OCS Study BOEM 2014-014

Ecological Analyses of Western Beaufort Sea Data

Final Report for contract M12PC00001

Prepared for and sponsored by: **Bureau of Ocean Energy Management**, U.S. Dept. of Interior, Alaska Outer Continental Shelf Regions, Environmental Studies Section, 3801 Centerpoint Drive, Suite 500, Anchorage AK 99503-5823

Principal investigators: Bodil Bluhm, School of Fisheries and Ocean Sciences (SFOS), University of Alaska Fairbanks (UAF), 905 Koyukuk Dr., Fairbanks AK 99775; Falk Huettmann (Institute of Arctic Biology, Biology and Wildlife Department, UAF); Brenda Norcross (SFOS, UAF)

Ecological Analyses of Western Beaufort Sea Data

Final Report for contract M12PC00001

Principal investigator and report author: Bodil Bluhm, School of Fisheries and Ocean Sciences (SFOS), University of Alaska Fairbanks (UAF), 905 Koyukuk Dr., Fairbanks AK 99775

Co-Principal Investigators and report co-authors: Falk Huettmann (Institute of Arctic Biology, Biology and Wildlife Department, UAF), Brenda Norcross (SFOS, UAF)

Start date: 11 July 2012

End date: 24 March 2014

Total amount: $ 189,911

Prepared for: Bureau of Ocean Energy Management, U.S. Dept. of Interior, Alaska Outer Continental Shelf Regions, Environmental Studies Section, 3801 Centerpoint Drive, Suite 500, Anchorage AK 99503-5823

Funding: This study was funded by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Alaska Outer Continental Shelf Region, Anchorage Alaska, under Contract No. M12PC00001 as part of the BOEM Environmental Studies Program.

Publication date: March 2014

Project organization

Report authors:	Bluhm BA, PhD, Research Associate Professor in Marine Biology – Data analysis and report writing
	Huettmann F, PhD, Associate Professor in Wildlife Ecology – Preparation of GIS maps, report co-author
	Norcross BL, PhD, Professor in Fisheries Oceanography - responsible for interpretation of fish analysis, report co-author
Other key personnel:	Mette Kaufman, technician – digitalization of historic data, formatting of report
	Brenda Holladay – compilation and formatting of BOEM 2011 data used in this report
Citation:	Bluhm BA, Huettmann F, Norcross BL (2014) Ecological analysis of Western Beaufort Sea data. Final Report for contract M12PC00001, OCS Study BOEM 2014-014

Contents

List of Figures 5
List of Tables 9
I. Summary 10
II. Objectives 11
III. Introduction, methods and results by objective 11
1. Objective 1: Fish and epifaunal community structure during the 2008 survey 11
1.1 Introduction 11
1.2 Methods 16
1.3 Results 18
2. Objective 2: Comparisons between 2008 unlined / lined hauls, and between 2008 / 2011 35
2.1 Introduction 35
2.2 Methods 36
2.3 Results 36
3. Objective 3: Historic fish data from the Beaufort Sea 44
3.1 Introduction 44
3.2 Methods 44
3.3 Results 45
4. Objective 4: Taxonomic inventory of demersal fish and benthic invertebrates 46
4.1 Introduction 46
4.2 Methods 46
4.3 Results 47
V. Brief conclusions 48
VI. References 49

List of Figures

Figure 1 Study are and sampling locations. a) BOEM 2008 survey stations from Rand and Logerwell (2011); b) BOEM 2008 and BOEM 2011 survey stations; c) BOEM 2008 sampling (black box) in the context of historic and 2010+ sampling efforts. Pink lines in b) and c) mark the average August sea ice extent from 1979-2000. Red line in c) marks the average September sea ice extent from 1979-2000.

Figure 2 Taxonomic composition of 83-112 trawl hauls collected in the Beaufort Sea during the BOEM 2008 survey. a) Composition of biomass calculated as grams wet weight per 1000 m^{-2}, with inset showing spatial distribution of biomass labeled by haul number; b) relative composition based on weights. Stars indicate stations sampled with lined and unlined net. Vertical lines separate hauls by net type (dotted line) and water depth (dashed line). >300 denotes stations deeper than 300 m. Red line in inset map marks the average August sea ice extent from 1979-2000.

Figure 3 Biomass of all hauls collected in the Beaufort Sea during the BOEM 2008 survey, standardized to grams wet weight per 1000 m^{-2}. The arrow indicates the suspected depth trend in biomass. We did not determine a true statistical relationship because of the low sample size and differences in mesh size.

Figure 4 Biodiversity indices for the combined fish and epifauna data from the BOEM 2008 survey for all stations combined. Stations in white font were trawled with lined nets, stations in black font were trawled with unlined nets. a) Shannon diversity H'; b) Pielou's evenness J'; c) estimated number of species $ES_{(50)}$. Red line marks the average August sea ice extent from 1979-2000.

Figure 5 Number of taxa in the BOEM 2008 survey (all stations). a) Spatial distribution of the number of taxa in BOEM 2008 hauls. b) Taxon accumulation curves for two depth strata based on all hauls in each stratum of the survey. S obs – Observed number of taxa, Chao 2 – estimated number of taxa using Chao 2 estimator. Red line marks the average August sea ice extent from 1979-2000.

Figure 6 Community structure of all stations of the BOEM 2008 survey with epifauna and fishes combined, using non-metric multi-dimensional scaling plots (nMDS) based on square-root transformed a) <u>biomass</u> data and b) <u>abundance</u> data. Numbers indicate station names (as in Figure 1). Green triangles in top panel are stations where lined nets were used; blue triangles are stations where unlined nets were used. Symbols in bottom panels indicate significant hierarchical clusters from SIMPROF routine. Green outlines denote groups of stations above 30% within group similarity level, with % values in boxes indicating specific similarity levels within each of those green-circled groups. Each green-circled group is characterized by the listed species which each contributed >5% to the similarity within a given group of stations within green circles.

Figure 7 nMDS of BOEM 2008 epifauna and fishes combined based on biomass data and three different data transformations, which produced almost identical results. A) Mild (square-root) transformation (used in all subsequent plots); b) moderate (fourth-root) transformation; c) strong (presence/absence) transformation. Otherwise as in Figure 6.

Figure 8 nMDS of BOEM 2008 a) epifauna and fishes combined (as in Figure 6b) and b) fish data only based on square-root transformed abundance data. Otherwise as in Figure 6, except that green circles show ≥40% similarity level in b), because there was no structure at the 30% level. Species in bottom right panel indicate taxa contributing to dissimilarity between green-circled clusters. Associated percent values in hatched boxes indicate level of dissimilarity between green-circled clusters.

Figure 9 nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed biomass data of a) all stations (as in Figure 6a) and b) lined hauls only. Otherwise as in Figure 6. Same-colored stations on maps show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by lined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

Figure 10 nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed biomass data of a) all stations (as in Figure 6a) and b) unlined hauls only. Otherwise as in Figure 6. Same-colored stations on map show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by unlined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

Figure 11 nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed abundance data of a) all stations (as in Figure 6b) and b) lined hauls only. Otherwise as in Figure 6. Same-colored stations on map show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by lined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

Figure 12 nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed biomass data of a) all stations (as in Figure 6b) and b) unlined hauls only. Otherwise as in Figure 6. Same-colored stations on map show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by unlined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

Figure 13 Long-term average salinity conditions along the Beaufort Sea shelf and slope.a) Sea surface salinity, b) bottom salinity; c) Long-term average water column stratification strength (stratification parameter per Fiedler et al. 1998. Data compiled during PacMARS (ongoing NPRB grant, http://pacmars.cbl.umces.edu/) by S. Okkonen (UAF) from multiple sources. Note the influence of rivers nearshore. Note that some casts in the Canada Basin were only to 200 m. Pink line marks the average August sea ice extent from 1979-2000; red line marks the average September sea ice extent from 1979-2000.

Figure 14 Long-term average water temperature conditions along the Beaufort Sea shelf and slope. a) Sea surface temperature and b) bottom temperature Data compiled during PacMARS (ongoing NPRB grant, http://pacmars.cbl.umces.edu/) by S. Okkonen (UAF) from multiple sources. Note the influence of rivers nearshore and of Pacific water inflow. Note that some casts in the Canada Basin were only to 200 m. Pink line marks the average August sea ice extent from 1979-2000; red line marks the average September sea ice extent from 1979-2000.

Figure 15 Environmental links between locations sampled during BOEM 2008 using 15 environmental variables in a principal component analysis (PCA). Station numbers are color coded based on station clusters from hierarchical clustering of square-root transformed species biomass data at 30% similarity level. See Table 2 for more PCA results.

Figure 16 Comparison of fish taxon richness per station, mostly at the species level, between BOEM 2011 and BOEM 2008 at (almost) identical stations. The station number is the haul number as used in the 2008 reports, followed by the BOEM 2011 station number. Slope stations were 143-318 m in depth, shelf stations were 38-86 m in depth.

Figure 17 Fish abundance by station and split into families from BOEM 2011 and BOEM 2008 at (almost) identical stations. a) Absolute densities, b) absolute densities, scale adjusted to more clearly show the data at stations with low densities, c) relative composition by families. The station number is the haul number as used in the 2008 reports, followed by the year. Slope stations were 143-318 m in depth, shelf stations were 38-86 m in depth. 'Other' includes Ammodytidae, Cyclopteridae, Hemitripteridae, Osmeridae and Pleuronectidae. Stars mark stations fished with lined 83-112 nets.

Figure 18 Mean relative composition of fish families from across all shallow (a, b) and deep (c, d) hauls for the 83-112 used in the BOEM 2008 survey (a, c) and the PSBT used in the BOEM 2011 survey (b, d), based on abundance. Families for which the relative abundance differed by >5% between nets are labeled on the pie charts.

Figure 19 nMDS of fishes (without epifauna) from the BOEM 2008 and BOEM 2011 surveys combined (at comparative stations) based on presence/absence data of all stations. Stations are color-coded by a) net type, b) depth category (deep is >100 m), c) significant cluster membership. Green circles indicate 40% similarity. Blue lines indicate stations separation of lined and unlined hauls. Otherwise as in Figure 6.

Figure 20 Taxonomic composition by phylum of trawl-caught species collected in the US Beaufort Sea in the combined WEBSEC 1972, OCSEAP 1976, BOEM 2008 and BOEM 2011 surveys. Taxa identified to coarser level than species were excluded.

List of Tables

Table 1 Station table of BOEM 2008 survey with matching re-sampled stations during BOEM 2011 survey. Note deviations in water depths in particular at slope stations. PSBT: plumb-staff beam trawl. PSBT-A: Modified PSBT.

Table 2 Results of the principal component analysis: coefficients in the linear combination of variables making up PCs based on normalized measurements. The three variables that load highest on each PC are printed in bold.

Table 3 Comparison of number of taxa present in different depth strata of the BOEM 2008 survey using all available hauls in each stratum. # of Stn – number of stations in stratum. >1 st – more than one station.

Table 4 List of taxa found during the BOEM 2008 survey organized by three depth strata. Eurybathic species are listed first, followed by slope species, slope/shelf species and shelf-only species. Taxa identified to coarse taxonomic level and those only found at one station were excluded. Fish species are in bold print.

Table 5 Comparison of taxon richness in the lined and unlined nets at comparable depths and/ or locations during the BOEM 2008 survey.

I. Summary

In the Alaskan Beaufort Sea, plans for further oil and gas development are ongoing. To address the Bureau of Ocean Energy Management's (BOEM) related requirement for biological baseline information for the Beaufort Sea, the *Western Beaufort Sea Marine Fish and Lower Trophic Survey* (BOEMRE 2010-048) was conducted in August 2008 on the Beaufort Sea shelf and slope (41 and 470 m) between 155° W and 152°W. Twenty-two successful trawl hauls, unfortunately using two different mesh sizes due to net loss and damage, produced valuable insights on the fish and epifaunal invertebrate fauna in the study area, their catch per unit effort (CPUE), and size distributions of dominant species. In 2011, the *Central Beaufort Sea Fish Survey* was conducted with a comparable goal, but covering a larger fraction of the US Beaufort Sea shelf. Using a smaller net with smaller mesh, that survey was able to resample many of the 2008 stations. The goals of the present study were to (1) elucidate ecological relationships of the fish and epifaunal prey communities in the western Beaufort Sea in 2008, and relate these to the environmental characteristics of the habitat in a multi-variate and spatially explicit approach; (2a) use multivariate methods (PRIMER software) and exploratory statistics to further evaluate the two net deployments used in the 2008 survey and (2b) compare the results of the 2008 and 2011 surveys at the same locations to the extent possible and meaningful; (3) add relevant historical data to the historical Beaufort Sea fish and epifaunal invertebrate database, and (4) create a taxonomically standardized inventory of trawl fauna found in the Beaufort Sea from the 2008 and 2011 plus historic surveys. At a region-wide scale, the most striking faunal patterns were a combination of a strong gradient in species and community distribution with increasing water depth and a less prominent east-west gradient in community structure. Arctic Cod, *Boreogadus saida* was the single fish species contributing most to within cluster similarity in the all-station data set as well as lined and unlined net subsets. Walleye Pollock, *Theragra chalcogramma* was also influential in structuring fish-only communities, while a larger number of invertebrate species characterized the communities, spread across different phyla including mostly echinoderms (in particular the brittle star *Ophiura sarsii*), crustaceans and molluscs. Mesh size / net type indeed influenced abundance, biomass and species composition patterns of trawl abundance, biomass and faunal similarity pattern of epifauna and fish. Generally, larger amounts of fish and invertebrates were caught with lined than unlined 83-112 nets. At shallow sites (n=3 only), lined nets caught more species (and biomass) than all unlined nets combined reflecting the small body size of particularly shelf species. Linking environmental data to trawl fauna data demonstrated influence, –besides that of mesh size, of the combination of water depth, bottom temperature and salinity, pH, and the availability of hard substrate on the faunal similarity patterns of epifauna and fish. The combination of trawl fauna inventories from the 1970s and 2000s+ totaled over 500 taxa with about two thirds of those identified to species level, of those 47 fish species. On the order of 100 species each were unique to either the 1970s or the 2000s+ with likely more for the latter period when 'bycatch' infaunal species were substracted, and given the Transboundary inventories (although not actually included here). Which and how many of the taxa unique to the 2000s+ might be related to distribution changes rather than a result of increased survey effort remains to be elucidated. Surveys since the 2000s have greatly advanced our knowledge of the epifauna and demersal fish communities of the Beaufort Sea.

II. Objectives

The objective of this study was to perform quantitative ecological analyses of the 2008 Western Beaufort Sea Marine Fish and Lower Trophic Survey (BOEM 2008) data. The specific scope of work was:

1. To elucidate ecological relationships between fish species and epifaunal invertebrate (prey) communities, and relate these to environmental characteristics of the habitat using a multivariate approach.
2. To further compare the results of the two net types used in the 2008 survey, and to compare the results of the 2008 and 2011 surveys at the same locations to the extent possible and meaningful.
3. To add relevant historic data currently missing from the historical Beaufort Sea fish survey database.
4. To create a taxonomic inventory (species list) of epifaunal invertebrate and demersal fish species found in the Alaskan Beaufort Sea based on 2008 and 2011 findings plus earlier validated records.

III. Introduction, methods and results by objective

1. Objective 1: Fish and epifaunal community structure during the 2008 survey

1.1 Introduction

The Western Beaufort Sea Marine Fish and Lower Trophic Survey was conducted onboard the F/V *Ocean Explorer* in the period of 6-22 August 2008 in the western US Beaufort Sea between 155° W and 152°W longitude. Twenty-two successful trawl deployments (of 26 attempts) were conducted between 41 and 470 m water depth with 0.4 - 3.6 km distance fished per haul (Rand and Logerwell 2011, Logerwell et al. 2011; Table 1, Figure 1 a-c). The net used was an 83-112 Eastern otter trawl as employed in the standard Eastern Bering Sea trawl surveys conducted by the Alaska Fisheries Science Center's RACE Division, except that a finer mesh liner (3.8 cm) was inserted into the body of the net. The lined nets lasted through trawl #13 when all lined nets had been destroyed. Unlined nets (8.9 cm mesh) had to be used subsequently for the remaining hauls, which hampers comparisons between the two station groups. Two station pairs (*10/22* and *12/24*) were sampled with both net types for comparison, one at 50 m and one at 175 m water depth. Stations sampled with lined nets were in 100 to 500 m water depth with three exceptions and were mostly trawled for 15 min. Stations sampled with unlined nets were in 41-83 m water depth with one exception and were mostly trawled for 5 min.

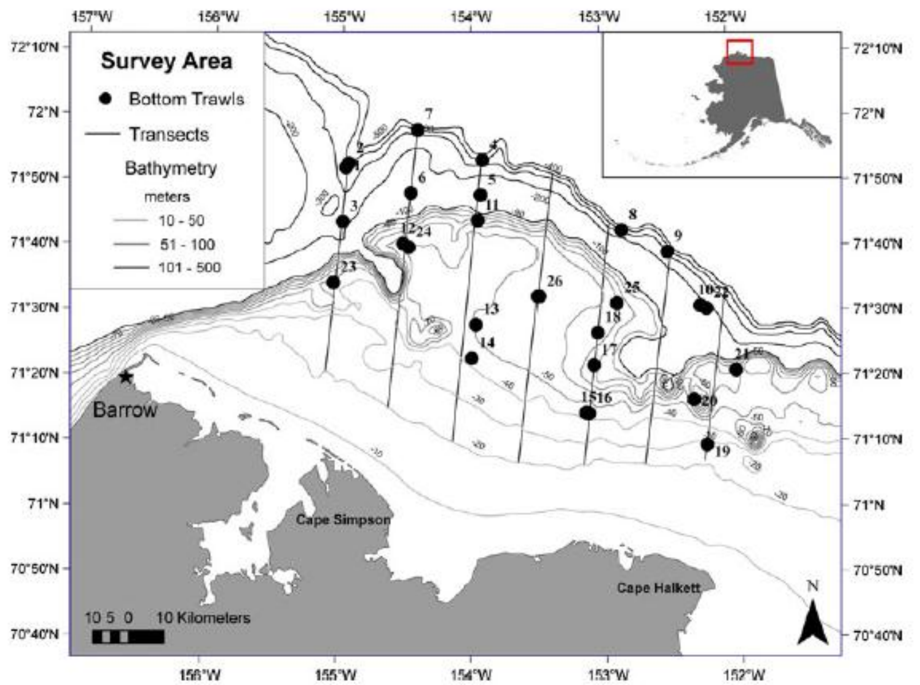
The study provided valuable information about the number of fish species (34) and invertebrate taxa (estimated at 174) present in the region, and their ranking in terms of counts and weights (Logerwell and Rand 2010, Rand and Logerwell 2011). Invertebrates made up 94% of the catches by weight with fish contributing the remaining 6%. Arctic cod by far dominated the hauls both in terms of abundance and biomass in both net types. Eelpouts (Zoarcidae), Bering Flounder (*Hippoglossoides robustus*) and Walleye Pollock (*Theragra chalcogramma*) also contributed significantly. Brittle stars (*Ophiura sarsii*) by far dominated abundance and biomass among the invertebrates in the lined net with various crustaceans including snow crab (*Chionoecetes opilio*), molluscs and echinoderms other than *O. sarsii* also contributing significantly. In unlined net hauls, several echinoderms were prevalent including the mud star *Ctenodiscus crispatus*, the sea urchin *Strongylocentrotus* sp. and the sea cucumber *Psolus peronii* (in the field identified as *P. fabricii*). Unreported for the region to our knowledge, large (>70 mm carapace width) snow crab were found, particularly in deeper water. The dominant Arctic Cod, eelpout and snow crab were associated with saline water (>33) over the shelf break (Logerwell et al. 2011). Size-frequencies and age distributions of *B. saida* were dominated by age 1 and 2 fish with larger fishes primarily found at deeper locations.

Per BOEM's Request for Quotation M12PS000007, the agency needed a better understanding of the "ecological relationships among fish species and communities, invertebrate prey and habitats" from the 2008 data. Also, BOEM stated they needed a better "understanding of the extent to which the sampling methods and data from the 2008 Western Beaufort Sea survey can be compared to the data and methods from multiple international and BOEM-supported surveys in the Chukchi Sea and the central Beaufort Sea". This first objective focused on the analysis of community structure of epifaunal invertebrates and demersal fishes collected with the otter trawls, and their linkage to relevant environmental conditions.

Table 1: Station table of BOEM 20008 survey with matching re-sampled stations during BOEM 2011. Note deviations in water depths in particular at slope stations. PSBT: plumb-staff beam trawl. PSBT-A: Modified PSBT.

BOEM 2008	Lat dec deg N	Long dec deg W	Net type	Depth (m)	BOEM 2011	Lat dec deg N	Long dec deg W	Net type	Depth (m)
Trawl 2	71.89	-154.95	83-112 lined	470	not sampled (too deep)				
Trawl 3	71.74	-154.99	83-112 lined	198	WB02	71.74	-154.96	PSBT-A	180
Trawl 4	71.90	-153.91	83-112 lined	347	not sampled (too deep)				
Trawl 5	71.81	-153.92	83-112 lined	143	WB04	71.84	-153.90	PSBT-A	180
Trawl 6	71.81	-154.46	83-112 lined	158	WB05	71.81	-154.41	PSBT-A	152
Trawl 7	71.98	-154.41	83-112 lined	322	not sampled (too deep)				
Trawl 8	71.72	-152.84	83-112 lined	318	WB07	71.71	-152.97	PSBT-A	180
Trawl 9	71.66	-152.49	83-112 lined	302	WB08	71.65	-152.65	PSBT-A	180
Trawl 10	71.52	-152.25	83-112 lined	175	WB20	71.50	-152.18	PSBT-A	181
Trawl 11	71.75	-153.94	83-112 lined	66	WB10	71.72	-153.87	PSBT-A	50
Trawl 12	71.69	-154.52	83-112 lined	50	WB22	71.68	-154.48	PSBT-A	48
Trawl 13	71.48	-153.96	83-112 lined	49	WB12	71.48	-153.99	PSBT-A	49
Trawl 16	71.25	-153.11	83-112 unlined	41	WB14	71.25	-153.10	PSBT	38
Trawl 17	71.37	-153.07	83-112 unlined	75	WB15	71.38	-153.02	PSBT-A	na
Trawl 18	71.46	-153.04	83-112 unlined	64	WB16	71.45	-153.01	PSBT-A	62
Trawl 20	71.28	-152.31	83-112 unlined	50	WB18	71.19	-152.26	PSBT	48
Trawl 21	71.35	-151.99	83-112 unlined	83	WB19	71.35	-151.96	PSBT-A	86
Trawl 22	71.51	-152.20	83-112 unlined	178	Repeat of Trawl 10 (WB20)				
Trawl 23	71.58	-155.05	83-112 unlined	44	WB21	71.59	-154.99	PSBT	45
Trawl 24	71.68	-154.48	83-112 unlined	50	Repeat of Trawl 12 (WB22)				
Trawl 25	71.53	-152.89	83-112 unlined	59	WB23	71.53	-152.85	PSBT-A	58
Trawl 26	71.55	-153.48	83-112 unlined	52	WB24	71.51	-153.56	PSBT-A	50

a)



b)

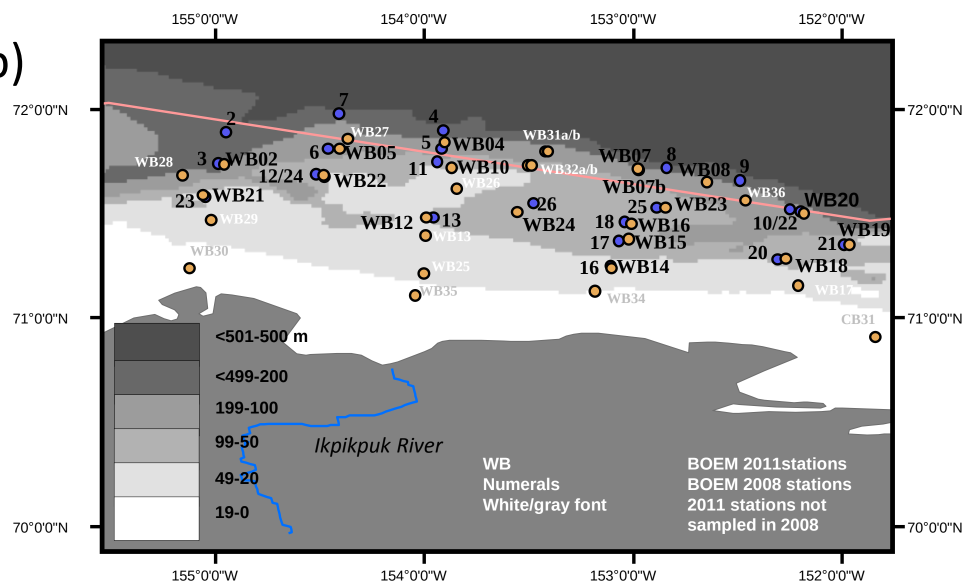
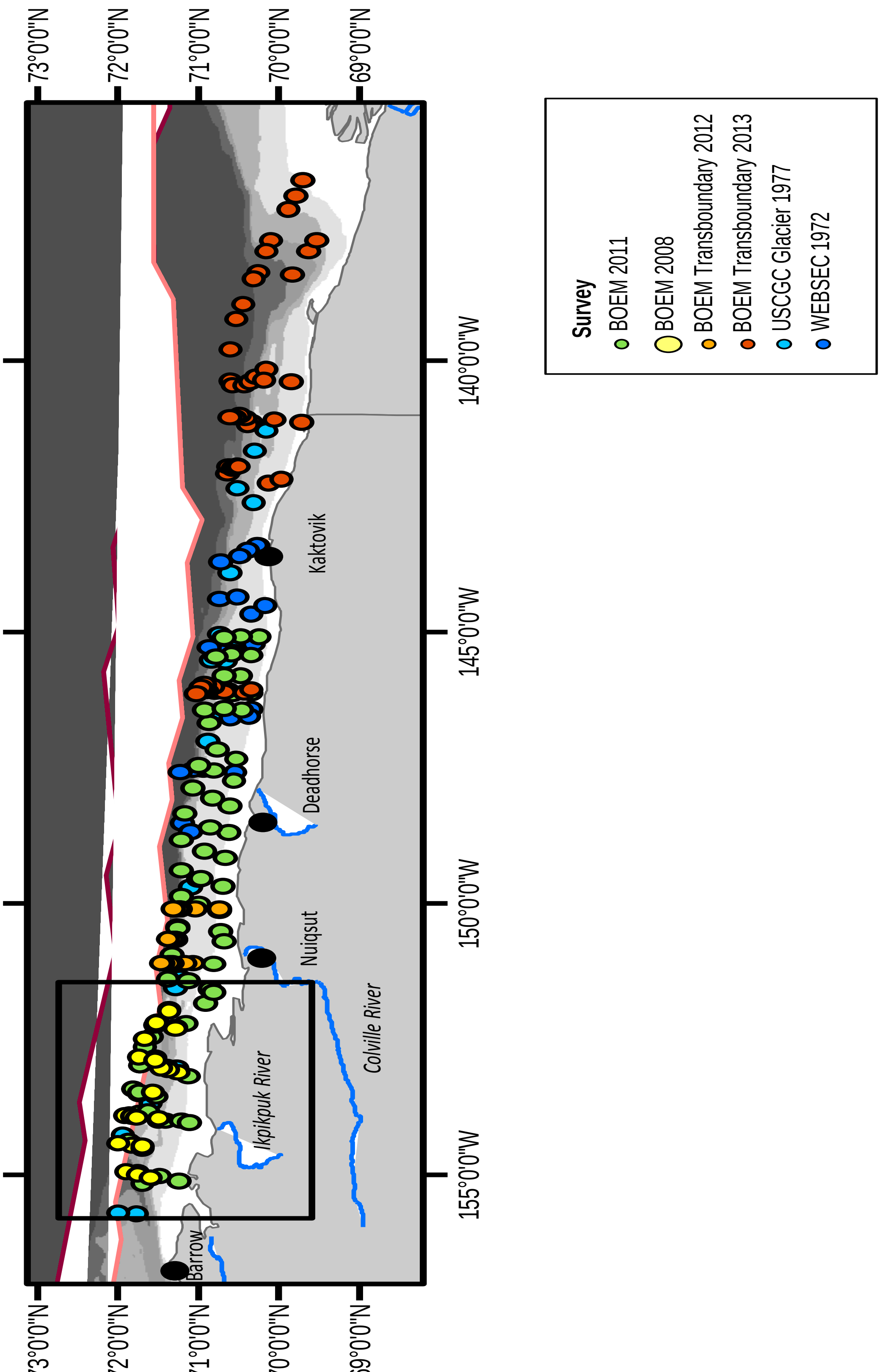


Figure 1. Study are and sampling locations. a) BOEM 2008 survey stations from Rand and Logerwell (2011); b) BOEM 2008 and BOEM 2011 survey stations; subsequent page: c) BOEM 2008 sampling (black box) in the context of historic and 2010+ sampling efforts. Pink lines in b) and c) mark the average August sea ice extent from 1979-2000. Red line in c) marks the average September sea ice extent from 1979-2000.

c)



73°0'0"N
72°0'0"N
71°0'0"N
70°0'0"N
69°0'0"N
155°0'0"W
150°0'0"W
145°0'0"W
140°0'0"W
Barrow
Ikpikpuk River
Colville River
Nuiqsut
Deadhorse
Kaktovik
Survey
BOEM 2011
BOEM 2008
BOEM Transboundary 2012
BOEM Transboundary 2013
USCGC Glacier 1977
WEBSEC 1972

1.2 Methods

The data set used for the below analyses was the 2008 haul data provided as counts and weights by species in an Access file (BSS_Database2008_Correct) by the Alaska Fisheries Science Center team who organized the 2008 survey. Collection methods and procedures are detailed in the final report of the original study (Logerwell and Rand 2010). The haul data file was first updated with regard to the invertebrate identifications and names. This procedure encompassed creating a unique taxon list and matching it to the World Register of Marine Species (www.marinespecies.org), the most widely accepted standard for current names of marine species. The match procedure flags misspelled species and taxon names, and outdated or otherwise unaccepted names. Example for typos thereby identified in the data set included 'Caridae' instead of 'Caridea' (for shrimps), 'Crinoidea' instead of 'Crinoidae' (for feather stars), '*Golfingia'* instead of 'Gonlfingia' (for a genus of sipunculan worms), etc. Examples for name changes include '*Lumpenus maculatus'* to '*Leptoclinus maculatus'*, '*Margarites beringensis'* to '*Margarites giganteus'* and others.

We also looked at voucher specimens of invertebrate taxa collected during the 2008 cruise by UAF technician Heloise Chenelot, and corrected or better resolved some taxonomic identifications, for example the ascidian '*Molgula* sp.' was changed to '*Chelyosoma macleayanum'*. Fish vouchers had already been verified by the AFSC team (Logerwell and Rand 2010). A number of invertebrate voucher specimens from the 2008 cruise were mailed out for species identifications including sea stars (Christopher Mah, Smithsonian Institution), sea cucumbers (Antonina Rogacheva, P.P. Shirshov Institute of Oceanology, Moscow), brittle stars (Gordon Hendler, Natural History Museum of Los Angeles County), sea anemones (Estefania Rodriguez, New York Museum), sea squirts (Linda Cole, Smithsonian Institution), sipunculan worms (Monika Kedra, Institute of Oceanology Polish Academy of Sciences) and moss animals (Piotr Kuklinski, London Natural History Museum / Institute of Oceanology Polish Academy of Sciences). In house experts were consulted for snails and bivalves (Nora Foster, retired from University of Alaska Museum of the North), amphipods (Ken Coyle, Institute of Marine Science) and polychaetes (Max Hoberg, also Institute of Marine Science). As expert identifications came in, the unique species list and haul data sets were corrected and updated as necessary. Sea anemone identifications have not yet been received.

For all following analyses, we excluded taxa from the haul data that were (1) *pelagic* such as jelly fish and euphausids, and (2) clearly *infaunal* (i.e. living inside rather than on top of the sediment) such as most clams and various polychaetes. Pelagic taxa occasionally get caught in the trawl while the net gets deployed through the water column. Infaunal taxa occasionally get caught when the net digs into the upper sediment layer (which is ideally avoided). Because pelagic and infaunal taxa were not the target fauna and were caught non-quantitatively, they should be excluded from the haul data for estimates of total abundance, biomass, species composition, biodiversity estimates etc. of epifaunal invertebrates and demersal fishes. In some cases, we combined several species from a genus or closely related genera where field notes or voucher identifications suggested doubtful or inconsistent identifications at the species level. Colonial invertebrates such as sponges, bryozoans and colonial ascidians were excluded in abundance-based analyses, because they cannot be enumerated. The cleaned data sets were then imported into PRIMER v.6 for community analysis.

Community analysis was performed combined and separately for the lined and unlined nets used during the BOEM 2008 survey. Within those strata, fish and invertebrate data sets were analyzed combined and individually using multivariate statistics of the software package PRIMER™ version 6 (Clarke and Gorley 2006) on a PC using Windows systems. Prior to hierarchical cluster analysis Bray-Curtis similarity (a distance measure between samples) was calculated using mild (square root), moderate (fourth root) and extreme (presence/absence) transformations on abundance and biomass matrices (Bray and Curtis 1957). Clusters were tested for actual structure in the data underlying branches of the cluster dendrogram, using the Similarity Profile permutation tests (SIMPROF routine; Clarke and Gorley 2006), and were plotted onto maps of the study area. Non-metric multi-dimensional scaling (nMDS) was used to visualize the resulting patterns in similarity among stations by placing stations in multi-dimensional space as best possible to preserve distance (reflecting dissimilarity) between stations. Species contributing most to the similarities within clusters, i.e. those best characterizing a given cluster, were identified using similarity of percentages (SIMPER) analysis. Taxa that contributed >5% to the within-cluster similarity were added to the nMDS plots. Diversity indices were determined using the DIVERSE routine, specifically the number of taxa S, Pielou's evenness J', Shannon diversity $\log_2$ H', and rarefaction ($ES_{(n)}$). Pielou's evenness J' is a measure of how evenly individuals are distributed among the species present and ranges from 0 (high dominance) to 1 (equal distribution) (Magurran 2004). The Shannon index H' integrates the number of species in a sample and their equitability and usually falls between 1.5 and 3.5. Rarefaction is a diversity measure that estimates the number of species in a sample size of n individuals (50 in our case) for a near-unbiased comparison. Between-group similarity was statistically tested using analysis of similarity (ANOSIM) for stations grouped by net type and water depth, with global R=1 indicating groups with completely distinct communities, and global R=0 indicating complete overlap in community composition between groups (Clarke and Warwick 2001). ANOSIM is a nonparametric permutation test based on Bray-Curtis similarity coefficients, analogous to the univariate ANOVA (Clarke and Gorley 2006).

We compiled a matrix of environmental data collected for each station either during the BOEM 2008 survey (temperature, salinity, bottom type from haul observations, water depth). Sediment was not characterized during the BOEM 2008 survey and sediment data were, therefore, supplemented from the BOEM 2011 survey (Table 2), because we consider it a reasonalbe assumption that sediment characteristics remained rather stable between 2008 and 2011. Deep stations (>300 m) had to be excluded from the analysis, because no data on sediment characteristics were available. We did not, however, use chlorophyll and phaeophytin concentrations from the 2011 cruise because of strong interannual and seasonal variability in that variable. Fifteen variables were used and included a combination of hydrographic characteristics (bottom temperature, bottom salinity), sediment characteristics (substrate category, grain size from 2011 survey), and indicators of quality and quantity of food supply (C/N ratio, sediment organic carbon content from 2011 survey) and carbon source ($\delta^{13}C$ as tracer of terrestrial versus marine carbon) as well as variables with (presumed) indirect relationships to community structure (latitude, longitude, water depth). Methods for sampling, laboratory and data analysis of these variables are described by Logerwell and Rand (2010), Norcross et al. (2014) and for $\delta^{13}C$ of similar samples in the Chukchi Sea by Iken et al. (2010). Prominent environmental links between sites and environmental variables were illustrated in a principal component analysis. In a second approach, the normalized environmental matrix was correlated with the species matrix using the BIO-ENV procedure in PRIMER to select variables that best explain the community pattern by maximizing a rank correlation between the resemblance matrices of the environmental and community data (Clarke and Gorley 2006). For background and to illustrate better spatial coverage of hydrography, we also provided long-term (1970s to present) integrated maps of surface and bottom temperature, surface and bottom salinity and stratification strength. These data were compiled under an NPRB-funded data synthesis project (Pacific Arctic Marine Regional Synthesis, PacMARS, PIs Grebmeier and Cooper, T/S data compiled by Steve Okkonen and available online by June 2014). Roughly 2000 CTD casts fell into the area covered by our map and were unfiltered for season and year to allow temporal variability to show up, although the vast majority of measurements were conducted between June and September.

Table 2. Results of the principal component analysis: coefficients in the linear combination of variables making up PCs based on normalized measurements. The three variables that load highest on each PC are printed in bold.

Variable	**PC1**	**PC2**	**PC3**
Station Depth	0.294	-0.169	0.185
LatdegN	0.088	-0.261	**0.516**
LongdegW	-0.143	0.160	0.366
T_bottom_11	**-0.322**	0.292	0.023
T_bottom08	-0.098	0.269	**0.401**
S_bottom	**0.360**	-0.169	0.089
pH	**-0.351**	0.146	-0.122
Sed Org Matter	0.317	0.159	0.193
%Gravel	-0.219	-0.069	**0.385**
%Sand	-0.187	**-0.436**	-0.248
%Mud	0.288	0.295	-0.198
Sed%H2O	0.332	0.242	-0.077
C/N	-0.167	**-0.338**	0.229
BottomType_08	-0.311	-0.058	-0.133
$\delta^{13}C$	-0.135	**0.433**	0.140

1.3 Results

1.3.1 Patterns in biomass, diversity and community structure

Biomass was overall higher at the slope stations than at the shelf stations (Figure 2a). Echinoderms dominated relative biomass composition at most stations (Figure 2b) with a few exceptions. Crustaceans, mollusks, cnidarians and fishes also contributed considerably to total biomass at both slope and shelf stations, while ascidians and ‘other’ taxa were only prominent on the shelf (Figure 2b). While the sample size is limited and gear differences introduce bias, the data suggest a biomass peak at the upper slope (Figure 3). In all but one haul, invertebrate biomass was overwhelmingly higher than fish biomass.

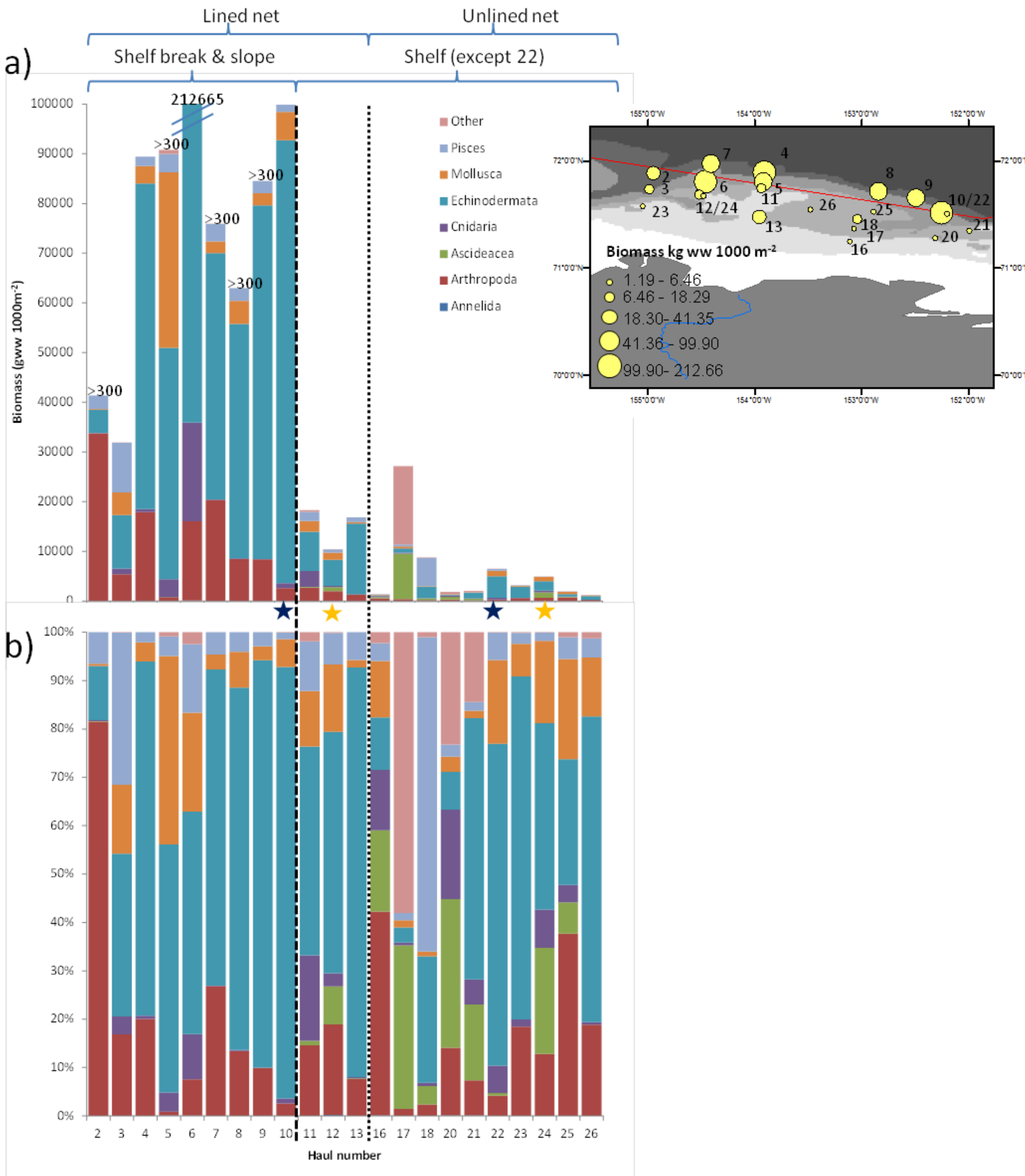


Figure 2. Taxonomic composition of 83-112 trawl hauls collected in the Beaufort Sea during the BOEM 2008 survey. A) Composition of biomass calculated as grams wet weight per 1000 m^{-2}, with inset showing spatial distribution of biomass labeled by haul number; b) relative composition based on weights. Stars indicate stations sampled with lined and unlined net. Vertical lines separate hauls by net type (dotted line) and water depth (dashed line). >300 denoted stations deeper than 300 m. Red line inset map marks the average August sea ice extent from 1979-2000.

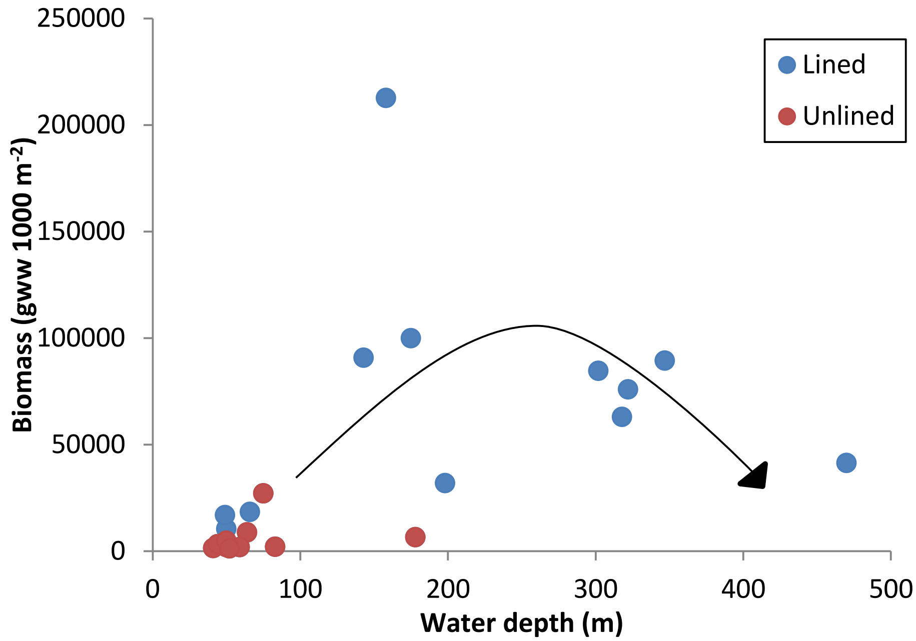


Figure 3. Biomass of all hauls collected in the Beaufort Sea during the BOEM 2008 survey, standardized to grams wet weight per 1000 m^{-2}. The arrow indicates the suspected depth trend in biomass. We did not determine a true statistical relationship because of the low sample size and differences in mesh size

Diversity metrics, Shannon diversity (H' log(e), Figure 4a), evenness (J', Figure 4b) and estimated number of species in a standardized number of individuals ($ES_{(50)}$, Figure 4c) showed generally lower values along the slope than on the shelf (also Figure 5a). Low evenness values at slope stations (Figure 4b) were related to dominance of very few species, in particular the brittle star *Ophiura sarsii*. This pattern was reflected in the higher estimated total number of taxa for the shelf versus the slope using the Chao 2 estimator as implemented in PRIMER, a measure of actual species richness that is based on the number of rare species in a data set, in the context of taxon accumulation curves (Figure 5b). This is noteworthy given that the number of individuals per haul was much higher at the deeper stations where the net was lined and hauled longer than at shallow stations.

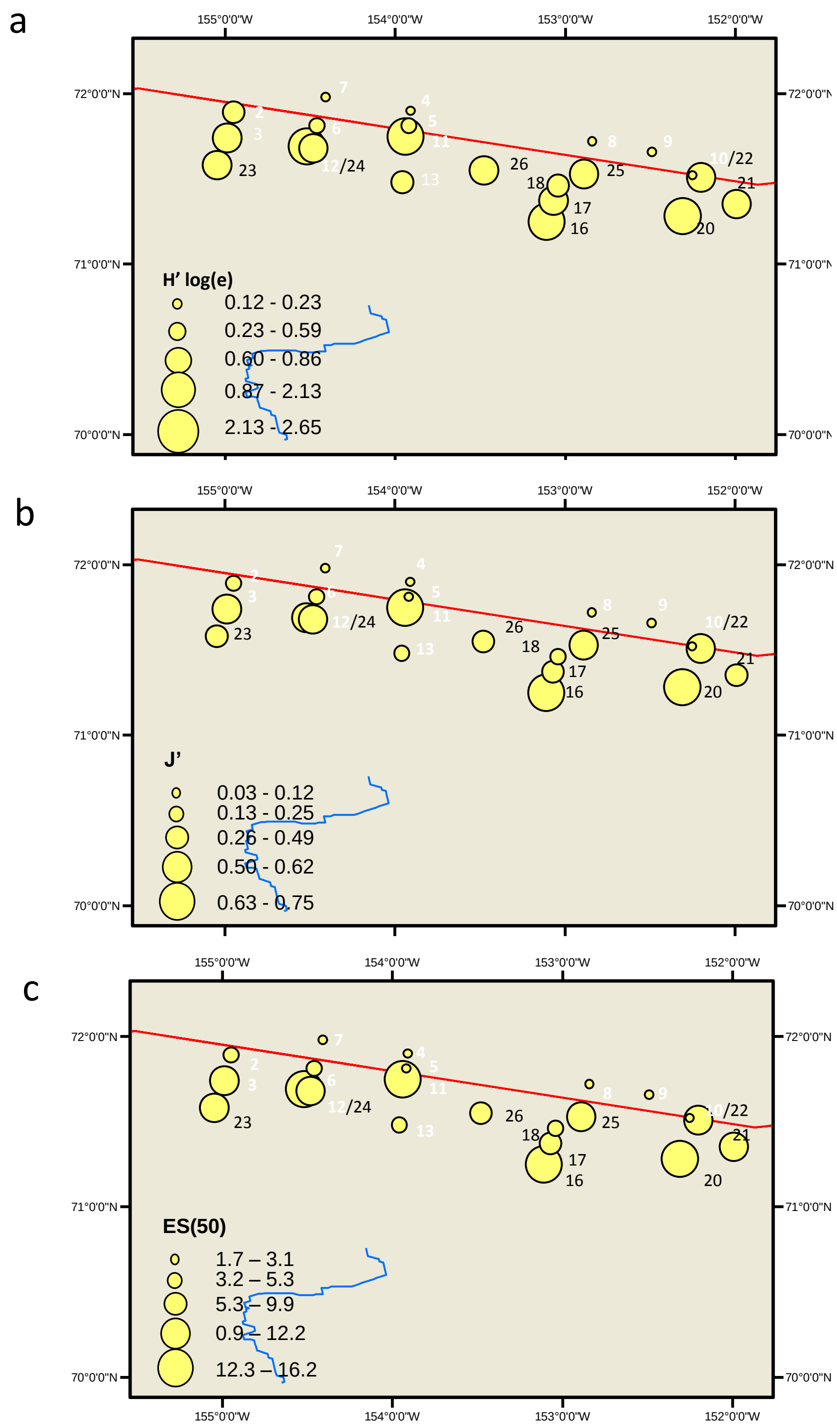


Figure 4. Biodiversity indices for the combined fish and epifauna data from the BOEM 2008 survey for all stations combined. Stations in white font were trawled with lined nets, stations in black font were trawled with unlined nets. a) Shannon diversity H'; b) Pielou's evenness J'; c) estimated number of species $ES_{(50)}$. Red line marks the average August sea ice extent from 1979-2000.

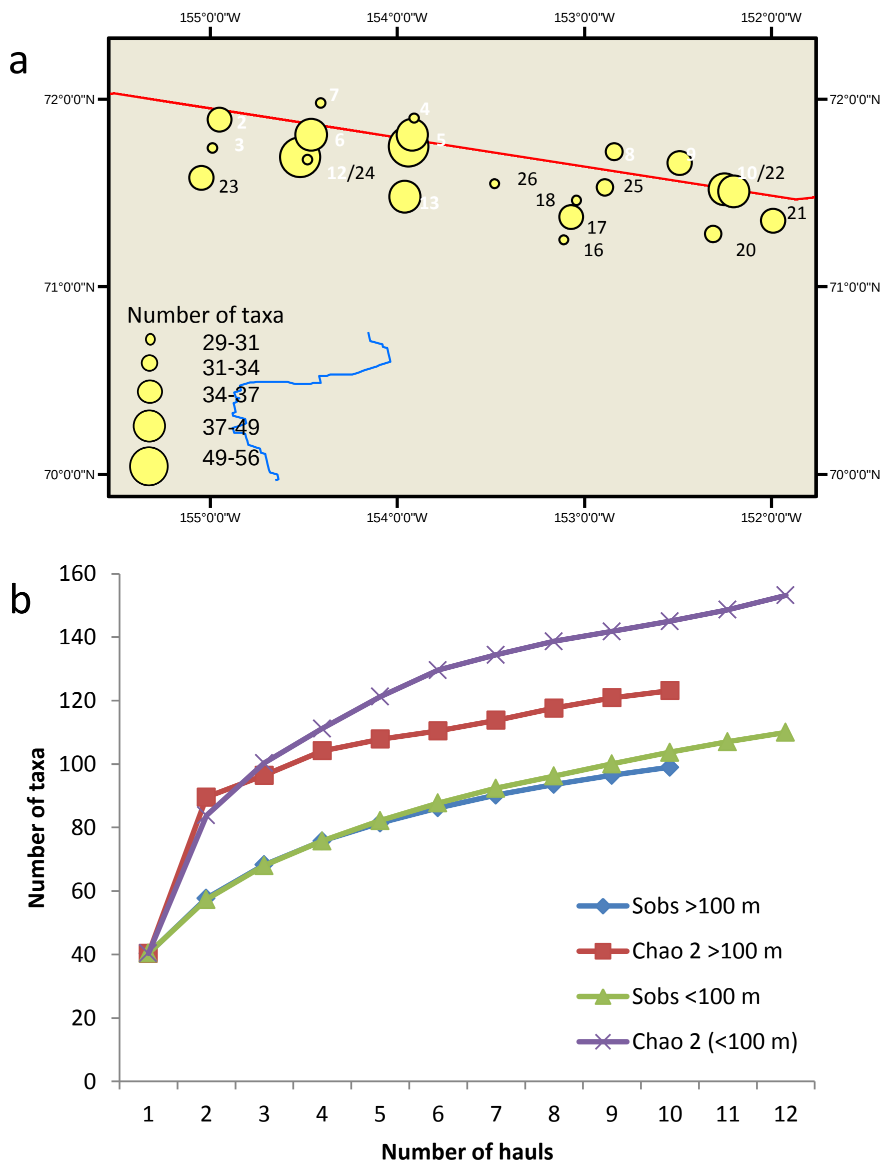


Figure 5. Number of taxa in the BOEM 2008 survey (all stations). a) Spatial distribution of the number of taxa in BOEM 2008 hauls. b) Taxon accumulation curves for two depth strata based on all hauls in each stratum of the survey. S obs – Observed number of taxa, Chao 2 – estimated number of taxa using Chao 2 estimator. Red line marks the average August sea ice extent from 1979-2000.

Community similarity patterns were generally similar in terms of the distribution of stations in multi-dimensional space in the nMDS plots when biomass or abundance data were used (Figure 6, top panels). Differences in specific cluster memberships between abundance and biomass-based similarity patterns when including all stations were primarily related to (1) large numbers of the brittle star *Ophiura sarsii*, a species that was slightly less influential in the biomass-based groupings (Figure 6, bottom panels), and (2) shelf stations 11-13 (the only shallow stations trawled with lined nets) grouping with other shelf stations in the biomass data set (Figure 6a, bottom panel) while grouping with the geographically close, but deeper stations 2 and 3 in the abundance data set and two other shelf stations (Figure 6b, bottom panel). Community similarity patterns were also generally similar between different data transformations, shown using biomass data (Figure 7). All subsequent figures are based on square-root transformation except where noted.

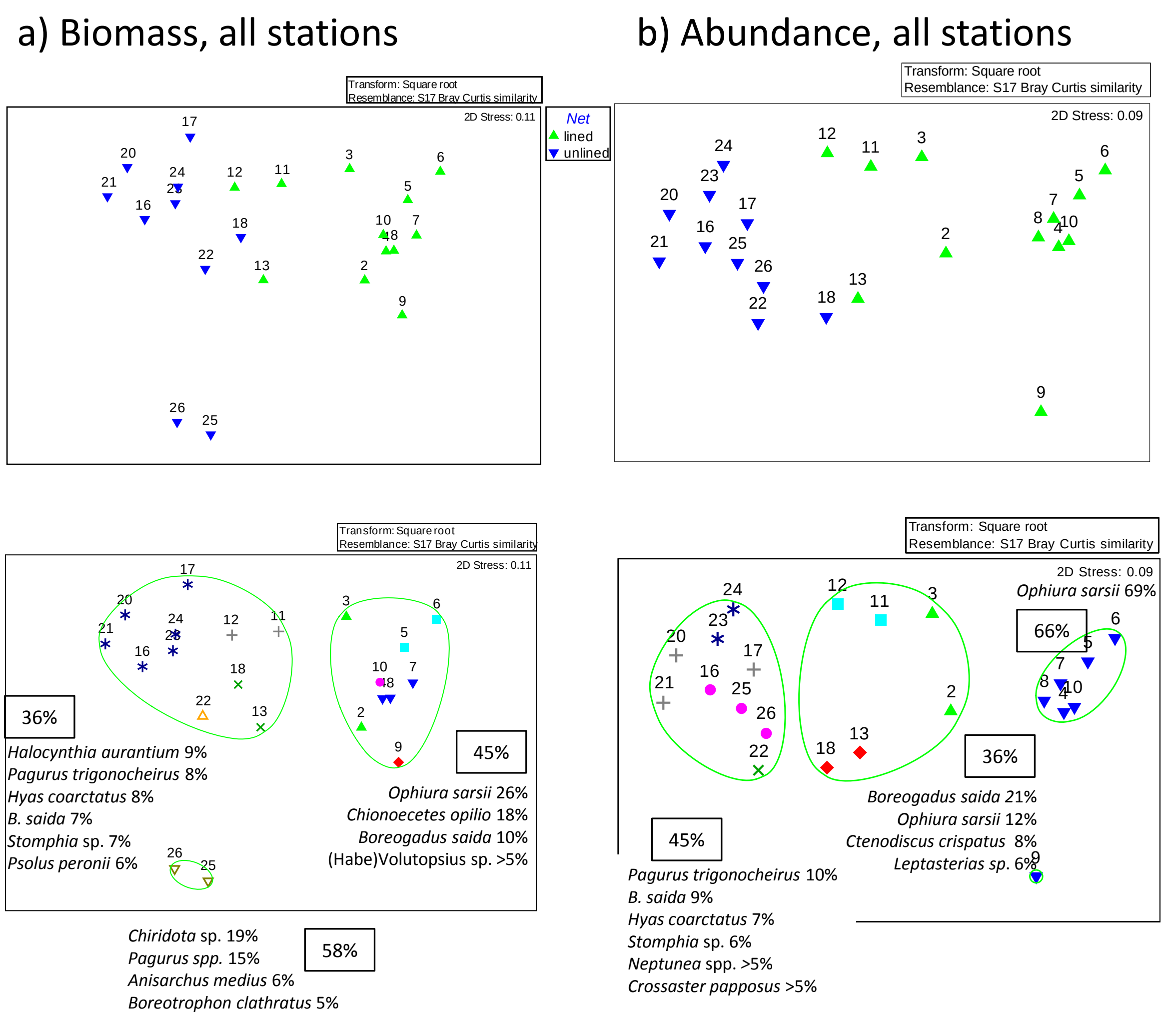


Figure 6. Community structure of all stations of the BOEM 2008 survey with epifauna and fishes combined, using non-metric multi-dimensional scaling plots (nMDS) based on square-root transformed a) <u>biomass</u> data and b) <u>abundance</u> data. Numbers indicate station names (as in Figure 1). Green triangles in top panel are stations where lined nets were used; blue triangles are stations where unlined nets were used. Symbols in bottom panels indicate significant hierarchical clusters from SIMPROF routine. Green outlines denote groups of stations above 30% within group similarity level, with % values in boxes indicating specific similarity levels within each of those green-circled groups. Each green-circled group is characterized by the listed species which each contributed >5% to the similarity within a given group of stations within green circles.

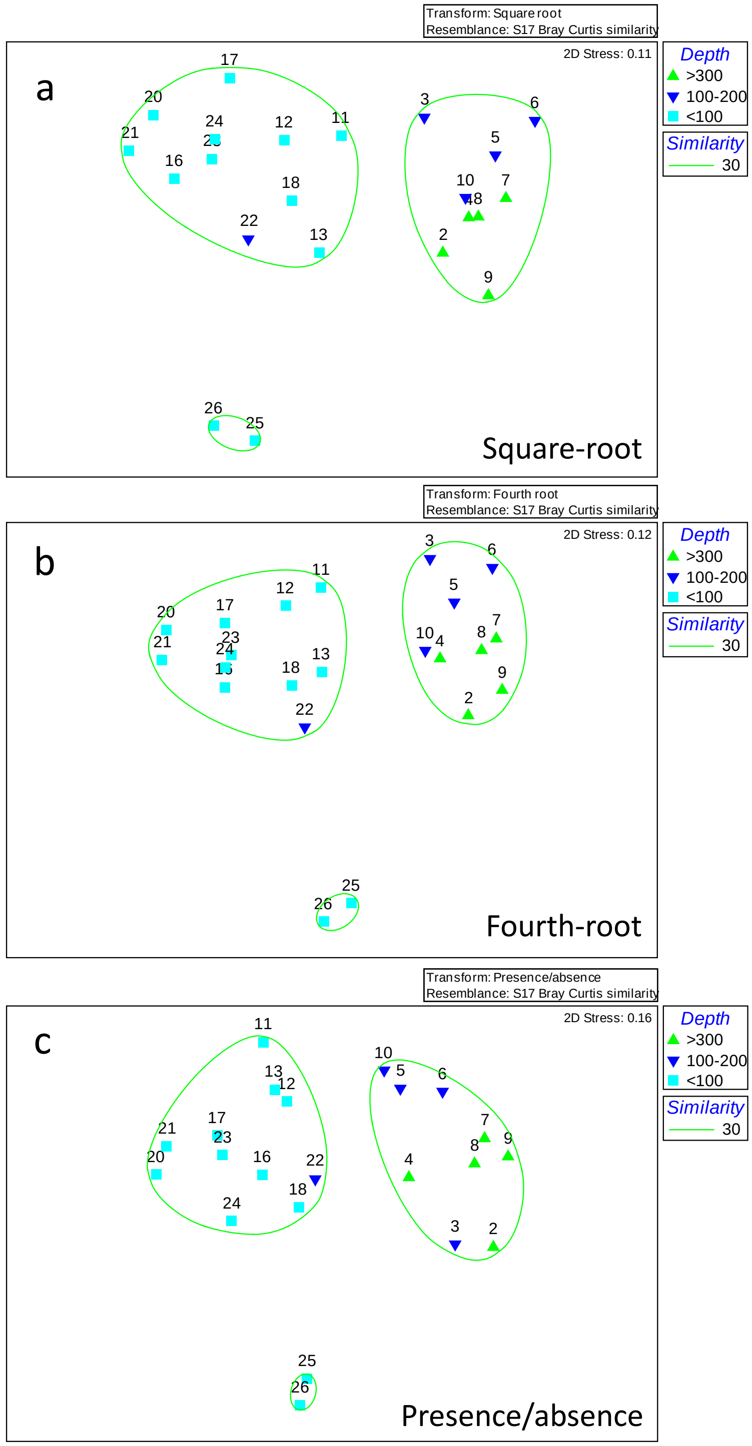


Figure 7. nMDS of BOEM 2008 epifauna and fishes combined based on biomass data and three different data transformations, which produced almost identical results. A) Mild (square-root) transformation (used in all subsequent plots); b) moderate (fourth-root) transformation; c) strong (presence/absence) transformation. Otherwise as in Figure 6.

Large-scale community similarity patterns were generally comparable when fish and invertebrate taxa were combined versus when the fishes were analyzed separately, shown using abundance data (Figure 8). Differences, however, included higher within-cluster similarity when fishes were analyzed separately (Figure 8, % values in middle panels), which is in part a function of the lower species number of fishes versus invertebrates (see section 5). In the fish-epifauna combined data set, the only fish species of taxa contributing most to within-cluster similarity was Arctic Cod, *Boreogadus saida* (Figure 8a, middle panel). The same species contributed most to within-cluster similarity in the fish-only data set, but with different average abundances in each cluster (Figure 8b, middle panel). Walleye Pollock, *Theragra chalcogramma*, was the second most important species that contributed both to within-cluster similarity and between-cluster dissimilarity in the fish-only data set (Figure 8b, middle and lower panel). The Marbled Eelpout, *Lycodes raridens*, also contributed to between-cluster dissimilarity. In the combined epifauna-fish data set, a larger number of taxa each contributed >5% to within-cluster similiarity. These included various crustaceans, echinoderms, gastropods, a cnidarian and an ascidian (Figure 8a, middle panel).

Generally, all nMDS plots that included all BOEM 2008 survey stations (Figures 6a-12a) showed shallow sites (11-26, except 22) (<100 m) on the left side of the plot and deep sites (2-10) on the right side of the plots. This separation indicates that water depth is an important factor structuring epibenthic and demersal fish communities which was confirmed by ANOSIM testing differences between stations <100 m and ≥100 m (Global $R = 0.50$, $p<0.001$; square-root transformed biomass data). Given that depth and net type in most cases coincided, unlined hauls grouped on the left side of the plots and lined hauls on the right hand side. Again, ANOSIM confirmed this separation in community similarity between lined and unlined hauls as strong and significant (Global $R=0.66$, $p<0.001$). The three shallow stations that were trawled with a lined net (11, 12 and 13), fell into the middle of the nMDS plots, between the other shallow sites on the left and the deep sites on the right. This position reflects that stations 11, 12 and 13 were shallow sites but lined nets were used. The exception to the overall pattern was station 22, a slope location that grouped with shelf locations. Stations 11, 12 and 13 had different cluster memberships in abundance-based versus biomass-based cluster analysis. Again, these stations clustered with other shelf stations in the biomass-based analysis, while they clustered with a mixture of geographically close deep stations (2, 3) and geographically distant shelf stations (13, 18) in the abundance-based analysis.

Lined and unlined hauls were also analyzed separately (Figures 9b-12b) which tended to spread stations out in multi-dimensional space except in the station ordination for unlined biomass-based hauls. By and large, the separate analysis of lined and unlined hauls found mostly the same dominant and cluster-defining taxa as in the all-station data set with some differences in their ranking and a few differences in taxa. This finding suggests that in the big picture, the community was captured somewhat consistently despite the different mesh sizes.

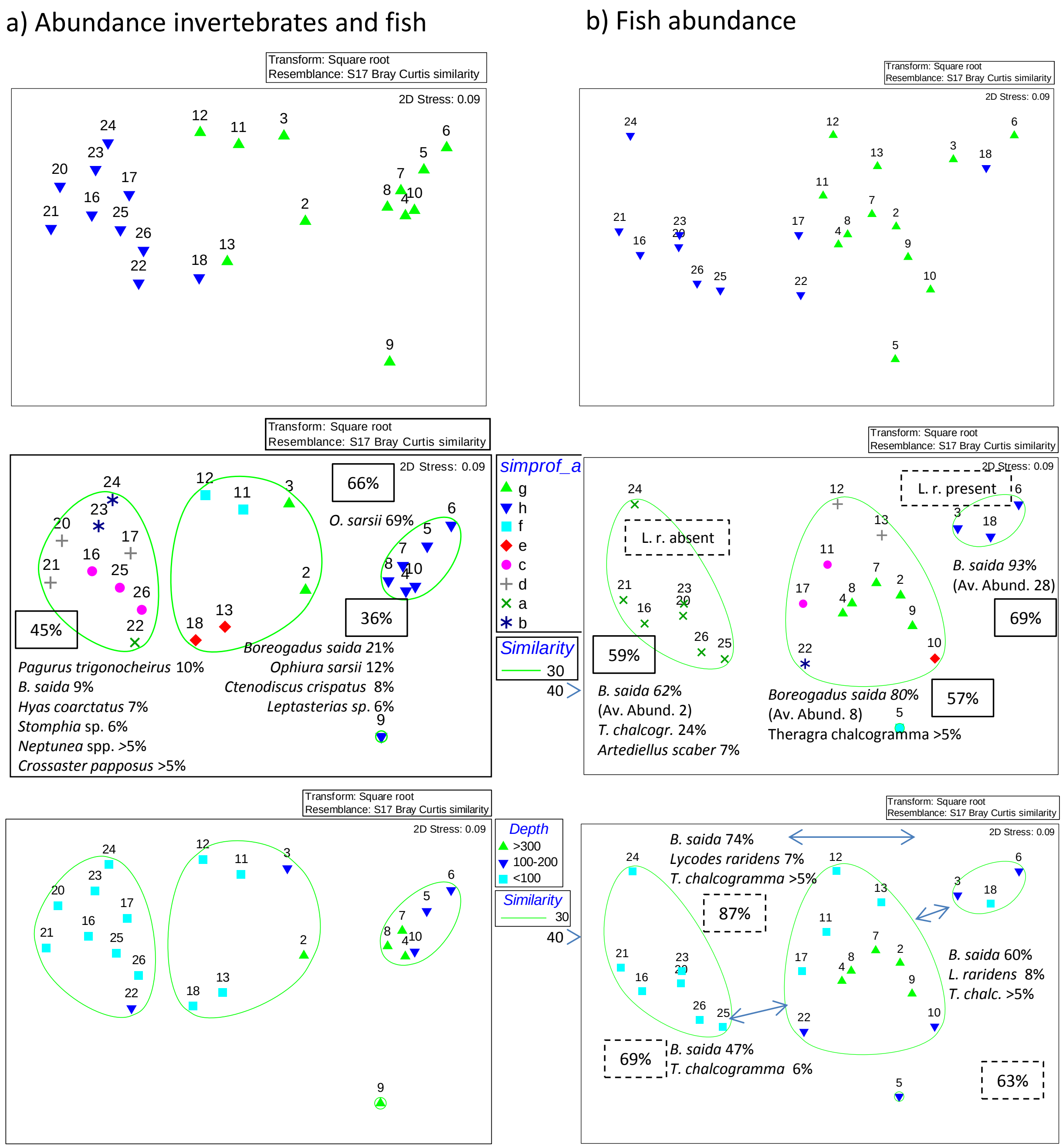


Figure 8. nMDS of BOEM 2008 a) epifauna and fishes combined (as in Figure 6b) and b) fish data only based on square-root transformed abundance data. Otherwise as in Figure 6, except that green circles show ≥40% similarity level in b), because there was no structure at the 30% level. Species in bottom right panel indicate taxa contributing to dissimilarity between green-circled clusters. Associated percent values in hatched boxes indicate level of dissimilarity between green-circled clusters. Av. Abund is average abundance (ind 1000 m^{-2}). L.r. is *Lycodes raridens*.

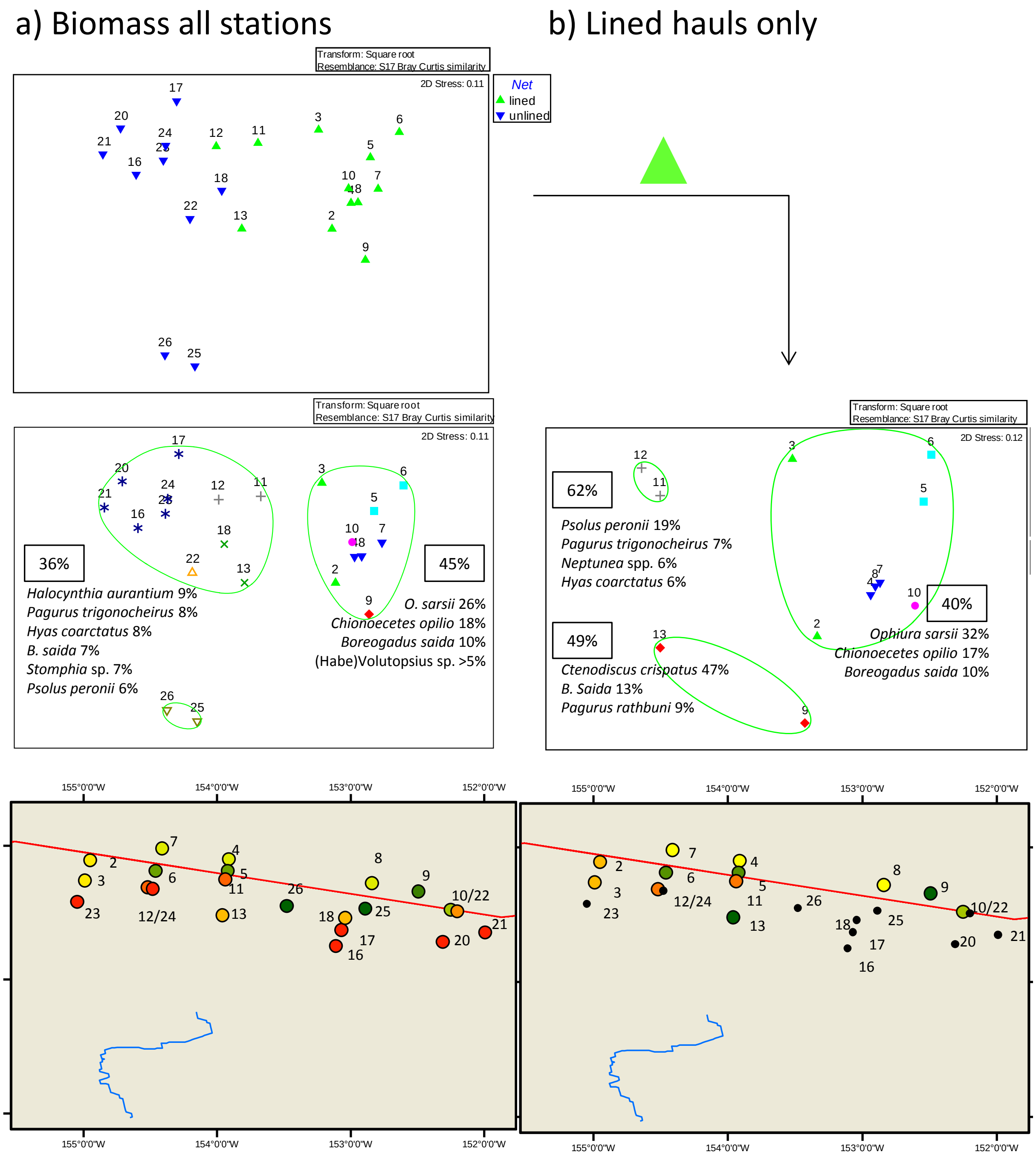


Figure 9. nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed biomass data of a) all stations (as in Figure 6a) and b) lined hauls only. Otherwise as in Figure 6. Same-colored stations on maps show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by lined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

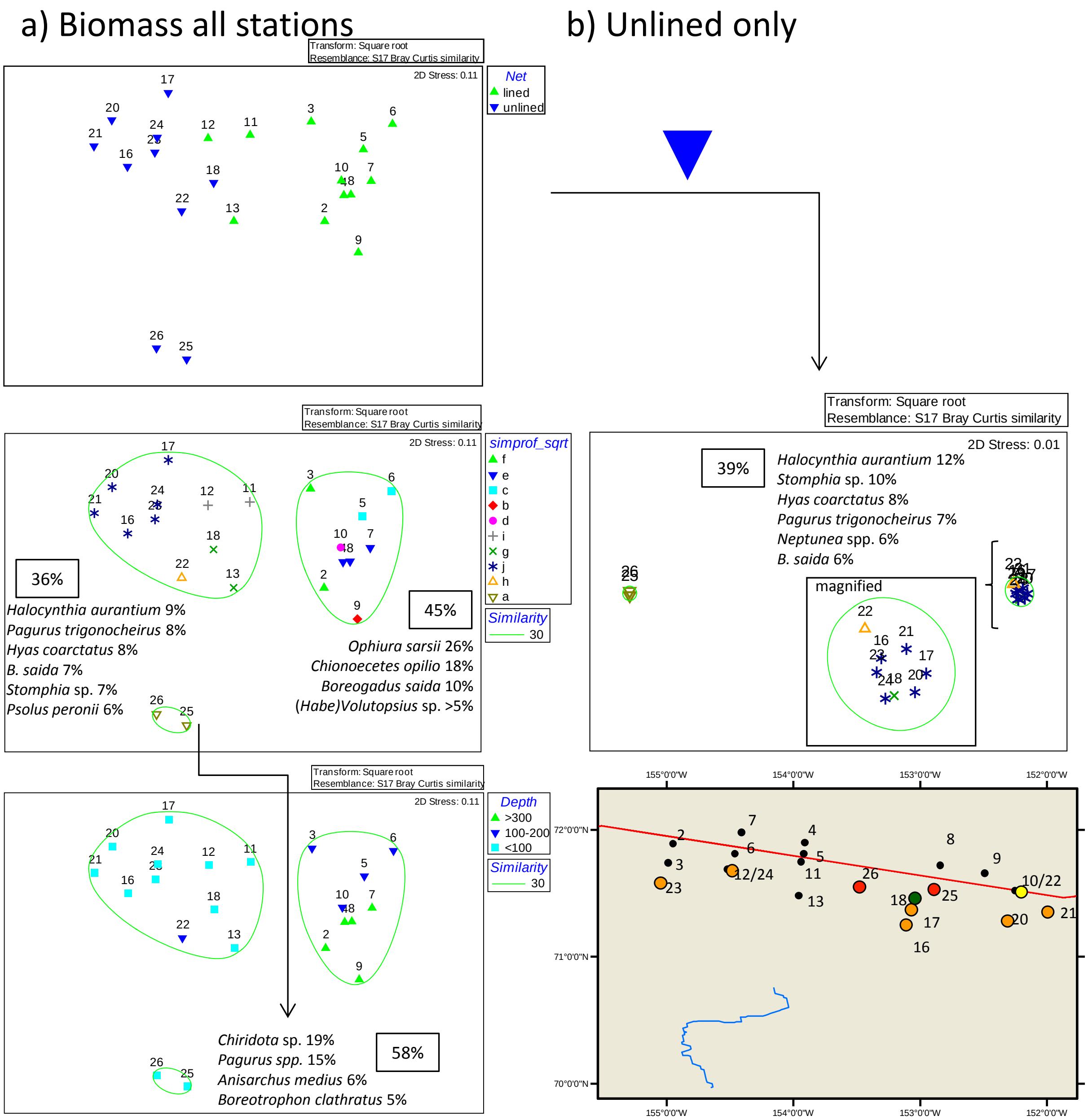


Figure 10. nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed biomass data of a) all stations (as in Figure 6a) and b) unlined hauls only. Otherwise as in Figure 6. Same-colored stations on map show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by unlined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

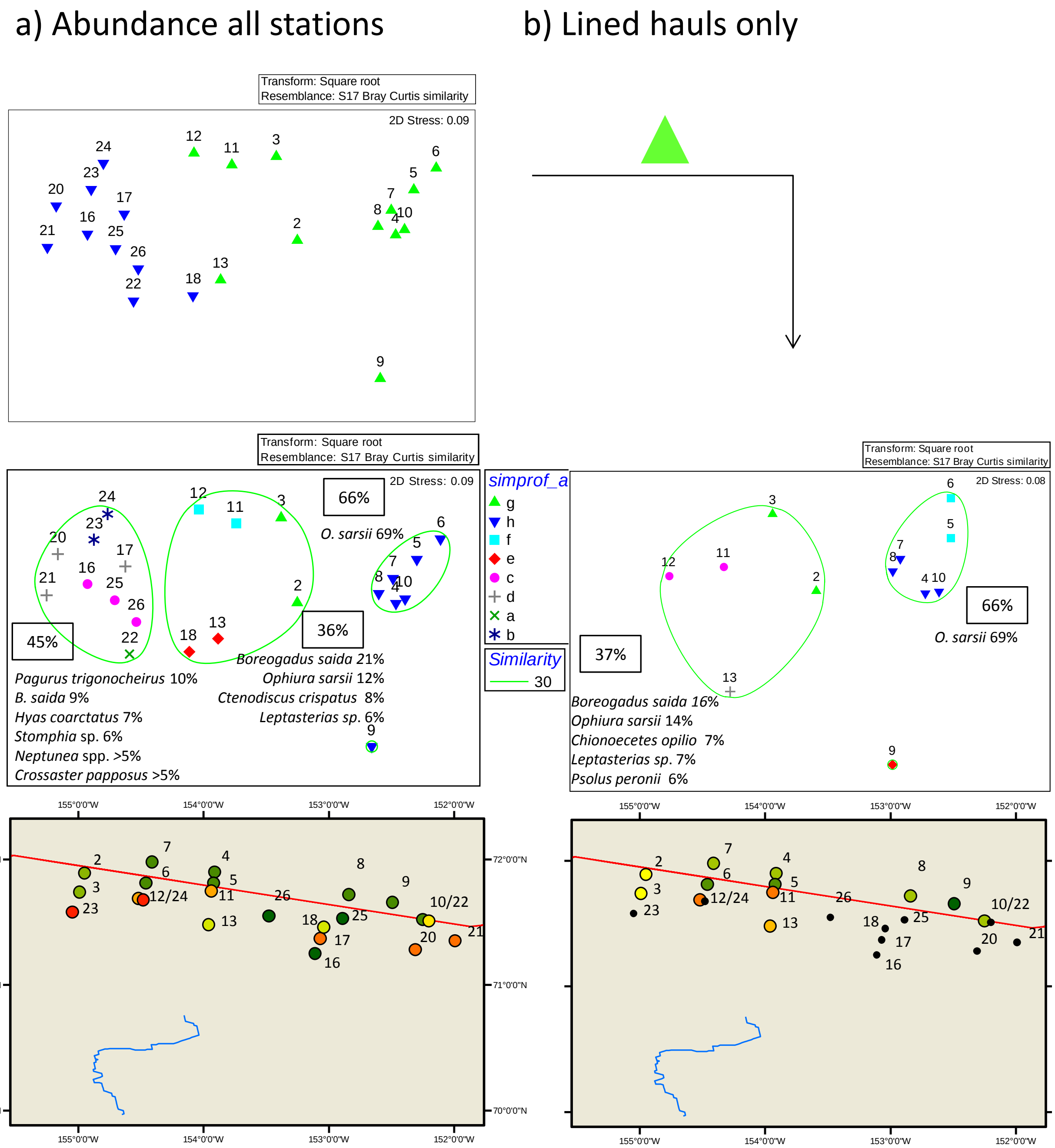


Figure 11. nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed abundance data of a) all stations (as in Figure 6b) and b) lined hauls only. Otherwise as in Figure 6. Same-colored stations on map show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by lined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

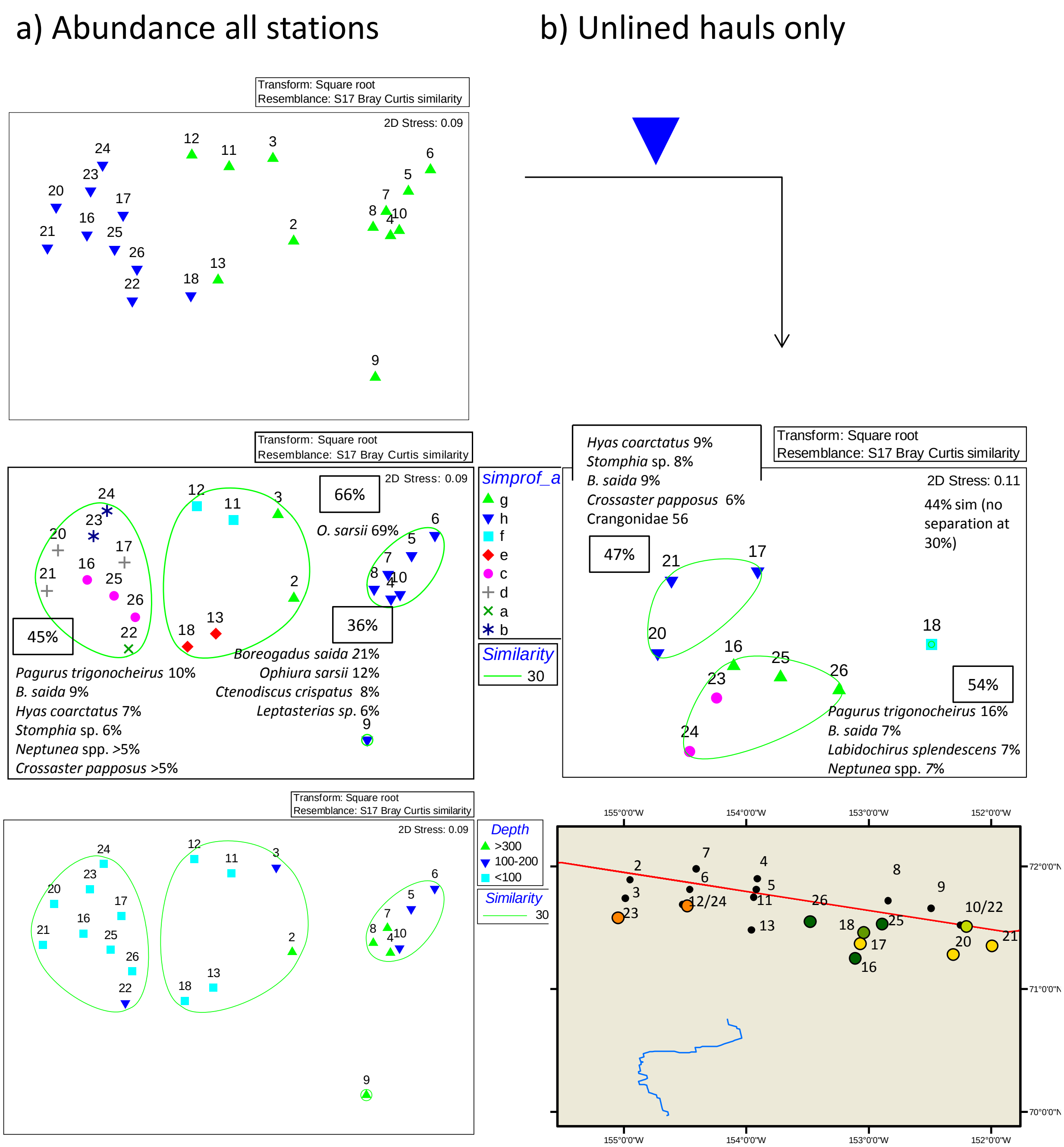
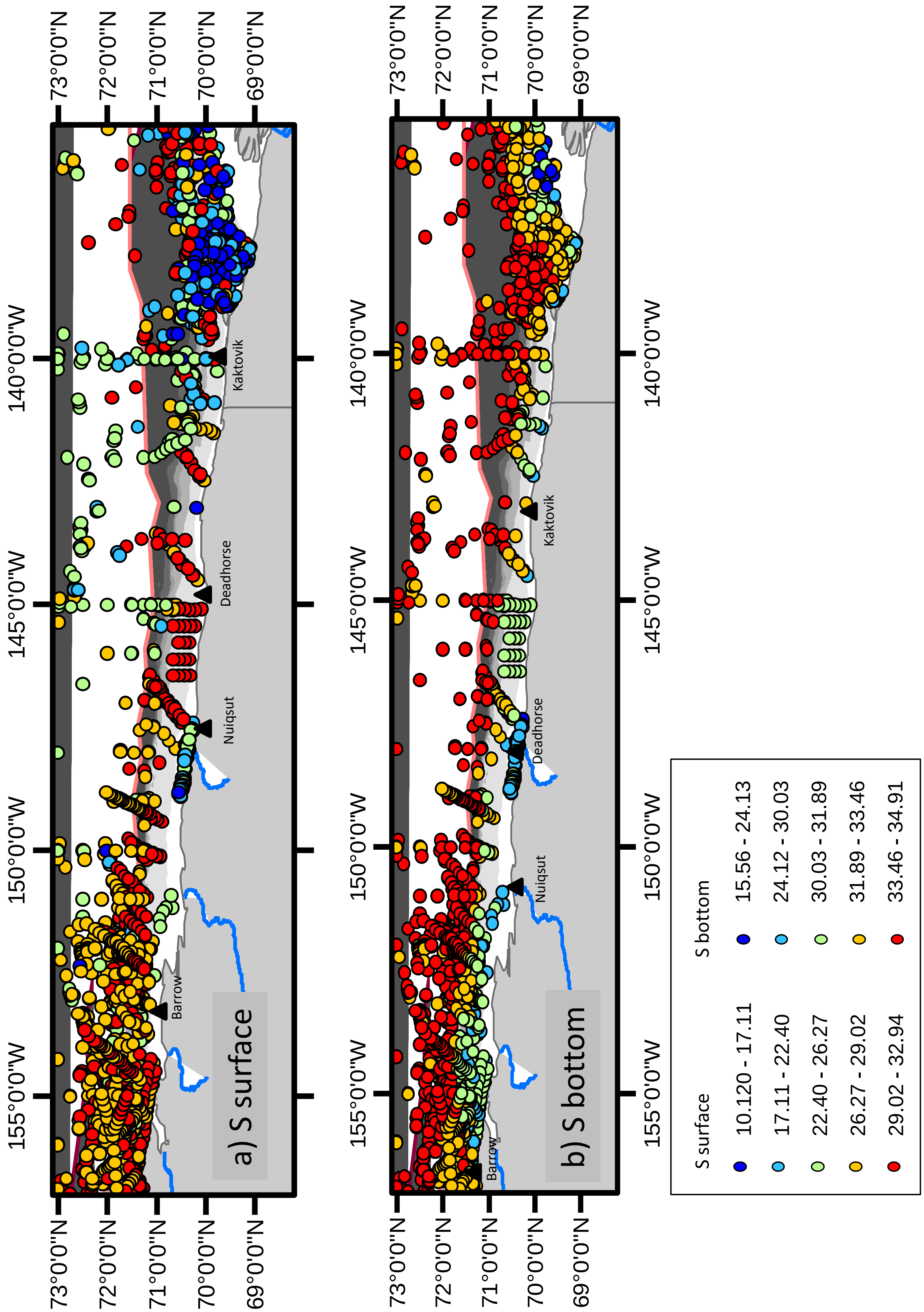


Figure 12. nMDS of BOEM 2008 epifauna and fishes combined based on square-root transformed biomass data of a) all stations (as in Figure 6b) and b) unlined hauls only. Otherwise as in Figure 6. Same-colored stations on map show spatial distribution of significant clusters from middle panels. Black dots show stations not sampled by unlined nets. Red line in inset map marks the average August sea ice extent from 1979-2000.

1.3.2 Environmental conditions relevant for epifaunal and demersal communities

The Beaufort Sea shelf was characterized by low and temporally variable salinities near the river outflows (Figure 13) that extended across the entire shelf and into the Canada Basin in the surface layers of the Mackenzie outflow (Figure 13a). Surface salinities on the mid and western shelf were higher than in the Canada Basin. Bottom salinities along the shelf break and in the basin were high, related to Atlantic-origin waters. Water temperatures were overall low (Figure 14), with warmest – but again seasonally variable - conditions near river outflows, and on the western Beaufort Shelf. A band of relatively warm water stretches along the basin perimeter at the depth of the Atlantic water (Figure 14b). Note that not all CTD casts in the basin were taken to full water depth. More detailed results from the BOEM 2008 and BOEM 2011 surveys can be found in the respective reports.

In the principal component analysis of 15 environmental variables (Figure 15, Table 2), hydrographic variables (bottom temperature (2011), bottom salinity and pH) loaded highest on PC1, sediment and food quality characteristics (% sand, $\delta^{13}C$ and C/N ratio) on PC2, and location (latitude, longitude) and bottom temperature (2008) on PC3. PC1 accounts for 43% of the variability in the data, PC2 for 17% and PC3 for 14%, i.e. 74% between them. The environmental variable combinations best matching the biological multi-variate similarity matrix based on the BEST-BIOENV analysis included (in variable rankings) water depth, bottom temperature and salinity, pH, latitude and bottom type (soft / hard) with a maximum correlation coefficient of 0.56.


a) S surface
b) S bottom
Barrow
Nuiqsut
Deadhorse
Kaktovik
73°0'0"N
72°0'0"N
71°0'0"N
70°0'0"N
69°0'0"N
155°0'0"W
150°0'0"W
145°0'0"W
140°0'0"W
S surface
10.120 - 17.11
17.11 - 22.40
22.40 - 26.27
26.27 - 29.02
29.02 - 32.94
S bottom
15.56 - 24.13
24.12 - 30.03
30.03 - 31.89
31.89 - 33.46
33.46 - 34.91

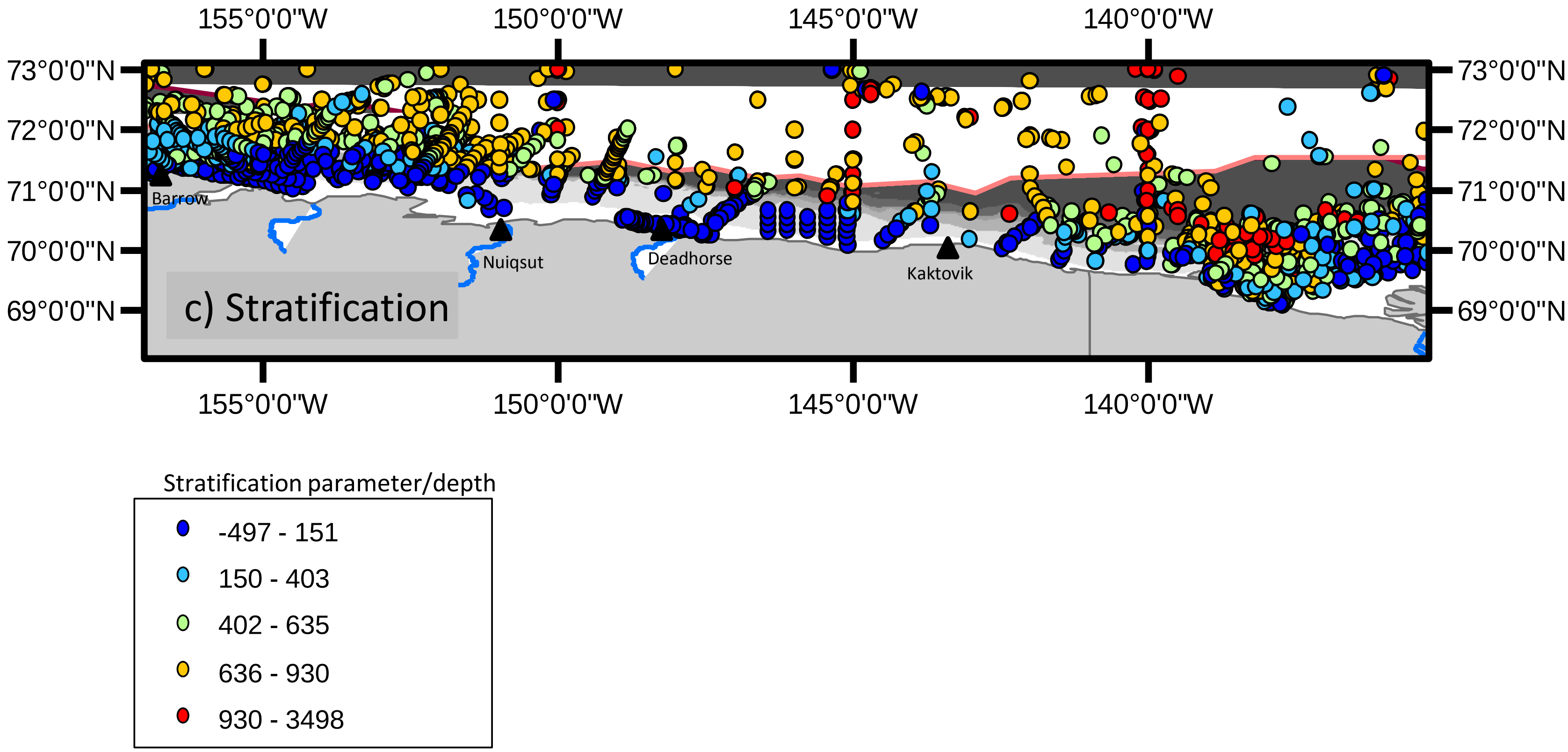


Figure 13c. Long-term average salinity conditions along the Beaufort Sea shelf and slope. a) Sea surface salinity, b) bottom salinity; c) Long-term average water column stratification strength (stratification parameter per Fiedler et al. 1998. Data compiled during PacMARS (ongoing NPRB grant, http://pacmars.cbl.umces.edu/) by S. Okkonen (UAF) from multiple sources. Note the influence of rivers nearshore. Note that some casts in the Canada Basin were only to 200 m. Pink line marks the average August sea ice extent from 1979-2000; red line marks the average September sea ice extent from 1979-2000.

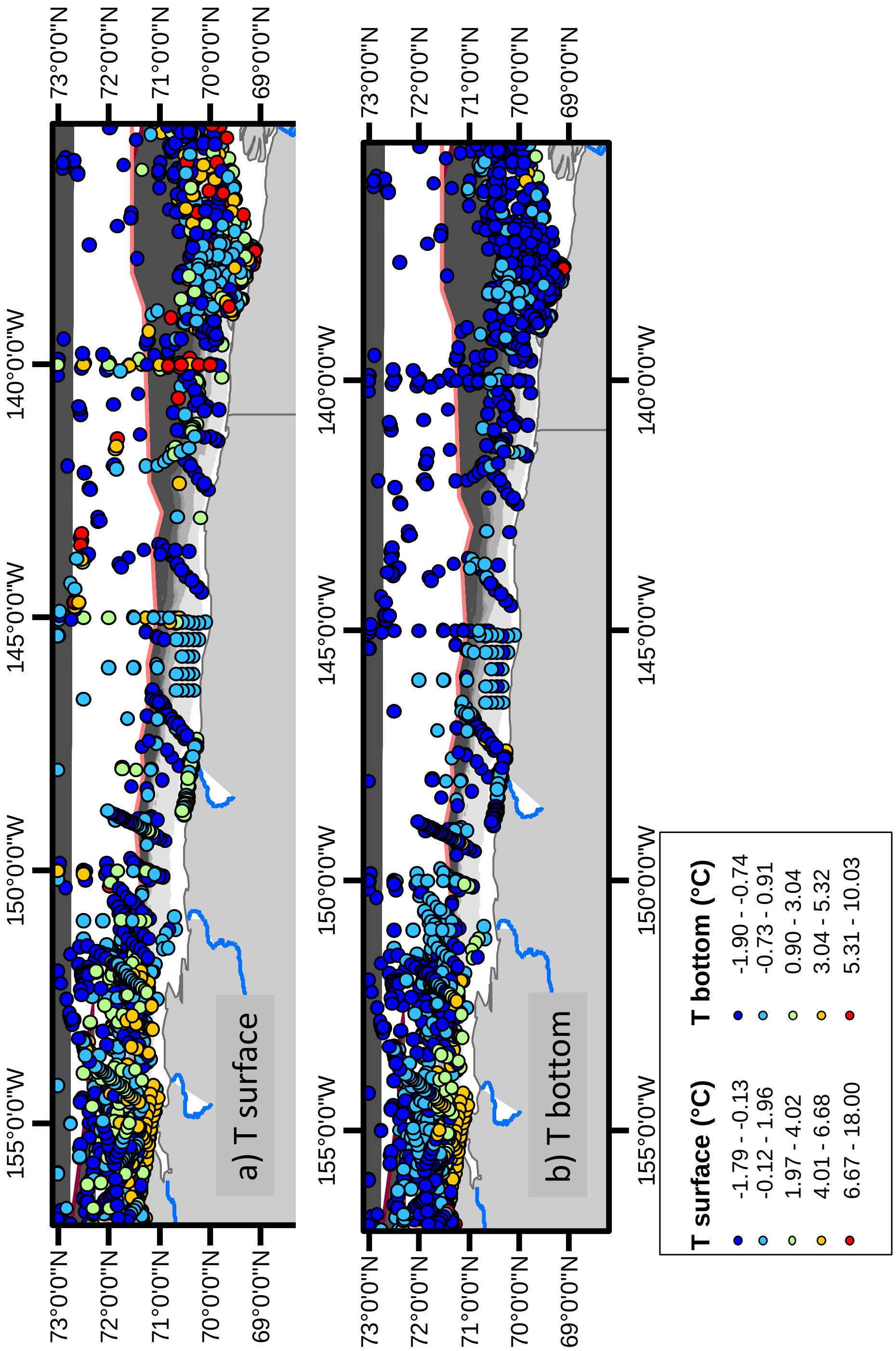


Figure 14. Long-term average water temperature conditions along the Beaufort Sea shelf and slope. a) Sea surface temperature and b) bottom temperature Data compiled during PacMARS (ongoing NPRB grant, http://pacmars.cbl.umces.edu/) by S. Okkonen (UAF) from multiple sources. Note the influence of rivers nearshore and of Pacific water inflow. Note that some casts in the Canada Basin were only to 200 m. Pink line marks the average August sea ice extent from 1979-2000; red line marks the average September sea ice extent from 1979-2000.

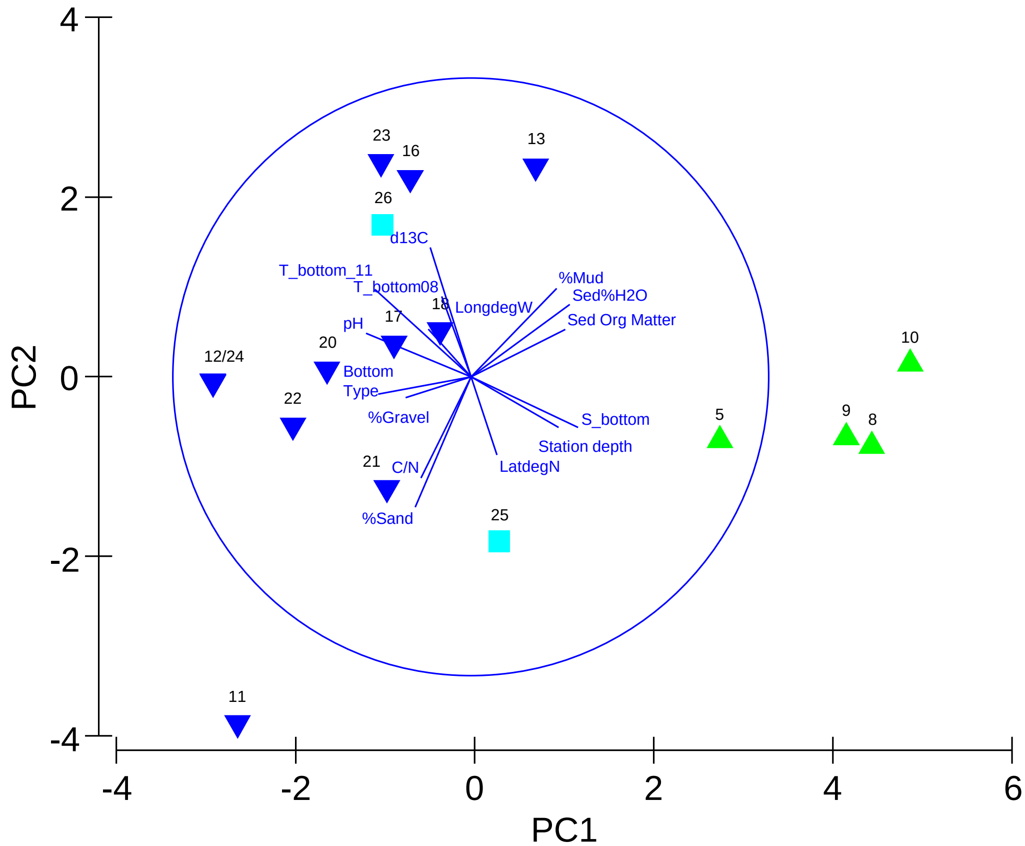


Figure 15. Environmental links between locations sampled during BOEM 2008 using 15 environmental variables in a principal component analysis (PCA). Station numbers are color coded based on station clusters from hierarchical clustering of square-root transformed species biomass data at 30% similarity level. See Table 2 for more PCA results.

2. Objective 2: Comparisons between 2008 unlined / lined hauls, and between 2008 / 2011

2.1 Introduction

Again, the net used for the 2008 survey was an 83-112 Eastern otter trawl, the standard net used by the Alaska Fisheries Science Center's RACE Division, except that a finer mesh liner (3.8 cm) was inserted into the body of the net. The lined nets lasted through trawl #13 when all lined nets had been destroyed. Unlined nets (8.9 cm mesh) had to be used subsequently for the remaining hauls, which hampers comparability between stations. Two station pairs (10/22 and 12/24) were sampled with both net types for comparison, one at 50 m and one at 175 m water depth. Stations sampled with lined nets were in 100 to 500 m water depth with three exceptions and were mostly trawled for 15 min. Stations sampled with unlined nets were in 41-83 m water depth with one exception and were mostly trawled for 5 min.

In 2011, BOEM funded the *Central Beaufort Sea Fish survey* (PI Norcross, University of Alaska Fairbanks) that sampled 79 locations between 145.09° and 155.25°W and 12 and 220 m water depth during 15 Aug - 4 Sept 2011 using a 3 m plumb-staff beam trawl with a 4 mm mesh in the cod end (Norcross et al. 2014). The 2011 survey was able to resample most (14 of 20) of the locations sampled in 2008, with the exception of the stations deeper than 200 m, because insufficient wire was available and the winch was not strong enough. Here, we made some additional comparisons between lined and unlined nets used in 2008 (also see section 1), and limited, mostly descriptive comparisons between 2008 otter trawl and 2011 beam trawl deployments.

2.2 Methods

Given the different mesh sizes used, the difference in water depths the two mesh sizes were primarily deployed in and the difference in trawl duration used for each mesh size, meaningful statistical comparisons are limited. Given those limitations, we instead explored what results the following approach yielded: Three lined net deployments (mesh size 3.8 cm) were conducted between 49-66 m. These three stations, therefore, fell in the same depth range as nine of the ten successful unlined (mesh size 8.9 cm in intermediate and cod end) trawl deployments (41-83 m). We compared those two stations groups by illustrating relative composition of the catch. Two station pairs were sampled with both the lined and the unlined net. A tabular presentation of the CPUEs at these station pairs was presented in Rand and Logerwell (2011). Further meaningful analysis was unwarranted given that only one shallow and one deep location each were sampled with both net types.

The second type of net comparison compared the 2008 net deployments of the NMFS 83-112 eastern bottom trawl with the 2011 3-m plumb-staff beam trawl hauls. We first matched up the 2008 and 2011 sampling locations based on latitude, longitude as well as water depths (Table 1). Depths differed some between the two cruises, especially at the slope stations where a short drift results in a large bottom depth change. Three deep stations sampled in 2008 were not fished in 2011, because the winch wire was not long enough. Before making any comparisons, we matched up the taxonomic names and taxonomic resolution of the fish from both cruises (see section 1). We refrained from statistical tests because of low sample sizes in the two 2008 net categories. The caveat for the interpretations of the results is that the data sets were collected three years apart.

2.3 Results

2.3.1 Unlined and lined 2008 deployments

Among lined net hauls, total haul biomass per station was higher at shelf break and slope stations (hauls 2-10) than at shallow shelf stations (hauls 11-13) (Figures 2a). The majority of stations sampled by both lined and unlined hauls were dominated by echinoderms by biomass (Figure 2b), and mostly by a single brittle star species, *Ophiura sarsii* (see section 1) Exceptions included hauls 2 (lined haul) and hauls 16-20 (unlined hauls). Arthropods and mollusks also contributed substantial biomass to most hauls. Ascideans were important at many shallow stations while cnidarian distribution was patchy across the entire area. Fish contributed less than 10% to most hauls by weight, with the exception of hauls 3, 6 and 18.

About 20 taxa occurred across all depths sampled, among those the three fish species *Boreogadus saida*, *Theragra chalcogramma* and *Hippoglossoides robustus* (Table 3).

Table 3. List of taxa found during the BOEM 2008 survey organized by three depth strata. Eurybathic species are listed first, followed by slope species, slope/shelf species and shelf-only species. Taxa identified to coarse taxonomic level and those only found at one station were excluded. Fish species are in bold print.

Taxon	Taxonomic group	> 300 m	100-200 m	40-80 m	Taxon	Taxonomic group	100-200 m	40-80 m
Benthoctopus sp.	Octopus	1	1	1	*Alcyonidium sp.*	Moss animal	1	1
Boreogadus saida	**Fish**	**1**	**1**	**1**	***Anisarchus medius***	Fish	**1**	**1**
Buccinum glaciale / angulosum	Snail	1	1	1	*Beringius sp.*	Snail	1	1
Buccinum scalariforme	Snail	1	1	1	*Bryozoa*	Moss animal	1	1
Chionoecetes opilio	Crab	1	1	1	*Hyas coarctatus*	Crab	1	1
Crossaster papposus	Sea star	1	1	1	*Labidochirus splendescens*	Hermit crab	1	1
Ctenodiscus crispatus	Sea star	1	1	1	***Lycodes polaris***	Fish	1	1
Eunoe sp.	Bristle worm	1	1	1	*Ophiopholis aculeata*	Brittle star	1	1
Gersemia sp.	Soft coral	1	1	1	*Pagurus trigonocheirus*	Hermit crab	1	1
Hippoglossoides robustus	**Fish**	**1**	**1**	**1**	*Plicifusus kroyeri*	Snail	1	1
Hydroidolina	Hydroid	1	1	1	*Psolus fabricii (peronii?)*	Sea cucumber	1	1
Leptasterias sp.	Sea star	1	1	1	*Pyrulofusus deformis*	Snail	1	1
Margarites spp.	Snail	1	1	1	*Amicula vestita*	Chiton		1
Naticidae	Snail	1	1	1	***Artediellus scaber***	Fish		1
Neptunea spp.	Snail	1	1	1	*Balanus sp.*	Barnacle		1
Ophiura sarsii	Brittle star	1	1	1	*Chelyosoma macleayanum*	Sea squirt		1
Pagurus rathbuni	Hermit crab	1	1	1	*Chlamys sp.*	Bivalve		1
Stomphia sp.	Sea anemone	1	1	1	***Eumicrotremus derjugini***	Fish		1
Strongylocentrotus sp.	Sea urchin	1	1	1	***Gymnocanthus tricuspis***	Fish		1
Theragra chalcogramma	**Fish**	**1**	**1**	**1**	*Halocynthia aurantium*	Sea squirt		1
Volutopsius and Habevolutopsius	Snail	1	1	1	*Henricia sp.*	Sea star		1
Pteraster sp.	Sea star	1		1	***Icelus spatula***	Fish		1
Boreotrophon clathratus	Snail	1	1		***Lumpenus fabricii***	Fish		1
Careproctus rastrinus	**Fish**	**1**	**1**		***Myoxocephalus verrucosus***	Fish		1
Hippolytidae	Shrimp	1	1		*Onchidiopsis sp. A*	Snail		1
Lycodes raridens	**Fish**	**1**	**1**		*Polymastiidae*	Sponge		1
Nemertea	Worm	1	1		*Solaster sp.*	Sea star		1
Musculus spp.	Bivalve	1	1		*Styela rustica*	Sea squirt		1
Pandalidae	Shrimp	1	1		***Triglops pingelii***	Fish		1
Tachyrhynchus sp.	Snail	1	1		*Urasterias lincki*	Sea star		1
Sipuncula	Worm	1	1		*Vulcanella*	Sponge		1
Clinopegma magna	Snail	1						
Liparis fabricii	**Fish**	**1**						
Lycodes rossi	**Fish**	**1**						
Reinhardtius hippoglossoides	**Fish**	**1**						
Trichotropis sp.	Snail	1						
Boltenia sp.	Sea squirt		1					
Bonelliopsis alaskana	Worm		1					
Cheilonereis cyclurus	Bristle worm		1					
Crinoidea	Feather star		1					
Gorgonocephalus spp.	Basket star		1					
Isopoda	Isopod		1					
Liparis gibbus	Fish		1					
Lycodes mucosus	Fish		1					
Ocnus sp.	Sea cucumber		1					
Pannychia moseleyi	Sea cucumber		1					
Polynoidae	Bristle worm		1					
Psolus phantapus	Sea cucumber		1					
Ulcina olrikii	Fish		1					

Of the other taxa that were found at more than one station, close to 30 were found exclusively deeper than 100 m including 8 fish species (several of the genera *Lycodes* and *Liparis*, *Careproctus rastrinus*, *Reinhardtius hippoglossoides* and *Ulcina olrikii*). Close to 20 species occurred exclusively shallower than 100 m including 7 fish species (mostly Cottidae). About a dozen taxa were found only between 40-200 m.

More taxa were collected at the combined shallow stations in lined net hauls (hauls 11-13) than in unlined net hauls (hauls 16-26 except 22) (Table 4, 5). This is not surprising given that the number of specimens collected was much higher in lined net hauls due to the smaller mesh and longer trawl durations at stations 11-13 (Table 1). The total number of fish species in the 40-80 m stratum was 27. The shallow lined net hauls caught 13 fish species that were not caught with the unlined net hauls. At shallow sites, only 4 fish species were caught in the unlined net hauls that were not found in the lined net hauls. The contrast between the net types was stronger when comparing the haul pair 12/24 (Table 5). At the shelf break stations pair 10/22, differences in the number of taxa caught were not as strong despite a drastic difference in individuals caught in each of the two hauls of different mesh size.

Table 4. Comparison of number of taxa present in different depth strata of the OE2008 cruise using all available hauls in each stratum. # of Stn – number of stations in stratum. >1 st – more than one station.

Stratum	Net	# of Stn	Taxa present	Taxa present at >1 st
>300 m	lined	5	58	45
>100-200 m	4 lined, 1 unlined	5	91	62
>100 m	9 lined, 1 unlined	10	99	72
40-80 m (random 5 st)	1 lined, 4 lined	5	73	44
40-80 m	3 lined, 9 unlined	12	110	62

Table 5. Comparison of taxon richness in the lined and unlined nets at comparable depths and/ or locations during the OE08 cruise.

Stations	Haul duration	Depth stratum	Net type	Individuals caught	Number of taxa	Fish species unique in comparison
11, 12, 13	15 min	40-80 m	lined	99558	93	13 (of 24)
16-26 (except 22)	5 min	40-80 m	unlined	20945	85	4 (of 16)
12	15 min	47 m	lined	21203	60	15 (of 19)
24	5 min	46 m	unlined	1297	32	0 (of 4)
10	15 min	172 m	lined	1777258	54	5 (of 8)
22	5 min	175 m	unlined	2198	49	2 (of 5)

2.3.2 83-112 trawls (2008) and plumb-staff beam trawls (2011)

A total of 51 fish taxa and 273 invertebrate taxa were identified at both cruises combined, of those 200 taxa were identified to species level including 40 fish species (electronic appendix 1). The BOEM 2011 data available for this report had *Lycodes* spp. and *Liparis* spp. combined to the genus level, so for the following comparisons, species of those genera were treated at that level also for the BOEM 2008 cruise. The following other taxa pairs were merged into one data row: *Ulcina olrikii* (2008) and *Aspidophoroides olrikii* (2011), *Icelus spatula* and *Icelus* spp., *Myoxocephalus verrucosus* (2008) and *M. scorpius* (2011), *Careproctus rastrinus* (2008) and *Careproctus* spp. (2011), *Gymnelus viridis* (2008) and *Gymnelus* spp. (2011). Different numbers of fish species/taxa were caught with the 83-112 and the plumb-staff beam trawl (PSBT) at the (almost) same locations (Figure 16). At slope stations, the 83-112 (lined) caught on average more species (mean 6.5± SD 1.2 per station) than the PSBT (4.5±1.0). This difference is not surprising given that the trawl duration was mostly 15 min with the lined 83-112 and only 2 min (on average) with the PSBT (Figure 11). Also, several of the slope stations were deeper in 2008 than in 2011 (although geographically close by) which added some taxa. At the shallow stations, in contrast, the 83-112 (unlined) caught on average less species (4.5±2.9) than the PSBT (10.6±3.1). Again, this disparity is not surprising given that trawl duration of the unlined 83-112 on the shelf was only 5 min and the large mesh size missed many of the smaller fishes. Species caught in 2011 but not in 2008 included *Ammodytes hexapterus, Podothecus veternus, Stichaeus punctatus*, and *Trichocottus brashnikovi*. Conversely, species caught in 2008 and not in 2011 included *Enophrys diceraus, Eumesogrammus praecisus, Gadus macrocephalus, Reinhardtius hippoglossoides, Sarritor frenatus, Theragra chalcogramma* and *Triglops pingelii*.

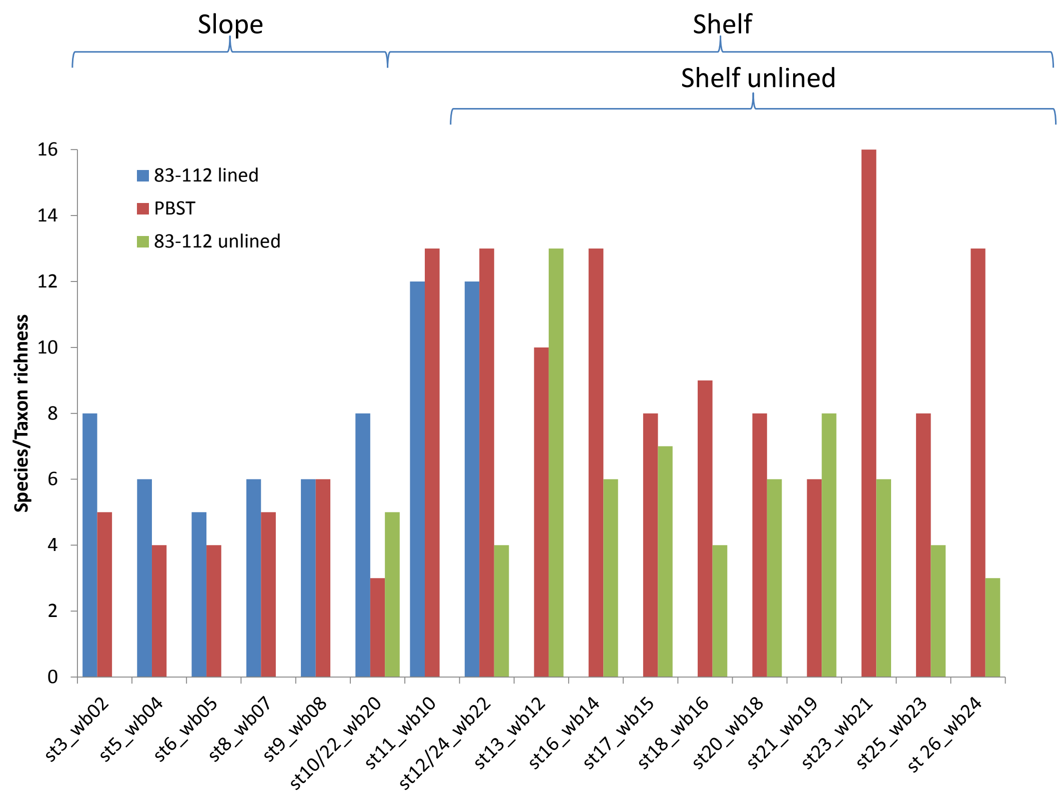
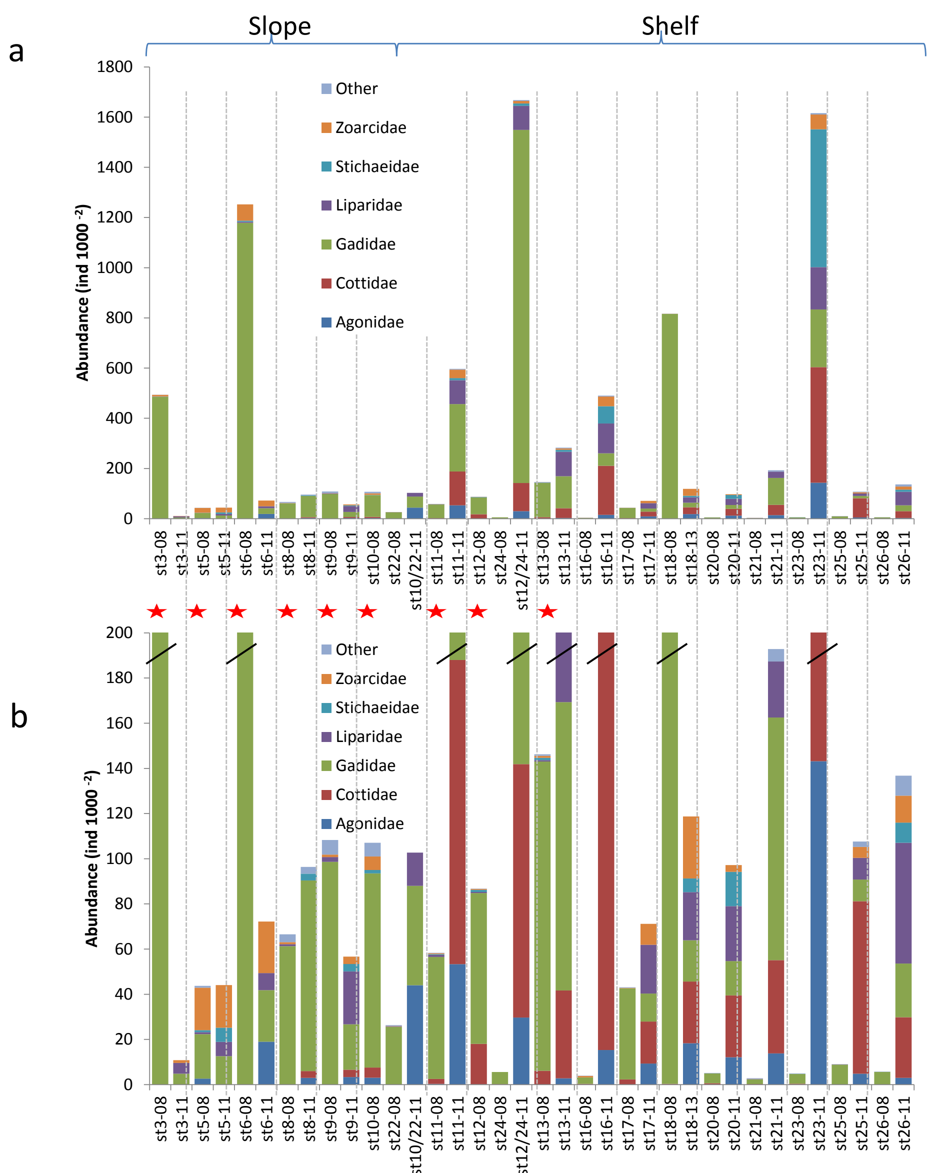


Figure 16. Comparison of fish taxon richness per station, mostly at the species level, between BOEM 2011 and BOEM 2008 at (almost) identical stations. The station number is the haul number as used in the 2008 reports, followed by the BOEM 2011 station number. Slope stations were 143-318 m in depth, shelf stations were 38-86 m in depth.

Average fish abundances showed a similar pattern as described for species richness, although abundances were very variable between stations with both gear types (Figure 17). The lined 83-112 hauls (deployed at deep stations) had, on average, higher abundances (345±475 ind 1000 m^{-2}) than the PSBT (140±34 ind 1000 m^{-2}). As with species richness, this difference is likely related to the longer trawl duration of the 83-112 versus the PSBT (Table 5). The unlined 83-112 hauls (deployed at shallow stations) in contrast resulted in lower abundance estimates (100±269 ind m^{-2}) than those from the PSBT at the same set of stations (489±595 ind m^{-2}). This difference is again likely explained by the difference in mesh size rather than the time fished, because the shelf stations were trawled with the unlined 83-112 that does not retain very small fishes. The three shallow stations fished with the lined 83-112 were not included in the above comparisons.



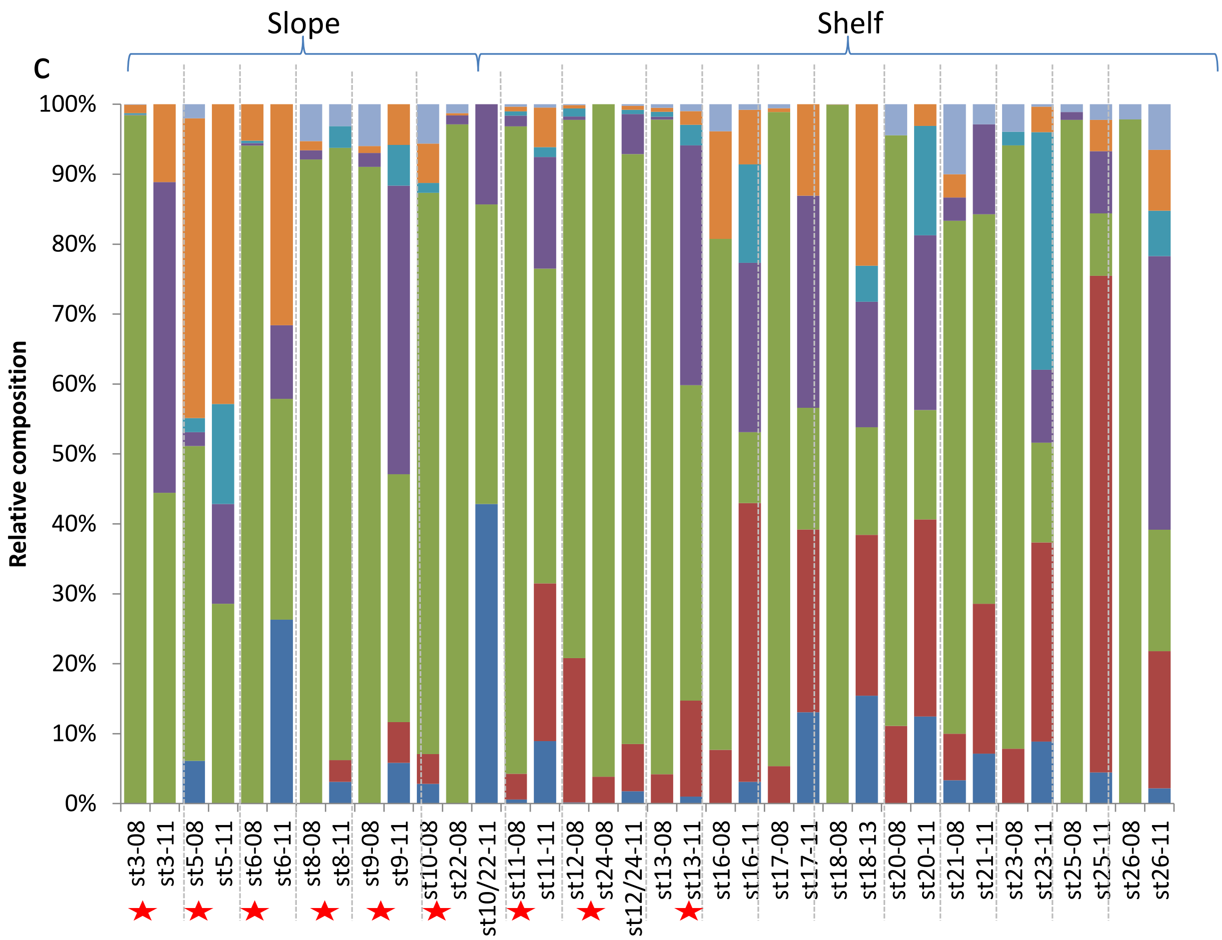


Figure 17. Fish abundance by station and split into families from BOEM 2011 and BOEM 2008 at (almost) identical stations. a) Absolute densities, b) absolute densities, scale adjusted to more clearly show the data at stations with low densities, c) relative composition by families. The station number is the haul number as used in the 2008 reports, followed by the year. Slope stations were 143-318 m in depth, shelf stations were 38-86 m in depth. 'Other' includes Ammodytidae, Cyclopteridae, Hemitripteridae, Osmeridae and Pleuronectidae. Stars mark stations fished with lined 83-112 nets.

At shallow stations the PSBT caught, on average, substantially higher percentages (i.e. >5% difference between nets) of Agonidae, Liparidae and Zoarcidae than the 83-112 (Figure 18). At deep locations, the PSBT caught substantially higher proportions of Agonidae, Cottidae, Liparidae and Stichaeidae. At both deep and shallow stations, the 83-112 caught a much higher fraction of Gadidae than the PSBT. These differences are in part related to different mesh sizes, because many of the snail fish and sculpins caught, for example, were very small and were obviously not retained in the 83-112. The nMDS plot of the combined 2008 and 2011 data sets and ANOSIM tests demonstrated that both net type (Global R=0.57, p<0.001) and depth (Global R=0.42, p<0.001) contribute strongly to the similarity patterns (Figure 19).

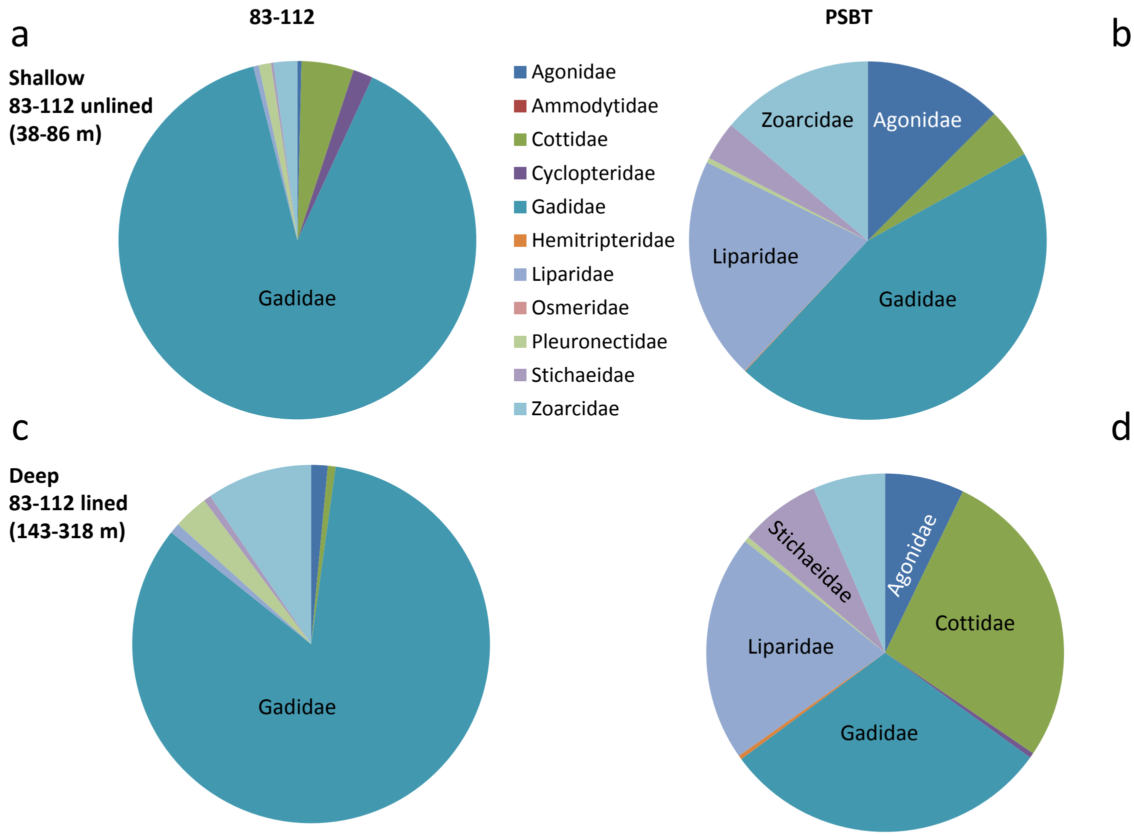
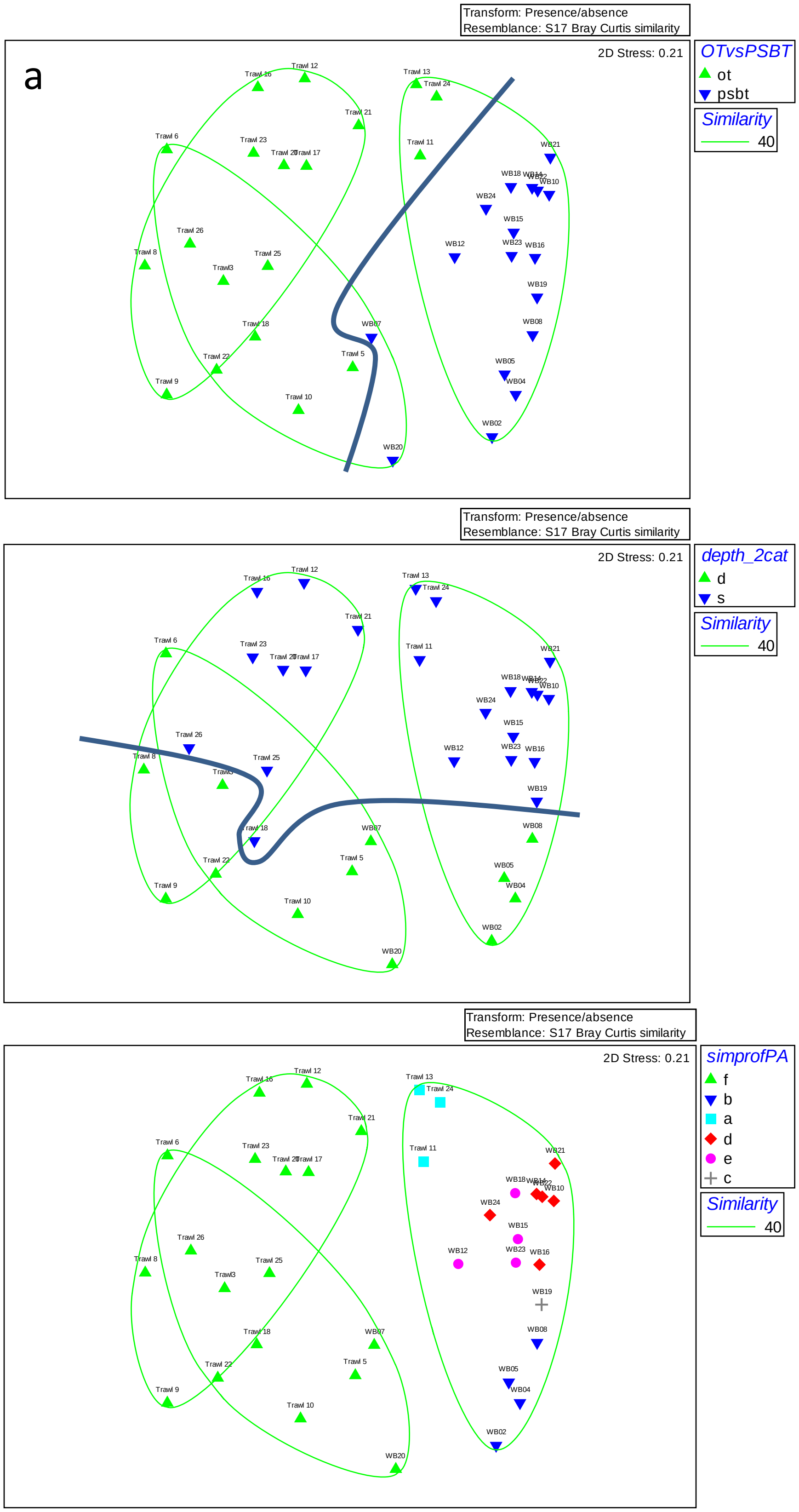


Figure 18. Mean relative composition of fish families from across all shallow (a, b) and deep (c, d) hauls for the 83-112 used in the BOEM 2008 survey (a, c) and the PSBT used in the BOEM 2011 survey (b, d), based on abundance. Families for which the relative abundance differed by >5% between nets are labeled on the pie charts.

Next page: Figure 19. nMDS of fishes (without epifauna) from the BOEM 2008 and BOEM 2011 surveys combined (at comparative stations) based on presence/absence data of all stations. Stations are color-coded by a) net type, b) depth category (deep is >100 m), c) significant cluster membership. Green circles indicate 40% similarity. Blue lines indicate stations separation of lined and unlined hauls. Otherwise as in Figure 6.



Transform: Presence/absence
Resemblance: S17 Bray Curtis similarity
a
2D Stress: 0.21
OTvsPSBT
ot
psbt
Similarity
40
Transform: Presence/absence
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.21
depth_2cat
d
s
Similarity
40
Transform: Presence/absence
Resemblance: S17 Bray Curtis similarity
2D Stress: 0.21
simprofPA
f
b
a
d
e
c
Similarity
40

3. Objective 3: Historic fish data from the Beaufort Sea

3.1 Introduction

Historic information about the Beaufort Sea shelf fish and invertebrate fauna was primarily collected during the 1970s. Bottom trawl surveys conducted in 1976/1977 provided inventories and CPUE data for demersal fishes and epibenthic invertebrates (Frost and Lowry 1983). The fish data and part of the invertebrate data from the survey were already entered into the historical Beaufort Sea data base as part of the original 2008 study (Logerwell and Rand 2010). However, the data of only the most abundant 40 (of 238) epifaunal invertebrate taxa were entered as those were individually listed in the electronic report appendix that contains copies of the original data sheets. Nearshore, epibenthic fish surveys took place between the Colville River mouth and Barter Island out 30 km offshore between 1988 and 1991 (Jarvela and Thorsteinson 1999) and these data sets have previously been digitized. Benthic macrofauna surveys were conducted in the 1970s as part of the WEBSEC and OCS efforts (e.g. Carey 1977). During a sub-set of those cruises, unfunded opportunistically collected benthic trawls were also taken by A. Carey and collaborators (Oregon State University at the time), but were neither completely processed nor published other than as fragmentary information in reports (Carey 1977). In a small data rescue project funded by the Oil Spill Recovery Institute Bluhm rescued relative composition data of over 100 invertebrate and fish taxa from 22 trawls. Extensive benthic macrofauna data from OCSEAP cruises were in part digitized by Dr. Ken Dunton and Mrs. S. Schonberg as part of the NSF-funded Shelf-Basin-Interactions project (Dunton et al. 2005), but the species-level raw data still await digitization which we highly recommend. In this contract, we digitized the geo-referenced invertebrate species records from the Frost and Lowry (1983) report that were still missing in the database. We also extracted fish distribution records, albeit non-georeferenced, of two fish species check lists.

3.2 Methods

We extracted relevant fish records from **Walters V (1955) Fishes of Western Arctic America and Eastern Arctic Siberia.** Bulletin of the American Museum of Natural History 106: 255-368. The format is an excel spread sheet where the fish are listed under column headers that contain the taxonomic hierarchy (family, genus, species, authority), both in the original nomenclature and as currently accepted by the World Register of Marine Species (WoRMS, http://www.marinespecies.org/). These columns are followed by regional column headers where the entry '1' means presence in that region. Since this work is focused on the Beaufort Sea, we extracted notes on the presence of a given species in the Beaufort Sea as well as adjacent areas (Chukchi Sea, Arctic Ocean, Wrangell Island where specifically mentioned). The subsequent 'notes' column details relevant comments on the distribution. No latitudes or longitudes were given in the source. Mecklenburg has several entries in her Western Arctic Fishes data base that refer to Walters as the identifier, and those are geo-referenced, presumably from museum voucher labels. We confirmed that those records are already in BOEM's historical Beaufort Sea fish data base.

The second reference we examined for relevant fish records was **Wilimovsky NJ (1954) List of the Fishes of Alaska.** Stanford Ichthyological Bulletin 4:279-294. This source is literally a list of species recorded for Alaskan waters at that time, categorized for marine species by the regions Gulf of Alaska, Bering Sea and Arctic Alaska. We extracted the species listed for Arctic Alaska and listed them in an excel spread sheet under column headers family, genus, species, authority. Again, names were checked against WoRMS and a column with WoRMS-accepted names was added.

The third reference examined was **Frost KJ, Llowry LF, Burns JJ (1978) Offshore demersal fishes and epibenthic invertebrates of the northeastern Chukchi and Western Beaufort Seas**. In: Environmental assessment of the Alaskan continental shelf, Annual Reports of Principal Investigators for the year ending March 1978. Vol I. Receptors – Mammals – Birds. US Dept. Commerce / US Dept. Interior / NOAA, Boulder, Colorado. Pp 231-353. While abundance and biomass of the fish and 40 dominant invertebrate species were already in the BOEM Beaufort Sea data base, we entered the presence of all additional invertebrate species into an excel spread sheet. No counts or weights were recorded for those species. The first few columns again contain the taxonomic information, followed by columns each representing one trawl haul at one location. Entries '1' indicate presence of a given species at a given station. The taxon list was again checked against WoRMS and a column of WoRMS-accepted names were added to the originally used names. We also digitized the station table that contains the station ID, date, latitude and longitude, water depth and trawling time at the bottom as well as Table 6 in the reference that contains total weights per phylum or class at each location.

3.3 Results

Walters (1955) (electronic Appendix 2) listed 39 species for the Beaufort Sea, 45 for the Chukchi Sea, 17 for the Arctic Ocean and nine where Wrangell Island was specifically mentioned. In several cases, wording was unclear in terms of distribution in those areas. In total, the reference contained 49 fish species in the combined areas of the Beaufort and Chukchi seas, the Arctic Ocean and Wrangell. In 14 cases, the WoRMS-accepted species names differed from the species name used by Walters.

Wilimovsky (1954) (electronic Appendix 2) listed 46 fish species for the Arctic Alaska region of which 15 had names that were different in WoRMS reflecting changes in taxonomic classification over time. Combined, the two data sources listed 69 unique species which means they interestingly only overlapped by about 25 species.

Frost et al. (1978) (electronic Appendix 2) found over 150 species of invertebrates during their 1977 survey. Names or spelling of 42 taxa differed between the source reference and WoRMS. Although abundance and biomass were not recorded for most invertebrate species, presence / absence still provides valuable information on taxon distribution ranges and local species richness in the Alaskan Beaufort Sea. The fish-related data was already included in the historic Beaufort Sea data base.

4. Objective 4: Taxonomic inventory of demersal fish and benthic invertebrates

4.1 Introduction

Over 1000 benthic invertebrate species – most of those in the macrofaunal range (i.e. not caught by trawl nets) - have been known from the Alaskan Beaufort Sea and slope since the 1970s (Carey 1977). This compares to at least ~3000 macro- and megabenthic invertebrate species on all Arctic shelves (Piepenburg et al. 2011) and slightly over 1000 benthic invertebrate taxa in the Arctic basin deeper than 500 m (Bluhm et al. 2011). The proportion of Pacific-boreal species on the Beaufort Sea shelf is lower than in the adjacent Chukchi Sea (Dunton 1992). This inventory is dominated by soft-bottom taxa such as polychaete worms, bivalves and amphipod crustaceans (Feder and Schamel 1976, Carey and Ruff 1977). Epifaunal communities, i.e. larger invertebrate and demersal fish fauna visible on photographs and collected in trawls, add a variety of gastropod and crustacean species as well as echinoderms and hard-bottom taxa such as bryozoans and sponges plus smaller phyla (Dunton et al. 1982, Konar and Ravelo 2013). These epifaunal taxa from the Beaufort Sea have not previously been compiled in an inventory from historic and modern studies to our knowledge, and a first such compilation was our fourth objective.

In a time of climate change, shifts in distribution ranges, diversity and community composition of benthic species can be expected and some are already documented in the southern areas of the Arctic, and it is, therefore, useful to have an inventory of the past and of the *status quo* for comparison. Changes already documented across the Arctic include switches from long-lived slow-growing Arctic to faster-growing temperate species. In the Pacific Arctic, first northern range extensions, probably due to climate change, have recently been documented in the Chukchi Sea for some epifaunal megafauna species and demersal fishes (Mecklenburg et al. 2007, Sirenko and Gagaev 2007, Mueter and Litzow 2008). Future or ongoing changes related to increased freshwater discharge, increased turbidity and sedimentation and increased influx of low salinity waters are conceivable (Bluhm and Gradinger 2008). Changes in Arctic benthic fauna can cause species richness to go up or down, and the final equilibrium state is impossible to predict at this time (Weslawski et al. 2011). A future project could integrate our inventory with macrofaunal distribution records from the 1970s and with macro- and epifaunal records from the Transboundary study to detect potential distribution changes.

4.2 Methods

The taxonomic inventory is based on the following cruises: BOEM 2008, BOEM 2011, WEBSEC 1972 and OCSEAP 1977. The Ocean Explorer field identifications were done by technician Heloise Chenelot (UAF / SFOS at the time) and the fish team onboard (AFSC). Subsequently identifications were later confirmed or corrected by studying voucher material by AFSC staff for fishes and by PI Bluhm and the experts listed in section 1.2 for invertebrates. Fish vouchers are archived at the AFSC, invertebrate vouchers are in Bluhm's lab at this time with the plan to transfer them to the University of Alaska Museum of the North. Field identifications for BOEM 2011 were done by Brenda Holladay and Lorena Edenfieldt and later confirmed or corrected by Kitty Mecklenburg (Norcross et al. 2014). Invertebrates from BOEM 2011 were identified in the field by Alexandra Ravelo, Martin Schuster, Katrin Iken and PI Bodil Bluhm and later verified and expanded by Ravelo, Bluhm and the above listed experts (Konar and Ravelo 2013). WEBSEC 1972 samples were field-identified by Andrew Carey and his onboard team (Carey et al. 1974) and later in part verified by various experts in particular at the Natural History Museum of Los Angeles County, where vouchers were archived. The OCSEAP 1977 collections were field-identified by Kathy Frost, Lloyd Lowry and their onboard team. Their report provides no details on who later verified the field identifications based on voucher identifications, but it does mention that fishes that were range extensions at the time were archived at the National Museums of Canada in Ottawa.

Separate and integrated lists of the above listed surveys were standardized to the World Register of Marine Species (WoRMS, www.marinespecies.org) using the match function to avoid duplication due to misspellings, synonymies or differences in taxonomic classifications. Taxon names not recognized by WoRMS were checked for spelling and other inconsistencies and corrected, and the list was rerun several times. Taxon names that could not ultimately be reconciled to WoRMS were kept in the data set if they were found in other recognized species lists such as the Integrated Taxonomic Information System (www.ITIS.gov) or in recent publications. The few remaining taxa (<1%) were deleted.

4.3 Results

A total of 543 invertebrate and fish taxa collected in trawls were found in the combined 1970s and 2000+ cruises that we included in the inventory (WEBSEC, OCSEAP, and BOEM 2008 and 2011 surveys) (electronic Appendix 3). Of those, 359 taxa were identified to species level, while all others reflect coarser identification. Several dozen of those species were infaunal that were collected embedded in sediment when the trawl dug into the seafloor. Of the 359 species, 71 were chordates of which 45 were fish species (Figure 20). Molluscs, arthropods (mostly crustaceans), chordates and echinoderms contributed most of the known species (Figure 20). Several groups are clearly underrepresented in the inventory, because their identification is not trivial, for example cnidarians (sea anemones), poriferans (sponges) and bryozoans (moss animals).

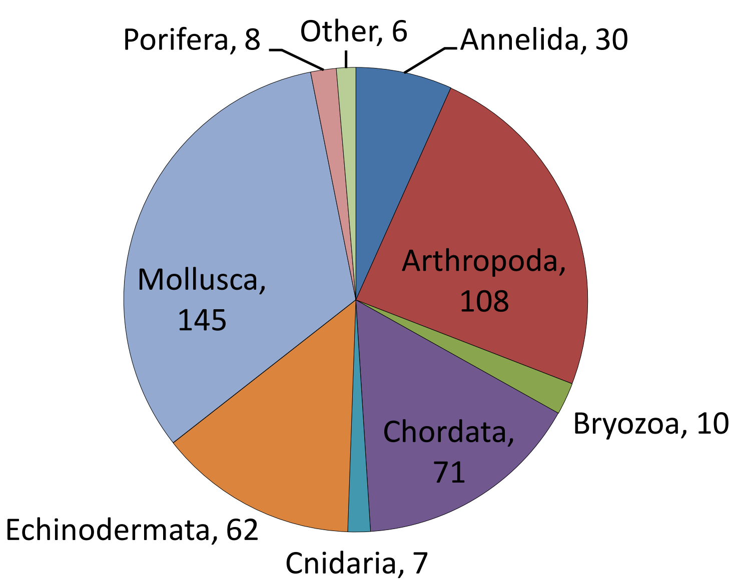


Figure 20. Taxonomic composition by phylum of trawl-caught species collected in the US Beaufort Sea in the combined WEBSEC 1972, OCSEAP 1976, BOEM 2008 and BOEM 2011 surveys. Taxa identified to coarser level than species were excluded.

Over 80 taxa at the species level were recorded from the 2000s and not from the 1970s. Over 100 species were recorded from the 1970s but not the 2000s, but the majority of those were either infaunal taxa which we excluded in the 2000s list, or species later found in the Transboundary study which is not yet included in the inventory.

V. Brief conclusions

- *Higher biomass was recorded at the slope than at the shelf* in the BOEM 2008 survey. This finding is biased by gear differences, but is consistent with the invertebrate results from the BOEM 2011 survey (Konar and Ravelo 2013) where epifauna biomass was also highest at slope stations in the western Beaufort Sea compared to the shelf. This pattern is thought to be related to the outflow of nutrient rich water from the Chukchi Sea through Barrow Canyon and along the upper Beaufort Sea slope (e.g., Weingartner et al. 2013, Pickart et al. in prep as part of BOEM-funded SOAR). Our and the BOEM 2011 biomass distribution are untypical for the average global ocean conditions where biomass tends to decline with increasing water depth rather than peak at the upper slope (Wei et al. 2010).

- Although the gear bias affects community patterns in various ways, we are confident that a *high species and community turnover with water depth* is a true feature of the Western Beaufort Sea slope, i.e. communities are more similar within certain depth strata than between depth strata. This pattern was confirmed during the Transboundary study that extended down to 1000 m in 2012 and 2013, and it was also recorded in the 1970s (Carey et al. 1977). In addition, a *west-east gradient* in community structure is suggested, but became more obvious during the BOEM 2011 survey where a much larger region was covered (Konar and Ravelo 2013).

- *Water depth, bottom temperature and salinity, pH, and the availability of hard substrate* larger than gravel were identified as relevant environmental variables matching – and presumably driving - the trawl-faunal community patterns. All variables but pH are known important structuring factors for epifaunal and fish assemblages. pH is not often included in such analyses, and we are therefore not sure if it is typically relevant or a factor specifically important to the study region. Recent work has, however, demonstrated gradients in aragonite saturation with slope and deeper waters of the Canada Basin aragonite-undersaturated in the last decade (Yamamoto-Kawai et al. 2009).

- Net comparisons showed, not surprisingly, that at comparable sites lined net hauls - which coincided with longer hauls - caught more fish by count and weight than shorter hauls with unlined nets. Biodiversity metrics for lined hauls (i.e. mostly deep sites), however, were lower compared to unlined (i.e. sshelf sites). In the comparison between 2008 and 2011, *longer tows coinciding with lined otter trawl nets caught more fish than PBST hauls, while PSBT hauls caught more compared to unlined otter trawl net hauls*. At least abundance and biomass patterns are, therefore, at the minimum obscured by gear differences. We point to the more extensive gear comparison done during the Arctic Eis 2012 field season that is based on a larger sample size and more systematic sampling strategy (Britt et al. 2013).

- *Over 350 species* are known from trawls collected in the Beaufort Sea shelf and upper slope in the 1970s, 2008 and 2011. By number of species, the inventory is dominated by *molluscs, crustaceans, echinoderms and chordates, including 45 fish species*. Over 100 taxa were recorded at a coarser taxonomic level and in part contribute additional species.

- *More epifaunal species were unique to the 2000+ era than to the 1970s trawling efforts* on the Beaufort Sea shelf and slope when removing infaunal taxa from the 1970s epifaunal taxon inventory and given the recent (not yet included) Transboundary study findings (2012, 2013). This finding is likely due to a combination of increased sampling effort since the 2000s and perhaps in some cases real species distribution changes. A more detailed comparison is warranted to distinguish between climate change effects that may have already taken place and potential future changes related to increased human activities.

VI. References

Barnes PW, Reimnitz E (1974) Sedimentary processes on Arctic shelves off the northern coast of Alaska. In: Reed JC, Sater JE (eds) The coast and shelf of the Beaufort Sea. Arctic Institute of North America, Arlington, VA, pp 439-476

Bluhm BA, Gradinger R (2008) Regional variability in food availability for Arctic marine mammals. Ecol Appl 18(Suppl. 2):77–96

Bluhm BA, Ambrose Jr WG, Bergmann M, Clough LM, Gebruk AV, Hasemann C, Iken K, Klages M, MacDonald IR, Renaud PE, Schewe I, Soltwedel T, Wlodarska-Kowalczuk M (2011) Diversity of the Arctic deep-sea benthos. Mar Biodiv 41:87-107

Bray JR, Curtis JT (1975) An ordination of the upland forest communities of Southern Wisconsin. Ecol Monogr 27:325-349

Britt LL, Lauth RR, Norcross BL (2013) Paired catch comparison from two standard bottom trawls used in Arctic surveys. Distribution of fish, crab and lower trophic communities in the Chukchi Sea AK-11-08, M12PG00018. Draft Report to BOEM

Carey AG Jr, Ruff RE, Castillo JG, Dickinson JJ (1974) Benthic ecology of the western Beaufort Sea continental margin: preliminary results. In: Reed JC, Sater JE (eds) The coast and shelf of the Beaufort Sea. The Arctic Institute of North America, Arlington, pp 665-680

Carey AG (1977) Summarization of existing literature and unpublished data on the distribution, abundance, and life histories of benthic organisms (Beaufort Sea). Outer Continental Shelf Energy Program, NOAA/BLM. Final Report Contract No 03-5-022-68, Volume I

Carey AG Jr, Ruff RE (1977) Ecological studies of the benthos in the western Beaufort Sea with special reference to bivalve molluscs. In: Dunbar MJ (ed) Polar Oceans. Arctic Institute of North America, Calgary, pp 505-530

Clarke KR, Warwick RM (2001) A further biodiversity index applicable to species lists: variation in taxonomic distinctness. Mar Ecol Prog Ser 216:265–278

Clarke KR, Gorley RN (2006) PRIMER v6: user manual/tutorial. PRIMER-E, Plymouth

Conlan KE, Kvitek RG (2005) Recolonization of soft-sediment ice scours on an exposed Arctic coast. Mar Ecol Prog Ser 286:21-42

Dunton K (1992) Arctic biogeography: the paradox of the marine benthic fauna and flora.

Trends Ecol Evol 7:183-189
Dunton KH, Reimnitz E, Schonberg S (1982) An Arctic kelp community in the Alaskan Beaufort Sea. Arctic 35:465-484
Dunton KH, Goodall JL, Schonberg SV, Grebmeier JM, Maidment DR (2005) Multi-decadal synthesis of benthic-pelagic coupling in the western arctic: role of cross-shelf advective processes. Deep Sea Res II 52:3462-3477
Dunton KH, Weingartner T, Carmack EC (2006) The nearshore western Beaufort Sea ecosystem: circulation and importance of terrestrial carbon in arctic coastal food webs. *Prog Oceanogr* 71:362-378
Dunton KH, Schonberg SV, Cooper LW (2012) Food web structure of the Alaskan nearshore shelf and estuarine lagoons of the Beaufort Sea. Estuar Coasts 35:416-435
Feder HM, Schamel D (1976) Shallow water benthic fauna of Prudhoe Bay. Assessment of the Arctic Marine Environment: Selected Topics, Chapter 22. Institute of Marine Science, University of Alaska, Fairbanks, pp 329-359
Fiedler PC, Reilly SB, Jewitt RP, Demer D, Philbrick VA, Smith S, Armstrong W, Croll DA, Tershy BR, Mate BR (1998) Blue whale habitat and prey in the California channel islands. Deep-Sea Res II 45, 1781–1801
Frost KJ, Lowry LF (1983) Demersal fishes and invertebrates trawled in the northeastern Chuckhi and western Beaufort Seas, 1976-77. NOAA Technical Report NMFS SSRF-764
Frost KJ, Llowry LF, Burns JJ (1978) Offshore demersal fishes and epibenthic invertebrates of the northeastern Chukchi and Western Beaufort Seas. In: Environmental assessment of the Alaskan continental shelf, Annual Reports of Principal Investigators for the year ending March 1978. Vol I. Receptors – Mammals – Birds. US Dept. Commerce / US Dept. Interior / NOAA, Boulder, Colorado, pp 231-353
Iken K, Bluhm BA, Dunton K (2010) Benthic food web structure serves as indicator of water mass properties in the southern Chukchi Sea. Deep-Sea Research II 57:71-85
Jarvela LE, Thorsteinson LK (1999) The epipelagic fish community of Beaufort Sea coastal waters, Alaska. Arctic 82:80-94
Logerwell E, Rand K (2010) Beaufort Sea marine fish monitoring 2008: pilot survey and test of hypotheses. Final Report of OCS study M07PG13152, MMS 2008-062
Logerwell E, Rand K, Weingartner TJ (2011) Oceanographic characteristics of the habitat of benthic fish and invertebrates in the Beaufort Sea. Polar Biol 34:783-1796
Konar B, Ravelo AM (2013) Epibenthic Community Variability on the Alaskan Beaufort Sea Continental Shelf. Final Report OCS Study BOEM 2013-01148
Magurran AE (2004) Measuring biological diversity. Blackwell, Oxford
Mecklenburg CW, Stein DL, Sheiko BA, Chernova NV, Mecklenburg TA, Holladay BA (2007) Russian-American long-term census of the Arctic: benthic fishes trawled in the Chukchi Sea and Bering Strait, August 2004. Northwest Nat 88:168–187
Mueter FJ, Litzow MA (2008) Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecol Appl 18(2):309-320
Norcross BL, Edenfield LE, Gray B, Holladay BA, Walker K (2014) Central Beaufort Sea Marine Fish Monitoring Final Report. Draft Final Report to Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, Alaska, USA
Pielou EC (1975) Ecological diversity. Wiley, New York
Piepenburg D, Archambault P, Ambrose WG Jr, Blanchard A, Bluhm BA, Carroll ML, Conlan K, Cusson M, Feder HM, Grebmeier JM, Jewett SC, Lévesque M , Petryashev VV, Sejr

MK, Sirenko B, Włodarska-Kowalczuk M (2011) Towards a pan-Arctic inventory of the species diversity of the macro- and megabenthic fauna of the Arctic shelf seas. Mar Biodiv 41:51-70

Rand KM, Logerwell EA (2011) The first demersal trawl survey of benthic fish and invertebrates in the Beaufort Sea since the late 1970s. Polar Biol 34:475-488

Sirenko BI, Gagaev SY (2007) Unusual abundance of macrobenthos and biological invasions in the Chukchi Sea. Russ J Mar Biol 33:355–364

Wacasey JW (1975) Biological productivity in the southern Beaufort Sea: zoobenthic studies. Beaufort Sea Technical Report #12b

Walters V (1955) Fishes of Western Arctic America and Eastern Arctic Siberia. B Am Mus Nat His 106:255-368

Wei C-L, Rowe GT, Escobar-Briones E, Boetius A, Soltwedel T, Caley MJ, Soliman Y, Huettmann F, Qu F, Yu Z, Pitcher CR, Haedrich RL, Wicksten MK, Rex MA, Baguley JG, Sharma J, Danovaro R, MacDonald IR, Nunnally CC, Deming JW, Montagna P, Levesque M, Weslawski JM, Wlodarska-Kowalczuk M, Ingole BS, Bett BJ, Billett DSM, Yool A, Bluhm BA, Iken K, Narayanaswamy BE (2010) Global patterns and predictions of seafloor biomass using random forests. PloS ONE 5(12):e15323, doi:10.1371/journal.pone.0015323

Weingartner T, Dobbins E, Danielson S, Winsor P, Potter R, Statscwich H (2013) Hydrolic variability over the northeastern Chukchi Sea shelf in summer-fall 2008-2010. Cont Shelf Res, doi: http://dx.doi.org/10.1016/j.csr.2013.03.012

Weslawski JM, Kendall MA, Wlodarska-Kowalczuk M, Iken K, Kedra M, Legeznska J, Sejr MK (2011) Climate change effects on Arctic fjord and coastal macrobenthic diversity – observations and predictions. Mar Biodiv 41:71-85

Wilimovsky NJ (1954) List of the Fishes of Alaska. Stan Ichthyol Bull 4:279-294

Yamamoto-Kawai M, McLaughlin FA, Carmack EC, Nishino S, Shimada K (2009), Aragonite undersaturation in the Arctic ocean: Effects of ocean acidification and sea ice melt, Science 326: 1098–1100

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.