2008 Environmental Studies Program in the Chukchi Sea:

Benthic Ecology of the Burger and Klondike Survey areas

Annual Report

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ConocoPhillips Alaska, Inc. and Shell Exploration & Production Company

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EXECUTIVE SUMMARY

ConocoPhillips Alaska, Inc. is managing an environmental studies program to establish baseline conditions for two survey areas in the northeastern Chukchi Sea in association with Shell Exploration and Production Company. The study sites are the Klondike and Burger survey areas where successful lease bids were made in the February 2008 Chukchi Sea Lease Sale 193. The field program will provide information on physical, chemical, biological (zooplankton and benthic ecology), and oceanographic baseline trends for the Klondike and Burger survey areas.

The objectives of the Benthic Ecology component of the 2008 Environmental Studies Program in the Chukchi Sea were to document benthic macrofaunal community structure within the Burger and Klondike survey areas and determine associations of community structures with environmental factors. Macrofauna and environmental parameters were sampled at 65 stations in the Burger (34 stations) and Klondike (31 stations) survey areas. Five locations in each survey area were sampled surrounding historic drill sites (a single drill site located in each survey area and drilled in 1989). This report summarizes the results of the Benthic Ecology portion of the 2008 Chukchi Sea Environmental Baseline Studies Program.

The benthic fauna in the Burger and Klondike survey areas reflect robust and diverse communities. Average abundance, biomass, and number of taxa (average of the number of taxa found at each station) were significantly higher at Burger than at Klondike but macrofaunal communities in both survey areas were robust. Most fauna occurred in both survey areas with faunal distributions more regular at Burger than at Klondike. Multivariate analyses indicated that macrofaunal community structure was correlated with environmental characteristics (water depth and percent sand) associated with topography, water currents, and other site-related factors. Burrowing activities of deep deposit-feeding organisms and bioturbation by macrofauna, fishes, and marine mammals may be critical factors for community structure as well.

Basin-scale environmental influences are important in the composition of faunal communities in the northeastern Chukchi Sea. The transport of warmer, nutrient-rich water from the Bering Sea greatly influences the ecological balance of the Chukchi Sea in a number of ways. Larvae of North Pacific macrofauna are transported to the Chukchi Sea resulting in a high similarity in the composition of fauna within the Bering and Chukchi Seas. The nutrient-rich water advected into the study area contributes to the high primary production for this marginal Arctic sea and the flux of unconsumed production to the benthos supports the rich macrofaunal assemblages found in the study area (Grebmeier et al., 2006). Pacific walrus and bearded seals feed on numerous species of macrofauna that were found in the Burger and Klondike survey areas (Lowry et al., 1980; Fay, 1982; Nelson et al., 1994). Benthic fishes also feed on macrofauna in the northeastern Chukchi Sea but the contributions of macrofauna to fish diets are not well known. The 2009 Chukchi Sea Environmental Studies Program, however, will evaluate the diet of benthic fishes to better understand the links between macrofauna and benthic fishes in the survey areas.

The macrofaunal communities sampled at the Burger and Klondike survey areas were similar in species to those described in earlier studies. Investigations in 1971-1974 and 1986 demonstrated a rich benthos dominated by similar species as those found in 2008. Thus, there appears to be limited temporal change in the macrofaunal community composition between studies.

INTRODUCTION

Concern for the Arctic environment is growing and efforts continue to be directed towards understanding the environment including the Chukchi Sea (Hopcroft et al., 2006). Resources in the Chukchi Sea are of great value to a broad variety of stakeholders including Native subsistence hunters, environmental organizations, and those interested in extracting resources of economic value. In the Chukchi Sea, biological resources of interest include marine mammals and seabirds, many of which feed on sediment-dwelling organisms (benthic species such as polychaete worms, amphipods, clams, shrimp, crabs) (Lovvorn et al., 2003; Grebmeier et al., 2006). Benthic organisms in the northern Bering Sea and Chukchi Seas are important food resources for higher trophic level organisms such as bottom fishes, bearded seals, walrus, and gray whales (e.g. Oliver et al., 1983; Feder et al., 1994a, b; Coyle et al., 1997; Green and Mitchell, 1997; Moore et al., 2003; Highsmith et al., 2006; Bluhm et al., 2007; Bluhm and Gradinger, 2008). Traditional feeding hot spots for gray whales and walrus are located south of St. Lawrence Island and the Chirikov Basin (both in the Bering Sea), and the south-central Chukchi Sea with a few areas identified in the northeastern Chukchi Sea (Moore and Clarke, 1990; Feder et al 1994b; Highsmith et al., 2006; Bluhm and Gradinger, 2008).

The northeastern Chukchi Sea is a productive shallow sea influenced by advective processes (Grebmeier et al., 2006). Water moving into the region includes Bering Shelf water and Alaska Coastal water (e.g., Coachman, 1987). Bering Shelf water has relatively high nutrient concentrations (derived in part from water from the Gulf of Anadyr off Russia) that enhance benthic biomass whereas the Alaska Coastal water along the Alaska coast is comparatively nutrient poor (Feder et al., 1994b; Codispoti et al., 2005; Grebmeier et al., 2006). The differences in nutrient concentrations in water masses lead to substantial differences in primary production, and thus, benthic community structure (Feder et al., 1994b) and food web structure. Factors identified as important predictors of benthic community structure in the Chukchi Sea include sediment granulometry and sediment organic carbon to nitrogen ratios (C/N ratio) (Feder et al., 1994b). Sediment granulometry (e.g., percent gravel, sand, or mud) reflects a number of environmental processes, such as hydrodynamics (strong currents, storms, ice gouging, etc.), sediment deposition, and proximity to sediment sources. The C/N ratio in sediments reflects availability of particulate organic carbon to benthic animals. A low C/N value is of particularly high nutrient value when derived from phytoplankton as opposed to terrigenous carbon where the C/N ratio is high.

Scientific studies conducted over the last 36 years provide a basis for understanding the benthic ecology of the NE Chukchi Sea. The first study of macrofaunal community structure in the northeast Chukchi Sea was performed in 1971 to 1974 by Stoker (1978, 1981). This study was followed in 1985 and 1986 by investigations of the benthos/environmental interactions by Feder et al. (1994a, b). Following the latter study, Grebmeier et al. (1988) documented the strong association between annual pelagic production reaching the bottom and the robust benthic communities (pelagic-benthic coupling) in the southeastern Chukchi Sea. The macrofauna of the Chukchi Sea is rich and biomass high due to the comparatively high quantities of unconsumed primary production (pelagic and ice-edge production) reaching the benthos (Grebmeier et al., 2006). A rich epifaunal community is also known for the northeastern and southeastern Chukchi including numerous mollusks, crabs, and echinoderms (e.g., Feder et al., 1994a, 2005; Ambrose et al., 2001). Recent and current investigations in the northeastern Chukchi Sea include the Shelf-Basin interaction study (SBI; http://sbi.utk.edu; Grebmeier et al., 2009), the Russian-American Long-term Census of the Arctic (RUSALCA), and the MMS Chukchi Sea Offshore Monitoring in Drilling Area (COMIDA) program. All of the latter programs focus on broad-scale sampling throughout the NE Chukchi Sea with SBI focusing on processes along the continental margin, RUSALCA encompassing the northern Chukchi Sea, and the COMIDA program focusing on the US offshore Lease Sale Planning area. These studies will contribute to building databases adequate for evaluating long-term trends with confidence (e.g., repeated sampling at similar locations over space and time) in macrofaunal communities of the NE Chukchi Sea. Multi-year environmental studies funded by ConocoPhillips Alaska Inc. (CPAI) and Shell Exploration and Production Company (SEPCO) within the Burger and Klondike survey areas will also provide ecological information valuable for documenting ecosystem-level baseline trends within the two survey areas.

The multi-year environmental studies initiated in 2008 funded by CPAI and SEPCO will contribute to understanding the benthic ecology within the survey areas and provide the basis for measuring the effectiveness of mitigation and monitoring activities conducted by the oil and gas industry during exploration and/or development. These studies will also provide the necessary benchmark to determine potential changes in the benthos from climate change or other natural environmental fluctuations.

OBJECTIVES

The objectives of the Benthic Ecology component of the 2008 Environmental Baseline Studies Program in the Chukchi Sea were:

- Sample the benthos within the Burger and Klondike survey areas to document benthic macrofaunal community structure;
- Sample the benthos where marine mammals were observed feeding in the area (no marine mammals were observed feeding in the survey areas in 2008); and
- Assess species composition, abundance, and biomass of macrofaunal communities within the two survey areas and determine associations of community structures with environmental factors.

METHODS

Sampling methods

Sampling for this project was performed from August 21 to September 25, 2008. Fifty-five sites were sampled in the Chukchi Sea lease sale area aboard the M/V *Bluefin* on cruise BLF0803 including three sites added due to the presence of sea ice at the Burger survey area (Table 1 and Fig. 1). Sampling included a portion of the sites from the fixed oceanographic grid and randomly selected sites. Thirteen fixed and thirteen random sites were targeted for sampling in the Klondike and Burger survey areas. Fixed locations were selected to maximize spatial coverage of sampling locations and the sites sampled included a subset of the sites for physical oceanography and zooplankton studies (Hopcroft et al., 2009; Weingartner, 2009). Random selection of additional sampling locations was also performed to match the desired range of inferences for the separate sampling program involving chemical characterization of biota and sediments to ensure that conclusions were valid over the whole of the study region. The benthic and chemical characterization programs sampled the same locations with samples collected at the same time using a double van Veen grab. Due to ice conditions in the Burger survey area, three additional stations (two extra random stations and one new station (BN001; N = new)) were added (Table 1). Five sites were also sampled surrounding the two historic (1989) drill locations, one each in the Burger and Klondike areas. Stations are labeled with a one character code for the two sites, Klondike (K) and Burger (B), a one character code for the type of site sampled as fixed (F), random (R), new (N), or historic drill site (D) and lastly, the station number.

Benthic infauna of the Chukchi Sea was sampled with a double van Veen grab with two 0.1 m^2 grabs to collect sediments for chemical characterization and macrofauna simultaneously. Material from each grab collected for macrofauna was washed on a 1.0 mm stainless steel screen and preserved in 10% formalin-seawater buffered with hexamine. In the laboratory, samples were rinsed and transferred to 50% isopropyl alcohol. During sorting, sediment was spread out in petri dishes, and rough sorted by hand under a dissecting microscope. Taxonomic identifications of benthic organisms were performed by trained taxonomists supervised by a taxonomic specialist. All organisms were counted and wet weights (weight after excess moisture was removed with an absorbent towel: Feder et al., 1990) measured. For each replicate sample, fragments were grouped together and recorded as one individual at the family level or higher,

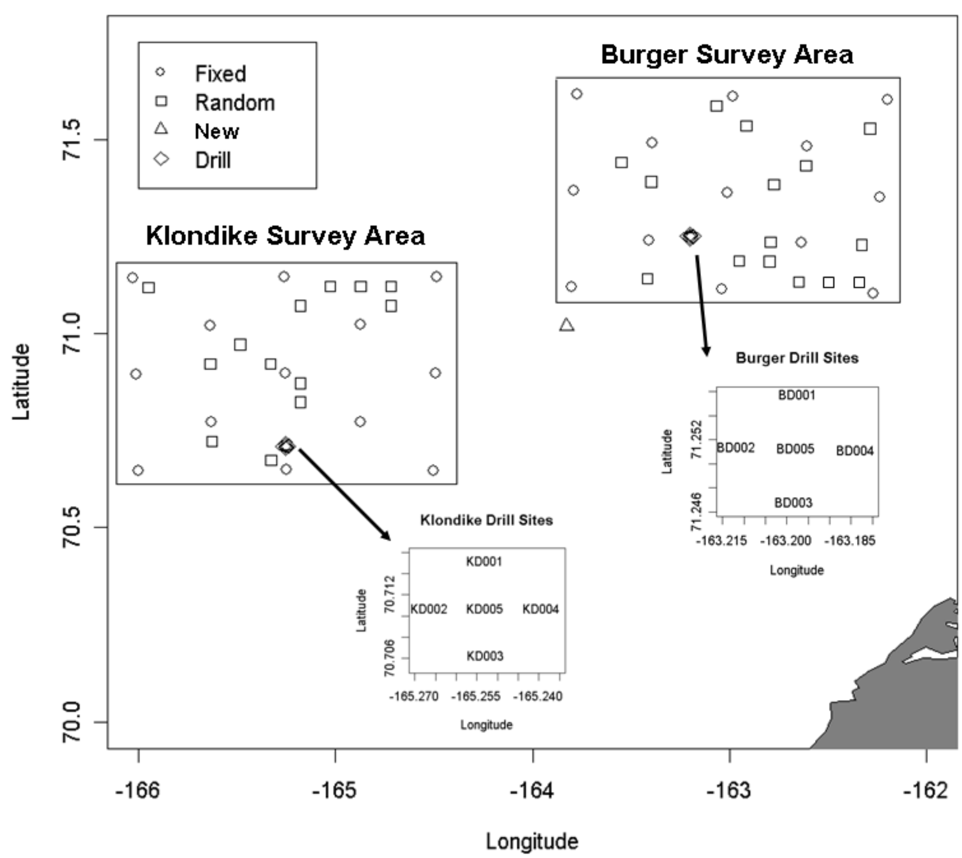

Figure 1. Map of 2008 sampling locations in the northeast Chukchi Sea at the Klondike and Burger survey areas.

Table 1. Intended positions (degree, minute format) and average sampling depths (determined from line-out indicator of the sampling winch) of sediment sampling in the Chukchi Sea, 2008. K= Klondike, B = Burger, F = fixed station, R = random station, and N = new station. Date = date of sampling, time = time of first sample, and depth = average depth of three replicates. Time = Alaskan Standard Time.

Station	Date	Time	Latitude, N	Longitude, W	Depth, m
BF001	9/16/2009	8:20	71.11987	163.80348	39.8
BF003	9/2/2009	2:56	71.11337	163.03470	42.6
BF005	9/20/2009	2:16	71.10371	162.26660	44.3
BF007	9/16/2009	2:18	71.24151	163.40892	42.2
BF009	9/20/2009	7:53	71.23337	162.63554	43.1
BF011	9/13/2009	23:28	71.36889	163.78808	42.5
BF013	9/16/2009	23:14	71.36230	163.00941	43.5
BF015	9/19/2009	8:12	71.35250	162.23145	42.5
BF017	9/12/2009	23:16	71.49048	163.38829	39.9
BF019	9/19/2009	1:15	71.48223	162.60491	41.1
BF021	9/13/2009	4:46	71.61790	163.77225	38.7
BF023	9/17/2009	23:49	71.61121	162.98343	40.1
BF025	9/18/2009	6:47	71.60127	162.19533	42.1
BN001*	9/4/2009	4:57	71.02080	163.82742	40.3
BR005	9/21/2009	1:31	71.58714	163.06481	39.4
BR016	9/18/2009	2:11	71.53570	162.91276	39.7
BR020	9/19/2009	3:32	71.52778	162.28473	42.1
BR032	9/14/2009	5:07	71.44195	163.54881	40.1
BR038	9/18/2009	21:51	71.43246	162.61110	42.2
BR043	9/14/2009	1:45	71.39089	163.39661	41.6
BR047	9/17/2009	2:47	71.38458	162.77307	44.7
BR077	9/20/2009	9:33	71.23525	162.79016	43.1
BR080	9/19/2009	21:12	71.22922	162.32640	43.2
BR086	9/1/2009	23:18	71.18722	162.95005	42.6
BR087	9/2/2009	21:44	71.18547	162.79579	43.1
BR093	9/2/2009	5:08	71.14192	163.41702	42.0
BR098	9/2/2009	23:48	71.13382	162.64757	42.2
BR099*	9/3/2009	4:46	71.13182	162.49376	42.5
BR100*	9/3/2009	2:51	71.12970	162.34000	42.7
KF001	8/21/2009	7:30	70.64598	166.00255	40.0
KF003	8/29/2009	5:11	70.64855	165.25147	39.8
KF005	8/31/2009	7:38	70.64804	164.50031	44.1
KF007	8/22/2009	4:02	70.77219	165.63094	38.5
KF009	8/24/2009	0:43	70.77323	164.87511	37.0
KF011	8/21/2009	0:40	70.89503	166.01511	39.2
KF013	8/23/2009	3:14	70.89764	165.25462	38.9

*Sites added due to the presence of sea ice at the Burger survey area during the benthic cruise.

Table 1. Continued.

Station	Date	Time	Latitude, N	Longitude, W	Depth, m
KF015	8/31/2009	3:31	70.89712	164.49405	35.6
KF017	8/30/2009	1:26	71.02126	165.63890	40.6
KF019	8/28/2009	6:28	71.02231	164.87354	32.5
KF021	8/27/2009	3:41	71.14407	166.02801	40.5
KF023	8/27/2009	10:11	71.14672	165.25786	41.6
KF025	8/27/2009	23:39	71.14619	164.48762	40.1
KR001	8/26/2009	23:30	71.11958	165.94980	40.3
KR007	8/30/2009	6:44	71.12199	165.02675	41.8
KR008	8/30/2009	8:14	71.12194	164.87290	38.6
KR009	8/30/2009	21:22	71.12178	164.71904	38.8
KR016	8/30/2009	5:07	71.07208	165.18015	40.0
KR019	8/30/2009	23:03	71.07196	164.71975	40.9
KR034	8/23/2009	6:01	70.97191	165.48461	39.4
KR043	8/22/2009	7:57	70.92163	165.63569	39.7
KR045	8/23/2009	4:31	70.92243	165.33109	39.0
KR056	8/23/2009	0:04	70.87282	165.17834	38.6
KR066	8/22/2009	22:32	70.82300	165.17790	39.2
KR083	8/22/2009	0:19	70.72238	165.62937	39.4
KR095	8/29/2009	1:50	70.67334	165.32699	40.4
Drill Sites					
BD001	9/21/2008	5:19	71.255292	–163.197561	43.2
BD002	9/15/2008	22:54	71.250944	–163.211907	43.5
BD003	9/21/2008	6:38	71.246330	–163.198391	42.9
BD004	9/21/2008	8:13	71.250677	–163.184046	42.9
BD005	9/15/2008	21:49	71.250811	–163.197976	43.0
KD001	9/01/2008	0:14	70.714725	–165.253089	40.0
KD002	9/01/2008	1:29	70.710223	–165.266593	40.2
KD003	9/01/2008	6:14	70.705759	–165.252975	39.9
KD004	9/01/2008	4:23	70.710260	–165.239471	40.0
KD005	9/01/2008	3:00	70.710242	–165.253032	40.0

and the wet weight of the composite fragment category weighed. Once weighed, organisms were placed into sealed plastic jars for storage. (Jar edges are wrapped with Teflon tape before screwing the lid on to reduce moisture loss during storage.) Organism names, counts, and weights were entered into a MS Access database and a datasheet printed. Datasheets are stored at IMS as a record of taxonomic changes and a backup for the electronic database.

Representative specimens of each taxon encountered in the 2008 Chukchi samples were archived at the Institute of Marine Science (IMS), University of Alaska Fairbanks. These voucher specimens provide records of identification of individual organisms encountered in the study. While archived specimens may be sent to experts for further identifications, a complete collection of fauna will be maintained at the IMS laboratory.

The following quality control procedures were followed in processing samples. The work of sorters was monitored throughout the project by a trained taxonomist. Once fully trained, a minimum of 10% of samples sorted by student employees were re-sorted to be certain that greater than 95% of the organisms in each sample were removed. One hundred percent of the work performed by junior taxonomists was checked and verified by a senior taxonomist with verification tapering off as they approach the skill level expected for a senior taxonomist. Work was verified to ensure that all counts are accurate and all organisms are correctly identified. Fauna identified in the 2008 study were compared to the voucher collection from the 1986 investigation of Feder et al. (1994b) and to current references (e.g., other benthic programs) to ensure accuracy, consistency between studies, and to the best of our abilities, consistency with current taxonomic status. After one year from the data of collection, the sorted debris (considered nonhazardous after rinsing and removal of biological tissues) will be discarded following protocols determined by UAF Risk Management. Original data forms and MS Access databases will be archived at IMS and delivered to ConocoPhillips Alaska, Inc. in accordance with prescribed data management protocols.

Sediment samples were collected from each station with the van Veen grab. The samples were wet sieved through 2 mm and 63 µm nested sieves to determine the weight of gravel (>2 mm) and sand (63 µm – 2 mm) (Wentworth, 1922). Additionally, the flow-through water containing suspended particles <63 µm was captured to determine the weight of mud (<63 mm). The resulting fractions were dried at 60°C for a minimum of 12 and up to 24 hours to determine dry weight. Water content of the entire sediment sample was determined by weighing a wet subsample, drying at 60°C for a minimum of 12 hours then reweighing.

Surface sediment samples were also collected from van Veen grabs to determine chlorophyll-*a* and phaeopigment concentrations. Sediment samples for chlorophyll analysis were kept frozen and in the dark until processing, at which time the sediment samples were thawed and chlorophyll extracted in 7 ml 90% acetone for 24 hours in the freezer. The extracts were allowed to come to room temperature in the dark and centrifuged for 5 minutes at 4000 rpm. Chlorophyll-*a* concentrations were determined using a Turner Trilogy fluorometer. Phaeopigment (the degradation product of algal chlorophyll pigment) concentrations were determined by adding 10% HCl to each sample and re-measuring fluorescence (Arar and Collins, 1992). Percent phaeopigment can be calculated by dividing average phaeopigment concentrations by the amount of total pigments, which is the sum of the average chlorophyll-*a* and average phaeopigment. Chlorophyll-*a* and phaeopigment concentrations were highly correlated so phaeopigments (reflecting detritus and decomposition products) were used to assess associations of faunal community structure to primary production in multivariate analyses.

Statistical Methods

Data were summarized using a variety of descriptive methods. Average abundance and biomass (wet weight), average and total number of taxa, and diversity values were calculated for each station. Multivariate statistical methods were applied to a Bray-Curtis similarity matrix calculated from species abundance values. Data are maintained and processed on a PC computer at the Institute of Marine Science (IMS), School of Fisheries and Ocean Sciences, University of Alaska Fairbanks.

Prior to analysis of multi-year data sets, taxonomic information was scrutinized for consistency. Pelagic, meiofaunal, and epibenthic taxa [i.e., tanaidaceans, benthic copepods, brittle stars, sea stars, crabs, etc.] were excluded from analytical data sets. Fragments and taxa identified at family level or above were included in abundance and biomass calculations and diversity indices but excluded from multivariate analyses.

Species diversity is a measurable attribute of an assemblage of taxa. It consists of two components: number of taxa or "taxon richness" and relative abundance of each taxa or "evenness." Four indices were calculated: Simpson dominance (Simpson, 1949; Odum, 1975), Shannon diversity (Shannon and Weaver, 1963), taxon richness (Margalef, 1958), and Whittaker's β diversity (Magurran, 2004).

The Simpson dominance index (Simpson, 1949; Odum, 1975) was calculated as:

$$S = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

where n_i = number of individuals of species $i_1, i_2, i_3 \ldots i_x$ and

N = total number of individuals.

As the Simpson dominance index increases, diversity decreases representing increasing dominance of the community by a few individual taxon categories (Magurran, 2004).

The Shannon diversity function was calculated as:

$$H' = -_i\sum p_i \log p_i$$

where $p_i = n_i/N$,

n_i = number of individuals of the ith species, and

N = total number.

The Shannon diversity function assumes that a random sample has been taken from an infinitely large population. Shannon diversity increases with greater numbers of taxon categories containing moderate to many individuals.

Taxon richness (Margalef, 1958) was calculated as:

$$TR = \frac{(T - 1)}{lnN}$$

where T = the number of taxa and

N = the total number of individuals.

Since some taxon levels higher than species were used for the calculation of richness in this study, this measure was always referred to as taxon richness in this report. Richness generally increases as the number of taxa increases.

Whittaker's β diversity (Magurran, 2004) was calculated as:

$$\beta = \frac{S}{\overline{\alpha}}$$

where S = the total number of taxa identified for the sites and

$\overline{\alpha}$ = the average number of taxa identified for each station.

β reflects the spatial change in faunal assemblages or replacement of species among stations. The maximum value possible is the number of sites used to calculate $\overline{\alpha}$. This measure is also commonly called turnover diversity as it reflects how species are replaced among stations and along gradients. Values close to 1 indicate little taxa replacement while values close to the maximum (sample size) reflect nearly complete replacement. When comparing two sites, β ranges from 1 to 2 with values near 1 indicating nearly total overlap of species and values near 2 indicating none or few species in common. When considering multiple sites, β may range from 1 to the number of sites (n, the maximum value possible). In the latter case, values near the maximum value of n indicate none or few species in common.

Analysis of ecological community data often begins with a multivariate analysis to determine the similarity among stations and species assemblages. Faunal community structure is then interpreted from the similarities among stations in the resulting plots and listing of the dominant organisms in each multivariate group. These procedures consist of four steps:

1. Calculation of a measure of similarity between entities to be classified.
2. Sorting through a matrix of similarity coefficients to arrange the entities in a hierarchy or dendrogram (for cluster analysis) or in a two-dimensional plot (ordination).
3. Recognition of classes within the hierarchy or plot based on the agreement of multiple multivariate procedures.
4. Determination of the dominant species assemblages comprising each station group.

Similarity of stations is determined by their closeness in the cluster dendrogram or ordination. This approach is called an indirect gradient analysis since environmental variables are not directly included in these relationships but are inferred from patterns in the plotted results. Indirect gradient analysis is useful for detecting patterns in overall community structure and similarities between species assemblages.

Cluster analysis and an ordination procedure (where new "axes" that summarize community structure are derived and can be plotted) were used for indirect gradient analysis of the 2008 benthic data from the Chukchi Sea. Data reduction prior to calculation of similarity coefficients consists of elimination of taxa that could not be identified at least to genus. Exceptions include organisms regularly identified to family level (due to taxonomic uncertainty in the genera and species) such as Cirratulidae which would be included in the multivariate analyses. The Bray-Curtis coefficient (Bray and Curtis, 1957) was used to calculate similarity matrices for cluster analysis and ordination. The Bray-Curtis coefficient is defined as:

$$S_{ij} = \left(1 - \frac{\sum_{j=1}^{n} \left| y_{ij} - y_{kj} \right|}{\sum_{j=1}^{n} \left(y_{ij} + y_{kj} \right)} \right) 100$$

where y_{ij} = the jth species of station i and y_{kj} = the jth species of station k. The Bray-Curtis coefficient is widely used in marine benthic studies. This coefficient is typically used with a square root, fourth root, or natural logarithmic transformation. In the context of multivariate analyses, transformations are made to control the influence of rare species relative to dominant species and a strong transformation such as the fourth-root or *ln*(x+1) are commonly chosen for benthic data to reduce the influence that dominant species have on the similarity coefficient (Clarke and Gorley, 2006). For the present study, the Bray-Curtis coefficient was used to calculate similarity matrices using natural logarithm-transformed abundance data [*ln*(ind. m^{-2} +1)].

Cluster analysis is useful to summarize data by sorting entities into "natural groupings" based on their attributes and results are summarized in a dendrogram (Johnson and Wichern, 1992). Similarity among station groups is inferred from a dendrogram by interpreting the joining of branches in the plot. Dendrograms were constructed using a group-average agglomerative hierarchical cluster analysis (Clifford and Stephenson, 1975). Normal cluster analysis, performed with stations as entities to be classified and species as their attributes, was utilized and the grouping of stations into patterns reflecting station similarities are interpreted as ecologically meaningful groupings.

Non-metric multidimensional scaling (nMDS: Kruskal and Wish, 1978; Clarke and Green, 1988) was used to complement the cluster analyses. Non-metric multidimensional scaling is used extensively for assessing species data from the marine environment (e.g., Gray *et al.*, 1988; Agard *et al.*, 1993; Clarke, 1993). As described by Gray *et al.* (1988) ". . . nMDS attempts to construct a 'map' of the sites in which the more similar . . . samples, . . . in terms of species abundances, are nearer to each other on the 'map'." The extent to which the relations can be adequately represented in a two-dimensional map (rather than three dimensions or higher) is summarized by a 'stress' coefficient (should be $\leq$ 0.15 for a good fit (Clarke and Ainsworth, 1993)). Non-metric multidimensional scaling is perhaps the most robust ordination technique available, using only rank order information of the form "Sample 1 is more similar to Sample 2 than it is to Sample 3." Agreement in the groupings of stations in the cluster and nMDS ordination provides evidence that the station groupings represent a reasonable summary of the multidimensional relationships of the data. Cluster analysis and nMDS were performed using the multivariate statistical analysis software PRIMER v6 (Clarke and Gorley, 2006).

The average abundance of the numerically dominant taxa was calculated for each survey area. Organisms were ranked by their abundance and biomass and the top twenty organisms listed. The program SIMPER from PRIMER (Clarke and Gorley, 2006) was also used to demonstrate taxa with the greatest contribution to community structure at each survey area based on the contribution of each taxon to the similarity coefficient used in the multivariate analyses.

To understand how benthic communities vary with respect to environmental gradients, canonical correspondence analysis (CCA) was applied to describe associations with the biotic community and environmental variables over time. CCA is one of the direct gradient analysis methods that can be used to directly evaluate relationships between environmental variables and community structure. This method uses correspondence analysis (an ordination technique based on methods for analysis of categorical data) to initially determine faunal structure but then regresses environmental variables against the results from the correspondence analysis (McCune and Grace, 2002). Thus, the CCA plot will reveal that portion of the structure of the biotic data accounted for by the environmental variables. Here, CCA was used to evaluate the faunal community structure associated with environmental variables to document and understand baseline relationships between fauna and environmental gradients. Environmental variables included in the CCA were water depth, percent sand, and percent gravel, phaeopigment concentration, and polycyclic aromatic hydrocarbon concentrations (PAH) and concentrations of heavy trace metals arsenic (As), barium (Ba), copper (Cu), mercury (Hg), and zinc (Zn). Water depth and sediment grain-size measures serve as proxies for larger environmental and oceanographic conditions, phaeopigments reflect nutrient inputs, and PAH and trace metals reflect natural, background conditions of potential stressors on fauna possibly with limited anthropogenic inputs from prior drilling activities in 1989. Data for PAH, As, Hg, and Zn (averaged for multiple laboratory and/or field replicates and cores (3 cores to 12 cm depth)) were from the chemistry composition database of the 2008 environmental baseline studies program (Battelle Memorial Institute et al., 2009). Trace metal concentration data were normalized to iron prior to analyses to remove the effects of covariance with iron variations on the metal concentrations, as performed in other investigations in the region (Naidu et al., 1997; Naidu et al., 2009). The metals used are presumed to be geochemically bound in sediment with the normalized values (the ratio of trace metals to iron: metals/Fe) reflecting baseline conditions (Naidu et al., 1997; Schiff and Weisberg, 1999). PAH data were *ln*-transformed. Highly correlated variables including percent mud, chlorophyll-a, and a number of metals were excluded to reduce the CCA environmental data set. The biotic data used was the abundance of dominant fauna (rare fauna excluded) from the Burger and Klondike survey areas. CCA was performed using the vegan library (Oksanen et al., 2007) on square-root transformed data in the statistical program R (R Core development Team, 2009). The square-root transformation was applied to reduce that effect of much higher abundances of some taxa at the Burger survey area.

Geostatistical analyses of select biological and environmental variables were presented to illustrate trends observed in the study and were performed using geoR (Cressie, 1993; Ribeiro and Diggle, 2001). Geostatistical analysis provides an effective means of demonstrating overall trends while retaining smaller-scale variability (the hotspots). The results of the geostatistical analyses were presented in contour plots (kriging plots) of predicted values.

RESULTS

Fixed and Random Sites

Macrofaunal organisms (animals living within the sediments and retained on a 1.0 mm mesh sieve) were placed into a total of 383 taxonomic categories ranging from species to phyla with 296 identifications to unique a species or genus (= genus with no identified species). Of the total number of organisms identified, 48% were polychaete worms, 19% were mollusks (clams and snails), and 30% were crustaceans (amphipods, cumaceans, and others). By region, polychaetes comprised 46% of total abundance for Burger and 54 % for Klondike. Mollusks were 17% of total abundance at Burger and 26% at Klondike. Crustaceans comprised 34% abundance at Burger and 14% at Klondike. Overall, wet weight comprised 28% polychaete biomass, 47% for mollusks, and 2% for crustaceans. Polychaetes were 18% of total biomass at Burger and 52% at Klondike. Fifty-five percent of the biomass at Burger was mollusks with 29% at Klondike. Crustaceans were 2% of the total biomass at Burger and 1% at Klondike. The listing of dominant fauna by stations (fixed and random stations) is included in Appendix I. Overall, average abundance, biomass, and the number of taxa (sample) were significantly higher ($\alpha = 0.05$) at Burger than at Klondike, as indicated by the lack of overlap in the 95% confidence intervals (Table 2). Differences in Simpson dominance, Shannon diversity, and taxon richness were small to moderate between Burger and Klondike with diversity values reflecting diverse communities in both survey areas. β diversity was relatively low, 3.4 and 4.4 for Burger and

Klondike as compared to the possible maximum values of 29 and 26 (the number of fixed and random sites sampled), respectively. The β diversity values suggested moderate replacement of taxa among stations within each site with a slightly greater rate of turnover at Klondike. Comparing between the two sites, Burger and Klondike, β diversity was 1.3 indicating that most species found in Burger were also found in Klondike although not necessarily in the same distributional patterns or abundance (Appendix II).

Environmental measures indicated little difference among sites (Table 2). Confidence intervals for chlorophyll, phaeopigment, and sediment grain-size measures overlap indicating no statistical differences ($\alpha = 0.05$). The confidence intervals for water depth do not overlap

Table 2. Descriptive measures for biotic variables, diversity indices, and environmental variables for the fixed and random stations sampled in the 2008 Chukchi Sea environmental study. The Sample # Taxon = the average number of taxonomic categories based on all station data (fixed and random) and the Total # Taxon = the number of taxonomic categories found in each sampling area. "--" = not calculated and an "*" indicates a significant difference at $\alpha = 0.05$.

	Burger			Klondike		
Variable	Average	SD	95% CI	Average	SD	95% CI
Abundance (ind. m^{-2})	3319.8	2843.0	(2044.6, 4595)	800.6	326.1	(648.2, 953.1)*
Biomass (g m^{-2})	299.7	127.6	(242.5, 356.9)	155.0	121.0	(98.4, 211.6)*
Sample # Taxon	91.5	12.4	(85.9, 97.1)	67.4	16.8	(59.5, 75.3)*
Total # Taxon	308	--	--	295	--	--
β Diversity	3.37	--	--	4.38	--	--
Simpson dominance	0.06	--	--	0.02	--	--
Shannon diversity	3.77	--	--	4.48	--	--
Taxon Richness	37.87	--	--	43.98	--	--
Water Depth	41.9	1.53	(41.28, 42.44)	39.4	2.11	(38.56, 40.26)*
Chlorophyll-a (mg m^{-2})	0.028	0.010	(0.024, 0.032)	0.025	0.009	(0.022, 0.029)
Phaeopigment (mg m^{-2})	0.102	0.025	(0.093, 0.112)	0.099	0.029	(0.087, 0.111)
% H_2O Content	7.7	1.57	(7.12, 8.31)	7.6	2.22	(6.69, 8.49)
% Sand	36.9	14.62	(31.32, 42.44)	45.9	16.05	(39.37, 52.33)
% Mud	60.6	15.74	(54.65, 66.63)	48.7	18.72	(41.12, 56.24)
% Gravel	2.5	3.93	(0.99, 3.98)	5.2	15.71	(-1.18, 11.51)

indicating statistically greater depth for the Burger site. Kriging plots from geostatistical analyses indicated increasing abundance, biomass, percent mud, and water depth from the southeastern corner of Klondike to the northwest corner of Burger (Fig. 2). The significant differences in abundance, biomass, and water depth between survey areas were reflected in the spatial trends demonstrated in the kriging plots. Whereas confidence intervals for percent mud did not indicate a significant difference at the 5% level of significance, the kriging plot did demonstrate a strong spatial trend of increasing percent mud to the northeast (Burger).

Average PAH and select trace metal concentrations demonstrated similar values between the Burger and Klondike survey areas and all values were comparable to the range of concentrations for the Chukchi and Beaufort Seas (Table 3). Kriging plots of chemical and metals data indicated larger, within-survey area variability for PAH and normalized mercury and zinc concentrations with normalized copper demonstrating an increasing trend from north to south (Fig. 3). All values were below associated sediment quality guidelines (Long and Morgan, 1990; Long et al., 1995).

Table 3. Descriptive measures for PAH and select trace metals and iron concentrations for the 2008 Chukchi Sea baseline environmental studies program (Battelle Memorial Institute et al., 2009). Average values for metals from historical studies of the Chukchi Sea (Naidu et al., 1997) and Beaufort Sea (Naidu et al., 2001; Naidu et al. 2009) are included for comparison. "--" = not available. Averages are for the fixed and random stations. Data are used for canonical correspondence analysis. ERL = Effects-Range Low and ERM = Effects-Range Medium criteria (Long et al., 1995).

Variable	Burger Average	SD	Klondike Average	SD	Chukchi Sea Average	Beaufort Sea Average	ERL	ERM
PAH (ng g^{-1})	482.01	94.20	451.37	92.31	--	603.86	4,022	44,800
As (µg g^{-1})	16.57	6.48	11.88	2.70	--	16.01	8.2	70
Ba (µg g^{-1})	685.62	77.38	598.64	55.56	--	570.53	--	--
Cu (µg g^{-1})	14.57	3.13	12.04	2.65	22.00	26.64	34	270
Hg (µg g^{-1})	0.04	0.01	0.03	0.01	--	0.017	0.15	0.71
Zn (µg g^{-1})	77.06	16.29	62.17	14.19	79.00	96.49	150	410

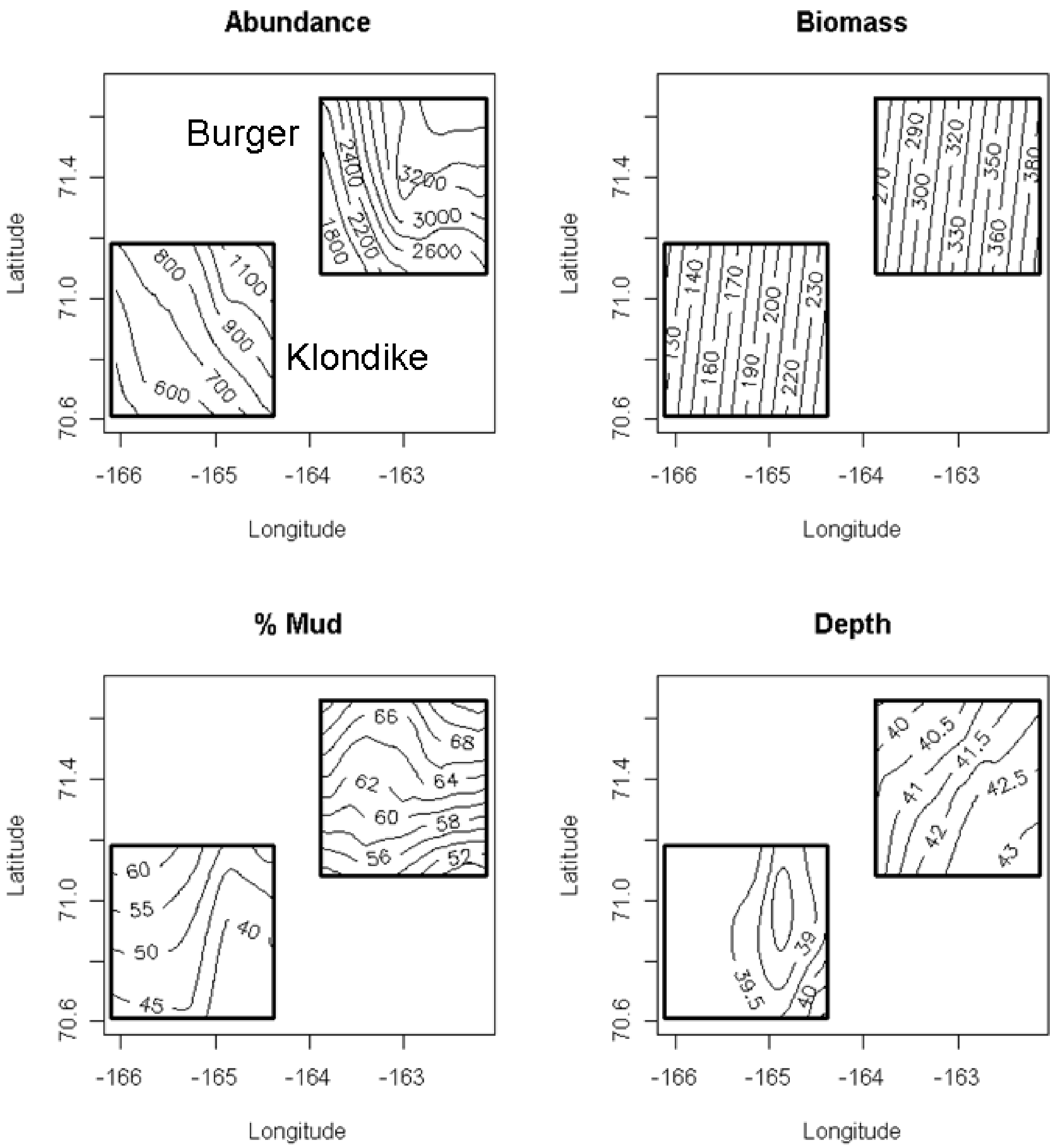

Figure 2. Kriging plots of abundance (ind. m^{-2}), biomass (g m^{-2}), percent mud, and depth (m) for the fixed and random stations from the 2008 Chukchi Sea baseline environmental studies program.

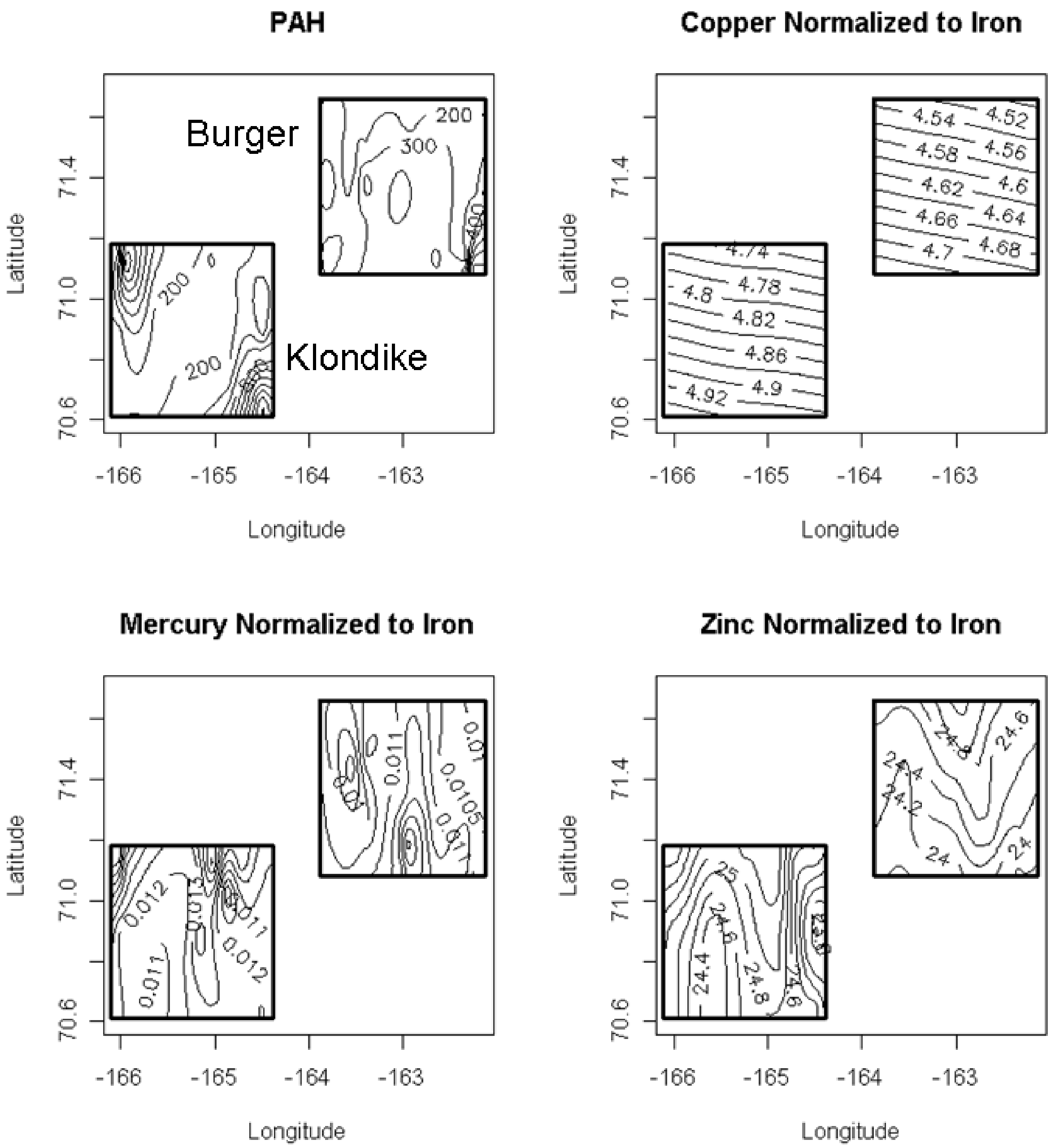

Figure 3. Kriging plots of PAH (ng g^{-1}) and normalized copper, mercury, and zinc (µg g^{-1}) for the 2008 Chukchi Sea environmental study.

Multivariate analysis of the macrofaunal abundance data indicated separate communities between Burger and Klondike survey areas. The cluster analysis and nMDS ordination largely separated Burger and Klondike stations into two groups with little mixing of stations (Figs. 4 and 5). The variability of the benthic communities was reflected in the low similarities of stations in the cluster analysis and scattering of Klondike station in the nMDS ordination. In the cluster analysis, the Burger stations were grouped together at approximately 55% similarity. Six Klondike stations join the Burger station group at about 45% similarity while the other Klondike stations group together at about 30% similarity (with the exception of KF021 which appears separate) suggesting greater variability of the benthic community at the Klondike survey area. The fauna contributing to the separation of multivariate groupings can be identified using SIMPER, an analytical routine in the PRIMER package (Table 4). This analytical routine determines the contribution of each taxa to the within group similarity and between group dissimilarity. SIMPER results mirrored the abundance rankings for each site (Tables 4 and 5). The five taxa contributing to within site similarity for Burger by abundance include the seed shrimp Ostracoda, smooth nutclam *Ennucula tenuis*, polychaete worm *Leitoscoloplos pugettensis*, lumbrinerid thread worm *Lumbrineris* spp. and marine scud (amphipoda) *Paraphoxus* spp., all which were in the top 10 most abundant species at Burger (Tables 4 and 5). For Klondike, the five taxa contributing most to within site similarity were *Ennucula tenuis*, spaghetti worms of the family Cirratulidae, the bamboo worms Maldanidae and *Maldane glebifex*, and polychaete worm *Sternaspis fossor* which, with the exception of Maldanidae, were listed as numerical dominants in the taxa ranking for Klondike (Tables 4 and 5). Taxa contributing most to the dissimilarity between the Burger and Klondike survey areas were *Lumbrineris* spp., *Leitoscoloplos pugettensis*, Ostracoda, *Paraphoxus* spp., and the hooded shrimp (cumacean) *Brachydiastylis resima.* All of the latter taxa were very abundant at Burger but occurred in much lower abundance at Klondike (Tables 4 and 5).

By biomass, the dominant taxa at Burger included the northern astarte clam *Astarte borealis*, *Ennucula tenuis*, chalky Macoma clam *Macoma calcarea*, the peanut worm *Golfingia margaritacea*, and *Maldane glebiflex* (Table 5). For Klondike, the top-ranked taxa by biomass included the bivalves *Astarte borealis*, *Macoma calcarea*, and the rayed nutclam *Nuculana radiata*, *Golfingia margaritacea*, and the bamboo worm *Axiothella catenata* (Family Maldanidae). Biomass values for Klondike were generally lower than at Burger.

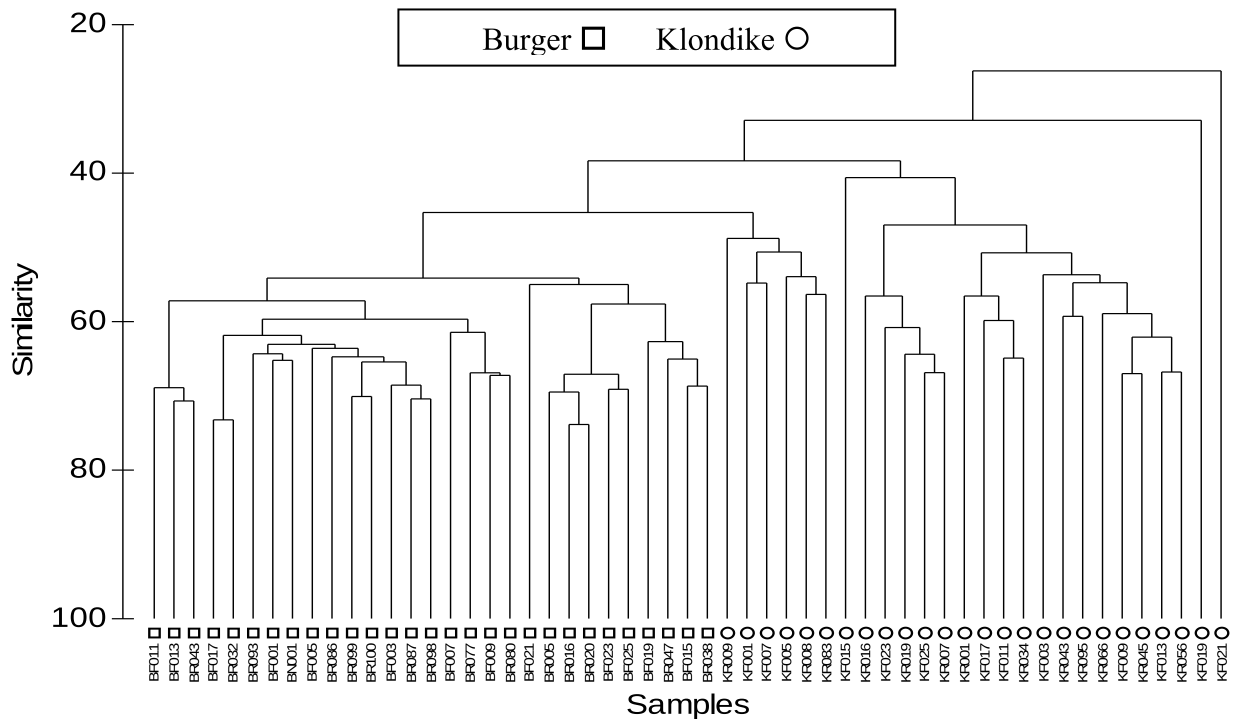

Figure 4. Cluster analysis of Bray-Curtis similarities based on *ln*(x+1)-transformed benthic abundance data from the Chukchi Sea, 2008. Fixed and random sites are included here.

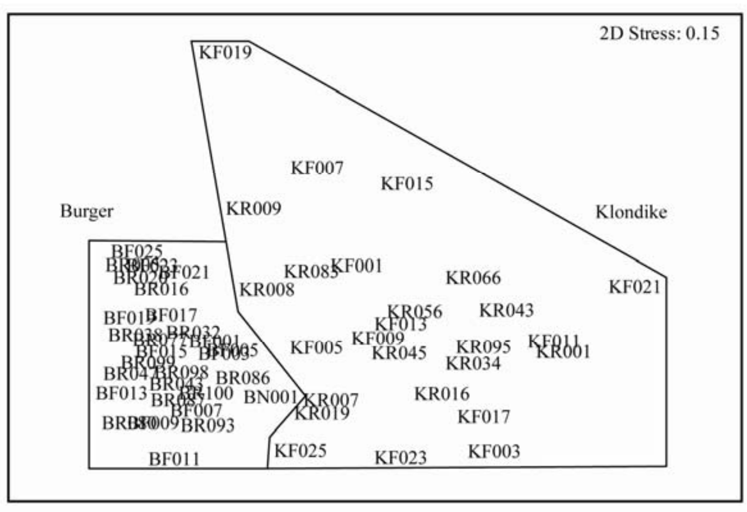

Figure 5. Nonmetric multidimensional scaling ordination plot of Bray-Curtis similarities based on *ln*(x+1)-transformed benthic abundance data from the Chukchi Sea, 2008. Fixed and random sites are included here.

Table 4. The five taxa contributing most to within station similarity (Sim) and between station dissimilarity (Diss). ln Abund = average *ln*(abundance+1), Sim = average similarity, Diss = average dissimilarity, % Contr = % contribution to (dis)similarity, and Cum. % = cumulative percent contribution. Stations for each site are those included in the nMDS ordination plot including fixed and random sampling locations.

Burger: Average similarity: 52.59

Taxon	ln Abund	Sim	% Contr.	Cum. %
Ennucula tenuis	4.93	2.67	5.07	5.07
Lumbrineris spp.	5.00	2.62	4.98	10.05
Leitoscoloplos pugettensis	4.30	2.2	4.17	14.22
Paraphoxus spp.	4.40	2.14	4.07	18.29
Ostracoda	4.25	1.77	3.36	21.65

Klondike: Average similarity: 42.66

Taxon	ln Abund	Sim	% Contr.	Cum. %
Ennucula tenuis	4.13	3.72	8.72	8.72
Cirratulidae	3.41	2.86	6.7	15.42
Maldane glebifex	3.38	2.34	5.5	20.91
Maldanidae	2.49	2.23	5.22	26.14
Sternaspis fossor	2.69	2.13	4.99	31.13

Burger & Klondike: Average dissimilarity = 64.63

Taxon	Burger ln Abund	Klondike ln Abund	Diss	% Contr.	Cum. %
Lumbrineris spp.	5.00	1.43	1.34	2.07	2.07
Ostracoda	4.25	1.14	1.31	2.03	4.1
Paraphoxus spp.	4.40	1.01	1.28	1.98	6.09
Leitoscoloplos pugettensis	4.30	1.37	1.12	1.73	7.82
Brachydiastylis resima	3.25	0.42	1.1	1.71	9.53

Table 5. Rank abundance (ind. m^{-2}) and rank wet biomass (g m^{-2}) of dominant taxa (first 20) by region.

Region	Taxon	Abundance	Taxon	Biomass
Burger	*Maldane glebifex*	583	*Astarte borealis*	53.9
	Ostracoda	294	*Golfingia margaritacea*	35.9
	Lumbrineris spp.	194	*Macoma calcarea*	29.5
	Maldane spp.	189	*Ennucula tenuis*	27.8
	Ennucula tenuis	182	*Maldane glebifex*	21.5
	Paraphoxus spp.	145	*Astarte montagui*	21.3
	Photis spp.	123	*Cyclocardia crebricostata*	12.4
	Leitoscoloplos pugettensis	105	*Macoma moesta*	5.8
	Brachydiastylis resima	76	*Axiothella catenata*	5.3
	Maldanidae	75	*Maldane* spp.	5.3
	Pontoporeia femorata	66	*Onuphis parva*	4.2
	Byblis sp.	64	*Lumbrineris* spp.	4.0
	Myriochele heeri	56	Maldanidae	3.7
	Cirratulidae	47	*Yoldia myalis*	3.5
	Ampharetidae	43	*Priapulus caudatus*	3.2
	Onuphis parva	43	*Ampelisca eschrichti*	3.0
	Prionospio steenstrupi	32	*Golfingia vulgaris*	2.9
	Barantolla americana	31	*Terebellides stroemi*	2.9
	Terebellides stroemi	31	*Liocyma fluctuosa*	2.6
	Macoma spp.	30	*Lumbrineris fragilis*	2.5
Klondike	*Ennucula tenuis*	68	*Golfingia margaritacea*	13.5
	Maldane glebifex	56	*Nuculana radiata*	9.3
	Barantolla americana	44	*Astarte borealis*	8.5
	Cirratulidae	42	*Macoma calcarea*	8.1
	Praxillella praetermissa	22	*Axiothella catenata*	5.5
	Sternaspis fossor	22	*Nephtys punctata*	4.6
	Leucon nasica	20	*Ennucula tenuis*	4.5
	Capitellidae	15	*Astarte montagui*	3.3
	Maldane spp.	15	*Maldane* spp.	2.6
	Thyasira flexuosa	14	Terebellidae	2.5
	Nephtys punctata	14	*Periploma aleuticum*	2.4
	Terebellidae	14	*Cyclocardia crebricostata*	2.0
	Leitoscoloplos pugettensis	13	*Sternaspis fossor*	1.8
	Nuculana radiata	13	*Liocyma fluctuosa*	1.8
	Lumbrineris spp.	10	Maldanidae	1.7
	Arcteobia anticostiensis	10	Rhynchocoela	1.6
	Spirorbis sp.	9	*Nicomache lumbricalis*	1.5
	Bivalvia	9	*Praxillella gracilis*	1.5
	Paraphoxus spp.	9	*Macoma moesta*	1.4
	Rhynchocoela	7	*Praxillella praetermissa*	1.4

Overlays of select species and families on the nMDS ordination plot highlight the distributions of organisms within survey areas as they relate to the ordination. The abundance overlays of the polychaetes *Lumbrineris* spp. and family Cirratulidae, the crustacean Ostracoda, and the bivalves *Astarte montagui* and *Ennucula tenuis* on the nMDS ordination reflected the trend of higher abundance at Burger stations positioned in the lower left corner (Fig. 6 and Appendix 1). The abundance of the polychaetes *Magelona longicornis* and *Sternaspis fossor*

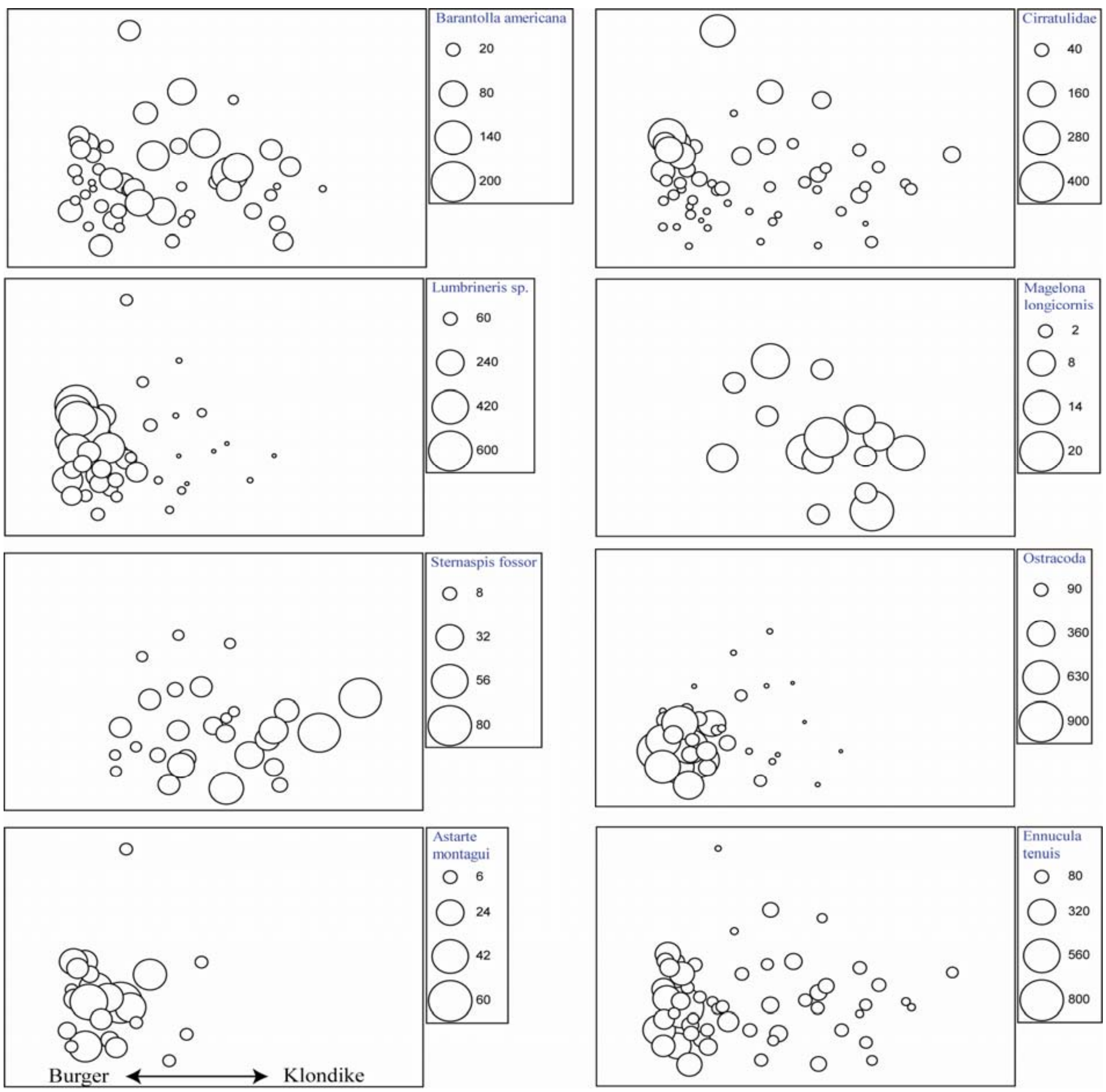

Figure 6. Overlays of family and species abundance (ind. m^{-2}) on the nMDS ordination. Bubble values reflect the relative abundance of the selected family or species.

demonstrated higher values towards Klondike to the right. Distributions of the latter two species represented a less common trend in the fauna as many of the abundant organisms occurred in greater abundance and more regularly in the Burger survey area. The polychaete worm *Barantolla americana* demonstrates a more even distribution of species across the survey areas.

Associations between macrofaunal community structure and environmental variables were demonstrated by canonical correspondence analysis (CCA). A CCA ordination presents only that portion of faunal variability associated with the environmental regressors so the presence of an environmental response by the fauna will be demonstrated by a spread of stations along the vertical and horizontal axes in the plot. The analysis of the 2008 data and plot of the first two axes from the CCA analysis indicates that faunal community structure was separated by survey area with the Burger stations located mostly in the upper right side of the plot and Klondike stations spread out towards the lower left portion of the plot (Fig. 7). The separation of stations by survey areas was similar to that demonstrated in the MDS ordination (compare Figs. 5 and 7).

Associations of environmental variables with CCA axes are demonstrated in the CCA ordination by the overlay of arrows representing environmental variables on the station plot. A longer arrow indicates a larger correlation and the direction of the arrow indicates the strength of association between each variable and the CCA axes. The arrows for water depth (depth), arsenic (As), and PAH are long and pointed to the right reflecting relatively strong, positive correlations with the horizontal axes (Table 6 and Fig. 7). The arrows for barium (Ba) and percent sand (Sand) are pointed in the opposite direction from water depth indicating negative correlations with depth with the Klondike stations more closely associated with sandier sediments. Thus, the spread of stations along first axis from the right to the left reflected a gradient in faunal community structure associated with water depth and sediment grain-size. The spread of stations along the vertical axis of the plot was negatively correlated with percent water content (Water) and copper (Cu) (Table 6 and Fig. 7). Mercury (Hg) was moderately correlated with both axes. Overall, the regression of the selected set of environmental variables summarized in the first two CCA axes accounted for 21% of variability in faunal data. As expected for background conditions, the environmental variables most closely associated with faunal structure were water depth and sediment parameters (water content and percent sand) with the other variables, including contaminants, covarying with one of these three.

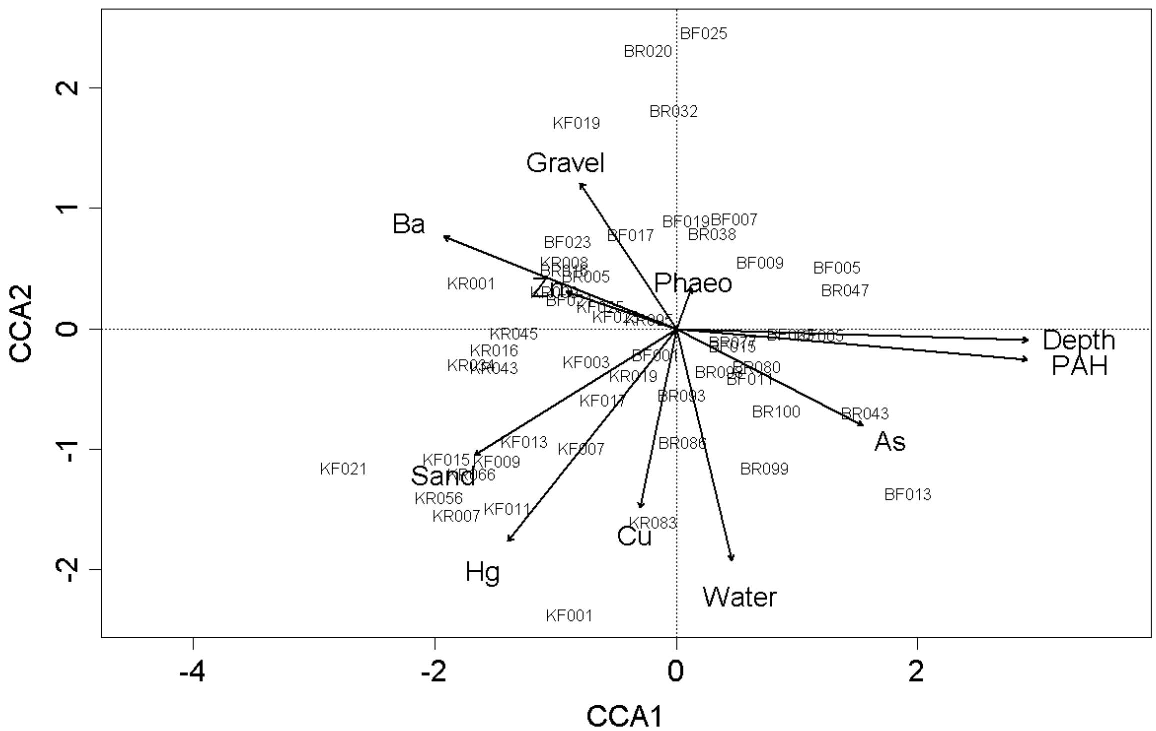

Figure 7. Plot of the first two axes from canonical correspondence analysis (CCA) for benthic double square-root transformed abundance data from the Chukchi Sea, 2008. Fixed and random sites are included here.

Table 6. Summary of correlations between CCA axes and environmental variables. Values in bold highlight moderate-sized correlations between environmental variables and CCA axes. Sign indicates direction of correlation.

CCA Label	Variable	CCA1	CCA2
Depth	Water Depth	**0.56**	0.06
Phaeo	Phaeopigments	0.01	0.05
Water	Water Content of Sediments (%)	0.10	**-0.33**
Sand	% Sand	-0.26	-0.27
Gravel	% Gravel	-0.06	0.28
PAH	*ln*(Total aromatic Hydrocarbons)	**0.50**	0.06
As	Arsenic	0.32	0.08
Ba	Barium	-0.27	0.13
Cu	Copper	-0.09	-0.19
Hg	Mercury	**-0.36**	**-0.42**
Zn	Zinc	-0.16	-0.03
	Cumulative % Variance Accounted for	13%	21%

Epifauna collected during sampling for macrofauna in 2008 include 6 phyla and 19 genera. The dominant epifaunal group comprised the echinoderms (sea cucumbers including *Psolus fabricii*, brittle stars dominated by *Ophiura sari,* and sea stars) (Table 6). Cnidarians (the soft coral *Gersemia rubiformis*), mollusks (the whelks *Buccinum* and *Neptunea*), tunicates, and crustaceans (the barnacle *Balanus crenatus*, hermit crabs, and the snow crab *Chionoecetes opilio*) were also found in the macrofaunal samples.

Table 7. Epifauna and barnacles collected during sampling at Burger and Klondike survey areas in 2008. Abundance (Abund. (ind. m^{-2})) and wet weight biomass (g m^{-2}) of all epifauna are presented.

Burger Taxon	Abund.	Biomass	Klondike Taxon	Abund.	Biomass
Ophiura sarsi	116.2	64.27	*Balanus* spp.	318.5	5.31
Diamphiodia craterodmeta	9.5	0.99	*Ophiura sarsi*	20.6	16.16
Cucumaria spp.	6.1	0.52	*Diamphiodia craterodmeta*	4.4	0.19
Ophiuroidea	4.8	0.08	Urochordata	4.6	0.02
Bryozoa	3.7	1.27	Ophiuroidea	4.6	0.02
Holothuroidea	2.1	0.53	Bryozoa	3.3	1.25
Unioplus macraspis	1.6	0.24	*Pagurus* spp.	2.3	4.79
Gersemia rubiformis	1.1	2.95	*Amphiophiura* spp.	1.7	0.86
Ophiocten sericeum	0.9	0.11	*Chelyosoma* spp.	1.5	1.54
Styelidae	0.9	0.67	Ascidiacea	2.0	4.60
Ascidiacea	1.1	0.07	Buccinidae	0.8	0.05
Asteroidea	0.7	0.01	*Balanus crenatus*	0.6	0.05
Unioplus spp.	0.5	0.10	*Boltenia echinata*	0.6	0.37
Gersemia rubiformis	0.4	1.55	Ophiuridae	0.4	0.00
Buccinum spp.	0.4	0.58	*Gersemia rubiformis*	0.4	0.94
Gorgonocephalus caryi	0.4	0.05	*Chionoecetes opilio*	0.4	17.45
Ophiura spp.	0.2	0.02	*Unioplus* spp.	0.2	0.12
Leptasterias arctica	0.2	0.08	*Volutopsius* spp.	0.2	3.29
Amphiura spp.	0.2	0.15	Decapoda	0.2	0.04
Balanus spp.	0.2	0.00	*Gersemia rubiformis*	0.2	0.13
Volutopsius spp.	0.2	0.00	Molgulidae	0.2	0.01
Colus spitzbergensis	0.2	1.01	*Neptunea* spp.	0.2	0.03
Buccinum polare	0.2	1.25			
Buccinidae	0.2	0.00			
Chionoecetes opilio	0.2	1.57			

Historic Drill Sites

Overall, sampling stations at the historic drill sites demonstrated minor difference relative to the surrounding sampling locations. Significant differences in biotic measures between drill stations and the associated survey areas occurred for the Klondike survey area where the drill stations had lower mean numbers of taxa in the samples and higher percent mud than the other stations in the Klondike survey area (the confidence intervals didn't overlap) (Tables 2 and 8). Sediment PAH and trace metals were similar as well between the survey areas and drill stations with the exception of barium which was slightly higher at drill stations but all values were below sediment quality guidelines (Tables 3 and 9).

Rankings of macrofauna by abundance and biomass for stations at the historic drill sites were similar to rankings for each survey area (Table 10). Dominant fauna of the Burger drill stations include Ostracods, the amphipod *Pontoporeia femorata*, *Brachydiastylis resima*, and the bivalve *Ennucula tenuis* all of which are among the most abundant fauna at the Burger survey area (Tables 3 and 10). At the Klondike historic drill stations, the polychaetes *Barantolla americana*, Cirratulidae, and *Sternaspis fossor*, and *Ennucula tenuis* were numerically abundant as they were at the Klondike survey area. By biomass, the highest ranked organisms at the Burger drill stations included the bivalves *Astarte borealis*, the narrow-hinged astarte *Astarte montagui*, *Ennucula tenuis*, *Macoma calcarea*, and the Aleutian spoonclam *Periploma aleuticum*, the peanut worms *Golfingia margaritacea* and *Golfingia vulgaris*, and the polychaete worm *Maldane glebiflex* which were among the highest ranked taxa for the Burger survey area. The peanut worm *Golfingia margaritacea* and the bivalves *Nuculana radiata*, *Macoma calcarea*, and *Ennucula tenuis*, and the polychaetes *Axiothella catenata* and *Maldane glebiflex* were among the highest ranked organisms by biomass at the Klondike drill stations, as they were in the remaining Klondike survey area.

Multivariate analysis of the macrofaunal community data for the drill site and fixed and random stations indicated little difference between the stations. The drill site stations did not group separately from the fixed and random stations in the cluster analysis or the nMDS but were positioned with their respective survey areas (Figs. 8 and 9). The dominant pattern was the separation of Burger from Klondike stations as shown in the analyses for the fixed and random stations alone (Fig. 5). The taxa contributing to the within group similarity of the Burger and Klondike historic drill site sampling locations include a number of the numerically abundant

Table 8. Descriptive measures, diversity indices, water depth, chlorophyll, phaeopigment, and sediment grain-size for the historic drill sites sampled in the 2008 Chukchi Sea environmental study. The # Taxon = the average number of taxonomic categories based on all station data (fixed and random), Richness = taxon richness, SD = standard deviation, and "--" = not calculated.

	BD001	BD002	BD003	BD004	BD005	Average	SD	95% CI
Abund.	1963.3	2193.3	2740	2373.3	2833.3	2420.6	365.8	(1848.8, 2992.5)
Biomass	148.8	245.9	139.2	140.7	233.6	181.6	53.4	(98.2, 265)
Num Taxa	80	87	107	104	102	96.0	11.8	(77.5, 114.5)
Simpson	0.15	0.13	0.12	0.12	0.1	0.12	0.02	(0.1, 0.15)
Shannon	2.94	3.06	3.24	3.31	3.25	3.16	0.15	(2.92, 3.4)
Richness	10.42	11.18	13.39	13.25	12.71	12.19	1.32	(10.12, 14.26)
Depth	43.2	43.5	42.9	42.9	43	43.1	0.3	(42.7, 43.5)
Chla	0.031	0.022	0.022	0.024	0.018	0.023	0.005	(0.016, 0.031)
Phaeo	0.097	0.084	0.112	0.088	0.052	0.087	0.022	(0.052, 0.121)
% Water	9.911	8.415	7.762	8.043	9.274	8.7	0.9	(7.286, 10.076)
% Sand	25.97162	32.3181	34.50993	33.61566	23.26653	29.9	5.0	(22.107, 37.765)
% Mud	74.02838	67.6819	65.49007	66.38434	54.12522	65.5	7.2	(54.279, 76.805)
% Gravel	0	0	0	0	22.60825	4.5	10.1	(-11.283, 20.327)

	KD001	KD002	KD003	KD004	KD005	Average	StDev	95% CI
Abund.	516.7	580	783.3	443.3	576.7	580.0	126.5	(382.2, 777.8)
Biomass	188.5	66.5	266.8	76.9	73.2	134.4	89.6	(-5.7, 274.5)
Num Taxa	52	52	52	41	53	50.0	5.0	(42.1, 57.9)
Simpson	0.05	0.05	0.08	0.06	0.05	0.06	0.01	(0.04, 0.08)
Shannon	3.49	3.46	3.24	3.22	3.46	3.37	0.13	(3.17, 3.58)
Richness	8.16	8.02	7.65	6.56	8.18	7.71	0.68	(6.65, 8.78)
Depth	40	40.2	39.9	40	40	40.0	0.1	(39.8, 40.2)
Chla	0.02	0.021	0.02	0.029	0.02	0.022	0.004	(0.016, 0.028)
Phaeo	0.089	0.079	0.078	0.123	0.103	0.094	0.019	(0.065, 0.124)
% Water	6.924	6.143	9.37	8.003	8.553	7.8	1.3	(5.793, 9.804)
% Sand	41.4557	34.07453	36.6474	38.92599	38.84326	38.0	2.8	(33.655, 42.323)
% Mud	58.5443	65.92547	63.3526	61.07401	61.15674	62.0	2.8	(57.677, 66.345)
% Gravel	0	0	0	0	0	0.0	--	--

Table 9. Descriptive measures for average PAH and select trace metals and iron concentrations for the 2008 Chukchi Sea environmental study (Battelle Memorial Institute et al., 2009). Data are used for canonical correspondence analysis.

Station	Total PAH	As	Ba	Cu	Hg	Zn	Fe	Water	Sand	Mud	Gravel
BD001	256.9	13.4	604	12.3	0.031	72.0	2.8	9.9	26.0	74.0	0.0
BD002	315.9	11.9	641	14.2	0.032	76.1	2.8	8.4	32.3	67.7	0.0
BD003	253.2	14.7	713	12.3	0.029	68.6	2.6	7.8	34.5	65.5	0.0
BD004	326.4	12.0	699	14.4	0.034	73.5	2.7	8.0	33.6	66.4	0.0
BD005	549.4	10.8	1912	18.1	0.045	88.1	3.2	9.3	23.3	54.1	22.6
Average	340.4	12.6	914	14.3	0.034	75.7	2.8	8.7	29.9	65.5	4.5
StDev	121.5	1.5	560	2.4	0.006	7.5	0.2	0.9	5.0	7.2	10.1
KD001	305.4	10.0	634	11.9	0.034	67.1	2.7	6.9	41.5	58.5	0.0
KD002	315.8	11.8	641	11.6	0.035	71.8	2.8	6.1	34.1	65.9	0.0
KD003	266.2	10.5	633	9.8	0.030	63.3	2.6	9.4	36.6	63.4	0.0
KD004	310.4	15.7	919	11.0	0.032	65.4	2.7	8.0	38.9	61.1	0.0
KD005	1359.4	11.0	1927	14.6	0.036	76.0	2.9	8.6	38.8	61.2	0.0
Average	511.4	11.8	951	11.8	0.033	68.7	2.8	7.8	38.0	62.0	0.0
StDev	474.4	2.3	559	1.8	0.002	5.1	0.1	1.3	2.8	2.8	0.0

species within the general Burger and Klondike survey areas. Ostracods, the bivalve *Ennucula tenuis*, and the polychaete *Lumbrineris* sp. contribute to within group similarities for the Burger survey area and the Burger historic drill sites (Tables 4 and 11). *Ennucula tenuis* and the polychaetes Cirratulidae, *Maldane glebiflex* and *Sternaspis fossor* contribute to similarities within the Klondike survey area and the Klondike drill locations. As with the analyses performed with the fixed and random stations alone, dominant taxa at Burger drill sites had higher abundance values than those of Klondike.

Positioning of stations in the CCA analysis with the fixed, random, and historic drill site sampling locations were very similar to the CCA ordination plot without the drill sites (Table 12 and Fig. 10). The largest difference in the ordination was the reversal of sites and the fit of the environmental variables along the horizontal axis but such reversals are artifacts of the fitting process and do not indicate an important change. Overall, water depth and sediment parameters (% water content), as proxies for the larger environmental characteristics, were again the strongest correlates with faunal community structure as with the CCA ordination without the drill sites (Tables 6 and 12 and Figures 5 and 10).

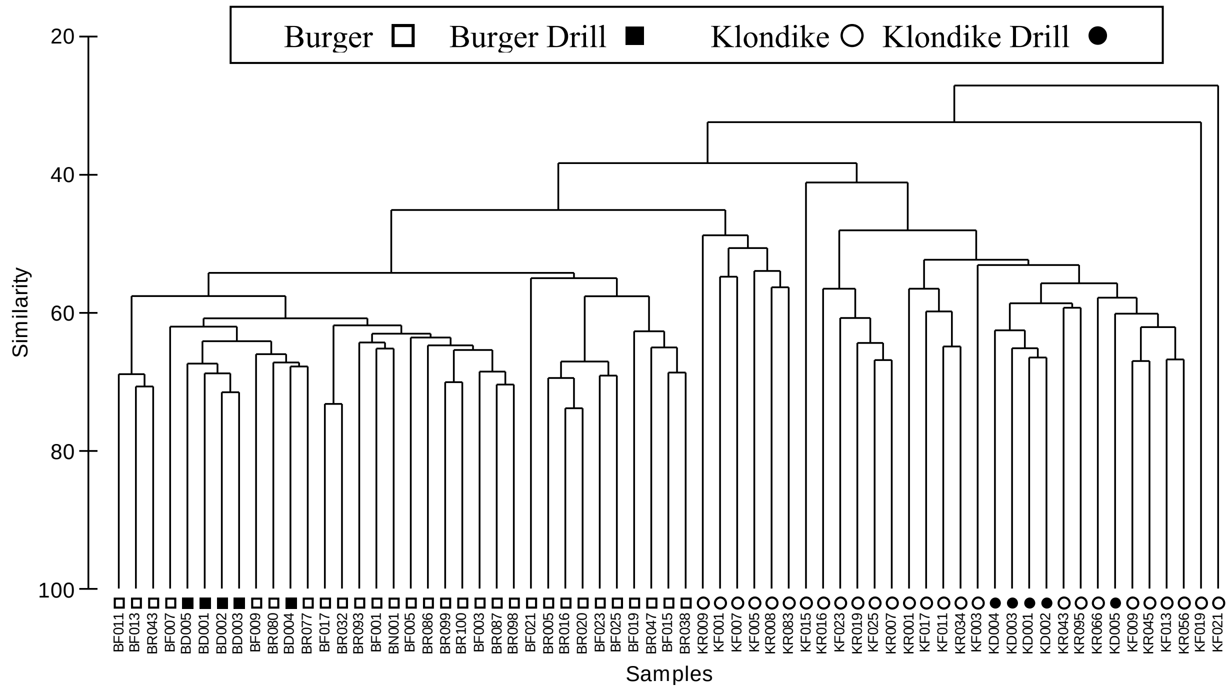

Figure 8. Cluster analysis of Bray-Curtis similarities based on *ln*(x+1)-transformed benthic abundance data from the Chukchi Sea, 2008. Fixed, random, and historic drill sites are included here.

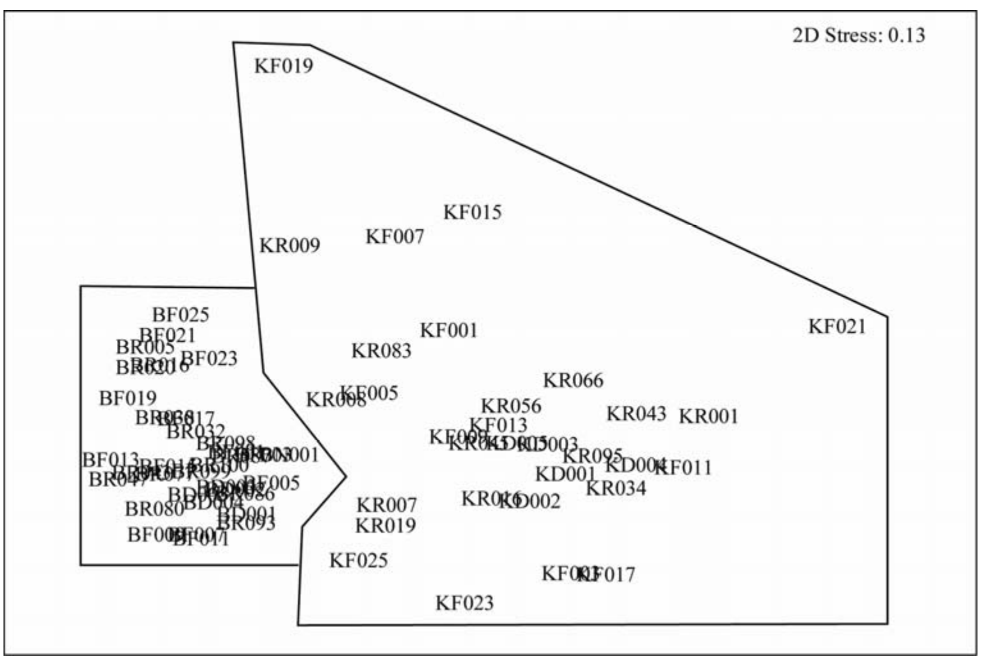

Figure 9. Nonmetric multidimensional scaling ordination plot of Bray-Curtis similarities based on *ln*(x+1)-transformed benthic abundance data from the Chukchi Sea, 2008. Fixed, random, and historic drill sites are included here.

Table 10. Rank abundance (ind. m^{-2}) and rank wet biomass (g m^{-2}) of dominant taxa (first 5 with ties) for sampling locations at the historical drill site in the Burger and Klondike survey areas, 2008.

Station	Taxon	Abundance	Taxon	Biomass
BD001	Ostracoda	717	*Macoma calcarea*	34.22
	Pontoporeia femorata	177	*Astarte borealis*	33.66
	Ennucula tenuis	130	*Ennucula tenuis*	20.44
	Brachydiastylis resima	93	*Maldane glebifex*	7.20
	Leitoscoloplos pugettensis	60	*Astarte montagui*	6.44
BD002	Ostracoda	733	*Macoma calcarea*	107.26
	Pontoporeia femorata	167	*Golfingia vulgaris*	50.89
	Ennucula tenuis	160	*Periploma aleuticum*	17.19
	Brachydiastylis resima	157	*Maldane glebifex*	15.27
	Photis spp.	70	*Astarte borealis*	6.58
BD003	Ostracoda	883	*Ennucula tenuis*	16.63
	Ennucula tenuis	183	*Periploma aleuticum*	15.28
	Pontoporeia femorata	153	*Astarte montagui*	14.79
	Brachydiastylis resima	130	*Maldane glebifex*	11.46
	Leucon nasica	97	*Onuphis parva*	7.92
BD004	Ostracoda	750	*Golfingia margaritacea*	32.29
	Brachydiastylis resima	140	*Astarte montagui*	19.83
	Pontoporeia femorata	137	*Maldane glebifex*	14.79
	Ennucula tenuis	113	*Cyclocardia crebricostata*	8.93
	Paraphoxus spp.	90	*Onuphis parva*	8.80
BD005	Ostracoda	757	*Macoma calcarea*	65.36
	Brachydiastylis resima	293	*Golfingia margaritacea*	53.23
	Caprellidea	213	*Ennucula tenuis*	27.26
	Ennucula tenuis	207	*Flabelligera mastigophora*	9.27
	Photis spp.	143	*Liocyma fluctuosa*	8.12

Table 10. Continued.

Station	Taxon	Abundance	Taxon	Biomass
KD001	*Barantolla americana*	67	*Golfingia margaritacea*	55.42
	Ennucula tenuis	60	*Golfingia* sp.	50.65
	Cirratulidae	37	*Axiothella catenata*	16.86
	Arcteobia anticostiensis	20	*Maldane glebifex*	12.54
	Leucon nasica	20	*Nephtys punctata*	9.43
KD002	*Sternaspis fossor*	80	*Nuculana radiata*	14.44
	Ennucula tenuis	53	*Golfingia margaritacea*	12.47
	Barantolla americana	43	*Maldane glebifex*	11.46
	Cirratulidae	27	*Liocyma fluctuosa*	5.28
	Leucon nasica	27	*Ampharete acutifrons*	3.76
KD003	*Barantolla americana*	190	*Golfingia margaritacea*	184.47
	Ennucula tenuis	63	*Macoma calcarea*	19.92
	Sternaspis fossor	43	*Maldane glebifex*	18.85
	Polydora sp.	37	*Nuculana radiata*	9.55
	Mysella planata	30	*Axiothella catenata*	6.04
	Cirratulidae	30		
KD004	*Ennucula tenuis*	60	*Maldane glebifex*	16.76
	Barantolla americana	53	*Nuculana radiata*	14.92
	Nephtys punctata	33	*Ennucula tenuis*	7.20
	Yoldia sp.	30	*Praxillella gracilis*	5.89
	Cirratulidae	27	*Macoma calcarea*	5.79
KD005	*Ennucula tenuis*	70	*Nuculana radiata*	16.28
	Barantolla americana	57	*Ennucula tenuis*	9.93
	Cirratulidae	47	*Axiothella catenata*	7.42
	Sternaspis fossor	43	*Maldane glebifex*	7.38
	Praxillella praetermissa	27	*Musculus niger*	5.94

Table 11. The five taxa contributing most to within station similarity (Sim) for Burger and Klondike drill sites. Abund = average abundance, Sim = average similarity, % Contr = % contribution to similarity, and Cum. % = cumulative percent contribution. Stations for each site are those included in the nMDS ordination plot including fixed and random sampling locations.

Burger Historical Drill Sites: Average similarity: 67.56

Taxon	Abund	Sim	% Contr.	Cum. %
Ostracoda	768.0	3.68	5.45	5.45
Ennucula tenuis	158.7	2.73	4.05	9.5
Brachydiastylis resima	162.7	2.66	3.94	13.44
Pontoporeia femorata	136.0	2.55	3.77	17.22
Lumbrineris sp.	53.3	2.18	3.23	20.44

Klondike Historical Drill Sites: Average similarity: 62.39

Taxon	Abund	Sim	% Contr.	Cum. %
Ennucula tenuis	61.3	4.7	7.53	7.53
Barantolla americana	82.0	4.56	7.31	14.84
Cirratulidae	33.3	3.89	6.24	21.08
Sternaspis fossor	40.0	3.61	5.78	26.86
Maldane glebifex	18.0	3.11	4.99	31.85

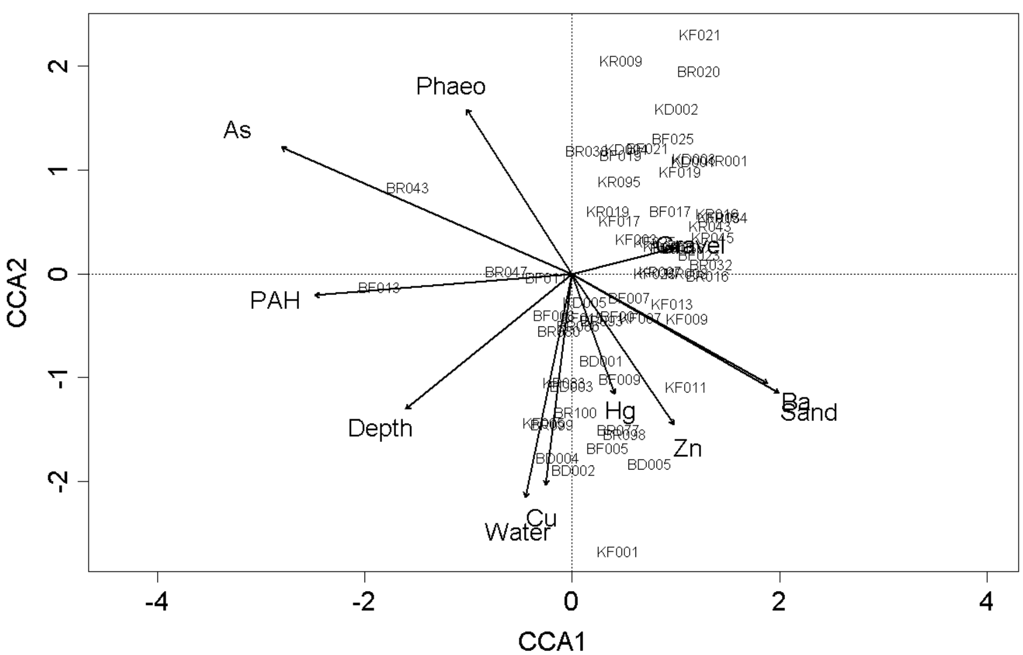

Figure 10. Plot of the first two axes from canonical correspondence analysis with historical drill sites from the Chukchi Sea, 2008.

Table 12. Summary of correlations between CCA axes and environmental variables for the analysis with drill sites included. Values in bold highlight moderate-sized correlations between environmental variables and CCA axes.

CCA Label	Variable	CCA1	CCA2
Depth	Water Depth	**-0.50**	**-0.42**
Phaeo	Phaeopigments	-0.01	0.16
Water	Water Content of Sediments (%)	-0.21	**-0.46**
Sand	% Sand	0.27	-0.12
Gravel	% Gravel	0.16	0.11
PAH	*ln*(Total aromatic Hydrocarbons)	-0.34	-0.16
As	Arsenic	**-0.39**	0.02
Ba	Barium	0.31	-0.06
Cu	Copper	-0.09	-0.28
Hg	Mercury	0.11	0.03
Zn	Zinc	0.05	-0.16
	Cumulative % Variance Accounted for	16%	25%

DISCUSSION

Benthic Ecology of the Burger and Klondike Survey areas

The benthic fauna of Burger and Klondike survey areas are diverse, very abundant, and representative of North Pacific benthic assemblages found throughout the Bering and Chukchi Seas (Feder et al., 1994b, 2005, 2007; Grebmeier et al., 2006). Overall, the communities at the survey areas reflect the high production in the nutrient-rich waters, short food chains, and shallow waters of the Chukchi Sea (Grebmeier et al., 2006). Although average abundance, biomass, and number of taxa per station were significantly higher at Burger than at Klondike, the faunal assemblages of taxa at both survey area sites were generally similar (containing most of the same species), as indicated by the low β diversity value, and both were rich and diverse (Fig. 11). The differences between the two sites in the multivariate analyses reflected lower abundances and more restricted distributions of animals at Klondike, as also shown by the diversity values and overlays of animal abundance on the MDS plot. CCA analyses indicated that environmental gradients within the study area are moderate creating moderate trends in communities. Associations with grain-size and water depth are common proxies for overall environmental characteristics (such as water currents, water temperature and salinity, and factors related to topography) and the high correlations of benthic community structure with water depth

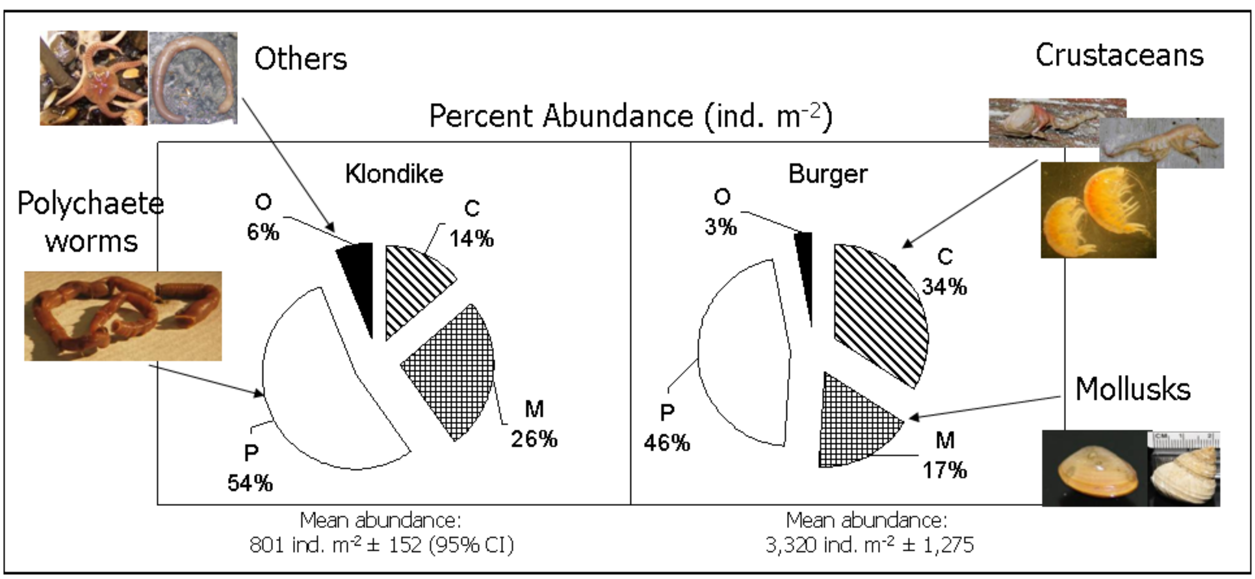

Figure 11. Percent abundance for the Klondike and Burger survey areas in the NE Chukchi Sea, 2008.

and percent sand observed in this study are reasonable for communities varying within undisturbed environments (e.g., Feder et al., 1994a and b; Grebmeier et al., 2006; Cochrane et al., 2009; Jewett et al., 2009). Relative to the present study area, Feder et al. (1994b) observed high abundance and biomass at sites surrounding the study area and related benthic production to the nutrient rich waters advected into the study area (see also: Grebmeier et al., 2006).

Fauna of ecological interest in the benthic database include the deep deposit-feeding polychaete worms of Family Maldanidae (bamboo worms) and the sipunculid worm *Golfingia margaritacea* (peanut worms). Maldanid polychaetes are known as conveyor-belt feeders as their habit of feeding on buried organic carbon results in sediments from depth (~10 cm) being transported to the surface. However, the transport is not one-way as these worms also move food resources and sediments down resulting in a well-mixed sediment column although the methods by which transport occurs are not fully known (Levin et al., 1997). Their tubes and feeding activities also irrigate and aerate deeper sediments. *Golfingia margaritacea*, in the phylum Sipuncula, is an enigmatic organism as there has been little interest in this group due to their generally low abundance and associated perceived lack of importance to benthic systems. However, sipunculid worms can be ecologically important by mixing the sediment column and facilitating transport of oxygen, nutrients, and organic carbon down to at least 50 cm depth (Romero-Wetzel, 1987). The specimens of *Golfingia margaritacea* found in this study were very large measuring up to 2 cm wide and 17 cm long (~0.75 X 6.75 inches) and have a large potential for bioturbation as they were observed at depth during sampling (H. Nichols, personal observation). Large polychaete, sipunculan, and priapulid worms and the numerous bivalves are prey sources for benthic-feeding organisms. The faunal evidence indicates high biological activity both on the sediment surface and to at least 20 cm depth (~ 8 inches) if not deeper (Nelson et al., 1994). The biological activity suggested by the rich faunal communities in the survey areas implies that potential contaminants from multiple sources (Naidu et al., 1997) could be transported downwards in sediments as well. The little information currently available indicates that heavy metal concentrations in sediments of the northeastern Chukchi Sea are comparatively low reflecting natural processes (except at sites of prior human activity) with no biological effects expected (Naidu et al., 1997; Battelle Memorial Institute et al., 2009).

Historic Drill Sites

The sampling locations at the historic drill sites demonstrated little difference in macrofaunal communities compared to the surrounding survey areas. Overall, macrofaunal community structure appeared the same at the drill sites relative to the surrounding stations. Investigation of sediment chemistry of historic drill sites in the Burger and Klondike survey area found slightly elevated PAH and barium concentrations in sediments at some drill sites (Battelle Memorial Institute et al., 2009). The distribution of sensitive fauna at the drill sites, (amphipods and tube-dwelling fauna) (Olsgaard and Gray, 1995; Peterson et al., 1996; Jewett et al., 1999; Blanchard et al., 2002, 2003) gave no evidence for an association of PAH or metals with macrofauna (Tables 10 and 11). Multivariate analyses demonstrated no evidence of a difference between the drill sites and the fauna of the neighboring survey areas (Figs. 8, 8, and 10). However, the polychaete worm *Barantolla americana*, abundant at the historic drill site in the Klondike survey area, belongs to the opportunistic family Capitellidae, which is well known for occurring in high abundances in stressed environments. Opportunistic responses of capitellid worms elsewhere in Alaska include increased abundance in response to disturbance from the 1964 earthquake, sediment hydrocarbons, fish wastes in Port Valdez and to sewage disposal (Blanchard et al., 2002; Blanchard and Feder, 2003; Jewett et al., 2009; Blanchard et al., 2010). Given the opportunistic behavior of capitellid worms worldwide to a wide range of disturbances (Seng et al., 1987; Weston, 1990; May and Pearson, 1995; Blanchard and Feder, 2003; Calabretta and Oviatt, 2008; Conlan et al., 2010), the increased abundance of *Barantolla americana* at the Klondike drill sites likely reflects a later stage in the temporal recovery of macrofauna from prior disturbance (drilling). Additionally, the mean values for faunal measures tend to be low for drill sites, though not statistically different from the survey area stations. Thus, the evidence points to lingering influences of prior drilling activities on benthic fauna (i.e., from changes in sediment structure, disruption of the biological matrix, or other related disturbing factors for which recovery can be a lengthy process in dynamic environments; Jewett et al., 1999b). Further, detailed assessments would be necessary to understand the small differences that exist at the drill sites and separate anthropogenic effects from responses to the strong, natural gradients present in the survey areas. Overall, the macrofauna in the survey areas, including the drill sites, reflected ecological conditions expected from prior studies in the NE Chukchi Sea (Feder et al., 1994b) rather than anthropogenic stressors.

Overview of Ecological Dynamics of the Chukchi Sea

Circulation and Hydrography

The Chukchi Sea is unique among arctic shelf seas as it is strongly influenced by waters derived from the Pacific Ocean entering through the Bering Strait (Weingartner et al., 2005). The northward current flow is derived from sea level differences between the Pacific and Arctic Oceans with rapid variations in flow (including current reversals) resulting from winds (Weingartner et al., 1998; Weingartner et al., 2005). Key water masses moving northward in the eastern Bering Sea to the Chukchi Sea include nutrient-rich Anadyr water, the nutrient-depleted Alaska Coastal water (ACW), and Bering Shelf water which moves north sandwiched between the other two water masses (Grebmeier et al., 2006). The Anadyr and Bering Shelf waters mix as they move through Bering Strait to form the Bering Shelf-Anadyr water (BSAW). These water masses move across the continental shelf through the Chukchi Sea into the Arctic basin. These southern water masses transport heat, nutrients, carbon, and animals to the Chukchi Sea and Arctic Ocean and are vitally important for maintenance of the ecological balance of the region (Weingartner et al., 2005; Grebmeier et al., 2006; Hopcroft et al., in submission).

Within the Chukchi Sea, the Bering Shelf inflow separates into a more saline, western branch flowing into the Hope and Herald sea valleys (composed of BSAW), and a dilute, eastern branch (composed of ACW) moving to the east and down into Barrow Canyon (Walsh et al., 1989). A third branch of cold, highly saline water flows northward over the central channel and slowly over the southern flank of Hanna Shoal ultimately to join waters exported into the basin of the Arctic Ocean through Barrow Canyon (Weingartner et al., 2005). The waters flowing over Hanna Shoal are nutrient-enriched relative to summer surface and ACW (Faulkner et al., 1994). The nutrient enrichment may be derived, in part, from remineralization of nutrients by the robust benthos in the Chukchi Sea (Faulkner et al., 1994; Feder et al., 1994a; Ambrose et al., 2001; Grebmeier et al., 2006). The Burger survey area lies towards the southern flank of Hanna Shoal with the Klondike a short distance to the south. Weingartner (2009) demonstrated higher water temperature and salinity values for the Klondike survey area in late summer 2008, as compared to the Burger survey area, reflecting the persistence of winter water at Burger (Fig. 12). As shown in this study, the benthic macrofaunal community at the Burger survey area has higher abundance and biomass which is evidence of different oceanographic conditions there (Fig. 11).

Feder et al., (1994b) also demonstrated higher biomass for stations closest to the Burger survey area related to environmental differences.

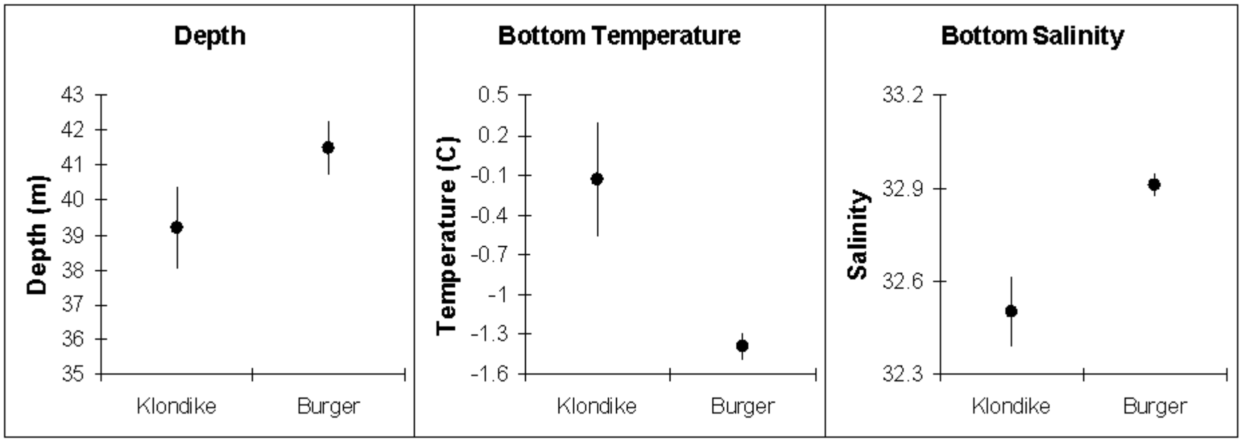

Figure 12. Mean depth, bottom water temperature, and bottom water salinity for the NE Chukchi Sea, 2008. Data were from the BLF0803 cruise from August 21 to September 25, 2008. Data are from Weingartner (2009).

Carbon Cycling

The seasonal ice cover and influx of water from the North Pacific Ocean through the Bering Strait are major influences on the productivity of the Chukchi Sea. The short growing season and seasonal ice cover limits primary productivity within the region to the late spring and summer months. Melting sea ice stratifies the water column creating the necessary conditions for primary productivity resulting in a summer phytoplankton bloom with the timing dependent on ice cover (e.g., Hopcroft et al., 2009). The mismatch of zooplankton community development and the lower numbers of zooplankton in the Chukchi Sea results in a large flux of unconsumed, primary production to the benthos enhancing benthic community growth (Grebmeier et al., 1988; Grebmeier et al., 2006). (In contrast, in other pelagic systems such as Port Valdez, Alaska, zooplankton can consume much of the primary productivity and very little phytoplankton may reach the sea floor; Blanchard et al., 2010). As discussed above, nutrient rich water is transported through Bering Strait and the Chukchi Sea into the basin of the Arctic Ocean (Weingartner et al., 2005) and as a result of the combination of physical and biological characteristics, the Chukchi Sea is one of the most productive continental shelves in the world (Grebmeier et al., 2006).

Investigations of carbon cycling in the Chukchi Sea demonstrated strong linkages between primary production and distributions of macrofauna. The reduced numbers of water-column grazers on phytoplankton in the Chukchi Sea results in strong pelagic-benthic coupling as the flux of ungrazed phytoplankton reaching the benthos drives a very robust and diverse macrofauna community (Dunton et al., 2005; Grebmeier et al., 2006). The nutrient-rich waters from the NE Bering Sea also contribute to the robust macrofaunal communities (Feder et al., 1994b). Hanna Shoal is recognized as a hotspot for benthic communities as biomass is greater surrounding the shoal partly in association with influences from the nutrient rich, colder waters that flow across the southern flank of the shoal (Dunton et al., 2005; Weingartner et al., 2005; Grebmeier et al., 2006). The macrofaunal community at the Burger survey area, closer to the southern flank of Hanna Shoal, is more robust (greater numbers and biomass with more regular distributions of species) than that of the Klondike survey area. Environmental characteristics of the Burger survey area suggest a depositional environment but data are lacking to fully understand the differences between the two survey areas. Data gaps in understanding the physical oceanographic characteristics and circulation patterns in the survey areas will be filled by the multi-year, oceanographic investigations included in the Chukchi Sea Environmental Studies Program (e.g., Weingartner et al., 2009).

Animal-Sediment Interactions

Animal-sediment interactions are a complex mosaic of biological-mediated relationships of fauna with their physical environment and there are many factors influencing community development of macrofauna. These factors include currents and current speeds, frequency of disturbance, flux of carbon to the benthos, adsorption of organics to sediment particles, deposition of organics, percent total organic carbon in sediments (TOC), and bioturbation (Weston, 1988; Snelgrove and Butman, 1994; Lenihan and Micheli, 2001; Bluhm and Gradinger, 2008). Community structure commonly correlates with sediment grain-size as a proxy for the range of physical processes covarying with grain-size and driving biodiversity, biomass, and community structure. Recent reviews have shown, however, that such generalizations are not entirely accurate and a more complex paradigm is developing (Snelgrove and Butman, 1994; Lenihan and Micheli, 2001). Bluhm and Gradinger (2008) and others suggest food resources, seawater salinity and temperature, disturbance, and sediment factors are major determinants of

Arctic benthic community structure (Cusson et al., 2007). Biological factors can also be important as the disruption of sediments by animals as they feed, build tubes, and move (called bioturbation) can result in a well-mixed sediment column with reduced layering of sediments, transport of surface carbon downward, and increased water circulation and greater oxygenation at depth (Snelgrove and Butman, 1994; Lenihan and Micheli, 2001; Levin et al., 1997; Shields and Kędra, in press). Additionally, disturbance, including bioturbation, ice-gouging, and human activities, can create mosaics of sediment patches where patches are at varying stages of recovery (Thistle, 1981; Hall, 1994; Jewett et al., 1999b). When the frequency of disturbance is not too high (relative to the ability of a communities to recover) disturbance may help to maintain diversity by reducing dominance of the most competitive species (Boesch and Rosenberg, 1981).

Animals associated with carbon and oxygen transport to depth in sediment include a number of worms found in the NE Chukchi Sea. The capitellid worm *Heteromastus filiformis*, maldanid worms (e.g., *Maldane glebiflex* in the current study), and another sipunculan (of the genus *Nephasoma*) are shown to transport sediments and carbon between the sediment surface to a suitable feeding depth with transport of carbon going both ways (e.g., Levin et al., 1997; Shields and Kędra, in press). The burrows and feeding activities serve to enhance exchange of oxygen and water-borne nutrients within sediments while the worms subduct a portion of annual primary production into their burrows. Together, these deep, deposit-feeding animals comprise a large proportion of the macrofaunal biomass in the survey areas and Nelson et al. (1994) found extensive burrowing activity by polychaete worms and sipunculans in sediment of the NE Chukchi Sea to 35 cm depth. Given the numbers of maldanid polychaetes and sipunculan worms found in the current study of the Burger and Klondike survey areas, it appears that these organisms play a vital role in the benthic ecosystem by transporting carbon through the sediment column, disturbing sediments, and creating pathways for oxygenated water and nutrients to irrigate deeper sediments.

Feeding by Fishes and Marine Mammals

The diet of a few benthic feeding fishes in the NE Chukchi Sea have been reported including the Arctic cod *Boreogadus saida*, Arctic staghorn sculpin *Gymnocanthus tricuspis*, Bering flounder *Hippoglossoides robustus*, saffron cod *Eleginus gracilis,* and the fish doctor

Gymnelus viridis (an eelpout) (Jewett and Feder, 1980, 1981; Coyle et al., 1997; Green and Mitchell, 1997; Feder et al., 2005). Prey of fishes ranged from planktonic (water column) and epibenthic (animals living on the sediment surface) crustaceans to polychaetes and other fishes. Arctic staghorn sculpin consumed macrofaunal prey (those living within sediments including bivalves and gastropods) and all species consumed epibenthic crustaceans. Barber et al. (1997) documented 66 species of fishes in the Chukchi Sea, many of which are also likely to utilize the benthos for food. Information on the feeding habits of fishes from the NE Chukchi Sea is limited and needs further study.

The gray whale primarily feeds in the northern Bering and southern Chukchi Seas but a population is known to feed in the northeastern Chukchi coastline and the Beaufort Sea (Moore and Clark, 1990; Feder et al 1994b; Highsmith et al., 2006). Coast Gray whales scoop sediment into their mouths to harvest amphipods and other macrofauna and favor sediments with dense beds of amphipods (Highsmith and Coyle, 1992; Nelson et al., 1994; Bluhm and Gradinger, 2008). In addition to known feeding areas along the northern coastline, Moore and Clark (1990) observed gray whales presumably feeding around Hanna shoal where very abundant ampeliscid amphipods were found during sampling by Nelson et al. (1994) in 1998. While amphipods are an important component of the macrofaunal community within the present study area, their numbers are lower in Burger and Klondike survey areas than in the known, preferred feeding areas indicating suboptimal habitat in the survey areas (Nelson et al., 1994; Highsmith and Coyle, 1992).

Walrus feed by rooting through the sediments as they dig for clams and other benthic organisms (Fay 1982; Born et al., 2003; Ray et al., 2006). They may consume up to ~3 million tons of benthic biomass and disturb sediments over thousands of km^2 yr^{-1} (Ray et al., 2006; Krupnik and Ray, 2007). It is the accepted opinion that walrus favor large bivalves. Fay (1982) and Sheffield et al. (2001), however, demonstrated that walrus in the Chukchi Sea feed on many other organisms including small and large soft-bodied benthic worms. Softer animals digest quickly in walrus stomachs leaving little trace of their presence and are therefore, underrepresented in walrus feeding studies (Sheffield et al., 2001). Fay (1982) provides pictures of walrus prey which includes large *Golfingia margaritacea* and *Priapulus caudatus*, both found in macrofaunal samples from the 2008 sampling and by Nelson et al. (1994). Bearded seals feed on an array of epifaunal and larger macrofaunal organisms and fishes (Lowry et al., 1980; Bluhm and Gradinger, 2008). The high biomass values and high numbers of bivalves, large polychaete and sipunculid worms, and amphipods represent a strong prey base for benthic feeding organisms in the Klondike and Burger survey areas.

The links between trophic levels in the NE Chukchi Sea are particularly short. Primary production directly supports a rich complex of benthic organisms. The robust macrofaunal communities in the NE Chukchi Sea support benthic-feeding fishes and marine mammals serving as a vital link between the high levels of primary production in this marginal sea and upper trophic organisms, some of which migrate long distances to feed here (Fay 1982; Lowry et al., 1980; Sheffield et al., 2001; Bluhm and Gradinger, 2008). This link extends to coastal residents that hunt marine mammals as well. Additionally, bioturbation of sediments by marine mammals mixes sediments, creates space for macrofauna to occupy, transfers buried nutrients to the surface, and contributes to increasing and maintaining diversity (via maintaining patches in various stages of recolonization and recovery; Boesch and Rosenberg, 1981). A positive feedback may therefore, exist between foraging of these higher trophic level predators on benthic communities as nutrient flux (and thus productivity) tends to increase as a result of the extensive disturbance caused by foraging activities (Ray et al., 2006). As a result, bioturbation by benthic-feeding organisms in the Chukchi Sea is likely a substantial and ecologically important source of sediment disturbance to macrofaunal community heterogeneity.

Historical Record of Science in the NE Chukchi Sea

The first sampling effort in the NE Chukchi Sea using western scientific methods was performed by Sam Stoker in the early 1970’s. Extensive investigations by Russian scientists of the benthic fauna in the Chukchi Sea have been largely unavailable but are becoming more accessible through increasing collaborations with western scientists (e.g., Nagel, 1992; Grebmeier et al., 2006). However, methods used by Russian scientists using large ocean grabs (a larger grab that creates a “bow wave” disrupting surface macrofauna) are incompatible with van Veen grab sampling employed to sample smaller, sediment-dwelling macrofauna near the surface. Stoker sampled fauna from the Bering Sea to the Arctic Ocean and determined large-scale trends in faunal composition providing the first insights into the region but used methods slightly different from standard benthic-sampling methods. Stoker’s study was followed by the multi-disciplinary studies of Feder et al. (1994 a and b, 2005, and 2007) which investigated various aspects of the benthic ecology of the southeastern and northeastern Chukchi Seas. Barber et al. (1997) led a fisheries oceanographic effort in the northeastern Chukchi Sea that studied aspects of demersal fishes and arctic cod as well as mollusks (Feder et al 1994a; Coyle et al., 1997). Nevertheless, little is still known about the ecology of the fishes of the Chukchi Sea. In terms of benthic processes, Jackie Grebmeier, Ken Dunton, and Lee Cooper have led a surge of arctic research leading to investigations in the Russian and American arctic waters and of the arctic shelf and basin processes (e.g., Grebmeier and Harvey, 2005; Grebmeier et al., 2009). Feder et al. (1994b) is to date, the only study with infauna composition data that is readily available and with enough sites overlapping the Burger and Klondike survey areas allowing temporal comparisons.

Currently, there are a number of broad-scale, interdisciplinary studies encompassing benthic ecology, fisheries ecology, plankton ecology, oceanography, and other disciplines including the Shelf-Basin Interchange (SBI), Russian-American (RUSALCA), and Chukchi Sea offshore monitoring program (COMIDA) with benthic sampling (macrofauna and epifauna) occurring in 2009. Ultimately, the results of the RUSALCA and COMIDA studies in 2009 will enable a large-scale comparison with the data of Feder et al. (1994a, b) which will continue to serve as the baseline, useful for a temporal comparison of fauna in NE Chukchi Sea.

The historical macrofauna data from the study area, published in Stoker (1971, 1981) and Feder et al. (1994b), will be available as the data have been re-entered into a database but faunal identifications need updating. Qualitatively, the fauna described in the current study were very similar to the communities described by Stoker (1978, 1981) and Feder et al. (1994b) suggesting little change over time in overall community structure. Additionally, qualitative summaries of data from box cores from the NE Chukchi Sea by Nelson et al. (1994) suggest an active sediment column and noted the presence of large bivalves (*Serripes groenlandicus*) and the sipunculan worm *Golfingia margaritacea*. Large bivalves are rarely captured by grab sampling and are poorly represented in the present study. Large *Golfingia margaritacea* were, however, present in grab samples from 2008. Quantitative comparisons of the historical data with that gained in the multi-year environmental assessment will be useful for understanding potential long-term changes in the survey areas.

Videos of the sea bottom in the study area were collected during surveys through Mineral Management Service (MMS) in 1989. Sites surveyed include the Burger (labeled as Burger Site tape #2B, 0810 GMT, August 9, 1989; 71.15' 05.00"N, 163.11' 40.499"W), Crackerjack (alternatively labeled as Burger Site tape #3B, 1515 GMT, August 9, 1989; 71.25' 07.14"N, 165.32' 29.506"W), and Popcorn (August 15, 1989; 71 51' 16.39"N**,** 165 48' 24.89"W) drill sites (the Klondike tape was lost). The videos are publicly available from the MMS library but necessary data for quantitative assessment (the frame size and tow distances, etc.) were lost. Qualitatively, the videos show the strawberry coral *Gersemia* spp., polychaete worms, large numbers of brittle stars, and numerous burrows at the Burger site. The video for the Burger survey area reveals a very rich epibenthos with numerous large organisms. Although not collected quantitatively with a grab (the scale of distribution of epibenthos is very different than the macrofauna which are the target community for grabs), the epibenthos collected in our study coincides with that shown by the MMS videos.

Future Directions

Sampling in 2009 (and presumably in 2010) included collection of fishes and epifaunal invertebrates by trawling. The joint effort by Drs. Brenda Norcross and Arny Blanchard will facilitate linking the macrofaunal organisms to their epifaunal predators. This joint investigation should allow for insights into distributions, trophic interactions (e.g., predator/prey interactions), and dynamics of the benthic ecosystem. Tissue samples will be collected from macrofaunal animals, epifaunal organisms, and fish species encountered throughout the study areas in 2009 and 2010 for isotope studies to determine feeding habits of different organisms.

Oceanographic data collected during the multi-year environmental study in the Chukchi Sea will be important for understanding how the physical environment influences fauna. The scale of oceanographic data collected in 2008 do not appear to be adequate for resolving the relationship between the benthos and water mass movement, as suggested in this report, but a larger-scale study planned for 2010 will be appropriate (S. Danielson, personal communication). The current physical oceanographic data are adequate for resolving seasonal trends appropriate for the zooplankton ecology. Macrofauna, however, do not respond to seasonal changes in surface conditions at the same scale that zooplankton do since macrofauna are influenced by year-round current flow of bottom water. Thus, the expanded work in 2010 will help to understand the oceanographic factors influencing macrofauna (S. Danielson, personal communication).

Prey resources for higher trophic levels are abundant throughout the Burger and Klondike survey areas. Prey resources found include bivalves and amphipods, known prey for walrus and gray whales, respectively, as well as other large-bodied organisms (polychaetes and sipunculans) used by benthic-feeding marine mammals. Abundance cycles of bivalves in the Chukchi Sea and Port Valdez, a glacial fjord in Prince William Sound, appear sensitive to climatic variability (A. L. Blanchard, personal observations; Sirenko and Kolutin, 1992; Blanchard et al., in press). As shown by Sirenko and Kolutin (1992), climate change has the potential to alter bivalve populations dramatically. Thus, determination of normal temporal and spatial variation of prey resources through long-term sampling will be important. The multi-year sampling currently in progress at the Burger and Klondike survey areas will contribute to understanding temporal cycles.

CONCLUSIONS

The benthic communities of Burger and Klondike survey areas were diverse and robust. The benthic assemblages were characteristic of species found throughout the Bering and Chukchi Seas (Feder et al., 1994 a, b, 2005, 2007). Overall, the robust communities at the survey areas reflected the high production in the nutrient-rich water and short food chains in the relatively shallow water of the Chukchi Sea (Grebmeier et al., 2006). Although average abundance, biomass, and number of taxa per station were significantly higher at Burger than at Klondike, the faunal assemblages at both survey area sites were generally similar (containing most of the same species) and both were rich and diverse. Environmental gradients within the study area were moderate (driven by a number of factors co-varying with water depth and sediment grain-size measures) and moderately associated with trends in benthic community structure. The numbers of large, deep-feeding organisms found in the sediments of the Burger and Klondike survey areas plus bottom fish and marine mammal feeding activities suggested that bioturbation may be an important factor in the benthic ecosystem of the study area.

The water masses from the North Pacific transport heat, nutrients, and carbon to the Chukchi Sea and Arctic Ocean and are vitally important to the ecological balance of the system (Weingartner et al., 2005; Grebmeier et al., 2006). Feder et al. (1994b) observed high abundance and biomass at sites surrounding the study area and related benthic production to the nutrient rich waters advected into the study area (Grebmeier et al., 2006). In the present study, benthic productivity (abundance and biomass) appeared to be different between the two survey areas with enhanced macrofaunal communities at the Burger survey area located towards the southern flank of Hanna Shoal relative to the Klondike survey area. The biological differences reflected the slightly different oceanographic and environmental regimes at the two sites.

Prey resources for higher trophic levels are abundant throughout the Burger and Klondike survey areas. Prey resources found included large worms, bivalves and amphipods which are known prey for bearded seals, walrus, and gray whales. Bottom-feeding fishes also prey on macrofauna (Coyle et al., 1997; Green and Mitchell, 1997). The robust macrofaunal communities in the NE Chukchi Sea support large numbers of benthic-feeding organisms serving as a direct link between primary production in this marginal sea and upper trophic organisms (Fay 1982; Lowry et al., 1980; Sheffield et al., 2001; Bluhm and Gradinger, 2008).

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Appendix I

Ranking of Fauna by Abundance and Biomass for each Fixed and Random Station for the 2008 Chukchi Sea Environmental Study

Table AI. Ranking of top five taxa by abundance (ind. m^{-2}) and biomass (g m^{-2}) for fixed and random stations sampled in the Chukchi Sea, 2008.

Station	Taxon	Abundance	Taxon	Biomass
BF001	Ostracoda	370	Astarte borealis	259.71
	Paraphoxus sp.	137	Astarte montagui	29.41
	Brachydiastylis resima	87	Maldane glebifex	18.17
	Praxillella praetermissa	80	Axiothella catenata	15.72
	Photis sp.	57	Nicomache lumbricalis	7.39
	Ennucula tenuis	57		
BF003	Lumbrineris sp.	93	Golfingia margaritacea	66.76
	Ostracoda	80	Maldane glebifex	28.62
	Orchomene sp.	77	Macoma calcarea	24.72
	Paraphoxus sp.	63	Astarte montagui	17.18
	Yoldia sp.	60	Axiothella catenata	16.08
	Ennucula tenuis	60		
BF005	Brachydiastylis resima	187	Astarte montagui	185.61
	Photis sp.	87	Astarte borealis	77.57
	Praxillella praetermissa	77	Cyclocardia crebricostata	47.71
	Ennucula tenuis	70	Yoldia myalis	24.05
	Paraphoxus sp.	63	Macoma calcarea	19.81
BF007	Ostracoda	757	Golfingia margaritacea	202.20
	Photis sp.	180	Golfingia vulgaris	30.76
	Brachydiastylis resima	133	Astarte montagui	29.65
	Ennucula tenuis	117	Maldane glebifex	22.40
	Lumbrineris sp.	70	Lumbrineris fragilis	8.05
BF009	Ostracoda	563	Golfingia margaritacea	103.54
	Ennucula tenuis	307	Astarte montagui	24.70
	Pontoporeia femorata	140	Ennucula tenuis	17.24
	Photis sp.	117	Cyclocardia crebricostata	6.65
	Brachydiastylis resima	117	Rhynchocoela	4.47
	Lumbrineris sp.	67		
BF011	Maldane glebifex	940	Golfingia margaritacea	78.42
	Ostracoda	640	Ampelisca eschrichti	27.53
	Maldane sp.	520	Ennucula tenuis	26.43
	Ennucula tenuis	280	Maldane glebifex	15.42
	Photis sp.	243	Lumbrineris sp.	5.43
BF013	Maldane glebifex	2520	Astarte borealis	95.79
	Maldane sp.	2447	Golfingia margaritacea	88.70
	Ostracoda	933	Ennucula tenuis	56.96
	Ennucula tenuis	410	Cyclocardia crebricostata	46.24
	Lumbrineris sp.	287	Maldane glebifex	35.05

Table AI. Continued.

Station	Taxon	Abundance	Taxon	Biomass
BF015	Ennucula tenuis	803	Macoma calcarea	95.08
	Pontoporeia femorata	710	Golfingia margaritacea	92.18
	Ostracoda	437	Ennucula tenuis	80.04
	Brachydiastylis resima	250	Cyclocardia crebricostata	18.95
	Leitoscoloplos pugettensis	160	Astarte montagui	16.17
BF017	Paraphoxus sp.	600	Astarte borealis	94.25
	Lumbrineris sp.	327	Astarte montagui	83.03
	Leitoscoloplos pugettensis	253	Cyclocardia crebricostata	28.75
	Photis sp.	147	Ennucula tenuis	26.12
	Prionospio steenstrupi	127	Lumbrineris sp.	17.61
BF019	Owenia fusiformis	390	Ennucula tenuis	34.70
	Lumbrineris sp.	387	Maldane glebifex	17.81
	Maldane glebifex	383	Macoma moesta	13.21
	Paraphoxus sp.	313	Lyonsia arenosa	10.22
	Myriochele heeri	307	Musculus corrugatus	6.83
BF021	Lumbrineris sp.	173	Maldane glebifex	29.75
	Paraphoxus sp.	140	Ennucula tenuis	29.24
	Ennucula tenuis	113	Macoma moesta	8.44
	Leitoscoloplos pugettensis	67	Ampelisca eschrichti	4.68
	Cirratulidae	57	Lumbrineris sp.	4.16
BF023	Lumbrineris sp.	250	Macoma calcarea	49.91
	Cirratulidae	147	Astarte borealis	46.61
	Paraphoxus sp.	143	Golfingia margaritacea	36.65
	Leitoscoloplos pugettensis	140	Astarte montagui	34.37
	Ennucula tenuis	87	Cyclocardia crebricostata	22.75
BF025	Lumbrineris sp.	450	Macoma calcarea	187.96
	Byblis sp.	427	Ennucula tenuis	76.78
	Cirratulidae	227	Macoma moesta	35.26
	Ennucula tenuis	200	Yoldia hyperborea	9.06
	Macoma calcarea	190	Cistenides granulata	7.11
BN001	Brachydiastylis resima	90	Astarte borealis	72.75
	Ostracoda	87	Maldane glebifex	21.28
	Ennucula tenuis	83	Golfingia margaritacea	18.65
	Barantolla americana	63	Axiothella catenata	17.80
	Maldane glebifex	57	Ennucula tenuis	10.50
BR005	Lumbrineris sp.	343	Ennucula tenuis	31.29
	Byblis sp.	150	Macoma calcarea	29.21
	Paraphoxus sp.	150	Astarte montagui	17.84
	Leitoscoloplos pugettensis	140	Terebellides stroemi	17.78
	Byblis frigidis, Ennucula tenuis	137	Boreotrophon muriciformis	15.06

Table AI. Continued.

Station	Taxon	Abundance	Taxon	Biomass
BR016	Lumbrineris sp.	457	Macoma calcarea	67.71
	Ennucula tenuis	233	Priapulus caudatus	66.87
	Leitoscoloplos pugettensis	200	Ennucula tenuis	62.50
	Byblis sp.	197	Macoma moesta	35.41
	Paraphoxus sp.	153	Astarte borealis	16.06
BR020	Byblis sp.	930	Macoma calcarea	105.91
	Lumbrineris sp.	390	Ennucula tenuis	31.34
	Byblis frigidis	273	Astarte borealis	20.83
	Paraphoxus sp.	250	Byblis frigidis	16.85
	Ennucula tenuis	150	Cyclocardia crebricostata	16.39
BR032	Lumbrineris sp.	323	Astarte borealis	213.61
	Paraphoxus sp.	290	Golfingia margaritacea	184.04
	Leitoscoloplos pugettensis	180	Astarte montagui	27.33
	Onuphis parva	140	Golfingia vulgaris	22.71
	Ostracoda	110	Axiothella catenata	17.46
BR038	Myriochele heeri	1073	Macoma calcarea	152.69
	Maldane glebifex	580	Ennucula tenuis	102.36
	Lumbrineris sp.	410	Liocyma fluctuosa	35.52
	Ennucula tenuis	333	Astarte montagui	21.14
	Leitoscoloplos pugettensis	273	Maldane glebifex	20.65
BR043	Maldane glebifex	8487	Maldane glebifex	115.11
	Ostracoda	1130	Golfingia margaritacea	64.21
	Photis sp.	1000	Cyclocardia crebricostata	21.43
	Maldane sp.	710	Astarte borealis	18.56
	Brachydiastylis resima	177	Lumbrineris fragilis	15.39
BR047	Maldane glebifex	2433	Macoma calcarea	56.55
	Maldane sp.	877	Ennucula tenuis	50.90
	Ostracoda	720	Maldane glebifex	35.94
	Prionospio steenstrupi	293	Cyclocardia crebricostata	24.10
	Paraphoxus sp.	280	Maldane sp.	17.10
BR077	Ostracoda	610	Cyclocardia crebricostata	26.72
	Ennucula tenuis	147	Astarte montagui	19.19
	Paraphoxus sp.	140	Ennucula tenuis	10.74
	Lumbrineris sp.	137	Yoldia myalis	5.65
	Brachydiastylis resima	123	Maldane sp.	4.62
BR080	Ostracoda	667	Lumbrineris fragilis	17.35
	Photis sp.	453	Maldane glebifex	12.02
	Pontoporeia femorata	377	Ennucula tenuis	8.77
	Ennucula tenuis	217	Flabelligera affinis	6.86
	Maldane glebifex	170	Cyclocardia crebricostata	6.80

Table AI. Continued.

Station	Taxon	Abundance	Taxon	Biomass
BR086	Ennucula tenuis	147	Astarte borealis	67.44
	Lumbrineris sp.	143	Golfingia margaritacea	53.08
	Ostracoda	110	Maldane glebifex	25.73
	Barantolla americana	90	Ennucula tenuis	16.18
	Leitoscoloplos pugettensis	70	Axiothella catenata	15.18
BR087	Ostracoda	147	Maldane glebifex	52.69
	Paraphoxus sp.	140	Axiothella catenata	22.03
	Lumbrineris sp.	137	Maldane sp.	16.65
	Maldane glebifex	97	Onuphis parva	9.58
	Ennucula tenuis	80	Astarte montagui	9.00
BR093	Ostracoda	197	Astarte borealis	158.35
	Ennucula tenuis	143	Maldane glebifex	40.16
	Maldane glebifex	70	Golfingia margaritacea	24.82
	Brachydiastylis resima	63	Astarte montagui	24.21
	Lumbrineris sp.	53	Golfingia vulgaris	21.66
BR098	Lumbrineris sp.	123	Astarte borealis	151.70
	Ostracoda	93	Maldane glebifex	26.54
	Brachydiastylis resima	90	Nicomache lumbricalis	7.87
	Retusa obtusa	77	Yoldia myalis	7.32
	Paraphoxus sp.	77	Ennucula tenuis	7.07
	Maldane glebifex	63		
BR099	Photis sp.	447	Astarte borealis	227.92
	Ostracoda	153	Cyclocardia crebricostata	22.54
	Paraphoxus sp.	133	Yoldia myalis	19.95
	Brachydiastylis resima	100	Maldane glebifex	17.04
	Lumbrineris sp.	80	Yoldia hyperborea	9.69
BR100	Photis sp.	210	Astarte borealis	53.65
	Ostracoda	180	Axiothella catenata	28.17
	Brachydiastylis resima	127	Maldane glebifex	23.30
	Maldane glebifex	97	Cyclocardia crebricostata	15.04
	Ennucula tenuis	87	Ennucula tenuis	12.05
KF001	Spirorbis sp.	160	Macoma calcarea	65.94
	Ennucula tenuis	107	Golfingia margaritacea	35.75
	Barantolla americana	87	Nuculana radiata	8.40
	Cirratulidae	63	Euspira pallida	7.90
	Maldane glebifex	60	Astarte montagui	7.35
KF003	Barantolla americana	90	Maldane glebifex	21.20
	Ennucula tenuis	47	Proclea emmi	9.34
	Cirratulidae, Maldane glebifex	37	Lanassa venusta	4.38
	Leucon nasica	23	Nuculana pernula	4.17
	Praxillella praetermissa, Maldane sp.	17	Maldane sp.	3.69

Table AI. Continued.

Station	Taxon	Abundance	Taxon	Biomass
KF005	Ennucula tenuis	110	Astarte borealis	75.52
	Maldane glebifex	110	Maldane glebifex	58.18
	Leucon nasica	57	Ennucula tenuis	8.55
	Protomedeia sp.	33	Cyclocardia crebricostata	7.49
	Cirratulidae	33	Rhynchocoela	6.38
KF007	Cirratulidae	117	Golfingia margaritacea	61.24
	Ennucula tenuis	87	Astarte borealis	33.41
	Maldane glebifex	80	Neoamphitrite groenlandica	15.09
	Barantolla americana	70	Maldane glebifex	12.16
	Cossura sp.	67	Ennucula tenuis	7.24
KF009	Maldane glebifex	70	Maldane glebifex	32.44
	Ennucula tenuis	67	Lumbrineris fragilis	9.41
	Barantolla americana	50	Maldane sp.	5.04
	Cirratulidae	37	Sternaspis fossor	3.25
	Leucon nasica, Maldane sp.	33	Nephtys paradoxa	3.23
KF011	Nuculana radiata	33	Nephtys punctata	71.57
	Ennucula tenuis	30	Nuculana radiata	27.48
	Maldane glebifex	23	Euspira pallida	9.99
	Sternaspis fossor	20	Maldane glebifex	8.88
	Byblis gaimardi ,Cirratulidae, Maldane sp.	17	Lanassa venusta	4.56
KF013	Barantolla americana	107	Macoma calcarea	77.53
	Ennucula tenuis	100	Maldane glebifex	53.37
	Maldane glebifex	67	Ennucula tenuis	10.23
	Cirratulidae	43	Ampharete acutifrons	10.19
	Leucon nasica	33	Proclea sp.	9.77
KF015	Praxillella praetermissa	103	Nephtys punctata	7.94
	Cirratulidae	63	Macoma calcarea	6.17
	Leitoscoloplos pugettensis	60	Liocyma fluctuosa	5.66
	Ennucula tenuis,	43	Ennucula tenuis	1.69
	Macoma sp.	43	Solariella varicosa	1.58
KF017	Ennucula tenuis	70	Axiothella catenata	11.50
	Leucon nasica	27	Lumbrineris fragilis	6.37
	Sternaspis fossor	20	Proclea emmi	5.88
	Axinopsida serricata	17	Maldane glebifex	4.96
	Barantolla americana, Cirratulidae	17	Lanassa venusta	3.45
KF019	Cirratulidae	230	Astarte montagui	17.98
	Leitoscoloplos pugettensis	150	Euspira pallida	10.85
	Barantolla americana	77	Cerianthidae	4.86
	Lumbrineris sp.	73	Cryptonatica affinis	3.79
	Terebellides stroemi	53	Terebellides stroemi	3.27

Table AI. Continued.

Station	Taxon	Abundance	Taxon	Biomass
KF021	Sternaspis fossor	60	Nuculana radiata	26.84
	Cirratulidae	50	Nuculana pernula	24.96
	Polydora sp.	40	Sternaspis fossor	3.62
	Ennucula tenuis	37	Rhynchocoela	2.54
	Nuculana pernula , Nuculana radiata	33	Ennucula tenuis	2.07
KF023	Ennucula tenuis	93	Maldane glebifex	15.82
	Sternaspis fossor	50	Golfingia margaritacea	13.58
	Maldane glebifex	37	Ennucula tenuis	9.52
	Nephtys punctata	30	Sternaspis fossor	5.44
	Thyasira flexuosa	30	Axiothella sp.	4.17
KF025	Maldane glebifex	97	Golfingia margaritacea	74.33
	Ennucula tenuis	80	Maldane glebifex	50.49
	Ostracoda	50	Axiothella catenata	30.32
	Praxillella praetermissa	33	Trichotropis kroyeri	16.66
	Leucon nasica	27	Praxillella gracilis	11.81
KR001	Nuculana radiata	120	Nuculana radiata	91.37
	Sternaspis fossor	100	Maldane glebifex	6.17
	Thyasira flexuosa	23	Chone duneri	3.97
	Cirratulidae	20	Sternaspis fossor	3.63
	Ennucula tenuis	20	Maldane sp.	3.60
KR007	Ennucula tenuis	130	Astarte borealis	39.15
	Maldane glebifex	53	Maldane glebifex	31.81
	Leucon nasica	30	Axiothella catenata	15.77
	Thyasira flexuosa	23	Ennucula tenuis	7.88
	Praxillella praetermissa	20	Liocyma fluctuosa	4.48
KR008	Barantolla americana	123	Astarte borealis	72.18
	Praxillella praetermissa	80	Astarte montagui	54.10
	Maldane glebifex	73	Cyclocardia crebricostata	27.13
	Ennucula tenuis	60	Maldane glebifex	24.11
	Cirratulidae, Ostracoda	57	Axiothella catenata	19.14
KR009	Paraphoxus sp.	83	Maldane glebifex	20.36
	Phascolion strombi	73	Nicomache lumbricalis	17.47
	Lepeta caeca	63	Cyclocardia crebricostata	15.90
	Maldane glebifex	63	Phascolion strombi	4.59
	Barantolla americana , Terebellides stroemi	50	Boreotrophon truncatus	2.99
KR016	Ennucula tenuis	87	Maldane glebifex	29.28
	Maldane glebifex	67	Periploma aleuticum	15.35
	Barantolla americana	57	Axiothella catenata	14.81
	Arcteobia anticostiensis	37	Clymenella sp.	14.08
	Cirratulidae, Leucon nasica,	30	Neoamphitrite groenlandica	9.66
	Sternaspis fossor	30		

Table AI. Continued.

Station	Taxon	Abundance	Taxon	Biomass
KR019	Maldane glebifex	83	Maldane glebifex	39.35
	Ennucula tenuis	70	Axiothella catenata	15.18
	Maldane sp.	43	Macoma calcarea	11.58
	Sternaspis fossor	30	Rhynchocoela	9.46
	Pontoporeia femorata ,Thyasira flexuosa	23	Yoldia hyperborea	7.86
	Retusa obtusa	23		
KR034	Ennucula tenuis	50	Maldane glebifex	12.98
	Cirratulidae	43	Macoma calcarea	10.37
	Barantolla americana	37	Nephtys punctata	5.88
	Nephtys punctata	30	Proclea sp.	1.86
	Sternaspis fossor	23	Ennucula tenuis	1.48
KR043	Ennucula tenuis	83	Maldane glebifex	46.92
	Maldane glebifex	53	Praxillella gracilis	7.73
	Barantolla americana	40	Nuculana radiata	5.26
	Cirratulidae Sternaspis fossor	27	Liocyma fluctuosa	4.99
	Arcteobia anticostiensis	27	Nicomache lumbricalis	4.77
KR045	Maldane glebifex	70	Golfingia margaritacea	64.80
	Ennucula tenuis	63	Maldane glebifex	58.06
	Barantolla americana	60	Axiothella catenata	23.25
	Praxillella praetermissa	40	Macoma moesta	14.23
	Heteromastus filiformis	33	Nephtys paradoxa	4.07
KR056	Maldane glebifex	150	Maldane glebifex	80.00
	Ennucula tenuis	110	Golfingia margaritacea	30.22
	Barantolla americana	87	Ennucula tenuis	17.93
	Cirratulidae	27	Periploma aleuticum	11.90
	Praxillella praetermissa, Protomedeia sp.	23	Nuculana radiata	9.78
KR066	Ennucula tenuis, Maldane glebifex	73	Golfingia margaritacea	55.48
	Barantolla americana	50	Maldane glebifex	40.97
	Cirratulidae	37	Nuculana radiata	18.72
	Praxillella praetermissa	33	Periploma aleuticum	14.72
	Leucon nasica	23	Nephtys caeca	11.21
KR083	Maldane glebifex	137	Maldane glebifex	40.83
	Barantolla americana	63	Macoma moesta	9.42
	Spirorbis sp.	60	Liocyma fluctuosa	9.13
	Cirratulidae	57	Nicomache lumbricalis	6.03
	Phascolion strombi	57	Ennucula tenuis	5.00
KR095	Capitella capitata	67	Nuculana radiata	43.53
	Ennucula tenuis	57	Golfingia margaritacea	15.84
	Nuculana radiata	57	Macoma calcarea	14.19
	Sternaspis fossor	37	Ennucula tenuis	5.21
	Leucon nasica	37	Maldane glebifex	4.27

Appendix II

Plots of distributions of Dominant Fauna from the
Burger and Klondike Survey areas
for the 2008 Chukchi Sea Environmental Study

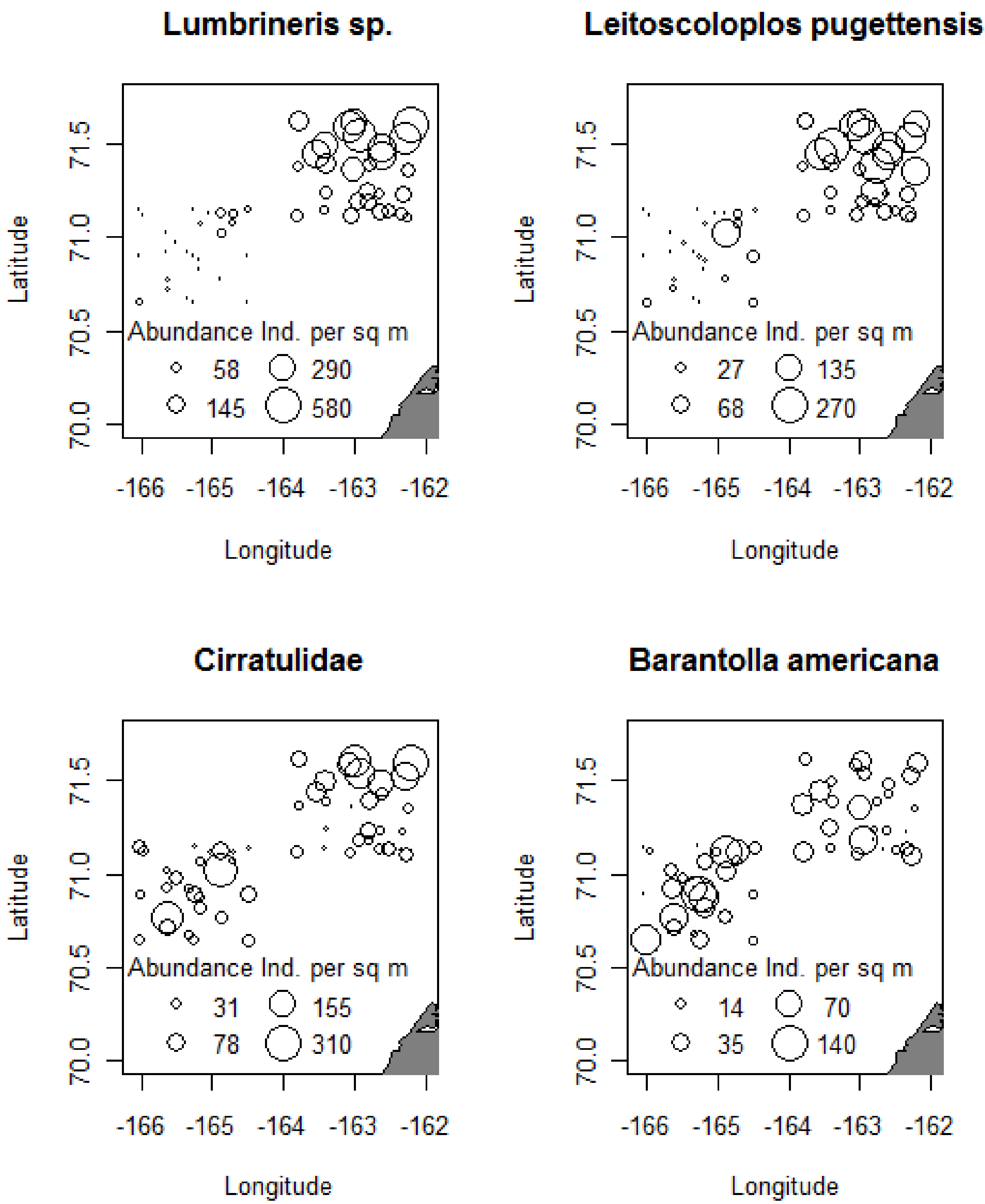

Figure A-1. Abundance of selected polychaete worms from Burger and Klondike survey areas, 2008.

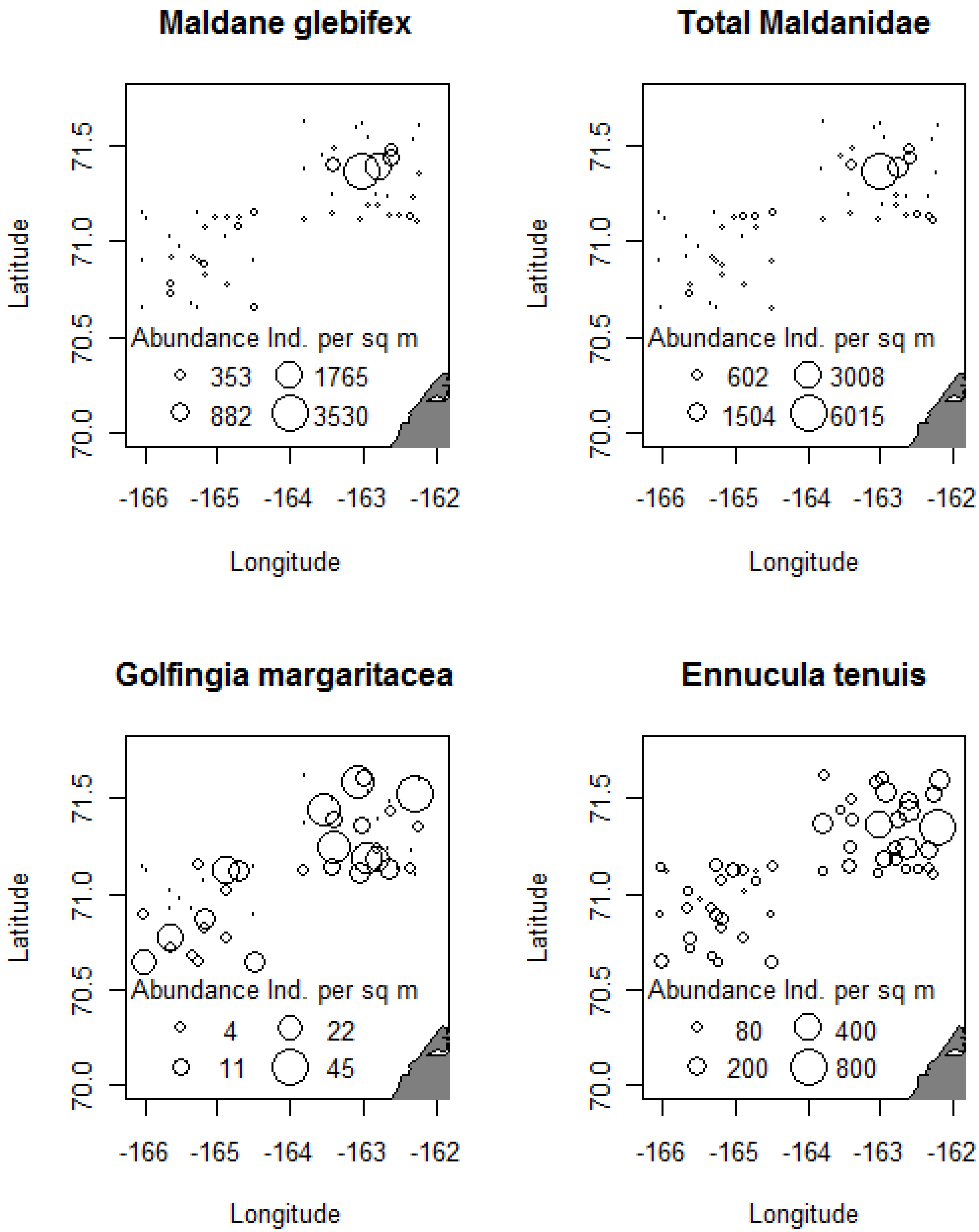

Figure A-2. Abundance of selected polychaete worms, the sipunculan worm *G. margaritacea*, and the bivalve *E. tenuis* from Burger and Klondike survey areas, 2008.

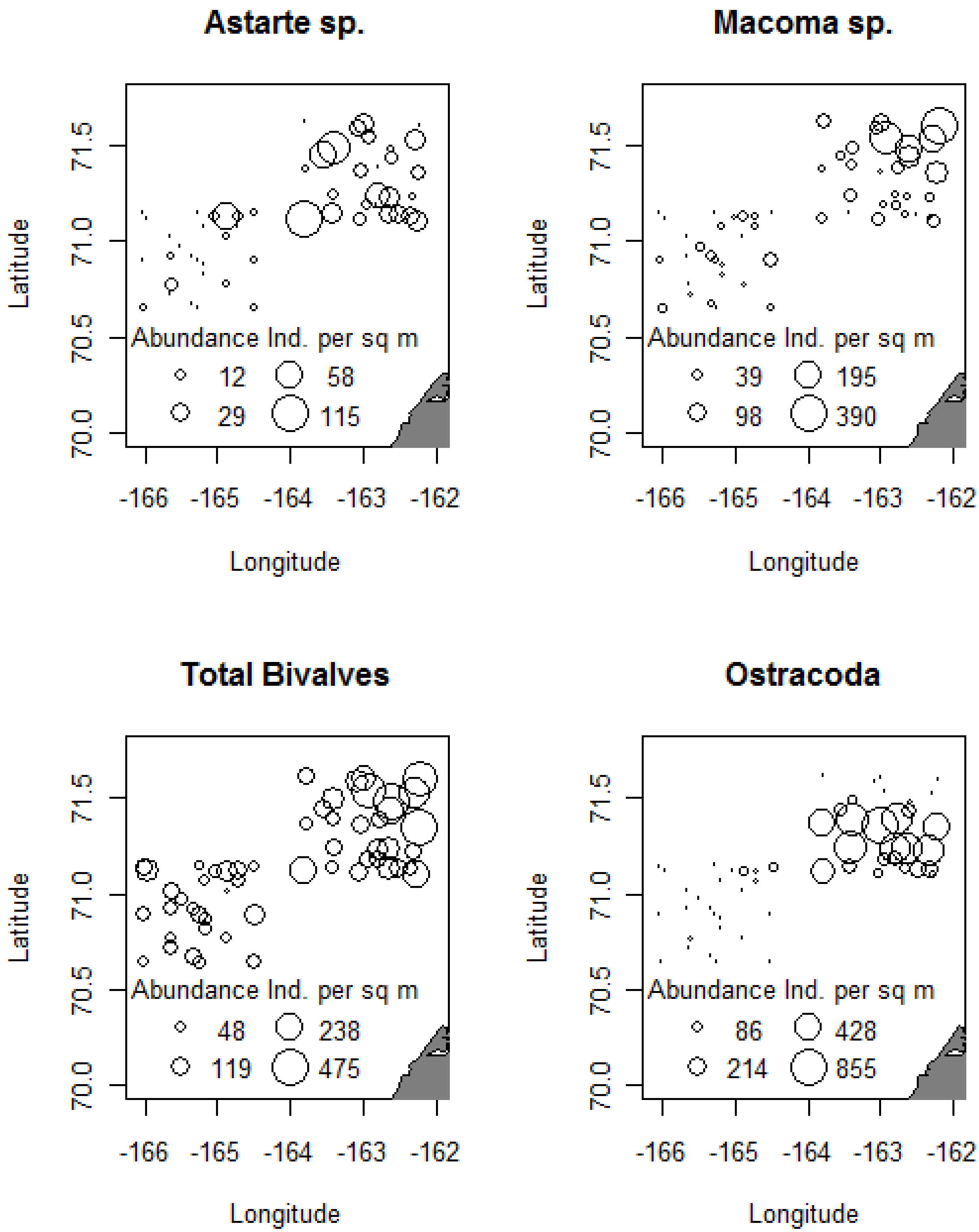

Figure A-3. Abundance of selected bivalves and Ostracods from Burger and Klondike survey areas, 2008.

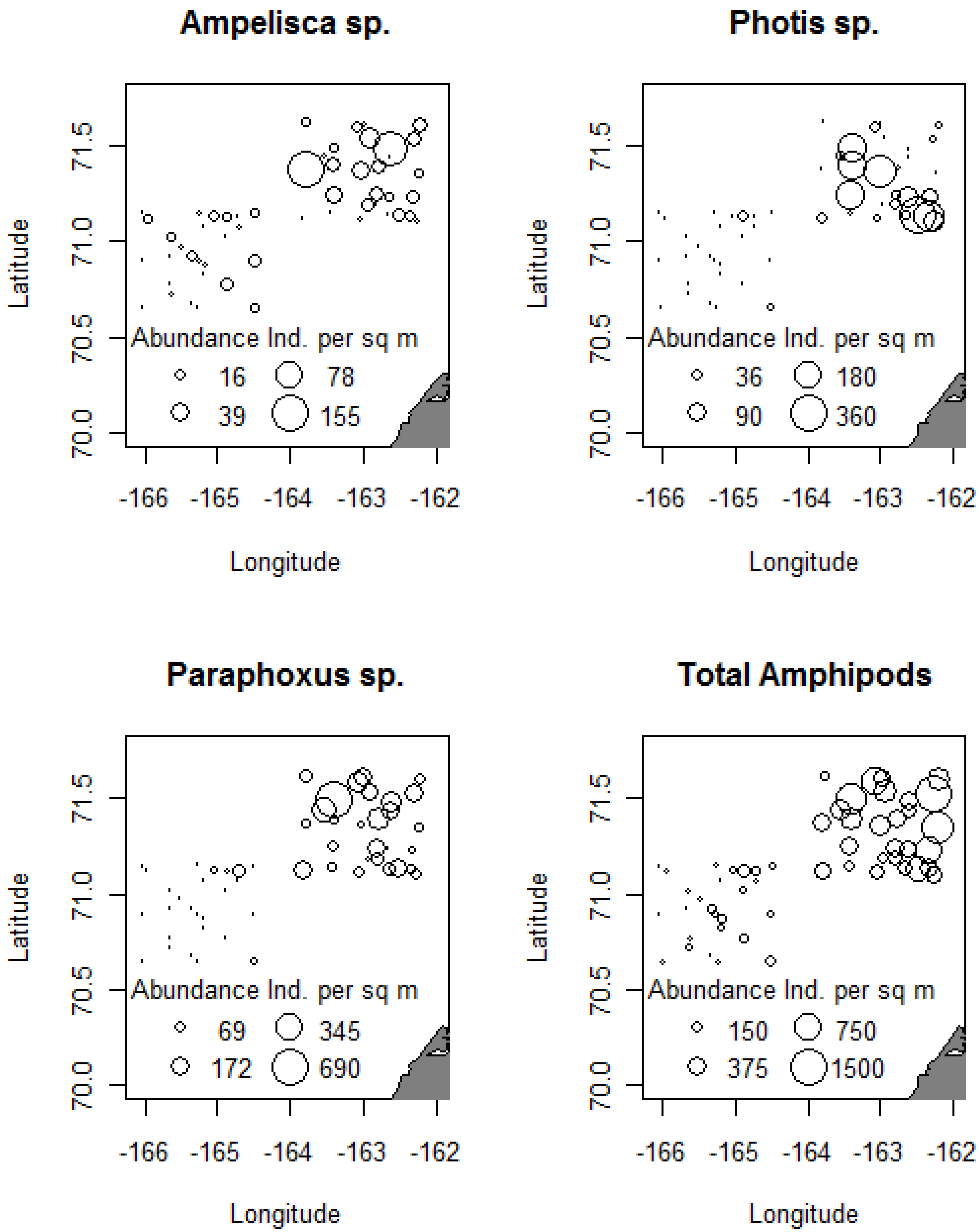

Figure A-4. Abundance of selected amphipods and total amphipods from Burger and Klondike survey areas, 2008.