CHUKCHI SEA ENVIRONMENTAL STUDIES PROGRAM

2008-2010:

BENTHIC ECOLOGY OF THE NORTHEASTERN CHUKCHI SEA

Prepared for

ConocoPhillips Alaska, Inc.
P.O. Box 100360
Anchorage, AK 99510-0360

Shell Exploration & Production Company
3601 C Street, Suite 1334
Anchorage, AK 99503

and

Statoil USA E & P, Inc.
2700 Gambell St
Anchorage, AK 99507

FINAL REPORT

Prepared by

Arny L. Blanchard
Carrie L. Parris
Ann L. Knowlton

Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775-7220

September 2011

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

ConocoPhillips, Shell Exploration and Production Company, and Statoil USA E&P are supporting a multi-disciplinary environmental studies program to establish ecological baseline conditions within three survey areas in the northeastern Chukchi Sea. The research program is managed by Olgoonik-Fairweather LLC. The Klondike, Burger, and Statoil survey areas are located where successful lease bids were made in the February 2008 Chukchi Sea Lease Sale 193. The overall field program will provide information on physical, chemical, and biological (including zooplankton and benthic ecology), and oceanographic baseline trends. The study was initiated in 2008 and sampling continued in 2009 and 2010.

Objectives of the benthic ecology component were to document infaunal and epifaunal community structure within the Klondike, Burger, and Statoil survey areas and to determine associations of community structures with environmental factors. For the first discipline within the benthic ecology study, infauna (sediment-dwelling organisms retained on a 1.0 mm sieve) and environmental parameters were sampled at 76 stations in the Klondike (26 stations), Burger (26 stations), and Statoil (24 stations, 2010 only) survey areas. Three (2010) to six (2009) stations, the Mammal Feeding stations, were also sampled in an area northwest of Wainwright where gray whales were observed feeding. In 2010, infauna were sampled at four Transition stations located between the Klondike and Burger areas along the environmental gradient between the survey areas. In the second discipline within benthic ecology, epifauna (larger invertebrate organisms residing on the sediment surface captured by trawling) were sampled twice in 2009 at 26 sites during two cruises (August and October) to the Klondike (13 stations) and Burger (13 stations) survey areas. The same sites sampled for epifauna in 2009 were resampled in 2010, plus an additional 11 stations were sampled in the Statoil survey area, with all the 2010 sampling occurring only once that year. Two Transition stations located between Klondike and Burger were also sampled for epifauna. This report summarizes the results of the benthic ecology portion of the 2008-2010 northeastern Chukchi Sea Environmental Studies Program (CSESP), providing insights into multiyear trends.

Benthic infauna in the Klondike, Burger, and Statoil survey areas were abundant, contained many taxa with high biomass, and comprised diverse communities. Significant differences in community characteristics were apparent with variance-weighted, repeated measures analysis of variance (rm ANOVA) indicating that Burger had greater average abundance, biomass, and sample number of taxa than Klondike. Statoil and Transition stations were intermediate along the gradient between Klondike and Burger. Multivariate analyses indicated separation of infaunal communities by survey area and community structure was correlated with water depth and water temperature reflecting the influence of topography, water currents, and other geologic and oceanographic differences among the survey areas.

The infaunal community found at the Mammal (gray whale) Feeding stations was quite different from the communities found in the Klondike, Burger, and Statoil survey areas. In 2009 and 2010, the Mammal Feeding stations were dominated by amphipods, a preferred prey item for gray whales, whereas the faunal communities found in the other study areas were dominated by bivalves and polychaete worms.

There appear to be substantial temporal differences in infaunal community composition over time. Average abundance and average number of taxa both increased in 2009, relative to 2008, and declined in 2010 in Burger and Klondike. In contrast, biomass declined in 2009 and rose in 2010. The trends in average abundance and the number of taxa appear to be related to strong environmental and oceanographic changes from 2008 to 2010 where winds from the south increased the flux of warmer water into the study area in 2009. Mechanisms explaining the responses by infauna to the variable environment include a greater flux of larvae to the north in 2009, changes in food resources through ecosystem variability, and altered survival and recruitment by direct influences of water temperature. Infaunal communities can respond quickly to changes in water masses and water temperature. Although the mechanisms are unknown, the response of the infaunal communities to climatic variations and water temperature changes from 2008 to 2010 follows patterns observed elsewhere in Alaska.

The epifaunal communities of Klondike, Burger, and Statoil comprised taxon groups with high abundance and biomass. Most species were shared between the survey areas but communities differed somewhat in composition. The multivariate analyses demonstrated differences in the epifaunal community of the survey areas as stations fell along a gradient from Klondike to Statoil to Burger. The gradient in community structure was associated with water temperature and total chlorophyll reflecting oceanographic conditions. No strong association was apparent between potential infaunal prey and epifaunal predators. Additionally, there was no direct evidence that epifaunal communities varied by season or year as rm ANOVA did not demonstrate differences among cruises. There were, however, significant differences by survey

area in the rm ANOVA with Burger having higher abundance and biomass than Klondike. Abundance and biomass at Statoil and the Transition stations were low and more similar to Klondike. Two multivariate procedures indicated a strong association between community structure and water temperature suggesting that the strong climatic change observed between 2009 and 2010 did have an influence on epifaunal communities although this was not apparent from the rm ANOVA results.

In summary, trends in the infaunal and epifaunal communities indicate that the oceanographic and topographic characteristics of the study area are important variables in determining community composition. The infauna and epifauna communities are a mix of Arctic and North Pacific invertebrate fauna resulting from the flow of water northward through the Bering Strait to the Arctic Ocean importing heat, nutrients, and larvae to the Chukchi Sea. Communities are comprised of numerous, large animals with diverse composition reflecting the flux of unconsumed ice algae and phytoplankton production. The large body size and known habits of animals found in the study area, including marine mammals, indicate a high level of biological activity within the sediment column (bioturbation) and interactions between animals (e.g., predator/prey relationships). As a result, biological interactions are important in maintaining the structure and diversity of benthic fauna in the study area. Both types of animals, those living within and those living on top of the sediments, demonstrated gradients in community characteristics and composition. The strongest difference was between Klondike and Burger in both studies, with Statoil and the Transition stations being intermediate in most characteristics. The environmental gradient appears to be associated with the change in depth at Burger as the survey area is at the head of a submarine valley. The change in topography interacting with water currents and oceanographic variables enhances the deposition of food (primary production) at Burger resulting in greater abundance and biomass of animals.

CHAPTER 1

GENERAL INTRODUCTION

ConocoPhillips (COP), Shell Exploration and Production Company (SEPCO), and Statoil USA E&P are supporting a multi-disciplinary environmental studies program to establish baseline conditions for three survey areas in the northeastern Chukchi Sea. The project is managed by Olgoonik-Fairweather LLC (OLF). The survey areas are Klondike, Burger, and Statoil (2010 only) where successful lease bids were made in the February 2008 Chukchi Sea Lease Sale 193. The overall research program will provide information on physical, chemical, biological (including zooplankton and benthic ecology), and oceanographic baseline trends for the Klondike, Burger, and Statoil survey areas. The Chukchi Sea Environmental Studies Program (CSESP) was initiated in 2008 and continued in 2009 and 2010.

Since the 2008 lease sale, interest in understanding the arctic environment has grown, with regulatory agencies and academia directing efforts toward improving the understanding of the environment, including the Chukchi Sea (Hopcroft et al., 2006). Resources in the Chukchi Sea are of great importance 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; Feder et al., 2005; Grebmeier et al., 2006; Feder et al., 2007). Benthic organisms in the northern Bering and Chukchi seas are important food resources for higher trophic level organisms such as demersal fishes, various seals, walrus, and gray whales (e.g. Oliver et al., 1983; Feder et al., 1994a, b, 2005, and 2007; 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 hot spots for feeding gray whales and walrus are located south of St. Lawrence Island and in 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 and Coyle, 1992; Highsmith et al., 2006; Bluhm and Gradinger, 2008).

Scientific studies conducted intermittently over the last 37 years provide a basis for understanding the ecology of offshore benthic communities in the northeastern Chukchi Sea.

The first study of macrofaunal community structure was performed in 1971 to 1974 by Stoker (1978 and 1981). This was followed in 1986 and 1987 by investigations of the benthos/environmental interactions by Feder et al. (1994a and b). Following the latter study, Grebmeier et al. (1988) documented the strong association between annual pelagic production reaching the bottom and the benthic communities (pelagic-benthic coupling) in the southeastern Chukchi Sea. The infauna of the Chukchi Sea are abundant 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 (larger animals residing on the sediment surface) is also present in the northeastern and southeastern Chukchi Sea, including numerous mollusks, crabs, and echinoderms (e.g., Feder et al., 1994a, 2005; Ambrose et al., 2001; Bluhm et al., 2009). Recent and on-going 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 Bureau of Ocean Energy Management, Regulation and Enforcement's (BOEMRE) Chukchi Sea Offshore Monitoring in Drilling Area (COMIDA) program. All of the latter programs focus on broad-scale sampling throughout the northeast 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 baseline databases adequate for evaluating long-term trends with confidence (e.g., repeated sampling at similar locations over space and time using similar sampling methods) in macrofaunal communities of the northeast Chukchi Sea.

The multi-year, COP/SEPCO/Statoil-sponsored CSESP initiated in 2008 and continued in 2009 and 2010 will contribute to understanding the benthic ecology within the survey areas. Overall, benthic communities in Burger and Klondike sampled in 2008 and 2009 were diverse and fauna abundant, comparable to those found in prior research and trends were related to apparent environmental gradients (Feder et al., 1994b; Blanchard et al., 2010). The results of the sampling in 2010 will allow for assessment of short-term temporal trends in addition to the evaluation of spatial trends, as performed in 2008 and 2009 (Blanchard et al., 2010). The results of this three-year investigation in the northeastern Chukchi Sea will contribute to developing the necessary benchmark to determine potential changes in the benthos from climate change or other natural environmental fluctuations.

This general introduction describes the overall sampling plans, details on annual variations to the sampling plan, and station coordinates for the 2008-2010 CSESP.

OBJECTIVES

The objectives of the benthic ecology component of the 2010 CSESP were similar to those of the 2008 and 2009 program, except that two new study areas were added:

- Sample infaunal and epifaunal organisms within the Klondike, Burger, Statoil, and the Transition sites that are located between Klondike and Burger survey areas to document benthic infaunal and epifaunal community structure;

- Assess species composition, abundance, and biomass of benthic communities within the three survey areas and determine associations of community structures with environmental factors; and

- Sample the infauna in areas where marine mammals were observed feeding (six stations were sampled where gray whales were observed feeding in 2009 and three stations in 2010).

METHODS

Nomenclature for the 2008-2010 Sampling Cruises

Vessels are identified by a unique letter code. The M/V Bluefin (BF) was used for sampling in 2008. The M/V Westward Wind (WW) was used for sampling in 2009 and 2010.

Cruises are identified by the ship name, year of sampling, and the number by which cruises are ordered within each year. Cruise designations are: BF0803 for benthic sampling in 2008 which occurred from August 21 to September 25. In 2009, three benthic cruises were accomplished and named WW0902, WW0903, and WW0904 with epifaunal sampling occurring on WW0902 (August 14-29) and WW0904 (September 25 - October 10) and infaunal sampling on cruise WW0903 (September 5-19). Infauna were sampled on cruise WW1002 (August 5-19) in 2010 and epifauna on cruise WW1003 (September 1-18).

The survey areas were identified with a one character code for the three areas, Klondike (K), Burger (B), and Statoil (S), a one character code for the type of station sampled as fixed (F) or random (R), and lastly, the station number. Mammal Feeding stations were given the character code TM and the Transition stations were coded as TF.

Infauna Sampling Methods

The term "infauna" is herein limited to invertebrate animals residing in sediments and retained on a 1.0 mm mesh screen. Large, mobile organisms or those not adequately sampled by the van Veen grab (the epifauna) are excluded. The term "macrofauna" is often considered synonymous with "infauna" but the exclusion of mobile and epifaunal organisms in this project favors use of the term "infauna".

Infauna was sampled using a double van Veen grab with two 0.1 m^2 adjoining grabs to collect sediments for analyzing sediment grain-size, chlorophyll, sediment and tissue stable isotopes, and infauna. Three replicate grabs were collected at each station (Table 1-1, Fig. 1-1). Material from each grab for infauna 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 specialist. All organisms were counted and wet weights measured (after excess moisture was removed with an absorbent towel, following protocols of Feder et al., 1994b). For each replicate sample, identifiable tissue fragments were grouped together and recorded as one individual at the family level or higher, and the wet weight of the composite fragment category recorded.

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 Microsoft (MS) Access database and a datasheet printed. Datasheets are stored at the University of Alaska's Institute of Marine Science (UAF IMS) as a record of current taxonomic status to track changes in nomenclature and a backup for the electronic database.

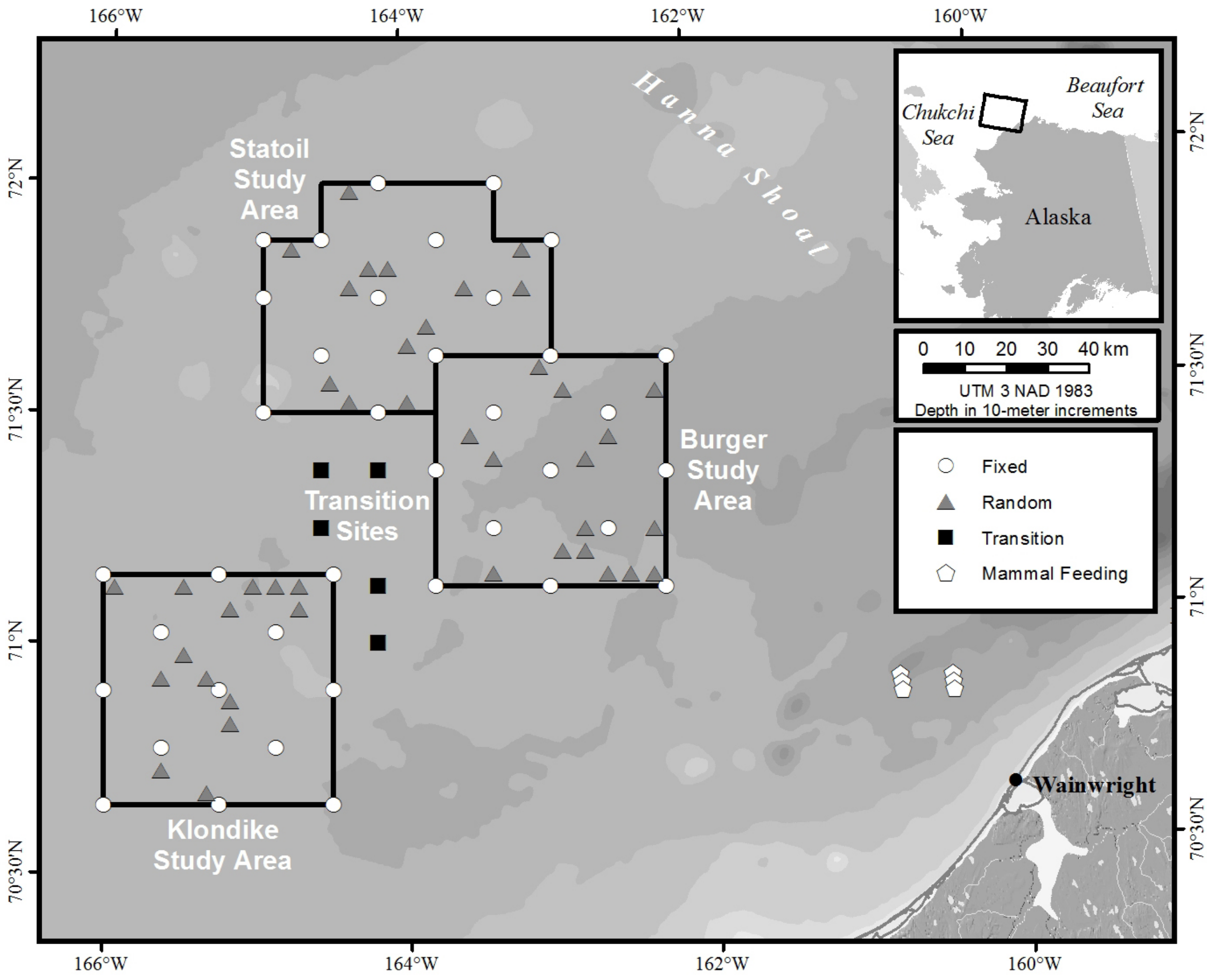


Figure 1-1. Map of all stations sampled during the 2008-2010 CSESP benthic surveys.

The first few centimeters of sediment were also collected from additional van Veen grab samples to determine chlorophyll-*a* and phaeopigment concentrations. Sediment samples for chlorophyll analysis were kept frozen and in the dark until processing, at which time they were thawed and the chlorophyll extracted in 10 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 for this study with 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 and absorbance (Arar and Collins, 1992; Montana Department of Environmental Quality, 2008). Chlorophyll *a* and phaeopigment concentrations were highly correlated so

Table 1-1. Station information for all benthic sampling during the 2008-2010 CSESP surveys. Intended positions (decimal degree format), year and type of sampling are given for each station. K = Klondike, B = Burger, S = Statoil, T = transition station between Burger and Klondike, F = fixed station, R = random station, TM = mammal feeding station.

			Infauna			Epifauna	
Station	Latitude, N	Longitude, W	2008	2009	2010	2009	2010
BF001	71.119873	-163.803481	x	x	x	x	x
BF003	71.113371	-163.034704	x	x	x	x	x
BF005	71.10371	-162.266597	x	x	x	x	x
BF007	71.241507	-163.408919	x	x	x	x	x
BF009	71.233368	-162.635541	x	x	x	x	x
BF011	71.368893	-163.788076	x	x	x	x	x
BF013	71.362297	-163.009414	x	x	x	x	x
BF015	71.352499	-162.231449	x	x	x	x	x
BF017	71.490482	-163.38829	x	x	x	x	x
BF019	71.482225	-162.604905	x	x	x	x	x
BF021	71.617904	-163.772246	x	x	x	x	x
BF023	71.611214	-162.983426	x	x	x	x	x
BF025	71.601273	-162.195332	x	x	x	x	x
BR005	71.587137	-163.064808	x	x	x		
BR016	71.535696	-162.912758	x	x	x		
BR020	71.527777	-162.284734	x	x	x		
BR032	71.441948	-163.548811	x	x	x		
BR038	71.432455	-162.611099	x	x	x		
BR043	71.390893	-163.396609	x	x	x		
BR047	71.384582	-162.773071	x	x	x		
BR077	71.23525	-162.79016	x	x	x		
BR080	71.229222	-162.326403	x	x	x		
BR086	71.187222	-162.95005	x	x	x		
BR093	71.141915	-163.417015	x	x	x		
BR098	71.133822	-162.647565	x	x	x		
BR099	71.131824	-162.493763	x	x	x		
KF001	70.645981	-166.002545	x	x	x	x	x
KF003	70.648553	-165.25147	x	x	x	x	x
KF005	70.648044	-164.500314	x	x	x	x	x
KF007	70.77219	-165.630936	x	x	x	x	x
KF009	70.773228	-164.875114	x	x	x	x	x
KF011	70.895031	-166.015109	x	x	x	x	x
KF013	70.897638	-165.254622	x	x	x	x	x

Table 1-1. continued

			Infauna			Epifauna	
Station	Latitude, N	Longitude, W	2008	2009	2010	2009	2010
KF015	70.897122	-164.494051	x	x	x	x	x
KF017	71.021259	-165.6389	x	x	x	x	x
KF019	71.022312	-164.873538	x	x	x	x	x
KF021	71.1431254	-166.029207	x	x		x	x
KF023	71.146717	-165.257859	x	x	x	x	x
KF025	71.146193	-164.487619	x	x	x	x	x
KR001	71.12019	-165.94887	x	x			
KR004	71.121349	-165.488305			x		
KR007	71.121985	-165.02675	x	x	x		
KR008	71.121943	-164.872895	x	x	x		
KR009	71.121776	-164.719042	x	x	x		
KR016	71.072084	-165.180147	x	x	x		
KR019	71.07196	-164.719754	x	x	x		
KR034	70.971906	-165.484612	x	x	x		
KR043	70.921632	-165.635689	x	x	x		
KR045	70.922426	-165.331094	x	x	x		
KR056	70.872819	-165.178341	x	x	x		
KR066	70.823002	-165.177895	x	x	x		
KR083	70.722375	-165.629369	x	x	x		
KR095	70.673343	-165.32699	x	x	x		
SF001	71.497437	-164.956047			x		x
SF003	71.618033	-163.771782			x		x
SF005	71.621472	-164.56105			x		x
SF007	71.746502	-164.955468			x		x
SF009	71.744678	-164.160892			x		x
SF011	71.739575	-163.36662			x		x
SF013	71.871032	-164.955173			x		
SF014	71.8714024	-164.549755					x
SF016	71.867037	-163.755503			x		x
SF018	71.860246	-162.956237			x		x
SF020	71.993709	-164.149686			x		x
SF022	71.988531	-163.344816			x		x
SR005	71.517422	-164.370156			x		
SR008	71.515719	-163.977649			x		
SR013	71.559319	-164.499923			x		
SR035	71.640232	-163.97096			x		
SR051	71.680981	-163.83675			x		

Table 1-1. continued

			Infauna			Epifauna	
Station	Latitude, N	Longitude, W	2008	2009	2010	2009	2010
SR077	71.766471	-164.361857			x		
SR083	71.762195	-163.566596			x		
SR086	71.758826	-163.169145			x		
SR093	71.807493	-164.227592			x		
SR094	71.806915	-164.09474			x		
SR104	71.850397	-164.758531			x		
SR116	71.841804	-163.161065			x		
SR137	71.974007	-164.354762			x		
TF001	70.99754	-164.19324			x		x
TF002	71.1239644	-164.179946					x
TF003	71.24788	-164.56949			x		
TF005	71.37241	-164.56671			x		
TF006	71.37112	-164.1774			x		
TM001	70.884	-160.74527		x	x		
TM002	70.86648	-160.73465		x	x		
TM003	70.8501	-160.73558		x	x		
TM004	70.87748	-160.39723		x			
TM005	70.86117	-160.39362		x			
TM006	70.84397	-160.39220		x			

chlorophyll *a* and total chlorophyll (chlorophyll *a* plus phaeopigments) were used to assess associations of faunal community structure with primary production in multivariate analyses.

Sediment samples (wet) collected from separate van Veen grabs from each station were washed through 2 mm and 63 µm nested sieves to determine proportions of gravel (>2 mm), sand (63 µm – 2 mm), and mud (<63 µm) (Wentworth, 1922). The flow-through water containing suspended particles <63 µm was collected to determine the weight of mud. The resulting fractions were dried at 60 °C for a minimum of 12 hours 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 and up to 24 hours then weighed again.

Epifauna Sampling Methods

The term “epifauna”, for the purposes of this report is limited to invertebrate animals residing on the sediment or closely associated with the surface sediment (e.g., large clams near the surface). Small organisms and those not adequately sampled by a bottom trawl (the infauna) are excluded. The term “megafauna” can be considered as synonymous with “epifauna” but may include a wider range of organisms, therefore, in this report, the term “epifauna” will be used to indicate invertebrate organisms collected by a bottom trawl.

Epifauna was sampled at the fixed stations in each survey area (Table 1-1, Fig. 3-1) using a plumb staff 3.05 m beam trawl with a 4 mm codend liner and 7 mm mesh. The beam trawl covered a swath that was 2.26 m wide. Trawls were towed at a constant speed of 1.5 knots for 2-3 minutes, with an occasional 5 minute tow. Material from each trawl was dumped onto a large sorting table and subsampled until the volume of the subsample was approximately 2 gallons, an amount that could be reasonably sorted. Occasionally an extremely muddy trawl sample was washed on a 4.0 mm stainless steel screen to remove mud particles before sorting. Taxonomic identifications of benthic organisms were performed by a trained taxonomist to verify identifications. All organisms in a subsample were counted and wet weights measured (weight after excess moisture was removed with an absorbent towel). Colonial organisms such as ascidiaceans, hydrozoans, bryozoans, and sponges were noted for presence and their wet weights determined. Once weighed, all organisms, except those kept for a voucher collection, were returned to the sea. Data collected in the field were recorded on water resistant paper and then entered into the TigerNav system.

Quality Assurance Procedures

The TigerNav system was developed for the CSESP to assist with data collection in the field while simultaneously linking field data with the ship’s navigation system. This allows for real-time geographic coordinates and oceanographic conditions to be linked with biological data. Data managers, onboard the vessel, were able to perform onsite quality control checks to assist with minimizing input errors of the data. The TigerNav system transcribed the data into a MS Access database which was archived along with the raw datasheets at UAF IMS.

Representative specimens of each taxon encountered during the CSESP were archived at IMS. These voucher specimens provide records of identification of organisms encountered in the study. While archived specimens may be sent to experts for further identification and/or verification, a complete collection of fauna will be maintained at IMS.

Quality control procedures were followed in processing infaunal samples in the laboratory. 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 approached the skill level expected for a more experienced taxonomist. Work was verified to ensure that all counts were accurate and all organisms were correctly identified. Fauna identified in the 2010 CSESP were compared to the voucher collection from the 1986 investigation by Feder et al. (1994b) and to current references (e.g., other benthic programs and our work in the same survey area throughout the years) to ensure accuracy, consistency between studies and, to the best of our abilities, consistency with current taxonomic status. After one year from the date 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 OLF, in accordance with prescribed data management protocols.

Prior to analyses of infaunal data sets, taxonomic information was scrutinized for consistency as a further quality control check. Pelagic, meiofauna, and epibenthic taxa [i.e., barnacles, tanaidaceans, benthic copepods, brittle stars, sea stars, crabs, etc.] were excluded from analytical data sets. Taxonomic information of epifaunal data sets was also scrutinized for consistency and pelagic and obvious infaunal taxa were excluded from data sets analyzed.

Representative samples of epifaunal organisms were preserved in 10% formalin-seawater buffered with hexamine and returned to Fairbanks to confirm identifications. Organisms were identified to the lowest taxonomic category possible and identifications evaluated by a team of taxonomists. Field identification of epifauna was to higher categories, due to the difficulty of species identifications without microscopes and other instruments.

REFERENCES

Ambrose, W. G., Clough, L. M., Tilney, P. R., and Beer, L., 2001. Role of echinoderms in benthic remineralization in the Chukchi Sea. Marine Biology, 139: 937-949.

Arar, E. J., and Collins, G. B., 1992. Method 445.0: In vitro determination of chlorophyll *a* and pheophytin *a* in marine and freshwater algae by fluorescence. National Exposure Research Laboratory, Office of Research and Development, US Environmental Protection Agency, EPA/600/R-97/072, Cincinnati, OH 45268.

Blanchard, A. L., Feder, H. M., Hoberg, M. K., 2010. Temporal variability of benthic communities in an Alaskan glacial fjord, 1971-2007. Marine Environmental Research, 69: 95-107.

Bluhm, B. A., Coyle, K. O., Konar, B., Highsmith, R., 2007. High gray whale relative abundances associated with an oceanographic front in the south-central Chukchi Sea. Deep Sea Research II, 54: 2919–2933.

Bluhm, B. A., Iken, K., Mincks Hardy, S., Sirenko, B. I., and Holladay, B. A., 2009. Community structure of the epibenthic megafauna in the Chukchi Sea. Aquatic Biology, 7: 269-293.

Bluhm, B. A., Gradinger, R., 2008. Regional variability in food availability for arctic marine mammals. Ecological Applications, 18 Supplement: S77–S96.

Coyle, K. O., Gillispie, J. A., Smith, R. L., Barber, W. E., 1997. Food habits of four demersal Chukchi Sea fishes. In Reynolds, J. (ed.), *Fish Ecology in Arctic North America*. American Fisheries Society Symposium 19, Betheseda, Maryland, p. 310-318.

Feder, H. M., Jewett, S. C., & Blanchard, A., 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology, 28: 402-421.

Feder H. M, Jewett, S. C., Blanchard, A. L., 2007. Southeastern Chukchi Sea (Alaska) Macrobenthos. Polar Biology, 30: 261-275.

Feder, H. M., Foster, N. R., Jewett, S. C., Weingartner, T. J., Baxter, R., 1994a. Mollusks of the northeastern Chukchi Sea. Arctic, 47: 145-163.

Feder, H. M., Naidu, A. S., Jewett, S. C., Hameedi, J. M., Johnson, W. R., Whitledge, T. E., 1994b. The northeastern Chukchi Sea: benthos-environmental interactions. Marine Ecology Progress Series, 111: 171-190.

Grebmeier, J. M., Cooper, L. W., Feder, H. M., Sirenko, B. I., 2006. Ecosystem dynamics of the Pacific-influenced Northern Bering and Chukchi Seas in the Amerasian Arctic. Progress in Oceanography, 71: 331–361.

Grebmeier, J. M., Harvey, H. R., Stockwell, D. A., 2009. The Western Arctic Shelf-Basin Interactions (SBI) project, volume II: An overview. Deep Sea Research Part II: Topical Studies in Oceanography, 56:1137-1143.

Grebmeier, J. M., McRoy, C. P., Feder, H. M., 1988. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. I. Food supply source and benthic biomass. Marine Ecology Progress Series, 48:57-67.

Green, J. M., Mitchell, L. R., 1997. Biology of the fish doctor, an eelpout, from Cornwallis Island, Northwest Territories, Canada. In Reynolds, J. (ed.), *Fish Ecology in Arctic North America*. American Fisheries Society Symposium 19, Bethesda, Maryland, pp. 140-147.

Highsmith, R. C., Coyle, K. O., 1992. Productivity of arctic amphipods relative to gray whale energy requirements. Marine Ecology Progress Series, 83: 141-150.

Highsmith, R. C., Coyle, K. O., Bluhm, B. A., Konar, B., 2006. Gray Whales in the Bering and Chukchi Seas. In Estes, J., DeMaster, D. P., Doak, D. F., Williams, T. M., Brownell, R. L. (eds) *Whales, Whaling and Ocean Ecosystems*. UC Press, pp 303-313.

Hopcroft, R., Bluhm, B., Gradinger, R., Whitledge, T., Weingartner, T., Norcross, B., Springer, A., 2006. Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research. Final report to North Pacific Research Board, 152 pp.

Lovvorn, J. R., Richman, S. E., Grebmeier, J. M., Cooper, L. W., 2003. Diet and body condition of spectacled eiders wintering in pack ice of the Bering Sea. Polar Biology, 26: 259-267.

Montana Department of Environmental Quality, 2008. Sample Collection and Laboratory Analysis of Chlorophyll-*a* Standard Operation Procedure. http://deq.mt.gov/wqinfo/qaprogram/sops.mcpx

Moore, S. E., Clarke, J. T., 1990. Distribution, abundance and behavior of endangered whales in the Alaskan Chukchi and western Beaufort Sea, 1989. Minerals Management Service, Anchorage, Alaska, 224 p.

Moore, S. E., Grebmeier, J. M., Davies, J. R., 2003. Gray whale distribution relative to forage habitat in the northern Bering Sea: current conditions and retrospective summary. Canadian Journal of Zoology, 81: 734-742.

Oliver, J. S., Slattery, P. N., O'Connor, E. F., Lowry, L. F., 1983. Walrus, *Odobenus rosmarus*, feeding in the Bering Sea: a benthic perspective. Fishery Bulletin, 81: 501-512.

Stoker, S. W., 1978. Benthic invertebrate macrofauna on the eastern continental shelf of Bering and Chukchi Seas. Ph.D. Dissertation. Institute of Marine Science, University of Alaska Fairbanks.

Stoker, S. W., 1981. Benthic invertebrate macrofauna on the eastern Bering/Chukchi continental shelf. In Hood, D. W., Calder, J. A. (eds.), *The Eastern Bering Sea Shelf: Oceanography and Resources*, vol. 2, NOAA, pp. 1069-1103.

Wentworth, C.R., 1922. A scale of grade and class terms for clastic sediments. Journal of Geology, 30:377-392.

CHAPTER 2

BENTHIC ECOLOGY 2010:

Association of Infaunal Community Structure with Environmental Variables

INTRODUCTION

Interest in understanding the arctic environment including that of the Chukchi Sea has grown, with regulatory agencies and academia directing efforts toward improving the understanding of the environment (Hopcroft et al., 2006). Resources in the Chukchi Sea are of great interest 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 Sea are important food resources for higher trophic level organisms such as demersal fishes, various 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 hot spots for feeding 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). Thus, variations within benthic communities are ultimately of concern to stakeholders.

The northeastern Chukchi Sea is a productive shallow body of water influenced by advective processes (Grebmeier et al., 2006). Water masses moving into the region include 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 the coast of Russia) that enhance benthic biomass. In contrast, the Alaska Coastal water 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; Grebmeier et al., 2006). Factors identified as important predictors of benthic community structure in the Chukchi

Sea include sediment granulometry (e.g., percent gravel, sand, or mud) and sediment organic carbon to nitrogen ratios (C/N ratio) (Feder et al., 1994b). Sediment granulometry reflects a number of environmental processes, such as hydrodynamics (strong currents, storm effects, ice gouging, etc.), sediment deposition, and proximity to sediment sources. Prior studies in the Chukchi Sea have been focused on large-scale variations of faunal communities and little information is available on small-scale factors structuring faunal distributions.

Investigations of carbon cycling in the Chukchi Sea demonstrated strong linkages between primary production and distributions of invertebrate fauna. The reduced numbers of pelagic (water-column) grazers results in strong pelagic-benthic coupling because of the large flux of uneaten phytoplankton reaching the benthos which drives a very abundant and diverse infaunal community (Dunton et al., 2005; Grebmeier et al., 2006). As a result, interannual and seasonal variability in primary production and zooplankton communities may be an important source of variability for benthic communities. Ice algae production is a substantial proportion of the annual carbon budget for invertebrate communities in arctic waters but the ecological importance of ice algae needs to be established for the Chukchi Sea (Ambrose et al., 2001). Evidence suggests that ice algae production may provide a large proportion of carbon to the energy budget of sediment-dwelling animals in the northeastern Chukchi (Ambrose et al., 2005). The macrofauna of the Chukchi Sea are abundant 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).

Scientific studies conducted intermittently over the last 37 years provide a limited basis for understanding the benthic ecology of and temporal change in the northeastern Chukchi Sea. The first study of infaunal community structure in the northeast Chukchi Sea was performed in 1971 to 1974 by Stoker (1978, 1981). This study was followed in 1986 and 1987 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 benthic communities (pelagic-benthic coupling) in the southeastern Chukchi Sea. Recent and on-going broad-scale 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 Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)

Chukchi Sea Offshore Monitoring in Drilling Area (COMIDA) program. The temporal and spatial discontinuity between studies weakens inferences about long-term change highlighting the need for repeated sampling of fixed stations within the Chukchi Sea (Grebmeier et al., 2010).

ConocoPhillips (COP), Shell Exploration and Production Company (SEPCO), and Statoil USA E&P are conducting the multi-disciplinary Chukchi Sea Environmental Studies Program (CSESP) to establish baseline ecological conditions for three areas in the northeastern Chukchi Sea 2008-2010. The study area encompasses three survey areas, called Klondike, Burger, and Statoil, where successful lease bids were made in the February 2008 Chukchi Sea Lease Sale 193. The overall research program will provide information on physical, chemical, biological (including benthic ecology), and oceanographic baseline trends for the study area. The objective of this portion of the benthic ecology component of the CSESP is to document species composition, abundance, and biomass of benthic communities within the survey areas. Hypotheses tested in the present study are that the spatial variability of faunal distributions is associated with local environmental factors and that temporal variability in community structure associated with climatic variations.

METHODS

Infauna Sampling Methods

Sampling for infauna was performed from August 21 to September 25, 2008 (cruise BF0803), September 5 to 19, 2009 (cruise WW0903), and August 5 to 19, 2010 (WW1002). Fifty two stations were targeted for sampling in 2008 and 2009 with six stations added in 2009 where marine mammals were observed feeding. In 2010, 82 stations were sampled including seventy-five stations from the survey areas, three stations where gray whales were observed feeding, and four stations between Klondike and Burger situated to sample the environmental gradient between the two areas and called Transition stations (Fig. 2-1). Thirteen fixed and thirteen random sites were targeted for sampling in the Klondike and Burger study areas during cruises in 2008 - 2010. Eleven fixed and thirteen random sites were sampled in the Statoil study area in 2010. Fixed locations were selected to maximize spatial coverage of sampling stations. They included a subset of the stations sampled for physical oceanography and zooplankton portions of the CSESP (Hopcroft et al., 2010 and in preparation; Weingartner and Danielson, 2010 and in preparation). Random selection of additional sampling stations was also done to

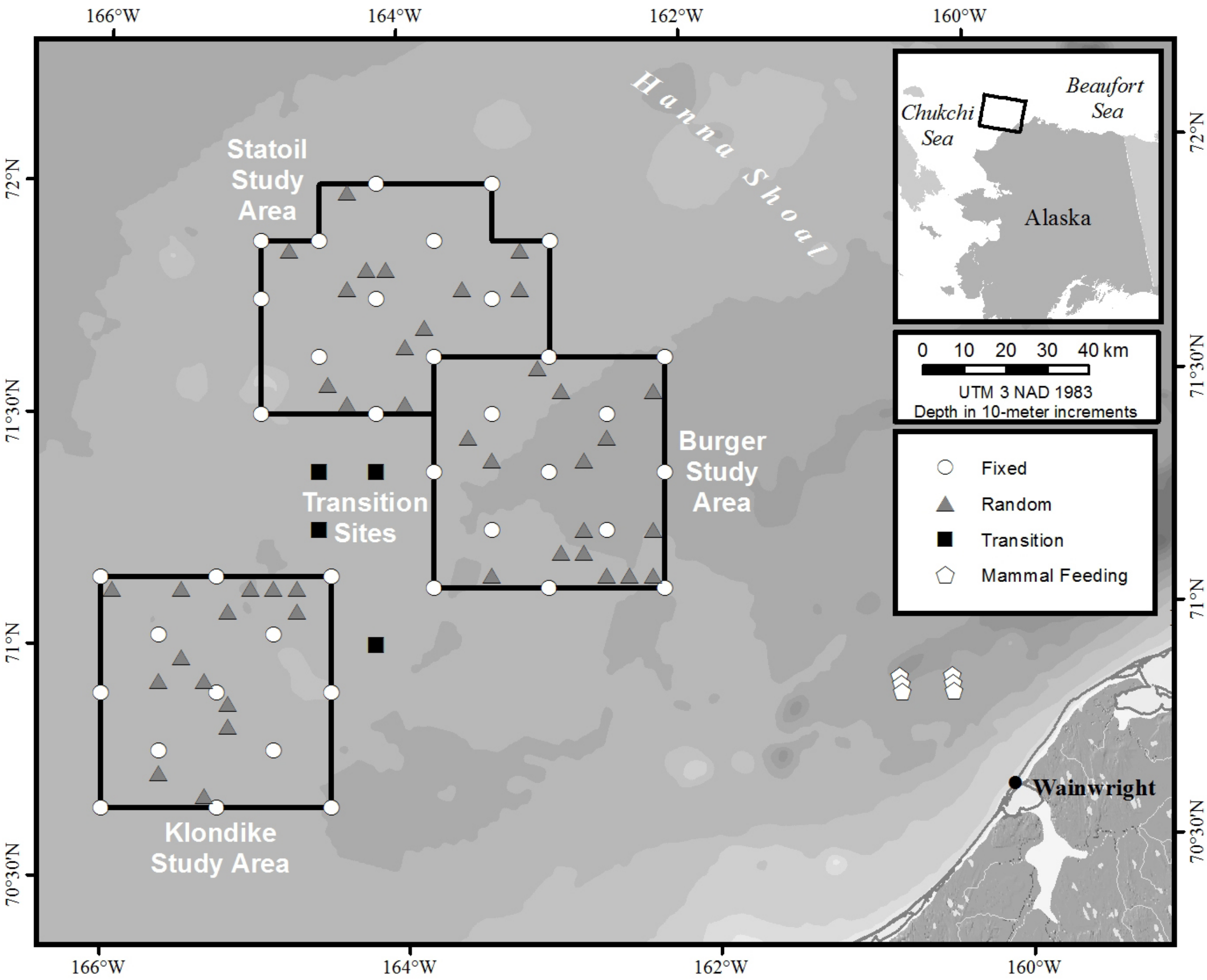


Figure 2-1. Map of stations sampled for infauna during 2008-2010 CSESP surveys.

ensure that conclusions were statistically valid over the whole of the study region. Additional sampling locations include Mammal Feeding stations (TM), located offshore of Wainwright, AK, and Transition stations (TF), located between Klondike and Burger, the latter to help define the environmental and biological gradient between the two areas.

Infauna were sampled using a double van Veen grab with two 0.1 m^2 adjoining grabs to collect sediments for analyzing sediment grain-size, chlorophyll, sediment stable isotopes, and infauna. Three replicate samples were collected at each station. Material from each grab collected for infauna was washed on a 1.0 mm stainless steel screen and preserved in 10% formalin-seawater buffered with hexamine. Benthic organisms were identified to the lowest taxonomic resolution possible, counted and wet weight was measured (protocol according to

Feder et al, 1994b). Sediment samples were also collected from van Veen grab samples and sieved in the laboratory to determine the proportion of mud, sand, and gravel (Wentworth, 1922). The top few centimeters of sediment were collected from grab samples to determine chlorophyll *a* concentration using a Turner Trilogy fluorometer.

Statistical Methods

Trends in community composition were evaluated using univariate and multivariate approaches (Appendix I). Descriptive summaries of the data provide insights into survey area variability and include average abundance, biomass, and number of taxa (sample number of taxa: average of replicates). Richness and diversity measures presented include the total number of taxon categories identified (total number of taxa), Simpson evenness, and Shannon Diversity (Magurran, 2004). Comparisons between years and survey areas were performed using repeated measures ANOVA (rm ANOVA) in a variance-weighted analysis of variance using the statistical program R (www.r-project.org). Non-metric multidimensional scaling (MDS) was applied to determine community structure and spatial and temporal variability of communities using PRIMER (www.primer-e.com). The SIMPER routine of PRIMER is used to evaluate the taxa contributing to each group based on similarity of the benthic community for the multi-year analysis. Associations of community structure were evaluated by correlating the environmental variables with biotic community structure and presented using the BIOENV routine with the MDS ordination.

RESULTS

Analysis of the 2008-2010 CSESP Infaunal Data

A total of 402 taxonomic categories of infaunal organisms were identified from the 2008-2010 CSESP surveys. Of the total abundance of infaunal organisms collected from the main study area during 2008-2010, 53% were polychaetes, 15% were amphipods, another 15% were bivalves, 6% were ostracods, 4% were cumaceans, and the remaining 7% included, gastropods, sipunculids, nemerteans, priapulids, and other taxa. Fifty-two percent of the infaunal biomass collected from the northeastern Chukchi Sea was comprised of bivalves, 26% polychaetes, 15% sipunculids, and the remaining 7% was comprised of gastropods amphipods, nemerteans, priapulids, decapods, and other taxa. By survey area, polychaetes comprised 40% of the biomass in Klondike, 33% at the Transition stations, 23% in Burger, and 15% in Statoil. The remaining biomass in Klondike consisted of 32% bivalves, 18% sipunculids, and the remaining 10% was gastropods, decapods, nemerteans, amphipods, echinoderms, and other taxa. At the Transition stations, biomass consisted of 34% sipunculids and 31% bivalves with other taxa comprising 2% of biomass. In Burger, bivalves comprised 56%, sipunculids comprised 13%, and the remaining 8% of biomass was from amphipods, gastropods, nemerteans, priapulids, and cnidarians. The biomass in Statoil was comprised of 69% bivalves, 12% sipunculids, and 4% of the biomass was from amphipods, gastropods, nemerteans, and other taxa. Average abundance (ind. m^{-2}) in the main study area ranged from 794 (Klondike 2008) to 3,979 (Burger 2009) during the study period; biomass (g m^{-2}) ranged from 115.0 (Klondike 2009) to 355.4 (Statoil 2010) (Table 2-1). The total number of taxonomic categories identified in the main study area ranged from 128 for Transition stations in 2010 to 288 for Klondike in 2009 (Table 2-1).

For the Mammal Feeding stations, total abundance was comprised primarily of amphipods (71%), and also included polychaetes (13%), bivalves (5%), sipunculids (4%), echinoderms (2%), isopods (2%), as well as cumaceans and other taxa (3%). Biomass consisted of 30% amphipods, 29% bivalves, 21% polychaetes, 8% echinoderms, 4% sipunculids, 2% isopods, with the remaining 6% consisting of gastropods, priapulids, decapods and other taxa. For the two years of sampling at the Mammal Feeding stations, the average abundance ranged from 8,209 individuals per square meter in 2009 to 10,928 in 2010. Biomass (g m^{-2}) similarly increased from 196.8 in 2009 to 274.2 in 2010 (Table 2-1). The total number of taxonomic categories identified decreased from 213 in 2009 to 174 in 2010 (Table 2-1).

Comparisons of biological measures indicate significant differences among survey areas. Repeated measures analysis of variance (rm ANOVA) of data from Klondike and Burger 2008-2010 indicated significant survey area by year interactions for abundance and the number of taxa, and survey area and year effects for biomass (Table 2-2). Multiple comparisons indicated that overall, Klondike had lower average abundance, sample number of taxa (replicate averages), and biomass than Burger (Table 2-1 and Fig. 2-2). By year, 2009 had greater abundance and number of taxa than 2008 and 2010, but biomass appears to be decreased in 2009 (Fig. 2-2). The significant survey area by year interactions for average abundance and the number of taxa appear to arise from significantly lower values for Burger in 2010. The lower values in Burger in 2010 demonstrated a much larger change from 2008 and 2009 than in Klondike thus resulting in

Table 2-1. Summaries of biotic variables for fixed and random stations sampled for infauna during the 2008-2010 CSESP. Ave. = average, SD = standard deviation, Sample # Taxon = average number of taxonomic categories, Total # Taxon = number of taxonomic categories found in each survey area, -- = not calculated, and ns = not sampled. Abundance was ind. m^{-2} and biomass was in g m^{-2}.

BF0803	Klondike		Transition		Burger		Statoil		Mammal Feeding	
Variable	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Abundance	793.8	334.3	ns	ns	2,784.3	1,608.35	ns	ns	ns	ns
Biomass	178.8	175.01	ns	ns	333.2	177.41	ns	ns	ns	ns
Sample # Taxa	34.3	9.65	ns	ns	51.6	8.53	ns	ns	ns	ns
Total # Taxa	273	--	ns	ns	268	--	ns	ns	ns	ns
Shannon Diversity	5.18	--	ns	ns	4.90	--	ns	ns	ns	ns
Simpson's Evenness	0.99	--	ns	ns	0.98	--	ns	ns	ns	ns
WW0903	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Abundance	1,119.7	685.6	ns	ns	3,979.1	2,723.8	ns	ns	8,209.4	4,466.2
Biomass	115.0	63.1	ns	ns	283.7	109.5	ns	ns	196.8	64.6
Sample # Taxa	41.4	13.5	ns	ns	58.3	7.6	ns	ns	63.0	8.5
Total # Taxa	288	--	ns	ns	260	--	ns	ns	213	--
Shannon Diversity	5.18	--	ns	ns	4.90	--	ns	ns	4.00	--
Simpson's Evenness	0.99	--	ns	ns	0.98	--	ns	ns	0.93	
WW1002	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Abundance	917	559	1,570	1,113	2,447	2,496	1,050	579	10,928	3,834
Biomass	191.5	105.3	437.0	270.8	285.3	86.4	355.4	286.7	274.2	89.0
Sample # Taxa	36	13	41	10	40	8	33	10	59	4
Total # Taxa	275	--	128	--	239	--	220	--	174	--
Shannon Diversity	5.35	--	4.50	--	4.66	--	5.13	--	3.57	--
Simpson's Evenness	0.99	--	0.99	--	0.96	--	0.99	--	0.91	--

Table 2-2. Repeated measures analysis of variance of summary statistics, environmental variables, and abundance (ind. m^{-2}) of major taxonomic groups for 2008-2010 CSESP surveys in the Klondike and Burger survey areas only. Total chlorophyll (µg cm^{-3}) is chlorophyll *a* plus phaeopigment. Values significant at $\alpha = 0.05$ are in bold type.

Summary Statistics

Abundance	F-value	p-value
Survey Area	39.9	**<0.0001**
Year	15.7	**<0.0001**
Survey:Year	31.5	**<0.0001**

Biomass	F-value	p-value
Survey Area	62.6	**<0.0001**
Year	4.8	**0.0099**
Survey:Year	0.1	0.8747

Taxa	F-value	p-value
Survey Area	25.0	**<0.0001**
Year	49.5	**<0.0001**
Survey:Year	17.6	**<0.0001**

Environmental Variables

% Sand	F-value	p-value
Survey Area	4.4	**0.0378**
Year	0.0	0.9699
Survey:Year	0.3	0.7445

% Mud	F-value	p-value
Survey Area	4.9	**0.0294**
Year	1.2	0.3187
Survey:Year	0.4	0.6637

Depth	F-value	p-value
Survey Area	19.7	**<0.0001**
Year	16.0	**<0.0001**
Survey:Year	2.9	0.0578

Sediment Chlorophyll

Chlorophyll *a*	F-value	p-value
Survey Area	0.0	0.8365
Year	48.1	**<0.0001**
Survey:Year	0.0	0.9978

Total Chlorophyll	F-value	p-value
Survey Area	0.0	0.9896
Year	61.7	**<0.0001**
Survey:Year	0.0	0.9539

Key Taxa

Amphipoda	F-value	p-value
Survey Area	47.4	**<0.0001**
Year	42.1	**<0.0001**
Survey:Year	38.2	**<0.0001**

Bivalvia	F-value	p-value
Survey Area	33.4	**<0.0001**
Year	22.2	**<0.0001**
Survey:Year	10.0	**0.0001**

Gastropoda	F-value	p-value
Survey Area	3.9	0.0549
Year	24.1	**<0.0001**
Survey:Year	8.8	**0.0003**

Polychaeta	F-value	p-value
Survey Area	28.9	**<0.0001**
Year	11.7	**<0.0001**
Survey:Year	32.3	**<0.0001**

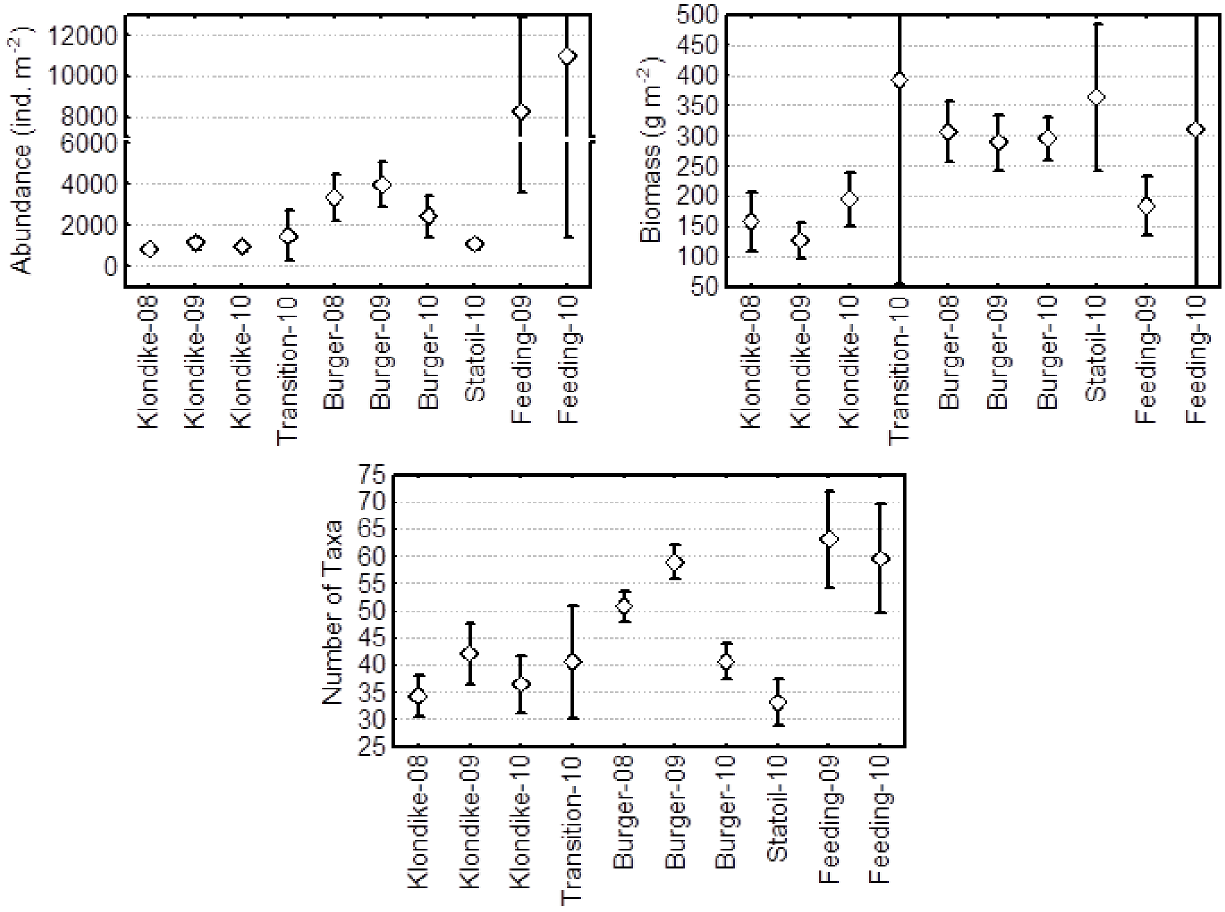


Figure 2-2. Plots of means and 95% confidence intervals based on the raw data for biological summary measures in survey areas over the 2008-2010 CSESP study.

statistically-significant interaction effects. Burger, however, had higher average number of taxa indicating higher numbers of animals at each station (Table 2-1). Statoil, sampled only in 2010, was intermediate between Klondike and Burger with lower abundance and average number of taxa like Klondike and higher biomass like Burger. The Transition stations had lower abundance than Burger and higher biomass than Klondike. The Mammal Feeding stations had much greater abundance than the other survey areas but biomass values similar to Burger.

The total number of taxa was highest at Klondike than Burger, Statoil or the other sampling locations (Table 2-1). In contrast, Burger had higher average number of taxa indicating higher numbers of animals at each station relative to Klondike but lower number of taxa overall indicating more diverse patches at Klondike. Statoil, sampled only in 2010, was intermediate between Klondike and Burger with a lower total number of taxa like Burger. The Transition stations had a low number of taxa overall (due to low number of locations sampled) whereas the number of taxa at the Mammal Feeding sites was high in spite of the low number of sampling locations (Table 2-1 and Fig. 2-2).

Shannon diversity and Simpson's evenness were similar for Klondike and Burger in 2008 and 2009 ranging from 4.90 to 5.18 reflecting small differences in diversity. In 2010, diversity increased slightly in Klondike to 5.35 and decreased in Burger to 4.66 creating a larger difference between the two. Simpson's evenness decreased slightly in Burger in 2010 as well from 0.98 to 0.96 and did not change in Klondike with a value of 0.99 for all years. Statoil was intermediate between Klondike and Burger with a diversity value of 5.1 and evenness of 0.99. The Transition stations had a diversity measure of 4.50 and an evenness of 0.99. The Mammal Feeding stations had the lowest diversity and evenness values of 4.0 and 0.93 in 2009 and 3.57 and 0.91 in 2010 reflecting both the low number of sites sampled and increasing dominance by a few taxa.

Environmental characteristics varied by survey area and by year. Comparison of data for Klondike and Burger 2008-2010 demonstrated a significant year effect for Chlorophyll measurements, significant survey area effects for percent sand and mud, and significant survey area and year effects for water depth (Table 2-2). Chlorophyll *a* and total chlorophyll (chlorophyll *a* plus phaeopigment) were significantly higher in 2010 than in 2008 and 2009 (Table 2-2, 2-3 and Fig. 2-3). Chlorophyll values were lowest in 2009. Overall, Burger and the Transition sites were muddier than Klondike and Statoil and the Mammal Feeding sites had the

Table 2-3. Summary of environmental characteristics at fixed and random stations sampled for infauna during 2008-2010 CSESP surveys. Chlorophyll *a* and total chlorophyll (chlorophyll *a* plus phaeopigment) are in µg cm^{-3}, water depth is in meters and ns = not sampled.

BF0803	Klondike		Transition		Burger		Statoil		Mammal Feeding	
Variable	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Chlorophyll *a*	0.071	0.024	ns	ns	0.078	0.029	ns	ns	ns	ns
Total Chlorophyll	0.349	0.105	ns	ns	0.365	0.089	ns	ns	ns	ns
% Sand	45.9	16.05	ns	ns	36.9	14.62	ns	ns	ns	ns
% Mud	48.7	18.72	ns	ns	60.6	15.74	ns	ns	ns	ns
Water Depth	39.4	2.11	ns	ns	41.9	1.53	ns	ns	ns	ns
WW0903	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Chlorophyll *a*	0.002	0.003	ns	ns	0.002	0.003	ns	ns	0.003	0.003
Total Chlorophyll	0.024	0.033	ns	ns	0.016	0.023	ns	ns	0.047	0.042
% Sand	45.5	15.4	ns	ns	34.1	15.2	ns	ns	67.5	8.5
% Mud	47.4	17.6	ns	ns	60.6	17.2	ns	ns	15.5	3.9
Water Depth	39.8	2.1	ns	ns	41.9	1.5	ns	ns	50.7	0.9
WW1002	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Chlorophyll *a*	0.602	0.537	0.097	0.083	0.614	0.650	0.649	0.461	0.329	0.281
Total Chlorophyll	2.024	1.635	0.385	0.278	1.912	1.698	2.416	1.820	0.914	0.569
% Sand	47.3	15.8	29.8	19.1	33.9	18.6	43.9	19.7	55.3	7.4
% Mud	45.1	18.5	70.0	19.6	61.0	19.7	53.9	20.2	12.8	5.3
Water Depth	39.7	2.1	41.9	1.5	42.1	1.6	38.8	2.5	50.4	0.6

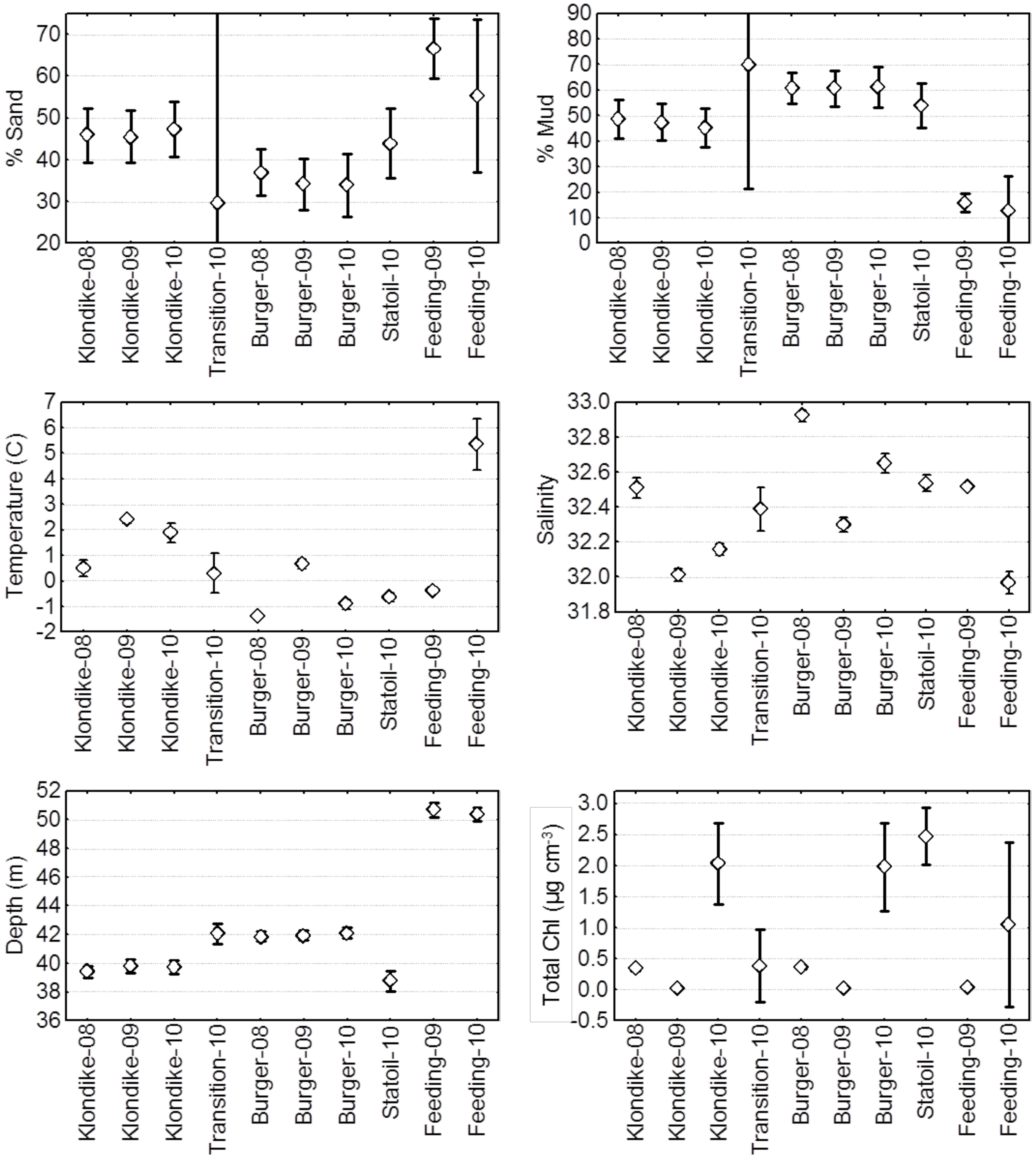


Figure 2-3. Plots of means and 95% confidence intervals based on the raw data for environmental variables in survey areas over the 2008-2010 CSESP study. Total Chl is chlorophyll *a* plus phaeopigment.

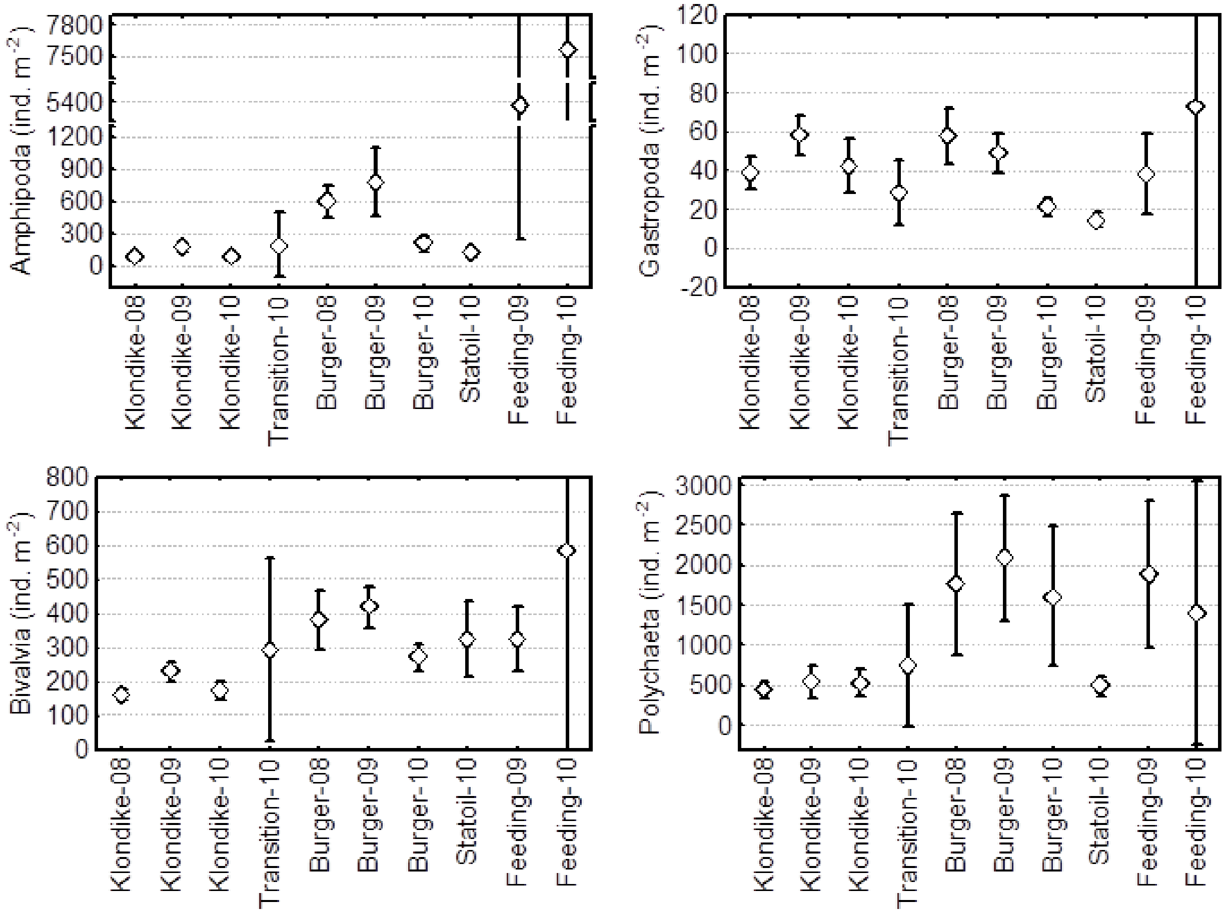


Figure 2-4. Plots of means and 95% confidence intervals based on the raw data of the abundance of major taxonomic groups in survey areas over the 2008-2010 CSESP study.

coarsest substrates of all (Table 2-2, 2-3 and Fig. 2-3). Klondike and Statoil were shallower than Burger and the Transition stations but the Mammal Feeding stations were deeper than all the other locations.

Analysis of abundance of the major taxonomic groups by rm ANOVA indicated significant survey area by year effects for all groups (Table 2-2). The four groups, amphipods, bivalves, gastropods, and polychaetes all demonstrated an increase in values from 2008 to 2009 and a decline in 2010 (Fig. 2-4). The decline in abundance for amphipods, bivalves, and gastropods in Burger in 2010 was larger than the decline for Klondike in 2010 (which was not large for polychaetes).

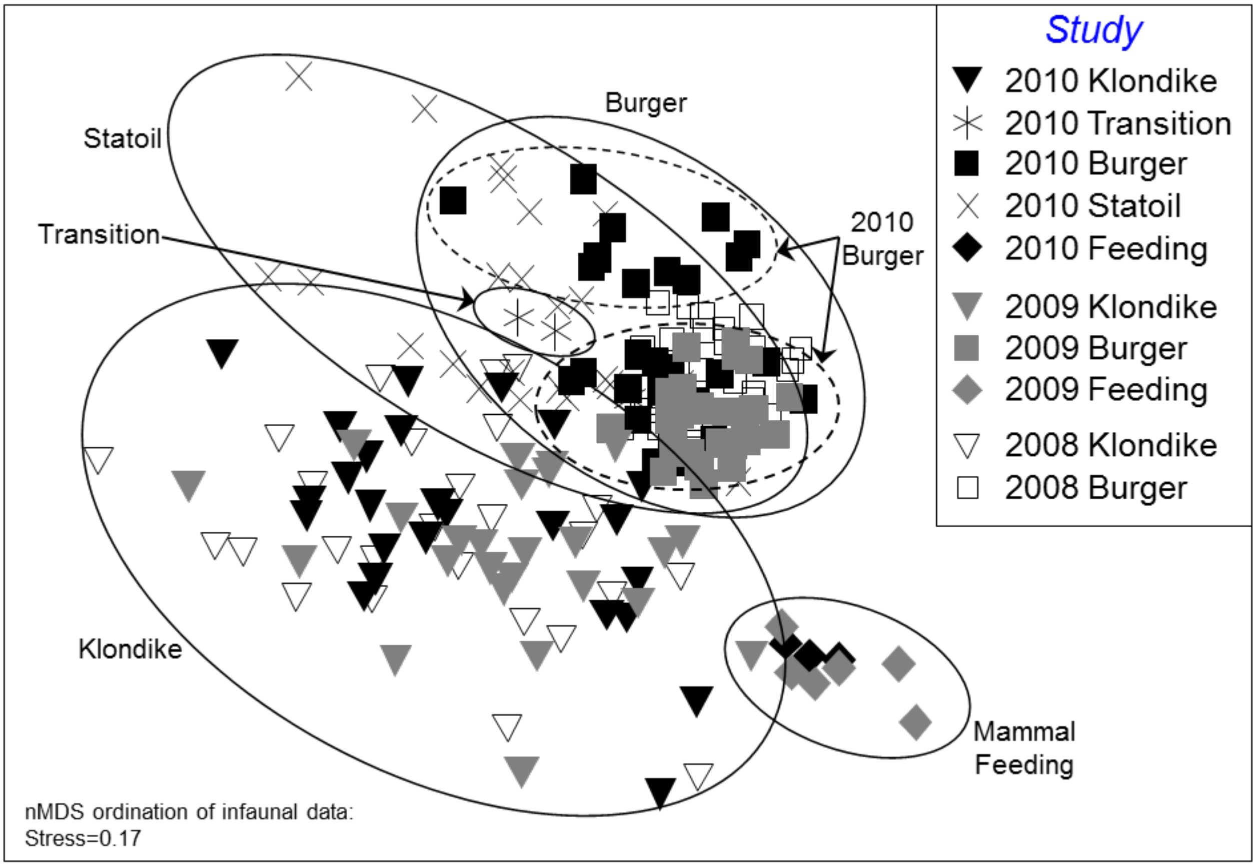


Figure 2-5. Nonmetric multidimensional scaling ordination plot of Bray-Curtis similarities for *ln*(x+1)-transformed benthic abundance data from 2008 - 2010 CSESP sampling.

Multivariate analysis of infaunal community composition (abundance) for all CSESP sampling years (2008-2010) indicates a gradient along the geographical distribution of stations (Fig. 2-5). Klondike stations cluster to the bottom left, Burger stations cluster above and to the right of the Klondike stations, and Statoil and the Transition stations fall in between, with the Statoil stations slightly above the Klondike stations. Mammal Feeding stations are in the bottom right corner of the plot. Thus, the MDS ordination for the infauna mirrors the physical relationships of the stations, reflecting the strong influence of the southwest to northeast environmental gradients in the study area. Additionally, a number of the Burger 2010 stations are positioned separately above the other Burger stations and more closely aligned with the Statoil stations positioned in the upper portion of the plot reflecting a small change in community composition for Burger in 2010.

Taxa (first three, by sampling period) contributing to survey area similarity by abundance at Klondike stations were in general, dominated by the bivalve *Ennucula tenuis* and the polychaetes Cirratulidae and *Maldane sarsi* (Table 2-4). At the Transition stations, the community was dominated by *M. sarsi*, *E. tenuis*, and Ostracods. Animals dominant at Burger stations were *E. tenuis*, the polychaetes *Lumbrineris* sp. and *M. sarsi*, the amphipod *Photis* sp., and ostracods. Taxa contributing to station similarity in Statoil include the bivalves *E. tenuis* and *Yoldia hyperborea*, and the maldanid polychaete *Praxillella praetermissa*. Mammal Feeding stations were dominated by the amphipods *Byblis* sp., *Ischyrocerus* sp., and *Protomedeia* sp.

The animals having the greatest biomass in Klondike were the polychaete *M. sarsi*, the peanut worm *Golfingia margaritacea*, and the bivalves *Astarte borealis* and *Nuculana pernula* (Table 2-4). Biomass at the Transition stations was greatest for *G. margaritacea*, *M. sarsi*, and *A. borealis*. In Burger, the animals with the greatest biomass included the bivalves *A. borealis*, *E. tenuis*, and *Macoma calcarea* and the peanut worm G. *margaritacea.* Biomass for Statoil was greatest for the bivalves *A. borealis*, *M. calcarea*, and *Y. hyperborea.* Mammal Feeding stations had the greatest biomass for the amphipods *Byblis* sp. and *B. pearcyi*, the bivalve *A. borealis*, and the brittle star *Ophiura maculate*.

Bubble plots of the biomass for the major taxa groups indicated highly variable distributions among groups. Amphipods had higher biomass in Burger in 2008 and 2009 but demonstrated lower biomass in Klondike 2008 and 2009 and at all sites in 2010 except for the Mammal Feeding stations which were very high in 2009 and 2010 (Fig. 2-6). Bivalves demonstrated a gradient of increasing biomass from the west side of Klondike to the east side of Burger in all years with biomass values in Statoil increasing along the west-east gradient as well in 2010 (Fig. 2-7). Gastropod biomass values were more variable with high biomass in the central region of the study area (northeast corner of Klondike and the southern portion of Burger) in 2008 and 2009, although higher overall in Klondike during 2009 (Fig. 2-8). Biomass of gastropods decreased in general in 2010 except for 1 station in Klondike. Gastropod biomass in Statoil was concentrated in the central and southcentral region. Polychaetes demonstrated consistently higher biomass in the central Burger area in all years (Fig. 2-9).

Table 2-4. The three infaunal taxa contributing most to within survey area average abundance and biomass. Sim = average similarity. Stations for each area are those included in the MDS ordination plot (Fig. 2-5).

2008 Klondike

Average similarity = 41.95

Taxon	Abundance	Sim
Maldane sarsi	70.51	6.22
Ennucula tenuis	67.95	7.96
Barantolla americana	43.97	3.26

Average similarity = 26.08

Taxon	Biomass	Sim
Maldane sarsi	29.56	12.93
Golfingia margaritacea	13.55	1.53
Nuculana pernula	10.59	1.53

2009 Klondike

Average similarity = 44.46

Taxon	Abundance	Sim
Ennucula tenuis	112.31	10.50
Cirratulidae	59.49	3.66
Maldane sarsi	47.05	3.15

Average similarity = 21.49

Taxon	Biomass	Sim
Maldane sarsi	16.21	8.06
Golfingia margaritacea	10.33	0.51
Nuculana pernula	9.77	1.61

2010 Klondike

Average similarity = 43.78

Taxon	Abundance	Sim
Ennucula tenuis	89.60	10.82
Maldane sarsi	78.00	6.57
Cirratulidae	64.53	3.20

Average similarity = 30.86

Taxon	Biomass	Sim
Golfingia margaritacea	51.51	10.50
Maldane sarsi	31.68	11.22
Astarte borealis	19.12	0.76

2010 Transition

Average similarity = 45.21

Taxon	Abundance	Sim
Maldane sarsi	172.50	6.82
Ennucula tenuis	156.67	6.57
Ostracoda	155.00	4.49

Average similarity = 45.26

Taxon	Biomass	Sim
Golfingia margaritacea	159.91	24.58
Maldane sarsi	71.34	8.49
Astarte borealis	41.93	1.49

2008 Burger

Average similarity = 38.27

Taxon	Abundance	Sim
Maldane sarsi	748.39	2.68
Ostracoda	286.67	3.98
Lumbrineris sp.	188.51	4.34

Average similarity = 31.95

Taxon	Biomass	Sim
Astarte borealis	54.59	5.06
Golfingia margaritacea	38.16	3.29
Macoma calcarea	28.52	2.14

Table 2-4. continued

2009 Burger

Average similarity = 40.30

Taxon	Abundance	Sim
Maldane sarsi	749.62	2.53
Ostracoda	289.49	3.47
Photis sp.	212.05	0.90

Average similarity = 34.48

Taxon	Biomass	Sim
Astarte borealis	57.51	7.40
Macoma calcarea	44.56	4.06
Ennucula tenuis	28.81	6.56

2010 Burger

Average similarity = 34.14

Taxon	Abundance	Sim
Maldane sarsi	1084.74	6.15
Ostracoda	135.26	2.59
Ennucula tenuis	130.90	5.41

Average similarity = 34.32

Taxon	Biomass	Sim
Golfingia margaritacea	55.62	5.14
Astarte borealis	42.29	6.25
Macoma calcarea	39.94	4.16

2010 Statoil

Average similarity = 35.06

Taxon	Abundance	Sim
Ennucula tenuis	87.08	5.93
Yoldia hyperborea	65.97	1.22
Praxillella praetermissa	59.86	3.11

Average similarity = 24.73

Taxon	Biomass	Sim
Astarte borealis	88.78	3.86
Macoma calcarea	42.12	2.16
Yoldia hyperborea	41.86	2.71

2009 Mammal Feeding

Average similarity = 35.80

Taxon	Abundance	Sim
Byblis sp.	3193.89	13.95
Protomedeia sp.	670.28	1.54
Ischyrocerus sp.	547.22	3.15

Average similarity = 21.80

Taxon	Biomass	Sim
Byblis sp.	36.07	7.71
Astarte borealis	14.92	0.88
Ophiura maculate	10.09	0.63

2010 Mammal Feeding

Average similarity = 32.49

Taxon	Abundance	Sim
Byblis sp.	4641.11	17.00
Protomedeia sp.	951.11	3.95
Ischyrocerus sp.	440.00	1.15

Average similarity = 23.47

Taxon	Biomass	Sim
Astarte borealis	35.86	1.72
Byblis sp.	33.20	5.00
Byblis pearcyi	22.41	4.39

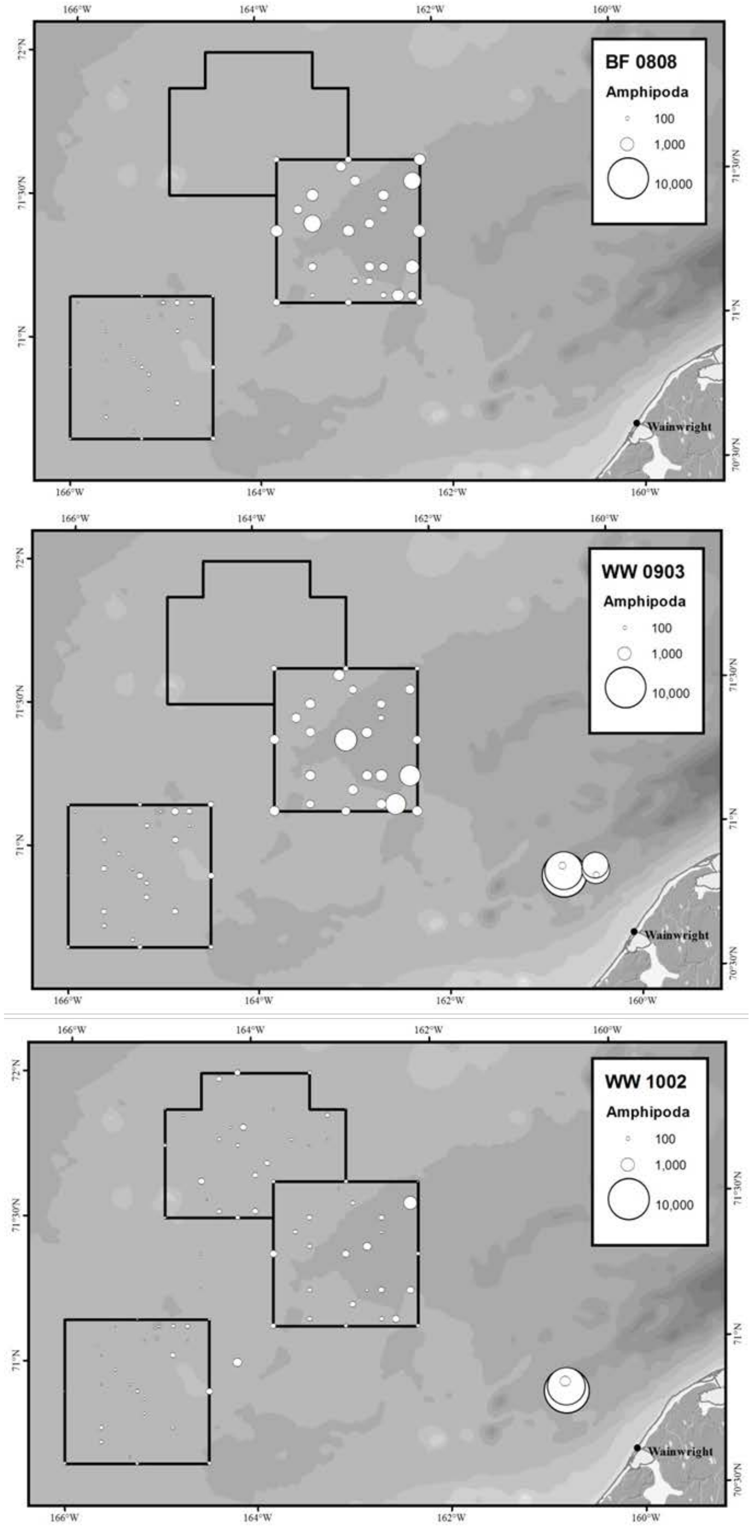


Figure 2-6. Bubble plots of biomass (g m^{-2}) for Amphipoda in Klondike, Burger, and Statoil survey areas collected during 2008-2010 CSESP surveys.

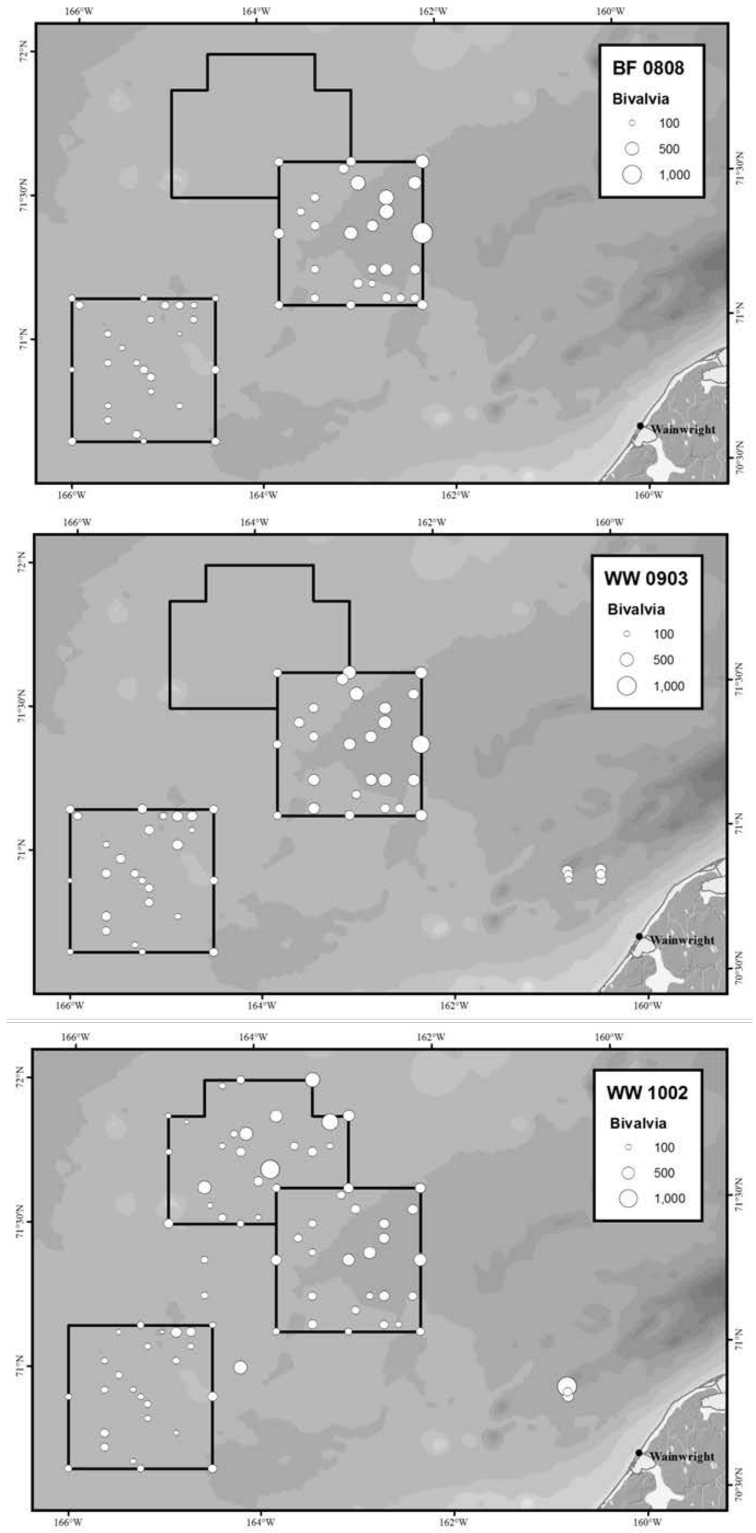


Figure 2-7. Bubble plots of biomass (g m^{-2}) for Bivalvia in Klondike, Burger, and Statoil survey areas collected during 2008-2010 CSESP surveys.

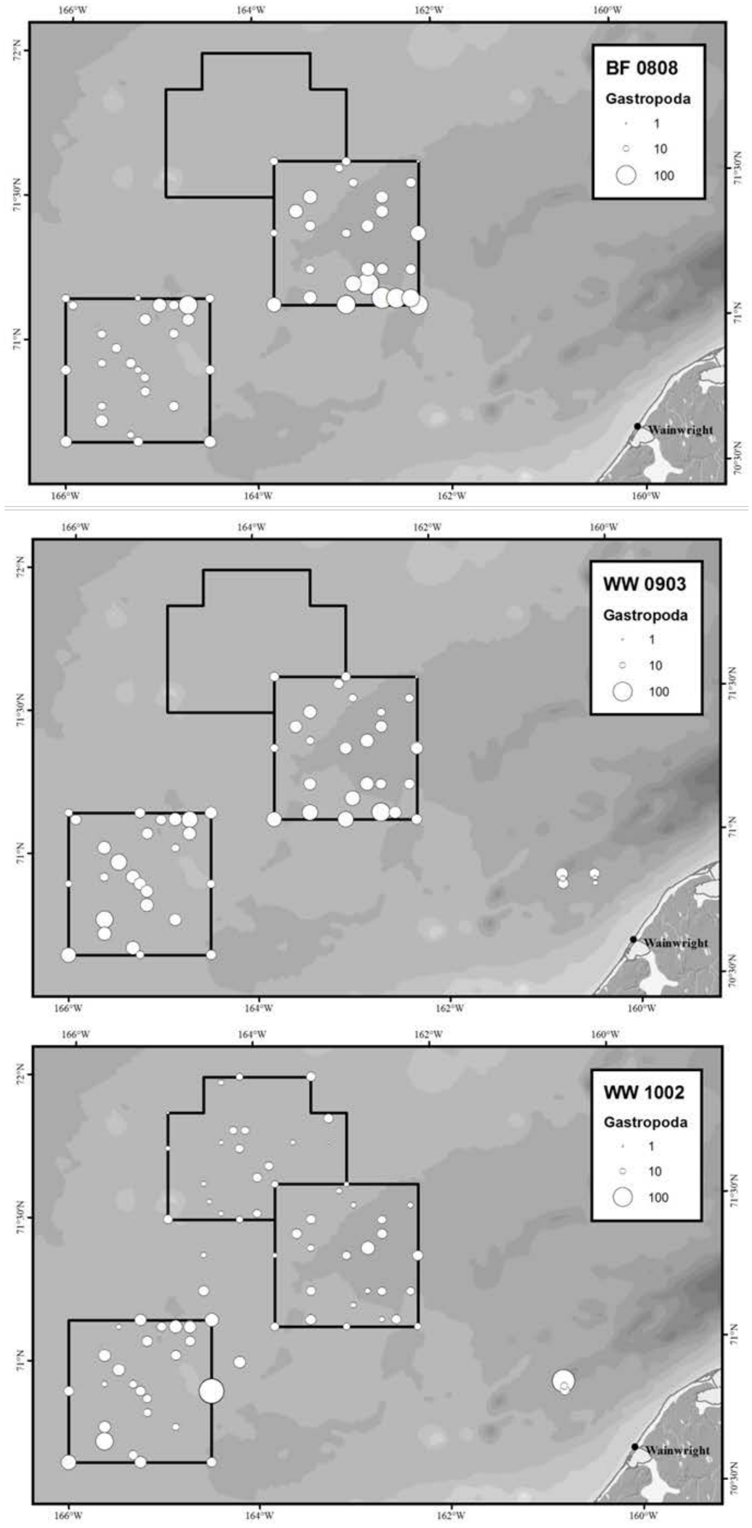


Figure 2-8. Bubble plots of biomass (g m^{-2}) for Gastropoda in Klondike, Burger, and Statoil survey areas collected during 2008-2010 CSESP surveys.

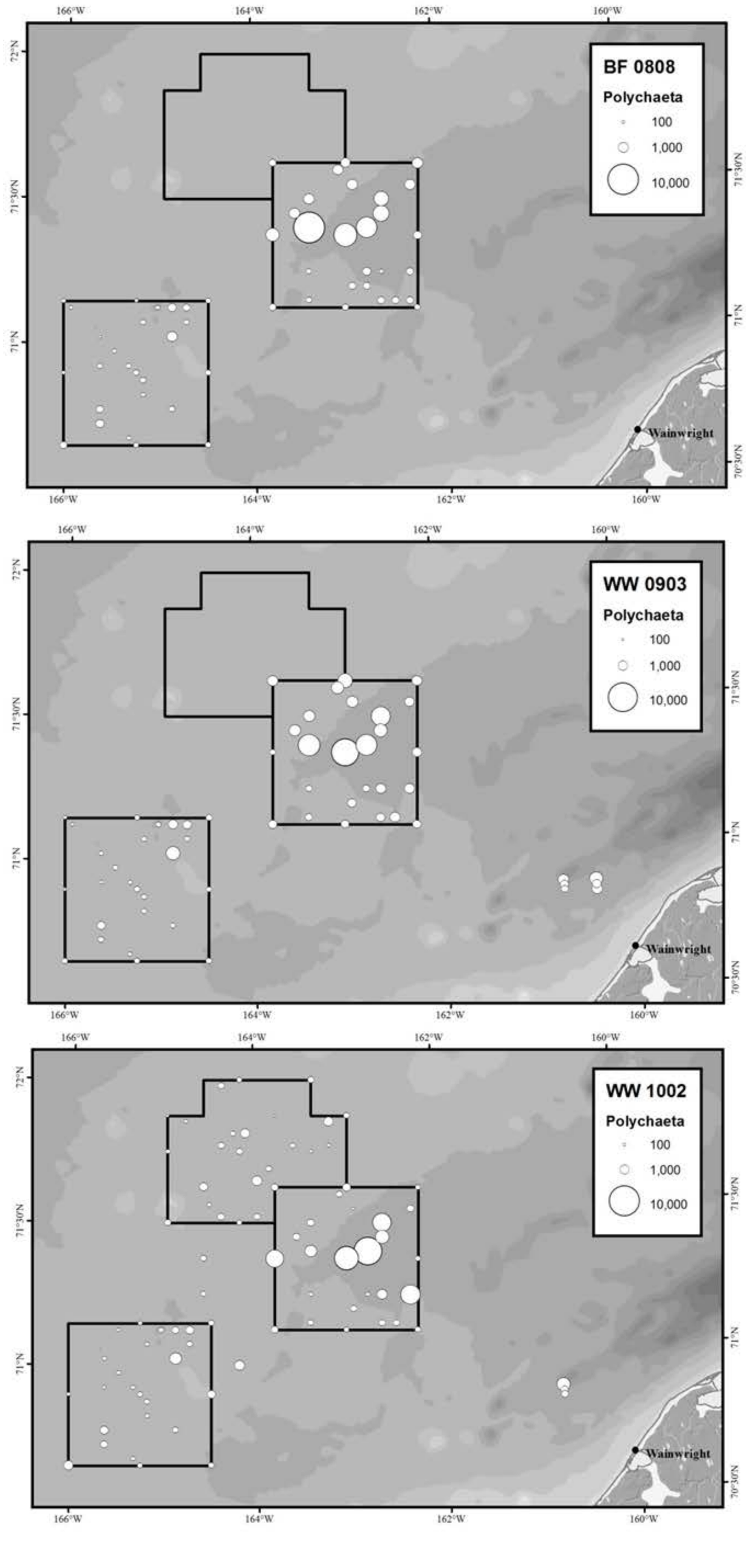


Figure 2-9. Bubble plots of biomass (g m^{-2}) for Polychaeta in Klondike, Burger, and Statoil survey areas collected during 2008-2010 CSESP surveys.

Associations between environmental variables and community structures for the combined 2008-2010 data set were moderate in strength (Table 2-5). Environmental variables used for the analysis (after removal of highly correlated variables) included total chlorophyll, water depth, water temperature, salinity, percent sand, and percent mud. Water depth had the highest correlation with the biotic community structure ($\rho = 0.340$) and the "best-fitting" variable combination with the two variables water depth and temperature had a slightly larger correlation ($\rho = 0.376$). Thus, most gradient captured by the MDS ordination through the Bray-Curtis similarity coefficient (Fig. 2-5) is related to water depth with water mass characteristics (water temperature) providing a small, additional contribution to the variability in the ordination.

Table 2-5. Best fitting Spearman correlations from BIOENV program listing the variables with the highest correlations with the biological station similarity matrix.

# Variables	Best Variable Combination	Second Best Variable Combination
1	Water depth (0.340)	Percent mud (0.284)
2	Water depth, water temperature (0.376)	Water depth, salinity (0.314)
3	Water depth, water temperature, salinity (0.348)	Total chlorophyll, water depth, water temperature (0.335)
4	Total chlorophyll , water depth, water temperature, salinity (0.309)	Total chlorophyll , percent mud, water depth, water temperature (0.300)
5	Total chlorophyll, percent mud, water depth, water temperature, salinity (0.289)	Total chlorophyll, percent mud, percent sand, water depth, water temperature (0.288)

DISCUSSION

Benthos of the Klondike, Burger, and Statoil Survey Areas

The Chukchi Sea is unique among arctic shelf seas as it is strongly influenced by waters derived from the Pacific Ocean and 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 (Weingartner et al., 2005). Key water masses moving northward in the 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. Water masses of southern origin transport heat, nutrients, carbon, and animals to the Chukchi Sea and Arctic Ocean, and are vitally important for maintenance of the ecological structure of the region (Weingartner et al., 2005; Grebmeier et al., 2006; Hopcroft et al., 2009). Thus, the presence of north Pacific fauna, rather than Arctic species alone, is expected given the northward flow of water. Additionally, the nutrient rich water supports abundant benthic production especially where nutrients and food concentrate (Sirenko and Gagaev, 2007). Such is the case where the waters flowing over Hanna Shoal are nutrient-enriched relative to summer surface and ACW, and thus, Hanna Shoal is recognized as a hotspot for benthic communities due to greater benthic biomass (Faulkner et al., 1994; Dunton et al., 2005; Weingartner et al., 2005; Grebmeier et al., 2006).

The benthic fauna of Klondike, Burger, and Statoil are diverse, very abundant, and representative of northern Pacific benthic assemblages found throughout the Bering and Chukchi Seas (Feder et al., 1994b, 2005, 2007; Blanchard et al., 2010). Fauna within the study area include all major groups found in Alaskan waters but are dominated by polychaetes and bivalves (Feder et al., 1994b). The most abundant fauna across the study area are polychaetes of the family Maldanidae and the bivalve *E. tenuis*, amphipods at mammal feeding stations, and ostracod crustaceans at Burger. Maldanid polychaetes (bamboo worms) 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. Presumably, the bivalves found in the study are filter feeders and surface deposit feeders although some are subsurface-deposit feeders. Bivalves can feed in many modes and habitats but, generally, those of the north Pacific feed on marine carbon from primary production or terrestrial sources. Amphipods have varying life habits and feeding modes but can be ecologically critical as some species are food resources for marine mammals. Ostracods have a wide range of feeding habits and the ecology of the species in the current study is unknown. From an ecological perspective, the large sipunculid worm *Golfingia margaritacea* is important as well, due to its potential importance as a walrus food source based on its large size and presence in walrus stomachs (Fay, 1982; Sheffield and Grebmeier, 2009). Ampeliscid amphipods are a preferred prey of gray whales in the northern Bering and Chukchi seas and as also indicated by observations of gray whale feeding activities ate Mammal Feeding stations where these amphipods were dominant (Highsmith and Coyle, 1992; Highsmith et al., 2006; Bluhm and Gradinger, 2008). Amphipods abundance values high enough to potentially support gray whale feeding were not found in Statoil, Burger, or Klondike in 2008, 2009, or 2010, as they were at the Mammal Feeding stations (Blanchard et al., 2010).

The high abundance and biomass values of the communities in the survey areas indicate high productivity in the nutrient-rich waters (Grebmeier et al., 2006). The reduced numbers of pelagic consumers of primary production in the Chukchi Sea results in strong pelagic-benthic coupling where the relatively large flux of phytoplankton to the benthos supports strong infaunal communities. As shown in this study, some differences in community structure and faunal measures do exist between survey areas. The benthic infaunal community in Burger has higher abundance and biomass and Burger has deeper water depth and a longer persistence of winter water indicating environmental and biological differences resulting from a change in oceanographic conditions relative to Klondike (Faulkner et al., 1994; Weingartner et al., 2005; Weingartner, 2009). Feder et al., (1994b) also demonstrated higher biomass for stations closest to the Burger survey area related to environmental differences. The high abundance and biomass values at Burger (adjacent to a documented biological hot spot) reflect the concentration of food resources within the sediments due to interactions of the bottom topography with water currents, as reflected in its greater depth (Grebmeier et al., 2006). Within each survey area, faunal communities were varied significantly from 2008-2010 in the presence of substantial change in oceanographic characteristics including temporal differences in nutrient fluxes, zooplankton communities, and water mass characteristics among the summers in 2008, 2009, and 2010 (Hopcroft et al., in preparation; Weingartner and Danielson, in preparation).

Associations of Fauna with Environmental Characteristics

Animal-sediment interactions are a complex mosaic of biologically-mediated relationships of fauna with their physical environment and there are many factors influencing community development of infauna. These factors include water 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, 1990; 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, 2009).

Factors associated with the large-scale structure and abundance of infaunal communities in the northeastern Chukchi Sea include sediment grain-size, sediment organic carbon concentrations, and the nutrient rich waters (Feder et al., 1994b; Grebmeier et al., 2006). Physical variables commonly examined in benthic studies (i.e., sediment granulometry, organic carbon, and water depth) are proxies for the broader environmental characteristics such as pelagic-benthic coupling, changes in physical dynamics with distance offshore, large current patterns, and nutrient availability (Lenihan and Micheli, 2001; Grebmeier et al., 2006; Cusson et al., 2007; Bluhm and Gradinger, 2008). At smaller scales, the distributions of fauna can be controlled by local environmental gradients such as interactions between geomorphology and currents, differences in organic carbon (food) sources, and local deposition. In the present study, Burger stations lay in a trough to the south of Hanna Shoal with Klondike stations to the southwest. Weingartner (2009) demonstrated higher water temperature and salinity values for the Klondike study area in late summer 2008, as compared to Burger, reflecting the persistence of winter water at Burger. The geologic and oceanographic differences between Burger and Klondike and sediment characteristics all indicate reduced current flow at Burger, and thus, the deposition of mud and primary production. The Statoil and Transition stations complete the environmental and biological gradient between Klondike and Burger, falling in between the two areas in most aspects. The physical and biological differences between the survey areas are reflected in the strong association community structure (as shown in the MDS ordination) with water depth and temperature from the BIOENV procedure (Table 2-5 and Fig. 2-5). The enhanced benthic community at Burger, as compared to Klondike and Statoil, reflects the increased availability of food at Burger. In contrast, the mammal feeding stations were deeper and sandier reflecting stronger coastal currents. The physical characteristics in this area (presumably under the Alaska Coastal Current) are presently not well defined although they are reflected by the dominance of amphipods in 2009 and 2010 (particularly *Byblis* sp.) instead of bivalves and polychaete worms, both of which were more abundant in the rest of the study area. Thus, the benthic fauna with the Chukchi Sea are as greatly influenced by small-scale environmental heterogeneity as to the larger-scale sources of variability described in prior studies (Feder et al., 1994b).

Animals associated with carbon and oxygen transport to depth in sediment include a number of abundant worms found in the northeast Chukchi Sea. The capitellid worm *Heteromastus filiformis*, maldanid worms (e.g., *Maldane sarsi* in the current study), and another sipunculid (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, 2009). The burrows and feeding activities of animals enhance the exchange of oxygen and water-borne nutrients within sediments while at the same time the worms subduct a portion of annual primary production into their burrows. 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). Nelson et al. (1994)

found extensive burrowing activity by polychaete worms and sipunculids in sediments of the northeast Chukchi Sea to 35 cm depth.

Environmental heterogeneity is a large influence on community structure and taxonomic diversity. Regions with higher environmental variability result in greater numbers of smaller patches of invertebrate communities, while more homogenous habitats result in larger patches of similar communities. The resulting mosaics of sediment patches reflect communities at varying stages of recovery if disturbed or different environmental conditions (Thistle, 1981; Hall, 1994; Jewett et al., 1999). As a result, diversity increases with increasing environmental variability and this process is called the intermediate disturbance hypothesis (Boesch and Rosenberg, 1981). Disturbance to marine benthic sediments is one source of variability and may arise from feeding activities of predators and the resulting bioturbation, ice gouging, large environmental change, or human activities. When the frequency of disturbance is moderate (relative to the ability of a communities to recover) disturbance may help to maintain greater diversity by reducing dominance of the most competitive species (Boesch and Rosenberg, 1981). The greater total number of taxa (per survey area)and the lower average number of taxa (per replicate values) at Klondike suggest that, relative to Burger and Statoil, individual samples from Klondike have fewer types of organisms but that there are greater numbers of heterogeneous patches over the landscape at Klondike. Thus, the biological evidence suggests that Klondike is environmentally more variable (e.g., has a greater number of sediment environments or habitats) than the other survey areas, possibly a result of exposure to different oceanographic conditions (Weingartner and Danielson, in preparation).

Temporal Variability

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 production within the region to the late spring and summer months. Melting sea ice stratifies the water column, creating the necessary conditions for primary production 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, zooplankton in other pelagic systems such as Port Valdez, Alaska, can consume much of the primary productivity and very little phytoplankton may reach the sea floor; Blanchard et al., 2010). Patterns of primary production and zooplankton community development in the study area is dependent on the variable environmental characteristics of the water column and large, annual differences of zooplankton abundance can result from environmental variations, as observed by Hopcroft et al. (in preparation) over the current study period 2008-2010. Zooplankton community composition and lower production in 2009 reflected the early warming of the Chukchi and melting of ice due to winds from the south (Weingartner et al., in preparation). Water temperatures were lowest in 2008 and highest in 2009 while salinity was highest in 2008 and lowest in 2009 reflecting the annual changes in melting patterns (Weingartner et al., in preparation).

Water temperature changes influence benthic communities through altering survival of pelagic larvae as well as causing variations in food resources. Some bivalve larvae are sensitive to water temperature and temperature variations have been suggested as a key factor in the varying distribution of *Macoma calcarea* in the Chukchi Sea (Pearson and Barnett, 1987; Sirenko and Gagaev, 2007). The increased abundance and diversity (number of taxon) of infaunal animals in the study area from 2008 to 2009 and decline in 2010 reflect observations of change in oceanographic conditions and zooplankton communities, suggesting responses of benthic animals to large-scale environmental variability. Chlorophyll measurements demonstrated a different trend with lower values in 2009, as compared to 2008, and much higher values in 2010. Seasonal variability may play a role in the greater variability for 2010 as sampling in 2010 was two weeks earlier than in 2008 and a month earlier than in 2009. Thus, greater consumption and decomposition could have occurred in 2008 and 2009, as compared to 2010. The great difference in values and variability were, however, matched by fluorescence measurements taken over the summer in the study area by oceanographic equipment (unpublished data). The large change in abundance and the number of taxa and lack of such a strong response in biomass at Burger in 2010 suggests a loss of smaller and less competitive (and thus, rare) species from the community rather than the larger, multi-year animals dominating biomass. The different trends in the faunal communities and chlorophyll measurements suggest that the source of change in benthic infauna may not be food-related but driven by the influence of oceanographic conditions on larval survival and recruitment. Blanchard et al. (2010) found a tight relationship between the Pacific Decadal Index (an index of climatic variability in the North Pacific Ocean) and infauna abundance in Port Valdez, Alaska, indicating that benthic communities throughout Alaska are very responsive to oceanographic variability.

Feeding by Higher Trophic Levels

Links between trophic levels in the northeast Chukchi Sea are short with primary production directly supporting a rich complex of benthic organisms. The abundant infaunal communities 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.

Barber et al. (1997) documented 66 species of fishes in the Chukchi Sea, many of which are likely to utilize the benthos for food. The diets of a few benthic-feeding fishes in the northeast Chukchi Sea have been reported including those of 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 infaunal prey (those living within sediments including bivalves and gastropods) and all species consumed epibenthic crustaceans. Investigations of fish ecology during the 2009-2010 CSESP studies indicate that a number of benthic organisms are preyed upon by benthic fishes (Gallaway et al., in preparation). Five fish species were analyzed for diet composition and infaunal organisms, primarily polychaete worms, were found in gut contents of all species. Polychaetes, however, were a major dietary component for only the Arctic staghorn sculpin (Gallaway et al., in preparation).

The gray whale feeds primarily in the northern Bering and south-central Chukchi seas but some also feed in the northeastern Chukchi and western Beaufort seas (Moore and Clark, 1990; Feder et al 1994b; Highsmith et al., 2006). Gray whales scoop sediment into their mouths to capture 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 feeding areas along the northern coastline, Moore and Clark (1990) observed gray whales presumably feeding to the northeast of 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 infaunal community within the present study area, their numbers are lower in the Burger and Klondike areas than in the known, preferred feeding areas (the Mammal Feeding stations), indicating suboptimal gray whale feeding habitat, as noted above (Nelson et al., 1994; Highsmith and Coyle, 1992).

Walrus feed by rooting in 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 primarily favor large bivalves. Fay (1982) and Sheffield et al. (2001), however, demonstrated that walrus in the Bering and Chukchi seas feed on many 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 based on gut analyses (Sheffield et al., 2001). Fay (1982) found a broad selection of walrus prey including large *Golfingia margaritacea* and *Priapulus caudatus*, and both were observed in infaunal samples from the 2008-2010 CSESP sampling and by Nelson et al. (1994). Bearded seals feed on an array of epifaunal and larger infaunal organisms and fishes as well (Lowry et al., 1980; Bluhm and Gradinger, 2008). Thus, the high biomass values and high numbers of bivalves, polychaetes, and sipunculid worms in the Klondike, Burger, and Statoil study areas represent an abundant prey base for benthic feeding organisms.

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, predation by benthic-feeding organisms in the Chukchi

Sea is likely a substantial and ecologically important source for infaunal community heterogeneity.

CONCLUSIONS

Benthic communities in the Klondike, Burger, and Statoil survey areas reflect 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). The infaunal assemblages of 2008–2010 were characteristic of species found throughout the Bering and Chukchi seas and were similar to those found in 1986 in the northeastern Chukchi Sea by Feder (1994b). Although average abundance of infauna was higher in Burger than in Klondike and Statoil, the assemblages at all survey areas were generally similar (containing most of the same species) and trends reflect local environmental gradients co-varying with sediment grain-size and water depth. Benthic community structure for benthic stations sampled during the 2008-2010 CSESP was moderately associated with water depth and temperature reflecting the environmental gradients resulting from geologic and oceanographic characteristics of the study area. The infaunal communities provide an abundant prey base for some benthic-feeding organisms in the Klondike, Burger, and Statoil study areas but not gray whales. Nearshore, the infaunal community at the Mammal Feeding stations was dominated by ampeliscid amphipods (the preferred food resource of gray whales). Short-term temporal differences in community structure from 2008–2010 were associated with climatic variations influencing the Chukchi Sea, which likely altered larval survival and recruitment.

ACKNOWLEDGMENTS

We thank ConocoPhillips, Shell Exploration and Production Co., and Statoil USA E & P for funding this study and opportunity for the research. We thank Olgoonik-Fairweather LLC for their support. We thank the crews of the M/V *Bluefin* (2008) and M/V *Westward Wind* (2009, 2010), marine technicians, and Aldrich Offshore Services for assistance and logistic support. Hilary Nichols, Tama Rucker, Jeannette Cochran, Crystal Cano, Kevin Fraley, Blake Neunneman, Sarah Moore, Hannah Stiver, Chaitanya Borade, Nicole Wade, Shona Snater, Eric Wood, Amy Tippery, Marissa Hajduk, and Kelley Tu assisted with processing of the samples. Howard Feder and John Burns reviewed the report and provided constructive comments.

REFERENCES

Ambrose, W. G., Clough, L. M., Tilney, P. R., and Beer, L., 2001. Role of echinoderms in benthic remineralization in the Chukchi Sea. Marine Biology, 139: 937-949.Ambrose Jr., W. G., von Quillfeldt, C., Clough, L. M., Tilney, P. V. R., Tucker, T. 2005. The sub-ice algal community in the Chukchi sea: large- and small-scale patterns of abundance. Polar Biology, 28: 784–795

Barber, W. E., Smith, Vallarino, M., Meyer, R. M., 1997. Demersal fish assemblages in the northeastern Chukchi Sea, Alaska. Fishery Bulletin, 95: 195-209.

Blanchard, A. L., Feder, H. M., Hoberg, M. K., 2010. Temporal variability of benthic communities in an Alaskan glacial fjord, 1971-2007. Marine Environmental Research, 69: 95-107.

Bluhm, B. A., Coyle, K. O., Konar, B., Highsmith, R., 2007. High gray whale relative abundances associated with an oceanographic front in the south-central Chukchi Sea. Deep Sea Research II, 54: 2919–2933.

Bluhm, B. A., Gradinger, R., 2008. Regional variability in food availability for arctic marine mammals. Ecological Applications, 18 Supplement, pp. S77–S96.

Boesch, D. F., Rosenberg, R., 1981. Response to stress in marine benthic communities. In Barrett, G. W., Rosenberg, R. (eds.), *Stress Effects on Natural Ecosystems*. John Wiley & Sons: New York, pp. 179-200.

Born, E. W., Rysggard, S., Ehlmé, G., Sejr, M., Acquarone, M., Levermann, N., 2003. Underwater observations of foraging free-living Atlantic walruses (Odobenus rosmarus rosmarus) and estimates of their food consumption. Polar Biology, 26:348–357.

Coachman, L.K., 1987. Advection and mixing on the Bering-Chukchi Shelves. Component A. Advection and mixing of coastal water on high latitude shelves. ISHTAR 1986 Progress Report, Vol. 1. Institute of Marine Science, University of Alaska Fairbanks, pp 1-42.

Codispoti, L.A., Flagg, C., Kelly, V., Swift, J.H., 2005. Hydrographic conditions during the 2002 SBI process experiments. Deep-Sea Res. II 52, 3199-3226.

Coyle, K.O., Gillispie, J. A., Smith, R. L., Barber, W. E., 1997. Food habits of four demersal Chukchi Sea fishes. Pages 310-318 in Reynolds, J. (ed.), Fish Ecology in Arctic North America. American Fisheries Society Symposium 19, Betheseda, Maryland.

Cusson, M., Archambault, P., Aitken, A., 2007. Biodiversity of benthic assemblages on the Arctic continental shelf: historical data from Canada. Marine Ecology Progress Series, 331: 291-304.

Dunton, K.H., Goodall, J.L., Schonberg, S.V., Grebmeier, J.M., Maidment, D.R., 2005. Multi-decadal synthesis of benthic-pelagic coupling in the western arctic: Role of cross-shelf advective processes. Deep-Sea Research Part I 52, 3462-3477.

Faulkner, K. K., MacDonald, R. W., Carmack, E. C., Weingartner, T., 1994. The potential of barium as a tracer of Arctic Water Masses. In: Muench, R., Johannessen, O. (eds.), The Polar Oceans and Their role in Shaping the Global Environment. Geophysical Monograph 85. American Geophysical Union, pp. 63-76.

Fay, F. H., 1982. Ecology and Biology of the Pacific Walrus *Odobenus rosmarus divergens* Illiger. North American Fauna, vol. 74. U.S. Department of the Interior, Fish and Wildlife Service: Washingotn, DC. 279 p.

Feder, H. M., Jewett, S. C., & Blanchard, A., 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology, 28: 402-421.

Feder H. M, Jewett, S. C., Blanchard, A. L., 2007. Southeastern Chukchi Sea (Alaska) Macrobenthos. Polar Biology, 30: 261-275.

Feder, H. M., Foster, N. R., Jewett, S. C., Weingartner, T. J., Baxter, R., 1994a. Mollusks of the northeastern Chukchi Sea. Arctic, 47: 145-163.

Feder, H. M., Naidu, A. S., Jewett, S. C., Hameedi, J. M., Johnson, W. R., Whitledge, T. E., 1994b. The northeastern Chukchi Sea: benthos-environmental interactions. Marine Ecology Progress Series, 111: 171-190.

Gallaway, B. J., Norcross, B., Holladay, B., in preparation. A synthesis of diversity, distribution, abundance, age, size and diet of fishes in the Lease Sale 193 Area of the northeastern Chukchi Sea. Final report to ConocoPhillips Alaska Inc., Shell Exploration and Production, and Statoil E & P.

Grebmeier, J. M., Cooper, L. W., Feder, H. M., Sirenko, B. I., 2006. Ecosystem dynamics of the Pacific-influenced Northern Bering and Chukchi Seas in the Amerasian Arctic. Progress in Oceanography, 71: 331–361.

Grebmeier, J. M., Harvey, H. R., Stockwell, D. A., 2009. The Western Arctic Shelf-Basin Interactions (SBI) project, volume II: An overview. Deep Sea Research Part II: Topical Studies in Oceanography, 56:1137-1143.

Grebmeier, J. M., McRoy, C. P., Feder, H. M., 1988. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. I. Food supply source and benthic biomass. Marine Ecology Progress Series, 48:57-67.

Grebmeier, J. M., Moore, S. E., Overland, J. E., Frey, K. E., Gradinger, R., 2010. Biological Response to Recent Pacific Arctic Sea Ice Retreats. EOS, Transactions, American Geophysical Union, 91: 161-162.

Green, J. M., Mitchell, L. R., 1997. Biology of the fish doctor, an eelpout, from Cornwallis Island, Northwest Territories, Canada. Pages 140-147 in Reynolds, J. (ed.), Fish Ecology in Arctic North America. American Fisheries Society Symposium 19, Bethesda, Maryland.

Hall, S. J., 1994. Physical disturbance and marine benthic communities: life in unconsolidated sediments. Oceanography and Marine Biology: an Annual Review, 32:179-239.

Highsmith, R. C., Coyle, K. O., 1992. Productivity of arctic amphipods relative to gray whale energy requirements. Marine Ecology Progress Series, 83: 141-150.

Highsmith, R. C., Coyle, K. O., Bluhm, B. A., Konar, B., 2006. Gray Whales in the Bering and Chukchi Seas. In Estes, J., DeMaster, D. P., Doak, D. F., Williams, T. M., Brownell, R. L. (eds) *Whales, Whaling and Ocean Ecosystems*. UC Press, pp 303-313.

Hopcroft, R., Bluhm, B., Gradinger, R., Whitledge, T., Weingartner, T., Norcross, B., Springer, A., 2006. Arctic Ocean Synthesis: Analysis of Climate Change Impacts in the Chukchi and Beaufort Seas with Strategies for Future Research. Final report to North Pacific Research Board, 152 pp.

Hopcroft, R. R., Questel, J., Clarke-Hopcroft, C., 2010. Oceanographic assessment of the planktonic communities in the Klondike and Burger prospect regions of the Chukchi Sea: Report for survey year 2009. Final report to ConocoPhillips Alaska Inc., and Shell Exploration and Production Company. Institute of Marine Science, University of Alaska Fairbanks, 54 pp.

Hopcroft, R. R., Questel, J., Clarke-Hopcroft, C., in preparation. Oceanographic assessment of the planktonic communities in the Klondike and Burger prospect regions of the Chukchi Sea: Report for survey year 2010. Final report to ConocoPhillips Alaska Inc., Shell Exploration and Production Company, and Statoil USA E&P. Institute of Marine Science, University of Alaska Fairbanks.

Jewett, S. C., Feder, H. M., 1980. Autumn food of the adult starry flounders, *Platichthys stellatus*, from the northeastern Bering Sea and the southeastern Chukchi Sea. Journal su Conseil. Conseil Permanent International pour l'Exploration de la Mer, 39: 7-14.

Jewett, S. C., Feder, H. M., 1981. Epifaunal invertebrates of the continental shelf of the eastern Bering and Chukchi Seas. In Hooe, D. W., Calder, J. A., (eds), *The Eastern Bering Sea Shelf: Oceanography and Resources*, vol. 2. Office of Marine Pollution Assessment, NOAA: Seattle, WA., p. 1131-1153.

Jewett, S. C., Feder, H. M., Blanchard, A. 1999. Assessment of the benthic environment following offshore placer gold mining in the northeastern Bering Sea. Marine Environmental Research, 48:91-122.

Krupnik, I., Ray, G. C., 2007. Pacific walruses, indigenous hunters, and climate change: Bridging scientific and indigenous knowledge. Deep Sea Research Part II: Topical Studies in Oceanography, 54:2946-2957.

Lenihan, H. S., Micheli, F., 2001. Soft-sediment communities. In: Bertness, M.D., Gaines, S.D., Hay, M.E. (Eds.), *Marine Community Ecology*. Sinauer Associates, Sunderland MA, USA, pp. 445-468.

Levin, L., Blair, N., DeMaster, D., Plaia, G., Fornes, W., Martin, C., Thomas, C., 1997. Rapid subduction of organic matter by maldanid polychaetes on the North Carolina slope. Journal of Marine Research, 55:595-611.

Lovvorn, J. R., Richman, S. E., Grebmeier, J. M., Cooper, L. W., 2003. Diet and body condition of spectacled eiders wintering in pack ice of the Bering Sea. Polar Biology 26, 259-267.

Lowry, L. F., Frost, K. J., Burns, J. J., 1980. Feeding of bearded seals in the Bering and Chukchi Seas and trophic interaction with Pacific walruses. Arctic, 33:330-342.

Magurran, A. E., 2004. *Measuring Biological Diversity*. Blackwell Publishing, Malden, MA, 256 pp.

Moore, S. E., Clarke, J. T., 1990, Distribution, abundance and behavior of endangered whales in the Alaskan Chukchi and western Beaufort Sea, 1989: Minerals Management Service, Anchorage, Alaska, 224 p.

Moore, S. E., Grebmeier, J. M., Davies, J. R., 2003. Gray whale distribution relative to forage habitat in the northern Bering Sea: current conditions and retrospective summary. Can. J, Zool, 81, 734-742.

Nelson, C. H., Phillips, R. L., McRea, Jr., J., Barber, Jr., J. H., McLaughlin, M. W., Chin, J. L., 1994. Gray whale and Pacific walrus benthic feeding grounds and sea floor interaction in the Chukchi Sea. Technical Report for Minerals Management Service, OCS Study, MMS 93-0042, US Department of the Interior, Anchorage, Alaska.

Oliver, J. S., Slattery, P. N., O'Connor, E. F., Lowry, L. F., 1983. Walrus, *Odobenus rosmarus*, feeding in the Bering Sea: a benthic perspective. Fishery Bulletin, 81:501-512.

Pearson, T.H., Barnett, P.R.O., 1987. Long-term changes in benthic populations in some west European coastal areas. Estuaries 3, 220-226.

Ray, G. C., McCormick-Ray, J., Berg, P., Epstein, H. E., 2006. Pacific walrus: Benthic bioturbator of Beringia. Journal of Experimental Marine Biology and Ecology, 330:403-419.

Romero-Wetzel, M. B., 1987. Sipunculans as inhabitants of very deep, narrow burrows in deep-sea sediments. Marine Biology, 96:87-91 .

Sheffield, G., Fay, F. H., Feder, H., Kelly, B. P., 2001. Laboratory digestion of prey and interpretation of walrus stomach contents. Marine Mammal Science, 17:310-330.

Sheffield, G., Grebmeier, J. M., 2009. Pacific walrus (*Odobenus rosmarus divergens*): Differential prey digestion and diet. Marine Mammal Science, 25: 761-777.

Shields, M. A., Kędra, M., 2009. A deep burrowing sipunculan of ecological and geochemical importance. Deep Sea Research Part I: Oceanographic Research Papers, 56:2057-2064.

Sirenko, B. I., Gagev, S. Y., 2007. Unusual abundance of macrobenthos and biological invasions in the Chukchi Sea. Russiona Journal of Marine Biology, 33: 355-364.

Snelgrove, P. V. R., Butman, C. A., 1994. Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology: an Annual Review, 32:111-177.

Stoker, S. W., 1978. Benthic invertebrate macrofauna on the eastern continental shelf of Bering and Chukchi Seas. Ph.D. Dissertation. Institute of Marine Science, University of Alaska Fairbanks.

Stoker, S. W., 1981. Benthic invertebrate macrofauna on the eastern Bering/Chukchi continental shelf. In Hood, D. W., Calder, J. A. (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, vol. 2, NOAA, pp. 1069-1103.

Thistle, D., 1981. Natural physical disturbances and communities of marine soft bottoms. Marine Ecology Progress Series, 6:223-228.

Weingartner, T. J., Aagaard, K., Woodgate, R., Danielson, S., Sasaki, Y., Cavalieri, D., 2005. Circulation on the north central Chukchi Sea shelf. Deep Sea Research II, 52: 3150-3174.

Weingartner, T. J., Danielson, S., 2010. Physical oceanographic measurements in the Klondike and Burger survey areas of the Chukchi Sea: 2008 and 2009. Final report to ConocoPhillips Alaska Inc., and Shell Exploration and Production Company. Institute of Marine Science, University of Alaska Fairbanks, 50 pp.

Weingartner, T. J., Danielson, S., in preparation. Physical oceanographic measurements in the Klondike and Burger survey areas of the Chukchi Sea: 2008-2010. Final report to ConocoPhillips Alaska Inc., Shell Exploration and Production Company, and Statoil USA E&P. Institute of Marine Science, University of Alaska Fairbanks.

Wentworth, C.R., 1922. A scale of grade and class terms for clastic sediments. Journal of Geology, 30:377-392.

Weston, D. P., 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. Marine Ecology Progress Series, 61:233-244.

CHAPTER 3

BENTHIC ECOLOGY 2010:

Associations of Epifaunal Community Structure with Environmental Covariates

INTRODUCTION

Invertebrate organisms fill an enhanced ecological role in the Chukchi Sea as a result of strong linkages with primary production. The reduced numbers of water-column grazers and relatively shallow depths result in strong pelagic-benthic coupling with the large flux of unconsumed production to the benthos driving very abundant and diverse macrofaunal assemblages (Ambrose et al., 2001; Dunton et al., 2005; Grebmeier et al., 2006). Production in the Chukchi Sea is supported by the advection of nutrient-rich waters from the Bering Sea. The abundant infauna is comprised of large individuals and is a major prey resource and critical habitat for benthic-feeding marine mammals. The epifaunal communities also have important roles in ecological processes of the Chukchi Sea including consumption as prey by marine mammals, predation on the infaunal communities, and mineralization of nutrients (Lowry, et al., 1980; Feder et al., 2005, 2007; Ambrose, et al., 2001). The reduced fish communities within the Chukchi Sea, particularly the northeastern part, may allow larger roles for invertebrate epifauna to exploit resources, as compared to the Bering Sea (Feder et al., 2005). The epifaunal communities in this area may, thus, be an important top predator of the system although the importance of epifauna in the northeast Chukchi Sea is still being investigated.

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 movement of water is driven by the pressure gradient from the Bering Sea to the Arctic Ocean (Weingartner et al., 2005). These water masses, the nutrient-rich Anadyr water, nutrient-poor Alaska Coastal water (ACW), and Bering Shelf water, of southern origin transport heat, nutrients, carbon, and animals to the Chukchi Sea and Arctic Ocean and are vitally important for maintenance of the ecological structure of the region (Weingartner et al., 2005; Grebmeier et al., 2006; Feder et al., 2007; Hopcroft et al., 2010 and in preparation). The combined effect of seasonal ice cover and the influx of water through the Bering Strait is a major influence on the productivity of the Chukchi Sea. Melting sea ice stratifies the water column creating conditions favorable for the primary production that results in a summer bloom supported by the nutrient-rich, Bering Sea water (e.g., Hopcroft et al., 2010 and in preparation). The combined influences of the absence of zooplankton grazers at the onset of the bloom and shallow water depths result in much of the primary production reaching the benthos of the Chukchi Sea. The strong pelagic-benthic coupling resulting from the increased proportion of production reaching the sediments (relative to other systems) supports rich benthic communities.

The epifauna of the northeastern Chukchi Sea are only now becoming quantitatively understood (Bluhm et al., 2009). The earliest recorded data from the Chukchi Sea are the qualitative surveys reported by Sparks and Pereyra (1966) who sampled 31 locations in the vicinity of Cape Thompson from inshore to 80 miles offshore. Data recorded from the survey comprise a species list with rank abundance values. Sea stars were reported as a dominant feature of the epifauna but curiously, brittle stars were not reported for sites in the northeastern Chukchi Sea in that study. Feder et al (1994a) document distributions of molluscan taxa in the northeastern Chukchi Sea while Bluhm et al. (2009) document an epifaunal community dominated by brittle stars and crabs. Epifaunal invertebrates in the Chukchi Sea, such as the brittle star *Ophiura sarsi*, are ecologically-important due to their great abundances and contribute to the larger ecosystem balance in many ways including remineralization of nutrients in the Chukchi Sea (Ambrose et al., 2001). Little other quantitative historical data are available. Epifaunal data will become available through broad-scale investigations in the northeastern Chukchi Sea such as the Russian-American Long-term Census of the Arctic (RUSALCA) and the Bureau of Ocean Energy Management, Regulation and Enforcement’s (BOEMRE) Chukchi Sea Offshore Monitoring in Drilling Area (COMIDA) program. For the southeast Chukchi and Bering seas, increases in abundance and biomass of epifauna over the last four decades have been correlated with increasing water temperature indicating responses to long-term climatic change (S. C. Jewett, unpublished data). Unfortunately, historical data are lacking for determining such trends in the northeastern Chukchi (Bluhm et al., 2009).

In the southeastern Chukchi Sea, the epifaunal community is dominated by crustaceans and echinoderms and trends are largely associated with water mass characteristics, current patterns, and sediment grain-size (Feder et al., 2005). Feder et al. (1994a) found that epifaunal molluscan communities were delineated by the amount of gravel in the sediment and bottom temperature. The broad-scale investigation of Bluhm et al. (2009) observed that the epifauna of the Chukchi Sea was dominated by echinoderms and crustaceans and demonstrated a latitudinal gradient of epifauna and an association with substrate. Environmental variables measured during ecological investigations often include sediment grain-size, organic carbon, water depth, bottom water temperature, and bottom water salinity (e.g., Feder et al., 1994 a and b; Bluhm et al., 2009). It is known, however, that such factors are proxies for the wide range of biological, oceanographic, and geological processes that drive the environment (Cochrane et al., 2009). Thus, in a broader perspective, the trends observed with variables such as sediment grain-size reflect the larger ecosystem processes and landscape-level changes. Prior sampling efforts for epifauna in the northeastern Chukchi Sea lack the power to understand how the animals respond to all but broad environmental gradients due to a mismatch between the scale of sampling and environmental gradients. The low sample sizes, high sampling variability, methodological differences, and absence of historical datasets make determination of changes in spatial trends and magnitude of temporal variability more difficult for the study area (Bluhm et al., 2009). In light of the absence of data on benthic fauna from the study area, the benthic ecology component of the CSESP contributes data critical to understanding the marine environment in the northeastern Chukchi Sea.

ConocoPhillips (COP), Shell Exploration and Production Company (SEPCO), and Statoil USA E&P are sponsoring the multi-disciplinary Chukchi Sea Environmental Studies Program (CSESP) to establish ecological conditions for three survey areas in the northeastern Chukchi Sea 2008-2010. The survey areas are Klondike, Burger, and Statoil, where successful lease bids were made in the February 2008 Chukchi Sea Lease Sale 193. The overall research program will provide information on physical, chemical, biological (including zooplankton and benthic ecology), and oceanographic baseline trends for the Klondike, Burger, and Statoil survey areas. The objective of this portion of the benthic ecology component of the CSESP is to assess species composition, abundance, and biomass of epifauna within the survey areas. We also test the hypothesis that epifaunal community structure is associated with small-scale environmental gradients and distributions of infaunal prey species.

METHODS

Epifauna Sampling Methods

Twenty-six (2009) to thirty-seven (2010) stations were targeted for sampling of epifauna in the Klondike, Burger, and Statoil survey areas from August 14 - 29, 2009 (cruise WW0902), September 25 to October 10, 2009 (WW0904), and September 1 – 18, 2010 (WW1003). In 2009, sampling was conducted at the 13 odd-numbered fixed stations in the Klondike and Burger survey areas on two cruises to evaluate seasonal variability. The Klondike and Burger stations were resampled in 2010 with the addition of 11 fixed stations in the Statoil survey area (Table 1-1 and Figure 3-1). Two stations (Transition stations) between the Burger and Klondike survey areas were sampled in 2010 as well.

Epifauna was sampled using a plumb staff 3.05 m beam trawl with a 4 mm codend liner and 7 mm mesh towed at a constant speed of 1.5 knots for up to 2-3 minutes with an occasional 5 minute tow. Material from each trawl was dumped onto a large sorting table located on deck

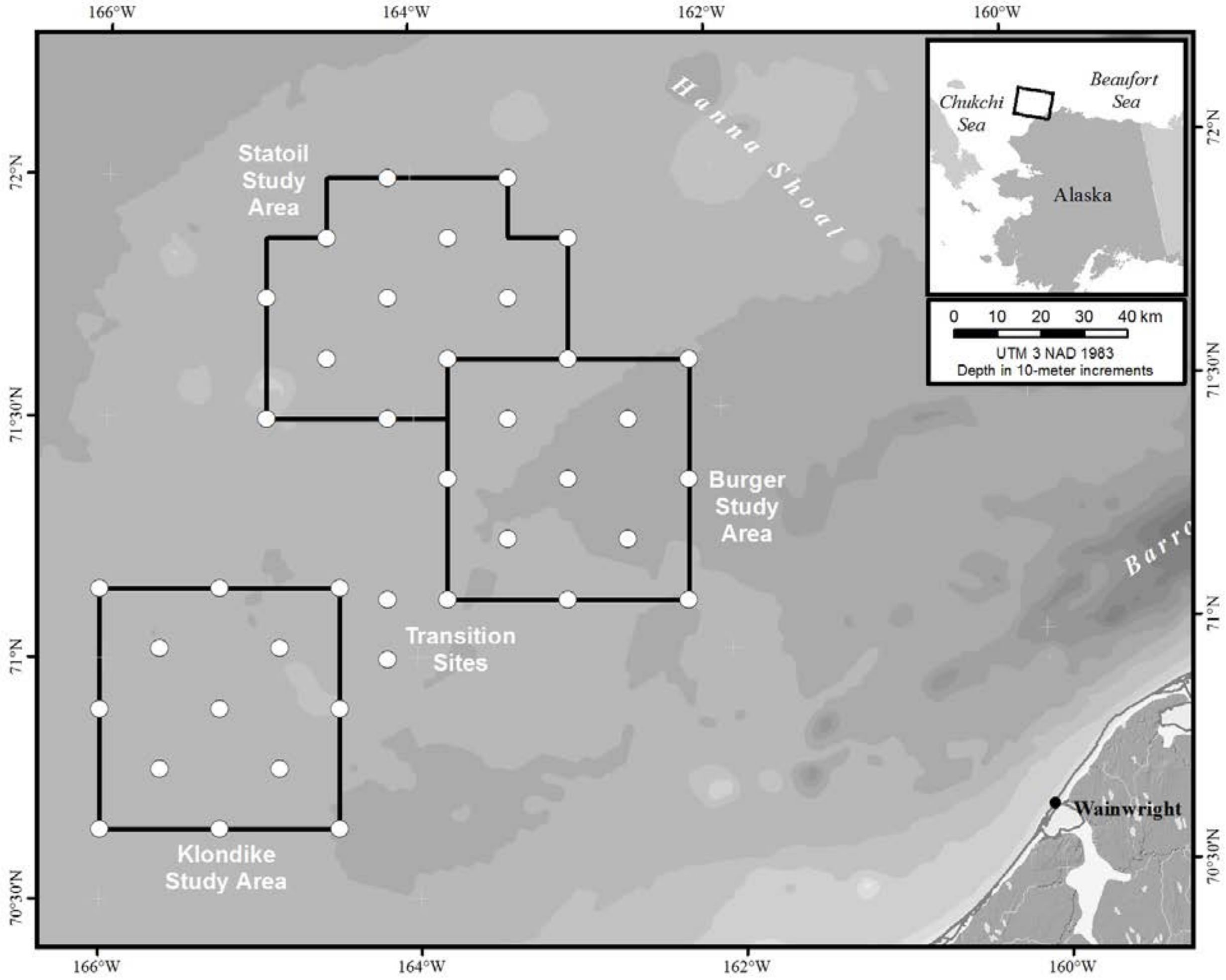


Figure 3-1. Map of stations sampled for epifauna during 2009-2010 CSESP surveys.

and a subsample of the catch sorted and organisms identified. All organisms in the subsample were counted and wet weights measured (weight after excess moisture was removed with an absorbent towel). Colonial organisms such as ascidiaceans, hydrozoans, bryozoans, and sponges were noted for presence and their wet weights determined. Sediment samples for analyzing sediment granulometry and chlorophyll concentrations were collected during the sampling for infauna during cruises WW0903 (2009) and WW1002 (2010) (Chapter 2).

Statistical Methods

Trends in community composition were evaluated using univariate and multivariate approaches (Appendix I). Descriptive summaries of the data provide insights into survey area variability and include average abundance and biomass. Diversity measures, including the number of taxa per survey area, are not presented as they are not applicable to epifaunal data given the rough definition of taxa categories in the field which were also used for the statistical analyses. Comparisons of average abundance, biomass, environmental variables, and biomass of major taxa groups between cruises and survey areas were performed using repeated measures ANOVA (rm ANOVA) in a variance-weighted analysis of variance using the statistical program R (www.r-project.org). Non-metric multidimensional scaling (MDS) was applied to determine community structure and spatial and temporal variability of communities using a Bray-Curtis similarity coefficient and an *ln*(x+1) transformation (Bray and Curtis, 1957; Clarke, 1993).
Associations of community structure were evaluated by correlating the environmental variables with biotic community structure and presented using the BIOENV program in PRIMER (Clarke and Ainsworth, 1993; Clarke and Gorley, 2006). Canonical correspondence analysis was also performed to evaluate the hypothesis that predatory epifaunal organisms were distributed according to infaunal prey.

RESULTS

Analysis of the Combined 2009-2010 Epifaunal Data

Epifauna of the survey area were field-identified to 99 unique taxa in 2009 and 2010 and expanded to 239 taxa in a laboratory setting (Appendix III).

Of the total abundance of epifaunal organisms collected from 2009-2010, 88% were brittle stars, 4% were shrimps, 3% were snails, 2% were sea cucumbers, and the remaining 3%

were crabs, amphipods and other taxa (abundance calculations do not include organisms that were assessed only for presence such as colonial ascidians (tunicates), hydrozoa, bryozoa, and porifera (sponges)). Seventy percent of the epifaunal biomass of the northeast Chukchi Sea was comprised of brittle stars, 7% snails and crabs, 5% sea cucumbers, 3% basket stars, 2% shrimps and sea stars, with the remaining 4% made up of sea urchins, sea anemones, soft corals, sea squirts, amphipods and other taxa. By site, brittle stars comprised 56% of the biomass in Klondike, 61% at the Transition stations, 74% in Burger, and 73% in Statoil. The remaining biomass in Klondike consisted of 17% crabs, 7% shrimps, 5% snails, 4% sea stars, 3% sea squirts, basket stars, and sea cucumbers, and the remaining 2% sea urchins, sea anemones, and other taxa. At the Transition stations, biomass consisted of 29% shrimps, 3% snails, and 2% sea cucumbers and sea anemones, and 3% crabs and other taxa. In Burger, snails comprised 8% of the biomass; sea cucumbers comprised 6%; crabs comprised 4%; basket stars comprised 3%; and shrimps, sea stars, soft coral, sea anemones, and sea urchins each comprised 1% of the biomass. The biomass in Statoil was comprised of 14% snails, 8% crabs, 2% shrimps, and 3% sea stars, sea cucumbers and other taxa. Average abundance ranged from 5,447 individuals per 1000 m^2 at the Transition stations in 2010 to 133,755 individuals in Burger in 2009; biomass ranged from 2,705.7 g 1000^{-1} m^{-2} at the Transition stations in 2010 to 95,764.8 g for Burger in 2009 (Table 3-1). The total number of taxonomic categories determined in the field ranged from 27 at the Transition stations in 2010 to 90 in Klondike in 2009 (Table 3-1).

Biotic measures varied significantly among survey areas but not by cruise. Variance-weighted repeated measures ANOVA (rm ANOVA) of biological data for Klondike and Burger 2009-2010 demonstrated significant survey area effects for abundance and biomass (Table 3-2). Abundance and biomass were significantly higher in Burger as compared to Klondike (Table 3-1 and 3-2 and Fig. 3-2). Statoil and the Transition stations were only sampled in 2010 so no temporal comparisons are possible. Compared to Klondike and Burger, Statoil demonstrated low abundance and biomass values while the values for Transition stations were similar to Klondike (Fig. 3-2).

Environmental measures indicated high variability with some significant differences among the survey areas (Table 3-1). ANOVA resulted in a significant survey area effect for

Table 3-1. Summaries of biotic and environmental variables for the fixed stations sampled for epifauna during the 2009-2010 CSESP. Ave. = average, SD = standard deviation, Total # Taxa = number of taxonomic categories found in each survey area, chlorophyll *a* (Chl *a*) and total chlorophyll (Total chl = chlorophyll *a* plus phaeopigment) are in ug cm^{-3}, -- = not calculated, and ns = not sampled. Abundance (ind. 1000^{-1} m^{-2}) calculations do not include organisms that assessed for presence such as colonial ascidians (tunicates), hydrozoa, bryozoa, and porifera (sponges) while Biomass (g 1000^{-1} m^{-2}) include colonial organisms.

WW0902	Klondike		Transition		Burger		Statoil	
Variable	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Abundance	37,224	99,294	ns	ns	133,755	154,831	ns	ns
Biomass	31,102.0	44,891.2	ns	ns	95,764.8	72,093.6	ns	ns
Total # Taxa	90	--	ns	ns	73	--	ns	ns
Chl *a**	0.003	0.002	ns	ns	0.002	0.001	ns	ns
Total Chl*	0.027	0.029	ns	ns	0.016	0.014	ns	ns
% Sand*	45.9	19.0	ns	ns	37.3	17.8	ns	ns
% Mud*	44.2	21.1	ns	ns	57.3	18.6	ns	ns
Depth (m)	39.5	3.5	ns	ns	41.9	1.9	ns	ns
WW0904	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Abundance	19,683	58,850	ns	ns	80,929	97,788	ns	ns
Biomass	20,110.5	40,651.1	ns	ns	54,114.2	51,668.7	ns	ns
Total # Taxa	74	--	ns	ns	71	--	ns	ns
Depth (m)	39.6	2.5	ns	ns	42.1	1.7	ns	ns
WW1003	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Abundance	8,268	11,034	5,447	759	83,759	80,648	15,760	26,458
Biomass	16,222.1	20,840.4	2,705.7	542.7	78,284.1	72,208.1	15,367.0	20,264.7
Total # Taxa	80	--	27	--	70	--	61	--
Chl *a**	0.628	0.560	0.162	--	0.396	0.305	0.572	0.231
Total Chl*	2.056	1.75	0.651	--	1.434	1.401	2.061	0.916
% Sand*	44.6	15.9	51.9	--	32.8	22.1	42.6	21.2
% Mud*	41.4	18.5	47.3	--	62.6	22.7	56.6	22.0
Depth (m)	39.2	2.8	40.4	0.5	42.1	1.5	38.3	1.8

* Sediment variables are for fixed stations from the infaunal sampling cruises for 2009 and 2010.

Table 3-2. Repeated measures analysis of variance of summary statistics, environmental variables, and biomass (g 1000^{-1} m^{-2}) of key epifaunal taxa for 2009-2010 CSESP study. Total Chl = chlorophyll *a* plus phaeopigment. Values significant at $\alpha = 0.05$ are in bold type.

Summary Statistics

Abundance	F-value	p-value
Survey Area	14.47	**0.0009**
Cruise	1.80	0.1785
Survey:Cruise	0.28	0.7607

Biomass	F-value	p-value
Survey Area	19.32	**0.0142**
Cruise	0.08	0.9210
Survey:Cruise	1.24	0.2999

Environmental Variables

% Mud	F-value	p-value
Survey Area	4.05	0.0555
Cruise	0.57	0.4586
Survey:Cruise	2.44	0.1319

Depth	F-value	p-value
Survey Area	6.56	**0.0171**
Cruise	0.03	0.8643
Survey:Cruise	1.42	0.2452

Total Chl	F-value	p-value
Survey Area	0.67	0.4212
Cruise	28.39	**<0.0001**
Survey:Cruise	0.85	0.3660

Key Taxa

Brittle Stars	F-value	p-value
Survey Area	41.67	**<0.0001**
Cruise	0.61	0.5498
Survey:Cruise	2.90	0.0661

Clams	F-value	p-value
Survey Area	0.02	0.8904
Cruise	0.24	0.7844
Survey:Cruise	0.22	0.8024

Crabs	F-value	p-value
Survey Area	4.84	**0.0377**
Cruise	4.64	**0.0151**
Survey:Cruise	1.92	0.1593

Sea Cucumbers	F-value	p-value
Survey Area	0.00	0.988
Cruise	0.11	0.8985
Survey:Cruise	0.20	0.8205

Sea Stars	F-value	p-value
Survey Area	2.32	0.1404
Cruise	0.04	0.9637
Survey:Cruise	0.93	0.4039

Shrimps	F-value	p-value
Survey Area	0.53	0.4737
Cruise	0.03	0.9680
Survey:Cruise	0.49	0.6140

Snails	F-value	p-value
Survey Area	1.02	0.3233
Cruise	0.23	0.7962
Survey:Cruise	4.21	**0.0215**

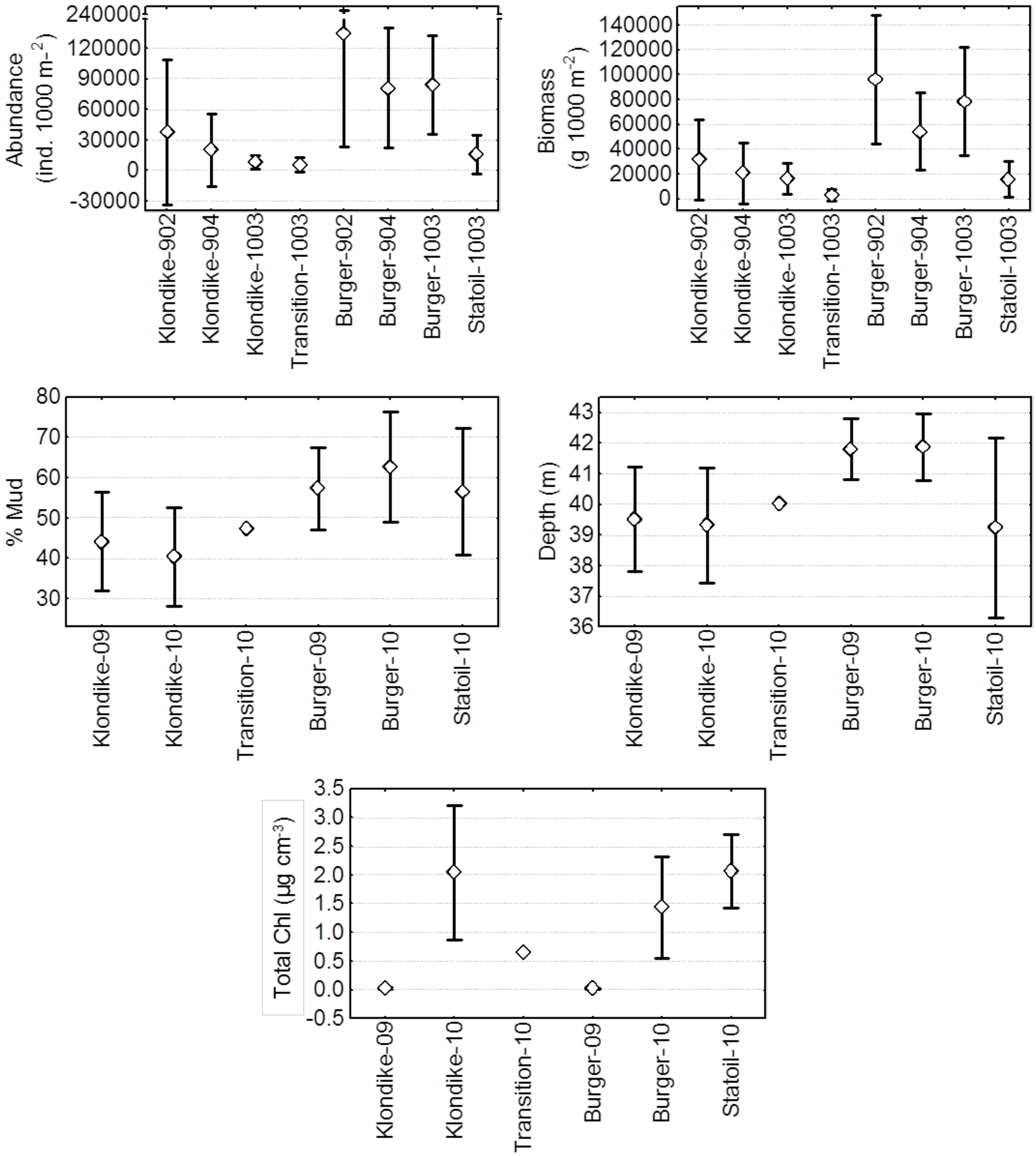


Figure 3-2. Plots of means and 95% confidence intervals based on the raw data for biological summary measures and environmental variables in survey areas over the 2009-2010 CSESP study.

water depth and a significant cruise effect for total chlorophyll (Table 3-2). Water depth for the fixed stations was significantly greater for Burger as compared to Klondike and Transition stations and Statoil were intermediate (Table 3-1 and Fig. 3-2). Total chlorophyll was significantly higher in 2010 than in 2009. Percent mud was marginally significant ($\alpha = 0.10$) with Burger having greater percent mud than Klondike. Overall, sediments in the Klondike survey area were coarser than sediments in Burger (Table 3-1 and Fig. 3-2). Percent mud for Statoil was similar to Burger while sediments at the Transition stations were again, intermediate between Klondike and Burger.

Analysis of biomass for dominant epifaunal taxa groups revealed significant differences for brittle stars and crabs. The biomass of brittle stars was significantly different between Klondike and Burger with Burger having greater biomass (Table 3-2 and Fig. 3-3). Significant effects were observed for survey area and cruise for crabs and snail. Biomass of crabs was higher in Burger than in Klondike and biomass of crabs in Klondike was lower in 2009 and increased slightly in 2010 but was higher in 2009 for Burger and decreased in 2010. Biomass of snails was lower in Klondike than in Burger and declined in Klondike over the cruises while in Burger, values were low for cruise WW0904 but increased for cruise WW1003. Differences between Klondike and Burger were minor for the other fauna groups. Transition stations and Statoil had lower biomass for all categories compared to Burger.

The MDS ordination of the combined 2009-2010 epifaunal data set indicated a gradient between sites and a lack of separation of sampling points among cruises. The Klondike stations are positioned in the lower left corner and the Burger stations on the right side of the of MDS ordination plot (Fig. 3-4). The Statoil stations are generally in the upper portion of the plot overlapping with Burger stations. The Transition stations are positioned between most of the Burger and Statoil stations. Thus, the plot generally reflects the geographic locations of the survey areas. Looking at temporal differences, Klondike stations varied similarly between 2009 and 2010 with little difference among cruises. Stations for Burger in 2010, however, deviated from that trend as some of the stations for 2010 were separate from the other cruises.

The biomass of Klondike stations in 2009 and 2010 was generally dominated by the crab *Chionoecetes opilio*, shrimps (Caridea), hermit crabs (Paguroidea), the sea stars *Leptasterias* sp., and sea squirts (Ascidiacea) (Table 3-3). Taxa dominant by biomass at Transition stations in

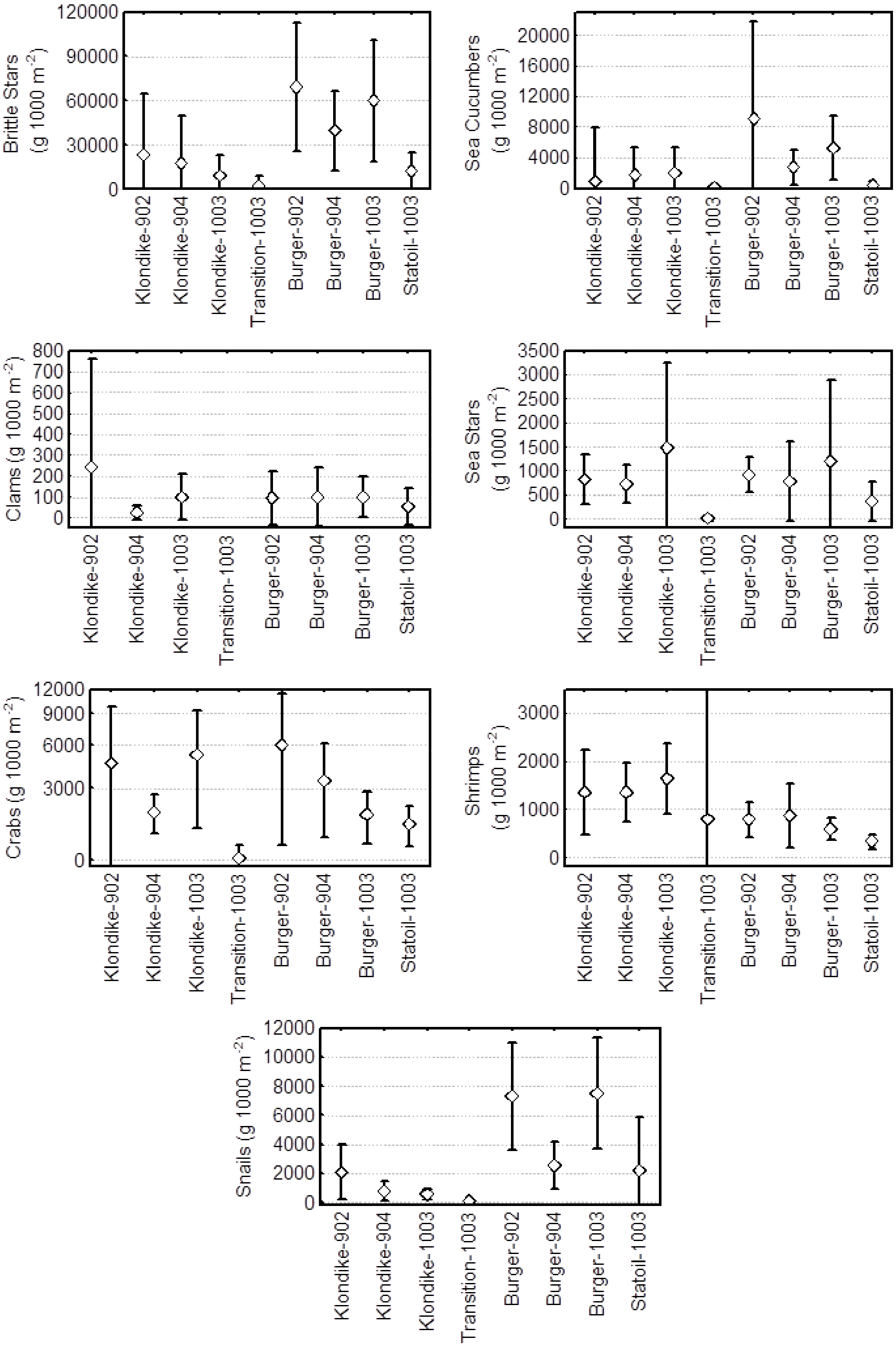


Figure 3-3. Plots of means and 95% confidence intervals based on the raw data of the biomass of key taxa in survey areas over the 2009-2010 CSESP study.

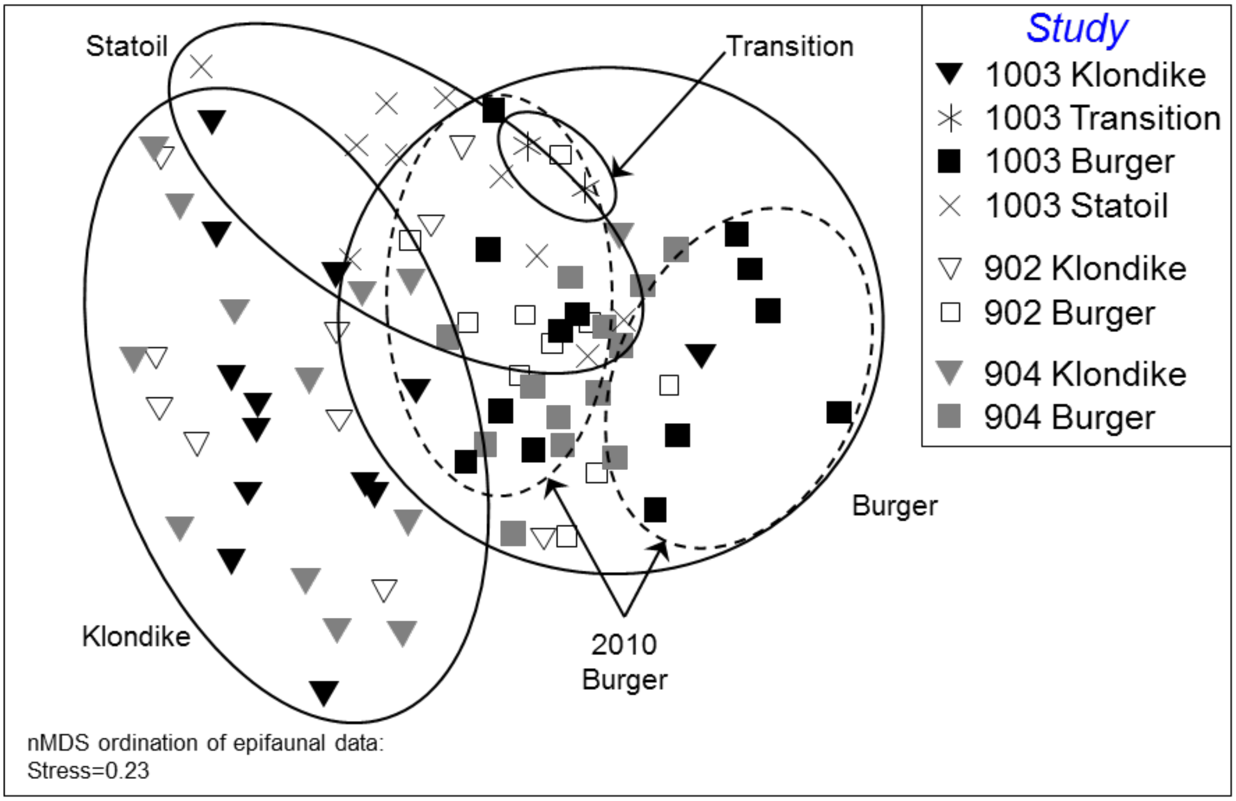


Figure 3-4. Nonmetric multidimensional scaling ordination plot of Bray-Curtis similarities based on *ln*(x+1)-transformed epifaunal biomass data, 2009 - 2010 CSESP.

Table 3-3. Epifaunal taxa contributing most to within survey area and cruise similarity (Sim). Biomass in g 1000^{-1} m^{-2}, Sim = average similarity, % Contr. = % contribution to similarity, and Cum. % = cumulative percent contribution. Stations for each area are those included in Figure 3-4.

2009 August Klondike: Average similarity = 7.63

Taxon	Biomass	Sim	% Contr.	Cum. %
Chionoecetes opilio	1891.97	2.07	27.16	27.16
Shrimps	1041.34	1.88	24.63	51.79
Paguroidea	829.61	0.69	9.02	60.81

2009 October Klondike: Average similarity = 21.64

Taxon	Biomass	Sim	% Contr.	Cum. %
Chionoecetes opilio	1158.37	6.25	28.87	28.87
Shrimps	1344.79	5.65	26.12	54.99
Leptasterias sp.	608.52	2.78	12.86	67.84

2010 September Klondike: Average similarity = 20.64

Taxon	Biomass	Sim	% Contr.	Cum. %
Chionoecetes opilio	4206.45	7.2	34.86	34.86
Shrimps	1637.53	6.81	33	67.86
Ascidiacea	760.74	1.85	8.97	76.83

2010 September Transition: Average similarity = 61.22

Taxon	Biomass	Sim	% Contr.	Cum. %
Ophiura sarsi	1645.62	39.17	63.97	63.97
Shrimps	782.56	19.95	32.59	96.56

2009 August Burger: Average similarity = 30.07

Taxon	Biomass	Sim	% Contr.	Cum. %
Ophiura sarsi	57724.59	25.09	83.43	83.43
Chionoecetes opilio	3276.88	1.65	5.48	88.91
Astarte sp.	1483.03	0.62	2.05	90.96

2009 October Burger: Average similarity = 35.53

Taxon	Biomass	Sim	% Contr.	Cum. %
Ophiura sarsi	39807.42	29.14	82.03	82.03
Chionoecetes opilio	2723.13	1.49	4.19	86.23
Shrimps	860.35	1.23	3.46	89.68

Table 3-3. continued

2010 September Burger: Average similarity = 32.70

Taxon	Biomass	Sim	% Contr.	Cum. %
Ophiura sarsi	59872.68	27.01	82.63	82.63
Astarte borealis	2086.42	1.55	4.76	87.38
Psolus fabricii	2334.43	0.76	2.32	89.71

2010 September Statoil: Average similarity = 23.83

Taxon	Biomass	Sim	% Contr.	Cum. %
Ophiura sarsi	10084.29	12.24	51.36	51.36
Chionoecetes opilio	993.81	7.28	30.56	81.92
Shrimps	286.25	1.99	8.37	90.29

2010 included the brittle star *Ophiura sarsi* and shrimps. Burger was dominated by *O. sarsi*, *C. opilio*, shrimps, the bivalves *Astarte* sp. and *A. borealis*, and the sea cucumber *Psolus fabricii*. Statoil sites were dominated by *O. sarsi*, *C. opilio*, and shrimps. There was moderate variability in the dominant species listings between 2009 and 2010 for Klondike and Burger but the dominants were largely similar over time.

Bubble plots indicated variable distributions for epifaunal animals over the study area. Brittle stars were present in large numbers in the northeast corner of Klondike, all of Burger, and southern portion of Statoil and provided the greatest biomass of all species sampled (Fig. 3-5). Crabs were present at all sites with varying biomass over the three time periods studied but were most numerous during cruise WW0902 (Fig. 3-6). Shrimps were present at all sites but had greatest biomass in Klondike (Fig. 3-7). Biomass of crabs and shrimps was less at the sites with greatest brittle stars biomass and the biomass of shrimp tended to be lower where the biomass of crabs was high.

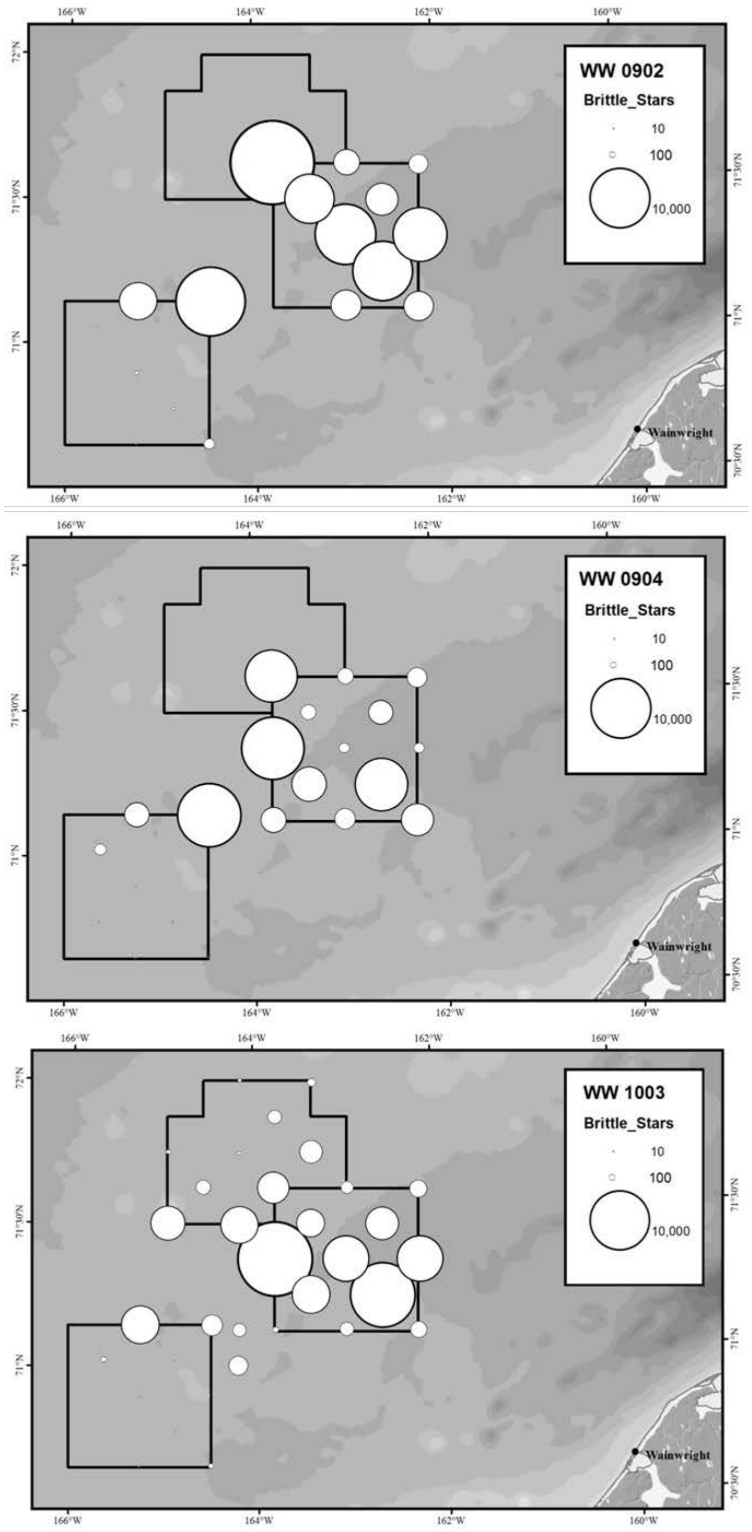


Figure 3-5. Bubble plots of biomass (g 1000^{-1} m^{-2}) for brittle stars in the Klondike, Burger, and Statoil survey areas collected during 2009-2010 CSESP.

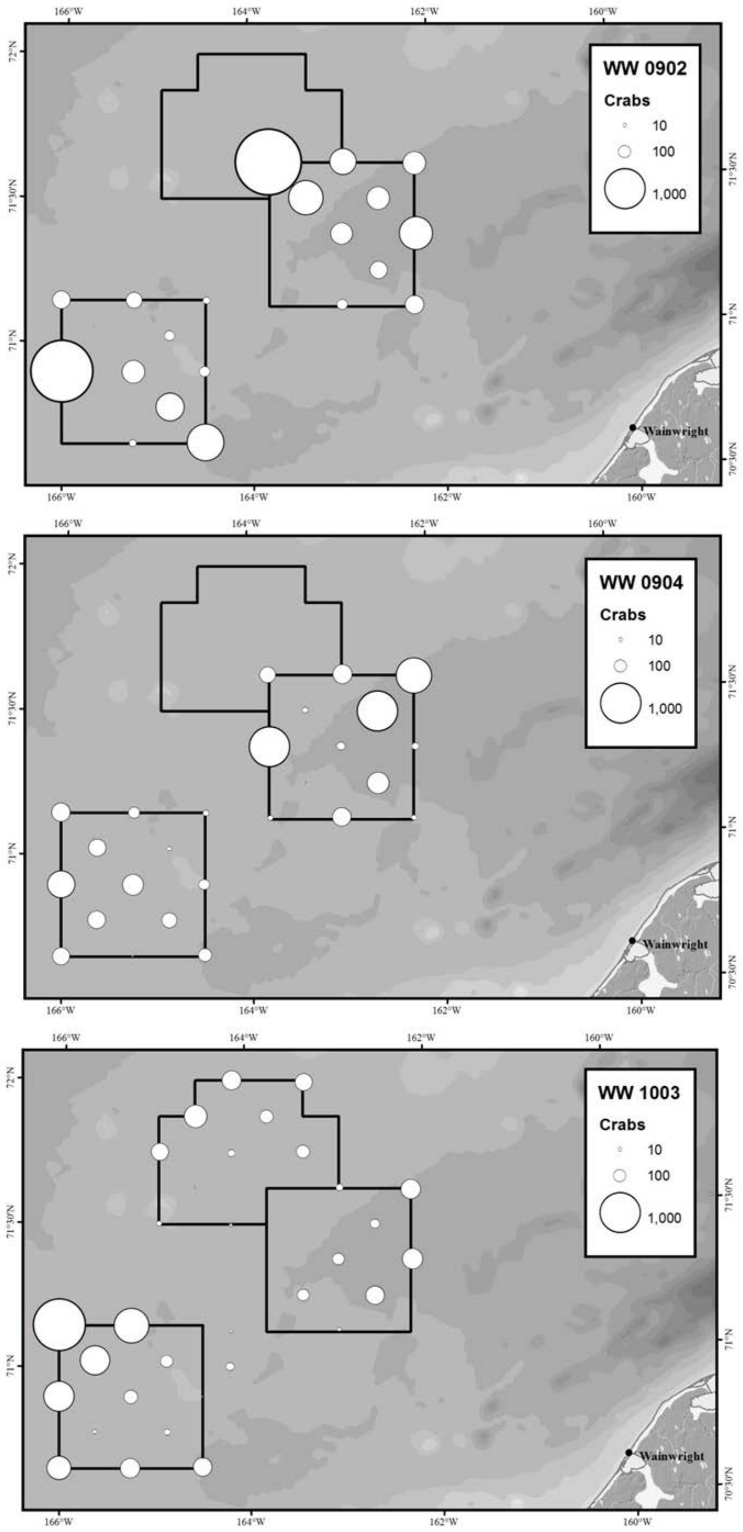


Figure 3-6. Bubble plots of biomass (g 1000^{-1} m^{-2}) for crabs in the Klondike, Burger, and Statoil survey areas collected during 2009-2010 CSESP.

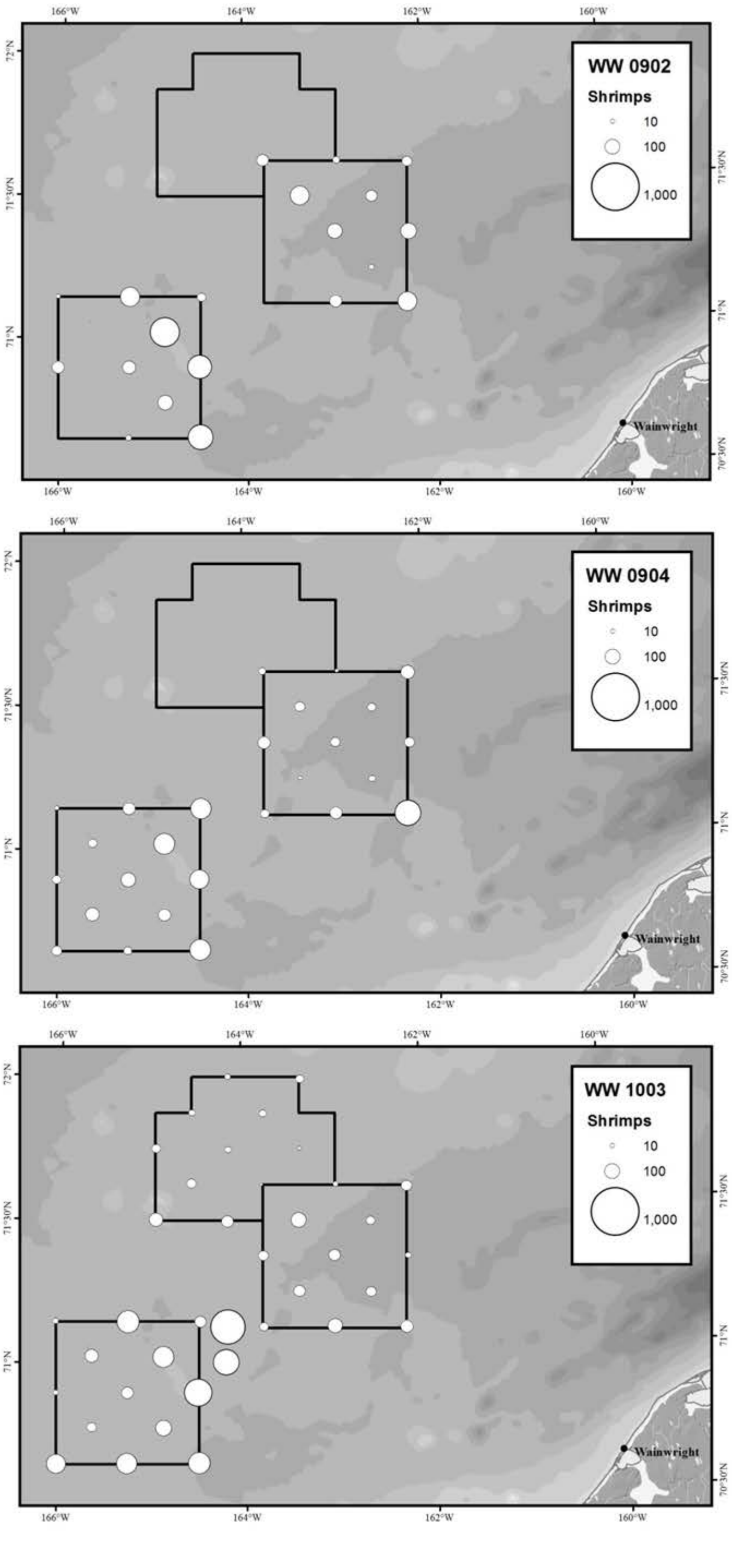


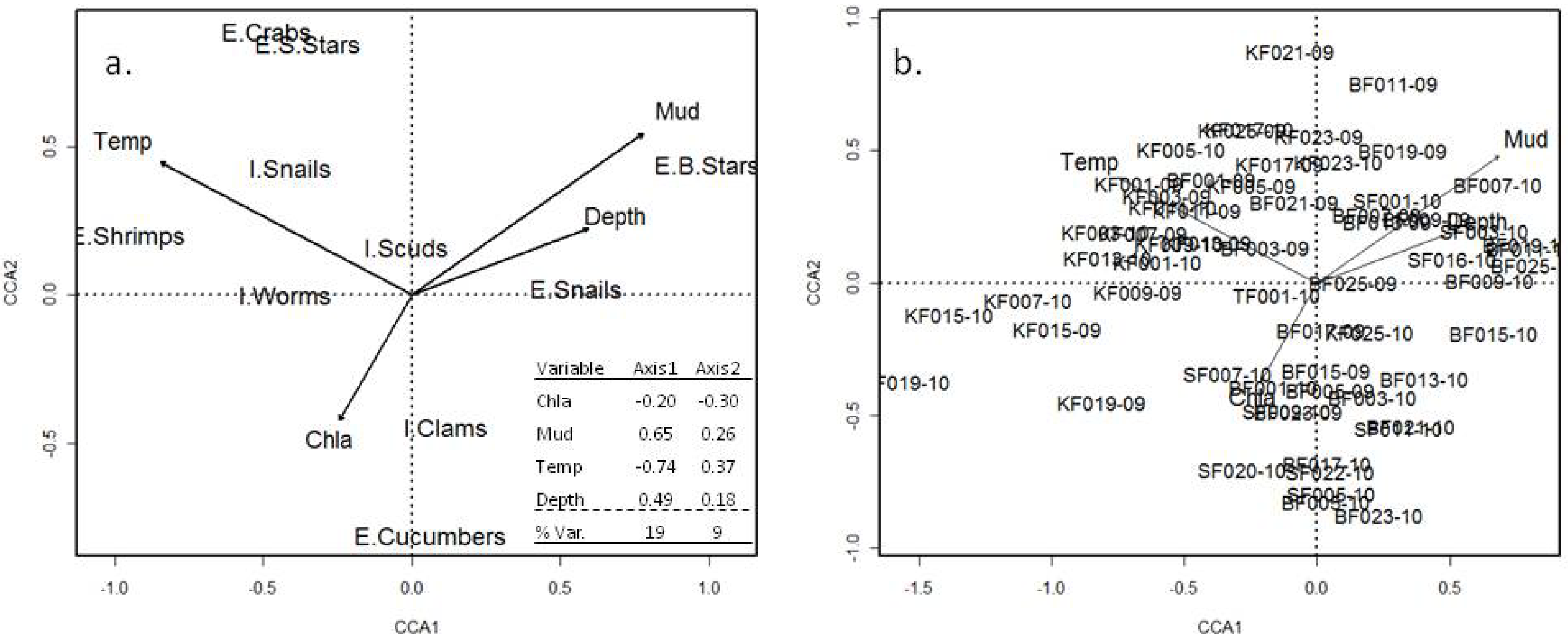
Figure 3-7. Bubble plots of biomass (g 1000^{-1} m^{-2}) for shrimps in the Klondike, Burger, and Statoil survey areas collected during 2009-2010 CSESP.

There were moderate associations between environmental variables and epifaunal community structure (Table 3-4). Environmental variables available for the analysis (after removal of highly correlated variables) included total chlorophyll, water depth, water temperature, salinity, percent sand, and percent mud. The two-variable combination of water temperature and total chlorophyll had the highest correlation with biotic community structure ($\rho = 0.304$) but that correlation was only slightly greater than the correlation value determined for water temperature alone ($\rho = 0.294$).

Table 3-4. Best fitting Spearman correlations from BIOENV program listing the variables with the highest correlations with the biological station similarity matrix.

Number of Variables	Best Variable Combination		Second Best Variable Combination
1	Water temperature (0.294)		Percent mud (0.270)
2	Total chlorophyll, water temperature (0.304)		Water temperature, salinity (0.291)
3	Total chlorophyll, water temperature, salinity (0.302)		Total chlorophyll, water temperature, water depth (0.287)
4	Total chlorophyll, water temperature, salinity, water depth (0.287)	tie	Mud, water temperature, salinity, water depth (0.276) Total chlorophyll, percent mud, water temperature, water depth (0.276)
5	Total chlorophyll, percent mud, water temperature, salinity, water depth (0.276)		Total chlorophyll, percent mud, percent sand, water temperature, water depth (0.256)

The hypothesis that the distributions of predatory epifaunal organisms may be associated with infaunal prey organisms was tested using canonical correlation analysis (CCA) of major taxonomic groups for infauna and epifauna. The analysis was limited to the total biomass of a few key taxonomic groups to meet the assumptions for the CCA. The CCA revealed strong associations of fauna with environmental characteristics but not among biological characteristics of the epifauna and infauna groups (Fig. 3-8). The first two derived axes of the CCA accounted for 28% of the variability in the faunal data with the first axis accounting for 19%. The strongest



Variable	Axis1	Axis2
Chla	-0.20	-0.30
Mud	0.65	0.26
Temp	-0.74	0.37
Depth	0.49	0.18
% Var.	19	9

Figure 3-8. Canonical correspondence analysis of major faunal taxonomic groups and environmental variables for the 2009-2010 CSESP. E. = Epifaunal organisms, I. = infaunal organisms, Scuds = amphipods, S.Stars = sea stars and B.Stars = brittle stars. Chla = total chlorophyll, Depth = water depth, Mud = percent mud, Temp = water temperature, and % Var. = percent variance accounted for by the regression of the environmental variables against benthic community structure in the CCA.

associations between epifaunal community structure (by major groups) and environmental variables were with water temperature, percent mud, and depth (Fig. 3-8).

Faunal groups are strongly associated with the CCA axes (Fig. 3-8a). The importance of a variable to the ordination is demonstrated by the length and direction of the arrow. A long arrow along one (or both axes) indicates a strong correlation with the axis. Thus, CCA Axis 1 is characterized by (has high correlations with) the environmental variables water temperature, percent mud, and water depth in descending order of strength. Associations of the faunal groups to environmental variables are demonstrated by the position of the labels for the group near the head of an arrow for an environmental variable or in the case of a strong negative association, in the opposite direction. Epifaunal crustaceans (predatory shrimps and crabs), sea stars and infaunal snails were most closely associated with water temperature reflecting associations with oceanographic conditions. Brittle stars and epifaunal snails were more closely associated with percent mud and secondly with water depth indicating associations with physical characteristics. Sea cucumbers and clams (both including suspension feeding groups) were most closely associated with total chlorophyll products representing possible direct associations with food resources. Infaunal worms and amphipods were not clearly associated with any one environmental variable. Strong associations between epifaunal predators and potential infaunal prey (clams and worms) were not apparent suggesting that if predators are responding to prey items, they are not focusing on any one prey group but feeding more generally on multiple groups.

In the plot of stations in the CCA ordination, stations grouped out largely by position along the temperature and percent mud gradient (Fig. 3-8b). Klondike stations, generally the shallower stations within the main study area, were positioned to the left as they tend to have shallower water depths, coarser sediments, and higher water temperatures. Burger stations were plotted to the right and they tend to be deeper, muddier, and colder. The positioning of the Statoil and Transition stations reflected their intermediate characteristics. Thus, the positioning of the stations roughly reflects the geographic locations of the stations, as was also shown in the MDS ordination.

DISCUSSION

Epifauna of the Klondike, Burger, and Statoil Study Areas

The epifauna of Klondike, Burger, and Statoil are representative of mixed Arctic and northern Pacific benthic assemblages found throughout the Bering and Chukchi seas (Feder et al., 1994b, 2005, 2007; Blanchard et al., 2010). The circumpolar, boreal-arctic brittle star, *Ophiura sarsi*, dominated the epifauna at all survey areas in the present study, consistent with observations by Feder et al. (1994b), Ambrose et al. (2001), and Bluhm et al. (2009). The dominance of echinoderms in the Chukchi Sea increases with latitude relative to crustaceans and fishes such that the dominant echinoderms switch from sea stars in the southeastern Chukchi Sea to *O. sarsi* in the north, possibly resulting from a lack of predation on brittle stars by flatfishes and large *Chionoecetes opilio* (present in southern waters) in the north (Feder et al., 1994b; Feder et al., 2007; Bluhm et al., 2009). The snow crab, *C. opilio*, was the second-most common organism and, unlike observations by Bluhm et al. (2009), crabs were, overall, a small proportion of the epifaunal community within the current study area compared to brittle stars although great variability among stations exists. Most epifaunal species were common within all survey areas although species compositions shifted with site-specific habitat characteristics. The north Pacific epifaunal species are maintained in the areas by the transport of larvae north with the movement of water which is established because of the pressure gradient from the Bering Sea to the Arctic Ocean (Weingartner et al., 2005; Feder et al., 2005). Bluhm et al. (2009) note that snow crabs are generally not common on Arctic shelves but the distribution of *C. opilio* is expanding due to recent climate variations. The movement of species northward does come at a cost for some species such as the snow crab, *C. opilio*, which are reduced in size relative to populations in southern waters due to physiological growth limits in cold water (Bluhm et al., 2009). In spite of the colder water, however, epifaunal communities in the northeast Chukchi Sea are diverse and large animals were abundant.

The high abundance and biomass of benthic communities in the Chukchi Sea result from the high productivity in the nutrient-rich waters from the Gulf of Anadyr and Bering Sea (Grebmeier et al., 2006; Sirenko and Gagaev, 2007; Bluhm et al., 2009). The shallow water depths, lack of pelagic consumers, transport of nutrients from the Bering Sea, and seasonal ice cover results in tight pelagic-benthic coupling in the Chukchi Sea. Feder et al. (1994b) also indicated that the transport of POC-rich water from the Bering Sea supplements local primary production thereby providing year-round availability of carbon and a persistent food source for benthic communities in the northeast Chukchi Sea. Extremely high abundance and biomass values have been identified in areas with gyres resulting from the concentration of nutrients and food resources for benthic-feeding animals (Feder et al., 1994b; Grebmeier et al., 2006; Sirenko and Gagaev, 2007). The epifaunal abundance and biomass of the present study were comparable to values found by Bluhm et al. (2009) although values in the Burger survey area were even higher than those recorded earlier. The extremely high densities of *O. sarsi* in the muddy Burger study area are consistent with the increased biomass of infaunal organisms found there resulting from the deposition of fine sediments and organics (Grebmeier et al., 1988; Feder et al., 1994a and b; Feder et al., 2007). Brittle stars are common worldwide and they can dominate epibenthic communities in various habitats including some polar shelves (Piepenburg and von Juterzenka, 1994; Piepenburg and Schmid, 1996; 1997; Piepenburg et al, 1997, Starmans et al., 1999; Ambrose et al., 2001). Overall, epifauna abundance and biomass in the northeast Chukchi Sea shown in this project are within the ranges reported for other Arctic shelf areas (Piepenburg and Schmid, 1996; 1997; Starmans et al., 1999).

Spatial Trends and Associations of Fauna with Environmental Characteristics

Feder et al. (2005) related distributions of epifauna of the southeastern Chukchi Sea to water masses (Alaska Coastal vs. Bering Shelf/Anadyr water) and associated nutrient concentrations. Feder et al. (1994a) reported higher abundance of epifaunal mollusks associated with water mass characteristics in the northeastern Chukchi Sea. Bluhm et al. (2009) found that environmental characteristics could not fully explain biomass patterns resulting in moderate correlations with environmental characteristics and concluded that associations with latitude and sediment grain-size were most important. A limitation of the past studies may be that epifaunal communities demonstrate high local and regional variability and sampling programs were not designed to evaluate faunal responses to environmental gradients with high power (e.g., the sample sizes were too small and sampling locations too dispersed). With appropriate designs for sampling gradients, as in the epifaunal surveys undertaken in the CSESP, it is possible to demonstrate stronger associations of biota with environmental gradients in the northern Chukchi Sea. Here, correlations of epifaunal community structure with environmental patterns and joint trends in faunal distributions and physical variables indicate the importance of environmental gradients on smaller scales. The suite of environmental covariates associated with epifaunal community structure in this study includes total chlorophyll, water temperature, and percent mud (covarying with water depth) reflecting responses to food availability, oceanographic characteristics, and physical features, respectively (Table 3-4 and Fig. 3-8). Epifaunal biomass and abundance are higher in the central region of the study area (an area that encompasses the northwest corner of Burger, which is muddier and deeper) than in the southern portion (an area that includes the southwestern corner of Klondike, which is shallower and sandier). Abundance and biomass were moderate in the Statoil survey area. The lingering pool of cold, winter water in Burger reflects the topographic, geologic, and oceanographic characteristics of Burger (Weingartner and Danielson, 2010 and in preparation). Similar patterns were observed in the abundance and biomass of the infauna as well (Chapter 2). Thus, the present study suggests that the topography (shoals and valleys) and the resulting influence of geological features on deposition of primary production (as reflected by the covarying trends in depth and sediment grain-size) may be large factors controlling the distribution of benthic fauna in the Chukchi Sea. Inferences of patterns from larger scale investigations not considering small-scale environmental gradients overlook important sources of variability for benthic communities but broadly agree with the results of this study (Feder et al., 1994a and b; Bluhm et al., 2009).

Trophic Interactions

The epifauna in the study area reflect the spectrum of feeding modes including predator/scavengers, surface deposit feeders, as well as filter- and suspension-feeding organisms (Table 3-5). The large biomass of sea cucumbers (*Myriotrochus rinkii*), brittle stars (*Ophiura sarsi*) and other deposit- and filter-feeders (including tunicates) indicate substantial competition for primary production with the infauna. The dominant species, *O. sarsi* (a deposit-feeding omnivore that feeds on diatoms and particulates deposited on sediments and consumes live prey it encounters), *C. opilio*, and shrimps, are predators whose diets include small polychaetes, bivalves, barnacles, and amphipods (Feder et al., 2005; Bluhm et al., 2009; Paul et al., 1979). Epifauna in the study area also include predatory gastropods (*Buccinum* spp. *Neptunea* spp., *Cryptonatica affinis,* and *Euspira pallida*) that prey on infaunal bivalves and polychaetes. Thus, epifauna influence infaunal community structure through disturbance via predation and bioturbation during feeding activities, competition for resources through mineralization of nutrients, and transfer of carbon to higher trophic levels.

The wide range of feeding strategies enables animals to take advantage of all sources of available carbon (Grebmeier et al., 1988; Grebmeier and McRoy, 1989; Grebmeier et al., 1989; Feder et al., 1994a and b; Feder et al., 2005; Iken et al., 2005; Brooks et al., 2006; Bluhm et el., 2009). In habitats exposed to greater currents that entrain sediment, and thus carbon, suspension-feeders will be numerous but may include other organisms dependent on advected food sources (Feder et al., 1994 and 2005). For example, the Klondike area was dominated by predators such as crab, shrimp, sea stars, as well as filter feeding/suspension feeding tunicates which feed on carbon sources likely transported into the area by stronger currents. Shrimp, such as *Pandalus* spp., are foragers that utilize benthic and pelagic food sources entrained by turbulence and eddies (Rice et al., 1980). Thus, the higher abundance of shrimps at Klondike may partially reflect the greater advection of food through that area. Conversely, the Burger area, where finer sediments accumulate, was dominated by deposit feeding and suspension feeding taxa such as brittle stars and sea cucumbers. Deposit feeding organisms take advantage of the unconsumed plankton that fall to the benthos which accumulates in Burger (as indicated by the muddier environment in Burger) (Feder, 1981; Iken et al., 2005; Harris et al., 2009). Both the Statoil and the Transition areas were dominated by epifauna with feeding strategies common to those found in both Burger and Klondike, indicating the transitory environment in these areas.

The presence of marine mammals in the study area emphasizes the productivity of the area (Feder et al., 2005). Marine mammals feeding on benthic fauna in the Chukchi Sea include the bearded seal, gray whale, and Pacific walrus. Walrus are known to feed within and to the northwest of the general study area and presumably, bearded seals do as well. (Suitable gray whale habitat has not been noted within the current study area). The benthic fauna serve as a vital link between the 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). Additionally, the feeding activities of bottom-feeding mammals resuspend organic detritus in the sediment making it available for suspension-feeding epifauna (Fay, 1982; Oliver and Slattery, 1985; Moore et al., 1986; Feder et al., 1994b). The

Table 3-5. Summary of epifaunal groups, their prey items and feeding strategies. uSDF—unselective surface deposit feeder; sSDF—selective surface deposit feeder; SSDF—subsurface surface deposit feeder; FF—filter feeder; SF—suspension feeder; P—predator; S—scavenger; DF—deposit feeder; SDF—surface deposit feeder; of—opportunistic forager; af—active forager; og—opportunistic generalist.

Organism	Prey Items	Feeding Strategy	Reference
Anemones			
Stomphia sp.		SF	Lundsten et al., 2010
Crustaceans			
Shrimp	decapods, ostracods, diatoms, polychaetes, bivalves	of, P	Tamelander et al., 2006; Rice et al., 1980
Crabs			
Hermit crabs		S, FF, DF	Ramsay et al., 1996
Chionoecetes sp.	Small bivalves, hermit crabs, barnacles, brittle stars, small gastropods	P/S	Paul et al., 1979; Feder et al., 1994b
Barnacles		SF	Feder et al., 1994b
Isopods		uSDF,SSDF	Iken et al., 2005; Tamelander et al., 2006
Synidotea sp.	hydrozoa, bryozoa		Menzies and Miller, 1972; Chapman and Carlton, 1994
Pycnogonida		P	Tamelander et al., 2006
Mollusks			
Bivalves		sSDF	Iken et al., 2005
Nuculana radiata		SSDF	Feder et al., 2007
Astarte sp.	phytodetritus	SF	Tamelander et al., 2006
Chlamys behringiana		SF	Feder et al., 1994a
Thyasiridae	reworked phytodetritus	uSDF	Iken et al., 2005; Feder et al., 1994a
Yoldiidae	reworked phytodetritus	SSDF	Iken et al., 2005

Table 3-5. continued

Organism	Prey Items	Feeding Strategy	Reference
Gastropods		P, af	Valentine et al., 2002
Buccinum spp.	polychaetes, bivalves, sea urchins, fish	P/S, af, og	Himmelman and Hamel, 1993; Ilano et al., 2005; Taylor, J.D., 1978; Rochette et al., 1995; Shimek, 1984
Neptunea spp.	polychaetes, bivalves, carrion, barnacles, fish	S, og	Tamburri and Barry, 1999; Miranda et al., 2009; Taylor, J.D., 1978; Shimek, 1984
Cryptonatica affinis	*Macoma calcarea, Ennucula tenuis*	P	Feder et al., 1994a
Euspira pallida	*Macoma calcarea, Ennucula tenuis*	P	Feder et al., 1994a
Boreotrophon sp.	*Macoma calcarea*	P	Feder et al., 1994a
Echinoderms			
Basket stars	organic detritus, benthic microalgae, benthic inverts	sSDF, P/S, SF	Iken et al., 2005; Harris et al., 2009
Brittle stars			
Ophiura Sarsi	Amphipods, polychaetes, cumacea, caprellids, small mollusks	sSDF, P/S, SF	Iken et al., 2005; Harris et al., 2009; Feder 1981; Feder et al., 1994b
Diamphiodia cratermodmeta		SDF	Feder et al., 2007
Sea stars		S	Tamelander et al., 2006
Crossaster papposum		P	Tamelander et al., 2006
Leptasterias polaris	bivalves, gastropods	P	Gaymer et al., 2001; Rochette et al., 1995
Sea cucumbers		DF, SF	Tamelander et al., 2006; O'Loughlin et al., 2011
Ascidiacean		FF, SF	Feder et al., 2007; Feder et al., 1994b
Halocynthia sp.		FF, SF	Armsworthy et al., 2001; Feder et al., 2007; Feder et al., 1994b
Boltenia sp.		FF, SF	Berrill, 1929; Feder et al., 2007; Feder et al., 1994b

benthos also provides ecological links to the people of northern Alaska who hunt marine mammals.

Temporal Trends

Temporal variability of epifaunal communities may result from a large number of sources including variations in oceanographic conditions, food supply, environmental changes, and biological interactions. Large environmental differences in oceanographic conditions have been observed between 2009 and 2010 but in the present study, no significant short-term trends could be identified (Chapter 2; Hopcroft et al., in preparation; Weingartner and Danielson, in preparation). Significant temporal differences were observed in the infaunal communities and are likely related to large climatic variations (Chapter 2). Such faunal changes as observed in the epifaunal communities were, however, not recognized in comparable statistical analyses of the 2009 and 2010 data. There was some evidence of differences among major taxonomic groups, (e.g., variations in biomass of crabs, Fig. 3-3) although consistent patterns were not apparent. There is also evidence from the multivariate analyses that the biomass of epifaunal organisms and community structure are associated with water temperature (Table 3-4 and Fig. 3-8). Given the large changes in oceanographic conditions in 2009 and 2010, the association of epifaunal community structure with water temperature suggests that conclusions of no annual variability may be due to low power (only two years) for testing temporal change. There is no evidence for seasonal differences in epifaunal abundance and biomass based on comparisons of data from the two cruises in 2009.

Long-term trends are difficult to determine from available epifaunal data for the eastern Chukchi Sea. In the northeastern Chukchi Sea, historic trawl data is limited to data partially reported in Feder et al. (1994a) and Barber et al. (1994) who found a community with the current dominants including O. *sarsi* (Barber et al., 1994). Bluhm et al. (2009) cautiously report evidence for increasing epifaunal biomass based on comparisons between the 1976 and the later study but the evidence was inconclusive due to gear differences. Three animals have been identified as potential invaders in the Chukchi Sea based on the absence of the animals in published scientific literature from the Chukchi Sea (Sirenko and Gagaev, 2007). The species in question, however, are either noted in literature difficult to attain (*Pododesmus macrochisma* and *Telemessus cheiragonus* in Sparks and Pereyra, 1966) or observed as minor by-catch in another study (*Oregonia gracilis*, found in Jewett et al., 1999, A. L. Blanchard, personal observations). The prior scientific investigations of epifauna in the Chukchi Sea highlight the lack of available data for the Chukchi Sea. There are so few studies performed and even less data available that it is extremely difficult to glean the scientific evidence necessary to understand long-term change. The lack of adequate sampling at appropriate scales and information on all habitats spatially and temporally is a critical data gap to which the benthic ecology component of the CSESP is a substantial contribution.

CONCLUSIONS

Epibenthic communities in the Burger, Klondike and Statoil 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 abundance and biomass of epifauna were higher in Burger than in Klondike or Statoil, the assemblages at all survey areas were similar (containing most of the same species). Environmental gradients were associated with trends in benthic community structure reflecting associations of epifauna with food supply, oceanographic conditions, and physical characteristics of the survey area. Short-term seasonal and annual variations were minimal as no consistent trends were apparent. The epifaunal communities appear to be largely structured by the environmental covariates associated with the geologic structure covarying with associated environmental gradients and oceanographic characteristics.

ACKNOWLEDGMENTS

We thank ConocoPhillips, Shell Exploration and Production Co., and Statoil USA E&P for funding this study through Olgoonik-Fairweather LLC. We thank the crews of the M/V *Westward Wind*, the marine technicians for their assistance, as well as Aldrich Offshore Services and Olgoonik-Fairweather LLC for logistic support and other assistance. Amy Tippery, Lorena Edenfield, Brenda Holliday, Robert Meyer, Mike Davis, Melinda Malek, and Jennie Barna assisted with field collections and sample processing. John Burns reviewed the report and provided constructive comments.

REFERENCES

Ambrose, W. G., Clough, L. M., Tilney, P. R., and Beer, L., 2001. Role of echinoderms in benthic remineralization in the Chukchi Sea. Marine Biology, 139: 937-949.

Armsworthy, S.L., MacDonald, B.A., and Ward, J.E., 2001. Feeding activity, absorption efficiency and suspension feeding processes in the ascidian, *Halocynthia pyriformis* (Stolidobranchia: Ascidiacea): responses to variations in diet quantity and quality. Journal of Experimental Marine Biology and Ecology, 260: 40-69.

Barber, W. E., Smith, R. L., Weingartner, T. J., 1994. Fisheries oceanography of the northeast Chukchi Sea. Final report to U. S. Department of the Interior Minerals Management Service Anchorage OCS Region. OCS Study MMS-93-0051.

Blanchard, A. L., Feder, H. M., Hoberg, M. K., 2010. Temporal Variability of Benthic Communities in an Alaskan Glacial Fjord, 1971-2007. Marine Environmental Research 69, 95-107.

Bluhm, B.A., Iken, K., Mincks Hardy, S., Sirenko, B. I., and Holladay, B. A., 2009. Community structure of the epibenthic epifauna in the Chukchi Sea. Aquatic Biology, 7, 269-293.

Bluhm, B. A., Gradinger, R., 2008. Regional variability in food availability for arctic marine mammals. Ecological Applications, 18 Supplement, pp. S77–S96.

Bray, J. R., Curtis, J. Y., 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs, 27: 235-249.

Brooks, R. A., Purdy, C. N., Bell, S. S., Sulak, K. J., 2006. The benthic community of the eastern US continental shelf: A literature synopsis of benthic faunal sources. Continental Shelf Research, 26: 804-818.

Berrill, N.J., 1929. The digestion in ascidians and the influence of temperature. Journal of Experimental Biology, 6: 275-292.

Chapman, J.W., Carlton, J.T., 1994. Predicted discoveries of the introduced isopod *Synidotea laevidorsalis* (Miers, 1881). Journal of Crustacean Biology, 14: 700-714.

Clarke, K. R., 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117-143.

Clarke, K. R., Ainsworth, M., 1993. A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series, 92: 205-219.

Clarke, K. R., Gorley, R. N., 2006. *PRIMER v6: User Manual/Tutorial*. Primer-E, Plymouth, 199 pp.

Cochrane, S. K. J., Denisenko, S. G., Renaud, P. E., Emblow, C. S., Ambrose, Jr., W. G., Ellingsen, I.H., Skarhamar, J., 2009. Benthic macrofauna and productivity regimes in the Barents Sea -- Ecological implications in a changing Arctic. Journal of Sea Research, 61:222-233.

Dunton, K.H., Goodall, J.L., Schonberg, S.V., Grebmeier, J.M., Maidment, D.R., 2005. Multi-decadal synthesis of benthic-pelagic coupling in the western arctic: Role of cross-shelf advective processes. Deep-Sea Research Part I 52, 3462-3477.

Faulkner, K. K., MacDonald, R. W., Carmack, E. C., Weingartner, T., 1994. The potential of barium as a tracer of Arctic Water Masses. In: Muench, R., Johannessen, O. (eds.), The Polar Oceans and Their role in Shaping the Global Environment. Geophysical Monograph 85. American Geophysical Union, pp. 63-76.

Fay, F. H., 1982. Ecology and Biology of the Pacific Walrus *Odobenus rosmarus divergens* Illiger. North American Fauna, vol. 74. U.S. Department of the Interior, Fish and Wildlife Service: Washingotn, DC. 279 p.

Feder, H. M. 1981. Aspects of the Feeding Biology of the Brittle Star, *Ophiura texturata*. Ophelia 20: 215-235.

Feder, H. M., Jewett, S. C., & Blanchard, A., 2005. Southeastern Chukchi Sea (Alaska) epibenthos. Polar Biology, 28: 402-421.

Feder H. M, Jewett, S. C., Blanchard, A. L., 2007. Southeastern Chukchi Sea (Alaska) Macrobenthos. Polar Biology, 30: 261-275.

Feder, H. M., Foster, N. R., Jewett, S. C., Weingartner, T. J., Baxter, R., 1994a. Mollusks of the northeastern Chukchi Sea. Arctic, 47: 145-163.

Feder, H. M., Naidu, A. S., Jewett, S. C., Hameedi, J. M., Johnson, W. R., Whitledge, T. E., 1994b. The northeastern Chukchi Sea: benthos-environmental interactions. Marine Ecology Progress Series, 111: 171-190.

Gaymer, C.F., Himmelman, J.H., and Johnson, L.E., 2001. Distribution and feeding ecology of the sea stars *Leptasterias polaris* and *Asterias vulgaris* in thenorthern gulf of St. Lawerence, Canada. Journal of the Marine Biological Association of the UK, 81: 827-843.

Grebmeier, J. M., Cooper, L. W., Feder, H. M., Sirenko, B. I., 2006. Ecosystem dynamics of the Pacific-influenced Northern Bering and Chukchi Seas in the Amerasian Arctic. Progress in Oceanography, 71: 331–361.

Grebmeier, J. M., Feder, H. M., McRoy, C. P., 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. II. Benthic community structure. Marine Ecology Progress Series, 51: 253-268.

Grebmeier, J. M., McRoy, C. P., 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. III. Benthic food supply and carbon cycling. Marine Ecology Progress Series, 53: 79-91.

Grebmeier, J. M., McRoy, C. P., Feder, H. M., 1988. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. I. Food supply sources and benthic biomass. Marine Ecology Progress Series, 48: 57-67.

Harris, J.L., MacIsaac, K., Gilkinson, K.D., Kenchington, E.L., 2009. Feeding biology of *Ophiura sarsii* Lütken, 1855 on Banquereau bank and the effects of fishing. Marine Biology, 156: 1891–1902.

Himmelman, J. H., and Hamel, J. -R., 1993. Diet, behaviour and reproduction of the whelk *Buccinum undatum* in the northern Gulf of St. Lawrence, eastern Canada. Marine Biology, 116: 423-430.

Hopcroft, R. R., Questel, J., Clarke-Hopcroft, C., 2010. Oceanographic assessment of the planktonic communities in the Klondike and Burger prospect regions of the Chukchi Sea: Report for survey year 2009. Final report to ConocoPhillips Alaska Inc. and Shell Exploration and Production Company. Institute of Marine Science, University of Alaska Fairbanks, 54 pp.

Hopcroft, R. R., Questel, J., Clarke-Hopcroft, C., in preparation. Oceanographic assessment of the planktonic communities in the Klondike and Burger prospect regions of the Chukchi Sea: Report for survey year 2010. Final report to ConocoPhillips Alaska Inc., Shell Exploration and Production Company, and Statoil USA E&P. Institute of Marine Science, University of Alaska Fairbanks.

Iken, K., Bluhm, B.A., and Gradinger, R., 2005. Food web structure in the high Arctic Canada Basin: evidence from $\delta^{13}C$ and $\delta^{15}N$ analysis. Polar Biology, 28: 238-249.

Ilano, A.S., Miranda, R.M.T., Fujinaga, K., and Nakao, S., 2005. Feeding behavior and food consumption of Japanese whelk, *Buccinum isaotakii* (Neogastropoda: Buccinidae). Fisheries Science, 71: 342-349.

Jewett, S. C., Feder, H. M., Blanchard, A. 1999. Assessment of the benthic environment following offshore placer gold mining in the northeastern Bering Sea. Marine Environmental Research, 48:91-122.

Lowry, L. F., Frost, K. J., Burns, J. J., 1980. Feeding of bearded seals in the Bering and Chukchi Seas and trophic interaction with Pacific walruses. Arctic 33, 330-342.

Lundsten, L., Paull, C.K., Schlining, K.L., McGann, M. and Usser III, W., 2010. Biological characterization of a whale-fall near Vancouver Island, British Columbia, Canada. Deep Sea Research Part I: Oceanographic Research Papers, 57: 918-922.

Menzies, R.J., and Miller, M.A., 1972. Systematics and zoogeography of the genus *Synidotea* (Crustacea: Isopoda) with an account of Californian species. Smithsonian Contributions to Zoology, 102: 1-33.

Miranda, R.M., Oba, T., and Goshima, S., 2009. Effect of water temperature and diet on growth and mortality of *Neptunea arthritica* juveniles. Aquaculture Research, 40: 428-436.

Moore, S. E., Ljungblad, D. K., Van Schoik, D. R., 1986. Annual patterns of gray whale (*Eschrichtius robustus*) distribution, abundance and behavior in the northern Bering and eastern Chukchi Seas, July 1980-83. Report of the International Whaling Commission (special issue), 8: 231-242.

Oliver, J. S., Slattery, P. N., 1985. Destruction and Opportunity on the Sea Floor: Effects of Gray Whale Feeding. Ecology, 66: 1965-1975.

O'Loughlin, P.M., Paulay, G., Davey, N., and Michonneau, F., 2011. The Antarctic region as a marine biodiversity hotspot for echinoderms: Diversity and diversification of sea cucumbers. Deep-Sea Research II, 58: 264-275.

Paul, A.L., Feder, H.M., and Jewett, S.J., 1979. Food of the snow crab *Chionoecetes bairdi* Rathburn 1924, from Cook Inlet, Alaska. Crustaceana, Supplement, 5: 62-68.

Piepenburg, D., and Schmid, M.K., 1996. Brittle star fauna (Echinodermata: Ophiuroidea) of the arctic northwest Barents Sea: composition, abundance, biomass and spatial distribution. Polar Biology, 16: 383-392.

Piepenburg, D., and Schmid, M.K., 1997. A photographic survey of the epibenthic megafauna of the Arctic Laptev Sea shelf: distribution, abundance, and estimates of biomass and organic carbon demand. Marine Ecology Progress Series, 147: 63-75.

Piepenburg, D., and von Juterzenka, K., 1994. Abundance, biomass and spatial distribution patterns of brittle stars (Echinodermata: Ophiuroidea) on the Kolbeinsey Ridge north of Iceland. Polar Biology, 14: 185-194.

Piepenburg, D., Voβ, J., and Gutt, J., 1997. Assemblages of sea stars (Echinodermata: Asteroidea) and brittle stars (Echinodermata: Ophiuroidea) in the Weddell Sea (Antarctica) and off Northeast Greenland (Arctic): a comparison of diversity and abundance. Polar Biology, 17: 305-322.

R Development Core Team, 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Ramsay, K., Kaiser, M.J., Hughes, R.N., 1996. Changes in hermit crab feeding patterns in response to trawling disturbance. Marine Ecology Progress Series, 144: 63-72.

Rice, R.L., McCumby, K.L., and Feder, H.M., 1980. Food of *Pandalus borealis*, *Pandalus hypsinotus*, and *Pandalus goniurus* (Pandalidae, Decapoda) from lower Cook Inlet, Alaska. Proceedings of the National Shellfisheries Association, 70: 47-54.

Rochette, R., Morissette, S., and Himmelman, J.H., 1995. A flexible response to a major predator provides the whelk *Buccinum undatum* L. with nutritional gains. Journal of Experimental Marine Biology and Ecology, 185: 167-180.

Sheffield, G., Fay, F. H., Feder, H., Kelly, B. P., 2001. Laboratory digestion of prey and interpretation of walrus stomach contents. Marine Mammal Science, 17:310-330.

Shimek, R.L., 1984. The diets of Alaskan *Neptunea*. The Veliger, 26: 274-281.

Sirenko, B. I., Gagev, S. Y., 2007. Unusual abundance of macrobenthos and biological invasions in the Chukchi Sea. Russiona Journal of Marine Biology, 33: 355-364.

Sparks, A. K., Pereyra, W. T., 1966. Benthic invertebrates of the southeastern Chukchi Sea. In: Wilimovsky, N. J., Wolfe, J. N. (eds), Environment of the Cape Thompson Region, Alaska. U.S. Atomic Energy Commission, Oak Ridge, CA, Vol. 2: 817-838.

Starmans, A., Gutt, J., and Arntz, W.E., 1999. Mega-epibenthic communities in Arctic and Antarctic shelf areas. Marine Biology, 135: 269-280.

Tamburri, M.N., and Barry, J.P., 1999. Adaptations for scavanging by three diverse bathyla species, *Eptatretus stouti*, *Neptunea amianta* and *Orchomene ebtusus*. Deep Sea Research I, 46: 2079-2093.

Tamelander, T., Renaud, P.E., Hop, H., Carroll, M.L., Ambrose Jr., W.G., and Hobson, K.A., 2006. Trophic relationships and pelagic–benthic coupling during summer in the Barents Sea Marginal Ice Zone, revealed by stable carbon and nitrogen isotope measurements. Marine Ecology Progress Series, 310: 33-46.

Taylor, J.D., 1978. The diet of *Buccinum undatum* and *Neptunea antiqua* (Gastropoda: Buccinidae). Journal of Conchology, 29: 309-318.

Valentine, J.W., Roy, K., and Jablonski, D., 2002. Carnivore/non-carnivore ratios in northeastern Pacific marine gastropods. Marine Ecology Progress Series, 228: 153-163.

Weingartner, T. J., Aagaard, K., Woodgate, R., Danielson, S., Sasaki, Y., Cavalieri, D., 2005. Circulation on the north central Chukchi Sea shelf. Deep Sea Research II, 52: 3150-3174.

Weingartner, T. J., Danielson, S., in preparation. Physical oceanographic measurements in the Klondike and Burger survey areas of the Chukchi Sea: 2008-2010. Final report to ConocoPhillips Alaska Inc., Shell Exploration and Production Company, and Statoil USA E&P. Institute of Marine Science, University of Alaska Fairbanks.

APPENDIX I:
STATISTICAL METHODS FOR THE ANALYSIS OF BENTHIC DATA FROM THE CHUKCHI SEA ENVIRONMENTAL STUDIES PROGRAM

STATISTICAL METHODS

Data were summarized using a variety of descriptive methods. Summary statistics include average abundance, biomass (wet weight), average number of taxa, total number of taxa, and diversity values. Standard deviations and 95% confidence intervals were also calculated. Multivariate statistical methods were applied to a Bray-Curtis similarity matrix calculated from species abundance values. Data are maintained and processed on a computer at UAF IMS. Fragments and taxa identified at family level or above were included in abundance and biomass calculations and diversity indices but excluded from multivariate analyses. For epifaunal analyses, organisms noted only as being present, as well as colonial organisms were excluded in abundance calculations and diversity indices but were included in biomass calculations and 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." Three indices were calculated: the number of taxa (sample and total), Simpson diversity (Simpson, 1949; Odum, 1975) andShannon diversity (Shannon and Weaver, 1963).

The Simpson diversity 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 diversity index increases, diversity increases whereas when S decreases, dominance of the community by a few taxon categories increases (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 taxa categories containing moderate to many individuals.

Analysis of ecological community data often includes 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 among species assemblages.

Cluster analysis and ordination (where new “axes” that summarize community structure are derived and can be plotted) were used for indirect gradient analysis of the 2010 benthic data from the survey areas. Data reduction prior to calculation of similarity coefficients consists of elimination of taxa that could not be identified to at least genus level. Exceptions include organisms regularly identified to the family level (due to taxonomic uncertainty of the genus 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 and is defined as:

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

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, strong transformations 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 the 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. The grouping of stations into patterns reflecting station similarities are interpreted as ecologically meaningful groupings.

Non-metric multidimensional scaling (MDS: Kruskal and Wish, 1978; Clarke and Green, 1988) is used extensively for assessing species composition data from the marine environment for ecological patterns (e.g., Gray et al., 1988; Agard et al., 1993; Clarke, 1993). As described by Gray et al. (1988) ". . . MDS 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 ≤ 0.15 for a good fit (Clarke and Ainsworth, 1993)). Non-metric multidimensional scaling is perhaps the most statistically robust (unaffected by extreme values) 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 MDS ordination provides evidence that the station groupings represent a reasonable summary of the multidimensional relationships of the data. Cluster analysis and MDS 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 ten organisms listed. The program SIMPER from PRIMER (Clarke and Gorley, 2006) was also used to demonstrate taxa with the greatest contribution to community structure in each survey area, based on the contribution of each taxon to the similarity coefficient used in the multivariate analyses.

Following the indirect gradient approach using MDS, a direct gradient method, canonical correspondence analysis (CCA), was applied to the faunal data. Results from the CCA method are particularly useful as the approach reveals the faunal structure directly associated with the environment (McCune and Grace, 2002). This ordination method is a two-step process. First, the faunal structure (e.g., similarities among stations) is reduced by correspondence analysis (CA) to a reduced set of variables, the axes, capturing the faunal structure and station associations. Then, environmental variables are regressed against the CA axes to remove the structure associated with natural environmental gradients and this step is called canonical correspondence analysis. Plots of the CCA ordinations with environmental variables are presented and interpreted to demonstrate associations of fauna with background environmental gradients. These analyses were performed in vegan (http://vegan.r-forge.r-project.org/), a specialized package for the statistical program R (R Development Core Team, 2006).

Canonical correspondence analysis is summarized in a plot of the ordination. There are three ways to plot the data: the station plot, the species plot, and the biplot. In the CCA algorithm, each station and species is given a score for each axis (axis = new variable derived by CCA) representing each items position in multivariate space along that axis. From this information, either stations or species can be plotted. The station plot is a scatterplot of the CCA axes for stations with text labels on the graph representing stations and is similar to an MDS ordination in that the plot represents a “map” of the station similarity based on faunal structure. Stations that are more alike with respect to the variables and fauna included will be plotted closer together. The species plot is a scatterplot of CCA axes for species with species represented as a text value. As in the station plot, two species positioned close together reflect similarity in their distributions. The biplot is a scatterplot of either the station or species scores overlain with an arrow representing the strength of correlation with environmental variables. To calculate a biplot, each environmental variable is correlated to the CCA axes and the correlations are plotted as the arrow on the plot. The direction of the arrow represents the direction of influence in the CCA plot and the length of the arrow reflects the strength of correlation to the axes. If the stations plotted in the ordination are spread out in a direction indicated by one of the arrows, this suggests a strong association between the environmental variable and faunal structure. Likewise, a strong association between fauna and an environmental variable will be apparent as the spread of fauna along the arrow for a variable. Stations or fauna positioned at or beyond the endpoint of the arrow indicate a strong association with that variable. A weak or negligible relationship will be apparent as a cluster of stations or species around the center of the plot and/or a very small arrow for the environmental variable.

REFERENCES

Agard, J. B. R., Gobin, J. Warwick, R. M., 1993. Analysis of marine macrobenthic community structure in relation to pollution, natural oil seepage and seasonal disturbance in a tropical environment (Trinidad, West Indies). Marine Ecology Progress Series, 92: 233-243.

Clarke, K. R., 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117-143.

Clarke, K. R., Ainsworth, M., 1993. A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series, 92: 205-219.

Clarke, K. R., Gorley, R. N., 2006. *PRIMER v6: User Manual/Tutorial*. Primer-E, Plymouth, 199 pp.

Clarke, K. R., Green, R. H., 1988. Statistical design and analysis for a 'biological effects' study. Marine Ecology Progress Series, 46: 213-226.

Clifford, H. T., Stephenson, W., 1975. *An Introduction to Numerical Classification*. Academic Press, New York, 229 pp.

Gray, J. S., Aschan, M., Carr, M. R., Clarke, K. R., Green, R. H., Pearson, T. H., Rosenberg, R., and Warwick, R. M., 1988. Analysis of community attributes of the benthic macrofauna of Frierfjord/Langesundfjord and in a mesocosm experiment. Marine Ecology Progress Series, 46: 151-165.

Johnson, R. A., Wichern, D. W., 1992. *Applied Multivariate Statistical Analysis*. Third edition. Prentice-Hall, Inc., 642 pp.

Kruskal, J. B., Wish, M., 1978. *Multidimensional Scaling*. Sage Publishers, CA, 93 pp.

Magurran, A. E., 2004. *Measuring Biological Diversity*. Blackwell Publishing, Malden, MA, 256 pp.

Odum, E. P., 1975. *Ecology*. Holt, Rinehart and Winston, New York, 244 pp.

R Development Core Team, 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Shannon, C. E., Weaver, W., 1963. *The Mathematical Theory of Communication*. Univ. Illinois Press, Urbana, 177 pp.

Simpson, E. H., 1949. The measurement of diversity. Nature, 163: 688.

APPENDIX II:

INFAUNAL TAXA COLLECTED DURING THE 2008-2010 CSESP

- PORIFERA
- CNIDARIA
  - Hydrozoa
  - Anthozoa
    - Actiniidae
    - Edwardsiidae
      - *Edwardsia* sp.
    - Nephtheidae
      - *Eunephthya rubiformis*
    - Halcampidae
      - *Halcampa crypta*
- NEMERTEA
- ANNELIDA
  - POLYCHAETA
    - Polynoidae
      - *Bylgides sarsi*
      - *Bylgides promamme*
      - *Arcteobia anticostiensis*
      - *Eunoe* sp.
      - *Eunoe oerstedi*
      - *Eunoe clarki*
      - *Gattyana* sp.
      - *Gattyana amondseni*
      - *Gattyana cirrhosa*
      - *Harmothoe* sp.
      - *Harmothoe beringiana*
      - *Harmothoe extenuata*
      - *Harmothoe imbricata*
      - *Polynoe canadensis*
      - *Polynoe gracilis*
      - *Hesperonoe* sp.
      - *Enipo torelli*
    - Pholoidae/Sigalionidae
      - *Pholoe minuta*
    - Phyllodocidae
      - *Anaitides groenlandica*
      - *Eteone* sp.
      - *Eteone pacifica*
      - *Eteone longa*
    - Syllidae
      - *Autolytus* sp.
      - *Syllis* sp.
      - *Syllis elongata*
      - *Typosyllis* sp.
      - *Typosyllis pigmentata*
      - *Exogone* sp.

Nephtyidae
    - *Nephtys* sp.
    - *Nephtys ciliata*
    - *Nephtys caeca*
    - *Nephtys punctata*
    - *Nephtys longosetosa*
    - *Nephtys paradoxa*

Sphaerodoridae
    - *Sphaerodorum papillifer*
    - *Sphaerodoropsis minuta*
    - *Sphaerodoropsis sphaerulifer*

Glyceridae
    - *Glycera capitata*

Goniadidae
    - *Glycinde wireni*

Onuphidae
    - *Paradiopatra* sp.
    - *Paradiopatra parva*

Eunicidae

Lumbrineridae
    - *Lumbrineris* sp.
    - *Lumbrineris fragilis*

Arabellidae

Dorvilleidae

Orbiniidae
    - *Scoloplos armiger*
    - *Leitoscoloplos pugettensis*

Paraonidae
    - *Aricidea* sp.
    - *Levinsenia gracilis*

Apistobranchidae
    - *Apistobranchus ornatus*

Spionidae
    - *Polydora* sp.
    - *Prionospio steenstrupi*
    - *Scololepis* sp.
    - *Spio cirrifera*
    - *Spiophanes bombyx*
    - *Pygospio elegans*

Magelonidae
    - *Magelona* sp.
    - *Magelona longicornis*

Trochochaetidae
    - *Trochochaeta carica*
    - *Trochochaeta multisetosa*

Chaetopteridae

- *Phyllochaetopterus* sp.

Cirratulidae

- *Cirratulus cirratus*
- *Chaetozone setosa*

Cossuridae

- *Cossura* sp.

Flabelligeridae

- *Brada* sp.
- *Brada granulata*
- *Brada villosa*
- *Brada nuda*
- *Flabelligera* sp.
- *Flabelligera affinis*
- *Flabelligera mastigophora*
- *Diplocirrus longisetosus*

Scalibregmatidae

- *Scalibregma inflatum*

Opheliidae

- *Travisia forbesi*
- *Travisia pupa*
- *Ophelina breviata*
- *Ophelina acuminata*

Sternaspidae

- *Sternaspis fossor*

Capitellidae

- *Capitella capitata*
- *Heteromastus filiformis*
- *Notomastus* sp.
- *Mediomastus* sp.
- *Decamastus gracilis*
- *Barantolla americana*

Maldanidae

- *Maldane sarsi*
- *Nicomache* sp.
- *Nicomache lumbricalis*
- *Nicomache personata*
- *Petaloproctus* sp.
- *Petaloproctus tenuis borealis*
- *Petaloproctus tenuis tenuis*
- *Axiothella* sp.
- *Axiothella catenata*
- *Praxillella gracilis*
- *Praxillella praetermissa*
- *Rhodine bitorquata*

Oweniidae

- *Owenia fusiformis*

- *Myriochele heeri*
- *Galathowenia oculata*

Sabellariidae

- *Idanthyrsus ornamentatus*
- *Idanthyrsus armatus*

Pectinariidae

- *Cistenides granulata*

Ampharetidae

- *Amage* sp.
- *Ampharete* sp.
- *Ampharete goesi goesi*
- *Ampharete acutifrons*
- *Ampharete finmarchica*
- *Lysippe labiata*
- *Asabellides sibirica*

Terebellidae

- *Neoamphitrite groenlandica*
- *Nicolea zostericola*
- *Thelepus* sp.
- *Thelepus cincinnatus*
- *Thelepus setosus*
- *Artacama proboscidea*
- *Lanassa nordenskioldi*
- *Lanassa venusta venusta*
- *Axionice maculata*
- *Laphania boecki*
- *Pista elongata*
- *Proclea* sp.
- *Proclea emmi*
- *Proclea graffii*

Trichobranchidae

- *Terebellides stroemi*
- *Trichobranchus glacialis*

Sabellidae

- *Chone* sp.
- *Chone infundibuliformes*
- *Chone mollis*
- *Euchone* sp.
- *Euchone analis*
- *Euchone incolor*
- *Bispira crassicornis*
- *Laonome kroeyeri*
- *Jasmineira pacifica*

Serpulidae/ Spirorbidae

- *Spirorbis* sp.

OLIGOCHAETA

MOLLUSCA
- GASTROPODA
  - Lepetidae
    - *Lepeta caeca*
  - Trochidae
    - *Margarites* sp.
    - *Margarites giganteus*
    - *Margarites costalis*
    - *Solariella* sp.
    - *Solariella obscura*
    - *Solariella varicosa*
  - Turbinidae
    - *Moelleria costulata*
  - Rissoidae
    - *Alvania* sp.
    - *Cingula* sp.
  - Turritellidae
    - *Tachyrhynchus* sp.
    - *Tachyrhynchus erosus*
    - *Tachyrynchus reticulatis*
  - Trichotropidae
    - *Trichotropis* sp.
    - *Trichotropis borealis*
    - *Trichotropis kroyeri*
    - *Iphinoe coronata*
  - Velutinidae
    - *Velutina undata*
  - Naticidae
    - *Cryptonatica affinis*
    - *Euspira pallida*
  - Muricidae
    - *Boreotrophon* sp.
    - *Boreotrophon clathratus*
    - *Boreotrophon truncatus*
    - *Boreotrophon muriciformis*
  - Buccinidae
    - *Buccinum* sp.
    - *Buccinum polare*
    - *Colus* sp.
    - *Colus spitzbergensis*
    - *Colus roseus*
    - *Liomesus* sp.
    - *Neptunea* sp.
    - *Neptunea communis*
    - *Neptunea borealis*
    - *Plicifusus* sp.

    - *Plicifusus kroyeri*
    - *Pyrulofusus deformis*
    - *Volutopsius* sp.
  - Cancellariidae
    - *Admete* sp.
    - *Admete regina*
    - *Admete viridula*
  - Conidae
    - *Oenopota* sp.
    - *Oenopota elegans*
    - *Oenopota excurvatus*
    - *Oenopota impressa*
    - *Obesotoma simplex*
    - *Propebela* sp.
    - *Propebela turricula*
    - *Propebela arctica*
    - *Propebela nobilis*
    - *Curtitoma incisula*
    - *Curtitoma novajasemljensis*
  - Pyramidellidae
    - *Odostomia* sp.
  - Cylichnidae
    - *Cylichna* sp.
    - *Cylichna occulta*
    - *Cylichna alba*
  - Diaphanidae
    - *Diaphana minuta*
  - Haminoeidae
    - *Haminoea virescens*
  - Retusidae
    - *Retusa obtusa*
- NUDIBRANCHIA
- OPISTHOBRANCHIA
- POLYPLACOPHORA
  - Leptochitonidae
    - *Leptochiton* sp.
  - Ischnochitonidae
    - *Ischnochiton albus*
  - Mopaliidae
    - *Amicula vestita*
- BIVALVIA
  - Nuculidae
    - *Ennucula tenuis*
    - *Nuculana* sp.
    - *Nuculana pernula*
    - *Nuculana minuta*

Yoldiidae
    Yoldia sp.
    Yoldia hyperborea
    Yoldia myalis
    Yoldia seminuda
Mytilidae
    Musculus sp.
    Musculus niger
    Musculus discors
    Musculus glacialis
Pectinidae
    Chlamys behringiana
Lucinidae
    Parvilucina tenuisculpta
Thyasiridae
    Adontorhina cyclia
    Axinopsida serricata
    Thyasira flexuosa
Lasaeidae
    Neaeromya compressa
    Mysella sp.
    Mysella planata
    Rochefortia tumida
Carditidae
    Cyclocardia sp.
    Cyclocardia crebricostata
    Cyclocardia crassidens
    Cyclocardia ovata
Astartidae
    Astarte sp.
    Astarte montagui
    Astarte borealis
Cardiidae
    Clinocardium sp.
    Clinocardium ciliatum
    Serripes groenlandicus
    Serripes laperousii
Tellinidae
    Macoma sp.
    Macoma calcarea
    Macoma brota
    Macoma moesta
    Tellina modesta
Veneridae
    Liocyma fluctuosa
    Nutricola lordi

- Myidae
  - *Mya* sp.
- Hiatellidae
  - *Hiatella arctica*
- Pandoridae
  - *Pandora glacialis*
- Lyonsiidae
  - *Lyonsia arenosa*
- Periplomatidae
  - *Periploma aleuticum*
- Thraciidae
  - *Thracia* sp.
  - *Lampeia adamsi*
- PYCNOGONIDA
- CRUSTACEA
  - OSTRACODA
  - CIRRIPEDIA
    - Balanidae
      - *Balanus* sp.
      - *Balanus crenatus*
      - *Balanus rostratus*
  - CUMACEA
    - Lampropidae
      - *Lamprops quadriplicata*
    - Leuconidae
      - *Leucon* sp.
      - *Leucon nasica*
      - *Eudorella* sp.
      - *Eudorella emarginata*
      - *Eudorella pacifica*
      - *Eudorellopsis* sp.
      - *Eudorellopsis integra*
      - *Eudorellopsis biplicata*
    - Diastylidae
      - *Diastylis* sp.
      - *Diastylis bidentata*
      - *Diastylis koreana*
      - *Diastylis paraspinulosa*
      - *Diastylis sulcata*
      - *Ektondiastylis robusta*
    - Nannastacidae
      - *Campylaspis* sp.
      - *Campylaspis clavata*
      - *Campylaspis rubicunda*
      - *Campylaspis papillata*
  - TANAIDACEA

ISOPODA
- Antarcturidae
  - *Pleuroprion murdochi*
- Idoteidae
  - *Synidotea* sp.
  - *Synidotea bicuspida*
  - *Synidotea muricata*
- Munnidae
  - *Munna* sp.

AMPHIPODA
- Odiidae
  - *Odius* sp.
- Ampeliscidae
  - *Ampelisca* sp.
  - *Ampelisca macrocephala*
  - *Ampelisca birulai*
  - *Ampelisca eschrichti*
  - *Byblis* sp.
  - *Byblis gaimardi*
  - *Byblis robusta*
  - *Byblis frigidis*
  - *Byblis pearcyi*
  - *Byblis breviramus*
  - *Haploops laevis*
- Argissidae
  - *Argissa hamatipes*
- Corophiidae
  - *Corophium* sp.
- Ischyroceridae
  - *Ericthonius* sp.
- Dexaminidae
  - *Guernea nordenskioldi*
- Eusiridae
  - *Eusirus cuspidatus*
  - *Pontogeneia* sp.
  - *Rhachotropis* sp.
  - *Rhachotropis aculeata*
- Gammaridae
- Melitidae
  - *Maera* sp.
  - *Maera loveni*
  - *Melita* sp.
  - *Melita dentate*
- Haustoriidae
  - *Eohaustorius eous*
- Pontoporeiidae

        - *Pontoporeia* sp.
        - *Pontoporeia femorata*
        - *Priscillina armata*
    - Isaeidae
        - *Photis* sp.
        - *Photis vinogradovi*
        - *Protomedeia* sp.
    - Ischyroceridae
        - *Ischyrocerus* sp.
    - Lysianassidae
        - *Anonyx* sp.
        - *Hippomedon* sp.
        - *Lepidepecreum* sp.
        - *Orchomene* sp.
    - Uristidae
        - *Centromedon* sp.
    - Melphidippidae
    - Oedicerotidae
        - *Aceroides latipes*
        - *Bathymedon* sp.
        - *Monoculodes* sp.
        - *Paroediceros* sp.
        - *Westwoodilla caecula*
    - Epimeriidae
        - *Paramphithoe polyacantha*
    - Phoxocephalidae
        - *Harpinia* sp.
        - *Harpinia kobjakovae*
        - *Harpinia gurjanovae*
        - *Paraphoxus* sp.
        - *Grandifoxus* sp.
        - *Grandifoxus acanthinus*
        - *Grandifoxus vulpinus*
        - *Grandifoxus nasuta*
    - Pleustidae
        - *Pleustes panoplus*
    - Podoceridae
        - *Dyopedos arcticus*
    - Stenothoidae
        - *Syrrhoe longifrons*
    - Synopiidae
        - *Tiron biocellata*
    - Caprellidea
- BRACHYURA
    - Pinnotheridae
        - *Pinnixa* sp.

- SIPUNCULA
  - SIPUNCULIDAE
    - Golfingiidae
      - *Golfingia margaritacea*
    - Phascoliidae
      - *Phascolion strombus*
- ECHIURA
    - Echiuridae
      - *Echiurus echiurus*
- CEPHALORHYNCHA
  - PRIAPULIDAE
      - *Priapulus caudatus*
- BRACHIOPODA

APPENDIX III:
EPIFAUNAL TAXA COLLECTED DURING THE 2009-2010 CSESP

(Taxa in bold were classifications used in the field)

PORIFERA

- Choanitidae
  - *Choanites luetkeni*
- Halichondriidae
  - *Halichondria* sp.
- Grantiidae
  - *Leucandra* sp.
- Esperiopsidae
  - *Semisuberites cribrosa*
- Suberitidae
  - *Suberites* sp.

CNIDARIA

- **Anthozoa**
  - ***Gersemia rubiformis***
  - ***Stomphia* sp.**
  - Halcampoididae
- **Hydrozoa (aka "Colonial organisms")**
  - *Keratosum maximum*
  - *Abietinaria* sp.
- Actiniaria

BRYOZOA (aka "Colonial organisms")

- Forms:
  - **Encrusting**
  - **Foliose**
  - **Upright**
- Alcyonidiidae
  - ***Alcyonidium* sp.**
  - *Alcyonidium gelatinosum*
  - *Alcyonidium vermiculare*
- Vesiculariidae
  - *Bowerbankia composita*
- Bugulidae
  - *Dendrobeania* sp.
- Scrupariidae
  - *Eucratea loricata*

NEMERTEA

- Emplectonematidae
  - *Emplectonema* sp.
- Tubulanidae
  - *Tubulanus* sp.

PLATYHELMINTHES

- Turbellaria

ANNELIDA
- **Polychaeta**
  - **Phyllodocidae**
    - *Anaitides groenlandica*
  - **Polynoidae**
    - *Enipo torelli*
    - *Arctonoe vittata*
    - *Eunoe* sp.
    - *Eunoe oerstedi*
    - *Eunoe depressa*
    - *Gattyana* sp.
    - *Gattyana cirrhosa*
    - *Gattyana amondseni*
    - *Harmothoe* sp.
    - *Harmothoe extenuata*
    - *Harmothoe imbricata*
  - **Spirorbidae**
    - *Spirorbis* sp.
  - Flabelligeridae
    - ***Brada granulata***
  - **Sabellidae**

MOLLUSCA
- **Bivalvia**
  - Astartidae
    - ***Astarte* sp.**
    - *Astarte borealis*
    - *Astarte montagui*
  - Cardiidae
    - *Clinocardium* sp.
    - ***Clinocardium ciliatum***
    - *Serripes* sp.
    - ***Serripes groenlandicus***
    - *Serripes laperousii*
  - Carditidae
    - ***Cyclocardia* sp.**
    - *Cyclocardia* cf. *ovata*
    - *Cyclocardia* cf. *borealis*
    - *Cyclocardia crassidens*
    - *Cyclocardia crebricostata*
  - Hiatellidae
    - ***Hiatella arctica***
  - Lyonsiidae
    - *Lyonsia arenosa*
  - **Mytilidae**
    - ***Musculus* sp.**

- *Musculus discors*
- *Musculus niger*

Pandoridae
- ***Pandora glacialis***

Pectinidae
- ***Chlamys* sp.**
- *Chlamys behringiana*
- *Chlamys rubida*

Periplomatidae
- *Periploma aleuticum*

Cephalopoda
- Octopodidae
  - ***Benthoctopus sibiricus***

Polyplacophora
- Ischnochitonidae
  - ***Ischnochiton albus***
  - ***Amicula vestita***

Gastropoda
- **Nudibranchia**
  - *Acanthodoris pilosa*
  - *Dendronotus* sp.
  - *Dendronotus dalli*
- Cancellariidae
  - *Admete* sp.
  - *Admete regina*
  - *Admete viridula*
- **Buccinidae**
  - *Beringius* sp.
  - ***Buccinum* sp.**
  - *Buccinum angulosum*
  - *Buccinum ciliatum*
  - *Buccinum glaciale*
  - *Buccinum plectrum*
  - *Buccinum polare*
  - *Buccinum scalariforme*
  - *Clinopegma magna*
  - ***Colus* sp.**
  - *Colus hypolispus*
  - *Colus martensi*
  - *Colus ombronius*
  - *Colus roseus*
  - *Colus stimpsoni*
  - ***Neptunea* sp.**
  - *Neptunea communis*
  - ***Neptunea heros***
  - *Neptunea lyrata*

- *Neptunea* c.f. *ventricosa*
- ***Plicifusus* sp.**
- *Plicifusus kroyeri*
- *Pyrulofusus* sp.
- *Pyrulofusus deformis*
- *Volutopsius* sp.
- *Volutopsius fragilis*

Epitoniidae
- *Acirsa* sp.

Fissurellidae
- *Puncturella noachina*

Muricidae
- ***Boreotrophon* sp.**
- *Boreotrophon clathratus*
- *Boreotrophon muriciformis*
- *Boreotrophon truncatus*

Naticidae
- ***Cryptonatica affinis***
- ***Euspira pallida***

Lepitidae
- ***Lepeta caeca***

Trochidae
- ***Margarites* sp.**
- *Margarites costalis*
- *Margarites giganteus*
- ***Solariella* sp.**
- *Solariella obscura*
- *Solariella varicosa*

Turritellidae
- ***Tachyrhynchus* sp.**
- *Tachyrhynchus erosus*
- *Tachyrhynchus reticulatus*

Capulidae
- ***Iphinoe coronata***
- *Trichotropis kroyeri*
- ***Trichotropis bicarinata***
- *Trichotropis borealis*
- *Trichotropis cancellata*

Velutinidae
- *Velutina conica*
- *Velutina undata*

Cylichnidae
- ***Cylichna alba***

Cerithiidae

Conidae

Onchidorididae

        - *Adalaria* sp.

PYCNOGONIDA

CRUSTACEA
- **Amphipoda**
  - Ampeliscidae
    - *Ampelisca eschrichti*
  - Uristidae
    - ***Anonyx nugax***
  - Oedicerotidae
  - Caprellidea
    - *Caprella* sp.
  - Lysianasidae
    - *Orchomene* sp.
  - Melitidae
    - **_Melita_ sp.**
  - Epimeriidae
    - ***Paramphithoe polyacantha***
  - Eusiridae
    - *Eusirus cuspidatus*
    - *Rhachotropis* sp. cf. *oculata*
    - *Rhachotropis aculeata*
  - Gammaracanthidae
    - *Gammaracanthus loricatus*
  - Stegocephalidae
    - ***Stegocephalus inflatus***
    - *Stegocephalus ampulla*
  - Stenothoidae
  - Synopiidae
    - *Syrrhoe longifrons*
  - Pleustidae
- **Isopoda**
  - Chaetiliidae
    - *Saduria* sp.
  - Idoteidae
    - **_Synidotea_ sp.**
    - *Synidotea muricata*
    - *Synidotea bicuspida*
- **Balanomorpha**
  - Balanidae
    - **_Balanus_ sp.**
    - *Balanus crenatus*
    - *Balanus glandula*
- **Decapoda**
  - Anomura

- Lithodidae
  - ***Paralithodes platypus***
- Oregoniidae
  - ***Chionoecetes opilio***
  - ***Hyas coarctatus***
- Paguroidea
  - **Paguridae**
    - ***Labidochirus splendescens***
    - ***Pagurus* sp.**
    - ***Pagurus rathbuni***
    - ***Pagurus trigonocheirus***
    - *Pagurus capillatus*
- **Caridea**
  - Crangonidae
    - *Argis* sp.
    - ***Argis lar***
    - *Crangon communis*
    - *Crangon dalli*
    - *Sclerocrangon boreas*
    - *Sabinea septemcarinata*
  - Hippolytidae
    - *Eualus* sp.
    - *Eualus fabricii*
    - *Eualus gaimardii*
    - *Eualus macrophthalmus*
    - *Eualus suckleyi*
    - *Spirontocaris arcuata*
    - *Spirontocaris lamellicornis*
  - Pandalidae
    - *Pandalopsis* sp.
    - *Pandalopsis ampla*
    - *Pandalopsis dispar*
- **Cumacea**
  - **Diastylidae**
    - *Diastylis bidentata*
  - Leuconidae
    - *Leucon nasica*
- **Ostracoda**

ECHINODERMATA
- **Asteroidea**
  - Solasteridae
    - ***Crossaster papposus***
  - Goniopectinidae
    - ***Ctenodiscus crispatus***
  - Echinasteridae

      - ***Henricia* sp.**
      - *Henricia tumida*
    - Asteriidae
      - ***Leptasterias* sp.**
      - *Leptasterias groenlandica*
      - *Leptasterias arctica*
      - ***Leptasterias polaris***
      - ***Urasterias lincki***
    - Pterasteridae
      - ***Pteraster obscurus***
  - Echinoida
    - Strongylocentrotidae
      - ***Strongylocentrotus droebachiensis***
  - **Holothuroidea**
    - Myriotrochidae
      - ***Myriotrochus rinkii***
    - Cucumariidae
      - ***Ocnus glacialis***
    - Psolidae
      - ***Psolus* sp.**
      - *Psolus fabricii*
  - Ophiuroidea
    - Ophiuridae
      - ***Amphiophiura pachyplax***
      - ***Ophiura sarsi***
    - Ophiactidae
      - *Ophiopholis aculeata*
    - Gorgonocephalidae
      - ***Gorgonocephalus* sp.**
      - *Gorgonocephalus arcticus*
      - *Gorgonocephalus eucnemis*
    - Amphiuridae
      - *Ampiura sundevalli*
      - *Diamphiodia craterodmeta*

- **SIPUNCULA**
  - Golfingiidae
    - ***Golfingia* sp.**
    - *Golfingia margaritacea*
  - Phascoliidae
    - ***Phascolion strombus strombus***

- **BRACHIOPODA**
    - Hemithyrididae
      - *Hemithiris psittacea*

CHORDATA

- **Ascidiacea (aka “Colonial organisms”)**
  - Pyuridae
    - ***Boltenia* sp.**
    - *Boltenia echinata*
    - ***Boltenia ovifera***
    - *Boltenia villosa*
    - ***Halocynthia aurantium***
  - Corellidae
    - ***Chelyosoma* sp.**
    - *Chelyosoma orientale*
  - Styelidae
    - *Styela* sp.
    - *Styela coriacea*
    - *Styela rustica*
    - ***Pelonaia corrugata***
    - cf. *Cnemidocarpa* sp.
  - Didemnidae