

FINAL

Characterization of Benthic Habitats in Camden Bay (Sivulliq Prospect and Hammerhead Drill Sites), Beaufort Sea Alaska

Summer 2008

Submitted to:



Shell Alaska
Anchorage, Alaska

15 July 2009

by

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	4
BACKGROUND	
1.0 Introduction.....	6
ME THODS	
2.0 OVERVIEW	
2.0.1 Approach.....	11
2.0.2 Site Selection	13
2.1 BENTHIC SEDIMENT MEASUREMENTS	
2.1.1 Isotope measurements – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	13
2.1.2 Chlorophyll <i>a</i>	14
2.1.3 Pore water ammonium (NH_4)	15
2.1.4 C:N Ratios.....	15
2.2 BENTHIC FAUNA MEASUREMENTS	
2.2.1 Station density, biomass and species composition	15
2.2.2 Isotope measurements – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	16
2.3 WATER COLUMN MEASUREMENTS	
2.3.1 Chlorophyll <i>a</i>	16
2.3.2 Zooplankton – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	17
2.3.3 POM vertical profiles - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	17
2.3.4 Nutrients (NH_4^+ , SiO_4 , PO_4^3 , $\text{NO}_2^- + \text{NO}_3^-$).....	17
2.4 GEOGRAPHICAL INFORMATION SYSTEMS (GIS)	18
2.5 COMMUNITY STRUCTURE ANALYSES (PRIMER)	19
2.6 QUALITY ASSURANCE	19

RESULTS & DISCUSSION

3.0 BENTHIC SEDIMENT BIOGEOCHEMICAL MEASUREMENTS	20
3.1 BENTHIC FAUNA	28
3.1.1 Station abundance, biomass and species composition.....	28
3.1.2 Benthic community structure.....	37
3.1.3 Isotope measurements – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	47
3.2 WATER COLUMN MEASUREMENTS	
3.2.1 Chlorophyll <i>a</i>	51
3.2.2 Zooplankton and POM vertical profiles – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	53
3.2.3 POM vertical profiles - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	58
3.2.4 Nutrients (NH_4^+ , SiO_4 , PO_4^{3-} , $\text{NO}_2^- + \text{NO}_3^-$).....	61
SUMMARY	62
ACKNOWLEDGEMENTS	63
REFERENCES	63
APPENDIX	67

EXECUTIVE SUMMARY

We describe a pre-drilling chemical and biological sampling program in the vicinity of Shell Alaska's Sivulliq prospect near Camden Bay, Alaska. Our research program, a joint effort between Ken Dunton (The University of Texas Marine Science Institute; UTMSI) and John Trefry (Florida Institute of Technology; FIT), was designed to help us achieve a better understanding of the local mid-shelf ecosystem. Our specific objective was to determine the general characteristics and natural variability of the area, and to enable us to detect any changes that might have occurred in the past as well as to assess any changes that might occur in the future. This report addresses the biological characterization of the Sivulliq prospect with specific emphasis on the benthos, with related water column measurements at selected sites.

Sediment grab samples collected from the *RV Arctic Seal* and field processed between 17 July and 22 July 2008, were used to describe the character of the seabed with respect to the organisms that live within the sediments (the infauna). We did not conduct bottom trawls which would provide us with information on the mobile organisms living on the surface of the sediments (this activity is planned for summer 2009). We also measured the isotopic signatures of the organisms we collected to help us better understand the benthic food web. This information provides some insight into which animals are lower (or higher) on the food chain, and whether their organic carbon (food) sources are largely marine or terrestrial. Density, biomass, stable isotopic composition ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$), and species composition of the infaunal community were determined from 45 sites at depths ranging from 22 to 38 m.

We collected over 118 benthic invertebrate species in the study area, with areal biomass ranging from a 0 to 133 g m⁻² and densities up to 1060 individuals m⁻². Polychaetes and bivalves composed over 90% of faunal abundance and biomass at most stations. The biomass and density of infaunal organisms were lower at shallower (22-26 m) stations along the Pipeline corridor, but biomass values at several sites are clearly among the highest recorded for the nearshore shelf of the central Alaskan Beaufort Sea. Multi-dimensional scaling (MDS) analyses (used to determine the percent similarity among stations) revealed that four of the five Pipeline stations possessed little resemblance to the remaining 41 stations, probably a consequence of frequent physical disturbance by deep draft ice and substrate differences.

Measurements of chlorophyll provide information on the abundance of phytoplankton in the water column and microalgae that live in the sediments on the bottom. These microalgae are very important food resources for organisms that live in marine environments. The ratio of carbon to nitrogen (C:N) in the sediments reflect a variety of biogeochemical processes, but ultimately provide information on the relative abundance of either carbon or nitrogen that is delivered to the sediments and then utilized by the organisms. At nearshore sites on the proposed undersea Pipeline corridor, subsamples of sediments from replicate grabs revealed strong correlations between sediment chlorophyll ($>130 \text{ mg m}^{-2}$), higher C:N (>10.7), and elevated sediment $\delta^{13}\text{C}$ values (-20 to -22‰). These data reflect the production of carbon by benthic microalgae (as identified by their less negative $\delta^{13}\text{C}$ values) in these shallower waters where more light is available at depth for photosynthesis. Higher water column chlorophyll and ^{13}C enriched detritus (particulate organic matter; POM) at these same sites at depth suggest that sediment resuspension may enhance water column production through the injection of benthic microalgae into the water. This process exemplifies benthic-pelagic coupling which provides a strong mechanism of positive feedbacks between sediments and overlying waters.

Nutrient levels (inorganic nitrogen is usually the most limiting nutrient in sea water) help determine the extent of primary production. We found water column inorganic-N levels were nearly undetectable but noted high levels of sediment pore water ammonium (over $200 \text{ }\mu\text{M}$ at some sites) at several stations. This indicates active biogeochemical processing of organic matter which potentially provides a major source of nutrients to overlying waters. Stable carbon and nitrogen isotopic ratios reveal a food web largely dependent on marine detritus (POM) and in situ sources of inorganic-N. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of POM were similar to both benthic and pelagic herbivorous invertebrates indicating that marine sources of production were most important (rather than organic matter derived from terrestrial sources). Based on $\delta^{15}\text{N}$ values of benthic filter feeders and consumers, the nearshore benthos in the Sivulliq prospect is characterized by three trophic levels. This is a minimum estimate since we made no collections of higher trophic level epibenthic organisms (fish, crabs, or larger mollusks). Our benthic biomass, density and organism isotopic data do not indicate that previous drilling activities at the Hammerhead (HH) 1 site (drilling activity took place in 1985) have had a measureable impact on the occurrence or trophic structure of the infaunal community at this site. One predatory species

of nemertean possessed an isotopic signature at station HH-5 that reflected a diet common to that of a herbivore, but no other fauna collected at HH-5 displayed unusual isotopic signatures. We could not discern any measureable changes in benthic community structure at Hammerhead as a result of drilling activities that took place over 20 years ago. If the benthic community was impacted during the drilling event, it has progressed well towards recovery.

We did not find extensive areas of hard rock substrata (“boulder patches”) although we noted scattered pebbles and cobbles at shallower depths (22-26 m) along the proposed Pipeline corridor. The large spatial variability in benthic infaunal biomass, abundance, and species diversity at the shallower inshore Pipeline stations is related to the heterogeneity of substrate types in this area and the intense physical disturbances (for example ice scour) that exemplify these inner-shelf benthic habitats. The additional data collected for this study has added an enormous amount of new information on the character of the Beaufort Sea shelf ecosystem that has greatly improved our knowledge of the region.

BACKGROUND

1.0 INTRODUCTION

Our knowledge of what currently lives in the Arctic Ocean is not as comprehensive as compared to other oceans, due to the logistical challenges imposed by its multi-year ice and inhospitable climate. Extreme changes in Alaska nearshore environmental conditions have been visible in recent years, particularly during open-water seasons 2007 and 2008. New data indicate that summer ice extent is now declining 11.7% per decade based on record low ice cover in 2007 (40% lower than the long-term average minimum) which was followed by the second lowest ice extent estimates in 2008 (National Snow and Ice Data Center; <http://nsidc.org/index.html>). These large losses in summer open-water ice cover are resulting in considerable coastal erosion (Dunton, pers. observation) that contribute enormous quantities of sediment into the coastal zone which can impact the marine biota on multiple levels, from populations to individuals. Species level information is, therefore, critical in delineating the effects of climate change versus those

caused by anthropogenic activities. For monitoring and assessment of change, the availability of data collected over both temporal and spatial scales is absolutely necessary.

The coast and shelf of the Beaufort Sea extends from Point Barrow, Alaska to Banks Island in Canada, and incorporates three distinct shelf environments (inner, mid, and outer) and two large river systems, the Colville and the Mackenzie. In marked contrast to the Chukchi-Bering ecosystem on the west and the Queen Charlotte Islands on the east, the Beaufort Sea, and the eastern Alaskan Beaufort in particular, is decidedly estuarine in character. The combined flows of the Colville and the Mackenzie Rivers annually add nearly 350 km³ of freshwater plus 130 x 10⁶ tons sediment to a relatively broad shelf that ranges in width from 40 km in Alaska to 150 km in Canada (Macdonald et al., 2004). In addition, the Alaskan Beaufort Sea coast, from Barrow to Demarcation Bay, is skirted by an irregular and discontinuous chain of barrier islands that enclose numerous shallow (<8 m) lagoons that are fed by many small rivers and streams.

The Sivulliq prospect is located in the eastern portion of the nearshore shelf of the Alaskan Beaufort Sea (see Figs. 3.0.1–3.0.5). The Beaufort Sea is blanketed predominantly by silty sands and mud (Barnes and Reimnitz, 1974) composed of 21% fine silt, 16% silt, 20% very fine sand, and 28% fine sand (Chin et al., 1979). These fine grained sediments support an infaunal assemblage dominated by polychaete worms, small mollusks and crustaceans (Feder and Schamel, 1976; Carey and Ruff, 1977; Broad et al., 1978; Woodward-Clyde Consultants, 1979; Griffiths and Dillinger, 1981; Feder and Jewett, 1982; Carey et al., 1984). Large scale quantitative studies of Beaufort Sea coastal benthic biota did not begin until relatively recently, following the discovery of oil in Prudhoe Bay. Surveys under the Outer Continental Shelf Environmental Assessment Program (OCSEAP) began in the 1970s and continued into the early 1990s. The two major studies under this program were by led by A.C. Broad who surveyed the nearshore between 1975 and 1980 and A.G. Carey Jr. who sampled from the mid-shelf to the edge of the Arctic Basin (in 1971 and 1975-1978). These studies occupied several benthic sampling stations in the general vicinity of the Sivulliq prospect (Dunton et al., 2005).

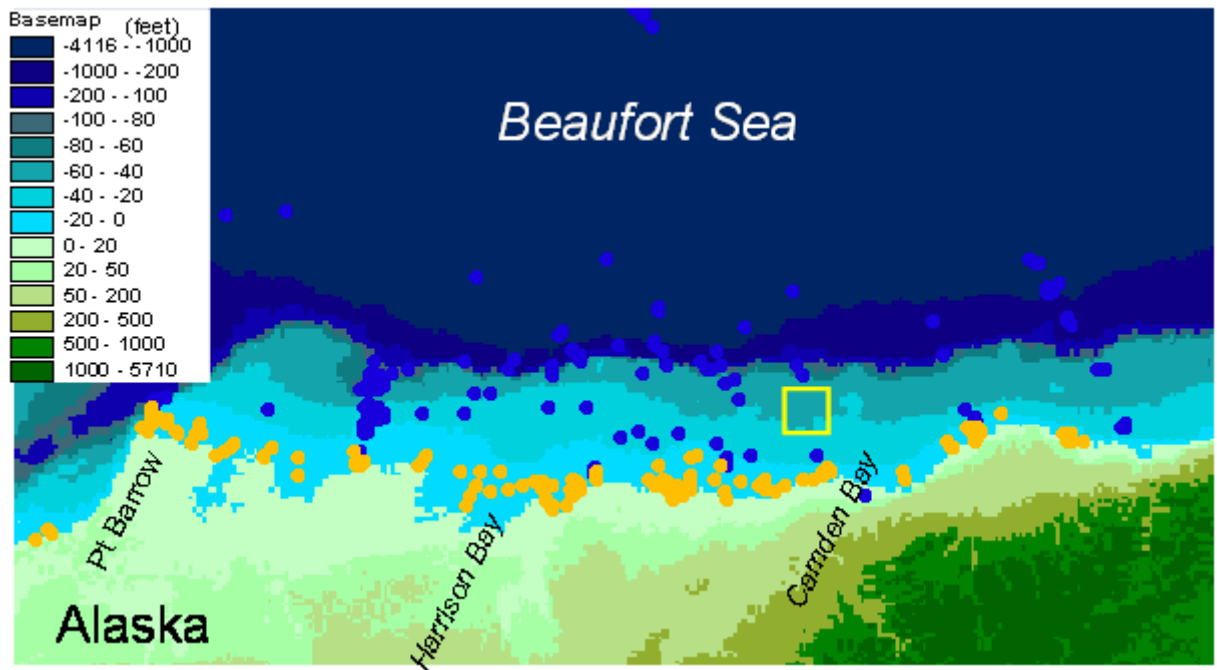


Figure 1.0.1. A bathymetric and topographic GIS map of the north coast of Alaska with historic benthic sampling stations indicated by dots. The yellow square denotes the general area of biological interest to Shell Oil. Blue dots are station locations occupied by Carey and orange dots are sites that Broad sampled. Both scientists worked in the 1970's and 1980 under the Outer Continental Shelf Program Environmental Assessment Program (OCSEAP).

The estimates provided by Dunton et al. (2005) for benthic biomass on the Alaskan Beaufort Shelf are based on historical data from stations that are not evenly distributed across or along the shelf, and consequently, our confidence in predicted values is quite variable. The Sivulliq study provides an excellent opportunity to add an enormous amount of information on the character of the Beaufort Sea shelf ecosystem that will greatly improve our quantitative knowledge of the region. Predicted biomass values for this region range from <25 to 50 g m^{-2} , nearly an order of magnitude less than the northeastern Chukchi shelf. In addition, we have little information on the composition of these benthic communities since earlier work only identified organisms to the level of family, not species. A detailed knowledge of benthic assemblages is also required for determination of spatial and temporal patterns in diversity as well as community structure.

Another enigma for this area is the source of carbon that supports the shelf biotic assemblages. We can distinguish terrestrial sources of organic material from marine sources based on their stable isotopic signatures. Terrestrial organic matter is characterized by $\delta^{13}\text{C}$ values of -27 to

-31‰ and $\delta^{15}\text{N}$ values of 0 to 1.5‰. In contrast, marine primary producers are identified by $\delta^{13}\text{C}$ values of -22 to -25‰ and $\delta^{15}\text{N}$ values of 5 to 7‰. We can use these endmember values in assessing the relative importance of these two sources of carbon to the marine consumers of the Sivulliq study area. Such knowledge provides us with an enhanced understanding of the system that can be used for impact assessment to minimize the effects of offshore development on populations through increased sensitivity to water quality (transparency) or coastal watersheds.

It is widely believed that phytoplankton production provides the ultimate source of food for both the pelagic and benthic components. However, isotopic data from sediments collected on the Beaufort Sea coast show a strong gradient of increasing terrestrial inputs of particulate organic carbon (POC) eastward along the coast and contributions from terrestrial POC along the nearshore portion of the eastern Beaufort (Naidu et al., 2000). On the Mackenzie shelf, isotopic evidence led Parsons et al. (1989) to conclude that terrigenous carbon was a significant component of the nearshore food web. The depleted $\delta^{13}\text{C}$ values in the organic carbon of arctic coastal sediments, particularly in regions around the Mackenzie and Colville Rivers, led Naidu et al. (2000) to conclude that at least 30-50% of the organic matter in nearshore and shelf sediments was of terrigenous origin. The sources of this allochthonous carbon include both river runoff and coastal erosion. Based on calculations made by Reimnitz et al. (1988) for the Alaskan Beaufort Sea and Are (1999) for the Laptev Sea, it appears that sediment influx derived from coastal erosion is greater than the riverine influx. However, the hydrological controls on biogeochemical feedbacks and linkages between arctic watersheds and their receiving basins on the northern Alaskan coast are not well understood.

The fate of this terrigenous carbon in arctic coastal food webs is largely unknown. Schell (1983) found evidence for the incorporation of ancient (8-12,000 yr BP; Schell and Ziemann, 1983) terrestrial peat carbon into freshwater aquatic food webs near the Colville River Delta based on depressed ^{14}C abundances in resident fish and ducks. However, ^{14}C activities in three marine invertebrate crustaceans were not depressed, leading Schell (1983) to conclude that utilization of terrestrial carbon in the arctic estuarine environment was very limited.

However, dissolved organic carbon (DOC) is by far the most abundant form of terrigenous carbon exported in arctic rivers (Gordeev et al., 1996; Lobbes et al., 2000) and, based on ^{14}C abundance data, this carbon pool is predominantly young (Benner et al., 2004). This study therefore provides an opportunity to examine the possible incorporation of terrestrial carbon into the food webs of the Beaufort Shelf from the inner shelf (just outside the barrier islands at 20 m) to the mid-shelf (about 40 m).

METHODS

2.0 OVERVIEW

2.0.1 Approach

The overall objective of the Sivulliq offshore baseline sampling program was to collect samples for water quality determinations, sediment chemistry, and benthic biological data for subsequent evaluation of possible future oil and gas development impacts. Unbiased, statistically rigorous statements about the status of chemistry and the biological communities in the proposed drill site area are also dependent on a spatially referenced dataset. This report is specifically focused on biological resources of the region surrounding the Sivulliq prospect and Hammerhead, an earlier prospect that was subject to exploratory drilling activities:

1. Biological and biogeochemical characterization of the benthos (isotopic composition of the sediments, chlorophyll *a*, pore water ammonium, sediment C:N ratios and benthic faunal density, biomass, species composition, diversity, and food web structure (based on stable isotopes of carbon and nitrogen)).
2. Water column parameters (concentrations of chlorophyll *a* and nutrients, zooplankton and POM isotopic composition).

Our strategy involved benthic and water column sampling at 45 designated stations (Fig. 2.0.1). Two benthic grabs were collected at each station, one for biology (infaunal abundance and biomass) and one for chemistry (sediment parameters and selective collection of biota for determination of trophic structure). Vertical profiles of water column characteristics were assayed at seven selected stations

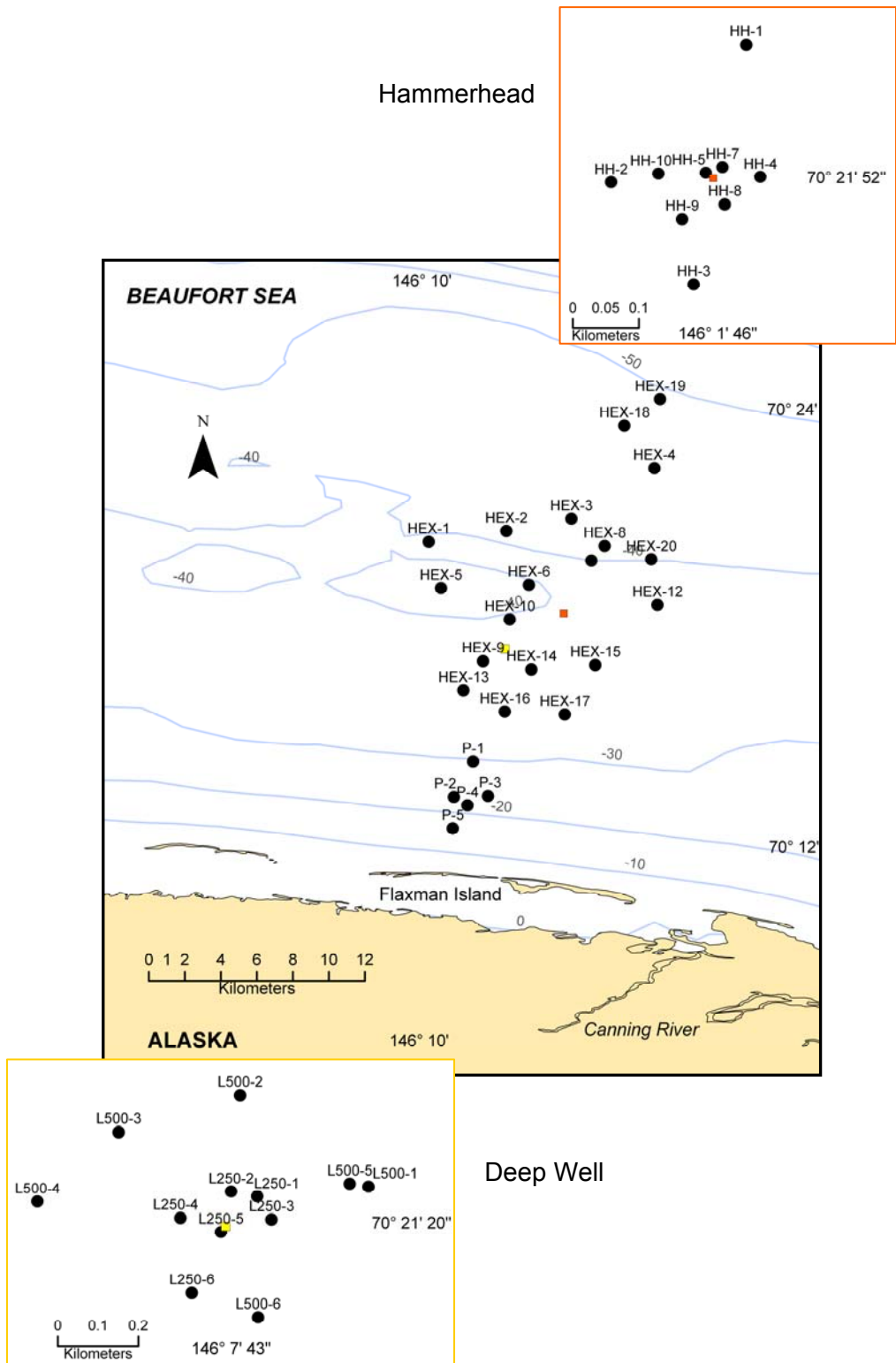


Figure 2.0.1. An area map showing Sivulliq biological sampling locations (black circles). Hammerhead site location is depicted with an orange square on center map with station detail in top right rectangle. Deep Well site location is denoted by a yellow square in center map with detail in bottom left rectangle. Depth contours are labeled in meters.

2.0.2 Site Selection

We collected samples at 19 sites (designated HEX) across the monitoring area to describe the spatial extent and patterns of biota biomass and density in the Sivulliq prospect on the nearshore shelf northwest of Camden Bay. The location for each site was chosen by laying a probability-based grid over the study site area and randomly choosing a location within each grid cell. This method allowed for sampling locations to be spaced quasi-evenly across the landscape while still maintaining assumptions required for a random sample (i.e., all locations have an equal chance of being sampled). To gain a better resolution of the variability around a specific site (Deep Well), we created a second probability grid over a smaller area (500 m). Six stations were located 250 m from Deep Well and another six stations were located at a distance of 500 m (designated L-250 and L-500 respectively). A third probability grid, similar to Deep Well, was created around a previous drill site (Hammerhead 1 drilled in 1985). Ten stations (designated HH) were sampled at this prospect but only nine benthic stations were sampled for biology. Finally, we sampled five stations that followed the course of the proposed Pipeline route from the Sivulliq prospect (designated P). Of the total number of sites sampled for benthic measurements (45), all but the five Pipeline stations were located in water depths greater than 30 m.

2.1 BENTHIC SEDIMENT MEASUREMENTS

2.1.1 Isotopic measurements – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

Ecologists use stable isotopes to examine the origins of materials in the environment and to determine trophic relationships among organisms in a food web. Origins of organic matter are based on the premise that the potential sources are isotopically distinct from each other and do not change, or change predictably as those materials are transported. In the Beaufort Sea for example, terrestrial organic matter is characterized by $\delta^{13}\text{C}$ values of -27 to -31‰ and $\delta^{15}\text{N}$ values of 0 to 1.5‰. In contrast, marine primary producers are identified by $\delta^{13}\text{C}$ values of -22 to -25‰ and $\delta^{15}\text{N}$ values of 5 to 7‰. We can use these end member values in assessing the relative importance of these two sources of carbon to the marine consumers. For determination of trophic relationships, the technique is based on the known or estimated isotopic fractionation (or discrimination) of carbon (C) or nitrogen (N) as a function of trophic level. For both C and N,

isotopic enrichment of the heavier isotope occurs with each successive trophic step in the food web. Consequently, organisms with higher $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values occupy higher trophic levels or positions in the food web.

At each site, aliquots were removed from a 0.01 m² van Veen surface sediments and placed in pre-labeled Crio-vials, stored in frozen, dark conditions, and transported to UTMSI for analyses of natural abundance isotopes (C, N). Samples were sub-sampled for an acidification/non-acidification technique to remove carbonates, placed in aluminum trays, and dried at 60 °C. Acidified samples were soaked in 1 N HCl for several hours until bubbling stopped, rinsed with distilled water, and dried completely. All samples were analyzed on an automated system for coupled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements using a Finnegan MAT Delta Plus mass spectrometer attached to an elemental analyzer (CE Instruments, NC 2500). Samples were combusted at 1,020 °C and then injected into the mass spectrometer with continuous flow. Results are expressed in standard δ notation relative to carbonate PeeDeeBelemnite and atmospheric nitrogen where:

$\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ (‰) = $[\text{R}_{\text{sample}}/\text{R}_{\text{standard}} - 1] \times 1000$ and $\text{R} = ({}^{13}\text{C}/{}^{12}\text{C}$ or ${}^{15}\text{N}/{}^{14}\text{N})$, respectively. By definition, as δ values increase (or decrease), the relative abundances of the heavier isotopes, ${}^{13}\text{C}$ or ${}^{15}\text{N}$, increase (or decrease). Secondary standards were used routinely for cross-calibration checks of tank reference gases, against which all samples were run. Our data were reproducible to within $\pm 0.2\%$. Machine analytical error was $\pm 0.15\%$.

2.1.2 Chlorophyll *a*

Measurements of chlorophyll provide information on the abundance of phytoplankton in the water column and microalgae that live in the sediments on the bottom. These microalgae are very important food resources for organisms that live in marine environments. Following Cooper et al. (2002), we extracted 2 cm deep aliquots from surface sediment samples collected from 0.01 m² van Veen grabs. The aliquot was placed in a pre-labeled 20-mL Falcon tube and promptly frozen in darkness. The frozen samples were transported back to UTMSI for extraction and analysis. Each sample was sub-sampled and chlorophyll *a* was extracted with 10 mL of 90% acetone for 12 hours at freezing temperature in darkness. The samples were centrifuged, and a

Shimadzu UV-2401 PC Spectrophotometer (Shimadzu, Tokyo, Japan) measured absorbance of the supernatant at wavelengths 750, 664, 647, and 630 nm. The combined sub-sample reading was then used to determine the amount of chlorophyll-*a* as expressed on an areal basis (mg m^{-2}).

2.1.3 Pore water ammonium (NH_4)

Ammonium is a critical nutrient for plants and its availability, along with nitrate, regulates benthic and water column primary productivity. Core samples were immediately collected from van Veen grabs on retrieval using a 60-mL syringe at each site. The cores were stored in dark, freezing conditions during transport to UTMSI for sediment pore water ammonium analysis. Pore water was extracted by centrifuging thawed sediments. The supernatant underwent colorimetric analysis as described by Parsons et al. (1984).

2.1.4 C:N ratios

The ratio of carbon to nitrogen (C:N) in the sediments reflect a variety of biogeochemical processes, but ultimately provide information on the relative abundance of either carbon or nitrogen that is delivered to the sediments and then utilized by the organisms. The top 2 cm of surface sediments were collected from undisturbed van Veen grab samples using a 10 cc syringe. Samples were placed in pre-labeled Crio-Vials and frozen in darkness for transport to UTMSI for elemental analysis. Carbon (C) and nitrogen (N) content of sediments were analyzed with an automatic elemental analyzer (model NC 2500, Fison Instruments, Rodano-Milan, Italy). Percent C and N were converted to molar (atomic) C:N ratios.

2.2 BENTHIC FAUNA MEASUREMENTS

2.2.1 Station density, biomass, and species composition

A total of 45 stations were sampled using a van Veen grab to collect 0.1 m^{-2} sediment sections. All samples were carefully washed over 0.1 mm sieve. From the sorted retained fraction,

invertebrates were sorted, identified, and counted where individuals could be distinguished. Species were weighed on a microbalance (Denver Instruments APX-60, Arvada, Colorado, USA) and preserved in 70% ethanol. All samples are stored at The University of Texas Marine Science Institute (UTMSI).

2.2.2 Isotope measurements - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

A subset of representative specimens were identified, labeled, frozen, and shipped to UTMSI for natural abundance isotope analysis (C, N), a technique used to elucidate community food web structure. In the lab, samples were dried in aluminum dishes at 60 °C following removal of extraneous organic matter. When possible, soft tissues were removed from shelled organisms, but all invertebrate samples were subsequently soaked in 1 N HCl for several hours (or until bubbling stopped) to remove carbonates, rinsed in distilled water, and then dried. Only muscle or body wall tissue was analyzed from bivalves, gastropods, and fish. All other organisms were analyzed whole. Entire organisms or tissues were manually ground for isotopic analyses. Replicate analyses reflect the analysis of individual organisms, not composite samples. All samples were analyzed on an automated system for coupled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements using a Finnegan MAT Delta Plus mass spectrometer.

2.3 WATER COLUMN MEASUREMENTS

2.3.1 Chlorophyll *a*

Replicate water samples were collected at near-surface (5 m), intermediate (10 m), and near-bottom depths (25 m) using an electrically powered peristaltic water pump attached to a hose reel of Tygon tubing. The Tygon tubing was lowered by hand to depths selected from the YSI water column profile and seawater was pumped to the surface for collection. All samples were placed in pre-labeled plastic bottles and placed in a dark cooler to be filtered in the shipboard lab. In the dark, water from each replicate sample was filtered through Whatman GF/F filters (Whatman, Maidstone, England). After filtration, the filters and residue were placed in pre-labeled opaque vials and frozen. The frozen filters were transported to UTMSI for subsequent chlorophyll analysis. At UTMSI, filters were removed from the vials and placed in pre-labeled test tubes containing 5 ml of 90% acetone for overnight extraction (Parsons et al., 1984). Chlorophyll *a*

concentration, in $\mu\text{g L}^{-1}$, was determined using a Shimadzu UV-2401 PC spectrophotometer by measuring absorbance at wavelengths 750, 664, 647, 630, and 600 nm. [Non-acidification techniques were used to account for the presence of chlorophyll *b* and phaeopigments (Welschmeyer, 1994).]

2.3.2 Zooplankton - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

Zooplankton were collected in vertical tows using a 335 μm plankton net. Plankton were sorted by eye using a dissecting scope into phyla and filtered onto GF/F filters (Whatman, Maidstone, England). Zooplankton filters were frozen in darkness for transport to UTMSI for elemental analysis. At UTMSI, samples were dried at 60 °C. To remove carbonates from zooplankton, samples were soaked in 1 *N* HCl for several hours, or until bubbling stopped, rinsed with distilled water, and dried. All samples were analyzed on an automated system for coupled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements using a Finnegan MAT Delta Plus mass spectrometer. Percent C and N were converted to molar (atomic) C:N ratios in zooplankton.

2.3.3 POM profiles - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

Particulate organic matter (POM) was collected by filtering replicate water samples from near-surface (5 m), intermediate (10 m), and near-bottom depths (25 m) onto Whatman GF/F filters (Whatman, Maidstone, England). POM filters were frozen in darkness for transport to UTMSI for elemental analysis. At the lab, samples were dried at 60 °C. To remove carbonates from zooplankton, samples were soaked in 1 *N* HCl for several hours, or until bubbling stopped, rinsed with distilled water, and dried. All samples were analyzed on an automated system for coupled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements using a Finnegan MAT Delta Plus mass spectrometer.

2.3.4 Nutrients (NH_4^+ , SiO_4 , PO_4^{3-} , $\text{NO}_2^- + \text{NO}_3^-$)

Water samples were frozen on board the ship and transferred to UTMSI for nutrient analysis. Nutrient concentrations (μM) for NH_4^+ , SiO_4 , $\text{NO}_2^- + \text{NO}_3^-$, and PO_4^{3-} were determined by

continuous flow injection analysis using colorimetric techniques on a Lachat QuikChem 8000 (Zellweger Analytics Inc., Milwaukee, Wisconsin, USA) with a minimum detection level of 0.03 μM .

2.4 GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Geographical Information Systems (GIS; ESRI, 2008) was used to construct a geospatial database and analyze the benthic and water column community at the Shell Sivulliq prospect site. Sample data were assembled in a relational database and analyzed using Arc/Info 9.3. A Geostatistical Analyst extension to ArcMap was employed to interpolate benthic biomass and density, sediment chlorophyll and ammonium, and natural abundance isotopes with kriging techniques. Since these data cannot be sampled on a spatially continuous scale but at point locations, Geostatistical Analyst was used to interpolate the biological point data to model trends across a landscape.

We used geostatistical methods to create a prediction surface and provide an estimation of the statistical error associated with the prediction. A great advantage of these methods is that they provide an estimate of how well they are predicting the surface (error of prediction). Several methods of gaining familiarity with the data were used before interpolation took place. Histograms were used to examine the frequency distribution of the data. Normal Quantile-Quantile plots (QQ-plots) were used to determine the normality of the data. The Trend Analysis option in the extension allowed identification of nonrandom trends in the data such as outliers.

Radial Basis Functions (RBS) was used to interpolate the Sivulliq data. RBS is a deterministic interpolation technique built on the basic law of geography that points closer together are more similar than points that are far apart. RBS fits a smooth surface through every measured point and minimizes the surface curvature. This interpolation is a kriging function based in multivariate statistics.

2.5 COMMUNITY STRUCTURE ANALYSES (PRIMER)

We used PRIMER (Plymouth Routines In Multivariate Ecological Research) software to analyze benthic biota abundance and biomass data for similarity among stations using non-metric multi-dimensional scaling plots (MDS) and cluster analysis with a SIMPROF significance test based on Bray-Curtis similarities. Data were transformed using the square root function prior to MDS analysis. Additionally, a range of standard diversity measures were calculated using the DIVERSE function available in PRIMER. Community structure of the Sivulliq stations was analyzed using three methods: Pielou's index, Shannon-Wiener index, and Simpson's index. Pielou's evenness was determined to measure equitability; i.e. how evenly the individuals are distributed among the different species. Shannon-Wiener diversity index was used to explore species diversity, calculated using the natural log of the measurements. Simpson's index is a dominance index, in that its largest values correspond to assemblages whose total abundance is dominated by one, or a very few, of the species present. The reciprocal of the index was used in this report so a smaller index number indicates fewer species of the total possible were measured at a station.

2.6 QUALITY ASSURANCE

Our processing of benthic and pelagic biological samples requires adherence to the following two basic principles:

Accuracy: Benthic sorting, identification, counting, weighing, and entering data is a human-based, not machine based process, and consequently accuracy is a function of a person's experience and training. The taxonomist in charge of this project, Susan Schonberg, has over 25 years of experience with arctic biota. Such accuracy includes verification by taxonomic group specialists, including Nora Foster (mollusks) and Ken Coyle (crustaceans).

Control: We track samples with pre-printed forms from field to lab and from lab to database to insure a clear chain of custody process.

RESULTS & DISCUSSION

3.0 BENTHIC SEDIMENT BIOGEOCHEMICAL MEASUREMENTS

Spatial trends over the Sivulliq study area reveal some interesting patterns among some parameters, particularly sediment C:N ratios, chlorophyll, and $\delta^{13}\text{C}$ values (Figs. 3.0.1 – 3.0.5). The higher sediment C:N ratios (maximum C:N 13.1) at the Pipeline sites, which are located at comparably shallower depths and closest inshore, compared to all other sites (maximum C:N <11.5), is likely correlated to high sediment chlorophyll values ($>130 \text{ mg m}^{-2}$) at the Pipeline sites. The elevated chlorophyll values are among the highest recorded in western arctic seas (Grebmeier et al., 2006) and reflect strong microphytobenthic carbon production. The presence of this microalgal assemblage is distinctly correlated with the highest $\delta^{13}\text{C}$ values in the area (-20 to -22‰), compared to more depleted values ($< -22\text{‰}$) measured throughout the rest of the study area. Isotopically enriched ^{13}C values are associated with marine primary producers, while more depleted values are attributed to terrestrial sources of carbon (i.e. transport from Colville and Mackenzie Rivers; see Dunton et al., 2006). Higher sediment chlorophyll values in the northern reaches of the study area are not correlated with C:N or $\delta^{13}\text{C}$ values, and probably represent ephemeral features.

There are no obvious spatial trends in sediment ammonium values, which were generally less than $140 \mu\text{M}$ except at a few sites where values exceeded $200 \mu\text{M}$. The pore water concentrations reported here for ammonium are higher than expected for these sediments and indicate that sufficient organic matter is present in the sediments to support aerobic decomposition processes (ammonification). We found sediment $\delta^{15}\text{N}$ values to range between 2 and 4.5‰, with values generally increasing seaward. The rather tight distribution of $\delta^{15}\text{N}$ values (2.5‰ range) reflects a system that is relatively homogeneous with respect to ultimate nitrogen sources.

Within the Hammerhead and Deep Well sites, no obvious trends in the distribution of the biogeochemical parameters were apparent. Values for sediment chlorophyll, reflective of benthic microalgal abundance, showed substantial spatial heterogeneity that could not be correlated with

any specific biotic or abiotic parameter. C:N ratios varied in a more predictable narrow range (from 9-11), very similar to that recorded by Grebmeier and Cooper (2009) along the inner shelf area of the Chukchi Sea (8.5-11). Values for TOC (Table 3.01) are also within the range reported by Grebmeier and Cooper (2009). Sediment C:N values greater than Redfield ratios (6.6) as depicted here suggest the delivery of other organic material (possibly terrestrial carbon), or more pronounced N limitation compared to other shelf environments.

Table 3.0.1 Surface sediment total organic nitrogen (TON) and total organic carbon (TOC), C:N ratios, and $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$

SEDIMENTS						$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
		Sample	TON	TOC	C:N	At-air	PDB
Site	Location	Name	(%)	(%)		(‰)	(‰)
Hex	1	285	0.05	0.58	10.44	2.99	-25.29
Hex	2	404	0.07	0.79	9.28	3.70	-25.42
Hex	3	286	0.09	1.00	9.23	3.70	-25.20
Hex	4	405	0.05	0.57	9.73	3.65	-25.46
Hex	5	287	0.08	0.84	9.01	2.83	-25.36
Hex	6	406	0.10	1.16	10.02	4.25	-24.96
Hex	7	288	0.09	0.98	9.70	2.36	-25.31
Hex	8	407	0.06	0.71	9.48	2.84	-25.56
Hex	9	289	0.08	0.98	10.20	2.86	-25.50
Hex	10	408	0.09	0.92	9.04	3.09	-25.69
Hex	12	409	0.06	0.70	9.59	3.16	-25.36
Hex	13	290	0.09	0.91	8.76	2.74	-25.09
Hex	14	410	0.07	0.73	8.70	2.95	-25.46
Hex	15	291	0.14	1.43	8.54	3.95	-25.34
Hex	16	411	0.09	1.00	9.79	3.37	-25.71
Hex	17	292	0.09	0.96	9.52	3.90	-25.40
Hex	18	412	0.14	1.54	9.26	4.25	-25.55
Hex	19	293	0.05	0.56	9.84	3.79	-24.98
Hex	20	413	0.08	1.04	10.89	3.77	-25.64
HH	1	275	0.07	0.74	9.25	3.61	-24.99
HH	2	276	0.03	0.45	11.38	3.71	-25.53

SEDIMENTS						$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
Site	Location	Sample Name	TON (%)	TOC (%)	C:N	At-air (‰)	PDB (‰)
HH	3	277	0.07	0.81	9.71	3.34	-25.72
HH	4	278	0.05	0.64	10.43	3.80	-25.71
HH	5	279	0.03	0.30	10.29	3.45	-25.84
HH	6	280	0.07	0.80	9.40	2.94	-25.98
HH	7	281	0.17	1.77	9.20	3.53	-26.13
HH	8	282	0.08	1.07	11.21	3.21	-26.19
HH	9	283	0.08	0.92	10.01	2.67	-25.45
HH	10	284	0.08	0.98	10.12	2.81	-25.33
L2	1	414	0.08	0.79	8.98	2.81	-25.92
L2	2	415	0.08	0.86	8.78	3.19	-25.91
L2	3	416	0.12	1.37	9.71	4.06	-25.70
L2	4	417	0.08	0.83	8.46	3.02	-25.35
L2	5	418	0.09	0.96	9.50	2.45	-25.42
L2	6	419	0.10	1.00	9.00	3.12	-25.63
L5	1	398	0.07	0.85	10.74	3.15	-25.90
L5	2	399	0.04	0.54	11.45	3.00	-25.78
L5	3	400	0.07	0.85	11.14	3.23	-25.84
L5	4	401	0.07	0.86	10.15	4.10	-25.97
L5	5	402	0.08	0.90	10.05	3.99	-25.81
L5	6	403	0.08	0.85	9.42	3.75	-25.38
P	1	294	0.11	1.33	10.67	3.36	-26.07
P	2	295	0.08	0.98	10.85	3.40	-25.77
P	3	296	0.05	0.71	12.63	2.75	-25.95
P	4	297	0.08	1.13	11.61	2.25	-22.36
P	5	298	0.09	1.42	13.11	2.64	-20.19

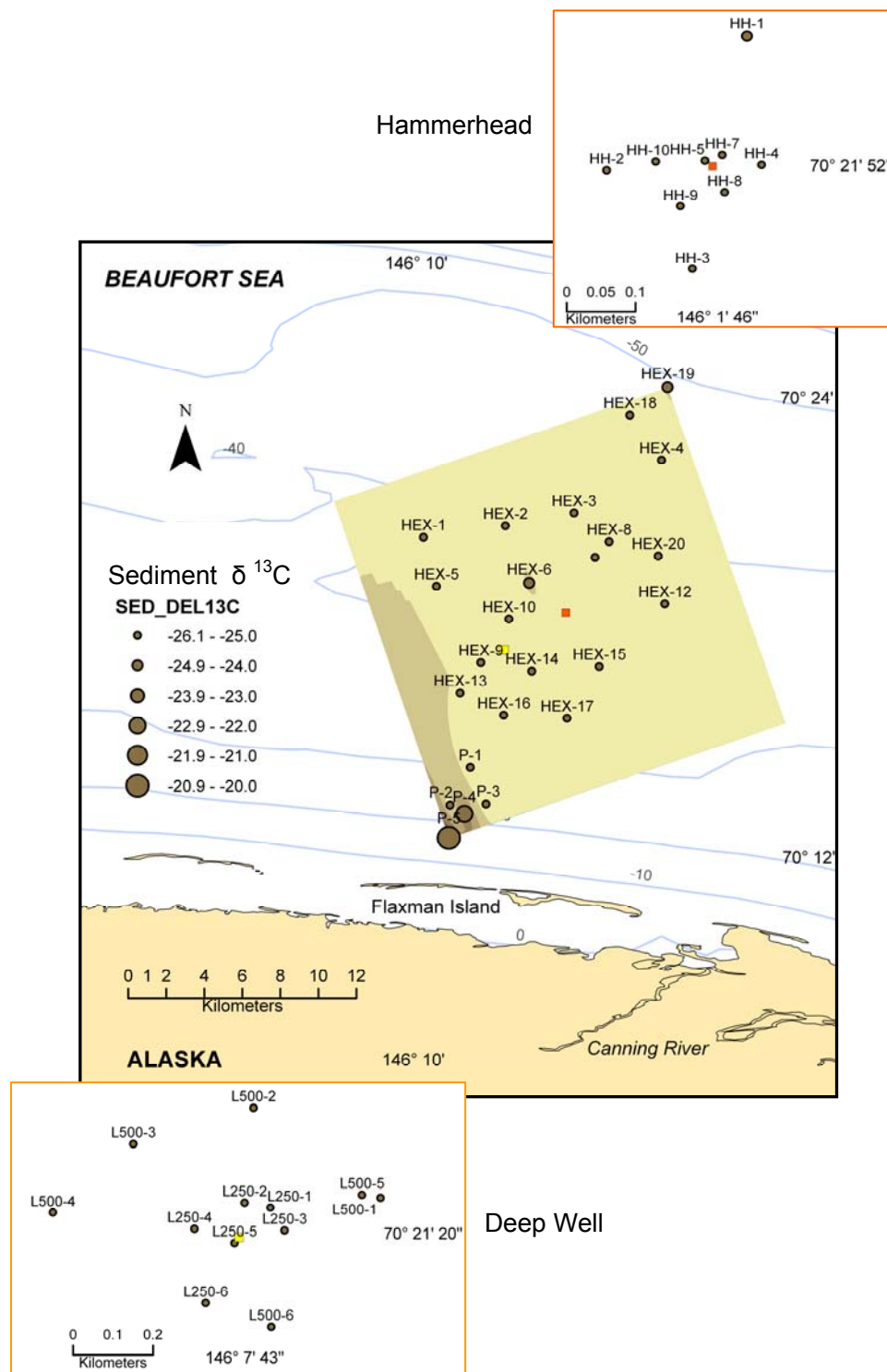


Figure 3.0.1 Distribution of sediment $\delta^{13}\text{C}$ values in the Sivulliq prospect area. Note that sediments become most enriched in ^{13}C at the most nearshore sites. Red and yellow squares denote the location of the Hammerhead and Deep Well sites, respectively, on the large projection. Depth contours are labeled in meters.

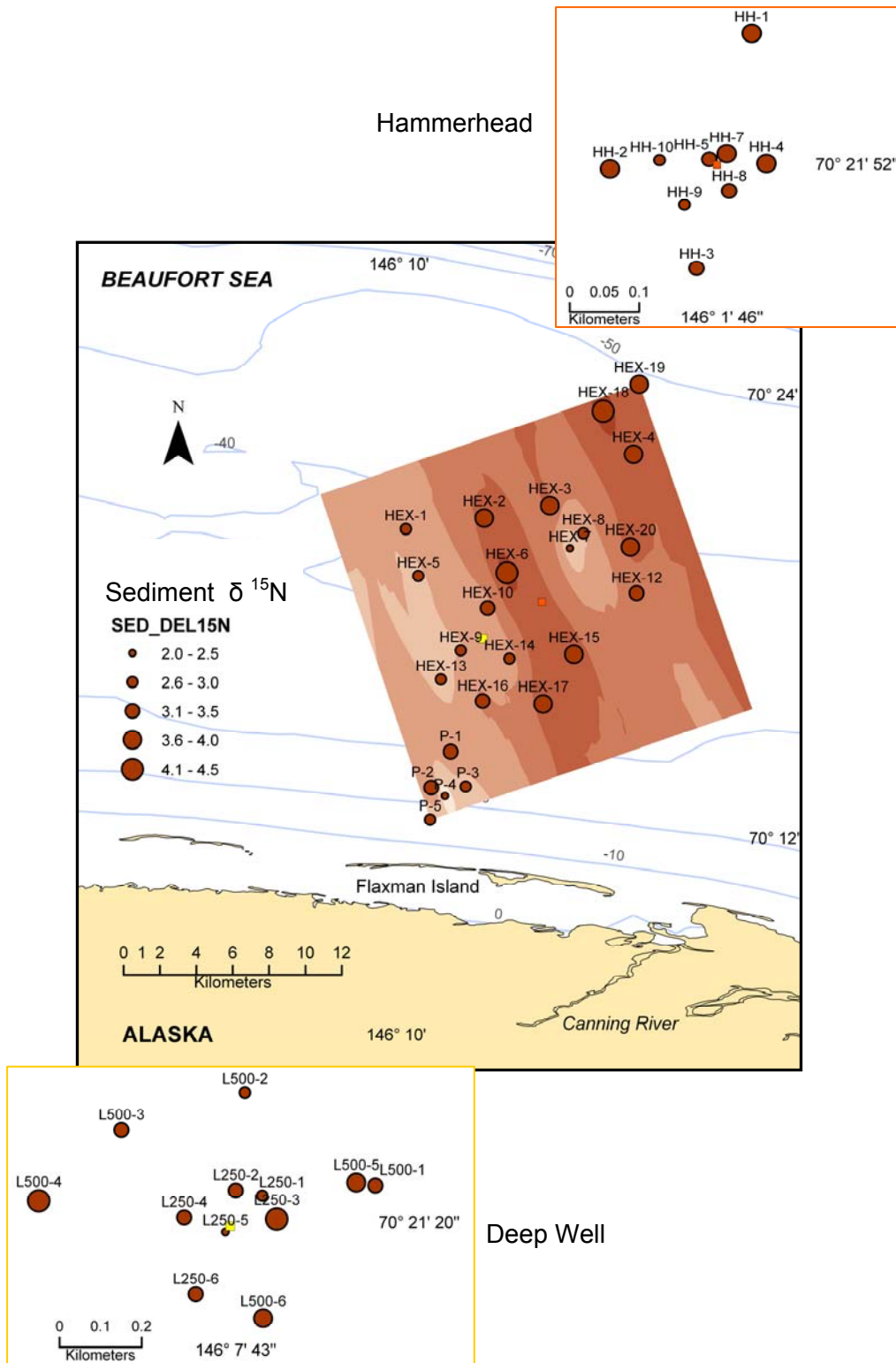


Figure 3.0.2 Distribution of sediment $\delta^{15}\text{N}$ values in the Sivulliq prospect area. Values become generally higher offshore but have a relatively small range (2.5‰), revealing a common inorganic-N source. Depth contours are labeled in meters.

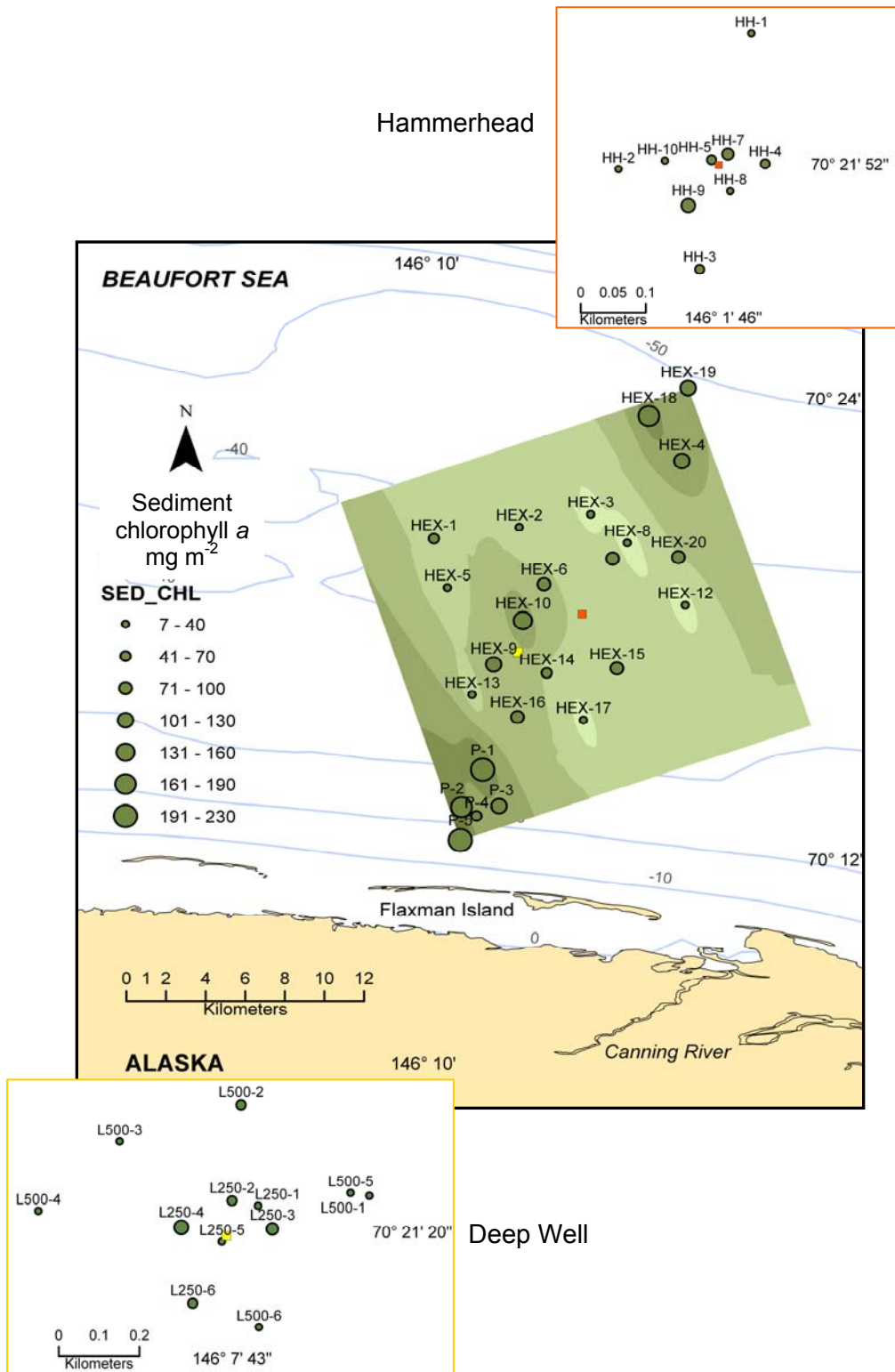


Figure 3.0.3 Variations in sediment chlorophyll *a* across the study. Values are highest nearest the coast and furthest offshore. Depth contours are labeled in meters.

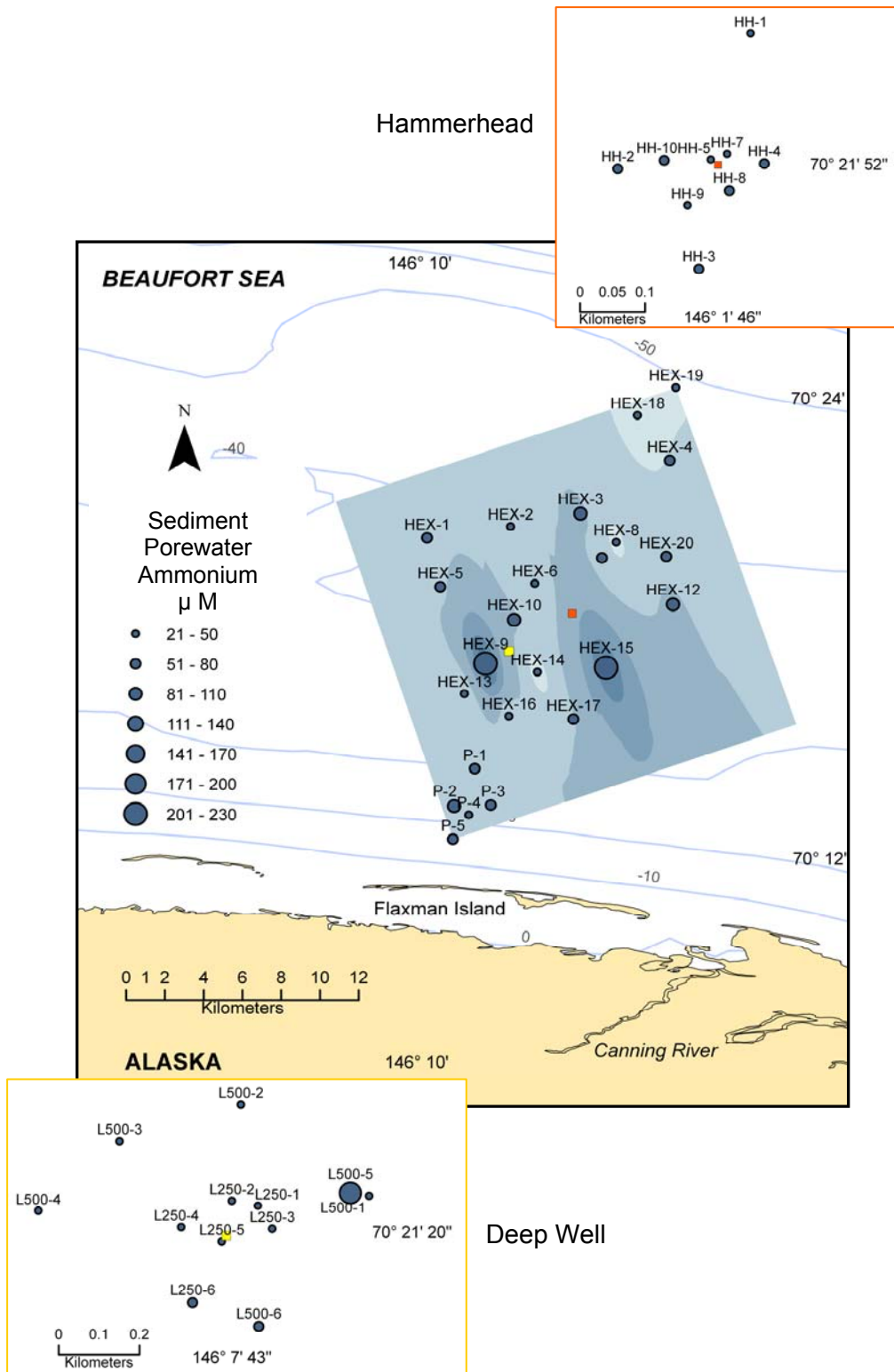


Figure 3.0.4 Sediment porewater ammonium values range over an order of magnitude across the study area, revealing areas of high organic matter decomposition processes. Depth contours are labeled in meters.

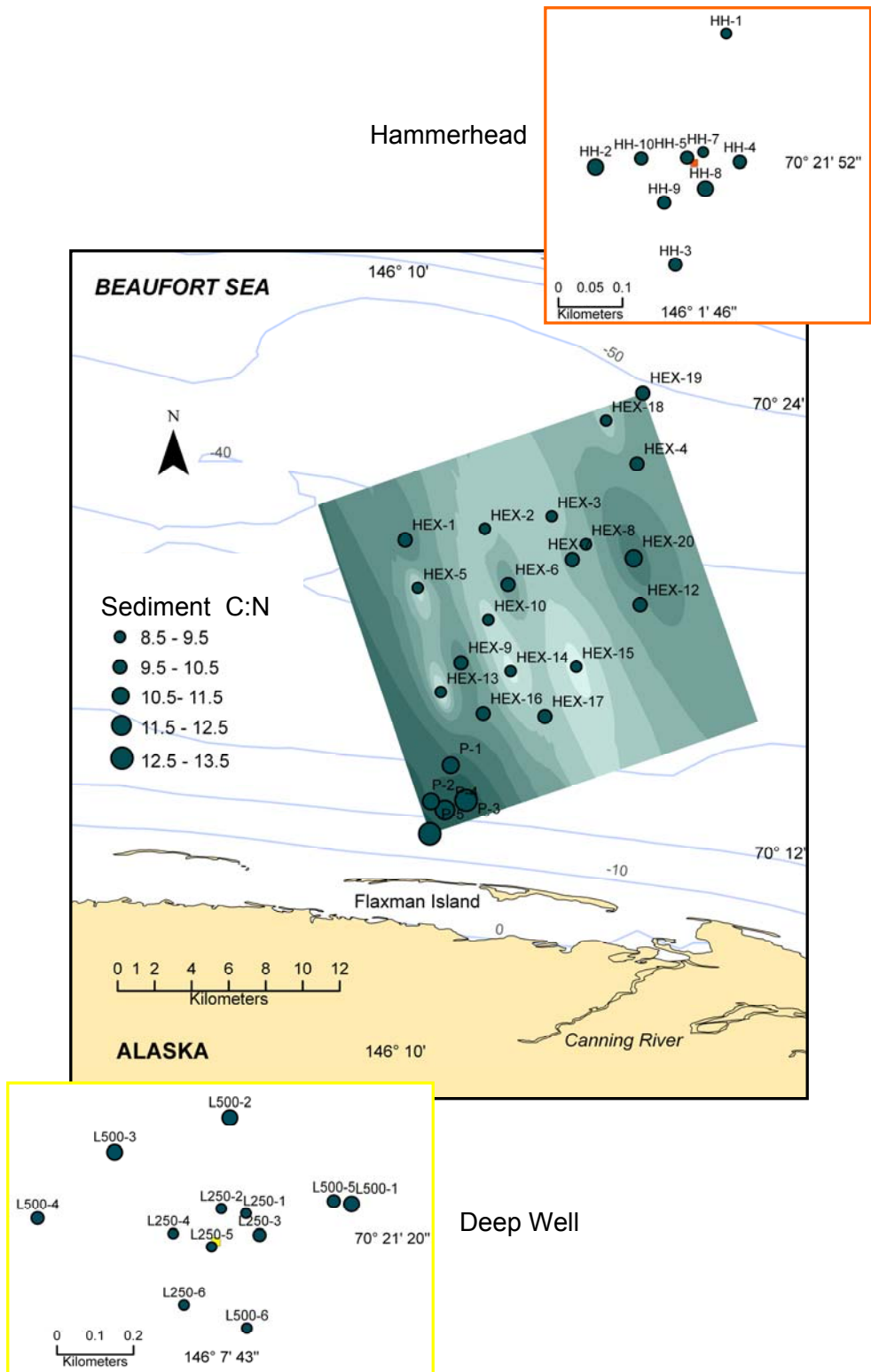


Figure 3.0.5 Distribution of sediment C:N values across the Sivulliq study area. C:N ratios are highest nearest the coast and correspond to elevated levels of sediment chlorophyll and increased $\delta^{13}\text{C}$ values (see Figs. 3.0.1 and 3.0.3). Depth contours are labeled in meters.

3.1 BENTHIC FAUNA

A total of 45 sites were sampled for benthic quantitative measurements in the Sivulliq study area. Benthic infauna were dominated by three groups; polychaetes, mollusks (bivalves and gastropods) and crustaceans (amphipods and cumaceans; Table 3.1.1). A total of 118 species were identified (Table 3.1.2). Benthic biota belonged to 12 major phyla: Porifera, Cnidaria (Anthozoa, Hydrozoa), Mollusca (Gastropoda, Bivalvia), Annelida (Polychaeta), Arthropoda (Amphipoda, Isopoda, Cumacea, Mysidea), Bryozoa, Echinodermata (Asteroidea, Holothurian), Tunicata (Ascideacea), Nemertea, Foraminifera, Priapula, Sipuncula, Osteichthyes.

3.1.1 Station abundance, biomass and species composition

No discernible broad scale geographic patterns in benthic infaunal abundance and biomass were observed within the Sivulliq prospect area (Fig. 3.1.1 and Fig. 3.1.2). Areal biomass ranged from 0 to 133 g m⁻² with densities from 0 up to 1060 individuals m⁻² (a zero value was obtained at Station Hex-16). Although low biomass values were expected for the nearshore shelf, many sites were characterized by values that exceeded 75 g m⁻², which are clearly among the highest recorded for the nearshore shelf of the central Alaskan Beaufort Sea (Dunton et al., 2005). In general, lowest values of infaunal density and biomass occurred in shallower nearshore coastal waters along the proposed Pipeline corridor. The higher benthic productivity associated with these shallower sites (22-25 m) is likely offset by severe and frequent disturbance by deep-draft ice in the Stamuki Zone which scours the seabed.

Table 3.1.1 Number of species in each major group from all Sivulliq sites.

Groups	No. Species	Groups	No. Species
Polychaete	41	Anthozoan	1
Bivalve	20	Ascidean	1
Amphipod	20	Caprellid	1
Gastropod	11	Foraminifera	1
Cumacea	7	Hydrozoan	1
Actinaria	3	Mysid	1
Bryozoan	3	Osteichthyes	1
Holothurian	2	Porifera	1
Isopod	2	Priapulid	1
Nemertean	2	Sipunculid	1

Table 3.1.2 Benthic species list from all Sivulliq sites sorted by group.

Group	Taxon
1 Amphipod	<i>Aceroides latipes</i>
2 Amphipod	<i>Ampelisca birulai</i>
3 Amphipod	<i>Ampelisca macrocephala</i>
4 Amphipod	<i>Ampelisca sp.</i>
5 Amphipod	<i>Anonyx nugax</i>
6 Amphipod	<i>Anonyx sp.</i>
7 Amphipod	<i>Arrhis luthkei</i>
8 Amphipod	<i>Byblis gaimardi</i>
9 Amphipod	<i>Corophiidae</i>
10 Amphipod	<i>Gammarus wilkitzkii</i>
11 Amphipod	<i>Haploops laevis</i>
12 Amphipod	<i>Haploops tubicola</i>
13 Amphipod	<i>Isaeidae</i>
14 Amphipod	<i>Ischyrocerus sp.</i>
15 Amphipod	<i>Lilljeborgia fissicornis</i>
16 Amphipod	<i>Lysianassidae</i>
17 Amphipod	<i>Lysippe labiata</i>
18 Amphipod	<i>Onisimus sp.</i>
19 Amphipod	<i>Podoceridae</i>
20 Amphipod	<i>Protomedeia fasciata</i>
21 Amphipod	<i>Protomedeia sp.</i>
22 Ascidian	<i>Pelonaia corrugata</i>
23 Bivalve	<i>Arctinula greenlandica</i>
24 Bivalve	<i>Astarte borealis</i>
25 Bivalve	<i>Astarte montagui</i>
26 Bivalve	<i>Crenella descussata</i>
27 Bivalve	<i>Cuspidaria glacialis</i>
28 Bivalve	<i>Ennucula tenuis</i>
29 Bivalve	<i>Hiatella arctica</i>
30 Bivalve	<i>Liocyma fluctuosa</i>
31 Bivalve	<i>Macoma calcarea</i>
32 Bivalve	<i>Musculus glacialis</i>

	Group	Taxon
33	Bivalve	<i>Mya arenosa</i>
34	Bivalve	<i>Nuculana pernula</i>
35	Bivalve	<i>Pandora glacialis</i>
36	Bivalve	<i>Periploma aleutica</i>
37	Bivalve	<i>Portlandia arctica</i>
38	Bivalve	<i>Portlandia lenticula</i>
39	Bivalve	<i>Serripes groenlandicus</i>
40	Bivalve	<i>Thracia myopsis</i>
41	Bivalve	<i>Thracia septentrionalis</i>
42	Bivalve	<i>Thyasira flexuosa</i>
43	Bivalve	<i>Yoldiella frigida</i>
44	Bryozoa	<i>Alcyonidium gelatinosum</i>
45	Bryozoa	Unidentified encrusting
46	Bryozoa	<i>Carbasea carbasea</i>
47	Bryozoa	<i>Eucratea loricata</i>
48	Caprellid	Unidentified
49	Cnidaria	<i>Gersemia rubiformis</i>
50	Cnidaria	Unidentified (3 actinaria species)
51	Cumacea	<i>Diastylis edwardsi</i>
52	Cumacea	<i>Diastylis goodsiri</i>
53	Cumacea	<i>Diastylis rathkei</i>
54	Cumacea	<i>Diastylis spinulosa</i>
55	Cumacea	<i>Eudorella emarginata</i>
56	Cumacea	<i>Leptostylis villosa</i>
57	Cumacea	<i>Leucon nasica</i>
58	Foraminifera	Unidentified
59	Gastropod	<i>Admete viridula</i>
60	Gastropod	<i>Buccinum ciliatum</i>
61	Gastropod	<i>Cryptonatica clausa</i>
62	Gastropod	<i>Curtitoma novajasemliensis</i>
63	Gastropod	<i>Cylichna alba</i>
64	Gastropod	<i>Neptunea heros</i>
65	Gastropod	<i>Oenopota elegans</i>
66	Gastropod	<i>Oenopota sp.</i>
67	Gastropod	<i>Retusa obtusa</i>
68	Gastropod	<i>Solariella obscura</i>
69	Gastropod	<i>Tachyrhynchus erosus</i>
70	Gastropod	Unidentified
71	Holothurian	<i>Cucumaria sp.</i>
72	Holothurian	<i>Holothurian</i>
73	Hydroid	<i>Lafoeina maxima</i>
74	Isopod	<i>Saduria sabini</i>
75	Isopod	<i>Synidotea marmorata</i>
76	Mysid	<i>Mysis sp.</i>
77	Nemertean	<i>Nemertean</i>
78	Osteichthyes	<i>Liparis sp.</i>
79	Polychaete	<i>Aglaophamus malmgreni</i>
80	Polychaete	<i>Ampharete arctica</i>

	Group	Taxon
81	Polychaete	<i>Artacama proboscidea</i>
82	Polychaete	<i>Brada inhabilis</i>
83	Polychaete	<i>Chaetozone setosa</i>
84	Polychaete	<i>Chone cincta</i>
85	Polychaete	<i>Cirratulus cirratus</i>
86	Polychaete	<i>Diplocirrus longisetosus</i>
87	Polychaete	<i>Eteone longa</i>
88	Polychaete	<i>Euchone analis</i>
89	Polychaete	<i>Euchone sp.</i>
90	Polychaete	<i>Eunoe senta</i>
91	Polychaete	<i>Gattyana cirrosa</i>
92	Polychaete	<i>Heteromastus filiformis</i>
93	Polychaete	<i>Laonice cirrata</i>
94	Polychaete	<i>Lumbrineris fragilis</i>
95	Polychaete	<i>Maldane sarsi</i>
96	Polychaete	<i>Melaenis loveni</i>
97	Polychaete	<i>Nephtys ciliata</i>
98	Polychaete	<i>Nereis zonata</i>
99	Polychaete	<i>Nicolea zostericola</i>
100	Polychaete	<i>Nicomache lumbricalis</i>
101	Polychaete	<i>Notomastus latericeus</i>
102	Polychaete	<i>Owenia fusiformis</i>
103	Polychaete	<i>Pectinaria hyperborea</i>
104	Polychaete	<i>Pectinaria japonica</i>
105	Polychaete	<i>Pholoe minuta</i>
106	Polychaete	<i>Phyllodoce groenlandica</i>
107	Polychaete	<i>Pista sp.</i>
108	Polychaete	<i>Praxillella praetermissa</i>
109	Polychaete	<i>Sabellides borealis</i>
110	Polychaete	<i>Scalibregma inflatum</i>
111	Polychaete	<i>Scoloplos armiger</i>
112	Polychaete	<i>Spinther sp.</i>
113	Polychaete	<i>Sternaspis scutata</i>
114	Polychaete	<i>Terebellides stroemi</i>
115	Polychaete	<i>Tharyx sp.</i>
116	Polychaete	<i>Thelepus cincinnatus</i>
117	Polychaete	<i>Trochochaeta multisetosum</i>
118	Porifera	<i>Phakellia cribrosa</i>

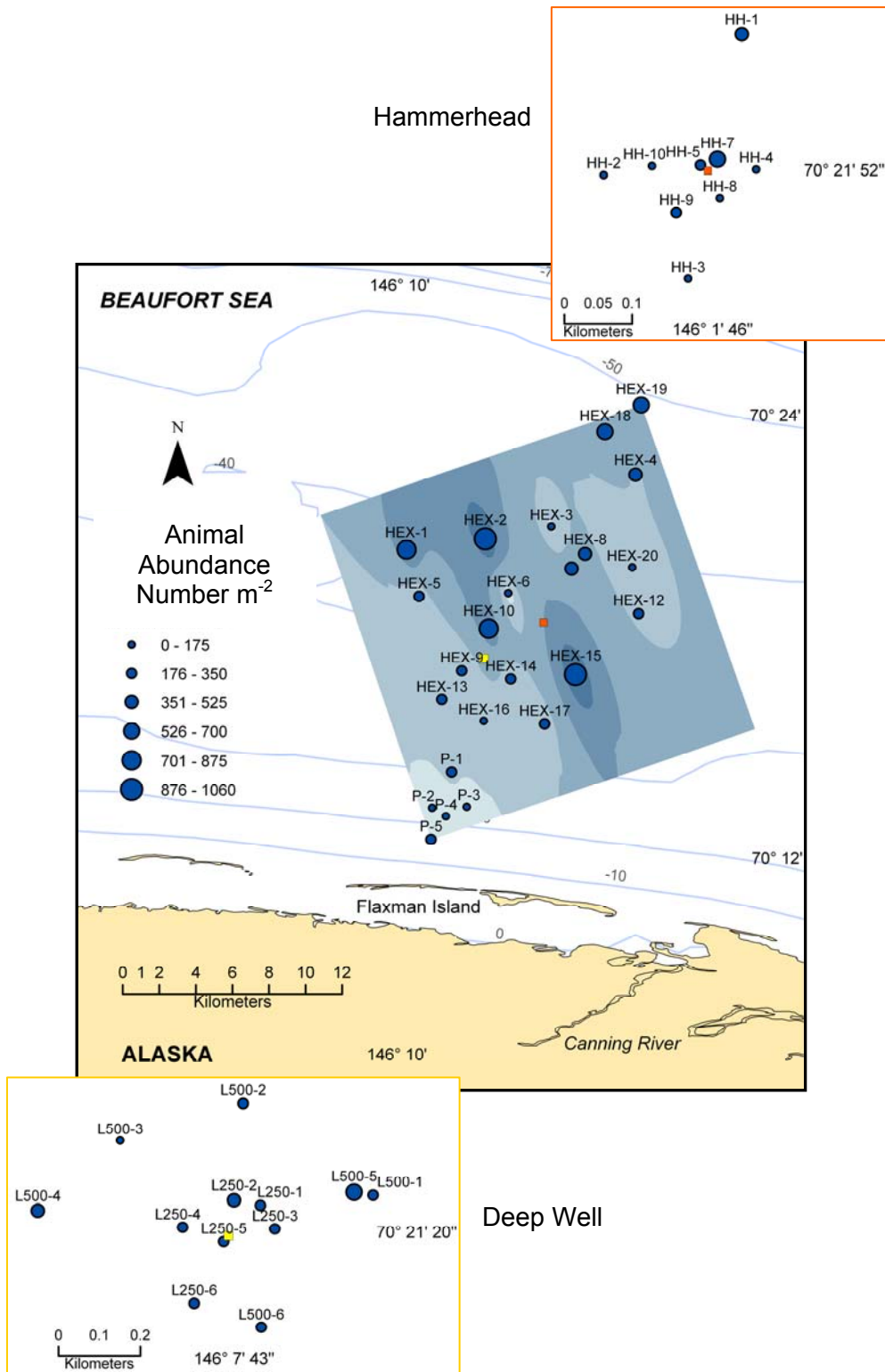


Figure 3.1.1 Spatial variation in benthic infaunal density over the Sivulliq study area. Depth contours are labeled in meters.

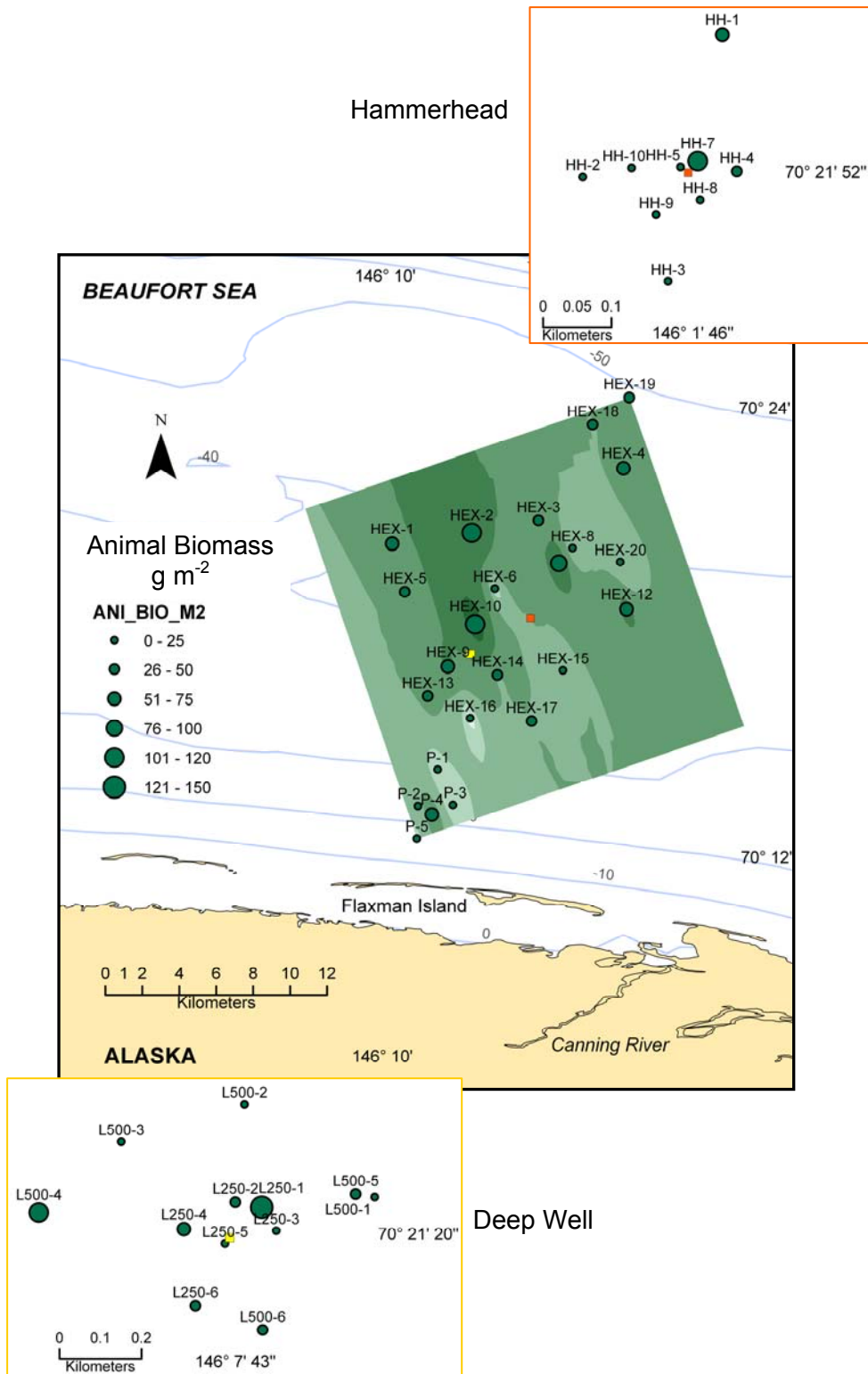


Figure 3.1.2 Spatial variation in benthic infaunal biomass over the Sivulliq study area. Depth contours are labeled in meters.

Station invertebrate abundance mean values ranged from 0 m⁻² at Station Hex-16 to 1060 m⁻² at Hex-15 (Fig. 3.1.3). Overall abundance was dominated by polychaetes, bivalves and amphipods. Highest abundance counts (>1000 m⁻²) were driven by numerous tiny juvenile *Pectinaria hyperborea* polychaetes. The maldanid polychaetes, *Praxillella praetermissa* and *Maldane sarsi* were found in most samples, often in comparatively large numbers.

Site invertebrate biomass values ranged from 0 m⁻² at Station Hex-16 to 129.1 m⁻² at Station L250-1 (Fig. 3.1.4). Sites with highest biomass values contained relatively large bivalves, nemerteans, and/or maldanid polychaete worms. The bivalves *Thracia septentrionalis*, *Astarte montagui* and *Portlandia lenticula* were widespread throughout the area and contributed to stations with higher biomass recorded in the study area.

Species groups that were collected infrequently and in small numbers were lumped into a miscellaneous group (Misc) for Figures 3.1.1 and 3.1.2. Included in this miscellaneous collection were the following groups: Ascideacea, bryozoa, caprellid, anthozoa, echinodermata, osteichthyes, asteroidea, foraminifera, holothurian, hydrozoa, isopoda, mysidea, porifera, priapulida and sipunculida.

Benthic density and biomass measurements yielded no discernable spatial trends in either parameter at Hammerhead or Deep Well (L250 and L500) sites. The recovery of drilling muds and copious bivalve shell material in grabs taken at HH-5 and HH-8 were of considerable interest. It is not known if the burial of benthic infaunal and epifaunal organisms during drilling activities results in long-term effects to benthic secondary production. No studies have addressed this question since it has not been logistically possible to re-visit drill sites to conduct benthic biological studies. Moreover, the chances of obtaining grab samples at a confirmed drill site location are extremely difficult. Our preliminary data indicate that if the benthic community was impacted during drilling, it has progressed well towards recovery in the two decades following the activity.

Sivulliq Benthic Biota

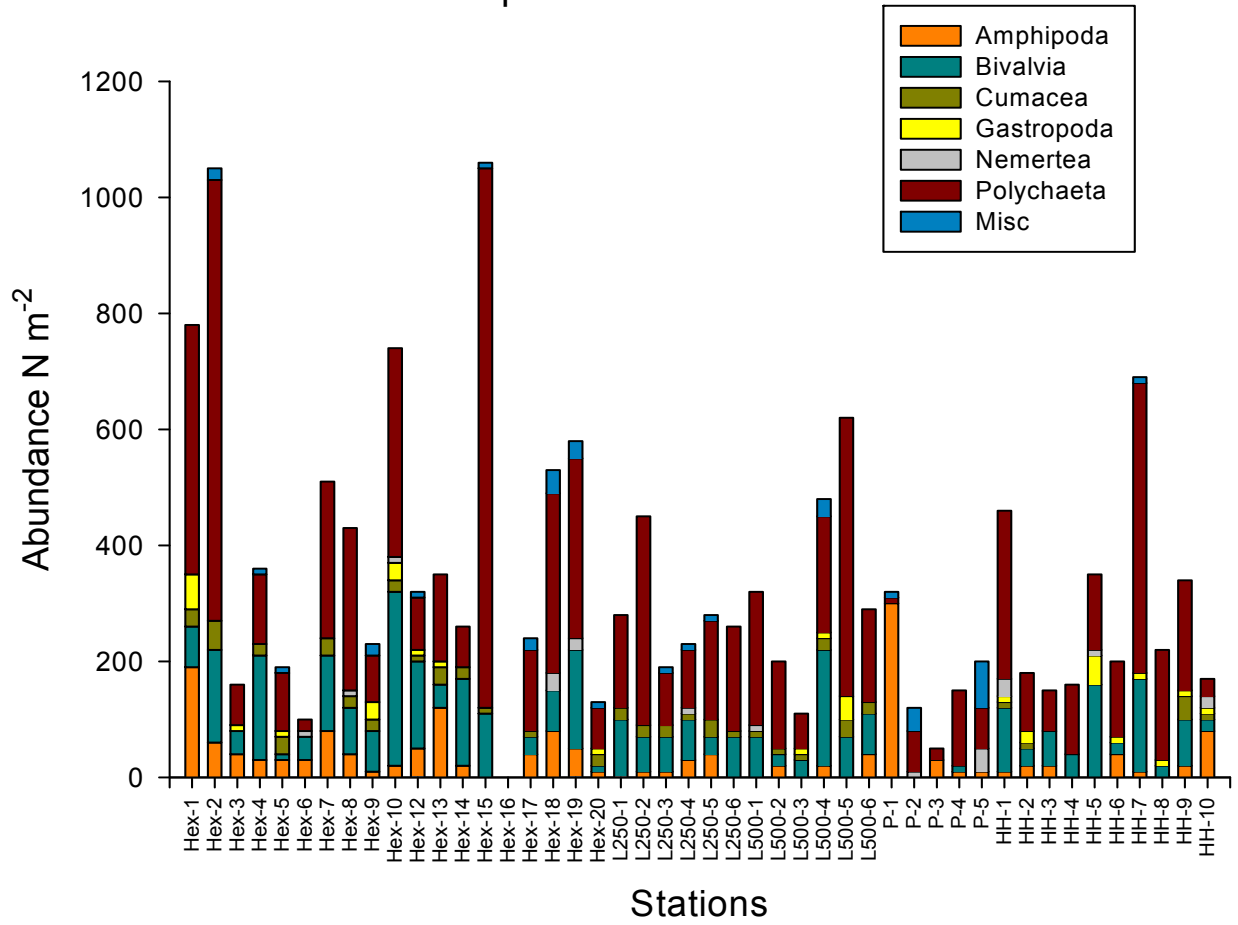


Figure 3.1.3 Variation in benthic infaunal abundance by group at each station in the Sivulliq study area. Misc (Miscellaneous) included infrequently sampled organisms (see text).

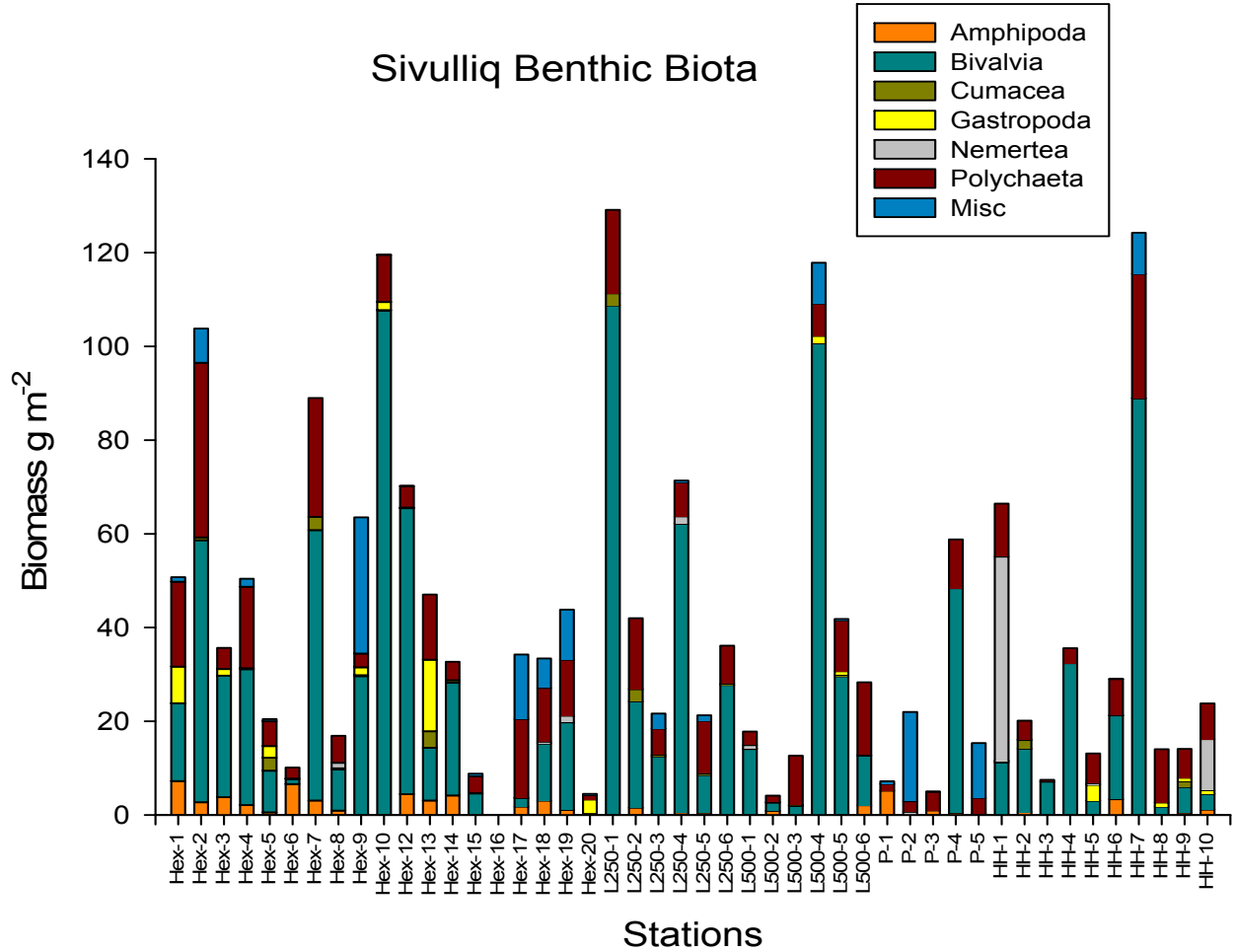


Figure 3.1.4 Variation in benthic infaunal biomass by group at each station in the Sivulliq study area. Misc (Miscellaneous) included infrequently sampled organisms (see text).

3.1.2 Benthic community structure

We used PRIMER software to examine benthic biota abundance and biomass data using multivariate and univariate routines. Benthic biota data were tested for species group similarity among Sivulliq stations using non-metric multidimensional scaling plots (MDS; Fig. 3.1.2 and Fig.3.1.3). Organisms were divided into the following 19 functional groups for analyses: amphipoda, actinaria, ascidiacea, bivalvia, bryozoa, alcyonaria, echinodermata, osteichthyes, foraminifera, gastropoda, holothuria, hydrozoa, isopoda, mysidacea, nemertea, polychaeta, porifera, priapulida and sipunculida. Data were transformed using the square root function prior to MDS analysis to reduce dominant contribution from extremely abundant or high biomass species to the Bray-Curtis similarities. MDS arrays data in multi-dimensional space such that points which are spatially closer together have greater similarity. With the exception of four Pipeline stations (P-1, P-2, P-3 and P-5), the Sivulliq stations clustered together in plots of both abundance (Fig. 3.1.5) and biomass (Fig.3.1.6). Pipeline stations (excluding P-4) were located in relatively shallow depths (22.0 to 26.0 m) contained less species, odd combinations of organisms, and no bivalves (see Fig. 3.1.3 and Fig. 3.1.4). Consequently, MDS analysis revealed that less than 25% of the 19 functional groups of these four stations were common to the remaining stations on the basis of abundance. P-1 contained a high abundance of amphipods and P-2 had none. P-2 and particularly P-5 were dominated by large numbers of miscellaneous species. But in contrast to other Pipeline stations, P-4 displayed similar abundance and biomass compositions to non-Pipeline stations. For biomass, MDS plots revealed that Hex-20 and Hex-17 stations were separated from other clusters and Hex-6 was binned with P-3 and P-1 at 50% similarity. Additional analysis revealed that Hex-20 had low biomass with a large proportionally large number of gastropods. Hex-17 contained a large number of miscellaneous species, and Hex-6 was dominated by gastropods and amphipods (same as P-1). Stations P-2 and P-5 remained distinct from all remaining stations, which is likely related to the large proportion of miscellaneous species at these sites.

Miscellaneous species at station P-5 included actinaria, holothurians, hydrozoans, bryozoans, and porifera which are organisms found on hard substrates. We noted the increased frequency of pebbles and cobbles at the Pipeline stations; these rocks were retained in grab samples, and explain the unique assemblage of organisms listed for stations P-5 and P-2. Pipeline stations in

general contained few organisms and/or had low diversity. These sites are located in shallower waters, where the seafloor is more prone to gouging and physical disruption by deep draft ice. Reimnitz et al. (1977) noted that pronounced linear pressure and shear between the undeformed fast ice (which extends to the 20 m isobath) and the westward drifting polar pack ice resulted in grounded ice ridges and rubble fields that extended up to 13 m high (the Stamuki Zone). At depths just seaward of 20 m, which correspond to the depths of the Pipeline stations (22-26 m), Reimnitz et al. (1977) noted that grounded pressure-ridge keels in the Stamuki Zone exerted tremendous stresses on the seabed. It is likely that benthic organisms in this region of the shelf are subject to frequent and devastating disturbances by grounded ice in both time and space, resulting in a mosaic of benthic assemblages in different stages of ecological succession.

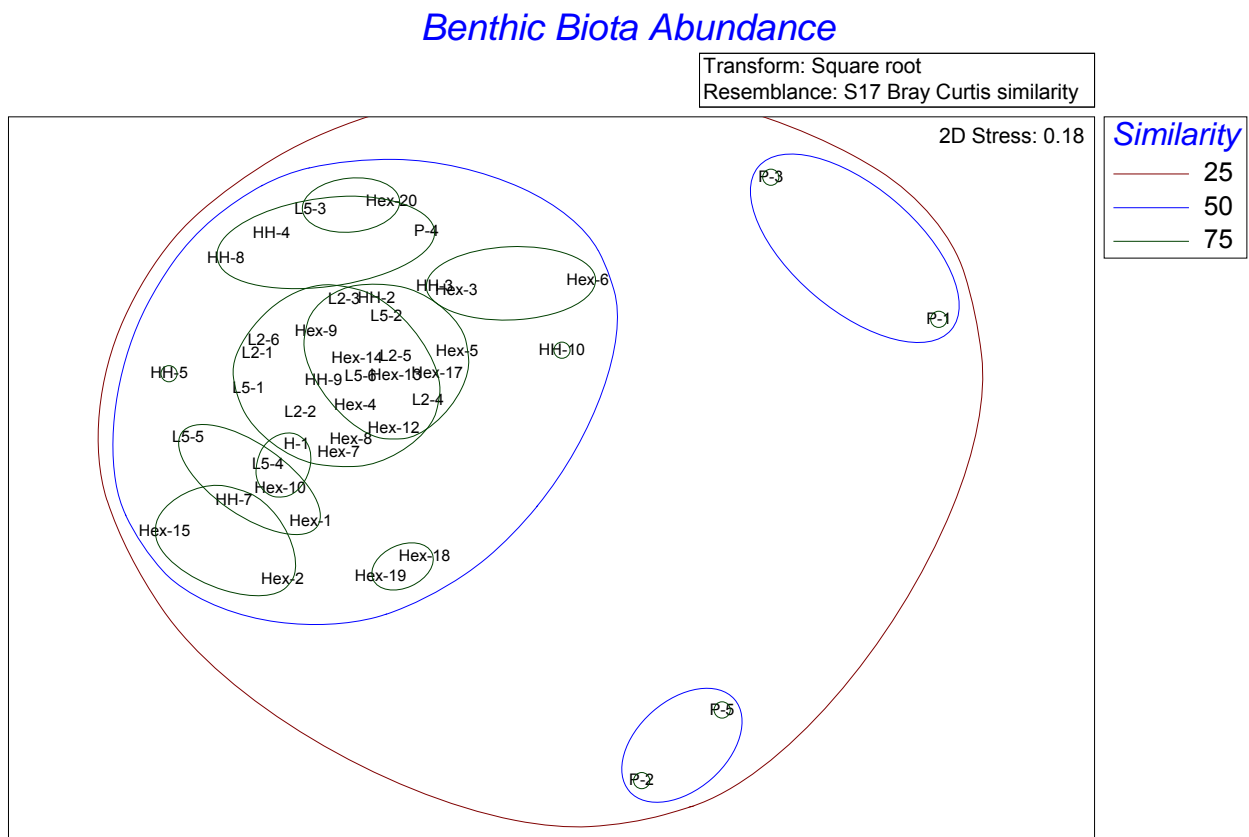


Figure 3.1.5 Similarity of benthic infaunal invertebrate communities based on MDS analyses of station abundance over the Sivulliq study area. L2 = L250 and L5 = L500. P = Pipeline, HH = Hammerhead. All MDS analyses use Bray-Curtis similarities on square root transformed data.

Benthic Biota Biomass

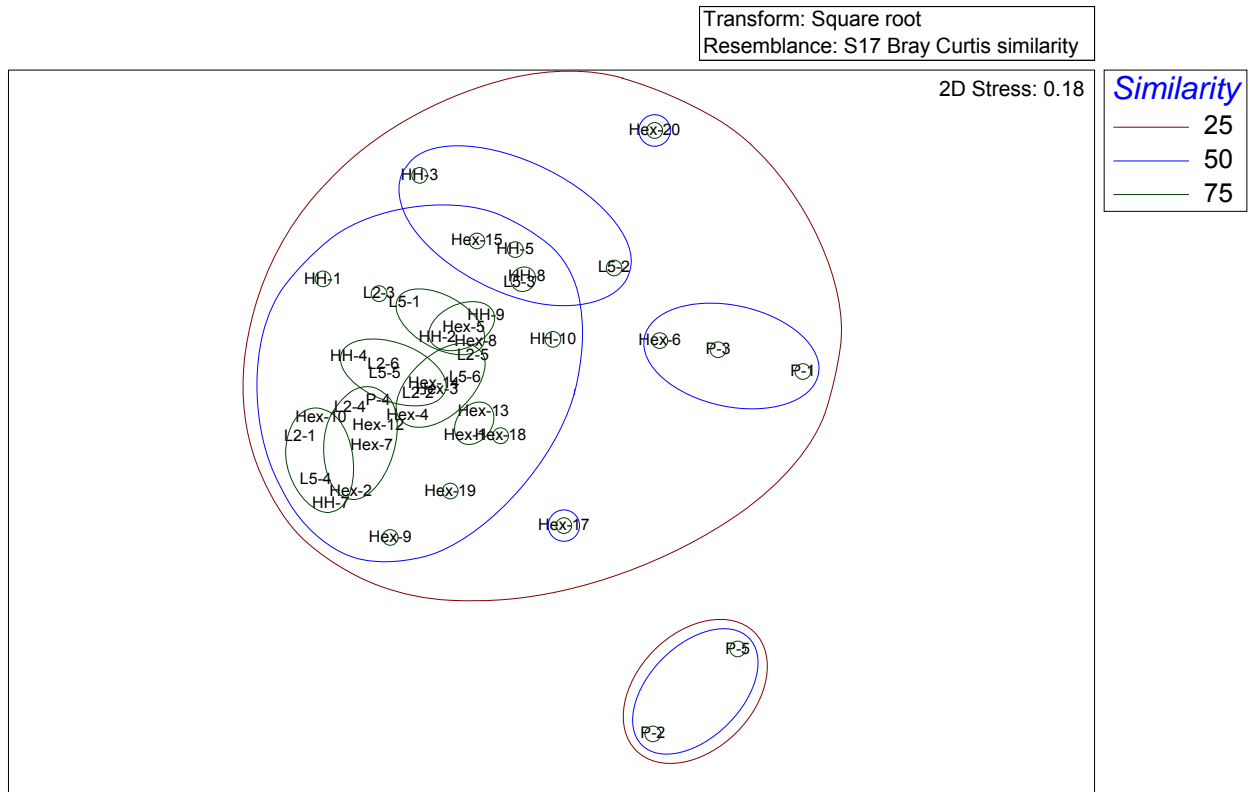


Figure 3.1.6 Similarity of benthic infaunal invertebrate communities based on MDS analyses of benthic biota station biomass over the Sivulliq study area. L2 = L250 and L5 = L500. P = Pipeline, HH = Hammerhead. All MDS analyses use Bray-Curtis similarities on square root transformed data.

Overall, mean abundance, Pielou, Shannon-Wiener, and Simpson index values were all lower at Pipeline stations compared to these average indices at all other stations (Table 3.1.4). Next lowest were Hammerhead and L stations. Hex stations had the highest mean values in all categories. Pielou's evenness index abundance mean for all sites was 0.70 with a range from 0.25 at station P-1 to 0.97 at station P-3 (Fig. 3.1.4). The Shannon-Wiener diversity index abundance mean value for all sites was 1.06 and ranged from a low of 0.28 at station P-1 to a high of 1.69 at station P-5 (Fig. 3.1.4). Simpson's diversity index abundance mean for all sites was 0.55 with a range from 0.12 at station P-1 to 0.78 at station P-5.

Mean biomass, Pielou, Shannon-Wiener and Simpson index values varied by group (Table 3.1.6). The lowest group mean weight was measured at the Pipeline stations, but the lowest

Pielou, Shannon-Wiener and Simpson values were measured at the L250 and L500 stations. Hex stations had the highest values in all categories. Pielou's mean biomass value was 0.58 for all sites and varied from a low of 0.19 at station Hex-10, to a high of 0.90 at station Hex-13 (Table 3.1.6). Shannon-Wiener's mean biomass value was 0.91 for all sites and varied from a low of 0.27 at station HH-3, to a high of 1.72 at station P-5 (Table 3.1.6). Simpson's mean biomass value was 0.52 for all sites and varied from a low of 0.14 at station HH-3, to a high of 0.87 at station L500-2.

Table 3.1.3 Indices of benthic community structure based on results of analyses from abundance data at all Sivulliq sites.

Station	Date	Water Depth (m)	Group Count	Abundance no. m ⁻²	Pielou	Shannon -Wiener	Simpson
HEX-1	8/20/2008	34.7	5	780	0.75	1.21	0.62
HEX-2	8/21/2008	35.4	6	1050	0.51	0.92	0.45
HEX-3	8/19/2008	34.4	4	160	0.89	1.23	0.68
HEX-4	8/19/2008	37.2	5	360	0.73	1.18	0.63
HEX-5	8/20/2008	32.9	6	190	0.77	1.39	0.67
HEX-6	8/18/2008	33.2	4	100	0.92	1.28	0.71
HEX-7	8/19/2008	32.9	4	510	0.82	1.14	0.63
HEX-8	8/19/2008	32.9	5	430	0.65	1.04	0.53
HEX-9	8/20/2008	30.8	6	230	0.87	1.56	0.76
HEX-10	8/18/2008	32.6	6	740	0.61	1.10	0.60
HEX-12	8/19/2008	31.1	6	320	0.74	1.33	0.68
HEX-13	8/20/2008	29.9	5	350	0.80	1.29	0.68
HEX-14	8/21/2008	31.4	4	260	0.77	1.07	0.59
HEX-15	8/21/2008	32.0	4	1060	0.32	0.44	0.22
HEX-17	8/21/2008	29.7	6	240	0.71	1.27	0.61
HEX-18	8/19/2008	38.1	5	530	0.76	1.22	0.61
HEX-19	8/19/2008	38.1	7	580	0.63	1.23	0.62
HEX-20	8/19/2008	32.3	6	130	0.79	1.41	0.67
L250-1	8/18/2008	31.7	3	280	0.80	0.88	0.54
L250-2	8/18/2008	31.7	4	450	0.48	0.67	0.34
L250-3	8/18/2008	31.4	5	190	0.79	1.27	0.66
L250-4	8/18/2008	32.0	6	230	0.78	1.40	0.70
L250-5	8/18/2008	31.1	5	280	0.73	1.18	0.59
L250-6	8/18/2008	31.4	3	260	0.67	0.73	0.45
L500-1	8/18/2008	30.8	4	320	0.57	0.79	0.44
L500-2	8/18/2008	31.7	4	200	0.60	0.83	0.42
L500-3	8/18/2008	31.4	4	110	0.81	1.12	0.62
L500-4	8/18/2008	31.7	8	480	0.63	1.32	0.65
L500-5	8/18/2008	31.7	4	620	0.55	0.77	0.38
L500-6	8/18/2008	31.4	4	290	0.81	1.13	0.62
P-1	8/22/2008	26.0	3	320	0.25	0.28	0.12
P-2	8/22/2008	23.5	4	120	0.78	1.08	0.59
P-3	8/22/2008	23.7	2	50	0.97	0.67	0.49
P-4	8/22/2008	23.5	3	150	0.44	0.49	0.24
P-5	8/22/2008	22.0	7	200	0.87	1.69	0.78
HH-1	8/17/2008	32.3	6	460	0.59	1.06	0.54
HH-2	8/17/2008	32.3	5	180	0.79	1.27	0.64
HH-3	8/17/2008	32.6	3	150	0.90	0.99	0.61

Station	Date	Water Depth (m)	Group Count	Abundance no. m ⁻²	Pielou	Shannon -Wiener	Simpson
HH-4	8/17/2008	31.7	2	160	0.81	0.56	0.38
HH-5	8/17/2008	31.7	4	350	0.80	1.11	0.63
HH-7	8/17/2008	32.6	5	690	0.47	0.76	0.42
HH-8	8/17/2008	32.9	3	220	0.44	0.49	0.24
HH-9	8/17/2008	32.6	5	340	0.74	1.19	0.62
HH-10	8/17/2008	31.7	6	170	0.84	1.50	0.72

Table 3.1.4 Summary of benthic community structure indices of abundance data at all Sivulliq sites.

	Water Depth (m)	Group Count	Abundance (no. m ⁻²)	Pielou	Shannon -Wiener	Simpson
All Samples						
Minimum	22.0	2.0	50	0.25	0.28	0.12
Maximum	38.1	8.0	1060	0.97	1.69	0.78
Mean	31.5	4.7	348	0.70	1.06	0.55
HEX						
Mean	33.3	5.2	445.6	0.72	1.18	0.61
HH (Hammerhead)						
Mean	32.3	4.3	302.2	0.71	0.99	0.53
L (Deep Well)						
Mean	31.5	4.5	309.2	0.69	1.01	0.53
P (Pipeline)						
Mean	23.7	3.8	168.0	0.66	0.84	0.44

Table 3.1.5 Indices of benthic community structure based on analyses from biomass data at all Sivulliq sites.

Station	Date	Water Depth (m)	Group Count	Weight (g m ⁻²)	Pielou	Shannon -Wiener	Simpson
HEX-1	8/20/2008	34.7	6	50.73	0.77	1.38	0.74
HEX-2	8/21/2008	35.4	6	103.78	0.58	1.04	0.58
HEX-3	8/19/2008	34.4	4	35.65	0.62	0.86	0.46
HEX-4	8/19/2008	37.2	5	50.41	0.59	0.96	0.56
HEX-5	8/20/2008	32.9	6	20.48	0.80	1.43	0.75
HEX-6	8/18/2008	33.2	4	10.11	0.64	0.89	0.56
HEX-7	8/19/2008	32.9	4	88.96	0.62	0.87	0.50
HEX-8	8/19/2008	32.9	5	16.90	0.69	1.12	0.64
HEX-9	8/20/2008	30.8	7	63.49	0.51	1.00	0.58
HEX-10	8/18/2008	32.6	7	119.52	0.19	0.38	0.18
HEX-12	8/19/2008	31.1	6	70.20	0.27	0.49	0.24
HEX-13	8/20/2008	29.9	5	47.04	0.90	1.44	0.76
HEX-14	8/21/2008	31.4	4	32.71	0.59	0.81	0.44
HEX-15	8/21/2008	32.0	5	8.82	0.58	0.94	0.63
HEX-17	8/21/2008	29.7	6	34.24	0.72	1.30	0.69
HEX-18	8/19/2008	38.1	5	33.38	0.82	1.32	0.73
HEX-19	8/19/2008	38.1	7	43.83	0.72	1.40	0.72
HEX-20	8/19/2008	32.3	6	4.51	0.64	1.15	0.72
L250-1	8/18/2008	31.7	3	129.10	0.45	0.50	0.27
L250-2	8/18/2008	31.7	4	41.99	0.72	0.99	0.59
L250-3	8/18/2008	31.4	6	21.66	0.61	1.09	0.61
L250-4	8/18/2008	32.0	6	71.37	0.29	0.52	0.25
L250-5	8/18/2008	31.1	5	21.26	0.63	1.01	0.60
L250-6	8/18/2008	31.4	3	36.12	0.52	0.57	0.37
L500-1	8/18/2008	30.8	4	17.82	0.46	0.64	0.37
L500-2	8/18/2008	31.7	4	4.14	0.83	1.15	0.87
L500-3	8/18/2008	31.4	4	12.63	0.38	0.53	0.31
L500-4	8/18/2008	31.7	8	117.82	0.27	0.56	0.26
L500-5	8/18/2008	31.7	5	41.81	0.46	0.74	0.44
L500-6	8/18/2008	31.4	4	28.32	0.66	0.91	0.57
P-1	8/22/2008	26.0	3	7.20	0.69	0.76	0.51
P-2	8/22/2008	23.5	5	22.00	0.66	1.06	0.57
P-3	8/22/2008	23.7	3	4.99	0.49	0.54	0.41
P-4	8/22/2008	23.5	3	58.81	0.47	0.51	0.31
P-5	8/22/2008	22.0	8	15.37	0.82	1.72	0.84
HH-1	8/17/2008	32.3	6	66.43	0.51	0.91	0.52
HH-2	8/17/2008	32.3	5	20.16	0.59	0.95	0.53
HH-3	8/17/2008	32.6	3	7.49	0.25	0.27	0.14

Station	Date	Water Depth (m)	Group Count	Weight (g m ⁻²)	Pielou	Shannon -Wiener	Simpson
HH-4	8/17/2008	31.7	2	35.61	0.44	0.30	0.17
HH-5	8/17/2008	31.7	4	13.12	0.82	1.14	0.70
HH-7	8/17/2008	32.6	6	124.22	0.43	0.78	0.44
HH-8	8/17/2008	32.9	3	14.05	0.55	0.60	0.35
HH-9	8/17/2008	32.6	5	14.10	0.76	1.22	0.70
HH-10	8/17/2008	31.7	6	23.79	0.71	1.27	0.69

Table 3.1.6 Summary of benthic community structure indices based on biomass data at all Sivulliq sites.

	Water Depth (m)	Group Count	Weight (g m ⁻²)	Pielou	Shannon -Wiener	Simpson
All Samples						
Minimum	22.0	2.0	4.1	0.19	0.27	0.14
Maximum	38.1	8.0	129.1	0.90	1.72	0.87
Mean	31.5	4.9	41.1	0.58	0.91	0.52
HEX						
Mean	33.3	5.4	46.4	0.63	1.04	0.58
HH (Hammerhead)						
Mean	32.3	4.4	35.4	0.56	0.83	0.47
L (Deep Well)						
Mean	31.5	4.7	45.3	0.52	0.77	0.46
P (Pipeline)						
Mean	23.7	4.4	21.7	0.63	0.92	0.53

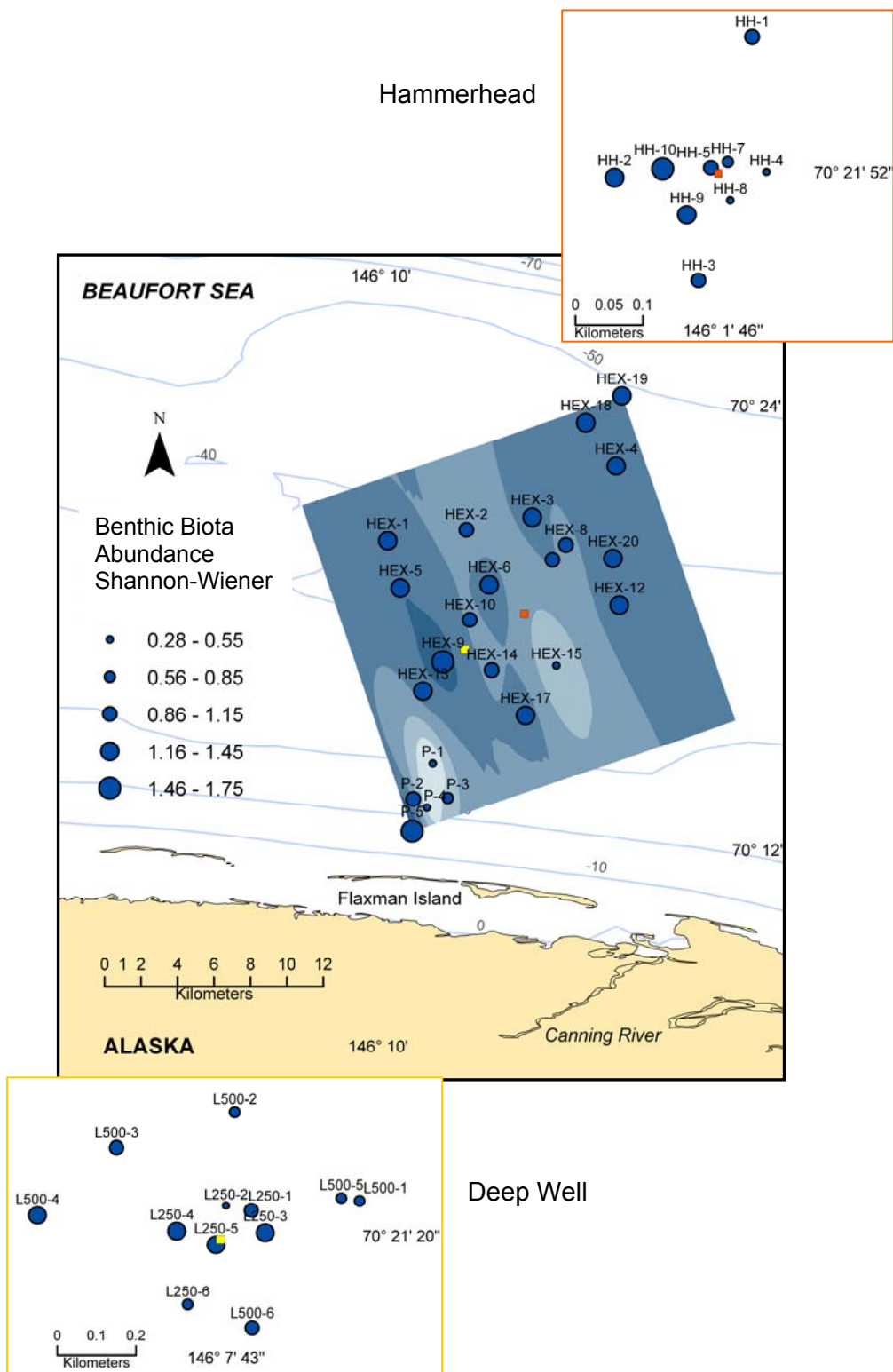


Figure 3.1.7 Spatial distribution of Shannon-Wiener data calculated from benthic biota abundance data. Depth contours are labeled in meters.

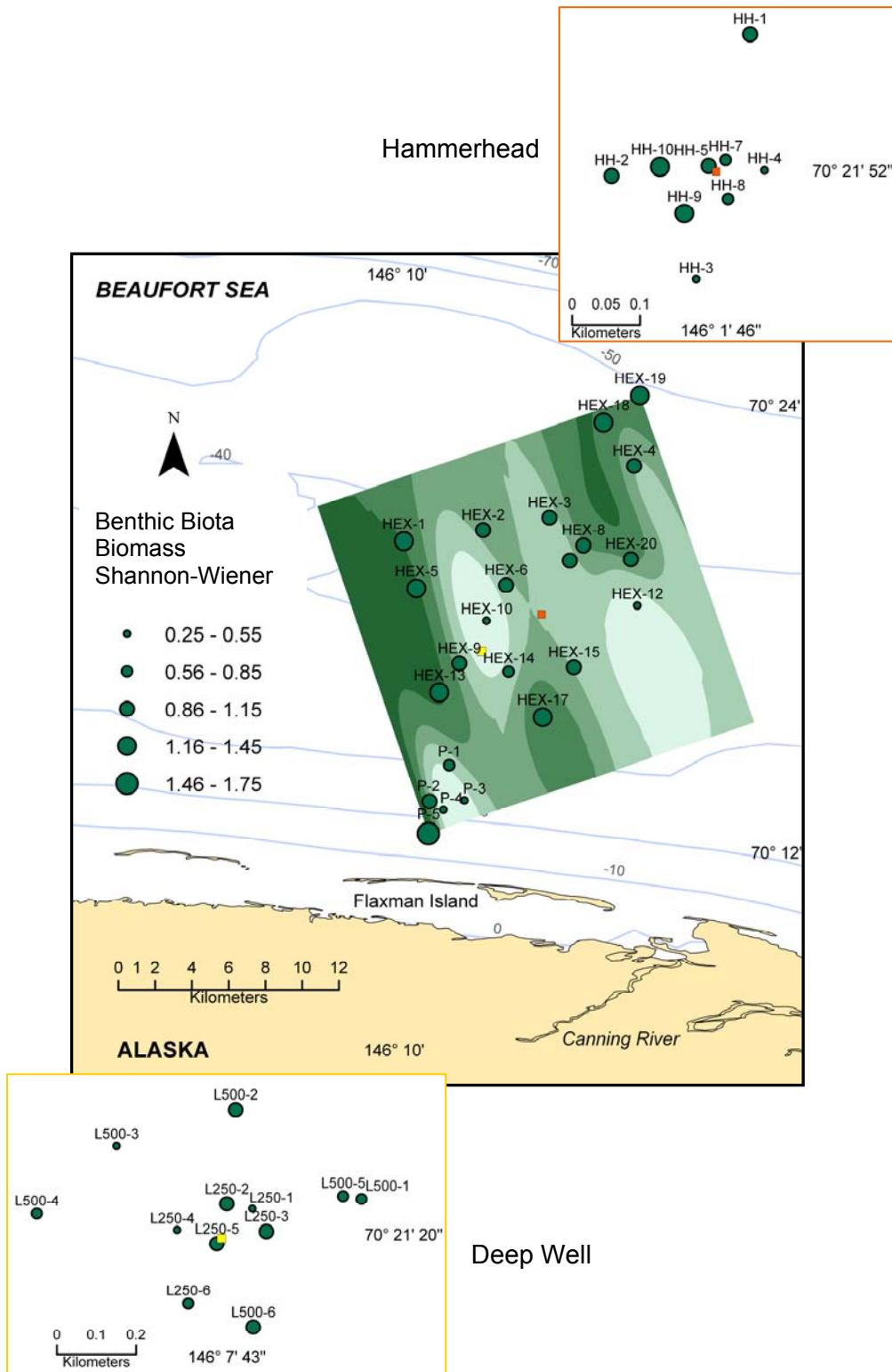


Figure 3.1.8 Spatial distribution of Shannon-Wiener data calculated from benthic biota biomass data. Depth contours are labeled in meters.

3.1.3 Isotopic measurements – $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

Measurements of ^{13}C and ^{15}N provide valuable markers in defining the isotopic signatures of organic matter available to consumers and in defining trophic structure. Dual measurements of ^{13}C and ^{15}N have previously been used to as a primary tool for determining the contributions of terrestrial and marine organic carbon and nitrogen in Beaufort Sea estuarine food webs (Schell, 1983; Schell et al., 1984a). In this study, we measured the C and N isotopic values of several hundred organisms from 45 sites to obtain a preliminary understanding of the trophic structure in the Sivulliq prospect area.

The variation in $\delta^{13}\text{C}$ values of the major taxonomic groups of biota range from -21.5 to -26.5‰ (Fig. 3.1.9). Primary consumers, notably amphipods were most depleted in ^{13}C , reflecting their dependency on particulate organic matter (POM). Secondary consumers are generally more ^{13}C enriched due to selective respiration of ^{12}C with increasing trophic level. Organisms that were most ^{13}C enriched included deposit feeding priapulids, benthic predators (e.g. nemerteans), and hydrozoans, which prey on zooplankton. The range of organism feeding habits are reflected in the variability in isotopic composition (length of error bars). Nereid polychaete worms for example, are extremely omnivorous, reflecting their diets as both predators and herbivores. Other species, such as ampharetid polychaetes, are more specialized, feeding exclusively on particles in the water column. In general the range in $\delta^{13}\text{C}$ values appear to reflect the importance of marine POM (average $\delta^{13}\text{C} = 25.5\text{‰}$) as an ultimate food source, although the contribution by benthic microalgae (average $\delta^{13}\text{C} > 23.0\text{‰}$; Fig. 3.0.1) at the shallower Pipeline sites, may be important.

Benthic food web structure, as reflected by $\delta^{15}\text{N}$ values ranging from 6.5 to 13.5‰ (Fig. 3.1.10), span three trophic levels in the Sivulliq prospect study area based on an average POM value of 5.5‰ (Fig. 3.11). This estimate is based on ^{15}N trophic level enrichments of 3‰ compared to only about 1‰ for ^{13}C (Dunton et al., 2006). Consistent with carbon isotopic data, $\delta^{15}\text{N}$ analyses showed that higher trophic level organisms included actinarians, priapulids, and nemerteans ($\delta^{15}\text{N}$ values from 12 to 13‰). Lower trophic level biota included crustaceans (amphipods,

Table 3.1.1. Comparative values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopic values between (HH-5) with five other Hammerhead sites that contained the same species. Values are means \pm SE (*n*).

GROUP	$\delta^{13}\text{C}$			$\delta^{15}\text{N}$	
	HH- 5	Other HH sites		HH-5	Other HH sites
Amphipod	-25.7 (1)	-26.0 \pm 0.6 (5)		8.4 (1)	8.8 \pm 0.6 (5)
Bivalve*	-23.3 (1)	-23.7 \pm 0.2(13)		7.1 (1)	8.0 \pm 2.2 (13)
Nemertean	-24.4 (1)	-20.1 \pm 0.6 (2)		8.0 (1)	14.6 \pm 0.4 (2)
Polychaete*	-22.4 (1)	-23.3 \pm 0.2 (7)		11.7 (1)	11.6 \pm 0.6 (7)

*Bivalve is *Nuculana*; Polychaete is *Nephtys*.

caprellids) and filter feeding bivalves (tellinids and *Yoldia*). The distribution of organism $\delta^{15}\text{N}$ values greater than 6‰ indicate that POM derived from marine sources (defined by $\delta^{15}\text{N}$ values from 5 to 7‰) are more likely the major source of organic nitrogen to marine food webs of the shelf than terrestrial sources (characterized by $\delta^{15}\text{N}$ values between 0 and 1.5‰; see Dunton et al., 2006).

We also used stable isotopic values to examine potential changes at Hammerhead related to drilling activities. We surmised that any serious long-term impacts to the benthic community at HH-5 would result in a change in organism dependence on ultimate carbon sources or a compromised food web structure as dictated by $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotopic values. A comparison of isotopic values of biota at HH-5 with the same species at five adjacent Hammerhead sites showed that of the four classes of invertebrates examined, three were not significantly different in either $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ signatures. However, the nemertean collected at HH-5 was significantly depleted in ^{13}C and ^{15}N compared to individuals collected at other Hammerhead sites, which indicates that this individual was feeding on different prey and occupied a lower trophic level than the same individuals at other sites. Collection of additional organisms would be required to document conclusively that nemerteans or other higher trophic level organisms have shifted their diets in response to changes in preferred prey density.

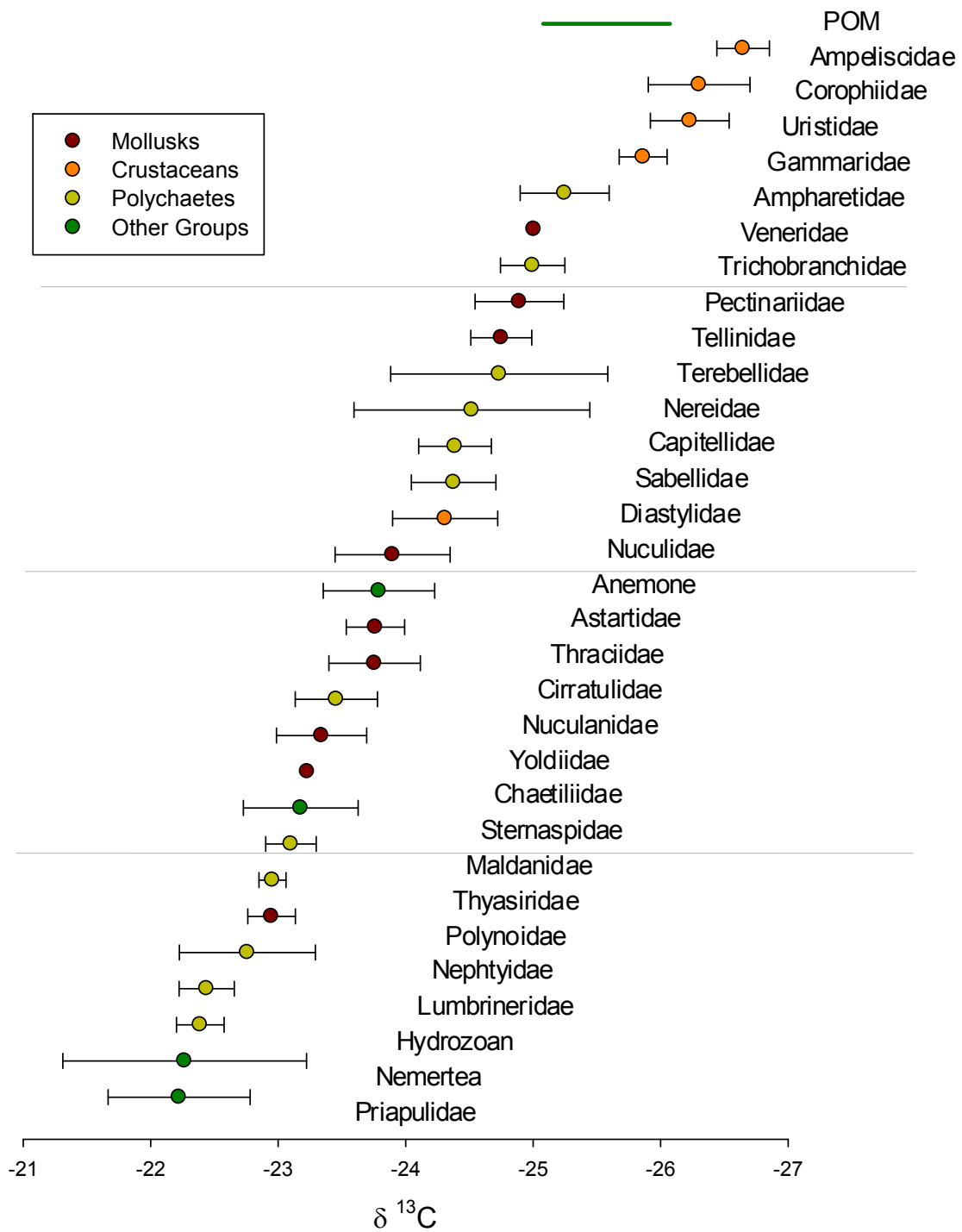


Figure 3.1.9 Stable carbon isotopic values of representative benthic biota in relation to POM based on collections in the Sivulliq study area. Values are mean \pm SE.

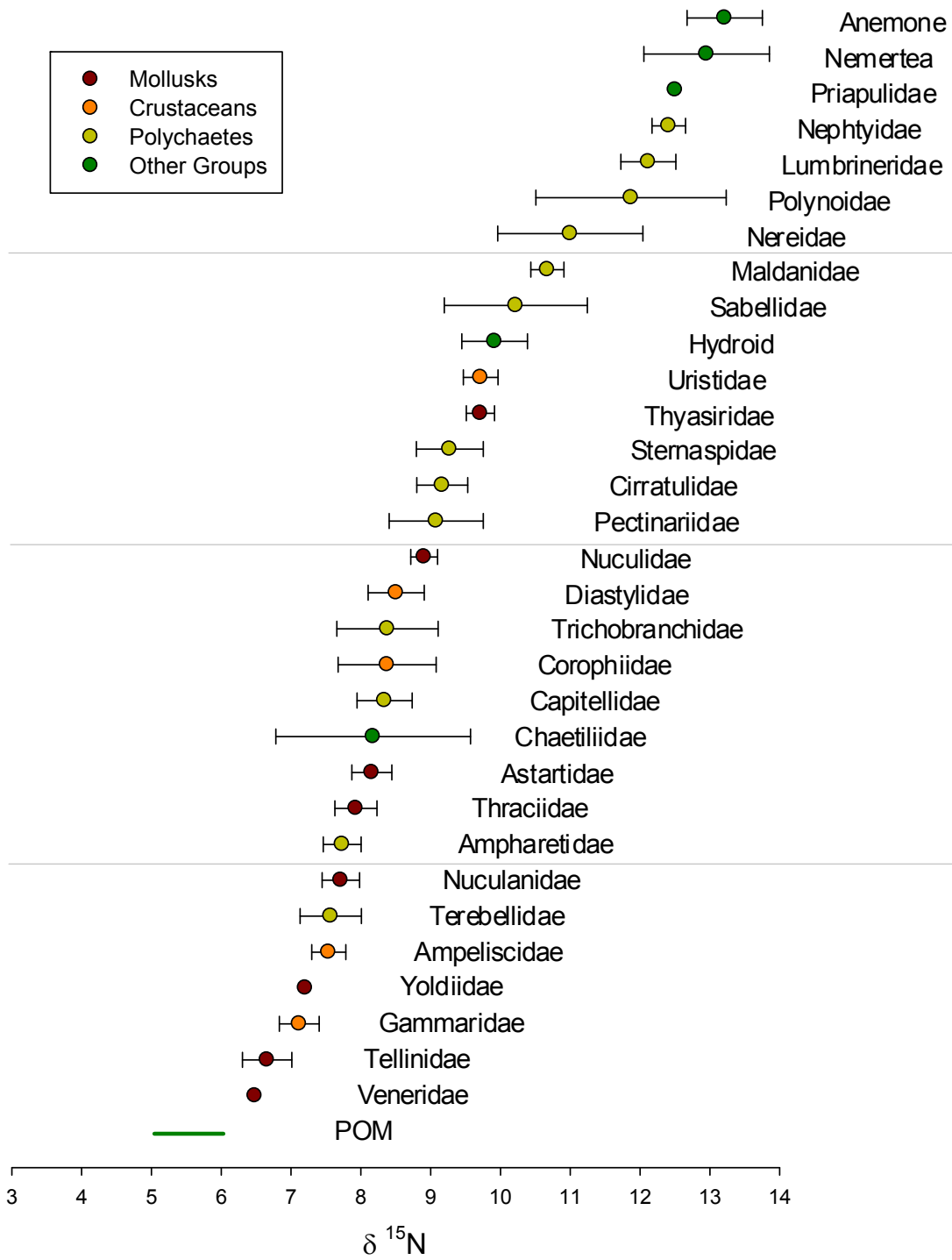


Figure 3.1.10 Stable nitrogen isotopic values of representative benthic biota in relation to POM in the Sivulliq study area. Values are mean \pm SE.

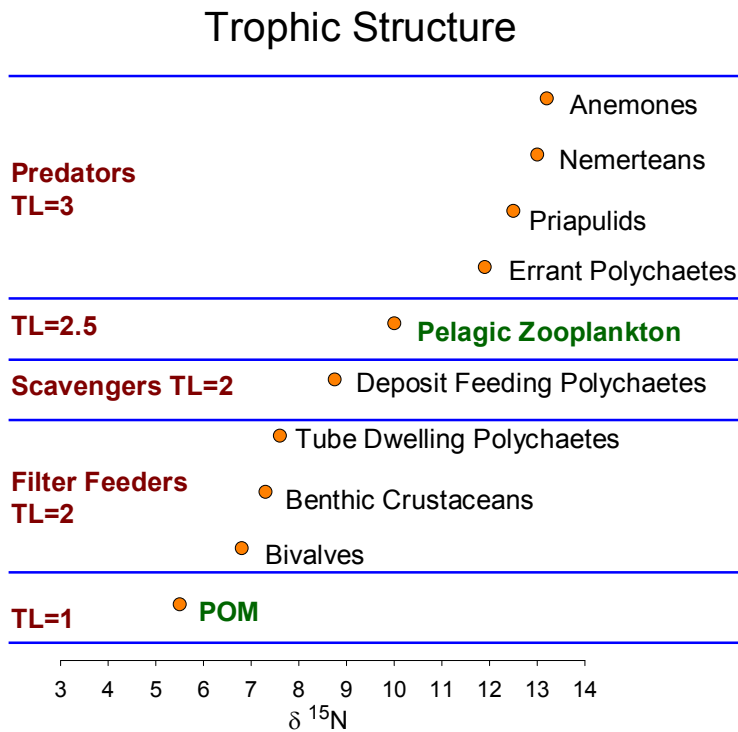


Figure 3.1.11 Stable nitrogen isotopic values of functional benthic trophic groups in relation to POM and zooplankton in the Sivulliq study area. Trophic level (TL) is indicated in red.

3.2 WATER COLUMN MEASUREMENTS

3.2.1 Chlorophyll *a*

Water column chlorophyll *a* was uniformly very low throughout the study area during the period of sampling (Fig. 3.2.1). Values ranged from undetectable to $0.5 \mu\text{g L}^{-1}$. Vertical profiles showed that offshore waters were relatively well mixed with respect to chlorophyll, but values were generally greater at depth. This was especially apparent at inshore sites (P-1, P-5), where values approached $0.5 \mu\text{g L}^{-1}$ compared to $0.1 \mu\text{g L}^{-1}$ near the surface. The higher values near the bottom may be related to the resuspension of benthic microalgae based on the higher sediment chlorophyll values recorded at these inshore sites.

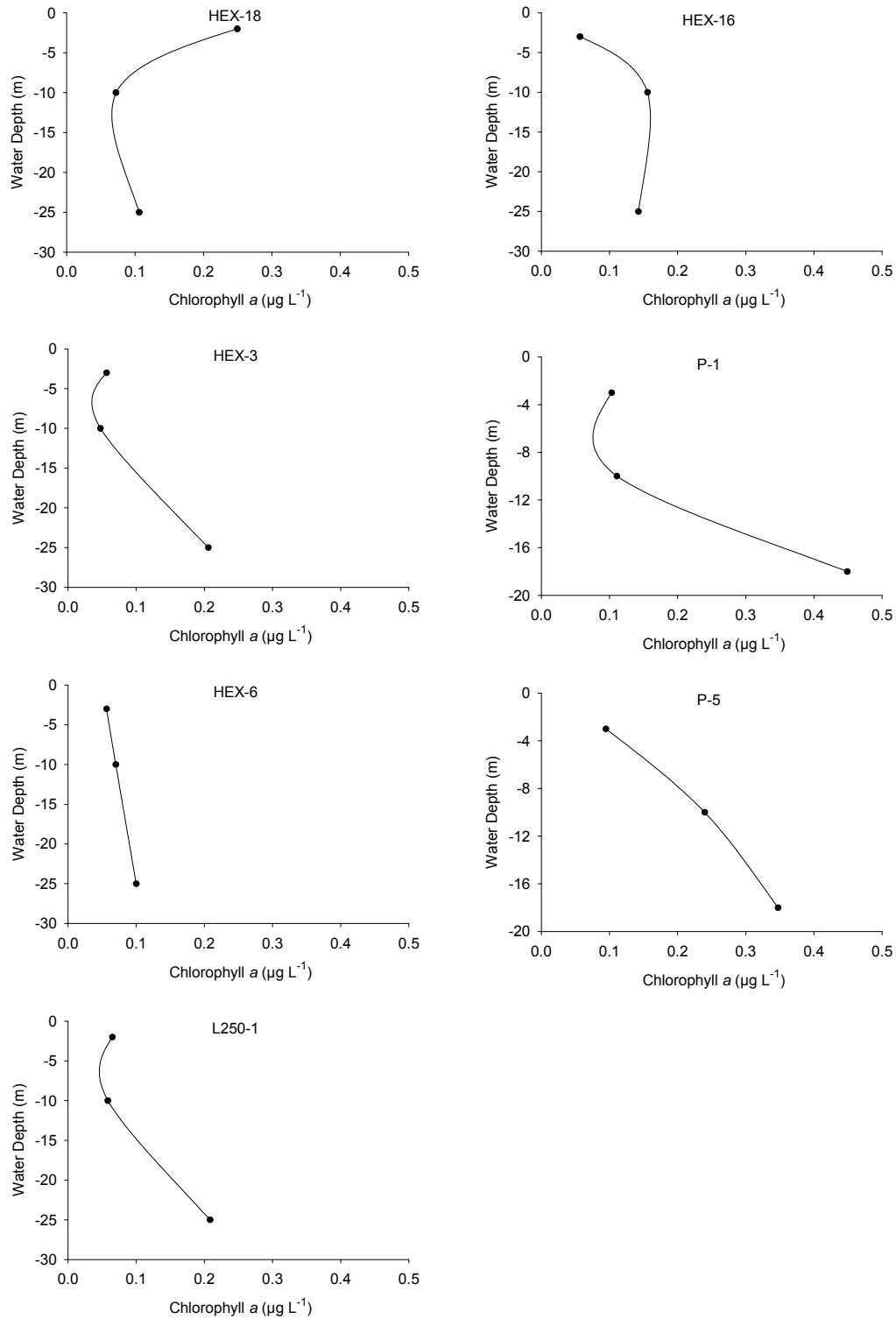


Figure 3.2.1 Vertical profiles of chlorophyll *a* at seven Sivulliq sites. Note the increase in chlorophyll levels with depth at the shallower Pipeline stations.

3.2.2 Zooplankton - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

Stable carbon isotopic values of both calanoid copepods (Fig 3.2.3) and gelatinous zooplankton (Fig. 3.2.4) yielded similar ranges in $\delta^{13}\text{C}$ values, from -23.3 to -26.7‰. Because of the opportunistic nature of this sampling effort, there is insufficient data to depict any real geographic trends in zooplankton ^{13}C or ^{15}N signatures across the study area. Similarly, stable nitrogen isotopic values of both calanoid copepods (Fig 3.2.5) and gelatinous zooplankton (Fig. 3.2.6) yielded similar ranges in $\delta^{15}\text{N}$ values, from 8.7 to -12.9‰. A notably high $\delta^{15}\text{N}$ value (13.6‰) was recorded for the carnivorous amphipod (*Thermisto*), reflecting its higher trophic level relative to the herbivorous copepods on which it feeds.

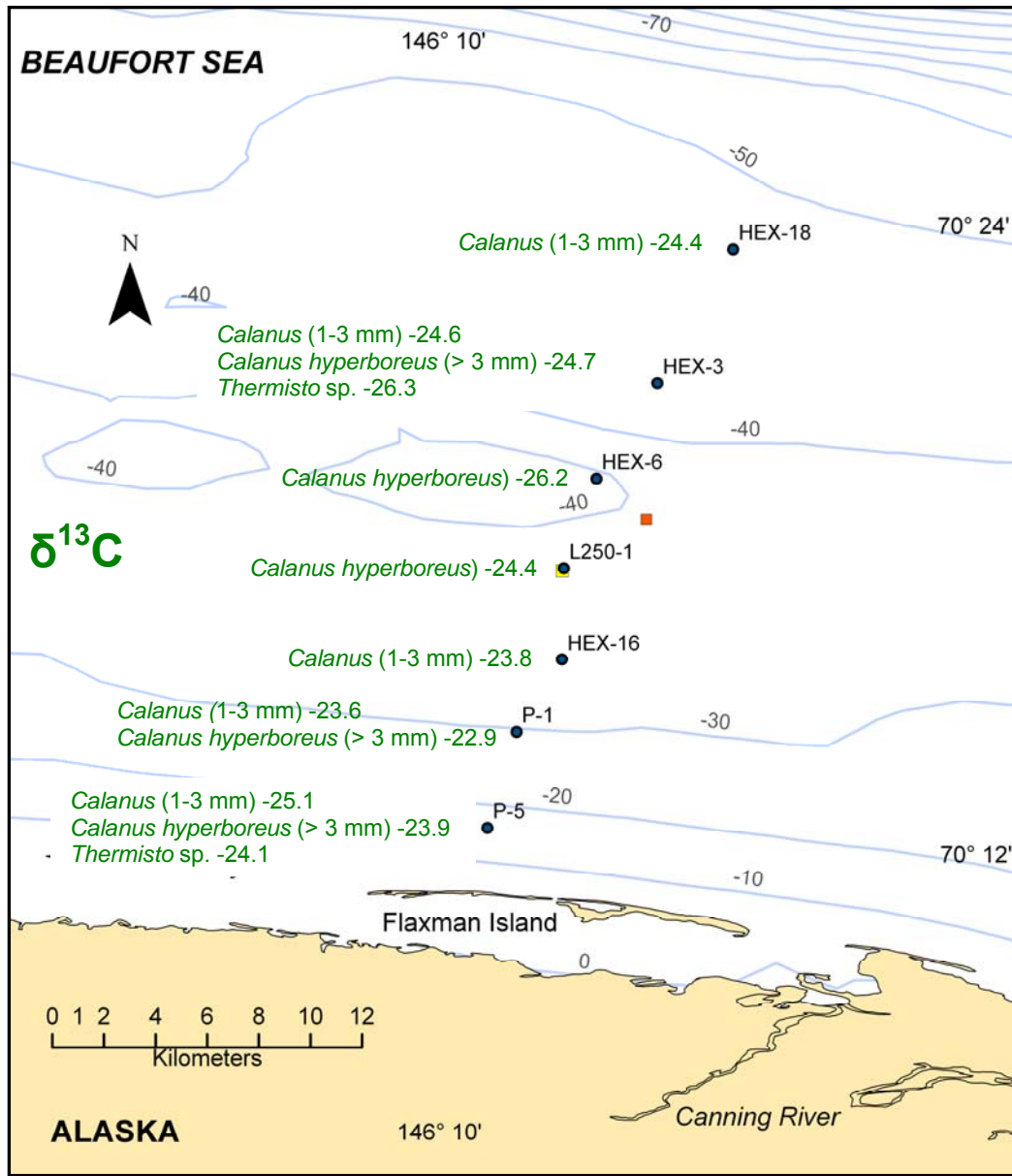


Figure 3.2.3 Stable carbon isotopic values of herbivorous calanoid copepods and a carnivorous amphipod (*Thermisto*) across the study area based on collections from vertical plankton tows. Isotopic values become increasing more negative with distance offshore, similar to sediment $\delta^{13}C$ values (see Fig. 3.0.1) that reflect an increasing more ^{13}C depleted carbon source. Depth contours are labeled in meters.

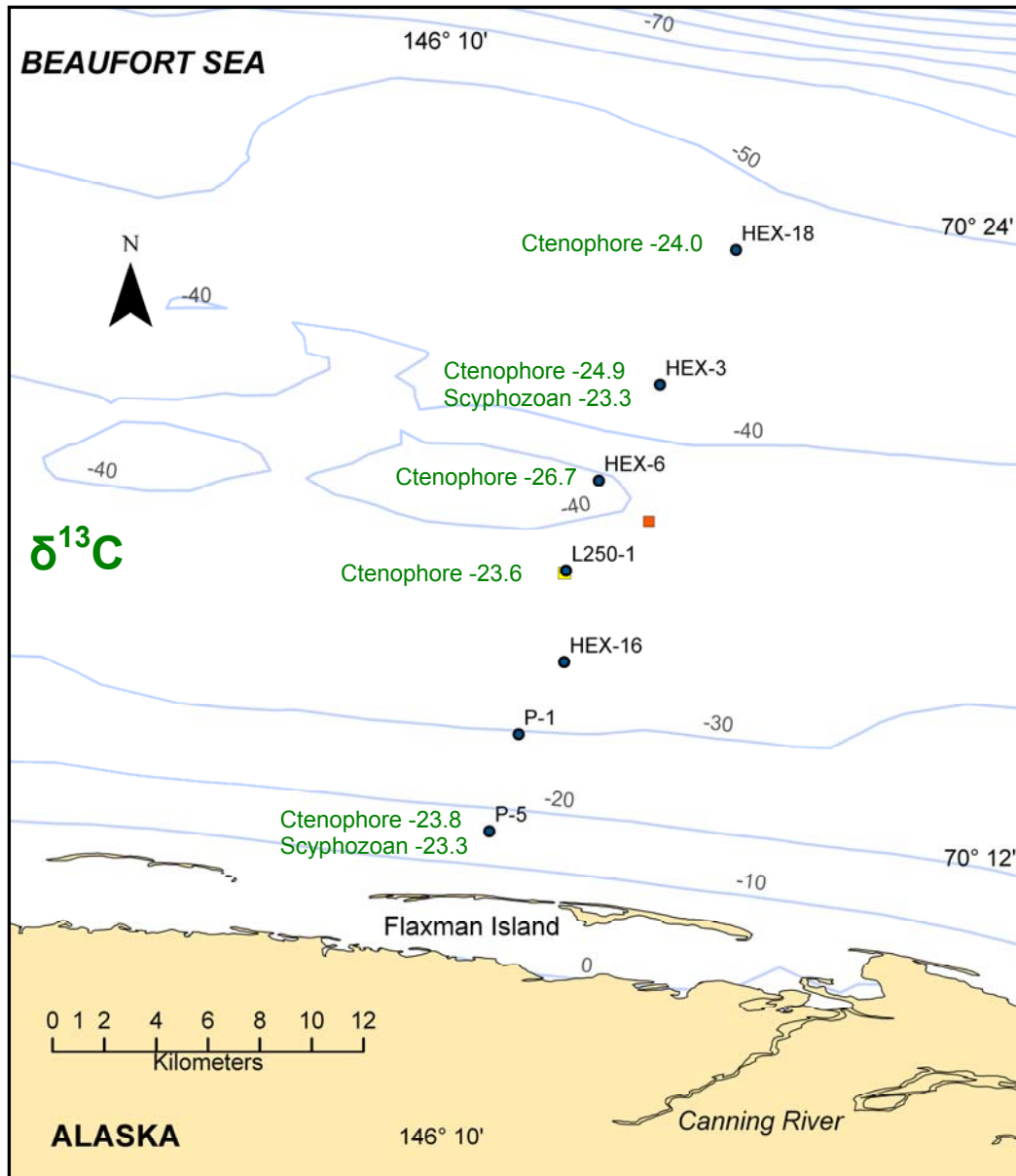


Figure 3.2.4 Stable carbon isotopic values of gelatinous zooplankton across the study area based on collections from vertical plankton tows. The gradient is similar to that reported in Fig. 3.2.3. Depth contours are labeled in meters.

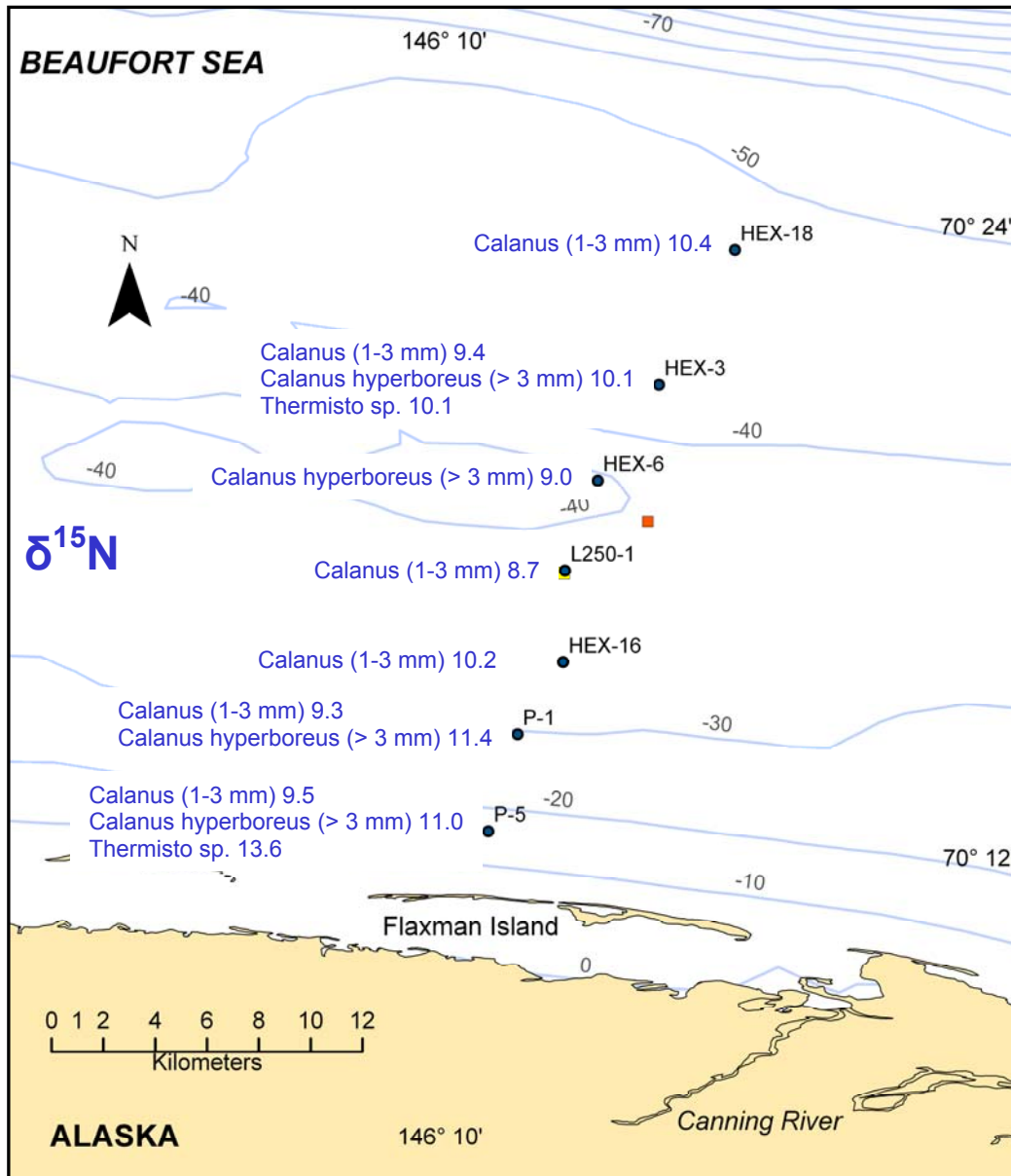


Figure 3.2.5 Stable nitrogen isotopic values of herbivorous calanoid copepods and a carnivorous amphipod (*Thermisto*) across the study area based on collections from vertical plankton tows. These isotopic ratios reflect their roles as primary consumers (see Fig. 3.1.11). Depth contours are labeled in meters.

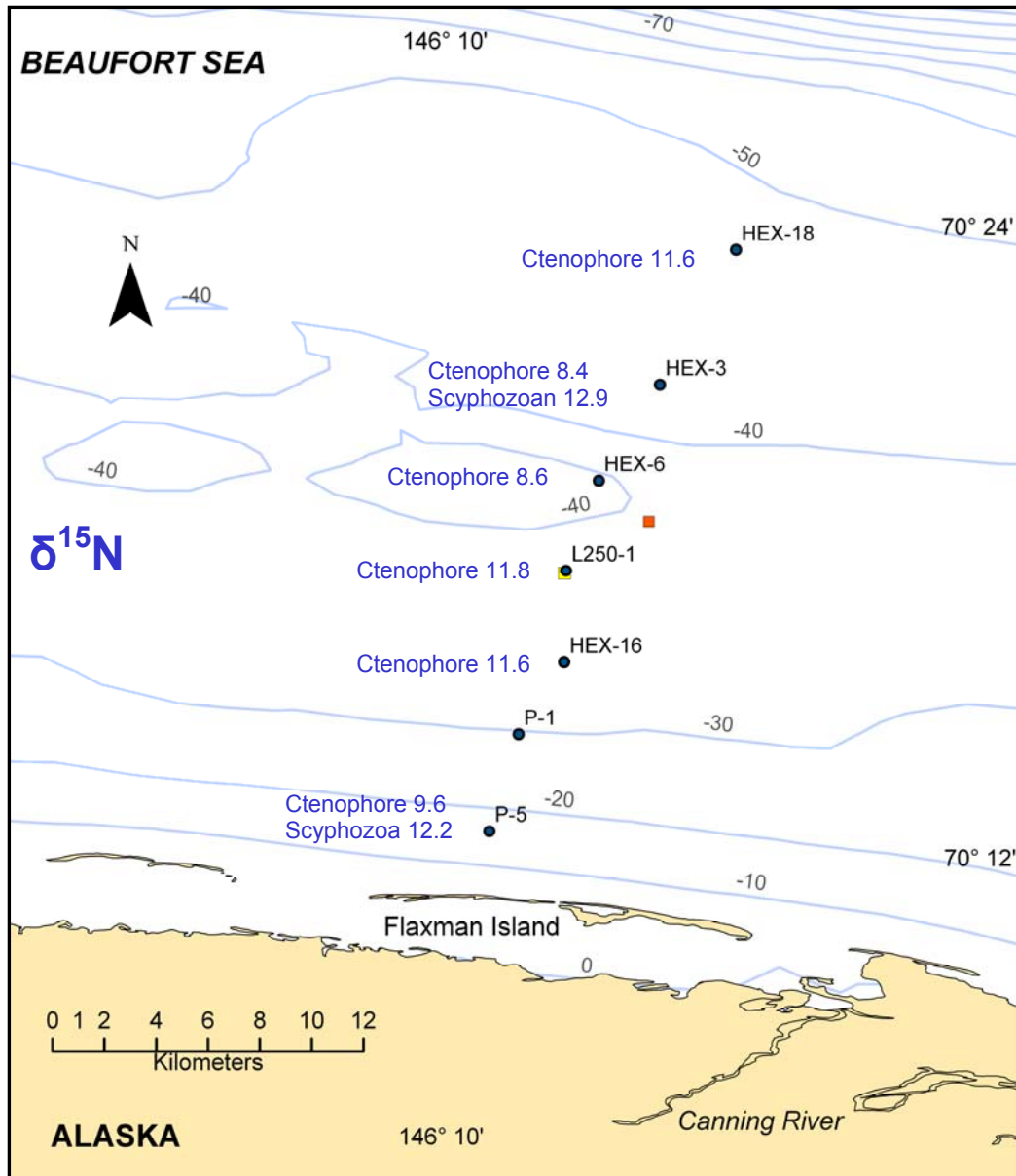


Figure 3.2.6 Stable nitrogen isotopic values of gelatinous zooplankton across the study area based on collections from vertical plankton tows. The values are generally similar is to that reported in Fig. 3.2.5. Depth contours are labeled in meters.

3.2.3 POM vertical profiles - $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

Stable carbon isotopic composition of POM (Fig. 3.2.7) ranged from -22 to -26‰ and strongly reflected the highly depleted ^{13}C signatures of zooplankton reported earlier (Fig. 3.2.3 and 3.2.4). Vertical profiles showed that offshore waters were relatively well mixed with respect to chlorophyll, but $\delta^{13}\text{C}$ values were generally greater at depth. This was especially apparent at inshore sites (P-1, P-5), where $\delta^{13}\text{C}$ values increased dramatically from the surface (-27‰) to the bottom (-22‰). The higher values near the bottom may be related to the resuspension of benthic microalgae and sediments that are ^{13}C enriched as noted earlier (Fig. 3.0.1), especially at the inshore sites where sediment chlorophyll levels were highest in the entire study area. In contrast, $\delta^{15}\text{N}$ values were variable as a function of depth, ranging from 2.5 to 6.5‰, but within the range of one trophic level (3‰) of herbivorous zooplankton and benthic filter feeders.

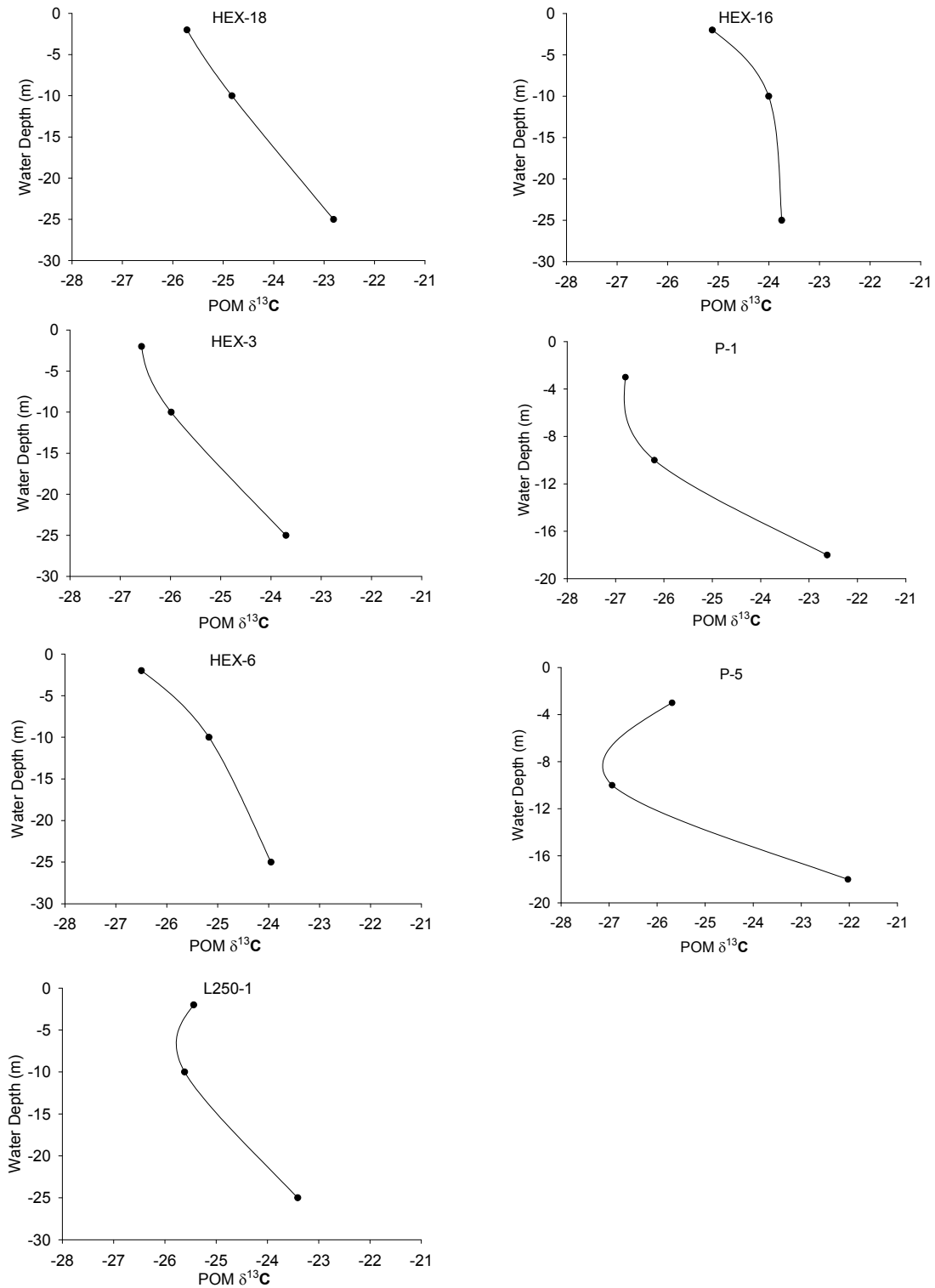


Figure 3.2.7 Vertical profiles of the stable carbon isotopic composition of POM at seven Sivulliq sites. The increase in $\delta^{13}\text{C}$ values with depth correlates with higher chlorophyll levels, particularly at Pipeline stations P-1 and P-5 (see Fig. 3.2.1).

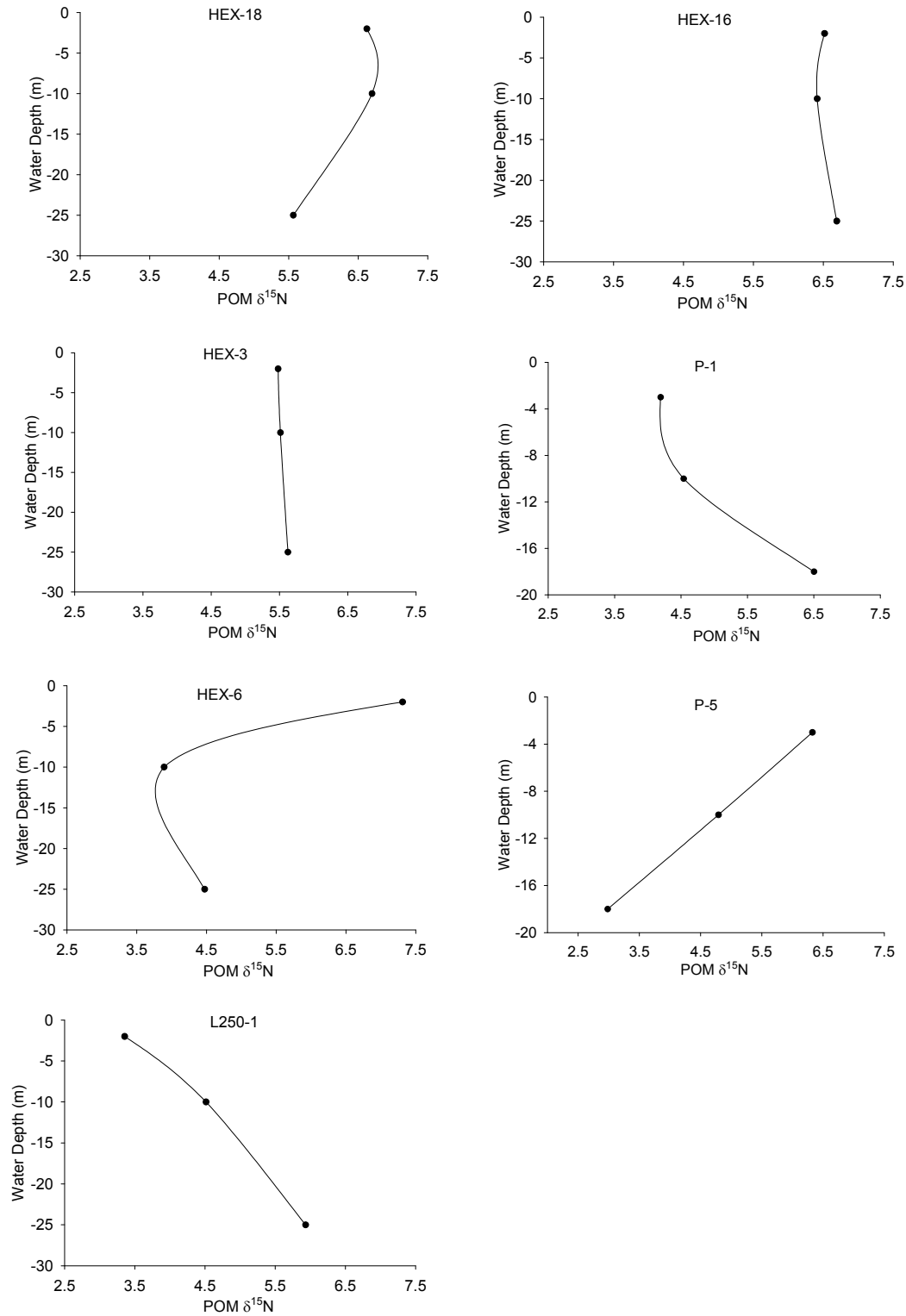


Figure 3.2.8 Vertical profiles of the stable nitrogen isotopic composition of POM at seven Sivulliq sites.

3.2.4 Nutrients (NH_4^+ , SiO_4 , PO_4^{3-} , $\text{NO}_2^- + \text{NO}_3^-$)

Concentrations of inorganic nutrients, especially the undetectable or extremely low levels for nitrate + nitrite and ammonium, strongly reflect the oligotrophic character of the Beaufort Sea in late summer (Table 3.2.4). Such N-limitation clearly explains the low chlorophyll concentrations observed throughout the study area (Fig. 3.2.1) and reveals the importance of nutrient regeneration in the sediments as reflected in pore water ammonium concentrations (Fig. 3.0.4).

Table 3.2.4 Concentrations (μM) of the major autotrophic inorganic nutrients collected at three sampling depths at eight stations in the study area.

Station	Sample Depth (m)	NH_4^+	SiO_4	PO_4^{3-}	$\text{NO}_2^- + \text{NO}_3^-$
HEX-18	2	<0.05	5.14	0.23	0.05
HEX-18	10	0.19	5.44	0.32	<0.05
HEX-18	25	0.24	3.14	0.30	0.05
HEX-3	2	<0.05	5.52	0.21	0.05
HEX-3	10	0.18	6.88	0.33	<0.05
HEX-3	25	<0.05	3.96	0.25	0.06
HEX-6	2	1.46	5.75	0.20	0.06
HEX-6	10	<0.05	2.84	0.29	<0.05
HEX-6	25	0.64	5.17	0.38	0.06
HEX-16	2	0.74	2.81	0.29	0.05
HEX-16	10	<0.05	3.85	0.27	<0.05
HEX-16	25	1.11	3.54	0.20	0.09
L250-1	2	0.34	3.16	0.27	0.05
L250-1	10	0.67	2.44	0.30	0.06
L250-1	25	<0.05	3.81	0.24	<0.05
HEX-19	2	0.42	5.81	0.25	0.05
HEX-19	10	0.07	3.07	0.32	0.05
HEX-19	25	<0.05	3.09	0.29	0.05

Station	Sample Depth (m)	NH ₄ ⁺	SiO ₄	PO ₄ ³⁻	NO ₂ ⁻ + NO ₃ ⁻
P-1	3	<0.05	4.16	0.27	<0.05
P-1	10	0.09	3.50	0.28	<0.05
P-1	12	0.62	3.40	0.31	<0.05
P-5	3	<0.05	3.63	0.24	0.05
P-5	10	0.30	3.73	0.29	0.07
P-5	12	1.53	2.73	0.30	0.06

SUMMARY

Our biological studies in the Sivulliq study area have clearly added a considerable amount of new information to our existing knowledge of the mid-shelf region of the Alaskan Beaufort Sea. Until now, very little information on the benthic food web structure has been available for this region. Isotopic data show that carbon derived from marine sources, not terrestrial, are most important to benthic consumers. We found that the benthos is fairly well coupled to overlying water column production based on (1) stable carbon and nitrogen isotopic ratios that denote three trophic levels and (2) much higher indices of biomass than predicted from historical studies. In contrast to the mid-shelf region, Pipeline stations on the inner shelf revealed that benthic microalgae may provide an additional carbon source to benthic consumers. Finally, comparison of community structure among the 45 stations revealed that the large spatial variability in benthic infaunal biomass, abundance, and species diversity at four of the five Pipeline stations likely reflect (1) the occurrence of a variable substrate, including scattered pebbles and cobbles, on the seabed, and (2) the predominance of extreme disruptive processes of ice scour at the shallower depths characteristic of this more inshore region, where massive ice ridges form as fast ice collides with floating pack ice.

ACKNOWLEDGEMENTS

We thank Captain Al and the crew of the *R.V. Arctic Seal* along with R. Thomason for providing a safe working platform for our oceanographic work, despite numerous logistic challenges. We are also very grateful to K. Borows and the Shell logistics staff in Deadhorse for facilitating the mobilization and demobilization of our field operations. The field component of this work would not have been possible without the collaboration and close friendship of our colleagues J. Trefry and R. Trocine at FIT. Finally, a special thanks to the science team at Shell, particularly M. Macrander, I. Voparil and E. Westlien, with whom we've developed a close relationship as we've worked together to overcome numerous challenges over two field seasons and great distances to make this project both a reality and a success.

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APPENDIX

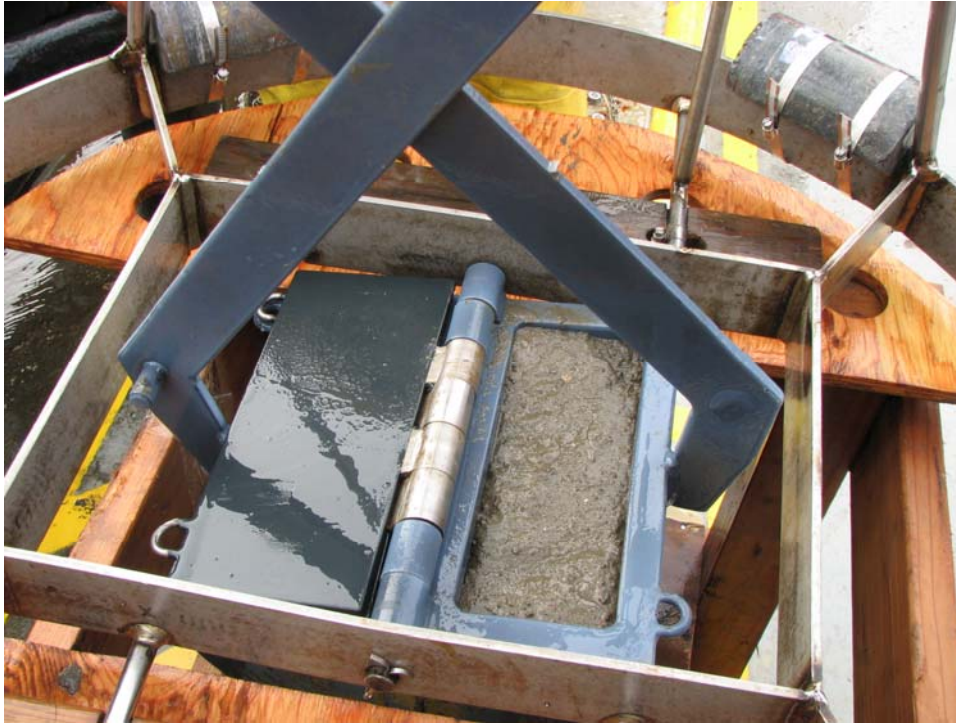


Figure A1. A sample of undisturbed seafloor sediments collected using a van Veen grab. The sample was sieved and sorted for infauna (see below).



Figure A2. Organisms sieved from sediments collected using a van Veen grab. This sample primarily contained different types of polychaete worms.