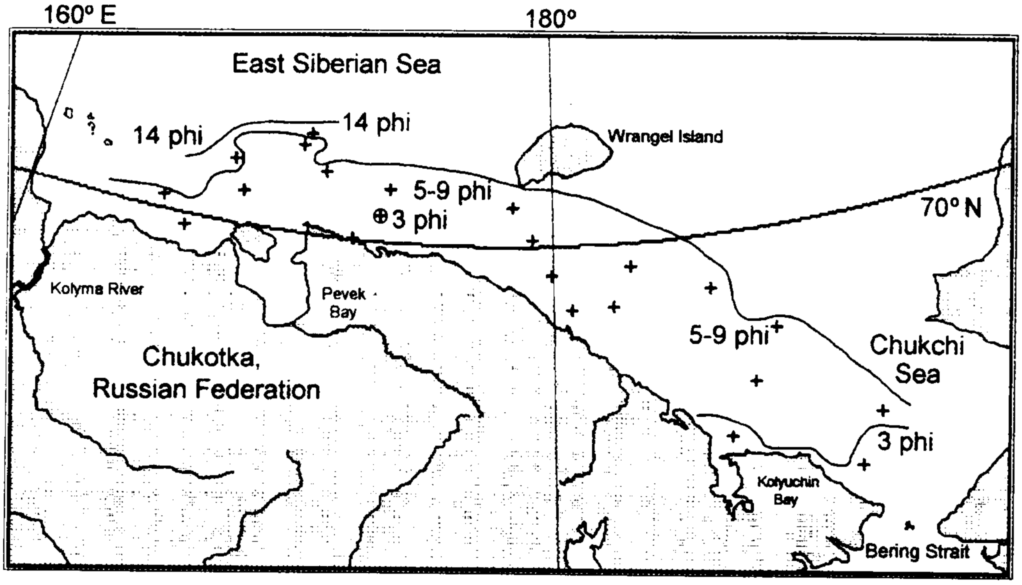


Figure 11. Sediment grain size analysis: distribution of modal phi sizes of sediment during cruise HX-189 (17 August through 5 September 1995).

The C/N ratio values of carbonate-free surface sediments in the study area reach a maximum value of 7.7 at station 9 near the Kolyma River mouth and a minimum value of 6.3 at station 76 in the Chukchi Sea (Figure 12). C/N ratios average 6.6 (s.d.= 0.22) in the Chukchi Sea and 6.93 (s.d.= 0.49) in the East Siberian Sea.

Among those stations included in the invertebrate survey, sediment chlorophyll-a concentrations ranged from 0.03 $\mu g\ g^{-1}$ at station 68, a nearshore station in the Chukchi Sea, to 1.41 $\mu g\ g^{-1}$ at station 15 in the East Siberian Sea (Figure 13). The quantification of sediment chlorophyll-a of other HX-189 stations reveals a patchy distribution of high concentrations (1.0 to 2.5 $\mu g\ g^{-1}$) at four stations in the East Siberian Sea. Generally, sediment chlorophyll-a values are lowest at nearshore stations and increase offshore in both the East Siberian and Chukchi Seas. Maximum values are generally greater in the East Siberian Sea.

Sediment $\delta^{13}C$ ratios ranged from a minimum (most negative) value of -26.8‰ at station 15 closest to the Kolyma River mouth to a maximum (least negative) value of -20.4‰ at station 73, closest to Bering Strait (Figure 14). Generally, values ranged from -24.5‰ to -23.0‰ in the East Siberian Sea and -23.0‰ to -21.0‰ in the Chukchi Sea. One station, 68, located close to the entrance of Kolyuchin Bay shows the lowest values in the Chukchi Sea (-23.5‰).

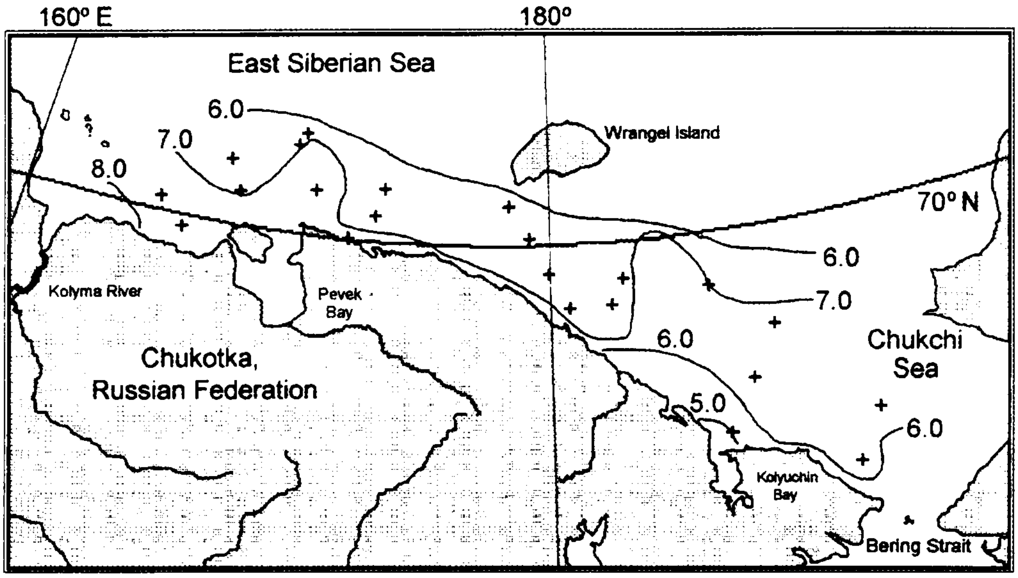


Figure 12. Distribution of Carbon/Nitrogen (C/N) ratios (wt./wt.) of carbonate-free surface sediments for cruise HX-189 (17 August through 5 September 1995).

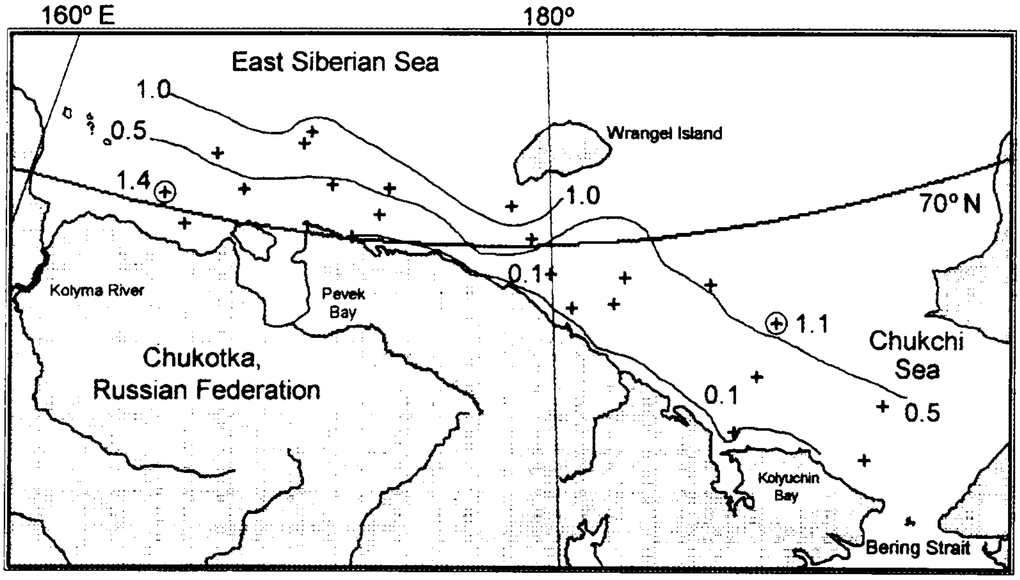


Figure 13. Distribution of sediment chlorophyll values (ug g^{-1}) for HX-189 (17 August through 5 September 1995).

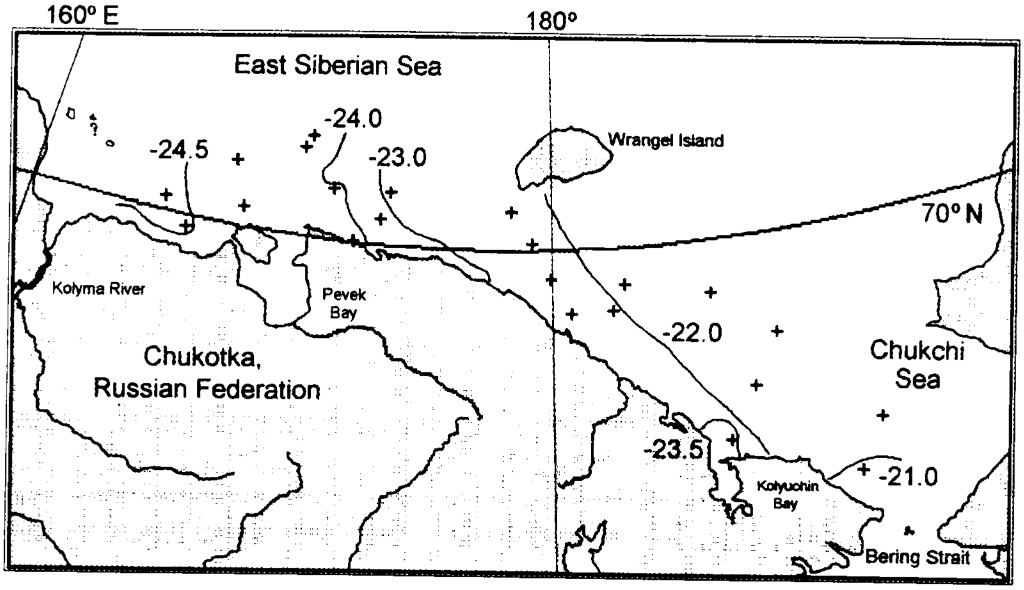


Figure 14. Distribution of $\delta^{13}C$ isotope ratios (‰) in carbonate-free surface sediments for HX-189 (17 August through 5 September 1995).

The percentage of total organic carbon (TOC) in sediments ranged from a low of 0.06% at station 68 to a high of 2.17% at station 65 (Figure 15). In the East Siberian Sea, values were generally less than 1.0% and increased to greater than 1.0% at the westernmost stations. TOC values were less than 1.0% along the coastline throughout most of the study area. In the Chukchi Sea, values were less than 1.0% just south of Wrangel Island and increased to above 2.0% at three offshore stations (61, 63 and 65).

The basic statistics for all environmental variables are shown in Table 2. A Pearson product-moment correlation matrix was calculated between all environmental variables and is shown in Table 3.

C. Benthic Invertebrate Biomass and Community Structure

The identification of invertebrates was completed to the lowest taxonomic level possible, but due to the scarcity of available literature on the taxonomy of the fauna of the area, some of the taxa are identified to family and in some rare instances, class. There were 66 taxonomic categories positively identified to a species level, 17 identified to genus level and 39 identified to family level. In most cases, individual species could be separated from similar species of the same family, but a positive scientific species name could not be assigned. So that the taxonomic resolution could be maintained at the highest possible level,

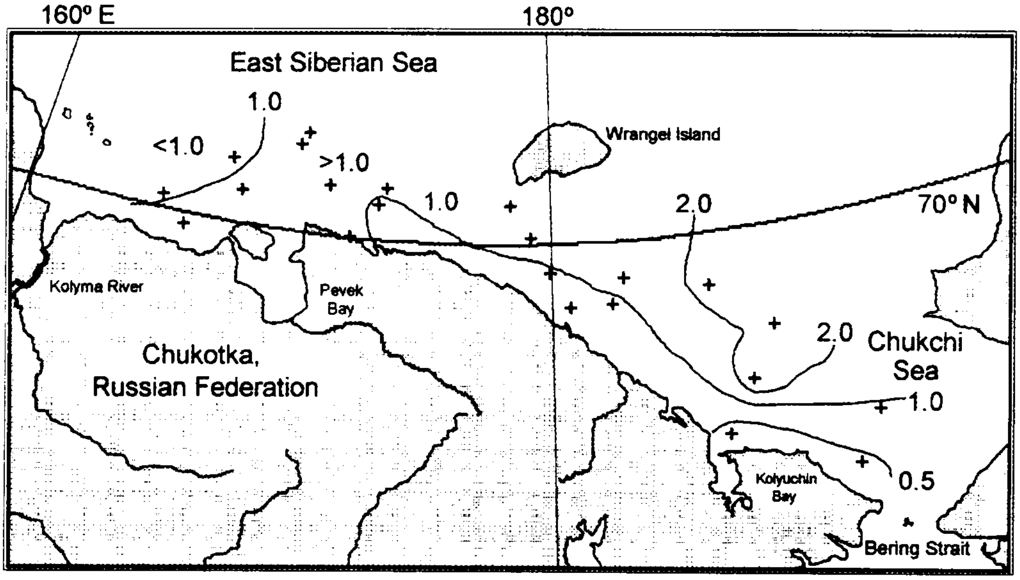


Figure 15. Distribution of the weight percentage of total organic carbon (TOC) in sediment for HX-189 (17 August through 5 September 1995).

Table 2. Basic statistics of all environmental variables.

Variable		Mean	Median	Min.	Max.	Range	Std. Dev.
depth	(m)	38.3	42.0	16.0	50.0	34.0	10.2
integrated chlorophyll	(mg m^{-2})	252.7	214.0	23.1	657.1	633.9	173.6
biomass	(g C m^{-2})	13.4	8.8	0.5	66.5	66.0	14.4
sediment phi size	(phi)	7.4	7.0	3.0	14.0	11.0	3.0
abundance	(ind. m^{-2})	1842.4	1071.5	248.0	12308.0	12060.0	2558.8
diversity	(H′)	1.7	1.6	0.5	3.0	2.5	0.8
bottom water chl.	(mg m^{-3})	14.0	8.6	0.6	68.4	67.8	17.7
sediment chlorophyll	(μg g^{-1})	0.5	0.4	0.0	1.4	1.4	0.3
bottom temperature	(°C)	-0.3	-0.7	-1.8	2.2	4.0	1.5
bottom salinity	(ppt)	32.3	32.7	30.3	33.1	2.8	0.9
TOC	(%)	1.1	1.0	0.1	2.9	2.8	0.7
sigma-t		25.9	26.2	24.3	26.7	2.3	0.7
silica	(μM)	27.1	23.5	0.0	50.0	50.0	15.6
phosphate	(μM)	2.1	2.2	0.1	2.9	2.8	0.7
nitrate	(μM)	10.1	9.1	0.5	18.0	17.5	5.1
C/N ratio	(wt./wt.)	6.6	6.7	3.5	7.7	4.2	0.8
delta C-13	(‰)	-22.9	-22.2	-26.8	-20.4	6.4	1.6

Table 3. Pearson's product-moment correlation matrix calculated among all environmental variables.

Variable	depth	integrated chlorophyll	biomass	sediment phi size	abundance	diversity	btm.wtr. chl.-a	sed. chlorophyll-a	bottom temperature	bottom salinity	sigma-t	TOC	SiO4-Si	PO4-P	NO3-NO2	C/N ratio	delta C-13
depth	1.00																
integrated chl.	-0.40	1.00															
biomass	**-0.45**	-0.09	1.00														
phi size	-0.16	0.07	-0.25	1.00													
abundance	0.33	-0.10	**0.65**	-0.35	1.00												
diversity	**0.47**	-0.18	**0.53**	-0.27	**0.45**	1.00											
btm. wtr. chl.-a	**-0.77**	0.28	-0.28	0.32	-0.08	**-0.47**	1.00										
sediment chl-a	-0.17	0.15	-0.32	**0.53**	-0.23	**-0.55**	**0.46**	1.00									
bottom temp.	0.43	-0.19	**0.52**	-0.24	0.40	0.41	-0.23	-0.14	1.00								
bottom salinity	0.08	-0.05	0.26	-0.33	0.25	0.07	-0.16	-0.15	-0.15	1.00							
sigma-t	**0.50**	-0.39	0.19	**-0.62**	0.19	0.40	**-0.53**	-0.34	0.20	**0.50**	1.00						
TOC	**0.45**	-0.08	-0.15	0.16	-0.35	-0.10	-0.24	0.26	0.39	-0.28	0.12	1.00					
SiO4-Si	-0.14	**0.43**	-0.23	0.14	-0.12	-0.22	0.02	0.14	**-0.49**	-0.02	-0.19	0.00	1.00				
PO4-P	0.24	0.08	-0.08	-0.10	-0.02	-0.11	-0.20	-0.08	0.09	-0.12	0.01	0.40	**0.60**	1.00			
NO3-NO2	**0.49**	-0.08	0.12	-0.39	0.37	0.16	**-0.47**	-0.11	0.22	0.11	0.42	0.24	**0.51**	**0.69**	1.00		
C/N ratio	0.05	0.41	-0.16	0.40	-0.04	-0.27	0.28	0.38	-0.07	-0.28	-0.38	**0.47**	0.29	0.19	0.01	1.00	
delta C-13	**0.82**	**-0.49**	**0.49**	**-0.47**	**0.52**	**0.49**	**-0.69**	-0.37	**0.60**	0.22	**0.72**	0.31	-0.26	0.17	**0.59**	-0.16	1.00

Bold correlations are significant at $p < 0.05$.
n=22 for all variables, except sediment chlorophyll (n=21).

arbitrary names (examples: sp.1, sp.2, etc.) were assigned to unidentified species. Only two groups of animals, the anthozoans and the rhynchocoels, were unidentified and grouped together under their respective class. One family of polychaetes, Nephtyidae, were grouped under a single arbitrary species name. A listing of all taxa identified in this study is shown in Appendix B.

More than 130 species representing 73 families from 11 phyla were identified from the 22 sampling stations. Number of taxa ranged from 9 species (both stations 9 and 18, near the Kolyma River mouth) to 76 species (station 73, in the Chukchi Sea). The carbon weight biomass ranged from 0.55 g C m^{-2} (station 15, near the Kolyma River mouth) to 66.6 g C m^{-2} (station 76, in the Chukchi Sea). Benthic biomass was relatively high (19.8 to 66.6 g C m^{-2}) in the easternmost portion of the study area (in the Chukchi Sea), decreased to 4.2 to 18.4 g C m^{-2} in the central portion of the study area and was lowest (0.5 to 5.5 g C m^{-2}) at stations closest to the Kolyma River mouth in the East Siberian Sea. Population density ranged from 248 individuals m^{-2} (station 9) to 12,308 ind. m^{-2} (station 73). Generally, there were more species per station, higher abundance and higher biomass in the Chukchi Sea. The number of species, the population densities and the carbon weight values for individual stations are shown in Table 4. The distribution of carbon biomass values for individual stations is shown in Figure 16.

Table 4. Number of species, density, wet weight and organic carbon weight for individual stations.

Station Number	Number of Species	Density (individuals m^{-2})	Wet Weight ($g\ m^{-2}$)	Standard Deviation	Organic Carbon Weight ($g\ C\ m^{-2}$)	Standard Deviation
2	9	1,130	7.57	11.95	5.16	8.95
9	15	248	3.57	2.47	1.58	0.66
15	9	553	0.98	0.76	0.55	0.55
18	20	1,005	14.38	11.04	5.05	3.38
23	13	728	46.61	27.22	18.15	10.63
24	43	813	41.54	30.24	13.17	10.37
28	31	1,478	7.58	12.70	5.46	5.16
33	13	265	6.70	9.59	2.58	2.85
35	45	1,093	48.10	22.16	16.24	2.83
36	13	1,033	44.39	29.52	15.93	10.17
45	45	1,835	23.39	11.66	7.79	5.29
46	31	2,063	24.43	6.62	8.08	2.78
47	36	1,815	55.17	13.63	15.60	3.52
48	47	1,748	33.27	15.83	9.42	3.02
54	31	2,363	57.78	11.93	13.73	4.09
56	36	2,675	74.12	19.59	15.11	1.89
61	18	283	12.04	12.04	4.09	1.52
63	16	678	16.30	8.63	5.96	2.05
65	30	1,050	52.19	28.10	19.75	9.42
68	29	498	16.62	16.62	7.21	2.96
73	76	12,308	97.44	39.01	37.45	13.59
76	49	4,870	196.36	19.12	66.6	10.10

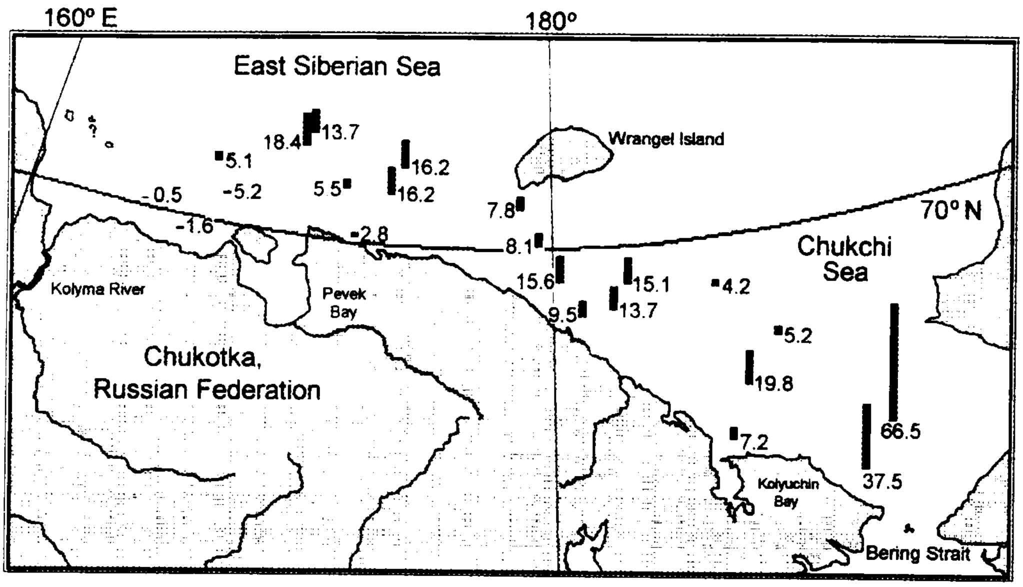


Figure 16. Distribution of carbon biomass values (g C m^{-2}) of benthic macrofaunal invertebrates for HX-189 (17 August through 5 September 1995).

Stations located in the East Siberian Sea are typically characterized by the presence of the Arctic endemic nuculanid bivalve *Portlandia arctica* (Zenkevich, 1963), the idoteid isopod, *Idotea ochotensis* and the tellinid bivalve, *Tellina lutea*. The benthic invertebrate samples taken from station 45 (south of Wrangel Island) and eastward in the Chukchi Sea show many more examples of species commonly found in the sub-Arctic northern Pacific Ocean, rather than endemic Arctic species. Examples include the tube-dwelling polychaete family Maldanidae: examples were found in large numbers (up to 165 ind. m^{-2}) at stations in the Chukchi Sea, and the tellinid bivalve *Macoma calcarea* (up to 375 ind. m^{-2}). The nuculid bivalve *Nucula belloti*, another sub-arctic Pacific species, was found in large numbers (up to 1200 ind. m^{-2}) and throughout the entire study area, but examples of the species are generally less abundant and smaller in the East Siberian Sea. The most abundant species in the study area was the astrorhizid foraminiferan *Rhabdammina abyssorum;* large numbers (up to 1500 ind. m^{-2}) were identified from seven stations, all south of Wrangel Island. Both *M. calcarea* and *N. belloti* bivalves constitute a majority of the biomass at several stations in the Chukchi Sea portion of the study area and have been shown to commonly occur in adjacent areas of the Chukchi Sea (Grebmeier, 1987; Grebmeier et al., 1989; Feder et al., 1994b). The dominant species by biomass and by abundance are shown in Table 5.

Table 5. Dominant species by species abundance and by species biomass for HX-189 statons.

Station	Dominant Species By Abundance (ind. m^{-2})	Station % Abundance	Dominant Species By Biomass (g C m^{-2})	Station % Biomass
2	*Yoldia hyperborea*	87.4	*Idotea ochotensis*	90.1
9	*Nucula belloti*	36.3	Madanidae sp.1	26.6
	Portlandia arctica	29.4	*Nuculana radiata*	6.7
15	*Portlandia arctica*	85.0	*Idotea ochotensis*	57.7
18	*Nucula belloti*	71.6	*Nucula belloti*	75.4
	Portlandia arctica	16.4		
23	*Nucula belloti*	89.3	*Nucula belloti*	45.8
24	Maldanidae sp.1	22.8	*Phascolosoma margaritaceum*	37.9
28	*Nucula belloti*	82.1	*Nucula belloti*	50.8
33	*Portlandia arctica*	67.9	*Idotea ochotensis*	39.5
35	*Nucula belloti*	42.1	*Nucula belloti*	44.5
			Macoma calcarea	17.9
36	*Nucula belloti*	36.0	*Nucula belloti*	81.2
			Macoma calcarea	16.5
45	*Rhabdammina abyssorum*	69.5	*Macoma calcarea*	17.8
			Astarte borealis	12.9
46	*Rhabdammina abyssorum*	70.3	*Macoma calcarea*	46.6
47	*Rhabdammina abyssorum*	39.4	*Macoma calcarea*	34.0
	Owenia fusiformis	18.1		
48	*Rhabdammina abyssorum*	69.8	Maldanidae	19.9
			Macoma calcarea	19.7

Station	Dominant Species By Abundance (ind. m^{-2})	Station % Abundance	Dominant Species By Biomass (g C m^{-2})	Station % Biomass
54	*Rhabdammina abyssorum*	63.5	*Nuculana radiata*	34.6
			Maldanidae	19.0
			Astarte borealis	13.2
			Macoma calcarea	9.5
56	*Rhabdammina abyssorum*	56.6	*Nuculana radiata*	56.4
	Nuculana radiata	19.1	Maldanidae	14.0
61	*Sternaspis scutata*	21.2	*Musculus niger*	54.8
	Rhabdammina abyssorum	20.5		
63	*Nucula belloti*	72.3	*Nucula belloti*	54.2
65	*Nucula belloti*	31.2	*Macoma calcarea*	48.0
	Pholoe minuta	21.9	*Nucula belloti*	30.0
68	*Liocyma fluctuosa*	48.2	*Liocyma fluctuosa*	32.7
			Macoma calcarea	31.4
73	Lysianassidae sp.1	15.1	*Ampelisca sp.*	13.6
	Ampelisca sp.	14.5	Anthozoans	13.4
	Isaeidae sp.1	12.3	*Macoma calcarea*	12.6
	Boreacola vadosus	9.9	Lysianassidae sp.1	9.1
			Yoldia hyperborea	8.9
76	Haustoridae sp.1	21.4	*Nucula belloti*	39.7
	Nucula belloti	20.5	*Macoma calcarea*	38.0
	Byblis sp.	9.0		
	Macoma calcarea	7.7		

Large numbers (>1500 ind. m^{-2}) of amphipods from the families Ampeliscidae, Isaeidae, Oediceratidae and Phoxocephalidae have been identified from the central Chukchi Sea, outside of, but adjacent to this study area (Grebmeier et al., 1989). Large numbers of the amphipod families Ampeliscidae, Haustoriidae, Isaeidae, Lyssianassidae, and Phoxocephalidae were limited to stations 73 and 76 in this study. Maximum abundances all occurred at station 73; Haustoriidae: 625 ind. m^{-2}, Ampeliscidae: 1935 ind. m^{-2}, Isaeidae: 2050 ind. m^{-2}, Lysianassidae: 2083 ind. m^{-2} and Phoxocephalidae: 733 ind. m^{-2}. Amphipod populations were high at station 76, but about half that of station 73. Amphipod abundances decreased again at station 65 and all stations west of station 61 showed low amphipod abundances (< 15 ind. m^{-2}). Only one station in the East Siberian Sea, station 23, showed an amphipod abundance of greater than 10 ind. m^{-2}, and most stations had an amphipod abundance of zero.

The species diversity, as measured by the Shannon-Weaver diversity index, was greatest (H′= 2.99) at station 73 and lowest (H′= 0.53) at station 2 (Table 6; Figure 17). East Siberian Sea stations averaged 1.33, less than the 2.05 average of the Chukchi Sea stations. Margalef's species richness index, SR, was greatest at station 73 (SR= 5.52) and lowest at station 2 (SR= 0.79). The species evenness measure, J′, was greatest at station 73 (J′= 0.69) and lowest at station 36 (J′= 0.20). Typically, East Siberian Sea stations are less

Table 6. Diversity indices, species richness and species evenness values of individual stations.

HX-189 Station	Shannon-Weaver Diversity Index	Margalef's Species Richness Index	Species Evenness
2	0.53	0.79	0.24
9	1.91	1.76	0.70
15	0.71	0.88	0.32
18	1.10	1.91	0.37
23	0.57	1.26	0.22
24	2.96	4.35	0.79
28	1.01	2.85	0.29
33	1.25	1.49	0.49
35	2.46	4.36	0.65
36	0.52	1.20	0.20
45	1.59	4.06	0.42
46	1.32	2.72	0.38
47	2.26	3.23	0.63
48	1.58	4.27	0.41
54	1.57	2.68	0.46
56	1.64	3.07	0.46
61	2.34	2.09	0.81
63	1.24	1.60	0.45
65	2.14	2.89	0.63
68	2.13	3.13	0.63
73	2.99	5.52	0.69
76	2.63	3.92	0.68

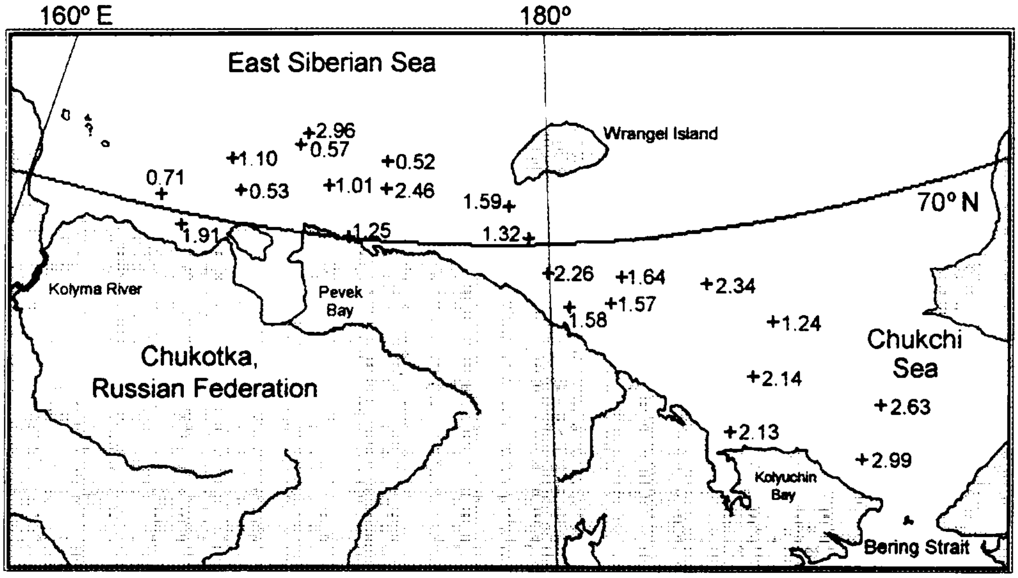


Figure 17. Distribution of station Shannon-Weaver diversity indices for HX-189 (17 August through 5 September 1995).

diverse, show a lower species richness and less species evenness than stations in the Chukchi Sea.

The diversity measures of benthic macrofaunal invertebrates of individual stations in this study show significant positive correlations with sediment $\delta^{13}C$ ratios ($r= 0.43$, $p< 0.05$), depth ($r= 0.47$, $p< 0.05$), carbon biomass ($r= 0.53$, $p< 0.05$) and abundance ($r= 0.45$, $p< 0.05$) (Table 3). Diversity measures were negatively correlated with sediment chlorophyll values ($r= -0.55$, $p< 0.05$) and bottom water chlorophyll ($r= -0.47$, $p< 0.05$).

The majority of stations were dominated by deposit-feeding invertebrates or invertebrates that are scavengers/carnivores (Table 7). Only one station, 68, primarily consisted of filter-feeding organisms (57.5%), although station 65 is numerically dominated by *Macoma calcarea,* a bivalve that can both deposit-feed and filter-feed. The overall mean percentage of deposit feeders is 53.7%; more than the overall mean percentage of scavengers/carnivores (24.2%) or filter-feeders (5.6%). There was no significant correlation ($p> 0.05$) between the percentage of deposit-feeding invertebrates vs. the percentage of silt and clay in the sediments.

Cluster analysis by species abundance delineated 8 station groups at the 33% similarity level (Figure 18), two of which consist of only a single station.

Table 7. Percentages of silt and clay in sediments and percentages (% individuals) of benthic macrofaunal invertebrates with various feeding strategies.

Station	% silt and clay in sediment	% Scavengers/ Carnivores	% Deposit Feeders	% Filter Feeders	% Dep. Feeders/ Filter Feeders	% Carnivores/ Scavengers/ Deposit Feeders
2	0.92	1.6	97.4	1.0	0	0
9	0.76	7.2	85.6	6.2	1.0	0
15	0.90	8.2	91.0	0	0.8	0
18	0.81	5.6	91.8	1.8	0.8	0
23	0.96	4.8	94.9	0	0.3	0
24	0.94	11.3	59.9	11.3	13.9	3.6
28	0.87	6.8	89.7	1.0	2.1	0.4
33	0.89	3.8	85.7	1.0	5.7	3.8
35	0.49	7.3	70.4	6.4	15.9	0
36	0.96	2.0	94.4	0.2	3.4	0
45	0.84	78.1	13.8	2.7	3.6	1.8
46	0.95	74.0	11.4	5.6	8.4	0.6
47	0.55	43.7	21.1	5.2	28.4	1.6
48	0.54	75.3	14.2	4.1	4.1	2.3
54	0.41	59.2	29.3	5.3	3.6	2.6
56	0.71	62.1	31.4	3.7	2.2	0.6
61	0.92	29.8	35.5	19.4	1.6	13.7
63	0.99	6.6	80.8	0.7	1.9	10.0
65	0.85	30.7	27.7	0.7	35.9	5.0
68	0.02	7.5	21.7	57.5	11.2	2.1
73	0.07	5.9	47.2	0.6	28.0	18.3
76	0.55	7.2	68.2	0.1	19.5	5.0
Mean	0.72	31.7	57.4	5.6	8.7	3.2

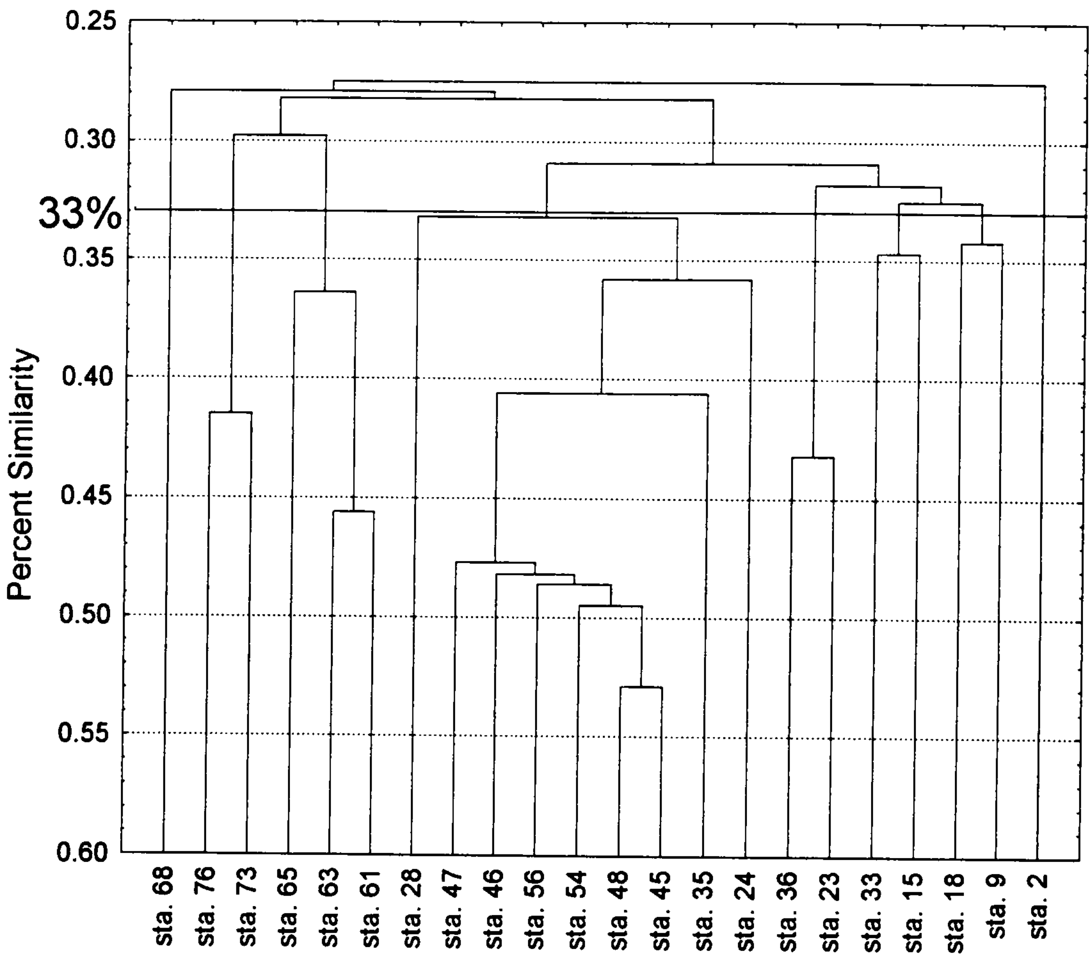


Figure 18. Cluster analysis dendrogram using the Bray-Curtis similarity measure based on species abundance. Eight groups are delineated at the 33% similarity level.

Groups 1, 2 and 3 are near the Kolyma River mouth (Figure 19) and show relatively low species diversity (H′=0.53 to 1.37; Table 8), species evenness values of 0.24 to 0.35 and average abundances of 409 to 1253 ind. m^{-2}. Groups 1 and 3 were dominated (by abundance) by the bivalve *Nucula belloti*, while Group 2 was dominated by the bivalve *Portlandia arctica*, as well as *N. belloti* (Table 9). Group 4 is located offshore of the Kolyma River mouth. Group 4 shows low average diversity (H′=0.58), an average abundance of 881 ind. m^{-2} and the lowest species evenness of any group (0.2); this group is dominated by only a few abundant species. *N. belloti* bivalves numerically dominated Group 4. Group 5 is the largest group (9 stations), and represents much of the central portion of the study area. Group 5 shows relatively high average diversity (H′=2.26), a species evenness value of 0.49 and a high average abundance (1767 ind. m^{-2}). Several species numerically dominated the stations of Group 5: *N. belloti*, *P. arctica* and *Nuculana radiata* bivalves, Maldanidae sp.1 and *Owenia fusiformis* polychaetes and the foraminiferan *Rhabdammina abyssorum*. Group 6 consists of three stations offshore in the Chukchi Sea. Group 6 (H′=1.52), has a species evenness value of 0.49 and shows a relatively low average abundance (670 ind. m^{-2}). Group 6 is numerically dominated by the bivalves *Macoma calcarea* and *N. belloti*. Group 7 consists of a single station at the entrance to Kolyuchin Bay in the Chukchi Sea. Group 7 shows relatively high diversity (H′=2.13), a species evenness value of 0.49 and the average abundance is the

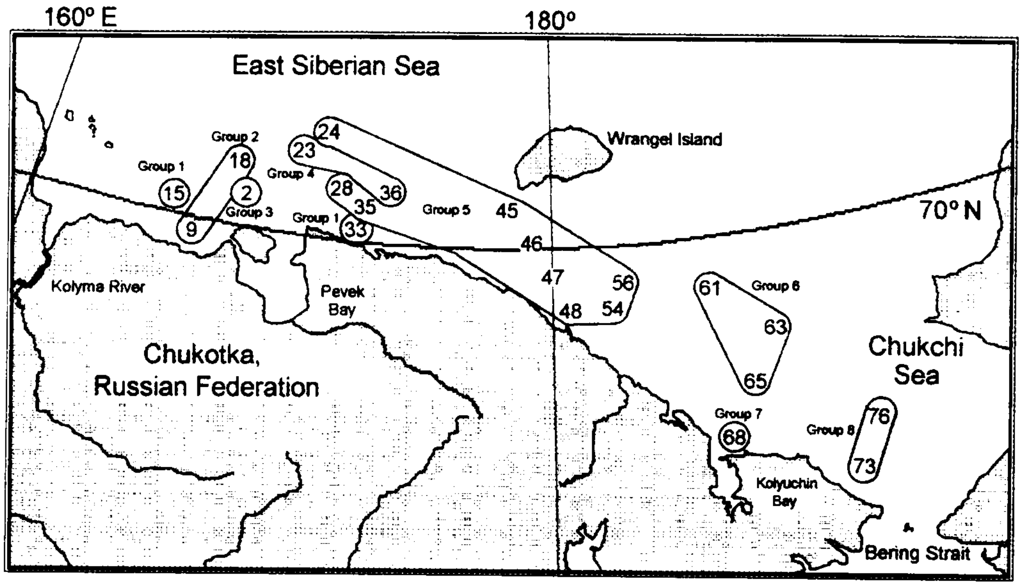


Figure 19. Station cluster groups delineated by species abundance for HX-189 (17 August through 5 September 1995).

Table 8. Diversity indices, species evenness, species richness values and average abundances of station groups clustered by species abundance.

Station Cluster Group	Station	Shannon-Weaver Diversity Index	Margalef's Species Richness	Species Evenness	Average Abundance
Group 1	15 33	0.98	1.65	0.35	409
Group 2	9 18	1.37	2.53	0.42	1253
Group 3	2	0.53	1.76	0.24	1130
Group 4	23 36	0.58	1.67	0.20	881
Group 5	24 28 35 45 46 47 48 54 56	2.26	6.91	0.49	1767
Group 6	61 63 65	1.52	1.93	0.49	670
Group 7	68	2.13	3.13	0.63	498
Group 8	73 76	3.15	6.18	0.70	8589

Table 9. Station cluster groups clustered by species abundance, along with dominant species in each cluster group.

Station Cluster Group	Stations	Dominant Species by Abundance
Group 1	15 33	*Portlandia arctica*
Group 2	9 18	*Nucula belloti* *Portlanida arctica*
Group 3	2	*Nucula belloti*
Group 4	23 36	*Nucula belloti*
Group 5	24 28 35 45 46 47 48 54 56	Maldanidae sp.1 *Nucula belloti* *Portlandia arctica* *Rhabdammina abyssorum* *Owenia fusiformis* *Nuculana radiata*
Group 6	61 63 65	*Nucula belloti* *Macoma calcarea*
Group 7	68	*Liocyma fluctuosa*
Group 8	73 76	*Nucula belloti, Macoma calcarea* *Yoldia hyperborea, Boreacola vadosus* *Nuculana radiata, Ampelisca* sp. *Byblis* sp., *Lysianassidae* sp.1 Anthozoans, Isaidae spp. Haustoriidae

lowest of any group (498 ind. m^{-2}). Groups 7 is numerically dominated by the bivalve *Liocyma fluctuosa*.

Cluster analysis by species biomass delineated 11 station groups at the 56% similarity level (Figure 20), eight of which consist of only a single station (Figure 21). Groups 1, 2 and 3 consist of only one station per cluster group and are found near the Kolyma River mouth. These groups have a low diversity (H′=0.53 to 1.91) and show a low range of biomass (0.55 to 5.16 g C m^{-2}) and evenness values of 0.24 to 0.70 (Table 10). Groups 2 and 3 are dominated (by biomass) by the isopod *Idotea ochotensis* and Group 1 is dominated by *I. ochotensis* as well as the polychaete Maldanidae sp.1 (Table 11). Group 4 consists of five stations representing much of the offshore East Siberian Sea. Group 4 shows a relatively low diversity (H′=0.88), has an average biomass of 10.11 g C m^{-2} and an average evenness value of 0.36. Three species dominate the fauna of Group 4: *M. calcarea, I. ochotensis* and *N. belloti.* Group 5 consists of only station 24, located at the northernmost point of the study area in the East Siberian Sea. Group 5 shows a high diversity (H′=2.96), the biomass is 13.17 g C m^{-2} and the evenness value is 0.79. Group 5 is dominated by the bivalve *M. calcarea*, the polychaete Maldanidae sp.1 and the sipunculid *Phascolosoma margaritaceum*. Group 6 consists of a single station located close to shore, just to the east of Pevek Bay, in the East Siberian Sea. Group 6 shows a relatively

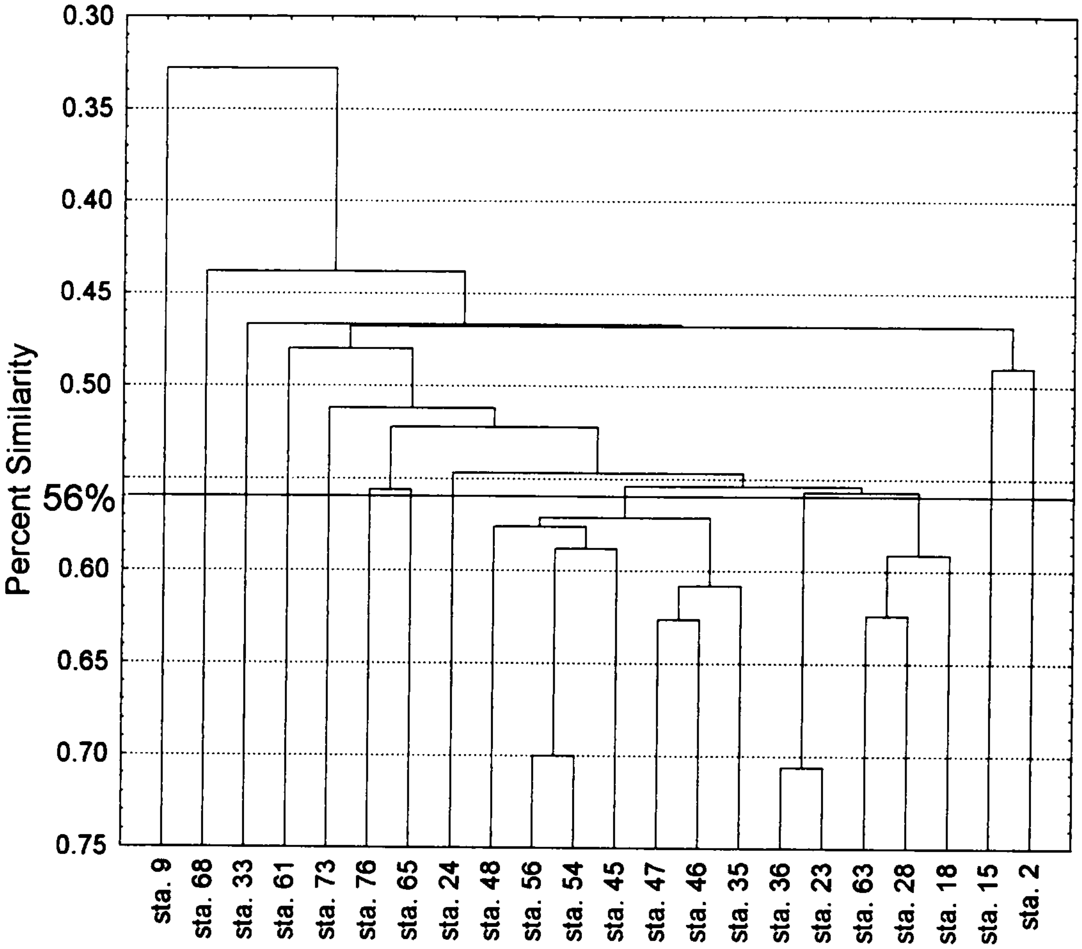


Figure 20. Cluster analysis dendrogram using the Bray-Curtis similarity measure based on species biomass. Eleven groups are delineated at the 56% similarity level.

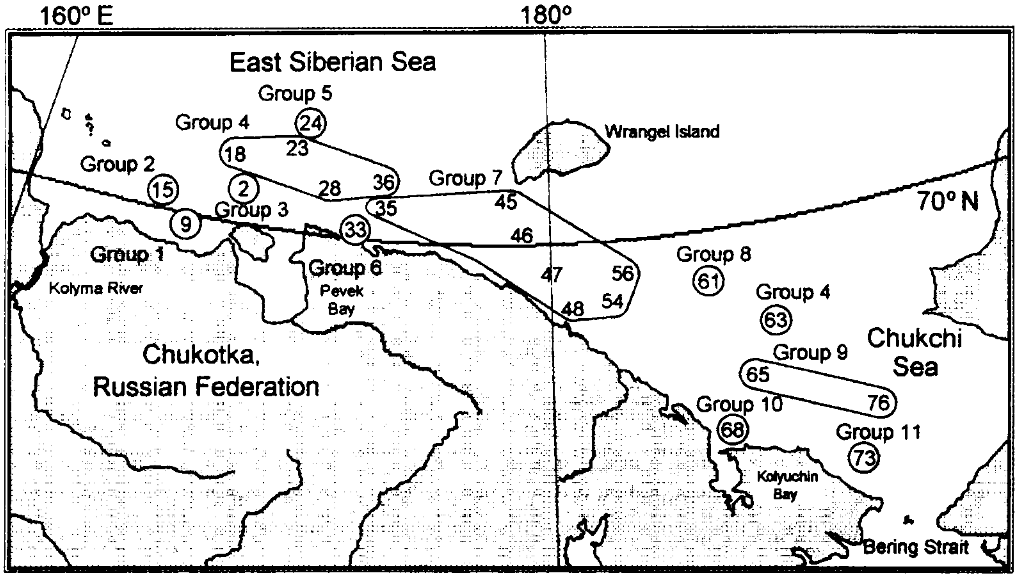


Figure 21. Station cluster groups delineated by species biomass HX-189 (17 August through 5 September 1995).

Table 10. Diversity indices, species evenness, species richness values and average biomass of station groups clustered by biomass.

Station Cluster Group	Stations	Shannon-Weaver Diversity Index	Margalef's Species Richness	Species Evenness	Average Biomass (g C m^{-2})
Group 1	9	1.91	1.76	0.70	1.58
Group 2	15	0.71	0.88	0.32	0.55
Group 3	2	0.53	0.79	0.24	5.16
Group 4	18 23 28 36 63	0.88	2.20	0.36	10.11
Group 5	24	2.96	4.35	0.79	13.17
Group 6	33	1.25	1.49	0.49	2.58
Group 7	35 45 46 47 48 54 56	1.77	3.48	0.49	14.60
Group 8	61	2.34	2.09	0.81	4.09
Group 9	65 76	2.68	4.63	0.66	43.18
Group 10	68	2.13	3.13	0.63	7.21
Group 11	73	2.99	5.52	0.69	37.45

Table 11. Station cluster groups clustered by species biomass, along with dominant species in each cluster group.

Station Cluster Group	Stations	Dominant Species by Biomass
Group 1	9	*Idotea ochotensis*, Maldanidae sp.1
Group 2	15	*Idotea ochotensis*
Group 3	2	*Idotea ochotensis*
Group 4	18 23 28 36 63	*Nucula belloti* *Macoma calcarea*
Group 5	24	*Phascolosoma margaritaceum* Maldanidae sp.1, *Macoma calcarea*
Group 6	33	*Idotea ochotensis*
Group 7	35 45 46 47 48 54 56	*Macoma calcarea* *Astarte borealis* Maldanidae *Nuculana radiata* *Nucula belloti*
Group 8	61	*Musculus niger*
Group 9	65 76	*Macoma calcarea, Nucula belloti* *Yoldia hyperborea*
Group 10	68	*Liocyma fluctuosa, Macoma calcarea* *Ampelisca* sp., *Yoldia hyperborea*
Group 11	73	Anthozoans, *Macoma calcarea* Lysianassidae sp.1

low diversity (H′=1.25) and low biomass (2.58 g C m^{-2}) and a species evenness value of 0.49. Group 6 is dominated by *I. ochotensis* and a few, large examples of the bivalve *Mya truncata*. Group 7 consists of seven stations, located offshore in the central portion of the study area. The diversity of Group 7 is about average (H′=1.77), the average biomass is fairly high (14.60 g C m^{-2}), and the species evenness value is 0.49. Group 7 is dominated by several species including the bivalves *Musculus niger, N. belloti, M. calcarea, N. radiata, M. truncata, Serripes groenlandicus and Yoldia hyperborea*. The polychaete species Maldanidae sp.1 and sp.2 as well as the sipunculid species *P. margaritaceum* also dominate. Group 8 consists of only station 61 in the Chukchi Sea. The diversity of Group 8 is high (H′=2.34), the biomass is low (4.09 g C m^{-2}) and the species evenness value is 0.81. Group 8 is dominated by the bivalve *M. niger*. Group 9 consists of two stations in the easternmost portion of the study area. The average diversity of Group 9 is high (H′=2.39) the average biomass (43.18 g C m^{-2}) is the highest of any group and the species evenness value is 0.66. Group 9 is dominated by the bivalve species *M. calcarea*, *N. belloti* and *Y. hyperborea*. Group 10 consists of a single station, station 68, located near the entrance of Kolyuchin Bay. Group 10 shows a relatively high diversity (H′=2.13), the biomass is low among stations in the Chukchi Sea (7.21 g C m^{-2}), and the species evenness value is 0.63. Group 10 is dominated by the bivalves *L. fluctuosa*, *M. calcarea* and *Y. hyperborea* as well as the amphipod *Ampelisca* sp.

Group 11 consists of only station 73 and is located close to Bering Strait. The diversity (H′=2.99), is the highest of any group, the biomass is high (37.45 g C m^{-2}), and the species evenness value is 0.69. Group 11 is dominated by anthozoans, the bivalve *M. calcarea* and the amphipod Lysianassidae sp.1.

D. Principal Components Analysis

Upon examination of the scree plot of eigenvalues (Figure 22), three principal components: PC1, PC2 and PC3, were extracted. The first principal component (PC1) accounted for 31.91% of the variance, PC2 accounted for 16.60% of the total variation and PC3 accounted for 12.49% of the total variance (Table 12). 61.00% of the total variance is explained by the first three principal components.

The factor loadings (the relative importance of the variables in each principal component) for PC1, PC2 and PC3 are shown in Table 13. The most important factor loadings have values greater than 0.70 or less than -0.70. Four variables are considered most important in determining PC1: depth (factor loading= 0.89), bottom water chlorophyll-a (factor loading= -0.72), bottom temperature (factor loading= 0.70) and $\delta^{13}C$ (factor loading= 0.94) (Table 13; Figure 23). Stations that are relatively deep, with a relatively low bottom water chlorophyll-a value, with a relatively warm bottom water temperature and a high $\delta^{13}C$ value scored high on PC1. Three variables are considered important in determining PC2 and all three are bottom water macronutrient values: silica

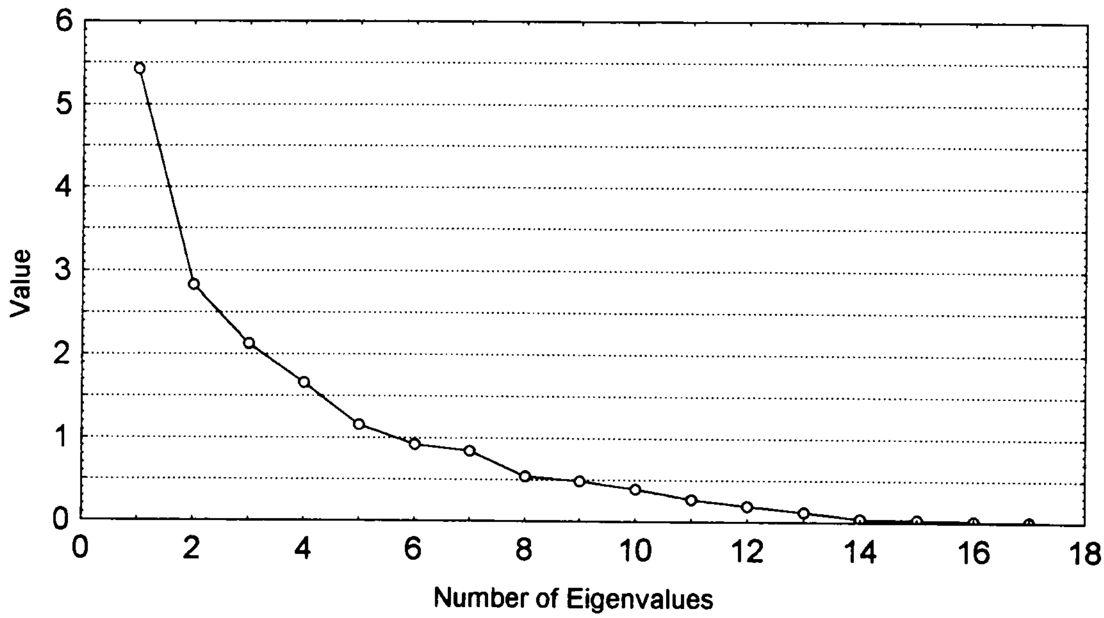


Figure 22. Scree plot of eigenvalues for the principal components analysis.

Table 12. Table of eigenvalues calculated by the principal component analysis.

Factor	Eigenvalue	% of Total Variance	Cumulative Eigenvalue	Cumulative %
1	5.42	31.91	5.42	31.91
2	2.82	16.60	8.25	48.51
3	2.12	12.49	10.37	61.00

Table 13. Factor loadings for each variable calculated by principal components analysis. Factor loadings shown in bold are greater than 0.70 or less than -0.70.

Variable	Factor 1	Factor 2	Factor 3
depth	**0.89**	0.11	0.13
integrated chlorophyll	-0.45	0.22	0.10
biomass	0.55	-0.25	-0.28
modal sediment phi size	-0.39	-0.16	0.63
abundance	0.46	-0.13	-0.36
diversity	0.58	-0.32	-0.26
bottom water chl.-a	**-0.72**	-0.23	0.17
sediment chlorophyll-a	-0.36	0.03	0.57
bottom temperature	**0.70**	-0.35	0.22
bottom salinity	0.08	0.15	-0.64
sigma-t	0.60	0.20	-0.47
TOC	0.42	0.24	**0.75**
SiO4-Si	-0.30	**0.86**	0.03
PO4-P	0.22	**0.78**	0.22
NO3-NO2	0.51	**0.77**	-0.10
C/N Ratio	-0.12	0.22	0.68
Delta C-13	**0.94**	0.09	-0.15
Explained Variation	5.42	2.82	2.12
Proportion of Total	0.32	0.17	0.12

Factor loadings shown in bold are greater than 0.70 or less than -0.70.

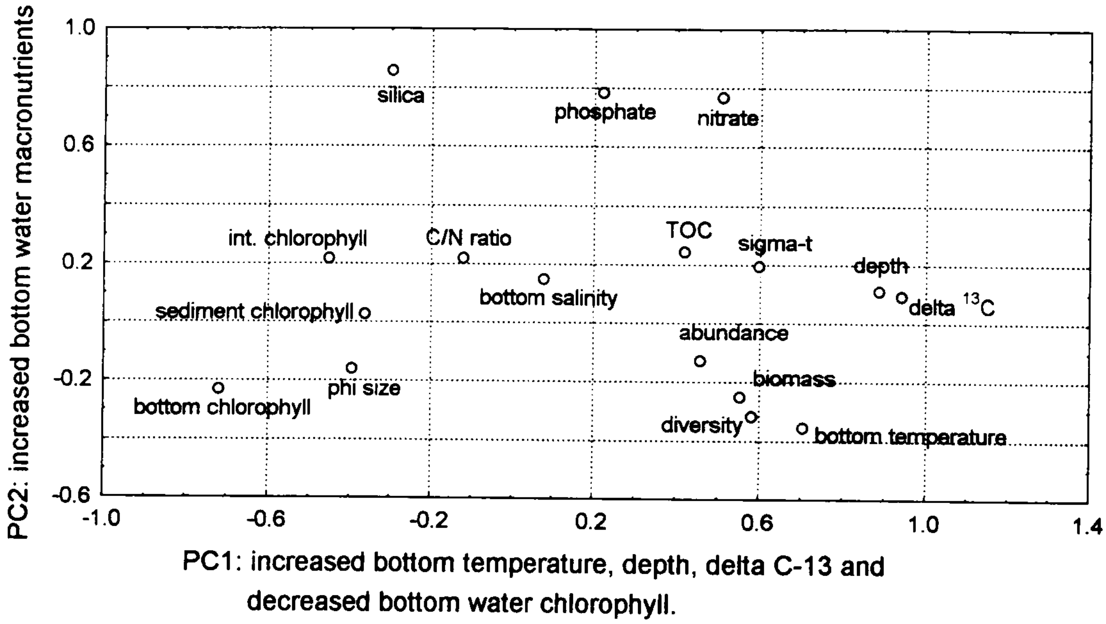


Figure 23. Plot of factor loadings for PC1 and PC2, calculated by the principal components analysis.

(factor loading= 0.86), phosphate (factor loading= 0.78) and nitrate (factor loading= 0.77) (Figure 24). Stations with high bottom water macronutrient concentrations scored high on PC2. Three variables are considered important in determining PC3: sediment phi size (factor loading= 0.63), C/N ratio (factor loading= 0.68) and sediment TOC (factor loading= 0.75). Stations with a relatively large modal sediment grain size, a relatively high C/N ratio and a relatively high amount of organic carbon in the sediments scored high on PC3.

The ordination of station factor scores for PC1 and PC2 is shown in Figure 25, PC2 and PC3 is shown in Figure 26, and the numerical factor scores are summarized in Table 14. Station 61 in the Chukchi Sea scored highest on PC1 (factor score = 1.52) and station 15 near the mouth of the Kolyma River in the East Siberian Sea (factor score= -2.25) had the lowest value. Chukchi Sea stations generally scored the highest on PC1 and East Siberian Sea stations generally scored the lowest on PC1. Stations 45 (factor score= 1.57) and 46 (factor score= 1.65) scored highest on PC2. Station 15 (factor score= -1.77) and station 47 (factor score= -1.72) had the lowest scores on PC2. The highest factor scores on PC3 were found at station 61 (factor score= 2.01) and the lowest score (factor score= -0.76) was found at station 68.

E. Detection of Gamma-emitting Radionuclides

The benthic macrofaunal biomass of the East Siberian Sea is, on the average, much lower than that of the Pacific Ocean influenced Chukchi Sea

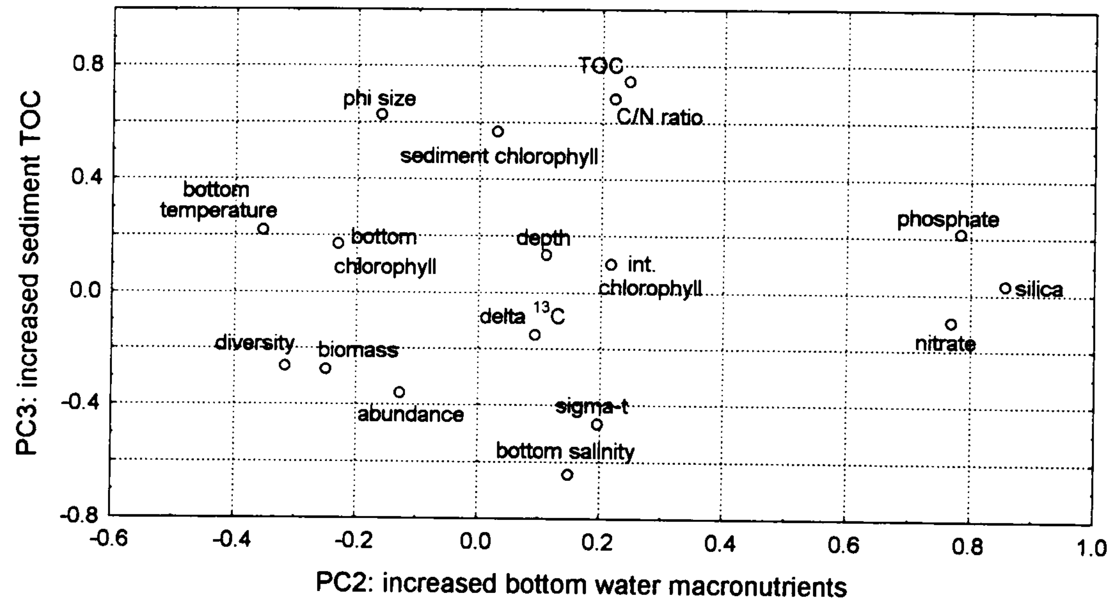
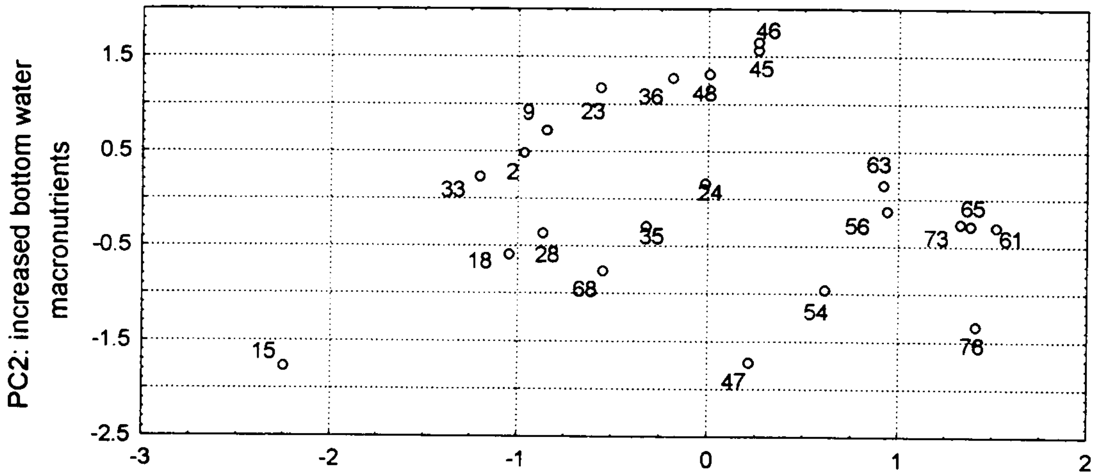


Figure 24. Plot of factor loadings for PC2 and PC3, calculated by the principal components analysis.



PC1: increased bottom temperature, depth, delta ^{13}C and decreased bottom water chlorophyll.

Figure 25. Ordination of factor scores for PC1 and PC2, computed by the principal components analysis.

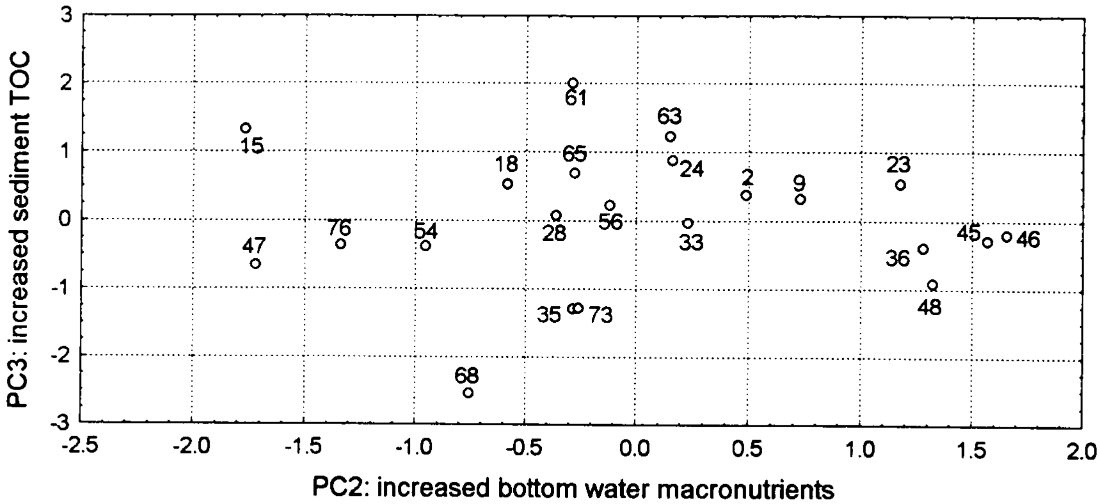


Figure 26. Ordination of factor scores for PC2 and PC3, computed by the principal components analysis.

Table 14. Factor scores of individual stations for principal components 1, 2 and 3.

HX-189 Station	PC1	PC2	PC3
2	-0.97	0.48	0.39
9	-0.85	0.73	0.32
15	-2.25	-1.77	1.33
18	-1.04	-0.59	0.54
23	-0.56	1.17	0.54
24	-0.02	0.16	0.89
28	-0.86	-0.36	0.08
33	-1.20	0.23	-0.03
35	-0.33	-0.29	-1.28
36	-0.19	1.28	-0.39
45	0.26	1.57	-0.28
46	0.26	1.65	-0.19
47	0.21	-1.72	-0.65
48	0.00	1.32	-0.91
54	0.61	-0.96	-0.38
56	0.94	-0.12	0.24
61	1.52	-0.29	2.01
63	0.92	0.15	1.24
65	1.38	-0.28	0.69
68	-0.55	-0.76	-2.54
73	1.33	-0.26	-1.28
76	1.41	-1.34	-0.36

(Zenkevitch, 1963; Grebmeier et al., 1989; this study). From this study, it has been shown that benthic macrofaunal biomass of 0.5 to 5.2 g C m^{-2} is typical of stations close to the mouth of the Kolyma River. A typical grab in this area consisted of many (>25) very small, juvenile *Portlandia arctica* bivalves weighing less than 1 gram (g C m^{-2}) total along with one or two nephtyid polychaetes and a small number of juvenile *Nucula belloti* bivalves. No amphipods were found in this area, and normally no more than 9 to 10 species were collected from any single grab. *Idotea ochotensis* isopods and *N. belloti* bivalves typically dominated the biomass and *N. belloti* and *P. arctica* bivalves typically dominated abundance. Biomass totals increased at intermediate stations moving eastward toward station 73 in the Chukchi Sea, the easternmost station included in this study (Figure 16). Grabs in the eastern portion of the study area typically contained 40 or more species with *Macoma calcarea* and *Boreacola vadosus* bivalves, anthozoans, and the amphipod families Ampeliscidae, Lysianassidae, Isaeidae and Haustoriidae dominating the biomass. Amphipod families Ampeliscidae, Haustoriidae, Isaeidae and Lysianassidae as well as the bivalves *M. calcarea* and *B. vadosus* dominated by abundance. Many species of polychaetes were also represented including large numbers of maldanid polychaetes. Biomass totals were 19.8 to 66.5 g C m^{-2}.

Individual sample descriptions:

<u>Amphipods, station 73, grabs 1 and 2</u>

This sample is a subset of amphipod assemblage #1 and contains 44.5 g C of mostly ampeliscid amphipods.

Amphipod assemblage #1, all stations with amphipods represented

This sample contains amphipods from station 73, grabs 1, 2 and 3 as well as from grabs 24, 35, 47, 48, 61, 65, 68. All geographic areas included in this study were represented. The amphipods from station 73 represent about 95% of the biomass present in the sample, while the remaining 5% come from twenty other grabs from the remaining stations. The weight amount of amphipods from each grab of station 73 is about 20 times greater than any other station sampled. Also, amphipods have been shown to concentrate the radionuclides ^{137}Cs, ^{90}Sr, ^{60}Co and ^{239}Pu in the Kara Sea (Joint Russian-Norwegian Expert Group, 1993) and ampeliscid amphipods have accumulated ^{137}Cs in the Bering and Chukchi Seas (Cooper and Grebmeier, unpublished). Therefore, this sample would provide the best opportunity to group together enough amphipods to get a minimum number of net counts to quantify any radioactivity present.

Amphipod breakdown #2, representatives from stations 24, 47, 48, 61, 68 and 73

This sample is a subset of amphipod assemblage #1. The sample was counted in a 200 mL dish that has a higher photon efficiency (1.96% at 662 KeV) than the 0.5 L Marinelli beaker (1.71% at 662 KeV) used in counting amphipod assemblage #1 in an effort to try and quantify the radioactivity present, without an unreasonably high amount of error.

Amphipod breakdown #3, representatives from stations 24, 35, 47, 48, 61, 65 and 68

This sample contained the amphipods in amphipod assemblage #1 that did not come from station 73.

Macoma calcarea bivalves, station 24, grab 2

Sample consisted of two large *Macoma calcarea* bivalves. These bivalves were two of the very few large, older *M. calcarea* bivalves collected in the study area. The logic used was that perhaps these bivalves were old enough to have concentrated some radionuclides into their tissues.

Nucula belloti bivalves, station 23, grab 2

This sample consisted of 59 mature *Nucula belloti* bivalves. While this species of bivalve tends to be small in terms of size and weight, this grab is one of the few that contained a large number of mature examples of this species. *N. belloti* bivalves had not previously been assayed for gamma emitters in this study and this grab contained a significant percentage of the total number of *N. belloti* bivalves collected in the study area. Also, other species of deposit-feeding bivalves have been shown to concentrate radionuclides in their tissues (Belot, 1986). Therefore, it was determined that this sample would have the best chance of determining if *N. belloti* bivalves had concentrated significant levels of radionuclides.

Nucula belloti bivalves, station 35, grab 2

This sample was counted for the same reasons as the previous sample.

<u>*Mya truncata* bivalve, station 35, grab 1</u>

This mature specimen was the only *Mya truncata* collected in the study area and is a favored food source of the Pacific walrus (Gay Sheffield, personal communication).

<u>Bivalve assemblage #1, representatives from stations 35, 36 and 65</u>

This sample contained *Macoma calcarea*, *Nucula belloti* and *Nuculana radiata* bivalves taken from many stations and packed together to help facilitate detection of radionuclides by virtue of sheer numbers of bivalves counted on the detector at one time. This sample contained the majority of the most mature examples of each species. This sample was counted to determine if any radionuclides had been concentrated in the tissues of bivalves in this study area.

<u>*Serripes groenlandicus* bivalve, station 48, grab 4</u>

This sample contained one large *Serripes groenlandicus* bivalve, the only large specimen collected from the study area.

<u>Mytilidae mussel, station 61, grab 1</u>

This sample contained one large, mature mytilid mussel, *Musculus niger*. Mytilidae mussels are filter feeders and have been shown to accumulate detectable amounts of radionuclides into their tissues (Belot, 1986). This specimen is one of only two mature examples collected in the study area so it was not possible to place a large number of mussels on the detector at one time.

Macoma calcarea assemblage #1, representatives from stations 24, 35, 36, 45, 46, 47, 65 and 73

Macoma calcarea bivalves have been shown to accumulate detectable amounts of radionuclides in their tissues (Cooper, 1995). These bivalves both deposit-feed and filter-feed. The majority of *Macoma calcarea* bivalves collected in the study area were packed into a 0.5 L Marinelli beaker and placed on the detector.

Polychaete assemblage, representatives from stations 23, 24, 28, 35, 45, 47, 48, 65 and 73

The largest and most mature polychaetes from the study area were assembled and packed into a 0.5 L Marinelli beaker. The sample weighed 48.02 grams and consisted of primarily deposit-feeding polychaetes of the families Maldanidae, Pectinaridae and Sternaspidae. Also included were the largest examples of the families Nephtyidae, Phyllodocidae, and Polynoidae, all of which are scavengers or carnivores, (Fauchald and Jumars, 1979).

Pelonaia corrugata assemblage, representatives from stations 24, 35, 46, 47 and 56

Sample consisted of several representatives of the filter-feeding tunicate *Pelonaia corrugata*.

Isopod assemblage, representatives from stations 15, 23, 28, 30 and 33

The largest and most mature examples of *Idotea ochotensis* isopods were packed together and counted on the detector. These isopods can grow very large (up to 10 cm) and represented the majority of the biomass in many of the westernmost stations.

Anthozoa assemblage, representatives from stations 35, 47, 65 and 73

Anthozoans represented the majority of biomass of soft-bodied animals in the study area and were present in many grabs. Also, anemones consume a wide variety of prey species (Barnes, 1980). For these reasons, these anemones were counted on the detector.

Complete grab, station 15, grab 2

This sample was collected at the westernmost station, closest to the mouth of the Kolyma River and consisted of 30 small, young *Portlandia arctica* bivalves, two *Idotea ochotensis* isopods and a small number of polychaete fragments. If there were significant radionuclide contributions from the Kolyma River to the East Siberian Sea, this grab would have the best chance to concentrate any radionuclides present. Grabs close to the river mouth have very low biomass (between 0.5 and 2 g C m^{-2}) and despite the small amount of total biomass present in this grab, this grab contained a total wet weight as high or higher than other stations from the vicinity of the mouth of the river.

Complete grab, station 45, grab 1

This sample contained all of the macrofaunal invertebrates collected from station 45, grab 1. This station is one of a few that contain a large number of different kinds of bivalves, while also having a relatively large weight amount of polychaetes.

Waste propanol, many stations represented

Waste propanol from >20 different grabs was consolidated into a 1 L Marinelli beaker and counted on the detector. This sample was counted to determine if any radionuclides were being put into suspension and therefore evading detection in any of the samples.

Waste formalin, many stations represented

Waste formalin preserving about 15 grabs was consolidated into a 1 L Marinelli beaker and counted on the detector. This sample was counted to determine if radionuclides were being leached from the animals and put into solution in the formalin before the animals could be counted.

Eight grabs were counted, unsorted, in their original formalin preservative with all rocks, organic material and debris included. These samples were counted in this state to eliminate the possibility of not detecting radionuclides that had been leached from the bodies of the animals and put into solution in the propanol or formalin, and consequently discarded. The samples counted in formalin were: station 2: grab 3, station 12: grab 1, station 21: grab 1, station 43: grab 4, station 47: grab 4, station 54: grab 2, station 63: grab 3, and station 76: grab 2.

^{137}Cs was not detected in most samples (Table 15). A trace amount of ^{137}Cs was detected in two samples but was not present in amounts large enough to quantify without an unacceptably high error term. The source of the trace

Table 15. Sample activities of Cs-137 and K-40. Numbers under sample descriptions identify the station and grab of samples.

Sample Description	Cs-137 (Bq sample^{-1})	Std. Dev.	K-40 (Bq sample^{-1})	Std. Dev.
amphipods :073 G2/G-1	trace	—	n.d.	—
amphipod assemblage #1	n.d.	—	1.87	0.42
amphipod breakdown #2	trace	—	n.d.	—
amphipod breakdown #3	n.d.	—	n.d.	—
Macoma calcarea :24 G-2	n.d.	—	n.d.	—
Nucula belloti :23 G-2	n.d.	—	n.d.	—
Nucula belloti :35 G-2	n.d.	—	n.d.	—
Mya truncata :35 G-1	n.d.	—	n.d.	—
bivalve assemblage #1	n.d.	—	n.d.	—
Serripes groenlandicus :48	n.d.	—	n.d.	—
mytilidae mussel :61 G-1	n.d.	—	n.d.	—
Macoma calcarea assem. #	n.d.	—	2.69	0.39
polychaete assemblage	n.d.	—	1.24	0.46
Pelonaia corrugata assem.	n.d.	—	1.61	0.43
isopod assemblage	n.d.	—	n.d.	—
anthozoa assemblage	n.d.	—	n.d.	—
complete grab :15 G-2	n.d.	—	n.d.	—
complete grab :45 G-1	n.d.	—	n.d.	—
grab in formalin :02 G-3	n.d.	—	17.80	0.43
grab in formalin :12 G-1	n.d.	—	48.40	0.64
grab in formalin :21 G-1	n.d.	—	14.70	0.68
grab in formalin :43 G-4	n.d.	—	23.66	0.78
grab in formalin :47 G-4	n.d.	—	11.93	2.11
grab in formalin :54 G-2	n.d.	—	32.85	2.44
grab in formalin :63 G-3	n.d.	—	23.65	0.70
grab in formalin :76 G-2	n.d.	—	31.57	0.82
waste formalin (1 liter)	n.d.	—	20.36	0.61
waste propanol (1 liter)	n.d.	—	2.00	0.44

n.d.= not detected

^{137}Cs in both samples was determined to be the large number of amphipods from station 73.

^{40}K was detected in three samples that were not counted in formalin: amphipod assemblage #1, *Macoma calcarea* assemblage #1 and *Pelonaia corrugata* assemblage (Table 16). Activities were 1.9, 2.7 and 1.6 Bq respectively. Concentrations were calculated to be 0.02, 0.015, and 0.017 Bq g^{-1}. ^{40}K was detected in amounts ranging from 11.9 to 48.4 Bq in the samples counted in formalin. The waste propanol sample detected 2.0 Bq and the waste formalin sample detected 20.4 Bq (0.02 Bq g^{-1} wet weight) of ^{40}K.

V. DISCUSSION

A. Quality, Origin and Quantity of Organic Carbon

The distribution patterns of sediment $\delta^{13}C$ values indicate that there are two distinct sources of organic carbon dominating the benthos of the two seas included in this study area: terrigenous carbon input from the Kolyma River in the East Siberian Sea and marine phytoplankton in the Chukchi Sea (Figure 14). It is assumed that the major marine organic carbon source is derived from ungrazed phytodetritus sinking to the benthos from the overlying water column, just as in studies conducted in the northern Bering and southern Chukchi Seas (Grebmeier et al., 1988; Walsh et al., 1989). Sediment $\delta^{13}C$ values were

Table 16. Radionuclides concentrated in benthic macrofauna: individual sample activities (Bq g^{-1}) wet weight.

HX-189 Sample Description	K-40 (Bq g^{-1})	Std. Dev.	whole sample K-40 (Bq)	Std. Dev.
amphipod assemblage #1	0.53	0.12	50.45	11.30
Macoma calcarea assem. #1	0.41	0.06	72.69	10.56
Pelonaia corrugata assem.	0.45	0.12	43.50	11.50

relatively low (-24.5‰ to -23.0‰) in the East Siberian Sea. These values are the likely result of the terrestrial carbon carried in the discharge of the Kolyma River, steered to the east (during some years) by the Siberian Coastal Current and deposited in the East Siberian Sea. With increasing distance from the Kolyma River mouth, the sediments receive progressively less terrestrially-influenced carbon. Also, the most negative $\delta^{13}C$ values in the central study area are confined to nearshore areas, the result of the nearshore nature and decreasing energy of the SCC as it moves eastward. The transition zone, where the two primary sources both have an effect on sediment $\delta^{13}C$ ratios, is located in the central portion of the study area. Higher quality organic carbon (based on low C/N ratios and low $\delta^{13}C$ ratios) reaches the benthos of the Chukchi Sea. The imprint of the terrestrial carbon from the Kolyma River can be seen in the low sediment $\delta^{13}C$ ratios that are at a minimum closest to the Kolyma River mouth and increase steadily eastward. From the results of this study, it appears that the measurement of low $\delta^{13}C$ values (about -23.5‰) at the mouth of Kolyuchin Bay is most likely due to the localized influx of terrigenous carbon coming from the confluence of several small rivers that drain into the bay. Additionally, terrigenous organic carbon shows relatively higher C/N ratios than carbon derived from marine sources (Naidu et al., 1993). The west to east decrease in sediment C/N ratios identified in this study support the conclusion that terrigenous carbon is the primary carbon source in the western portion of the study area in the East Siberian Sea and carbon derived from marine phytodetritus is the primary carbon source in the eastern portion of the study area in the Chukchi Sea. In the central portion of the study area, both sources of carbon appear to influence sediment C/N ratios. Grebmeier et al. (1989) concluded that high quality organic carbon transported in Bering Shelf/Anadyr Water north through Bering Strait is deposited into the sediments of the western Chukchi Sea (Grebmeier et al., 1989). The results of this study support this conclusion and extend the investigation of the effects of the quality, origin and quantity of organic carbon on benthic biomass and community structure further west into the Russian Chukchi and East Siberian Seas.

B. Benthic Macrofaunal Biomass and Community Structure

The variations shown between stations in the East Siberian Sea and stations in the Chukchi Sea are best explained, based upon PCA, by the relative depth, bottom water temperature, $\delta^{13}C$ ratios and bottom water chlorophyll concentrations (Figure 27). PC1 most clearly separates East Siberian Sea stations from Chukchi Sea stations. Factors associated with the influence of the Kolyma River and the more productive Chukchi Sea appear to be the major factors influencing the benthic biomass and community structure of the study area.

Knowledge of the origin and the geographic influence of water masses can help to explain the biomass and community structure of benthic macrofaunal invertebrates because water masses greatly influence the physical environment and the distribution of resources. The results of this study indicate that the freshwater inflow from the Kolyma River and the relatively high biological productivity of the more productive Chukchi Sea appear to be dominant oceanographic features in this area. Previous studies (Grebmeier et al., 1988; Grebmeier, 1993) have demonstrated that the relatively productive Bering Shelf-Anadyr Water (BSAW) flows north through Bering Strait and is bathymetrically steered into the eastern portion of this study area. This water mass has been shown to deposit considerable amounts of high quality organic carbon to the benthos of the Chukchi Sea, resulting in high biomass values of up to 50-60 g C m^{-2}. These stations consisted of a diverse fauna dominated by the amphipod families Ampeliscidae and Isaeidae as well as the bivalve families Nuculidae and Tellinidae (Grebmeier et al., 1988; Sirenko and Koltun, 1992). The current biomass from this study (37.5 g C m^{-2} at station 73 and 66.5 g C m^{-2} at station 76 as well as numerical dominance by most of the same faunal families) generally confirm Grebmeier's results. The current study extends the investigation of benthic community studies further west into the Russian Chukchi Sea and on into the East Siberian Sea.

Biomass values were lowest at stations that were closest to the Kolyma River mouth and situated close to shore (Figure 16). The biomass at these stations appear to be limited by factors resulting from the influence of the Kolyma River plume. Stations 2, 9, 15 and 33 (Groups 1, 2, 3 and 6 of the groups delineated by species biomass, Figure 23) all show low biomass values (0.5 to 5.2 g C m^{-2}) apparently as a result of low quality carbon (C/N ratios of 6.96 to 7.70) of primarily terrestrial origin ($\delta^{13}C$ ratios of -24.2‰ to -26.8‰) (Appendix D). Based upon the ordination of factor scores for PC1 and PC2 (Figure 27) and an extremely low $\delta^{13}C$ ratio (-26.8‰), station 15 is the station most adversely affected by the factors associated with the Kolyma River plume. Therefore, it is not surprising that station 15 showed the lowest biomass of any station (0.5 g C m^{-2}). Additionally, examples of common non-motile species at stations 2, 9 and 15 (*Portlandia arctica, Nucula belloti* and *Tellina lutea* bivalves) are much smaller than those found at most other stations, possibly as a result of lower metabolic rates caused by the low temperature bottom water identified at these stations (- 0.91 °C to -1.34 °C) (Appendix E). Biomass was significantly correlated ($r = 0.52$, $p < 0.05$) with bottom water temperature, indicating that low bottom water temperatures may play a role in limiting benthic production in portions of this study area. The biomass of the stations closest to the Kolyma River mouth appear to be limited by a combination of both a low quality food supply and possibly, low bottom water temperature. It is important to note, however, that benthic biomass was not found to be limited by low temperatures in the northern Bering Sea and northeastern Chukchi Sea. The highest benthic biomass values were found in areas with the lowest bottom water temperatures and biomass was determined to be more directly related to the quality and quantity of the food supply (Grebmeier et al., 1988, 1989; Grebmeier and McRoy, 1989).

The biomass values of stations 18, 23, 28, 35, 36 (the westernmost stations of Group 4) and station 24 (Group 5) were found to be low to medium (5.1 g C m^{-2} to 16.2 g C m^{-2}) (Figure 16) with somewhat higher quality carbon (C/N ratios of 5.96 to 6.91) of more marine origin ($\delta^{13}C$ ratios of -24.2‰ to -22.4‰) indicating that these stations are less affected by the factors associated with the Kolyma River plume than those further west. As freshwater from the Kolyma River flows into the East Siberian Sea, it is steered to the east and along the coastline by the Siberian Coastal Current, during the years that it is present (Weingartner et al., 1996). Stations 18, 23, 28, 35 and 36 are situated more offshore than stations 2, 9, 15, and 33 and therefore may be avoiding heavy influence from the Kolyma River because of the nearshore nature of the SCC. The generally higher bottom water salinity values (30.61 ppt to 32.96 ppt, Appendix E) at these stations support this conclusion.

Stations 45, 46, 47, 48, 54 and 56 make up the majority of the eastern portion of Group 4 (Figure 23) and show biomass values near the mean value (13.43 g C m^{-2}, Table 2) for all stations (7.8 g C m^{-2} to 15.6 g C m^{-2}, Figure 16). These stations were tightly grouped together in the ordination of the factor scores of PC1 (Figure 27) as well as PC3 (Figure 28), indicating that these stations show similar biomass as a result of a decreased influence of the Kolyma River input. This decreased riverine influence results from the increased distance from the river mouth and the average content of TOC in the sediment (0.80% to 1.57%) that are of a more marine origin (relatively high sediment $\delta^{13}C$ ratios of -22.0‰ to -21.1‰). Additionally, large numbers of the astrorhizid foraminiferan *Rhabdammina abyssorum* (up to 1513 ind. m^{-2}) overwhelmingly dominated the abundance at stations 45, 46, 47, 48, 54 and 56. This species thrives in the central part of the study area probably because of a sufficient food supply of high quality carbon in combination with the low bottom water temperatures in the region (-1.77 °C to 0.26 °C, among the lowest temperatures of all stations, Appendix E). Astrorhizid foraminifera are characterized by a coarse, sandy and relatively porous test (Zenkevitch, 1963) and foraminifera with small, porous tests are most often associated with colder water temperatures (Kozloff, 1996). Temperature increased steadily eastward from station 54 and 56 (Figure 5) and a relatively small number, 58 ind. m^{-2}, of *R. abyssorum* were identified from station 61. No examples of the species were identified from stations to the east.

Group 7 (consisting of only station 61) and station 63 (the easternmost member of Group 4) both show the lowest biomass (4.2 and 5.2 g C m^{-2}, respectively) and among the lowest abundance values (283 and 678 ind. m^{-2}) among Chukchi Sea stations (Table 4). Both stations show relatively high quality carbon (C/N ratios about 6.8, Appendix D) of a primarily marine origin ($\delta^{13}C$ ratios of -21.2‰ and -21.4‰, respectively) in large amounts (TOC values of 2.02 and 2.20, respectively). These results indicate that the biomass of these stations is not limited by the quality, quantity or origin of the organic carbon available to the benthos. It is not clear from variables directly measured by this study what is the limiting factor at these stations. It is possible that high TOC content and high silt/clay content could result in reduced pore water oxygen, limiting benthic production in this region.

There is only one station in the Chukchi Sea with a negative score on PC1: station 68 (the lone member of Group 9), situated at the entrance to Kolyuchin Bay. Because of the apparent influence of the localized riverine input, (as indicated by $\delta^{13}C$ ratios, Figure 14) station 68 has many environmental factors that can help to explain the low biomass. The sediment chlorophyll concentration and the sediment TOC values are the lowest of any station, by an order of magnitude. Also, the bottom water temperature is much lower (-0.3° C, as opposed to about 2.0° C for other stations west of station 61) and the modal sediment phi size, 3 phi, is relatively coarse sand, a result of increased current speeds present along coastlines in the Arctic (e.g. Feder et al., 1994b). The amount of the available food supply appears to be the major factor in limiting benthic biomass at this station.

Stations 73 and 76 showed the highest biomass values (37.5 and 66.5 g C m^{-2}, Figure 16). As a result of their geographic position, these stations directly receive highly productive BSAW advected north from the northern Bering Sea and organic carbon of high quality and quantity is deposited to the benthos (Grebmeier et al., 1989). Additionally, these stations show the highest $\delta^{13}C$ ratios, indicating that the organic carbon is under the least terrestrial influence of any station included in the study. These stations show the highest biomass values as a result of a combination of sufficient amounts of organic carbon, or high quality of a primarily marine origin.

C. Factors Affecting Diversity

The diversity of benthic invertebrate communities can be controlled by a number of factors including food supply, hydrodynamics, sedimentary characteristics, predation, competition, environmental stability and disturbance (e.g. Gray, 1981; Valiela, 1995). Additionally, some studies (e.g. Kröncke, 1994; Gambi et al., 1997) postulate that the community structure of some benthic communities depends more upon depth than on sediment parameters. Both factors, along with the origin of available organic carbon, need to be considered for this study area. Depth was determined to be an important variable in separating East Siberian Sea stations from Chukchi Sea stations, but it is not likely that depth alone is an important factor because depths were shallow throughout the study area (18 to 50 m, Figure 6). Depth had a significant positive correlation ($p < 0.05$) with five other variables: diversity, sigma-t, TOC, nitrate and $\delta^{13}C$. This indicates that increased depth is coincident with stations with higher benthic diversity, higher sediment $\delta^{13}C$ values, etc., but depth is not necessarily a controlling factor in benthic biomass and community structure.

The highest biomass and highest diversity values are found in the Chukchi Sea (an obvious exception being station 24 in the East Siberian Sea, $H'= 2.96$, the second highest diversity value of any station). The correlation coefficient between the two variables ($r= 0.53$) is significant at $p< 0.05$. In this study, higher species diversity appears to be most associated with an apparent increase in productivity, apparently following the *productivity hypothesis* of species diversity (Valiela, 1995) as stated in the second hypothesis. The *productivity hypothesis* states that with all other environmental variables equal, the greater the productivity, the greater the diversity because increased resources allow an increased number of species (Valiela, 1995). Based on the non-significant correlation between species diversity and the percentage of silt and clay of the sediments, sediment grain size is not the major factor affecting the diversity of the benthic fauna, contradicting part of the second hypothesis proposed in this study.

Grebmeier et al. (1989) showed in the northern Bering and southern Chukchi Seas that higher bottom water chlorophyll-a concentrations (a proxy for food availability) were negatively correlated with benthic diversity. They postulated that this parameter, acting in concert with other factors, may have had a negative influence on diversity. In this study, bottom water chlorophyll-a concentrations have a significant negative correlation ($r= -.47$, $p< 0.05$) with diversity, which is generally consistent with the Grebmeier et al. (1989) study. Eighteen of the twenty-two total stations showed uniformly low bottom water chlorophyll-a concentrations. Interestingly, the four stations with the highest bottom water chlorophyll-a (2, 15, 28 and 33) all showed TOC percentages in the middle range of all stations (0.84% to 1.27%, Appendix D) but showed diversity measures among the lowest of any station (H′= 0.53, 0.71, 1.01 and 1.25, respectively). This indicates that food availability does not limit faunal diversity in this system; the origin (and therefore the digestibility) of the organic carbon appears to be more important. $\delta^{13}C$ ratios were correlated ($r = 0.49$, $p < 0.05$) with diversity. This is in agreement with part of the second hypothesis evaluated in this study.

Considering the ongoing debate over the relative merits of any single diversity hypothesis and the fact that this study does not attempt to quantify all factors that can affect diversity, it is probably more logical to conclude that the diversity of the benthic community in this study is affected by a number of different factors (Valiela, 1995). The *environmental stability hypothesis* of species diversity states that the more stable the environmental variables (temperature, salinity, sediment grain size, etc.), the more species will be present because it is less likely that any particular species will not survive due to the variation in environmental conditions (Valiela, 1995). The environment is extremely variable both seasonally and spatially in the marginal seas of the Arctic Ocean (Dayton, 1990) and the effects of disturbance events not directly measured in this study almost certainly play a role in influencing the biomass and community structure of the East Siberian and Chukchi Seas. The benthos of the Arctic is subjected to many types of disturbance. Large seasonal variations in salinity extremes occur in the area. During the winter, when high salinity water sinks to the bottom, salinity is at a maximum; the opposite is true in the summer (Dayton, 1990). Summer melt triggers a large influx of freshwater from the numerous rivers along the coast, decreasing overall salinity. Also, ice gouging is thought to disrupt and modify the sea floor on the continental shelves of the Arctic and consequently influence faunal abundance and biomass (Carey, 1991; Grebmeier and Barry, 1991). In this study area, ice gouging probably occurs over a more widespread area and with greater severity in the East Siberian Sea due to the generally shallower depths and longer seasonal ice cover.

The feeding activities of gray whales (*Eschrichtius robustus*) and Pacific walrus (*Odobenus rosmarus divergens*) also may have an effect on the benthic community in the study area. More than 15,000 gray whales and 200,000 Pacific walrus migrate to the Chukchi Sea during the summer (Fay, 1982). Gray whales feed by ingesting sediment into their mouths and filtering out amphipods (primarily ampeliscid amphipods) through their baleen. Walrus have been historically considered to be a benthic feeder concentrating on bivalves, although they are now thought to have depleted their favored bivalve populations and consequently supplement their diet with a larger variety of prey species (Gay Sheffield, personal communication). This is the likely result of increasing populations and the ever-increasing demand for appropriate forage. These marine mammals are not likely to greatly disturb the benthos of the East Siberian Sea portion of the study area because of the lack of appropriate forage for the animals, especially the lack of significant numbers of amphipods in the central and western portions of the study area. These feeding methods can greatly disturb the benthos, resuspending large amounts of sediment into the water column. This can be particularly important in the resuspension of nutrients considering the vertical stratification of the water column during the summer (and Barry, 1991). The gray whale feeding pits, but not the walrus pits, are taken over by swarms of amphipods (primarily by species lysianassid amphipods) and the pits trap new sediment (Oliver et al., 1985). This can lead to a locally patchy distribution of food available to the benthos. Also, this sediment disturbance can serve to create new settlement areas for invertebrate larvae and new attachment sites for more mature invertebrates. Considering the variable nature of disturbance events, it is possible that a disproportionate distribution of these events over the study area could have some effect on the diversity, biomass and community structure of the East Siberian and Chukchi Seas.

The high diversity (H′= 2.96) found at station 24 may be a result of unique localized conditions. All of the stations in the East Siberian Sea are typically dominated by one or two species of bivalve, normally small examples of *Portlandia arctica* or *Nucula belloti,* with station 24 being the lone exception; this station contained a variety of polychaete species and was dominated by maldanid polychaetes. Perhaps this lack of a single dominant bivalve species (possibly as a result of localized predation pressure by gastropods or other predators) has allowed the available resources to be partitioned more evenly among a number of other species.

The sedimentary preferences of invertebrates with various feeding strategies has been well documented in benthic studies in general (e.g. Long and Lewis, 1987) and the Arctic in particular (e.g. Grebmeier and McRoy, 1989; Feder et al., 1994b). The fact that the percentage of individual deposit-feeding invertebrates is not significantly correlated to the percentage of silt and clay in the sediments (Figure 19) in this study indicates that other factors, acting along with sediment grain size, are important in controlling the distribution of deposit-feeding invertebrates in the study area. The differences in fauna between stations 68 and 73 in the Chukchi Sea allow for an interesting comparison. In this study, the stations with the greatest percentage of sand in the sediment were 68 and 73. The sediment taken from both stations had a greater than 90% sand content, both stations are close to shore and are relatively close together, yet the stations differ greatly in their faunal composition apparently due to factors that are not related to sediment grain size alone. Station 73 is directly influenced by carbon-rich Bering Shelf/Anadyr Water while station 68 is more directly influenced by water carried from the west by the Siberian Coastal Current and freshwater outflow from Kolyuchin Bay. Station 73 was dominated by large numbers (1935 ind. m^{-2}) of ampeliscid amphipods, a tube-dwelling facultative deposit/suspension feeder, as well as the montacutid bivalve *Boreacola vadosus* (a surface deposit-feeder) and isaeid and lysianassid amphipods. No ampeliscid amphipods and only a small number of other species of amphipods were identified from station 68. Ampeliscid amphipods depend on a high quantity and quality food supply (Highsmith and Coyle, 1990). The biomass of station 68 appears to be limited by both a higher terrestrial carbon content as well as carbon quantity of the organic carbon reaching the benthos. Station 73 showed a combination of the quality, origin and quantity of organic carbon that resulted in the highest benthic biomass of any station. The fauna of station 68 consisted of 57.5% filter feeders, easily the highest percentage of any station, while station 73 consisted of only 0.6% filter- feeders (Table 7). Even considering the fact that much of dominant fauna of station 73 can act as deposit-feeders or suspension-feeders, station 68 still had the highest percentage of primarily filter-feeders. This indicates that because filter-feeding invertebrates are consuming sinking carbon before it reaches the bottom, filter-feeders are out competing deposit-feeders in areas with low sediment TOC. Therefore the origin and quantity of the food supply act in conjunction with sediment grain size in determining the distribution of invertebrates with various feeding strategies.

D. Radionuclides in Benthic Macrofaunal Invertebrates

The extremely low trace levels or non-detectable levels of anthropogenic radionuclides present in the samples indicate that the benthic macrofaunal invertebrates of the study area have not been contaminated with anthropogenically introduced radionuclides. It may have been possible to detect trace amounts of ^{137}Cs in other samples, given extremely long counting times (more than four days) but this would not have been any more useful in drawing conclusions about the state of contamination in this area. It is reasonable to assume that the low trace levels of ^{137}Cs detected in the amphipod samples can be reasonably attributed to the radioactive fallout observed in areas of this latitude, about 100 mBq cm^{-2} (Cooper et al., 1998).

Considering the very low or nonexistent amounts of detected ^{137}Cs, I was unable to test the hypothesis that deposit-feeding, carnivorous or scavenging invertebrates concentrate radionuclides in amounts greater than filter-feeding invertebrates.

The levels of ^{40}K detected in the three samples not counted in formalin, amphipod assemblage #1, *Pelonaia corrugata* assemblage and *Macoma calcarea* assemblage were not substantially higher than levels of ^{40}K present in the surrounding seawater. These three samples average 0.017 Bq g^{-1} of wet tissue weight and seawater averages about 0.011 Bq g^{-1}. It is reasonable to attribute the detection of slightly elevated levels of ^{40}K to natural variation in localized ^{40}K concentrations due to varying amounts of ^{40}K present in benthic sediment.

Because benthic macrofaunal invertebrates have not accumulated significant amounts of ^{40}K over what is present in the surrounding environment, no conclusions can be drawn about the relationship between ^{40}K concentration and different sediment grain sizes, animal types, geographic locations or feeding strategies.

V. CONCLUSIONS

1. The freshwater inflow of the Kolyma River and the nutrient-rich water flowing north through Bering Strait appear to be the major oceanographic influences in the portions of the East Siberian and Chukchi Seas included in this study. This influence has many significant ecological consequences on the benthic

macrofauna of the area. As a result of the freshwater inflow, steered by the SCC, the organic carbon available to the benthos of the East Siberian Sea and the western Chukchi Sea is of relatively low nutritional value, much of it being of terrestrial origin. Higher quality organic carbon is available to the benthos of the eastern Chukchi Sea. The quality of the organic carbon, and as a result, benthic biomass, generally increases with increasing distance from the Kolyma River and reaches a maximum in the Chukchi Sea in the eastern portion of the study area.

2. The species diversity of the benthic macrofaunal invertebrates, as measured by the Shannon-Weaver diversity index, is generally greatest in the areas of highest benthic production, tending to confirm the *productivity hypothesis* of species diversity (Valiela, 1995). Sediment grain size doesn't appear to greatly affect the diversity of the fauna. Disturbance events have a less quantifiable and spatially variable influence.

3. Sediment grain size, acting in concert with the origin and quantity of organic carbon, controls the distribution of benthic invertebrates with differing feeding strategies in the study area.

4. Benthic macrofaunal invertebrates of the portions of the East Siberian and Chukchi Seas included in this study have not concentrated anthropogenic gamma-emitting radionuclides in their tissues. The trace levels of ^{137}Cs detected in this study can be reasonably attributed to radioactive fallout.

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Appendix A. Protocol used for the analysis of sediment grain size. Adapted from Krumbein and Pettijohn, 1938; Royse, 1970; Carver, 1971; Stockham and Fochtman, 1977; Buchanon, 1984; Blake and Hartge, 1986; Kunze and Dixon, 1986; Gee and Bauder, 1996.

Analysis of Marine Sediment Grain Size

1. Sample Preparation

Begin grain size analysis with about 20 g of dry sediment. This sample contains both sediment grains and organic material. Take an initial dry weight and record. Place sample into a 250 mL or larger beaker.

2. Removal of Organic Matter

Place beakers under a fume hood. Have a shallow ice and water bath ready to slow the hot, exothermic reaction that may occur in some samples. Add 30 mL of 30% hydrogen peroxide. Stir to mix completely. The hydrogen peroxide dissolves the organic material and releases carbon dioxide gas. The sample in the beaker will bubble audibly and the bubbles may build up and overflow the beaker. Place in ice bath if beaker gets hot or if bubbling becomes vigorous. Stir frequently to keep the amount of bubbles down. The reaction is complete and organic material is removed when audible bubbling stops. Heat until mixture boils gently (120°C) to remove excess hydrogen peroxide. This step is likely to take between 2-3 hours but can take several more hours (or overnight) to complete. Dry to a sludge.

3. Removal of Iron Oxides

Sodium Citrate Buffer Preparation

1. 1 L of Distilled Water
2. 88 g L^{-1} of Sodium Citrate
3. 84 g L^{-1} of Sodium Bicarbonate

It is likely that the mixture will require extended mixing on a shaker machine to dissolve the chemicals. Shake for approximately 1 hour. The target pH is 7.3 +/- 0.05 and citric acid or sodium hydroxide can be added to adjust the pH. This initial mixture will yield a pH of about 8.5. To one liter of initial buffer mixture (pH 8.5), addition of about 29 g of citric acid will bring the pH down into the required range. However, the pH of the buffer should be measured before use.

Removal of Iron Oxides

Remove samples from beakers and place into 250 mL plastic screw-top bottles.

To each bottle of sample:

1. add 60 mL of sodium citrate buffer
2. cap and shake vigorously to loosen all sediment from the bottom of the bottle
3. place in 80°C water bath for 10 minutes
4. add 1 to 1.5 g of sodium dithionite
5. swirl with vigor, being careful not to let sediment stick to sides of bottle
6. place in hot water bath for 5 minutes
7. swirl with vigor, being careful not to let sediment stick to sides of bottle
8. place in hot water bath for 5 minutes
9. centrifuge for 5 minutes at 1500 rpm
10. decant supernatant, being careful to retain all sediments (supernatant can be retained for determination of iron oxides in solution or can be discarded)
11. repeat steps 1-10 for a total of two treatments

Fill sample bottles to 250 mL level with distilled water. Shake vigorously. Place sample into open beakers. Let stand for 1-2 hours. If flocculation occurs, add 50 mL of 10% sodium hexametaphosphate (commercial brand-name Calgon). Stir and let stand. Look for flocculation after 1 hour. The Calgon treatment should sufficiently disperse the individual grains. If flocculation still occurs, repeat Calgon treatment. Allow sediment in open glass beakers to dry completely at room temperature under a vacuum hood. It is likely that it will take several days to dry completely. Record a second dry weight. This dry weight represents the weight of sediment minus any organic material present in the original sample, plus the molecular weight of the chemicals required in the treatment.

5. **Wet Sieving**

Hydrate sample with enough distilled water to put all grains into solution. Stir well. Pour hydrated sample into a sieve stack containing a 2 mm sieve, a 62 µm sieve and a catch pan. Swirl and rinse with distilled water until grains have migrated into the appropriate sieve. Sediment retained in 2 mm sieve and 62 µm sieve (sand sized grains and larger) are dried and weighed and will be dry sieved for further separation. Sediments in the catch pan (silts and clays, <62 µm) are centrifuged and retained for X-Ray Diffraction analysis. Sand sized grains (>62 µm) are resieved on a sieve shaker with sieve sizes of 420, 250, 177, 125 and 62 µm and weighed. Individual grain size percents are then computed.

Appendix B. Classification and carbon conversions of East Siberian and Chukchi Sea benthic fauna. Adapted from Stoker (1978), Fauchald and Jumars (1979), Barnes (1980) and Grebmeier (1987).

SDF = surface deposit feeder
SSDF = subsurface deposit feeder
FF = filter feeder
DF = deposit feeder
S = scavenger
C = carnivore

TAXA		Organic Carbon Conversion Factor	Feeding Type
PHYLUM PROTOZOA			
ORDER FORAMINIFERA			
Astrorhizidae	*Rhabdammina abyssorum*	0.010	C/S
Lituolidae	*Alveolophragmium orbiculatum*	0.010	C/S
Nonionidae	*Elphidium oregonense*	0.010	C/S
Reophacidae	*Ammofrondicularia arctica*	0.010	C/S
PHYLUM CNIDARIA			
ORDER ANTHOZOA			
Anthozoans		0.061	C
ORDER ALCYONACEA			
Nephtheidae	*Eunephyta rubiformis*	0.040	FF
PHYLUM RHYNCHOCOELA			
Rhynchocoela	spp.	0.093	C

PHYLUM ANNELIDA

CLASS POLYCHAETA

Ampharetidae	*Ampharete acutifrons*	0.069	SDF
Capitellidae	*Capitella capitata*	0.069	DF
Cirratulidae	*Cirratulus cirratus*	0.069	SDF
Cirratulidae	sp.1	0.069	SDF
Flabelligeridae	*Brada sp.*	0.044	SDF
Flabelligeridae	*Flabelligera sp.*	0.044	SDF
Glyceridae	*Glycera capitata*	0.069	C/S
Goniadidae	sp.1	0.069	C/S
Lumbrineridae	*Lumbrineris sp.*	0.093	C/S/SDF
Lumbrineridae	sp.2	0.093	C/S/SDF
Maldanidae	sp.1	0.070	SSDF
Maldanidae	sp.2	0.070	SSDF
Nephtyidae	*Nephtys spp.*	0.072	C/S
Ophelidae	*Ophelia limacina*	0.069	DF
Ophelidae	*Ophelia sp.*	0.069	DF
Ophelidae	*Ophelia kerguellensis*	0.069	DF
Orbiniidae	sp.1	0.061	SSDF
Oweniidae	*Owenia fusiformis*	0.061	FF/SSDF
Pectinaridae	*Pectinaria hyperborea*	0.045	SSDF
Phyllodocidae	*Eteone sp.*	0.087	C/S
Phyllodocidae	sp.2	0.087	C/S
Phyllodocidae	sp.3	0.087	C/S
Polynoidae	sp.1	0.073	C/S
Polynoidae	sp.2	0.073	C/S
Sabellidae	sp.1	0.069	FF
Scalibregmidae	*Scalibregma inflatum*	0.069	SSDF
Sigalionidae	*Pholoe minuta*	0.069	C/S
Spionidae	sp.1	0.069	FF/SSDF
Sternaspidae	*Sternaspis scutata*	0.041	SSDF
Syllidae	sp.1	0.069	C/S
Syllidae	*Syllis fasciata*	0.069	C/S
Terebellidae	*Neoamphitrite figulus*	0.061	SDF

PHYLUM MOLLUSCA

CLASS BIVALVIA

Astartidae	sp.1	0.015	FF
Astartidae	*Astarte borealis*	0.015	FF
Cardiidae	*Serripes groenlandicus*	0.028	FF
Cardiidae	*Clinocardium sp.*	0.028	FF/SDF
Carditidae	*Cyclocardia sp.*	0.028	
Glycimeridae	sp.1	0.028	

Lucinidae	sp.1	0.028	
Lyonsiidae	*Lyonsia arenosa*	0.028	
Montacutidae	*Boreacola vadosus*	0.028	SDF
Montacutidae	*Pseudopythia compressa*	0.028	SDF
Myidae	*Mya truncata*	0.028	FF/SDF
Myidae	*Mya arenaria*	0.028	FF/SDF
Mytilidae	*Musculus niger*	0.028	FF
Mytilidae	sp.2	0.028	FF
Nuculanidae	*Nuculana sp.*	0.033	SDF
Nuculanidae	*Nuculana minuta*	0.033	SDF
Nuculanidae	*Nuculana pernula*	0.033	SDF
Nuculanidae	*Nuculana radiata*	0.019	SDF
Nuculanidae	*Portlandia arctica*	0.033	SDF
Nuculanidae	*Yoldia hyperborea*	0.047	SDF
Nuculidae	*Nucula belloti*	0.039	DF
Tellinidae	*Macoma sp.*	0.035	SDF/FF
Tellinidae	*Macoma calcarea*	0.035	SDF/FF
Tellinidae	*Macoma moesta*	0.035	SDF/FF
Tellinidae	*Tellina lutea*	0.029	SDF/FF
Thyasiridae	sp.1	0.028	FF
Thyasiridae	sp.2	0.028	FF
Veneridae	*Liocyma fluctuosa*	0.028	FF

CLASS GASTROPODA

Buccinidae	sp.	0.062	C/S
Buccinidae	*Buccinum sp.*	0.062	C/S
Cancellaridae	*Admete viridula*	0.062	C/S
Cyclichnidae	sp.1	0.062	C/S
Cyclichnidae	sp.2	0.062	C/S
Nassiridae	sp.1	0.062	C/S
Pyranidellidae	sp.1	0.062	C/S
Trichotropidae	*Trichotropis coronata*	0.062	C/S
Trochidae	sp.1	0.062	C/S
Trochidae	*Margarites sp.*	0.062	C/S
Trochidae	*Solariella sp.*	0.062	C/S
Turridae	sp.1	0.062	C/S
Turritellidae	*Turritella sp.*	0.062	C/S

PHYLUM ARTHROPODA

CLASS CRUSTACEA

Order Amphipoda

Ampelicidae	*Ampelisca sp.*	0.068	FF/SDF
Ampelicidae	*Byblis sp.*	0.068	FF/SDF

Aoridae	*Lembos arcticus*	0.074	SDF
Corophidae	*Erichtonius hunteri*	0.074	DF
Gammaridae	sp.1	0.074	SDF
Haustoriidae	sp.1	0.074	SDF
Isaeidae	*Photis sp.*	0.068	SDF
Isaeidae	sp.1	0.068	SDF
Isaeidae	sp.2	0.068	SDF
Isaeidae	sp.3	0.068	SDF
Lysianassidae	sp.1	0.074	C/S/SDF
Lysianassidae	*Anonyx nugax*	0.074	C/S/SDF
Lysianassidae	*Lepidepecreum umbo*	0.074	C/S/SDF
Lysianassidae	*Socarus bidentuculatus*	0.074	C/S/SDF
Oedicerotidae	*Monoculoides crassirostris*	0.074	C/S/SDF
Photidae	*Protomedeia grandimana*	0.074	SDF
Phoxocephalidae	sp.1	0.074	SDF/FF
Phoxocephalidae	sp.2	0.074	SDF/FF
"Slit-eye" Amphipod	sp.	0.074	
Stenothoidae	*Metopa clypeata*	0.074	

ORDER CUMACEA

Diastylidae	sp.1	0.074	SDF
Lampropridae	*Lamprops beringi*	0.074	SDF
Leuconidae	*Eudorella emarginata*	0.074	SDF/S
Leuconidae	*Eudorellopsis derzhavini*	0.074	SDF/S
Leuconidae	*Eudorellopsis biplicata*	0.074	SDF/S
Leuconidae	*Leucon nasica*	0.074	SDF/S

ORDER ISOPODA

Idoteidae	*Idotea ochotensis*	0.074	SDF
Idoteidae	sp.2	0.074	SDF
Anthuridae	*Calathura brachiata*	0.074	SDF

PHYLUM PRIAPULIDA

Priapulidae	*Priapulus caudatus*	0.045	C/S

PHYLUM SIPUNCULIDA

Sipunculidae	*Phascolion strombi*	0.045	C/S
Sipunculidae	*Phascolosoma margaritaceum*	0.045	C/S

PHYLUM ECHIURIDA

Echiuridae	*Echiurus echiurus*	0.051	SDF
Echiuridae	sp.2	0.051	SDF

PHYLUM ECHINODERMATA

CLASS ASTEROIDEA

Porcellanasteridae	*Ctenodiscus crispatus*	0.018	SDF

CLASS ECHINOIDEA

Echinarachnidae	*Echinarachnius parma*	0.018	FF/SDF

CLASS OPHIUROIDEA

Ophiuridae	*Ophiura sarsi*	0.014	SDF/C
Ophiactidae	*Ophiolopholis aculeata*	0.014	SDF/C

CLASS HOLOTHUROIDEA

Cucumariidae	*Cucumaria japonica*	0.021	SDF
Cucumariidae	*Pentemera lissoplaca*	0.021	SDF
Cucumariidae	*Cucumaria calcigera*	0.021	SDF
Synaptidae	sp.	0.021	SDF

PHYLUM UROCHORDATA

CLASS ASCIDIACEA

Styelidae	*Pelonaia corrugata*	0.014	FF
Styelidae	sp.2	0.014	FF

Appendix C. HX-189 station latitudes, longitudes, depths and sampling dates.

HX-189 Station Number	Latitude	Longitude	Depth (m)	Day Sampled
2	70.4485 °N	167.9973 °W	31	24 Aug. 1995
9	69.8343 °N	165.9983 °W	32	24 Aug. 1995
15	70.1678 °N	164.9958 °W	16	25 Aug. 1995
18	70.8283 °N	167.4500 °W	31	25 Aug. 1995
23	71.1668 °N	169.9988 °W	41	26 Aug. 1995
24	71.3127 °N	170.3427 °W	46	26 Aug. 1995
28	70.6670 °N	171.3332 °W	28	27 Aug. 1995
33	69.9997 °N	172.3362 °W	18	27 Aug. 1995
35	70.3340 °N	173.3323 °W	34	27 Aug. 1995
36	70.6688 °N	173.6692 °W	36	27 Aug. 1995
45	70.4993 °N	178.4960 °W	45	28 Aug. 1995
46	70.0645 °N	179.2360 °W	43	28 Aug. 1995
47	69.5987 °N	179.9983 °W	47	29 Aug. 1995
48	69.1490 °N	179.2493 °W	39	29 Aug. 1995
54	69.1673 °N	177.7672 ° E	47	29 Aug. 1995
56	69.4998 °N	177.2680 ° E	49	30 Aug. 1995
61	69.3008 °N	174.2015 ° E	50	30 Aug. 1995
63	68.6672 °N	171.9972 ° E	46	31 Aug. 1995
65	67.9988 °N	173.0000 ° E	46	31 Aug. 1995
68	67.4163 °N	173.9982 ° E	24	31 Aug. 1995
73	66.6658 °N	170.0012 ° E	45	1 Sept. 1995
76	67.3332 °N	168.9980 ° E	48	1 Sept. 1995

Appendix D. Raw sediment data: sediment Total Orgain Carbon (TOC), C/N ratios, delta C-13 ratios, modal sediment phi size and sediment chlorophyll-a for the 22 invertebrate sampling stations.

Station	T.O.C. (%)	C/N ratio (wt./wt.)	delta C-13 (‰)	modal phi size (phi)	sediment chlorophyll (μg g^{-1})
2	1.065	6.96	-24.33	7	0.462
9	1.014	7.70	-24.93	7	0.121
15	0.840	7.05	-26.76	14	1.431
18	0.765	6.48	-24.18	14	0.543
23	1.263	6.90	-24.03	7	1.010
24	1.294	6.98	-24.00	14	0.685
28	1.007	7.21	-23.95	7	0.676
33	1.274	7.42	-24.19	7	0.381
35	0.800	5.96	-23.88	3	0.378
36	1.234	6.67	-22.35	7	no data
45	1.404	6.78	-21.96	7	0.498
46	1.235	6.68	-22.14	7	0.740
47	0.862	6.57	-21.96	7	0.445
48	0.797	6.16	-22.12	7	0.315
54	0.927	6.47	-21.98	7	0.205
56	1.571	6.54	-21.38	7	0.548
61	2.096	6.86	-21.20	7	0.429
63	2.020	6.83	-21.38	7	1.108
65	2.166	6.50	-21.31	7	0.231
68	0.063	no data	-23.59	3	0.034
73	0.339	6.60	-20.36	3	0.290
76	0.982	6.28	-21.32	7	0.146

Appendix E. Hydrographic variables for individual stations for HX-189.

Station	depth (m)	integrated chlorophyll (mg m^{-2})	bottom water chlorophyll (µg L^{-1})	bottom water temperature (°C)	bottom water salinity (ppt)	sigma-t
2	31	182.96	36.6	-1.330	30.880	24.823
9	32	539.16	5.9	-1.340	30.651	24.638
15	16	239.50	68.4	-0.908	30.282	24.329
18	31	296.64	11.1	-1.553	30.609	24.607
23	41	657.06	10.3	-0.741	31.801	25.553
24	46	354.30	11.7	-0.643	31.911	25.639
28	28	291.47	48.3	-0.698	32.441	26.069
33	18	640.10	36.6	-0.438	32.384	26.014
35	34	347.21	12.8	-1.256	32.928	26.482
36	36	188.40	12.8	-1.735	32.958	26.519
45	45	271.78	4.2	-1.766	33.118	26.650
46	43	23.14	1.5	-1.699	32.953	26.514
47	47	112.58	1.9	-1.568	33.083	26.617
48	39	139.93	9.7	-1.297	33.021	26.559
54	47	99.06	0.7	0.265	32.919	26.414
56	49	93.93	0.6	0.064	32.904	26.411
61	50	104.55	0.8	2.031	32.756	26.172
63	46	246.80	1.8	2.184	32.734	26.143
65	46	95.85	4.9	2.178	32.934	26.303
68	24	127.50	7.4	-0.262	32.940	26.455
73	45	320.25	17.7	2.066	32.737	26.154
76	48	187.00	3.2	2.234	32.343	25.826

VITA

Andrew Reed was born in Nashville, Tennessee on December 7, 1971. He attended schools in the public system of Nashville where he graduated from McGavock High School in June, 1990. He entered the University of Tennessee, Knoxville, Tennessee during August of 1990 where in May, 1995 he received the Bachelor of Science in Organismal and Systems Biology with a minor in Zoology. He entered the Master's program in Ecology and Evolutionary Biology at the University of Tennessee, Knoxville in August of 1995, officially receiving the Master's degree in May, 1998. During his time at U.T., he participated in four oceanographic research cruises in the Bering, East Siberian and Chukchi Seas as well as a terrestrial radionuclide survey at the Bilibino Nuclear Power Station, Bilibino, Siberia. He has recently accepted a Ph.D. studentship studying hydrothermal vent ecology at Rutgers University under the supervision of Dr. Richard Lutz.