OCS Study
BOEM 2017-33

Central Beaufort Sea Marine Fish Monitoring

US Department of the Interior

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CITATION

Norcross B, Holladay B, Apsens S, Edenfield L, Gray B, Walker K. 2017. Central Beaufort Sea marine fish monitoring, Final Report. Fairbanks, AK: US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2017-33. 191 p.

ACKNOWLEDGEMENTS

This research was primarily conducted under project “Central Beaufort Sea Marine Fish Monitoring”, Principal Investigator Dr. Brenda L. Norcross. Funding for this project was provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Alaska Outer Continental Shelf Region, Anchorage Alaska, through Cooperative Agreement Award No. M10AC20004 between BOEM and the University of Alaska Fairbanks (UAF), as part of the BOEM Alaska Environmental Studies Program. UAF is an AA/EO employer and educational institution. Additional funding for collaborative projects was provided by Shell Exploration and Production Company (plankton), Prince William Sound Oil Spill Recovery Institute (epibenthos), Coastal Marine Institute and North Pacific Research Board (snow crabs), and US Fish and Wildlife Service (seabirds and marine mammals). The authors thank the R/V *Norseman II* crew and scientific personnel who contributed to the successful BOEM-2011 cruise. We thank W. Carter for assistance with age assignments and the other technicians at the University of Alaska Fisheries Oceanography Laboratory in Fairbanks, Alaska for processing fishes. C.W. Mecklenburg, Auke Bay, Alaska, resolved problematic fish identifications through analysis of morphological characters, and provided voucher specimens to the University of Alaska Museum of the North (primary collection) and the California Academy of Sciences (San Francisco, CA), and provided genetic samples to the Fish Barcode of Life. Thoughtful discussions with the BOEM Project Officer, K. Wedemeyer, helped improve this research. Wedemeyer and select personnel of BOEM (Anchorage, AK) reviewed drafts of this report.

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List of Abbreviations and Acronyms

Acronym	Description
2RT	square root
4RT	fourth root
ACW	Alaska Coastal Water
ADCP	accoustic Doppler current profiler
AKMAP	Alaska Monitoring and Assessment Program
ANOSIM	Analysis of Similarity
ANOVA	analysis of variance
ArcticEIS	Arctic Ecosystem Integrated Survey
ARIS	adaptive resolution imaging sonar
AW	Atlantic Water
BOEM	Bureau of Ocean Energy Management
BOT	bottom of trawl
BPUE	biomass per unit effort
BS	beach seine
BT	beam trawl
cm	centimeters
CPUE	catch per unit effort
CTD	conductivity, temperature, and density
DIDSON	dual-frequency identification sonar
EA-IRMS	Elemental Analysis-Isotope Ratio Mass Spectometry
EBS	East Beaufort Sea
FL	fork length
FY	fyke net
gill	gill net
IKMT	Isaacs-Kidd midwater trawl
IRI; %IRI	Iidex of relative importance of prey taxon, expressed as percentage
LE	tissues that have been treated to extract lipids
%MN	mean number of prey taxon, expressed as percentage
%MW	mean weight of prey taxon, expressed as percentage
m	meters
MANOVA	multivariate analysis of variance
mm	millimeters
MMS	Minerals Management Service
MW	midwater trawl
NCS	north Chukchi Sea
Non-LE	tissues that have not been treated to extract lipids
nMDS	non-metric multidimensional scaling
nmi	nautical miles
NT	no transformation
%O	percent occurrence
OT	otter trawl

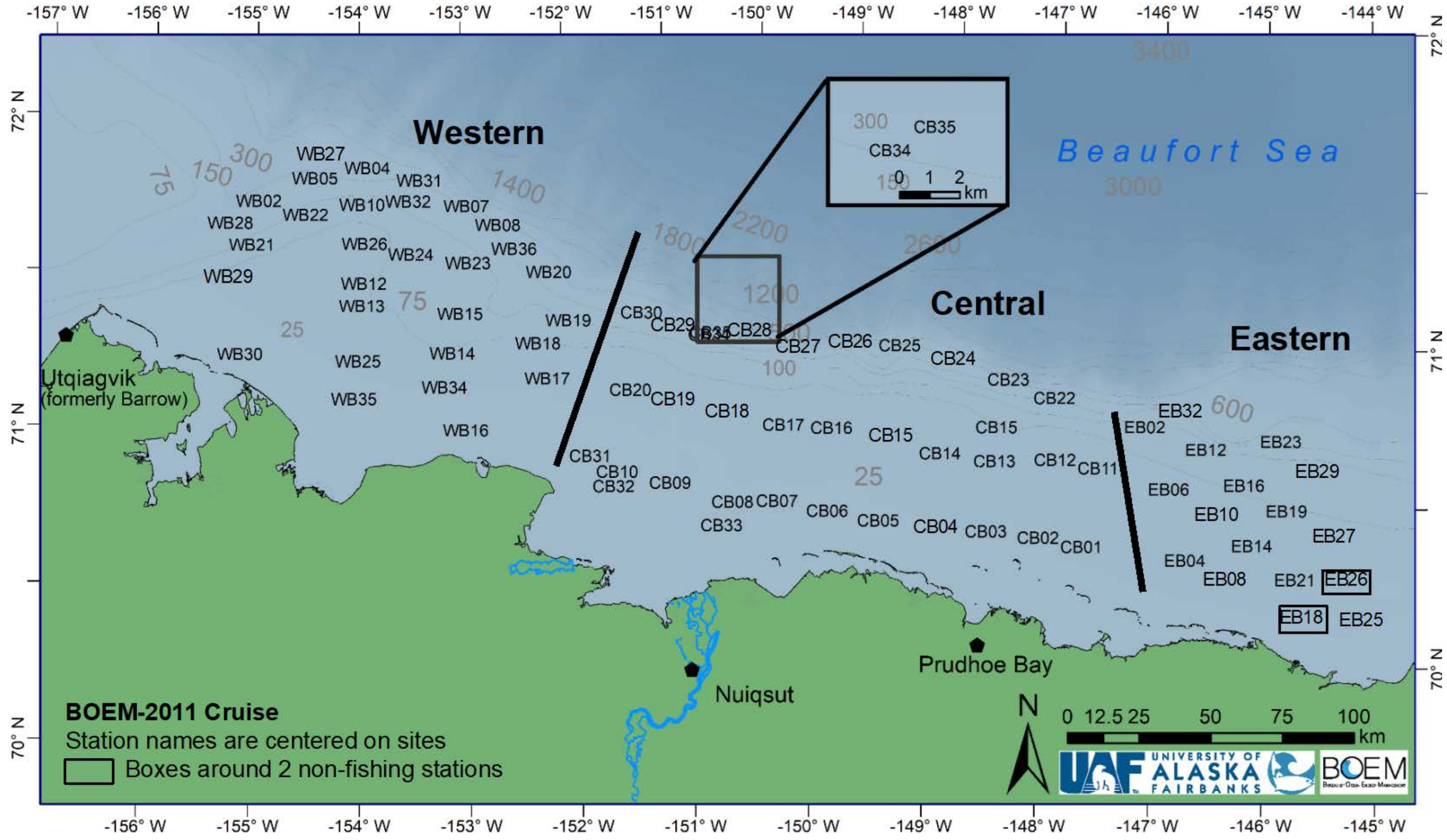
Acronym	Description
PL	plankton net
PSBT	plumb staff beam trawl
PSBT-A	modified plumb staff beam trawl
ROV	remotely operated vehicle
SC1	size class one; smallest size class of a fish species examined for diet
SC2	size class two; largest size class of a fish species examined for diet
SCS	South Chukchi Sea
SCUBA	self-contained underwater breathing apparatus
SD	standard deviation
SL	standard length
SSW	Shelf Summer Water
SWW	Shelf Winter Water
TL	total length
WBS	West Beaufort Sea
WEBS	West and East Beaufort Sea

1 Introduction

The Central Beaufort Sea Marine Fish Monitoring study was developed to fill a need for baseline and benchmark information on fish distribution and abundance in the Central Beaufort Sea (**Figure 1-1**).

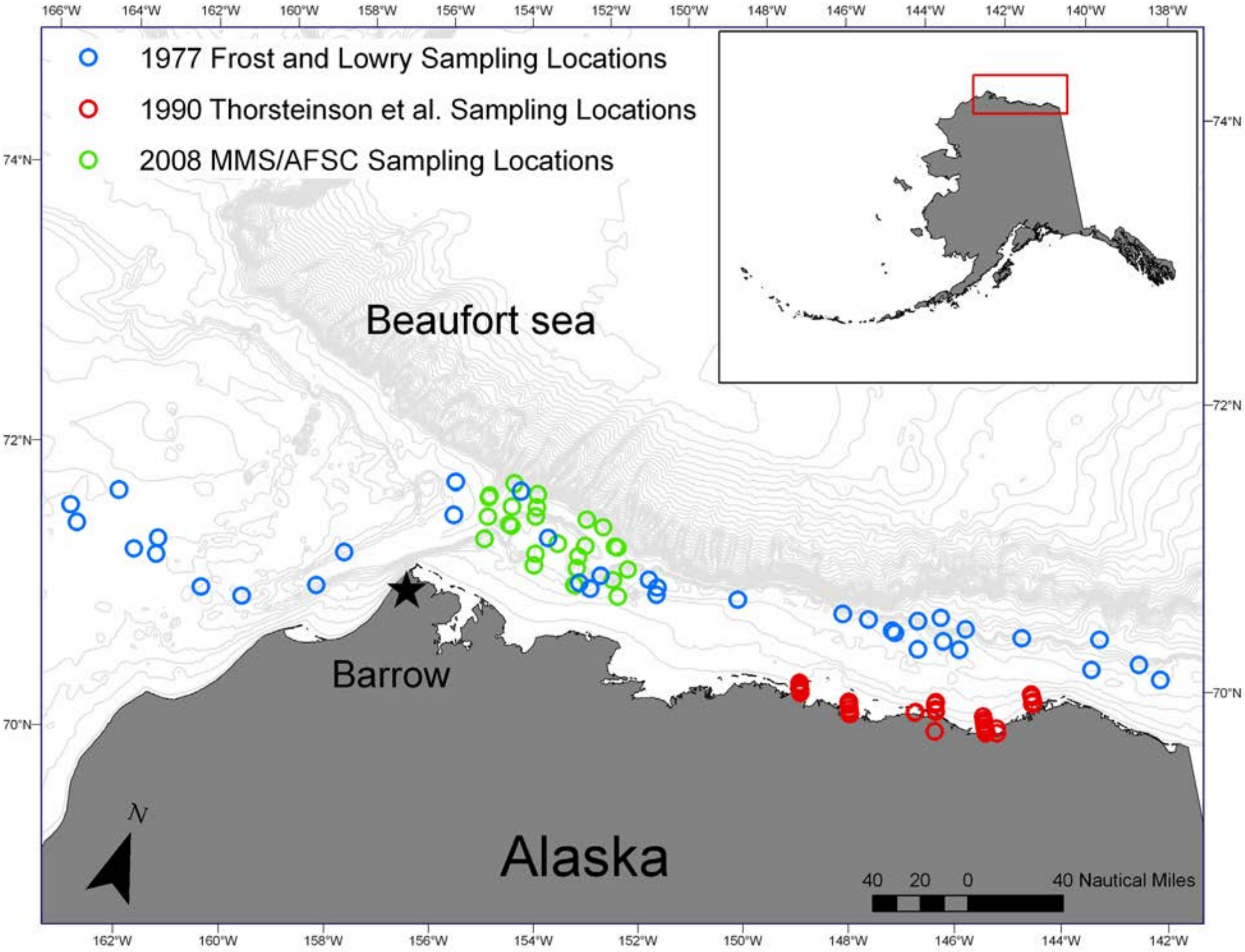
As offshore oil exploration interest expands in the US Arctic, more information is required about the sparsely documented fish species inhabiting the area.

Fish are important food and cultural resources in the Beaufort Sea ecosystem for birds, marine mammals, and humans. It is unknown whether the data from fish surveys collected decades (**Figure 1-2**) ago represents present conditions. A current benchmark for marine fish is important to facilitate Beaufort Sea environmental analyses especially as the geographic occurrence and trends in subsistence harvests may be changing. Fish and invertebrate assemblages in other marine ecosystems off Alaska have undergone observable regime shifts in abundance and diversity over the last 20–30 years; this geographically widespread reorganization of fish communities has been observed in the Gulf of Alaska (Anderson and Piatt 1999), the Bering Sea (Hollowed et al. 2001), and may be occurring in the Chukchi Sea as well (Grebmeier 2012, Hollowed et al. 2013). While the same is likely true of the Beaufort Sea, it is unconfirmed. The age and paucity of data introduce difficulties in delineating important spawning, rearing, feeding, and migration habitats.



Zooplankton only, no fishing, at eastern stations with boxes around names.

Figure 1-1 Map of Stations Sampled during BOEM-2011 Cruise in Alaskan Beaufort Sea between August 15 and September 4, 2011



Source: Frost and Lowry 1983, Thorsteinson et al. 1992, Logerwell and Rand 2010

Figure 1-2 Map Indicating Sites of Demersal Fish Sampling in the Beaufort Sea Prior to the Present Research

Because the Beaufort Sea Planning area is under ice much of the year, knowledge of marine fish during the ice covered seasons is essential to understanding the life history and distribution of fishes. One issue of concern to residents of the Beaufort Sea coast is the potential impact of an oil spill on the local ecosystem. Thus, it is important to understand fish distribution and abundance, especially during the under-ice and broken-ice seasons. The Bureau of Ocean Energy Management (BOEM) funded a workshop to review methods and make recommendations for sampling fish in the US Arctic during the ice-covered season. The outcome of that workshop was used as a foundation for structuring this pilot under-ice fish survey.

Marine fishes form various assemblages that fill many ecologically important roles in the Beaufort Sea food web. This project was multi-disciplinary in nature (**Appendix A**). Concurrent observations of fishes, zooplankton and epibenthic fauna (fish food and competitors), and birds and marine mammals (fish consumers) from the same research vessel can greatly enhance spatial data in offshore areas where information for many of those taxa is as sparse as for fish species.

1.1 Objectives

1) Examine abundance and distribution of marine fish species that occupy the Central Beaufort Sea during the open-water season.
2) Examine diets of abundant fish species in the Central Beaufort Sea.
3) Implement a portion of the pilot under-ice survey design developed in the 2007 Minerals Management Service (MMS) Under-Ice Sampling Workshop to quantitatively test abundance and distribution hypotheses about marine fish species that occupy the Central Beaufort Sea Planning Area during the ice-covered season.

2 Fish Catches

2.1 Introduction

Prior to 2011, the shelf of the Beaufort Sea was relatively unexplored for demersal fauna. The only continuous long-term monitoring (1981 to present) has been in shallow nearshore waters in the Prudhoe Bay oil development region (Craig et al. 1985, Thorsteinson et al. 1992, LGL 1999, Fechhelm et al. 2010). Surveying fish on the shelf has been limited to the broad but sparse sampling in 1976–1977 (Frost and Lowry 1983) and dense sampling in the western Beaufort Sea in 2008 (**Figure 1-2**; Logerwell and Rand 2010, Rand and Logerwell 2011). The Central Beaufort Sea Fish Monitoring 2011 cruise (BOEM-2011) was conducted from August 15 through September 4, 2011. A total of 81 stations were sampled in the Beaufort Sea between longitudes 155.25°W and 145.09°W (**Figure 1-1**).

The overall objective of the BOEM-2011 cruise was to generate fish data comparable to, but broader in geographic scope than, previous fish surveys in the US Beaufort Sea (Frost and Lowry 1983, Rand and Logerwell 2011). The BOEM-2011 cruise was extremely successful; excellent weather allowed an unprecedented number of stations to be sampled. Based on our experience trawling in the Chukchi Sea from 2004–2010 (Norcross et al. 2010, 2013), and difficulties experienced with excessive mud in the trawl catches during BOEM-2008, three separate bottom trawls were available onboard in anticipation of muddy substrate, including an otter trawl and two variants of beam trawl, all single warp and relatively small.When time was available after sampling the planned stations, we conducted opportunistic comparison hauls at select stations in the western area and assessed whether the trawl gears collected the same abundance, species and lengths of fishes.

2.2 Methods

2.2.1 Sampling Fishes

From August 15 to September 4, 2011, 79 stations were sampled using bottom and/or pelagic trawls between longitudes 155.25°W and 145.09°W and latitudes 70°N to 72°N in the Beaufort Sea (**Figure 1-1 and Table 2-1**). All stations, except one at 223 meters (m), were on the shelf or shelf break at bottom depths of 14-184 m. Midwater and bottom trawls were used to survey fish fauna. Not all trawl gears were fished at every station (**Figure 2-5**). Although the ranges of depth, latitude, and longitude were similar among gears (**Table 2-1**), mean depth was least for the Plumb Staff Beam Trawl (PSBT) (47.0 m), intermediate for the Modified Plumb Staff Beam Trawl (PSBT-A) (59.0 m), and deepest for the Otter Trawl (OT) (69.8 m). The PSBT-A was deployed throughout the study region, while most OT and PSBT hauls were in the eastern and western areas. Eastern stations were sampled at the start of the cruise while assessing which of the three bottom trawls could be deployed safely in the most time-efficient manner. Toward the end of the cruise when sampling was limited to the area west of 150°W, time was available in the western area for opportunistic deployments of multiple trawl gears. Successful hauls were able to be quantified. Hauls were unsuccessful (qualitative) if the net was damaged, the codend was overfull, or there were problems with launching and retrieving the net. Specimens were collected from a sample of qualitative hauls to document species presence or to provide specimens for laboratory research.

Larval and small juvenile pelagic fishes were collected using an Isaacs-Kidd midwater trawl (IKMT) that was fished from the surface to 10 m above the benthic substrate. The IKMT had 3 millimeter (mm) mesh throughout the body and codend with mouth dimensions of 1.5 m wide by 1.8 m high, and had an effective fishing area of 2.137 m^2 when fished at a 45° angle. A rigid diving vane kept the mouth of the net open during towing and exerted a depressing force to stabilize the net vertically. The IKMT was deployed from the stern of the vessel and towed with the current at approximately 4 knots speed over ground in a double oblique tow. During the haul, the towing cable was continuously released and retrieved at the rate of approximately 30 m/min; rate was modified to maintain the target 45º wire angle. Catch per unit effort (CPUE) of IKMT hauls was calculated as (# fish x 1,000) / (haul distance in m x 2.137 m^2 net opening) and reported as # fish / 1,000 m^3. The weight of larval fishes was negligible, and therefore we did not report larval biomass during IKMT catches.

Table 2-1 Ranges of Depth, Latitude, and Longitude for Successful Bottom Trawl Deployments during BOEM-2011 for which Abundance of Fishes was Calculated

Gear	Count of Hauls	Depth (m)		Latitude (°N)	Longitude (°W)
		Mean	Range		
Otter trawl	32	69.8	15-180	70.23-71.81	155.22-145.08
Plumb staff beam trawl	13	47.0	13-124	70.34-71.59	154.99-145.41
Modified plumb staff beam trawl	68	59.0	10-223	70.34-71.84	155.16-145.43

Demersal fishes were collected with an OT with a 9.1 m headrope, 38 mm mesh body, 19 mm mesh codend, 27.5 m bridles, and 61 x 122 cm (23 kg) doors. All bottom trawls were deployed from the stern of the vessel at 30 m/min with a ratio of 2.5–5 m of towing cable to 1 m of water depth. All tows were made in the direction of the current. Haul distance was calculated as linear distance between the positions of the vessel when the towing cable was fully deployed and retrieved. Otter trawl doors do not maintain a static distance apart during a haul; instead, the doors dynamically move together and apart with changes in vessel speed and substrate. The net was too small to allow for mensuration gear that could record distance between doors, and thus area swept could not be calculated. CPUE of OT hauls was calculated as (# fish x 1,000) / (haul distance in m) and was reported as number fish per 1,000 m distance. Biomass per unit effort (BPUE) was similarly calculated using the weight of fish and was reported as grams of fish 1,000 m^{-1}.

Demersal fishes also were collected with PSBT of two equivalent configurations. The PSBT and PSBT-A each had a 4.7 m headrope and 4.6 m footrope, 7 mm mesh in body and 4 mm mesh as codend liner, and a rigid 3.05 m pipe forward of the mouth holding it open for an effective swath of 2.26 m, thereby allowing for accurate quantifications of trawl effort by area swept (Gunderson and Ellis 1986). The trawl referred to in this report as PSBT had been previously modified from the Gunderson and Ellis design for work in in Chukchi Sea (Norcross et al. 2010, 2013b; Britt et al. 2013), Eastern Bering Sea (Cooper et al. 2014), and Gulf of Alaska (e.g., Norcross et al. 1995, 1997, 1999; Abookire and Norcross, 1998; Abookire et al., 2001; Mueter and Norcross 1999, 2000a, 2000b; Dressel and Norcross 2005) by seizing a lead-filled line to the footrope and 6-inch (15 cm) lengths of chain at 15 cm intervals along the footrope, lengthening the codend from 1 m to 4 m to avoid overfilling the codend, and building ‘weak links’ into the bridle and footrope. The weak links were six (#15 size) or four (#18 size) wraps of tarred twine between two connection points; they allow a snagged net to collapse or tear away rather than ripping, thus maintaining the integrity of the net and avoiding time-consuming repairs. The PSBT was further modified for the BOEM-2011 cruise, and in this report the resulting net is referred to as PSBT-A. Modifications were according to Abookire and Rose (2005): (1) 10.2 cm disks were threaded on a central steel chain that was added below the footrope to exclude boulders and rocks and to avoid digging into mud substrate, and (2) the headrope was secured to the beam in several places to reduce escapement above the headrope. At stations where boulders or dense mud made it impractical to haul a regular PSBT containing a lead-filled line seized to the footrope (Norcross et al. 2013b), a PSBT-A was used instead. Vessel speed was 1–1.5 knots during beam trawl (BT) hauls. Haul distance was calculated between the positions of the vessel when the scope was fully deployed and when haul back began. CPUE of BT catch was calculated as (# fish x 1,000) / (haul distance in m x 2.26 m net swath) and reported as # fish 1,000 m^{-2}. Likewise, BPUE was calculated and reported as grams of fish 1,000 m^{-2}.

Fishes were identified in the field and identifications were reviewed in the laboratory and confirmed or revised. The scientific and common names of fishes follow Thorsteinson and Love 2016.

2.2.2 Analysis

For each gear type (IKMT, OT, or BT), catch data at each station were averaged over all successful deployments. CPUE values were calculated for each gear, but the units of effort were not the same and therefore values of CPUE could not be directly compared among gear types. The project database consists of a series of tables that report station collection and environmental data, fish catch data, and data about individual fish specimens (**Appendix B**). Large numbers of fish species were captured; therefore, distribution was compared among families although maps of both species and families are available in **Appendix C.2**. Species' abundance was compared among gear types in 2011, while species' presence was compared to historical collections.

Taxa were aggregated into groups for analyses. Small specimens within the genera *Liparis* and *Lycodes* were difficult and overly time-consuming to identify to species, therefore analyses were by genus. Furthermore, specimens of *Liparis* spp. were degraded by freezing rendering more precise identification impossible. As *Icelus* larvae had not fully developed characteristic lateral line scales it was not possible to determine if the unidentified *Icelus* were *I. bicornis* or *I. spatula;* to eliminate potential errors of underestimating the contribution of those species, all *Icelus* were analyzed together.

The cumulative species encountered over hauls by each gear type were estimated using the Species-Accumulation function in PRIMER v.7. Observations of taxon presence were permuted in random order 999 times, and the mean value at each consecutive haul was graphed. PRIMER calculated a standard deviation for each consecutive haul, and the mean over hauls is presented in the text.

For the 15 stations where PSBT and PSBT-A, or multiple hauls of one type of beam trawl, were deployed, fish abundance was compared. CPUE was calculated for each taxon (n = 30), gear type, and haul. Within each station, the mean CPUE across all species for each gear was used in 2-tail t-tests (Bonferroni adjusted p = 0.003). Statistical comparisons were not made with the OT due to the lack of an accurate measure of area swept.

Size selectivity of demersal trawl gears was assessed using only quantitative hauls (**Table 2-1**). For each of the three trawl gears, the distance-towed CPUE (per 1,000 m) by 10 mm fish length class was calculated over all fish taxa and all hauls; the proportion of total catch at each 10 mm length class was graphed for visual comparison. Similarly, fish lengths of twenty-one abundant species caught by OT, PSBT, and PSBT-A were visually examined as the proportional catch at each 10 mm length class (number standardized to 100% total catch by gear). In plots, length classes were referred to as the midpoint, e.g., the length class 41–50 mm is referred to as 45 mm.

Proportions that each fish family contributed to abundance of all gear types and biomass of the bottom trawls were graphed. All maps were created using ArcMap 10.2.1 for Desktop (ESRI 2013) and datum D_WGS_1984. To create bubble maps of CPUE and BPUE, data were classified into 1 to 4 groups using the Natural Breaks (Jenks) function in ArcMap, which seeks to reduce variance within classes and maximize the variance between them. In addition to overall fish abundance and biomass, bubble maps were plotted to show spatial distribution of each fish family whose total CPUE or BPUE composed >10% of the overall catch by that gear.

2.3 Results

2.3.1 Fish Catches and Gear Comparison

A total of 13,797 fishes were captured during this cruise, from at least 38 species representing 11 families (**Table 2-2**). Some small individuals could not be identified at the species level. As larvae, the unidentifiable specimens were grouped at the family level. Small, difficult to identify juveniles were classified to the genus level. Some larger specimens of *Liparis* spp. were degraded by freezing, which limited identification to genus. Therefore, for purposes of comparison across all gears and hauls the number of taxa depicted were 30 (**Table 2-3**). Supplementary data on abundance for each gear and biomass for bottom gears, by family and species, are in **Appendix C.2**.

The top 10 most abundant CPUE species captured were assessed separately for IKMT, OT, and BT and comprised 15 taxa. Comparison of abundance among gears was relative as each had a different expression of CPUE. Only nine of the 15 taxa were abundant in more than one gear type. However, one species, *Boreogadus saida*, ranked as first in catches by all three types of gear (**Table 2-3**). Similarly, *Gymnocanthus tricuspis* and *Liparis* spp. ranked as second or third for each gear. While *Myoxocephalus scorpius*, *Aspidophoroides olrikii*, and *Lumpenus fabricii* were also among the top 10 for each gear, their ranks were less consistent. Three taxa were abundant in both types of bottom trawls: *Icelus* spp., *Triglops pingelii*, and *Lycodes* spp. No taxon was abundant in both the IKMT and only one of the bottom trawl types. The remaining seven taxa were ranked in the top 10 most abundant fishes in only one type of gear, four of which were in IKMT hauls. *Eleginus gracilis* and *Stichaeus punctatus*, and stichaeid larvae were among the top ten most abundant in IKMT (**Table 2-3**). The mid-ranking cottid larvae were either too small to be retained by bottom gear or were not found in the lower water column.

Table 2-2 Fish Taxa Reported from the Alaskan Beaufort Sea from Scientific Surveys 1976–2011

Survey years	1976–77	1977–78	1981–2010	1990	2008		2011 (present survey)	
Gears	BOT	Gill BS FY PL	Gill BS FY	MW	MW	BOT	MW	BOT
Citation	Frost and Lowry 1983	Craig et al. 1985	LGL 1999, Fechhelm et al. 2010	Thornsteinson et al. 1991	Parker-Stetter et al. 2011	Rand and Logerwell 2011	present study	
Family and Taxon								
Clupeidae								
Clupea pallasii		x	x					
Osmeridae								
Mallotus catervarius		x*	x*	x*	x*	x*		x
Osmerus dentex		x	x					
Salmonidae								
Coregonus autumnalis		x	x	x				
C. laurettae		x	x					
C. nasus		x	x					
C. pidschian		x	x					
C. sardinella		x	x					
Oncorhynchus gorbuscha		x	x					
O. keta		x	x					
O. nerka		x						
Prosopium cylindraceum^{W}		x	x					
Salvelinus alpinus alpinus		x*		x*				
S. malma			x					
Thymallus pallasi^{W}		x*	x*					
Gadidae								
Arctogadus glacialis	x							
Boreogadus saida	x	x	x	x	x	x	x	x
Eleginus gracilis		x	x			x	x	x
Gadus chalcogrammus						x*		
G. macrocephalus						x		

Table 2-2 continued

Survey years	1976–77	1977–78	1981–2010	1990	2008		2011 (present survey)	
Gears	BOT	Gill BS FY PL	Gill BS FY	MW	MW	BOT	MW	BOT
Citation	Frost and Lowry 1983	Craig et al. 1985	LGL 1999, Fechhelm et al. 2010	Thornsteinson et al. 1991	Parker-Stetter et al. 2011	Rand and Logerwell 2011	present study	
Family and Taxon								
Gasterosteidae								
Gasterosteus aculeatus		x	x					
Pungitius pungitius		x	x	x				
Cottidae								
Artediellus scaber	x					x		x
Enophrys diceraus						x		
Gymnocanthus tricuspis	x			x		x	x	x
Icelus bicornis	x							x
Icelus spatula	x					x	x	x
Myoxocephalus spp.		o						
M. jaok								x
M. quadricornis		x	x	x			x	x
M. scorpius						x*	x	x
Trichocottus brashnikovi								x
Triglops nybelini						x		x
T. pingelii	x					x	x	x
Cottidae unid.		o			x	o	o	
Hemitripteridae								
Nautichthys pribilovius						x		x
Agonidae								
Aspidophoroides olrikii	x					x	x	x
Leptagonus decagonus								x
Podothecus veternus								x
Agonidae unid.					x			
Cyclopteridae								
Eumicrotremus derjugini	x					x		x

Table 2-2 continued

Survey years	1976–77	1977–78	1981–2010	1990	2008		2011 (present survey)	
Gears	BOT	Gill BS FY PL	Gill BS FY	MW	MW	BOT	MW	BOT
Citation	Frost and Lowry 1983	Craig et al. 1985	LGL 1999, Fechhelm et al. 2010	Thornsteinson et al. 1991	Parker-Stetter et al. 2011	Rand and Logerwell 2011	present study	
Family and Taxon								
Liparidae								
Careproctus reinhardti						x*		x
Liparis spp.	o	x				o	o	o
L. bathyarcticus							x	x
L. fabricii						x	x	x
L. gibbus						x		x
L. marmoratus						x		
L. tunicatus	x		x	x			x	x
Liparidae unid.					x			
Zoarcidae								
G. hemifasciatus								x
G. viridis	x					x		x
Gymnelus spp.								o
Lycodes spp.						o		o
L. mucosus	x					x		x
L. polaris	x					x		x
L. raridens	x					x		x
L. reticulatus								x
L. rossi	x					x		
L. seminudus								x
Stichaeidae								
Anisarchus medius	x*			x*		x*	x	x
Eumesogrammus praecisus	x					x		x
Leptoclinus maculatus	x*					x*		x
Lumpenus spp.						o		x
Lumpenus fabricii	x			x		x*	x	x
Stichaeus punctatus							x	x
Stichaeidae unid.	o*				x	o*	o	o

Table 2-2 continued

Survey years	1976–77	1977–78	1981–2010	1990	2008		2011 (present survey)	
Gears	BOT	Gill BS FY PL	Gill BS FY	MW	MW	BOT	MW	BOT
Citation	Frost and Lowry 1983	Craig et al. 1985	LGL 1999, Fechhelm et al. 2010	Thornsteinson et al. 1991	Parker-Stetter et al. 2011	Rand and Logerwell 2011	present study	
Family and Taxon								
Ammodytidae								
Ammodytes hexapterus		x					x	x
Pleuronectidae								
Hippoglossoides robustus						x		x
Limanda proboscidea							x	
Limanda sp., other (larval)								x
Liopsetta glacialis		x	x	x				
Reinhardtius hippoglossoides						x		
Total count of unique species	n≥19	n≥22	n = 20	n = 11	n≥6	n≥30	n≥16	n≥38

Gears are abbreviated: BOT = bottom trawl of any configuration, MW = midwater trawl, Gill = gill net, BS = beach seine, FY = fyke net, PL = plankton net.
Taxa counted as number of species captured are indicated by "x" whereas taxa not contributing an additional species with certainty are indicated by "o." Colors are the same as proportional family maps, e.g., Figure 2-2 species names follow the Alaska Arctic marine fish ecology catalog (Thorsteinson and Love 2016) and the American Fisheries Society's Common and scientific names of fishes from the United States, Canada, and Mexico (Page et al. 2013).
Asterisks (*) indicate taxon was reported with a different name.

Table 2-3 Summary of CPUE by Gear and Taxa

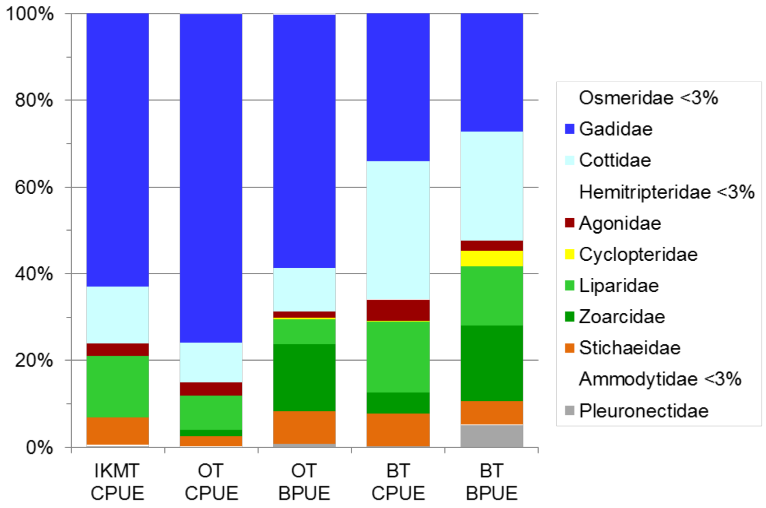
	IKMT			Otter trawl						Beam trawls					
Taxa	#/1,000 m^3	%CPUE	top 10	#/1,000 m	%CPUE	top 10	g/1,000 m	%BPUE	top 10	#/1,000 m^2	%CPUE	top 10	g/1,000 m^2	%BPUE	top 10
Osmeridae	**-**	**-**		**0.2**	**<0.1%**		**3.0**	**0.3%**		**-**	**-**		**-**	**-**	
Mallotus catervarius	-	-		0.2	<0.1%		3.0	0.3%		-	-		-	-	
Gadidae	**46.1**	**63.0%**		**345.9**	**75.8%**		**617.4**	**58.3%**		**74.7**	**34.0%**		**132.9**	**27.2%**	
Boreogadus saida	44.0	60.0%	1	344.1	75.4%	1	616.3	58.2%	1	74.3	33.8%	1	132.7	27.1%	1
Eleginus gracilis	2.2	3.0%	8	1.8	0.4%		1.1	0.1%		0.4	0.2%		0.2	<0.1%	
Cottidae	**9.5**	**13.0%**		**42.0**	**9.2%**		**106.5**	**10.1%**		**70.0**	**31.9%**		**122.9**	**25.1%**	
Artediellus scaber	-	-		3.3	0.7%		13.6	1.3%		8.9	4.1%	7	31.8	6.5%	5
Gymnocanthus tricuspis	4.4	6.0%	3	15.2	3.3%	3	20.6	1.9%	8	36.7	16.7%	2	32.7	6.7%	4
Icelus spp.	0.1	0.2%		9.0	2.0%	5	17.9	1.7%	10	8.8	4.0%	8	16.0	3.3%	10
Myoxocephalus jaok	-	-		-	-		-	-		0.0	<0.1%		0.0	<0.1%	
Myoxocephalus quadricornis	0.0	<0.1%		-	-		-	-		0.0	<0.1%		2.7	0.6%	
Myoxocephalus scorpius	2.4	3.2%	5/6	7.1	1.6%	7	19.2	1.8%	9	9.4	4.3%	6	19.6	4.0%	7
Trichocottus brashnikovi	-	-		-	-		-	-		0.1	0.1%		0.0	<0.1%	
Triglops nybelini	-	-		-	-		-	-		0.1	0.1%		1.1	0.2%	
Triglops pingelii	0.3	0.4%		7.4	1.6%	6	35.1	3.3%	4	6.0	2.7%	10	19.1	3.9%	8
Cottidae larvae unid.	2.4	3.2%	5/6	-	-		-	-		-	-		-	-	
Hemitripteridae	**-**	**-**		**0.2**	**<0.1%**		**0.1**	**<0.1%**		**0.4**	**0.2%**		**0.1**	**<0.1%**	
Nautichthys pribilovius	-	-		0.2	<0.1%		0.1	<0.1%		0.4	0.2%		0.1	<0.1%	
Agonidae	**2.2**	**3.0%**		**13.1**	**2.9%**		**16.4**	**1.5%**		**10.5**	**4.8%**		**11.9**	**2.4%**	
Aspidophoroides olrikii	2.2	3.0%	7	13.1	2.9%	4	16.4	1.5%		10.3	4.7%	5	10.7	2.2%	
Leptagonus decagonus	-	-		-	-		-	-		0.1	<0.1%		1.2	0.2%	
Podothecus veternus	-	-		-	-		-	-		0.1	<0.1%		0.0	<0.1%	
Cyclopteridae	**-**	**-**		**0.6**	**0.1%**		**3.5**	**0.3%**		**0.5**	**0.3%**		**16.8**	**3.4%**	
Eumicrotremus derjugini	-	-		0.6	0.1%		3.5	0.3%		0.5	0.3%		16.8	3.4%	9
Liparidae	**10.3**	**14.1%**		**36.2**	**7.9%**		**60.8**	**5.7%**		**35.9**	**16.3%**		**66.9**	**13.7%**	
Careproctus reinhardti	-	-		0.2	<0.1%		2.8	0.3%		0.4	0.2%		5.0	1.0%	
Liparis spp.	10.3	14.1%	2	36.0	7.9%	2	58.0	5.5%	3	35.5	16.2%	3	61.8	12.6%	3
Zoarcidae	**-**	**-**		**6.6**	**1.4%**		**163.5**	**15.4%**		**10.7**	**4.9%**		**85.2**	**17.4%**	
Gymnelus spp.	-	-		1.1	0.2%		6.0	0.6%		2.4	1.1%		6.4	1.3%	
Lycodes spp.	-	-		5.5	1.2%	8	157.5	14.9%	2	8.3	3.8%	9	78.8	16.1%	2

Table 2-3 continued

	IKMT			Otter trawl						Beam trawls					
Taxa	#/1,000 m^3	%CPUE	top 10	#/1,000 m	%CPUE	top 10	g/1,000 m	%BPUE	top 10	#/1,000 m^2	%CPUE	top 10	g/1,000 m^2	%BPUE	top 10
Stichaeidae	**4.7**	**6.4%**		**10.6**	**2.3%**		**78.9**	**7.4%**		**16.4**	**7.5%**		**27.2**	**5.6%**	
Anisarchus medius	0.3	0.4%		4.3	0.9%	10	20.9	2.0%	7	4.1	1.9%		11.2	2.3%	
Eumesogrammus praecisus	-	-		0.4	0.1%		34.4	3.2%	5	0.0	<0.1%		1.4	0.3%	
Leptoclinus maculatus	-	-		-	-		-	-		0.1	<0.1%		0.9	0.2%	
Lumpenus fabricii	1.2	1.7%	9	5.3	1.2%	9	23.3	2.2%	6	11.5	5.2%	4	13.4	2.7%	
Stichaeus punctatus	0.8	1.0%	10	0.1	<0.1%		0.2	<0.1%		0.2	0.1%		0.0	<0.1%	
Stichaeidae larvae unid.	2.4	3.3%	4	0.5	0.1%		0.1	<0.1%		0.5	0.2%		0.2	<0.1%	
Ammodytidae	**0.3**	**0.3%**		**0.1**	**<0.1%**		**0.0**	**<0.1%**		**0.1**	**<0.1%**		**0.0**	**<0.1%**	
Ammodytes hexapterus	0.3	0.3%		0.1	<0.1%		0.0	<0.1%		0.1	<0.1%		0.0	<0.1%	
Pleuronectidae	**0.1**	**0.2%**		**0.7**	**0.1%**		**9.0**	**0.8%**		**0.5**	**0.2%**		**25.3**	**5.2%**	
Hippoglossoides robustus	-	-		0.7	0.1%		9.0	0.8%		0.5	0.2%		25.3	5.2%	6
Limanda proboscidea	0.1	0.2%		-	-		-	-		-	-		-	-	
Limanda sp. larva, other	-	-		-	-		-	-		0.1	<0.1%		0.0	<0.1%	
All fishes	**73.2**	**100.0%**		**456.2**	**100.0%**		**1059.0**	**100.0%**		**219.8**	**100.0%**		**489.3**	**100.0%**	

%BPUE is biomass. Effort is not equivalent between gears, as IKMT effort is volume, otter trawl effort is distance, and beam trawl effort is area.
%CPUE is abundance

BPUE among the two bottom trawls was similar to CPUE; the most notable difference being only 13 taxa composed the top ten by weight (**Table 2-3**). *B. saida*, *Lycodes* spp., *Liparis* spp., and *Icelus* spp. were ranked identical as: 1, 2, 3 and 10 in both gears. The top species were *G. tricuspis*, *M. scorpius*, and *Triglops pingelii*. The remaining six taxa ranked among the top 10 fishes that had the greatest aggregate biomass in only one type of gear. Though *Aspidophoroides olrikii* was abundant in all three gear types, the catches were too small to make a notable contribution to the relative biomass. Differences in top-ten ranks between CPUE and BPUE within and between bottom trawls were attributed to catches of few large individuals, e.g., *Hippoglossoides robustus*, or relative catches, e.g., *Anisarchus medius* (**Table 2-3**).



IKMT – Isaacs Kidd midwater trawl
CPUE – abundance catch per unit effort

OT – otter trawl, BT – beam trawls
BPUE – biomass catch per unit effort

Figure 2-1 Proportional Catch and Biomass of Fish Families for Each Gear Averaged Over All Quantitative Hauls

2.3.1.1 Midwater Fishes

There were 73 quantitative hauls out of 84 hauls by the IKMT at 72 stations; 2,408 fish were captured from seven families (**Figure 2-2**) and grouped as 14 taxa for analyses. Percentage distribution of fish families at each station revealed interesting patterns. Gadidae dominated almost all midwater catches across the whole study area. Cottids were principally found in the east, and stichaeids were mainly found in the west. At a few nearshore stations off Nuiqsut, Liparidae was the dominant fish family. The overall abundance distribution of fishes captured by IKMT showed stations of highest densities in the east (**Figure 2-3**). Other stations with high CPUE values were scattered across the sampling area with little pattern. Taxa specific density plots are available in **Appendix C**.

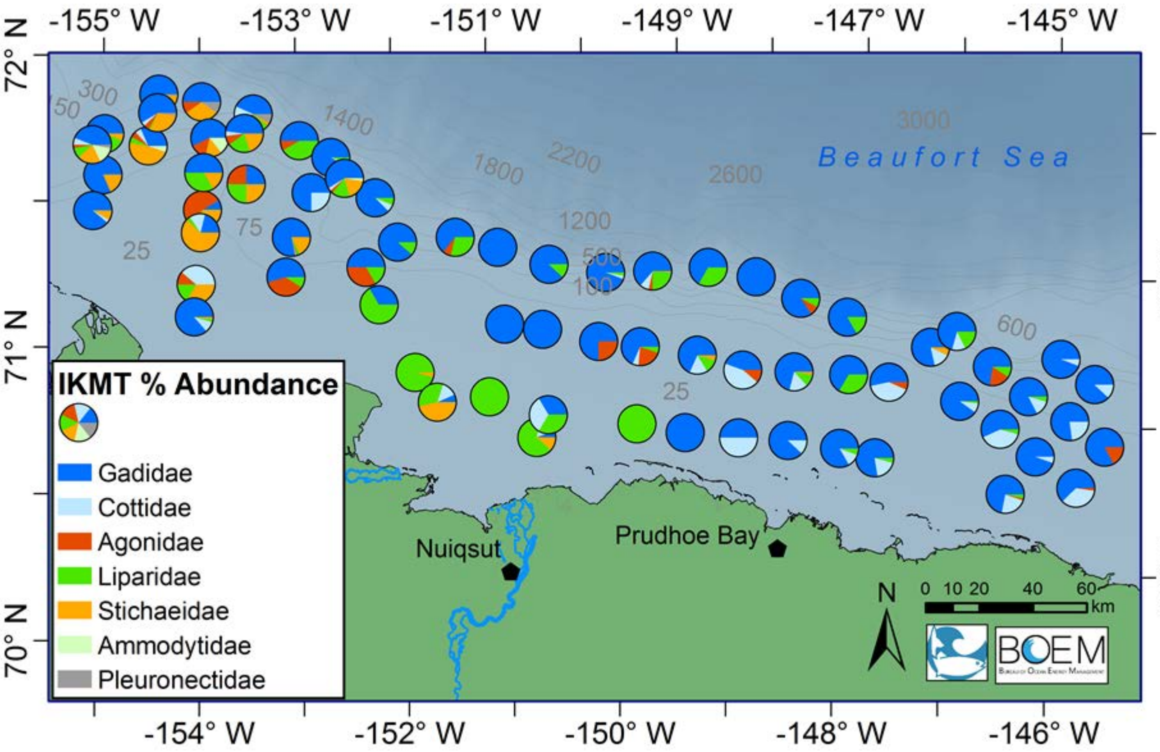


Figure 2-2 **Proportional Composition of Abundance of Fish Families Captured at Each Station by Isaacs-Kidd Midwater Trawl**

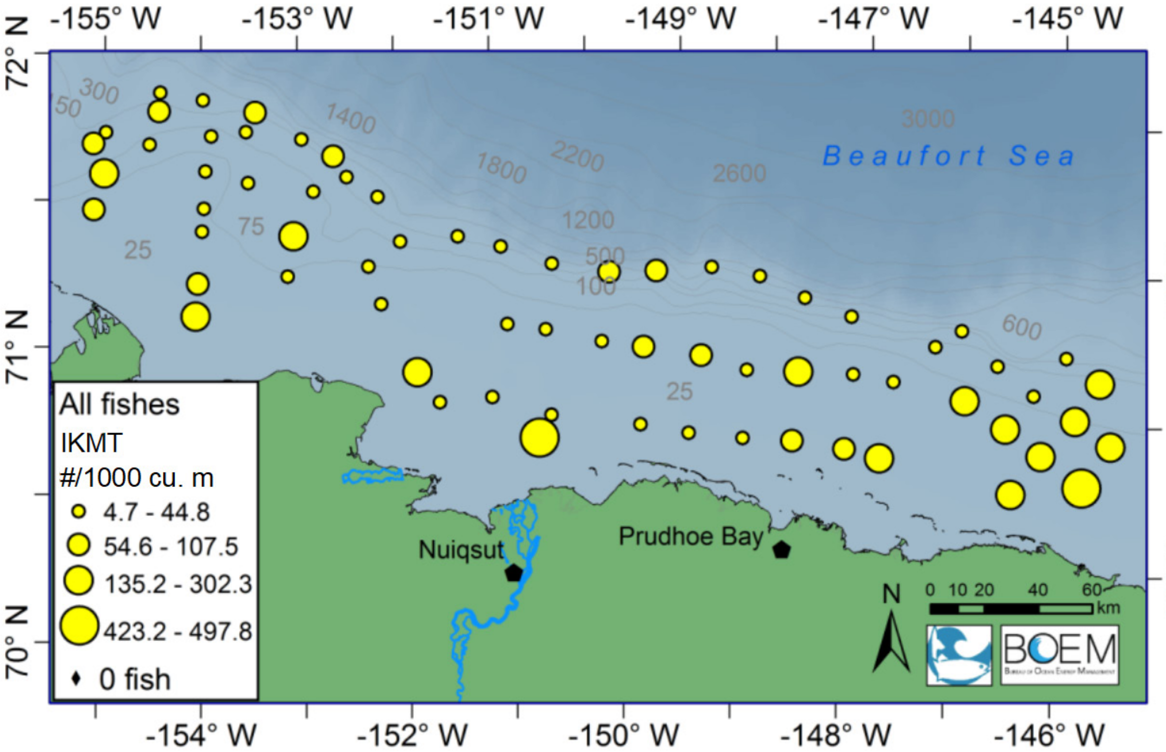


Figure 2-3 **Density of All Fish Taxa Captured by Isaacs-Kidd Midwater Trawl**

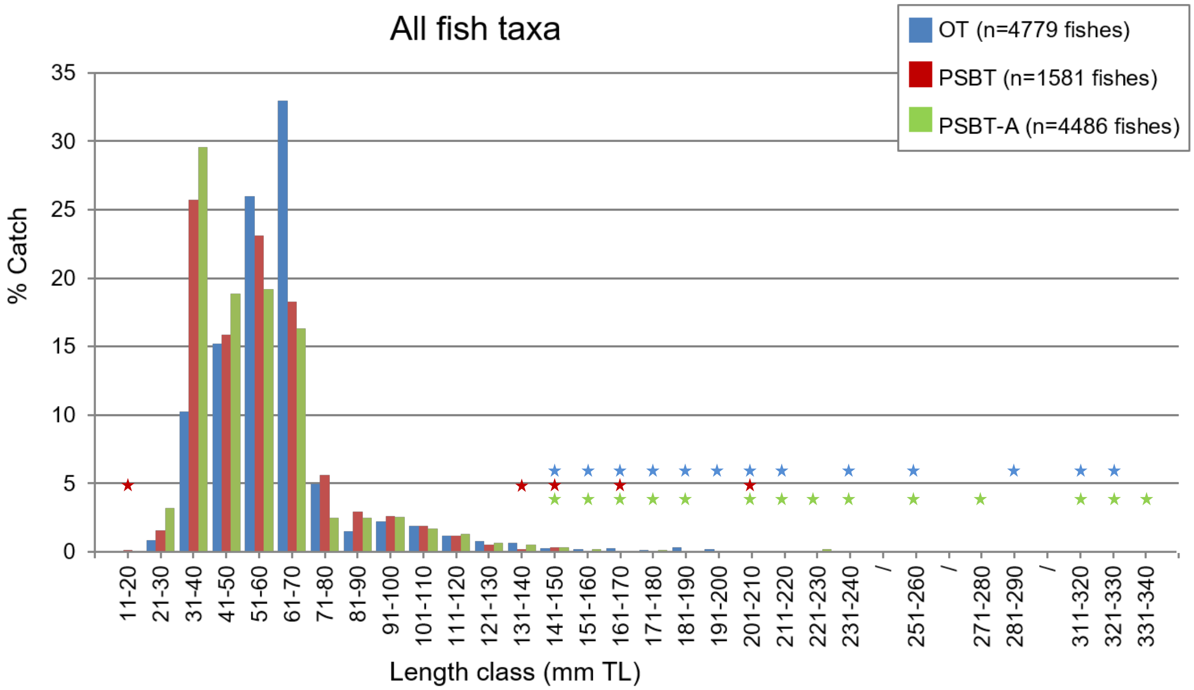
2.3.1.2 Demersal Fishes

2.3.1.2.1 Bottom Trawl Comparisons

Fishes were collected from 79 of the 81 stations. Sampling effort was not equal by gear; successful hauls that were quantified by distance CPUE were: OT = 32, PSBT = 13, PSBT-A = 68 (**Figure 2-5**, **Table 2-1**). There were twice as many PSBT-A hauls as OT hauls, yet only about 25% more species were taken by PSBT-A. Likewise, though only 25% as many hauls were made by the PSBT as the PSBT-A, the PSBT was able to capture two-thirds of the species captured by the PSBT-A (**Table 2-3**). All species caught by the PSBT were also caught by the PSBT-A. No fish species were captured that were unique to the PSBT, though the OT captured *Mallotus catervarius* and two *Lycodes* species that were not captured by the other gears. The more numerous hauls taken by the PSBT-A yielded nine fish species not captured by either of the other gears: three Cottidae, two Agonidae, one Liparidae, two Zoarcidae, and one Pleuronectidae larva (**Table 2-3**). Despite these differences, the patterns of accumulation of aggregated taxa were very similar among gears (**Figure 2-6**). The mean cumulative number of taxa was 23 ±1.3 over 32 OT hauls, 18 ±1.6 over 13 PSBT hauls, and 29 ±1.6 over 68 PSBT-A hauls. Observed differences among catches by these gears were likely biased by the unequal quantity of deployments, geographic extents, and habitats at which gears were deployed (**Table 2-1**).

Comparison hauls were focused on determining equivalence of catches by PSBT and PSBT-A trawls. There were 15 stations during the BOEM-2011 cruise at which more than one haul was made with a plumb staff beam trawl (PSBT and / or PSBT-A) (**Figure 2-5**). Two hauls were made at 13 of these stations, and three hauls were made at the remaining two stations. That enabled one comparison of replicate hauls of the PSBT, 12 comparisons between replicate hauls of the PSBT-A, and six comparisons between the two beam trawls. Of the 19 total statistical comparisons of CPUEs, there were no significant differences (adjusted $p = <0.003$) between any pairings of gear within a given station (**Table 2-6**). As there was no significant difference in quantitative catch between the PSBT and PSBT-A gears, all analyses beam trawl catch data were combined.

Proportional catch of all fish species were examined for the three bottom trawls (**Figure 2-4)**. At least 98% of the catch (**Table 2-4**) of each trawl was of fish smaller than 135 mm; the maximum lengths of captured fishes were 325 mm for OT, 205 mm for PSBT, and 335 mm for PSBT-A. It was expected that the otter trawl – with a codend liner mesh five times as large as that of the beam trawls – would capture larger fish, but this was not always the case. The most notable difference was that larger numbers of 35 mm fishes were caught by the beam trawls, whereas higher catches of 65 mm fishes were caught by otter trawl. There were some differences among sizes and abundances of fish species captured by bottom trawls (**Appendix F**).



Catch is standardized to count per 1000 m towed. * indicates catch ≤0.05%.

Figure 2-4 Frequency of Lengths of Fishes Captured by Bottom Trawls, all taxa combined

Table 2-4 Length Ranges of Most Abundant Species by Gear (# of Tows)

	Otter trawl (32)				PSBT (13)				PSBT-A (68)			
Taxa	**N**	**Range (mm)**	**Mode (mm)**	**%**	**N**	**Range (mm)**	**Mode (mm)**	**%**	**N**	**Range (mm)**	**Mode**	**%**
All species	4,779	25-325	65	30	1,581	15-205	35	25	4,486	25-335	35	25
Gadidae												
Boreogadus saida	3,593	225-325	65	40	278	25-205	65	45	1,678	25-335	65	30
Cottidae												
Gymnocanthus tricuspis	151	25-115	35	60	223	35-85	35	85	781	25-125	35	75
Icelus spp.	139	35-85	45	45	102	25-85	45	40	180	25-95	45	40
Myoxocephalus scorpius	71	25-165	55	70	100	15-95	55	60	157	25-125	55	55
Agonidae												
Aspidophoroides olrikii	102	35-105	45	35	106	35-65	45	50	157	25-75	45	55
Liparidae												
Liparis spp.	384	25-185	35	65	207	25-105	35	70	733	22-225	35	60
Liparis fabricii	8	35-145	35	55	1	65	65	100	19	25-155	75	20
Liparis gibbus	29	25-155	25	25	13	35-105	35	50	88	25-215	35	55
Liparis tunicatus	14	45-135	55	25	13	35-105	95	30	95	25-125	35	45
Zoarcidae												
Gymnelus hemifasciatus	10	85-145	95	40	31	35-115	75	25	33	45-125	105	20
Gynmelus viridis	9	95-145	115	40	7	75-115	85,95,115	86	1	115	115	100
Lycodes spp.	62	45-325	185	20	56	35-205	45	35	194	35-335	45	15
Lycodes mucosus	7	75-115	95	50	3	45	45	100	7	45-315	85	30
Lycodes polaris	34	45-325	185	35	44	35-165	45	35	122	35-335	45	15
Lycodes raridens	17	45-315	85	40	8	45-85	75	60	53	45-225	75	15
Lycodes reticulatus	0				0				6	45-115	65	50
Lycodes seminudus	4	155-255	255	50	0				3	65-145	65,95	65
Stichaeidae												
Anisarchus medius	44	55-145	125	35	84	55-125	95	25	51	55-155	115	20
Lumpenus fabricii	54	55-195	75	15	238	55-145	65	35	150	55-155	55	40
Pleuronectidae												
Hippoglossoides robustus	7	55-205	55	55	0				9	55-255	55	25

N = Number of Fish Range = min/max lengths Mode = most frequent length class captured % = percentage in modal size class

Table 2-5 List of Fish Taxa Caught by Bottom Trawl Gears Including Quantitative and Non-quantitative Hauls during BOEM-2011

Family	Aggregated taxa (n = 30)	n Taxa in aggregate	Scientific name	PSBT	PSBT-A	OT
Osmeridae	*Mallotus catervarius*	1	*Mallotus catervarius*			x
Gadidae	*Boreogadus saida*	1	*Boreogadus saida*	x	x	x
	Eleginus gracilis	1	*Eleginus gracilis*	x	x	x
Cottidae	*Artediellus scaber*	1	*Artediellus scaber*	x	x	x
	Gymnocanthus tricuspis	1	*Gymnocanthus tricuspis*	x	x	x
	Icelus spp.	2	*Icelus* spp. larvae unid.	o		
			Icelus bicornis		x	x
			Icelus spatula	x	x	x
	Myoxocephalus jaok	1	*Myoxocephalus jaok*		x	
	Myoxocephalus quadricornis	1	*Myoxocephalus quadricornis*		x	
	Myoxocephalus scorpius	1	*Myoxocephalus scorpius*	x	x	x
	Trichocottus brashnikovi	1	*Trichocottus brashnikovi*	x	x	
	Triglops nybelini	1	*Triglops nybelini*		x	
	Triglops pingelii	1	*Triglops pingelii*	x	x	x
Hemitripteridae	*Nautichthys pribilovius*	1	*Nautichthys pribilovius*	x	x	x
Agonidae	*Aspidophoroides olrikii*	1	*Aspidophoroides olrikii*	x	x	x
	Leptagonus decagonus	1	*Leptagonus decagonus*		x	
	Podothecus veternus	1	*Podothecus veternus*		x	
Cyclopteridae	*Eumicrotremus derjugini*	1	*Eumicrotremus derjugini*	x	x	x
Liparidae	*Careproctus reinhardti*	1	*Careproctus reinhardti*		x	x
	Liparis spp.	≥3	*Liparis* spp. unid.	o	o	o
			Liparis bathyarcticus		x	
			Liparis fabricii	x	x	x
			Liparis tunicatus	x	x	x
Zoarcidae	*Gymnelus* spp.	2	*Gymnelus hemifasciatus*	x	x	x
			Gymnelus viridis	x	x	x
	Lycodes spp.	≥5	*Lycodes* spp. unid.	o	o	
			Lycodes mucosus	x	x	x
			Lycodes polaris	x	x	x
			Lycodes raridens	x	x	x
			Lycodes reticulatus		x	
			Lycodes seminudus			x
Stichaeidae	Stichaeidae larvae unid.	≤3	Stichaeidae larvae unid.	o		o
	Anisarchus medius[1]	1	*Anisarchus medius*	x	x	x
	Eumesogrammus praecisus	1	*Eumesogrammus praecisus*		x	x
	Leptoclinus maculatus[1]	1	*Leptoclinus maculatus*	x	x	
	Lumpenus fabricii[1]	1	*Lumpenus fabricii*	x	x	x
	Stichaeus punctatus	1	*Stichaeus punctatus*	x	x	x
Ammodytidae	*Ammodytes hexapterus*	1	*Ammodytes hexapterus*		x	x
Pleuronectidae	*Hippoglossoides robustus*	1	*Hippoglossoides robustus*		x	x
	Limanda sp. larva	1	Limanda sp. larva unid.		x	
	Total stations (hauls)			18(23)	65(89)	41(43)
	Total taxa			≥22	≥35	≥27
	Total unique taxa			0	8	2

Gears are abbreviated: plumb staff beam trawl (PSBT), modified plumb staff beam trawl (PSBT-A), and otter trawl (OT). Taxa were aggregated for subsequent analyses. A taxon contributing to the total number of taxa is indicated by "x" whereas “o” indicates it could possibly be a species not listed in the table.

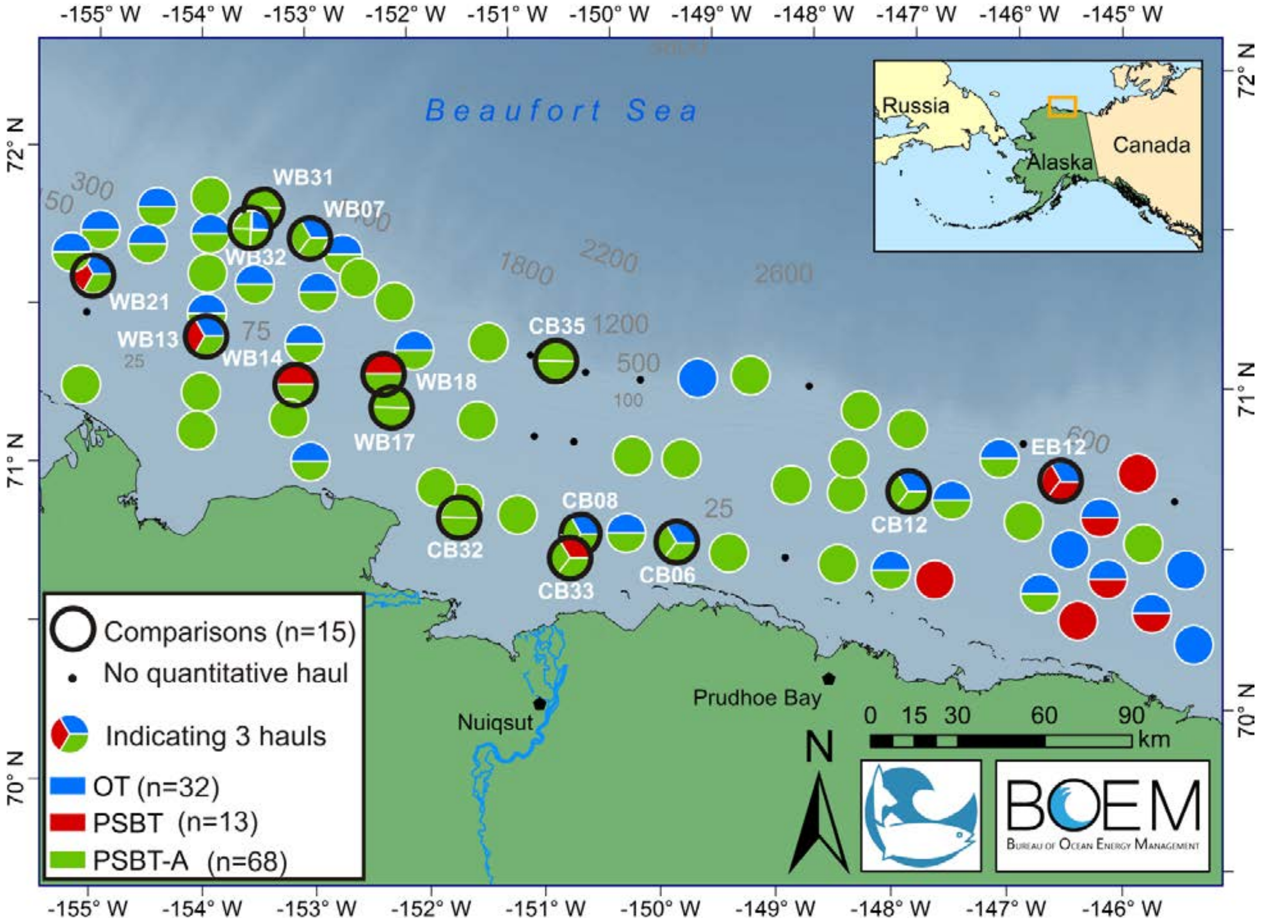
[1] Likely in aggregate of Stichaeidae larvae unid.

Table 2-6 Paired t-tests of Total CPUE between Two Hauls of PSBT and/or PSBT-A at the Same Station during BOEM-2011

Station	Depth (m)	Gear and Haul	CPUE		df	t-stat	P (2-tailed)
			Mean	StDev			
CB32	16	PSBT-A-80	14.5	308.9	6	-3.534	0.012
		-81	22.3	397.1			
CB33	16	PSBT-23	62.6	1,826.7	7	0.733	0.490
		PSBT-A-82	51.0	1,249.6			
		PSBT-23	62.6	1,826.7	7	-0.017	0.990
		PSBT-A-83	63.0	2,383.6			
		PSBT-A-82	51.0	1,249.6	7	-0.980	0.360
		-83	63.0	2,383.6			
CB06	19	PSBT-A-23	24.6	517.2	8	1.364	0.210
		-24	15.7	180.2			
CB08	19	PSBT-A-36	16.6	116.3	6	1.444	0.200
		-37	7.4	28.2			
WB17	24	PSBT-A-41	11.0	266.9	9	-1.890	0.090
		-42	30.0	653.9			
CB12	41	PSBT-A-10	11.1	64.7	7	1.225	0.260
		-11	8.2	30.4			
WB14	41	PSBT-20	35.0	294.5	13	1.755	0.100
		PSBT-A-73	15.9	189.1			
WB13	43	PSBT-18	121.1	5,717.7	13	3.370	0.005
		PSBT-A-69	18.1	328.0			
WB21	48	PSBT-17	101.0	5,271.5	15	1.508	0.150
		PSBT-A-65	53.5	2,253.5			
WB18	51	PSBT-21	8.1	16.1	11	-2.972	0.013
		PSBT-A-79	27.6	185.1			
EB12	68	PSBT-8	0.6	0.5	8	-2.454	0.040
		-9	10.0	48.5			
WB32	83	PSBT-A-49	16.3	111.8	9	0.143	0.890
		-74	15.9	111.4			
		PSBT-A-49	16.3	111.8	9	1.566	0.152
		-75	9.3	41.2			
		PSBT-A-74	15.9	111.4	9	1.832	0.100
		-75	9.3	41.2			
WB07	183	PSBT-A-47	2.5	14.3	4	-1.219	0.290
		-77	19.3	593.1			
WB31	183	PSBT-A-48	4.5	5.9	6	-0.699	0.511
		-76	7.3	34.3			
CB35	223	PSBT-A-88	9.4	72.2	10	-0.998	0.342
		-89	11.5	78.8			

Stations are in order by depth. The number after the gear is the consecutive haul. CPUE is # fish per 1,000 m2. There are no significant differences (adjusted $p<0.003$).

Plumb Staff Beam Trawl = PSBT Modified Plumb Staff Beam Trawl = PSBT-A



Within-station catch differences were compared at 15 stations where multiple PSBT and/or PSBT-A hauls were taken; catch differences by OT were also examined at two stations. Stations with comparison hauls are circled in black and labeled with station name.

Figure 2-5 Map of All Hauls during BOEM-2011 Where Specimen Lengths Were Examined

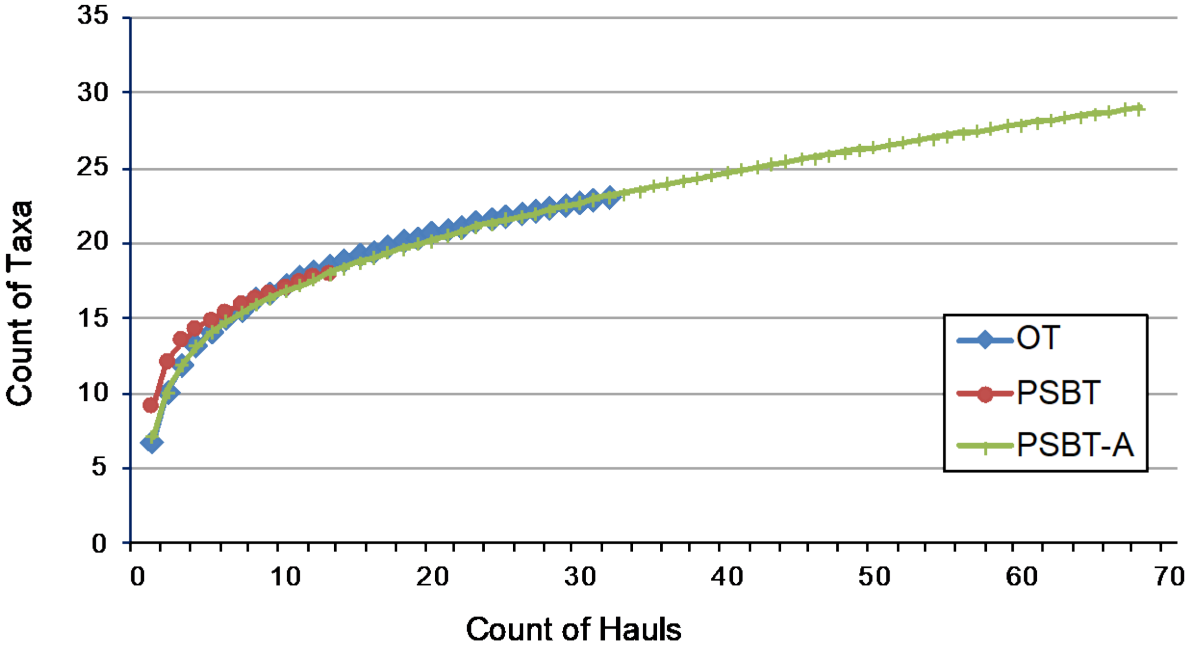


Figure 2-6 **Cumulative Number of Fish Taxa Caught by Bottom Trawl Gears Based on Presence Observed in Quantitative Hauls during BOEM-2011 by Otter Trawl, Plumb Staff Beam Trawl, and Modified Plumb Staff Beam Trawl**

2.3.1.2.2 Otter Trawl (OT) Catch

The otter trawl captured 5,316 fish from 11 families (**Table 2-3**). Within-station diversity was high, and evenness was low. While the percentage abundance and percentage biomass tracked closely at most stations, the biomass of liparids was comparatively higher than expected from abundance proportions at a few stations. The abundance and biomass of fish captured by otter trawl was greatest in the west (**Figure 2-8**). Gadids accounted for more than half of the abundance and biomass (**Figure 2-7**). Cottids were more evenly distributed across the sample range than gadids. Zoarcids were much less evenly distributed than gadids; they were absent from half of the stations. Catches of other fish families were quite small (**Appendix Tables C2.2.1–2; Figures C2.2.1–28)** compared to Gadidae, Cottidae and Zoarcidae (**Figure 2-1**), their density and biomass distribution patterns reveal little. Only Liparidae is of interest in that stations in the west with little abundance had unexpectedly high biomass indicating catches of few individual fish; each of which was relatively heavy (**Appendix Table C2.2.1–2; Figure C2.2.15**).

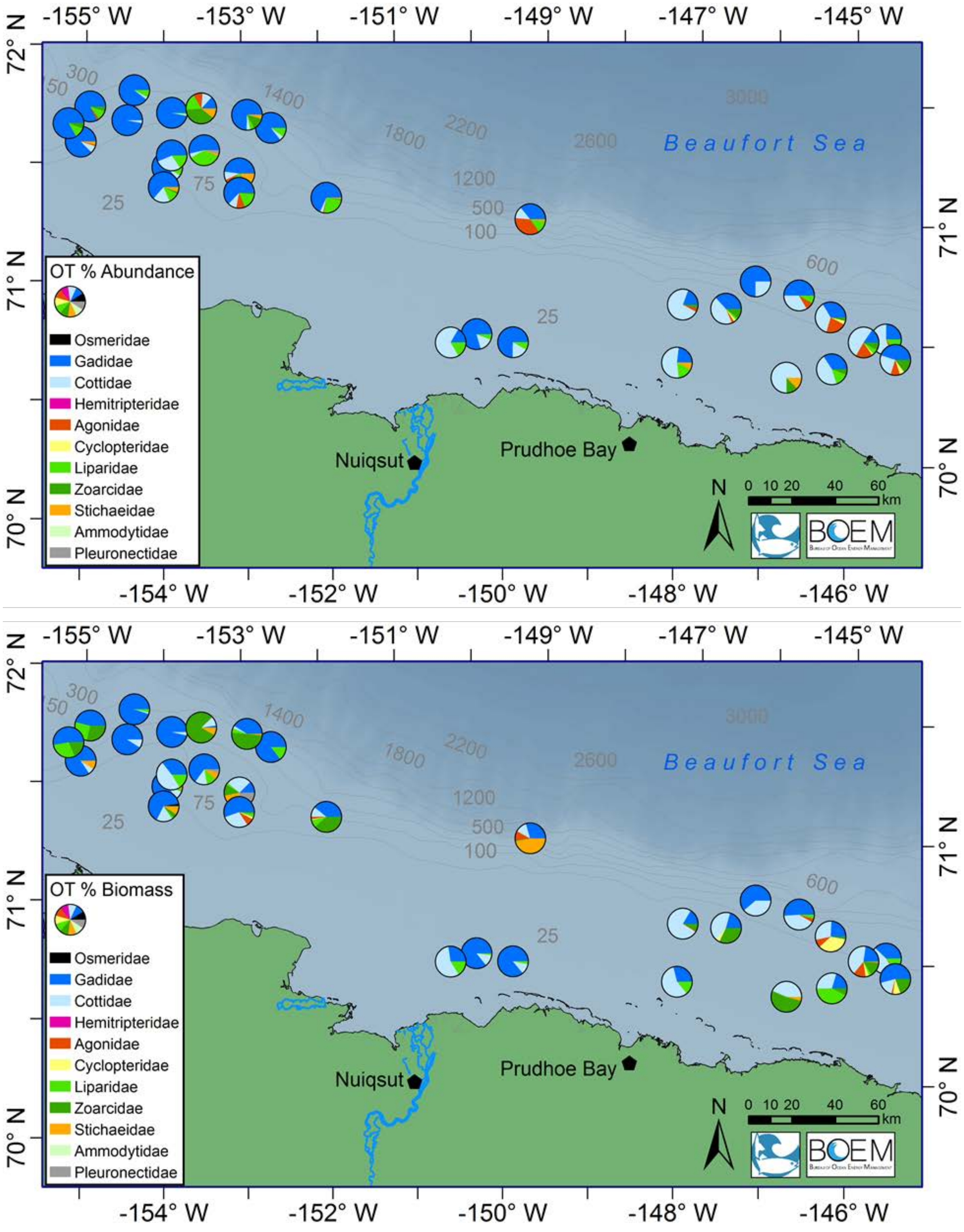


Figure 2-7 **Proportional Composition of Abundance (Upper) and Biomass (Lower) of Fish Families Captured at Each Station by Otter Trawl**

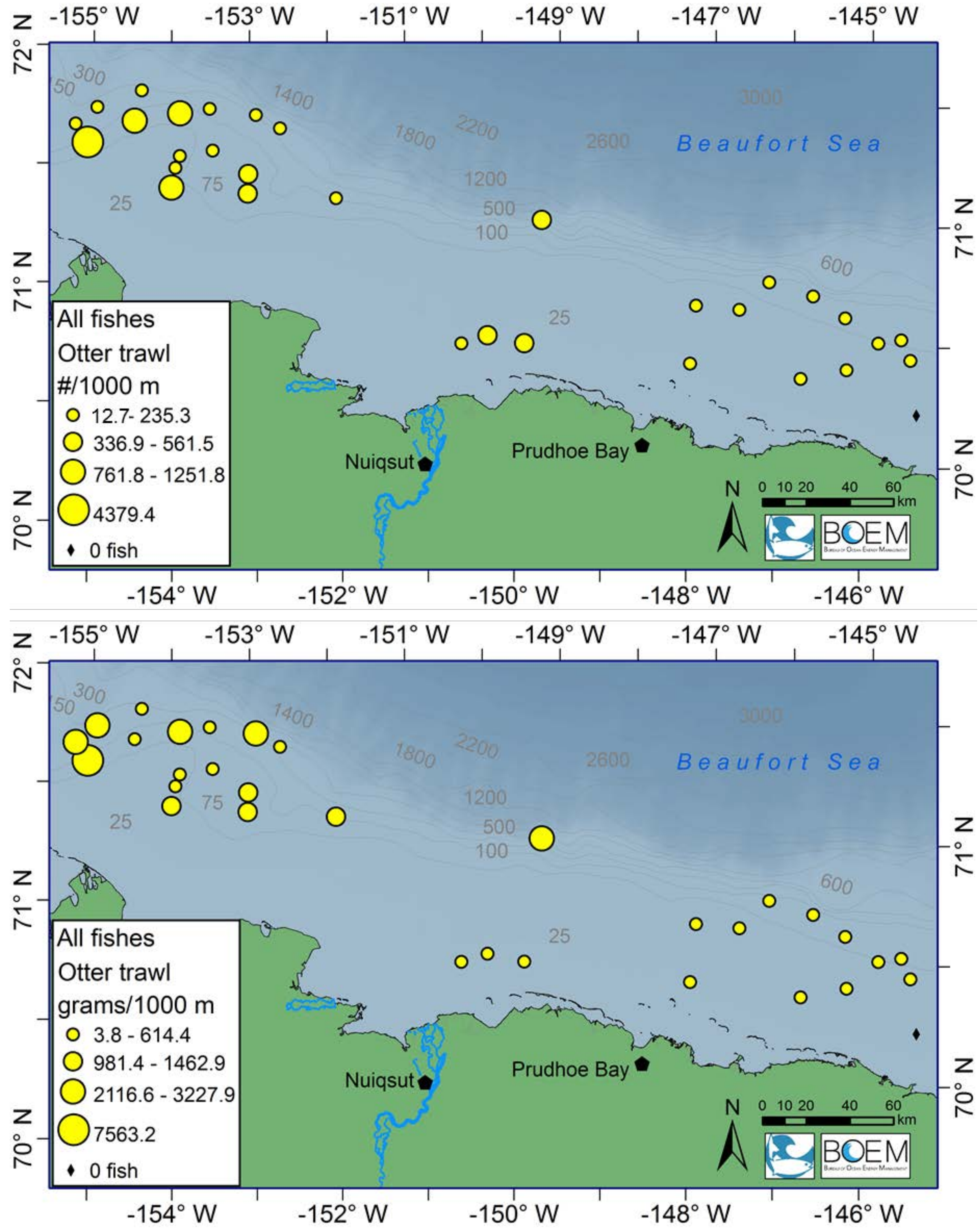


Figure 2-8 Density (Upper) and Biomass (Lower) of All Fish Taxa Captured by Otter Trawl

2.3.1.2.3 Beam Trawl (BT) Catch

Together the beam trawls caught 6,406 fish in 10 families and 30 taxa in 79 stations. The PSBT had 13 quantitative hauls out of 23 hauls at 15 stations and captured 1,651 fish, while the PSBT-A had 68 quantitative hauls out of 89 hauls at 64 stations and captured 4,755 fish. As we showed that there was no difference in quantitative CPUE between the two beam trawls (Section 2.3.1.2.1), all analysis was conducted on BT combined. The patterns of distribution of all fishes combined were unlike those seen in the other gear types. While the density of fishes was greatest at stations from 154°W westward, the biomass was greatest at stations in that area and along the shelf break from 151°W westward (**Figure 2-10**). In beam trawl catches, Gadidae, Cottidae and Liparidae had both abundance and biomass greater than 10% of the total catch while Zoarcidae had that only by biomass alone. Gadidae were captured at all but two stations, with highest density in the western stations on the shelf. Cottidae were captured across the entire study area except in the northwestern-most stations at the shelf break; the highest abundance and biomass was at western stations. Liparidae and Zoarcidae biomass was comparatively higher than abundance at the shelfbreak than at nearshore stations. Pleuronectids were somewhat of interest because of high biomass and very low density (**Figure 2-1**) at one station (**Appendix Figure C2.3.21**). Minimal contribution to beam trawl catches was made by the other fish families (**Appendix Tables C2.3.1–2; Figures C2.3.1–35**).

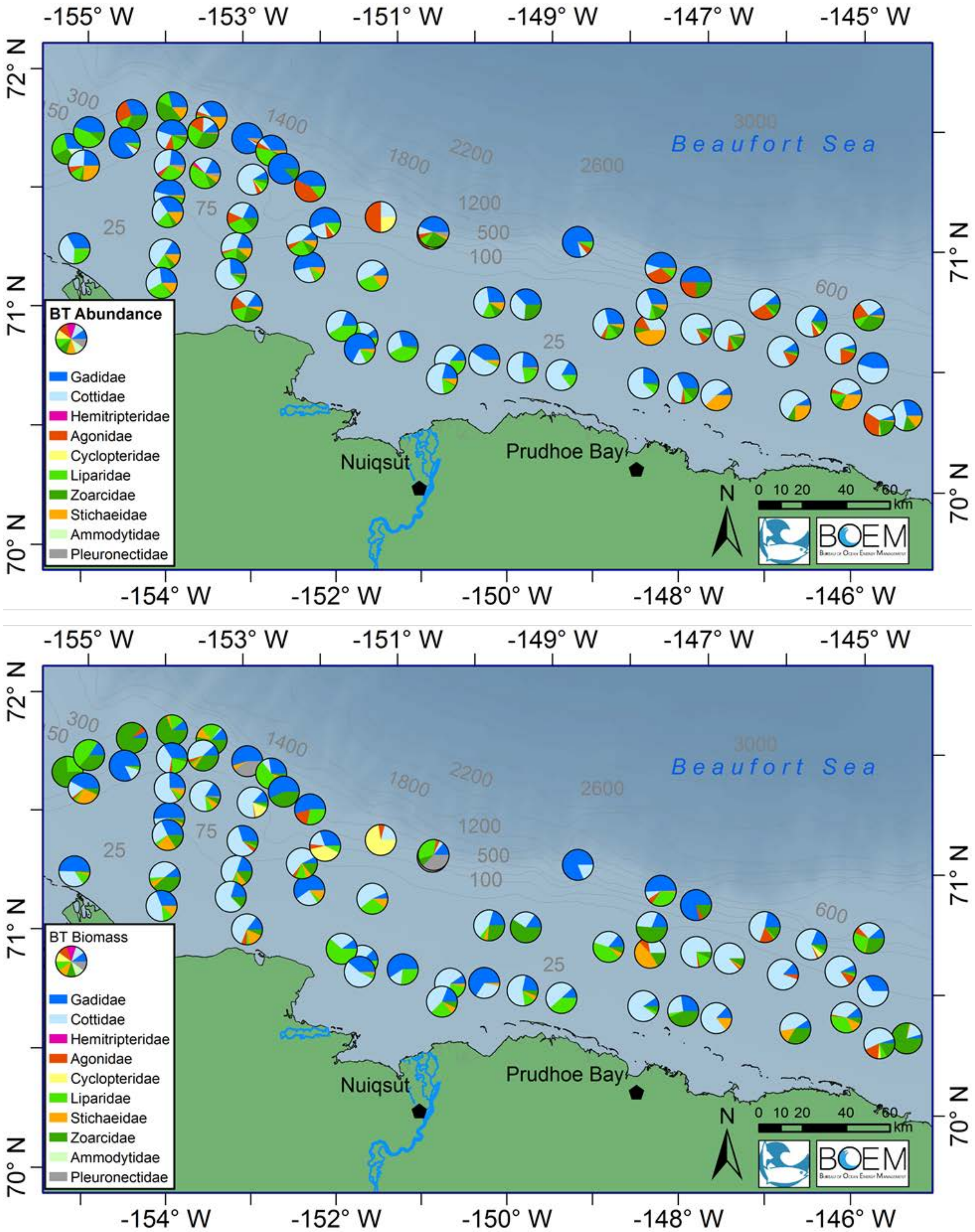


Figure 2-9 **Proportional Composition of Abundance (Upper) and Biomass (Lower) of Fish Families Captured at Each Station by Beam Trawls**

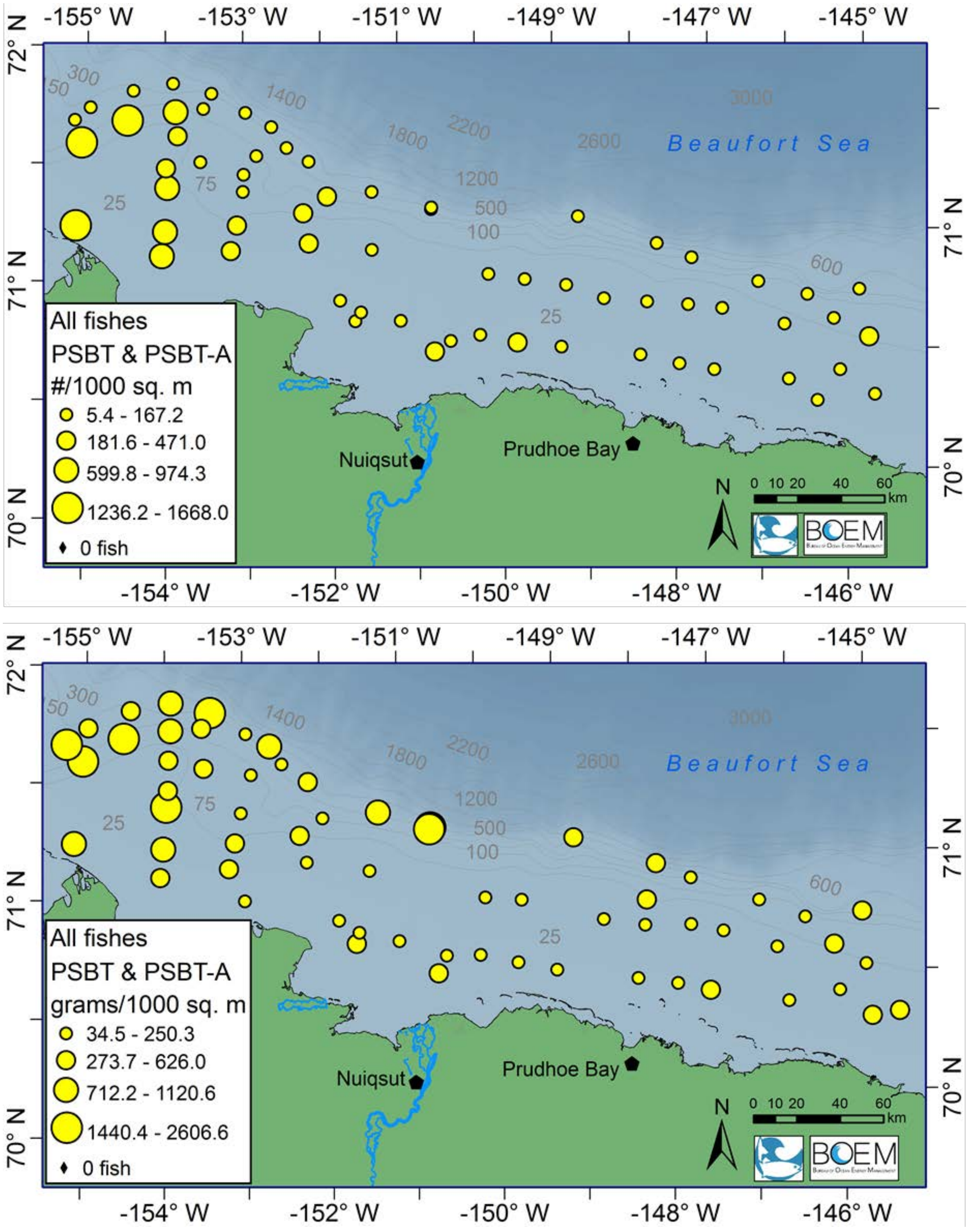


Figure 2-10 **Density (Upper) and Biomass (Lower) of All Fish Taxa Captured in the Beaufort Sea in 2011 by Beam Trawls**

2.3.2 Discussion

What the Beaufort-2011 program observed during the single year survey was a predominance of cods and sculpins across the entire shelf, with some differences in distribution of density and biomass. Patterns of numbers of fishes collected on the bottom were opposite to those collected in midwater. The density of demersal fishes captured by BT was greatest from 154ºW and westward in the Beaufort Sea (**Figure 2-10)**. Similarly, density of fishes captured by OT was greatest west of 153ºW (**Figure 2-8**). In contrast, the density of small, often larval midwater fish was greatest at two nearshore stations at ~151º and 145ºW (**Figure 2-3**).When comparing our results to the historical context we found some similarities and differences in species of fish captured (**Table 2-2**). We found species compositions similar to surveys conducted along the shelf and shelf break (Frost and Lowry 1983, Logerwell et al. 2011, Rand and Logerwell 2011). Despite the longitudinal and depth differences in areas surveyed, 20 species captured along the shelf historically (1970s to 2010s) were also captured in this program. Conversely, differences in depth and gear made assessing disparities between shelf and nearshore communities difficult. There appears to be little taxonomic overlap in fishes occupying the Beaufort Sea shelf and the area very nearshore, which was sampled in the 1970s (**Table 2-2**). We found 10 species that occurred historically in those nearshore areas, but in our survey they occurred farther out on the shelf in areas where some historical surveys were unable to sample (Craig et al. 1985, Fechhelm et al. 2010, LGL 1999, Thorsteinson et al. 1992). Historic data from the nearshore region suggests that large Salmonidae are common, however, our gear was not designed to capture large anadromous fish.

Knowledge of the distribution of fishes in the Beaufort Sea provides insight and a basis for analysis of other components of this research, e.g., the stomach contents of fish (**Chapter 5**). The contribution of this current research brings the total number of species known to have been caught in the Beaufort Sea since the mid-1970s to 1974. We expect that number to increase with the addition of fish species captured in the BOEM US-Canada Transboundary fish cruises in 2012, 2013, and 2014.

3 Demersal Fish Communities

3.1 Introduction

Fish communities are groups of species that respond similarly to environment cues (Tyler et al. 1982; Overholtz and Tyler 1985) and consist of mainly the same group of species in comparable proportions over time, although their geographical distribution might change (Fossheim et al 2006). Surveys of bottom fishes have the potential to provide information about fish communities over broad areas as well as environmental parameters (Ellis et al. 2000). Surveying bottom fishes on the Beaufort Sea shelf has been limited to a broad but sparse sampling since 1976–77 (Frost and Lowry 1983) and a relatively dense sampling in the western Beaufort Sea in 2008 (Logerwell et al. 2011, Rand and Logerwell 2011). Neither of those studies, however, assessed fish communities.

The extensive and inclusive sampling of this project allowed us to explore fish communities in the Beaufort Sea. In **Chapter 2** we described the distribution patterns of fish density and biomass in the Beaufort Sea based on collections by midwater and bottom trawls in 2011. Sampling across 200 km of the Beaufort Sea coast, the study was much more comprehensive than previous studies. The objective of this chapter is to describe the composition of fish communities in the Beaufort Sea based on CPUE of fishes collected by midwater and bottom trawls in 2011, and the corresponding BPUE of bottom trawl collections. As described in **Chapter 2**, we caught midwater fishes with an IKMT and demersal fishes, which are fishes that spend most of their time on or near the seafloor, with PSBTs and OTs. Though demersal fishes are caught together with an assortment of epibenthic invertebrates that are predator, prey, and competition, epibenthic invertebrates were not part of this BOEM-funded project and were analyzed separately (Ravelo et al. 2015). However, the comprehensive collection of environmental data that accompanied each haul allowed us to define physical characteristics associated with the fish community assemblages. Such information will support an improved understanding of the ecosystem of the Beaufort Sea shelf.

3.2 Methods

3.2.1 Sample Collection

A conductivity, temperature, density (CTD) cast was made at each station when weather permitted.

Bottom temperature and salinity data were available at 60 of 64 BT stations, and substrate was available at 61 of 64 BT stations. OT were used at 32 stations. Of these, 31 had valid bottom temperature and salinity data, and 30 had associated substrate samples. Gaps in data represent sampling times where poor weather prevented deployment of the Van Veen grab. When possible, a sample of the surface layer of substrate was frozen and returned to the University of Alaska Fisheries Oceanography Laboratory in Fairbanks, Alaska for grain size analysis (Folk 1980). In the laboratory, sediment samples were thawed, wet-sieved and dried, and then proportional dry weight was calculated for gravel, sand, and mud. Particle sizes were classified by the Wentworth grain-size scale, and the mud component was subdivided into silt and clay (Sheppard 1973).

When multiple hauls with a PSBT or PSBT-A were conducted at the same station, catches were averaged to produce one catch value per station. BT hauls were considered solely qualitative if net damage during the tow led to loss of catch or altered the net dimensions, overfull codend occurred, a high proportion of pelagic rather than demersal animals was collected, or the catch was compromised due to problems with net launch or retrieval. Qualitative hauls were included in the biodiversity analysis but excluded from all other analyses; the rationale was to be comprehensive and not lose information by ensuring the breadth of species for biodiversity.

As with all bottom trawl collections, it is possible that some fishes were captured off the sea floor. Nets are open during setting and retrieving as well as while on the bottom. The OT is larger with a higher net opening than the BT; therefore, it is more likely to catch fishes that are higher off the bottom. Fishes generally considered to be demersal may also be caught in midwater, including larval and early juvenile stages of cods, sculpins, poachers, snailfishes, pricklebacks and flatfishes, and late juvenile and adult cods, all of which can be present in large numbers in the water column during the same timeframe they are caught near the sea floor. Larval and early juvenile stages of some species of deepwater snailfishes and eelpouts (Mecklenburg et al. 2002), and shallower eelpouts, develop at the same depths the adults inhabit (Matarese et al. 1989), so their presence in our BT and OT catches was most likely due to bottom contact. Regardless, there is no way to assess with certainty whether fishes were caught in the water column or on the sea floor. For BT, OT, and IKMT community analyses, we included all fish species that were caught in quantitative hauls. In addition to the demersal fishes, we included the pelagic species, *Mallotus catervarius,* of which only three individuals were caught by OT (**Table 3-1**).

3.2.2 Statistical Analyses

Bottom temperature and salinity data were examined using both cluster analyses and standard potential density plots to delineate bottom water masses. Temperature and salinity data were normalized and Euclidean distances were calculated between stations, as is appropriate for physical data (Clarke and Gorley 2006). Cluster analysis, which is commonly employed by biologists and ecologists, was used to delineate water masses. Water masses were identified using potential density plots derived from temperature and salinity (Ocean Data View v.2.3.3, Schlitzer 2007), a standard oceanographic technique that is described in **Appendix A1**.

Biodiversity was examined for each gear type using a suite of standard indices (DIVERSE, PRIMER v.7) for each of the three gear types. Richness is the total number of fish taxa at each sample site and is dependent upon the sampling effort, i.e., the longer a net is deployed, the more likely a different species will be captured. We used a richness index that is not biased by the sample size and that considers the number of taxa (S) present for a given number (N) of individuals captured: Margalef index: $d = (S-1)/\log(N)$. A smoothed species accumulation (rarefaction) curve was generated from the number of distinct taxa captured with respect to the number of hauls; 999 permutations of the data were run. The smoothed curve represented the statistical expectation for the number of species that would be caught for a given number of hauls (Gotelli and Colwell 2001). Diversity indices provide information in addition to richness because they consider the relative abundance of individual species, i.e., each species captured compared to all species captured at a station (Clarke and Gorley 2006). When all taxa are equally abundant, the taxonomic diversity is maximized and Pielou’s evenness (J’) is maximized (Clarke and Warwick 2001). We did not use the standard Shannon diversity index because our sampling design was not equal, which could affect the Shannon index. We used Simpson’s diversity index because it corrects for bias. Simpson’s diversity is the probability that two individuals randomly selected from a sample are different species (Clarke and Warwick 2001): $1-\lambda' = 1-\mathrm{SUM}(Ni*(Ni-1)/(N*N-1))$. The value is always <1 and the higher the value, the more diverse and even the sample. Maps were created to show spatial patterns of richness and diversity (ArcMap v. 10.2, ESRI 2010). Most groupings were approximately equal-space intervals, with the smaller class sizes assigned in places to visualize more subtle differences in richness and diversity within the large number of hauls.

To analyze fish assemblages, we used fourth root (4RT) transformations to construct Bray-Curtis dissimilarity coefficients used in cluster and similarity analyses (see **Appendix E** for additional Transformation effects). Cluster analysis was used because it resolves inter-species associations allowing an examination of community structure (as adapted from Doyle et al. 2002). A hierarchical cluster analysis for 999 permutations identified fish assemblages that grouped stations according to their taxa composition. The resulting dendrogram displayed stations progressively aggregated into smaller numbers of groups containing more stations. Cluster analysis may find groups even if they are not relevant in nature, i.e., it is possible for random data to produce groups. We used SIMPROF (PRIMER v.7) to introduce some rigor as an *a posteriori* test of significance of dissimilarities among cluster groups ($p<0.05$, $p<0.01$, or $p<0.005$). The significance level used was chosen to represent fish groups but not to create so many clusters as to render the results meaningless. A Similarity Profile test (SIMPROF, PRIMER v.7) is a permutation test of the null hypothesis (Clarke and Gorley 2006), i.e., it tests whether distributions of fishes are equal. SIMPROF was used to test the significance of each grouping of fish taxon density that resulted from the cluster analysis. When the statistical test of clusters (SIMPROF) is not significant, further differentiation should not be considered (Clarke et al. 2008). Alternatively, it may be appropriate to group supersets of statistically different clusters when cluster analysis results in only one or two stations, as those might not be valid groups (Clarke et al. 2008). RELATE (PRIMER v.7) compares resemblance matrices of each combination of two transformations.

Species that were good discriminators within designated fish community groups were identified using Similarity Percentage (SIMPER, PRIMER v.7). SIMPER provides a statistical mechanism to show similarities within cluster groups. This test is a breakdown, by taxa, of Bray-Curtis similarities within groups. SIMPER can characterize groups and be used to compare between groups. The objective was to find typicality, i.e., what species typify group A and not group B, and vice versa. The result was a list, in decreasing order, of each species' contribution to a fish community group.

Non-metric multidimensional scaling plots (nMDS; Kruskal 1964) were used to examine patterns among sample groups. nMDS ordination plots have no numerical interpretable axes, are based on simple matching coefficients calculated between pairs of species, and describe the precise biotic relationships among samples (Clarke et al. 2008; Somerfield et al. 2008). A stress of <0.1 is considered to be a good fit, while a stress of <0.2 is potentially useful (Clarke and Warwick 2001). nMDS ordinations were presented of fish density assemblages for each transformation (nMDS, PRIMER v. 7). Bubble plots of *B. saida* were plotted on the same nMDS representations of fish assemblages.

Analysis of Similarity (ANOSIM, PRIMER v.7) was used to estimate differences in species abundance and composition relative to bottom depth, bottom temperature, bottom salinity, longitude, latitude, sediment (category), and water mass (category). ANOSIM is a nonparametric, multivariate permutation test, somewhat analogous to the parametric, univariate ANOVA (Clarke et al. 2014). ANOSIM treatment groups were defined *a priori,* i.e., they were the environmental factors examined. Multiple 1-way ANOSIMs were run because the habitat parameters were not symmetrical; the Bonferroni adjustment was not applied to ANOSIM.

Bray-Curtis dissimilarity matrices of transformed CPUE values for each taxon at each station were used for ANOSIM calculations. To provide the best reasonable result, 999 permutations were run for each ANOSIM. An R statistic, defined as a comparison of the average between-group rank similarity to the average within-group rank similarity, was calculated using the following formula:

$$R = \frac{\left(\bar{r}_B - \bar{r}_W\right)}{n(n-1)}$$

where $\bar{r}_B$ and $\bar{r}_W$ are the average rank similarities for each pair of intervals between and within groups, respectively, and n is the sample size. The R value is between -1 and 1, and the closer R is to 1, the more distinct the groups are (Clarke et al. 2014).

Environmental variables were matched with fish community structure (based on abundance and biomass, 4RT) to assess which variable combination was most influential in determining community composition. The Biota and/or Environment + STepwise matching test (BEST, PRIMER v. 7) identifies the 'best' match between the multivariate fish assemblage patterns and the environmental variables associated with those samples (Clarke and Gorley 2006). Determination of the best subset of correlated variables, i.e., habitat characteristics, was based on the highest overall Spearman rank correlation. However, fewer explanatory parameters are preferable when minimal improvement in correlation would be gained by including additional parameters. Habitat characteristics of fishes at each station were examined using latitude, longitude, bottom temperature (ºC), bottom salinity, bottom depth (m), percent gravel, percent sand, and percent mud. In all of these analyses, biological data were 4RT transformed and environmental variables were normalized to bring them to the same measurement scale.

Table 3-1 Fishes Captured in the Beaufort Sea in 2011 by BT, OT, and IKMT

Family - Scientific (common)	Analysis Level	Scientific Name	Common Name	BT	OT	IKMT
Osmeridae (smelts)	*Mallotus catervarius*	*Mallotus catervarius*	Pacific Capelin		x	
Gadidae (cods)	*Boreogadus saida*	*Boreogadus saida*	Arctic Cod	x	x	x
	Eleginus gracilis	*Eleginus gracilis*	Saffron Cod	x	x	x
Cottidae (sculpins)	*Artediellus scaber*	*Artediellus scaber*	Hamecon	x	x	
	Gymnocanthus tricuspis	*Gymnocanthus tricuspis*	Arctic Staghorn Sculpin	x	x	x
	Icelus spp.	*Icelus bicornis*	Twohorn Sculpin	x	[2] x	
		Icelus spatula	Spatulate Sculpin	x	x	x
		Icelus spp. unid.		o		o
	Myoxocephalus jaok	*Myoxocephalus jaok*	Plain Sculpin	x		
	Myoxocephalus quadricornis	*Myoxocephalus quadricornis*	Fourhorn Sculpin	x		x
	Myoxocephalus scorpius	*Myoxocephalus scorpius*	Shorthorn Sculpin	x	x	x
	Trichocottus brashnikovi	*Trichocottus brashnikovi*	Hairhead Sculpin	x		
	Triglops nybelini	*Triglops nybelini*	Bigeye Sculpin	x		
	Triglops pingelii	*Triglops pingelii*	Ribbed Sculpin	x	x	x
	Cottidae larvae unid.	Cottidae larvae unid.	Larval sculpins, unid.			o
Hemitripteridae (sailfin sculpins)	*Nautichthys pribilovius*	*Nautichthys pribilovius*	Eyeshade Sculpin	x	x	
Agonidae (poachers)	*Aspidophoroides olrikii*	*Aspidophoroides olrikii*	Arctic Alligatorfish	x	x	x
	Leptagonus decagonus	*Leptagonus decagonus*	Atlantic Poacher	x		
	Podothecus veternus	*Podothecus veternus*	Veteran Poacher	x		
Cyclopteridae (lumpsuckers)	*Eumicrotremus derjugini*	*Eumicrotremus derjugini*	Leatherfin Lumpsucker	x	x	
Liparidae (snailfishes)	*Careproctus reinhardti*	*Careproctus reinhardti*	Sea Tadpole	x	x	
	Liparis spp.	*Liparis bathyarcticus*	Nebulous Snailfish	x		x
		Liparis fabricii	Gelatinous Seasnail	x	x	x
		Liparis tunicatus	Kelp Snailfish	x	x	x
		[1] *Liparis* spp. unid.	*Liparis* spp., unid.	o	o	o
Zoarcidae (eelpouts)	*Gymnelus* spp.	*Gymnelus hemifasciatus*	Halfbarred Pout	x	x	
		Gymnelus viridis	Fish Doctor	x	x	
	Lycodes spp.	*Lycodes mucosus*	Saddled Eelpout	x	x	
		Lycodes polaris	Canadian Eelpout	x	x	
		Lycodes raridens	Marbled Eelpout	x	x	
		Lycodes reticulatus	Arctic Eelpout	x		
		Lycodes seminudus	Longear Eelpout		x	
		[1] *Lycodes* spp. unid.	*Lycodes* spp., unid.	o		
Stichaeidae (pricklebacks)	*Anisarchus medius*	*Anisarchus medius*	Stout Eelblenny	x	x	x
	Eumesogrammus praecisus	*Eumesogrammus praecisus*	Fourline Snakeblenny	x	x	
	Leptoclinus maculatus	*Leptoclinus maculatus*	Daubed Shanny	x		
	Lumpenus fabricii	*Lumpenus fabricii*	Slender Eelblenny	x	x	x
	Stichaeus punctatus	*Stichaeus punctatus*	Arctic Shanny	x	x	x
	Stichaeidae larvae unid.	[3] Stichaeidae larvae unid.	Larval pricklebacks,	o	o	o
Ammodytidae (sand lances)	*Ammodytes hexapterus*	*Ammodytes hexapterus*	Arctic Sand Lance	x	x	x
Pleuronectidae (righteye flounders)	*Hippoglossoides robustus*	*Hippoglossoides robustus*	Bering Flounder	x	x	
	Limanda proboscidea	*Limanda proboscidea*	Longhead Dab			x
	Limanda sp. larva, other	*Limanda* sp. larva, other	*Limanda* sp. larva, other	x		
11 Families Captured	32 Taxa Analyzed	≥38 Species Captured		≥35 Spp	≥27 Spp	≥16 Spp

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[1] Specimens are reported at the genus level of precision where identification could not be verified in the laboratory.

[2] *Icelus bicornis* was caught by OT only in non-quantitative hauls, and was excluded from community analyses.

[3] Stichaeidae larvae unid. are of the subfamily Lumpeninae, and may include *Anisarchus*, *Leptoclinus*, and *Lumpenus* spp.

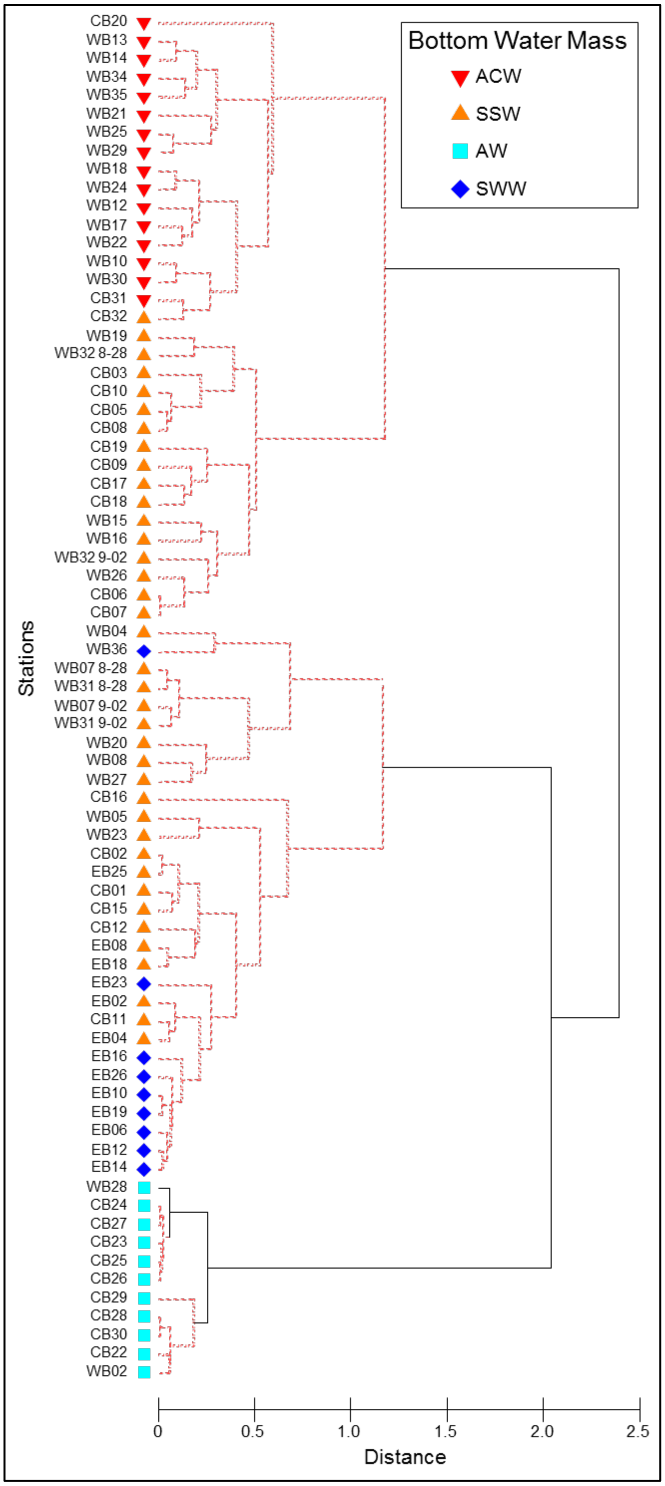
Taxa caught in quantitative and non-quantitative hauls are included. Analysis level is the taxonomic precision used for community composition as identification to species was not possible for all individuals. Taxa counted as number of species captured are indicated by "x" whereas taxa not contributing an additional species with certainty are indicated by "o."

3.3 Results

3.3.1 Environmental Variables

3.3.1.1 Water Masses

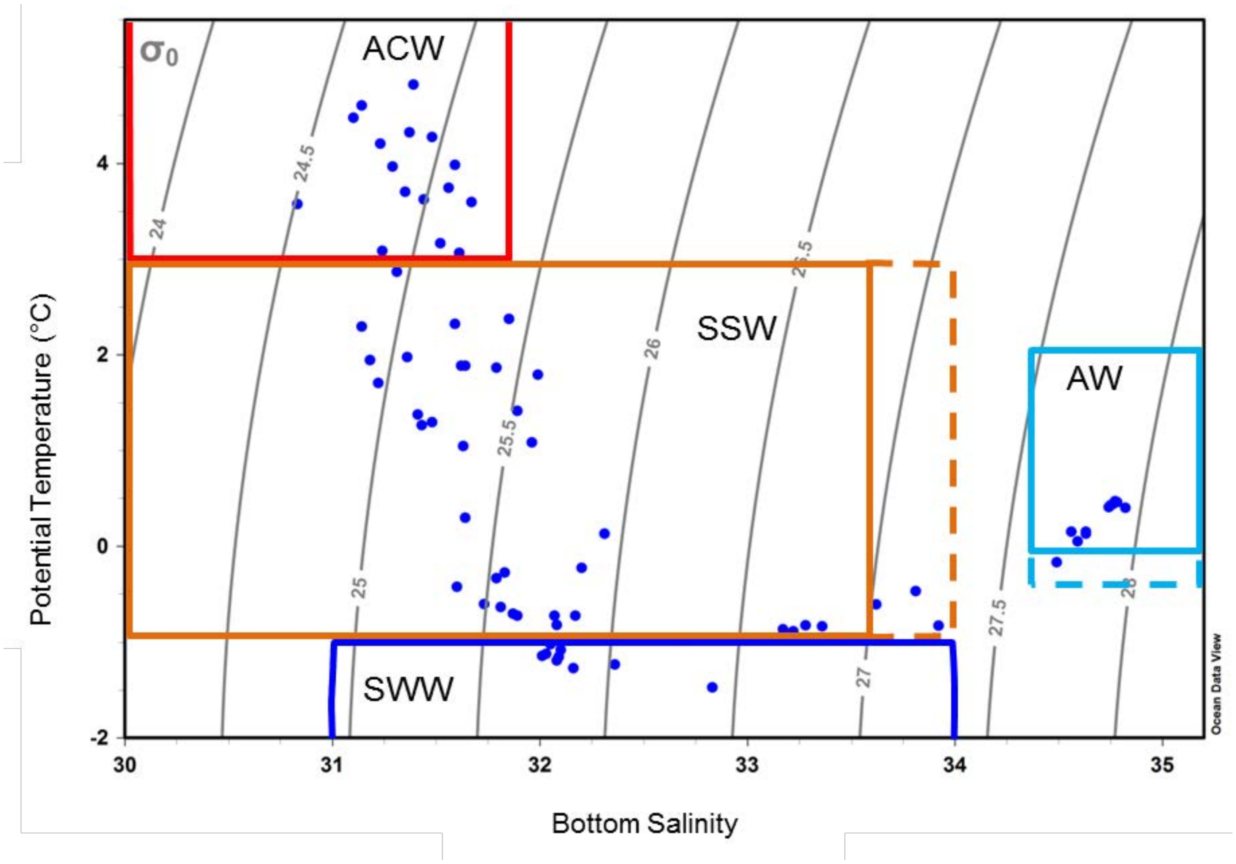
Four bottom water masses were distinguished. Dendrograms showed station grouping by water mass, though not all groupings were significantly different from each other (**Figure 3-1**). Atlantic Water (AW) was statistically different from each of the other three water masses. Alaska Coastal Water (ACW) and Shelf Winter Water (SWW) were statistically different from each other, but Shelf Summer Water (SSW) overlapped both of those groups. Those clusters were used to inform the standard potential density plot and to extend the water mass boundaries beyond those determined by CTD transects (**Appendix A1**) to include all stations where fish were collected (**Figure 3-2**). Distribution of bottom water masses on the Beaufort Sea shelf show west to east patterns (**Figure 3-3**). Warmer near-bottom temperatures (>3°C) and lower near-bottom salinities (<31.5) reveal ACW advected from the eastern Chukchi Sea over the westernmost stations on the Beaufort shelf (**Appendix A1**). SSW extended across almost the entire shelf area sampled from offshore of ACW to inshore of AW; SSW temperatures (-1°–3°C) and salinities (30–34) were intermediate to the values of the water masses surrounding it. SWW covered the easternmost stations, perhaps influenced by wind events immediately preceding collections (**Appendix A1**). Sub-zero temperatures and slightly elevated shelf salinities ($31<S<32.5$) at the bottom across the shelf east of 148°W suggest that the near-bottom shelf waters may be remnant from the previous winter, i.e., SWW (**Appendix A1**). AW was present at the shelf break and had bottom temperatures as warm (0°–3°C) as those of SSW, but was much more salty ($S>34$).



Date is indicated in the labels of two stations that were sampled twice. Black lines indicate significant differences between groups of stations (p<0.05).

Water masses: ACW = Alaska Coastal Water SSW = Shelf Summer Water
AW = Atlantic Water SWW = Shelf Winter Water

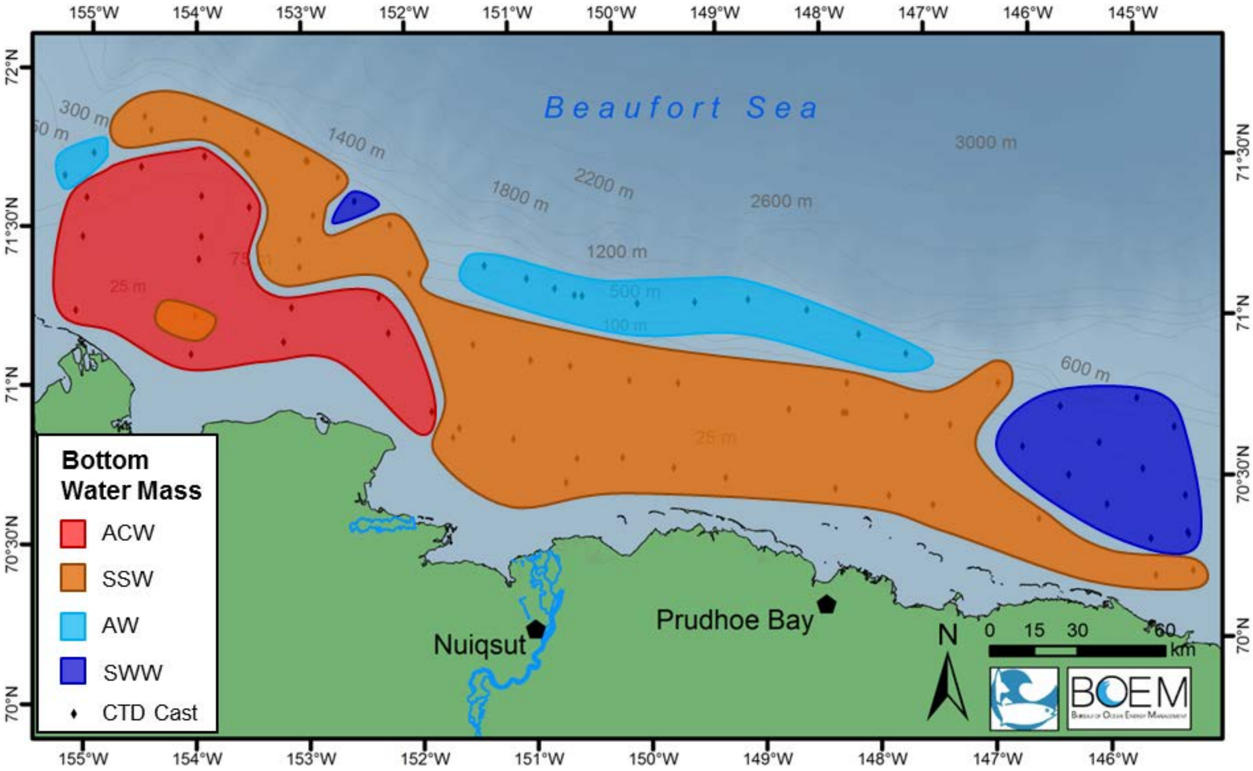
Figure 3-1 Dendrogram of Bottom Temperature and Salinity from 74 stations in the Beaufort Sea in 2011



Solid colored rectangles indicate water mass boundaries as per Appendix A1. Summary of BOEM-2011 Physical Hydrography; dashed lines encompass additional data.

Water masses: ACW = Alaska Coastal Water SSW = Shelf Summer Water
AW = Atlantic Water SWW = Shelf Winter Water

Figure 3-2 Potential Density Plot of Temperature and Salinity of Water near the Sea Floor in the Beaufort Sea in 2011



Water masses: ACW = Alaska Coastal Water SSW = Shelf Summer Water
AW = Atlantic Water SWW = Shelf Winter Water

Figure 3-3 Bottom Water Mass Based on 74 Stations Having Bottom Temperature and Salinity Data in the Beaufort Sea in 2011

3.3.1.2 Sediments

Sediments were generally classified as gravel, sand, or mud. Mud sediment was predominant across the whole shelf with heavier concentrations of mud in the west and gravel in the east (**Figure 3-4**). The percentage of gravel was very low at almost all locations. Only a few non-contiguous stations had percentages of gravel as high as 60% (**Figure 3-5**). Percentage of sand was as high as 95% at a few nearshore sites, though mostly-sand was <40% (**Figure 3-6**). The percentage of mud was very high, up to 94%, in the western Beaufort Sea west of 152ºW (**Figure 3-7**). At a given location the highest percentage of silt or clay was only about 50% (**Appendix C5**).

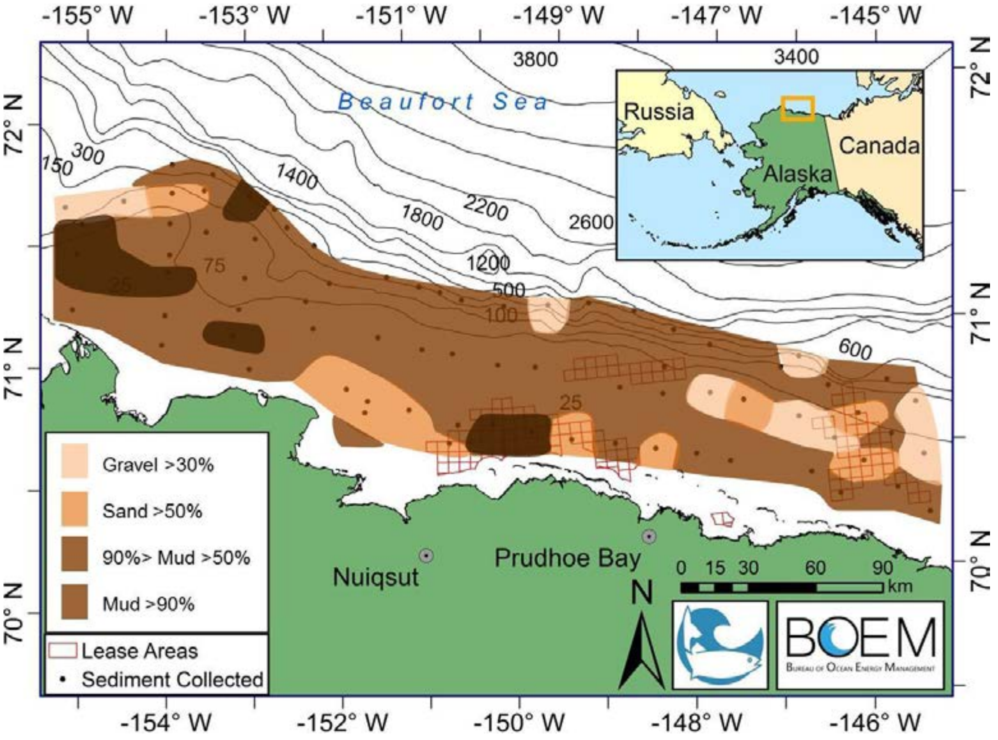


Figure 3-4 **Primary Sediment Grain Size in the Beaufort Sea in 2011**

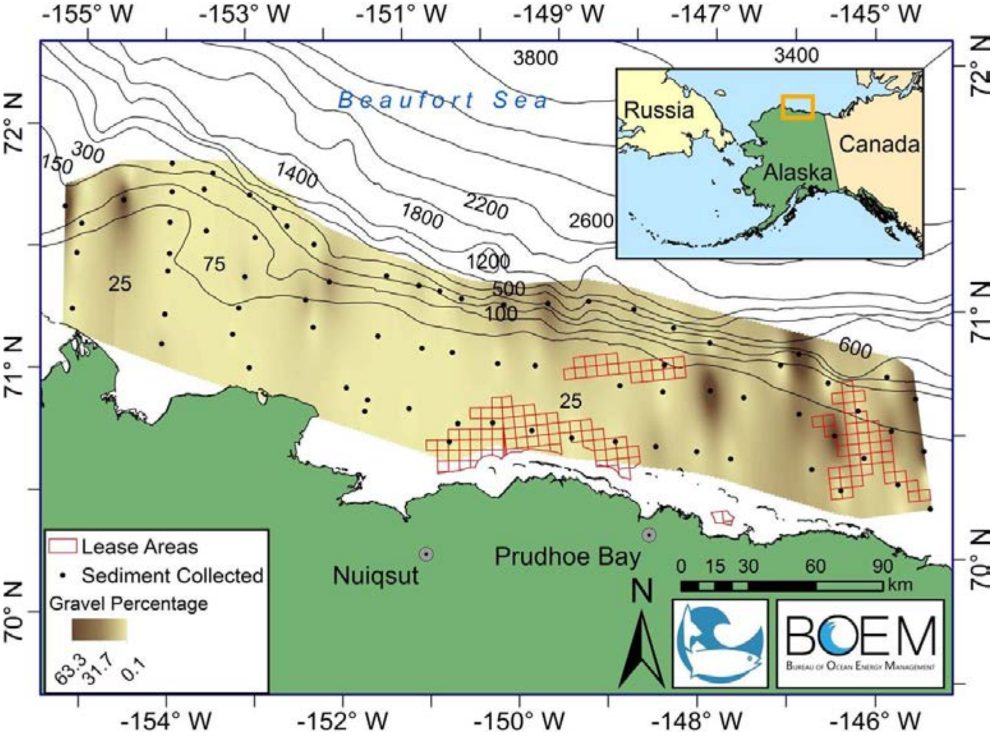


Figure 3-5 **Percentage of Gravel in the Beaufort Sea in 2011**

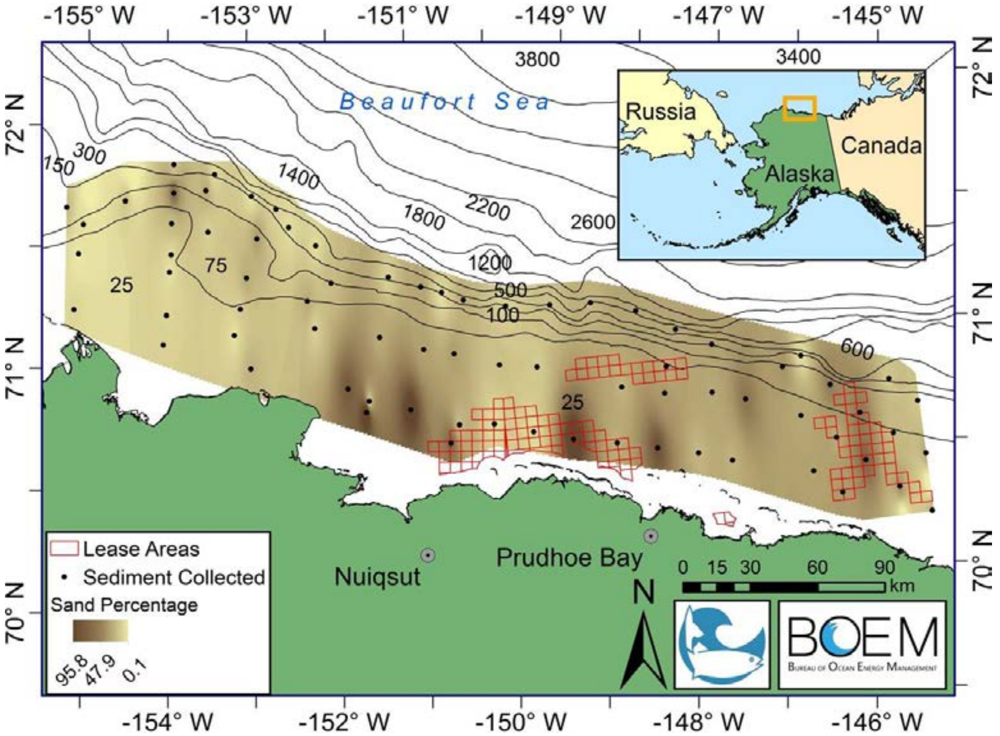


Figure 3-6 Percentage of Sand in the Beaufort Sea in 2011

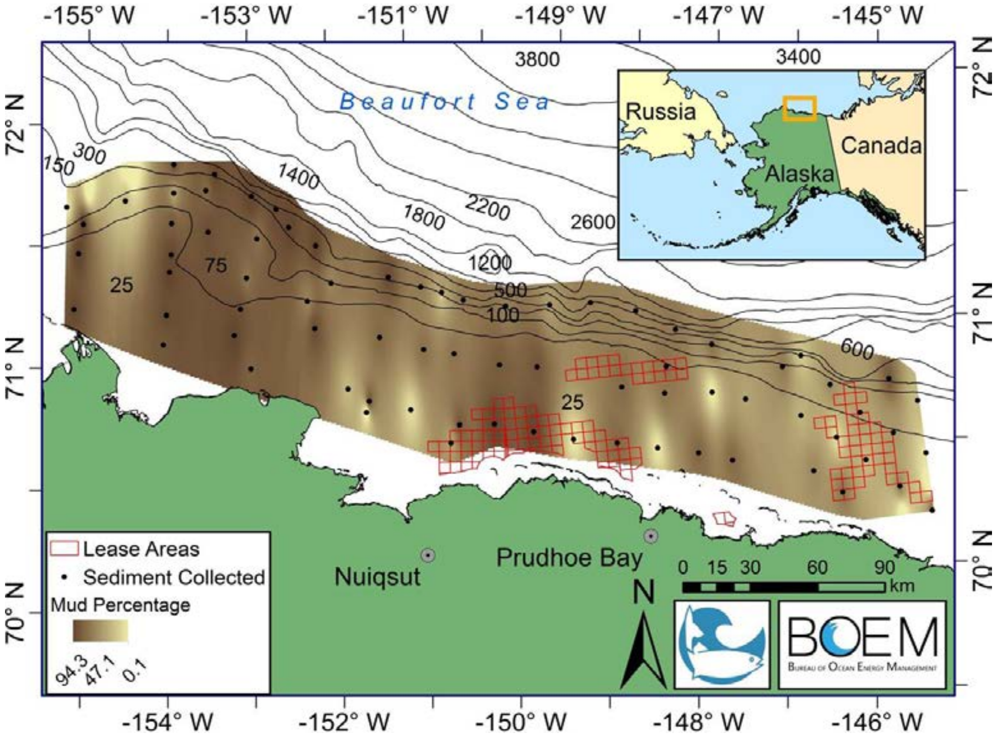


Figure 3-7 Percentage of Mud in the Beaufort Sea in 2011

3.3.2 Fish Community Analysis

3.3.2.1 Beam Trawl (BT)

The six fish communities formed by 4RT transformation (**Figure 3-21**) could be characterized by combinations of 2 to 7 taxa (**Table 3-2**). These communities had distinct profiles of abundant taxa. Four of the six communities had *B. saida* as a substantial component. Community “a” was composed of only one station. Of three species collected there, *Aspidophoroides olrikii* made up 50% of the abundance. In the three stations of community “b”, 75% of the catch consisted of prickleback (*Anisarchus medius),* sculpin (*Gymnocanthus tricuspis),* or eelpouts (*Lycodes* spp.). Community “c” was made up of 14 stations, the majority of which were on the wider shelf of the western Beaufort Sea nearest to Barrow. Community “c” was the most diverse, seven taxa contributed 77% of the similarity, and it was characterized by four taxa *B. saida*, *Liparis* spp., *G. tricuspis*, and *Artediellus scaber.* Although the number of stations was similar to “c”, only three taxa made up 72% of the catch in community “d”: *B. saida*, *G. tricuspis* and *Liparis* spp. Locations were spread across nearshore and shallow waters. The 24 stations of community “e”, which were mainly in the eastern part of the study area (**Figure 3-21**), were dominated by four taxa: *B. saida*, *A. olrikii*, *Liparis* spp., and *Icelus* spp. Community “f”, found in the outer, deeper shelf break stations of the western-most part of sampling area, was described by *B. saida* and *Lycodes* spp.

Table 3-2 Beam Trawl CPUE, 4RT Transformation

		Fish Communities					
		a	b	c	d	e	f
	# Stations	1	3	14	15	24	7
Taxa	# Taxa Observed	3	7	22	12	19	7
Gadidae	*Boreogadus saida*			16.4	27.2	22.6	59.6
Cottidae	*Gymnocanthus tricuspis*		23.0	10.3	26.0		
	Artediellus scaber			9.5			
	Icelus spp.					12.7	
	Myoxocephalus scorpius			8.7			
	Triglops pingelii	25.0					
Agonidae	*Aspidophoroides olrikii*	50.0				17.9	
	Eumicrotremus derjugini	25.0					
Liparidae	*Careproctus reinhardti*						
	Liparis spp.			15.4	18.3	17.0	
Zoarcidae	*Gymnelus* spp.						
	Lycodes spp.		23.0	7.8			22.6
Stichaeidae	*Anisarchus medius*		28.6				
	Lumpenus fabricii			8.5			
Total % Contributed		100.0	74.6	76.5	71.5	70.2	82.2
# Taxa Contributing >70% Density		3	3	7	3	4	2
Within-Community Similarity		100.0	64.1	70.9	63.2	60.6	44.4

Percent contribution of taxa density to each of six fish communities (*p*<0.01) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the Figure 3-21 shade dendrogram.

In the western Beaufort Sea community patterns for beam trawl catches were similar for abundance and biomass data (Bluhm et al. 2014). As that study used fish data from a subset of the stations in this analysis, we used the same 4RT for beam trawl BPUE that was determined to be valid for abundance (CPUE).

A 4RT of BT BPUE, yielded 12 groups ("a" through "l") of taxa (Spp) at $p<0.005$ (y-axis, **Figure 3-23**). Because these clusters were based on biomass (g 1,000 m^{-2}) and not on abundance, they were grouped somewhat differently. As with 4RT of abundance (**Figure 3-21**), *B. saida* was also the most dominant by biomass, although for this it was only a 5-species cluster ("l", green squares). *G. tricuspis* was again clustered with *B. saida*. *Liparis* spp. did not group with *B. saida* and *G. tricuspis*; but rather was in a 2-species group ("g", gold open triangles) with *Lycodes* spp., the taxon contributing the most biomass after *B. saida*. *Eumicrotremus derjugini*, which had been its own group for abundance, and *Hippoglossoides robustus*, made relatively large biomass contributions in group "f" (turquoise circles). The same five fish species were captured at only one station. These species made single-species clusters for both abundance and biomass ("a", "b", "c", "d", and "e").

Beam trawl 4RT BPUE formed seven station clusters at $p<0.005$ (x-axis, **Figure 3-23**). As with species clusters, station clusters were different for biomass than for abundance (**Figure 3-21**). The biggest difference was that there was one very large 38-station cluster ("g", red inverted diamonds); in that community, *B. saida* was dominant, though there also was considerable biomass of *G. tricuspis* and *Artediellus scaber*. However the most substantial biomass contributions of *Lycodes* spp. and *Liparis* spp. came from different stations and formed a 7-station community ("c", turquoise circles) at the shelf break in the western Beaufort Sea. The seven fish communities formed by 4RT BPUE (**Figure 3-23**) could be characterized by combinations of 2 to 6 taxa (**Table 3-3**). Community "a" was the same station as community "a" for CPUE, CB30; however, *Aspidophoroides olrikii* made up only 25% of the biomass as opposed to 50% of abundance. Four of the six communities had *B. saida* as a substantial component. The dominance of *B. saida* was evened out across all groups (**Figure 3-24**) as it had been for abundance (**Figure 3-22**). Station WB22, which was dominated by both abundance and biomass of *B. saida* (see largest bubble, **Figure 3-22 and Figure 3-24**), did not form a separate community and did not have any other characteristics (51 m, 3.75ºC, 31.6 salinity) markedly different from the surrounding stations.

Table 3-3 Beam Trawl BPUE, 4RT Transformation

		Fish Communities						
		a	b	c	d	e	f	g
	# Stations	1	4	7	4	6	4	38
Taxa	# Taxa Observed	3	12	10	10	9	10	23
Gadidae	*Boreogadus saida*		44.7	36.0	14.1	27.0	33.4	20.0
Cottidae	*Gymnocanthus tricuspis*				13.3	27.0		10.2
	Artediellus scaber							13.2
	Icelus spp.				16.4			8.5
	Myoxocephalus scorpius							
	Triglops pingelii	32.0					24.6	10.8
Agonidae	*Aspidophoroides olrikii*	24.2	16.1					
	Eumicrotremus derjugini	43.8						
Liparidae	*Careproctus reinhardti*							
	Liparis spp.					33.4	21.4	12.4
Zoarcidae	*Gymnelus* spp.							
	Lycodes spp.			46.0	35.5			
Stichaeidae	*Anisarchus medius*							
	Lumpenus fabricii							
Pleuronectidae	*Hippoglossoides robustus*		18.2					
Total % Contributed		100.0	79.0	82.0	78.3	87.4	79.4	75.0
# Taxa Contributing >70% Density		3	3	2	4	3	3	6
Within-Community Similarity		100.0	45.2	54.7	54.0	65.0	63.7	59.1

Percent contribution of taxa biomass to each of seven fish communities ($p<0.005$) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the Figure 3-21 shade dendrogram.

3.3.2.2 Otter Trawl (OT)

For OT CPUE, at $p<0.05$ there were eight groups (“a” through “h”) of taxa (Spp, y-axis, **Figure 3-25).** The most abundant taxon, *B. saida*, dominated one 11-species cluster (“h”, red inverted triangles); other taxa, including *G. tricuspis,* and *Liparis* spp., also were relatively abundant. There was a 5-species cluster in which *Icelus* spp. was the most abundant (“h”, grey plus sign). The other six groups were single-species clusters (“a”, “b”, “c”, “d”, “f”, and “g”).

A 4RT of otter trawl CPUE yielded five station groups (at $p<0.05$) (**Figure 3-25**). *B. saida* was the most abundant species in four of the five groups; the exception was the single station group “b” (pink diamonds). The largest and most diverse group was made up of 16 taxa (“e”, blue triangles). Group “d” contained the most abundant taxa: *B. saida, G. tricuspis, and Aspidophoroides olrikii* (**Table 3-5**). There was not a clear geographical pattern observed from the 31 taxa creating communities from OT abundance. In the nMDS, the dominance of *B. saida* in one community (“d”) was apparent (**Figure 3-26**), unlike for BT catches (**Figure 3-22**). Catch abundance of OT-caught fishes was not significantly affected by any of the physical factors that were tested.

Table 3-4 Beam Trawl CPUE, 4RT Transformation

	Group “a” - 1 station	Group “b” - 3 stations		Group “c” - 14 stations		Group “d” - 15 stations	
	Value	Min–Max	Avg ± StDev	Min–Max	Avg ± StDev	Min–Max	Avg ± StDev
Count of Fish Taxa	3	5–7	5.7±1.2	8–16	12±2.1	3–10	6.6±2.1
Total CPUE (#/1000 m^2)	62.9	25.1–33.6	30.3±4.5	136.8–1668.0	686±508.4	36.7–250.4	122.3±52.8
Station Depth (m)	183.0	30–43	36±6.6	13–53	38.2±15.6	16–33	22.1±5.7
Latitude (°N)	71.4	70.3–70.8	70.5±0.3	70.7–71.7	71.4±0.3	70.5–71.1	70.8±0.2
Longitude (°W)	151.3	148.1–145.1	146.5±1.5	155.1–150.6	153.6±1.2	153.2–145.4	150±2
Bottom Temperature (°C)	0.1	-0.7–3	0.7±2	1.9–4.8	3.8±0.8	-1.1–4	1.6±1.5
Bottom Salinity	34.6	31.3–32.1	31.7±0.4	31.1–31.8	31.5±0.2	30.8–32	31.5±0.3
Percent Gravel	0.4	0–13.5	4.7±7.6	0–49.7	5±13.5	0–29.4	3.7±8.3
Percent Sand	14.4	32.8–37.1	35.2±2.2	7.8–58.3	21.6±16.4	8.6–96	40±31
Percent Mud	84.9	53.5–63.3	59.9±5.5	31–91.9	73.2±21	3.8–91.1	56.2±31.8
Percent (Sand + Mud)	99.4	86.3–99.8	95.1±7.6	50.1–99.8	94.8±13.4	70.4–99.8	96.1±8.3

	Group “e” - 24 stations		Group “f” - 7 stations		All - 64 stations	
	Min–Max	Avg ± StDev	Min–Max	Avg ± StDev	Min–Max	Avg ± StDev
Count of Fish Taxa	4–10	7.5±1.6	3–5	3.9±0.9	3–16	7.7±3.1
Total CPUE (#/1000 m^2)	35.9–251.8	90.7±51.6	5.4–102.7	43±32	5.4–1668.0	219.8±342.8
Station Depth (m)	28–223	96±62.3	154–184	179.3±11.2	13–223	73.7±63.9
Latitude (°N)	70.3–71.8	71.1±0.4	71.0–71.8	71.6±0.3	70.3–71.8	71.1±0.4
Longitude (°W)	154.4–145.4	149.4±3.1	155.2–147.5	152.8±2.6	155.2–145.1	150.7±3.1
Bottom Temperature (°C)	-1.3–2.4	-0.1±1.1	-1.5–0.4	-0.5±0.7	-1.5–4.8	1.1±1.9
Bottom Salinity	31.6–34.8	32.4±0.9	32.7–34.8	33.8±0.9	30.8–34.8	32.1±1
Percent Gravel	0–58.5	7.8±13.9	0–61.4	10.8±24.8	0–61.4	6.2±13.5
Percent Sand	11.4–61	31.3±12.9	8.6–32.9	17.3±9.7	7.8–96	29.7±20.3
Percent Mud	11.2–88.3	60.7±18.7	14.6–91.1	71.6±29.8	3.8–91.9	63.9±24.1
Percent (Sand + Mud)	41.4–99.8	92±13.9	38.4–99.7	88.9±24.8	38.4–99.8	93.6±13.5

Summary of physical characteristics at stations inhabited by six fish communities at 64 stations in the Beaufort Sea in 2011. See Table 3-4 for description of fishes associated with each community and Figure 3-21 shade dendrogram for the proportional within-community similarity.

Table 3-5 Otter Trawl CPUE, 4RT Transformation

		Fish Communities				
		a	b	c	d	e
	# Stations	2	1	3	9	16
Taxa	# Taxa Observed	3	5	7	17	15
Osmeridae	*Mallotus catervarius*					
Gadidae	*Boreogadus saida*	56.8		48.4	38.5	25.8
	Eleginus gracilis					
Cottidae	*Artediellus scaber*	43.2				11.4
	Gymnocanthus tricuspis		25.0		17.5	
	Icelus spp.		37.5			19.0
	Myoxocephalus scorpius					
	Triglops pingelii		12.5			
Hemitripteridae	*Nautichthys pribilovius*					
Agonidae	*Aspidophoroides olrikii*					9.1
	Eumicrotremus dejugini					
Liparidae	*Careproctus reinhardti*					
	Liparis spp.			27.2	18.4	12.7
Zoarcidae	*Gymnelus* spp.					
	Lycodes spp.		12.5			
Stichaeidae	*Anisarchus medius*		12.5			
	Eumesogrammus praecisus					
	Lumpenus fabricii					
	Stichaeus punctatus					
	Stichaeidae larvae unid					
Ammodytidae	*Ammodytes hexapterus*					
Pleuronectidae	*Hippoglossoides robustus*					
Total % Contributed		100.0	100.0	75.6	74.4	77.9
# Taxa Contributing >70% Density		2	3	2	3	5
Within-Community Similarity		70.0	100.0	73.3	62.8	57.5

Percent contribution of taxa abundance to each of five fish communities ($p<0.05$) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 3-25** shade dendrogram.

A 4RT of BT BPUE yielded six groups ("a" through "f") of taxa (Spp) at $p<0.01$ (y-axis, **Figure 3-27**). *B. saida* was not only the most abundant taxon (**Figure 3-25**), but it also accounted for more biomass than any other taxon captured by OT dominating species cluster "c" (red inverted triangles). As for BT CPUE, *Lycodes* spp. and *Liparis* spp. formed a 2-species group ("h", grey plus sign). There were only two single-species clusters ("a" and "b").

There were more station groups for OT BPUE than for OT CPUE (nine at $p = 0.05$). *B. saida* dominated the biomass in eight of the nine communities (**Figure 3-27**, **Table 3-6**). *G. tricuspis* was again clustered with *B. saida*. *Liparis* spp. did not group with *B. saida* and *G. tricuspis*; rather, *Liparis* spp. was in a 2-species group with *Lycodes* spp. ("g", gold open triangles), the taxon contributing the most biomass after *B. saida*. *Eumicrotremus derjugini*, which had been its own group for abundance, and *Hippoglossoides robustus* made relatively large biomass contributions in group "f" (turquoise circles). The three single-station clusters for biomass were each distinguished by absence, "b" – no *B. saida* (turquoise circles), or presence, "c" – *Lumpenus fabricii*, and "h" – *Eumesogrammus praecisus*, of one particular species. Unlike OT CPUE, there was one geographical pattern, cluster "i", in the western Beaufort.

Fish biomass of OT catches was significantly affected by some of the physical factors that were tested. Catch biomass differed with bottom depth (ANOSIM, Global $R = 0.13$, $p = 0.054$); the only difference was between fish biomass at 26–50 m ($p<0.001$) and >180 m ($p<0.001$). Differences could be seen in fish biomass between water masses (Global R = 0.15, p = 0.045). Biomass of fishes in the warm, low salinity ACW (**Figure 3-2 and Figure 3-3**) were different from SWW (p = 0.002) and AW ($p<0.012$), and fish biomasses in SWW and AW were different from each other. Catch biomasses differed with longitude (Global R = 0.255, p = 0.002) but not depth, bottom water temperature, bottom salinity, or substrate.

3.3.2.3 Isaacs-Kidd Midwater Trawl (IKMT)

The 16 taxa captured by IKMT CPUE clustered into three groups ("a" through "c") at $p<0.05$ (Spp, y-axis, **Figure 3-28**). The most abundant taxon was *B. saida*, which dominated one 9-species cluster ("b", pink diamonds), but *Liparis* spp. was also very abundant at two stations. There was a 4-species cluster in which *Eleginus gracilis* was abundant at one station ("c", inverted red triangles). There was also one single-species cluster made up of Cottidae larvae collected at two stations ("a", green squares).

A 4RT of IKMT CPUE yielded four station groups (at $p<0.01$; (**Figure 3-28**). *B. saida* was the most abundant species in just two of the four groups, unlike communities formed from collections of BT and OT. The largest group was made up of 16 taxa ("c", blue triangles), but it was dominated by two taxa, *B. saida* and *Liparis* spp. (**Table 3-7**). Community "c" comprised 52 stations that we spread across the entire sample range. However, the contribution of *Liparis* spp. in "b" was overshadowed by its dominance (74%) in the 5-taxa group "d" (red inverted triangles). The 10-station group "b" (green squares) had 12 taxa, was in the western Beaufort Sea, and was more diverse than any other pelagic group as seven taxa, including *Eleginus gracilis*, were required to make up 70% of abundance. The community "b" was made up of nearshore (<20 m) stations. The single-station group "a" (pink diamond) was dominated by *E. gracilis*; the station (WB29) was in the extreme western Beaufort in nearshore waters. These two communities ("a" and "b") were the only ones collected by any gear in which *E. gracilis* contributed to the top 70% of taxa abundance or biomass. In the nMDS, the dominance of *B. saida* in one community ("c") was apparent (**Figure 3-29)**.

Table 3-6 Otter Trawl BPUE, 4RT Transformation

		Fish Communities								
		a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
	# Stations	2	1	1	2	2	7	11	1	4
Taxa	# Taxa Observed	3	5	6	4	7	15	14	7	16
Osmeridae	*Mallotus catervarius*									
Gadidae	*Boreogadus saida*	52.8		25.9	37.8	24.7	18.7	35.4	20.8	25.1
	Eleginus gracilis									
Cottidae	*Artediellus scaber*	47.2								
	Gymnocanthus tricuspis		21.9					14.1	7.6	14.3
	Icelus spp.		19.9			21.1	17.3			
	Myoxocephalus scorpius								7.0	11.3
	Triglops pingelii		16.3	13.7			11.8		16.4	
Hemitripteridae	*Nautichthys pribilovius*									
Agonidae	*Aspidophoroides olrikii*						10.5		15.9	
	Eumicrotremus dejugini					17.7				
Liparidae	*Careproctus reinhardti*									
	Liparis spp.			15.1	32.4			20.5	9.1	11.9
Zoarcidae	*Gymnelus* spp.					14.7				
	Lycodes spp.		27.3	27.2			15.9			
Stichaeidae	*Anisarchus medius*		14.4	7.3						10.9
	Eumesogrammus praecisus								23.2	
	Lumpenus fabricii			10.7						
	Stichaeus punctatus									
	Stichaeidae larvae unid									
Ammodytidae	*Ammodytes hexapterus*									
Pleuronectidae	*Hippoglossoides robustus*									
Total % Contributed		100.0	85.4	81.9	70.1	78.2	74.1	70.0	76.3	73.6
# Taxa Contributing >70% Density		2	4	4	2	4	5	3	4	5
Within-Community Similarity		41.3	100.0	100.0	92.0	80.2	62.4	60.5	100	69.8

Percent contribution of taxa abundance to each of five fish communities ($p<0.05$) and mean similarity of taxon biomass within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 3-27** shade dendrogram.

Table 3-7 Isaacs-Kidd Midwater Trawl (IKMT) CPUE, 4RT Transformation

		Fish Communities			
		a	**b**	**c**	**d**
	# Stations	1	10	52	6
Taxa	# Taxa Observed	3	5	2	1
Gadidae	*Boreogadus saida*		21.0	68.4	
	Eleginus gracilis	50.1	11.6		
Cottidae	Cottidae larvae unid				
	Gymnocanthus tricuspis	21.3			
	Icelus spp.				
	Myoxocephalus quadricornis				
	Myoxocephalus scorpius				
	Triglops pingelii				
Agonidae	*Aspidophoroides olrikii*		14.0		
Liparidae	*Liparis* spp.		11.0	15.9	73.8
Stichaeidae	*Anisarchus medius*				
	Lumpenus fabricii	28.0			
	Stichaeus punctatus		20.3		
	Stichaeidae larvae unid				
Ammodytidae	*Ammodytes hexapterus*				
Pleuronectidae	*Limanda proboscidea*				
Total % Contributed		78.1	77.8	84.3	73.8
# Taxa Contributing >70% Density		2	5	2	1
Within-Community Similarity		100.0	58.5	54.2	45.2

Percent contribution of taxa abundance to each of four fish communities (p<0.01) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 3-23** shade dendrogram.

3.3.3 Fish and Environmental Variables

The physical characteristics associated with stations were wide-ranging and characterized the six fish communities formed by 4RT of CPUE (**Table 3-4**). CPUE differed by three orders of magnitude across hauls. The lowest values were in group "f" and the highest in group "c". All bottom temperatures were cold, but in varying degrees (-1.5°C to 4.8°C). Groups "e" and "f", mostly at the shelf break, had the lowest temperature ranges and "c", in the western Beaufort in ACW had the highest. The lowest salinities were in the nearshore community "d". The highest salinities were in groups "a" and "f", which had the largest average depth. The substrate in the whole sample area was sandy mud, with slightly different amounts of gravel. In every community there were stations where no gravel was present. The nearshore stations in "d" had the highest average percentage sand (40%), and the communities in the western Beaufort Sea ("c" and "f") had the highest average percentage of mud (~72%).

Analysis of Similarity (ANOSIM, PRIMER v.7) was used to estimate differences in species abundance and composition in relation to bottom depth, bottom temperature, bottom salinity, longitude, latitude, sediment, and water mass. Catch abundance of fishes was significantly affected by some of the physical factors that were tested. Catch sizes differed with bottom depth (ANOSIM, Global R = 0.368, p = 0.001). Fishes at stations >150 m were distinctly separate from stations shallower than 50 m (p<0.001) and 51–75 m (p<0.002). The shallowest stations of 1–25 m formed their own group, separate from 26–75 m (p<0.001) and 76–100 m (p<0.012).

Differences could be seen in fish catch between water masses (Global R = 0.248, p = 0.002). Abundance of fishes in the warm, low salinity ACW (**Figure 3-2 and Figure 3-3**) were higher than those in AW

($p<0.001$), SSW ($p<0.013$) and SWW ($p<0.001$). The fishes in AW differed from SSW ($p<0.001$) and SWW ($p = 0.028$), but those in SSW and SWW were not significantly different. Catch sizes differed with bottom water temperature (Global R = 0.242, $p<0.001$), bottom salinity (Global R = 0.453, $p<0.001$), and longitude (Global R = 0.143, $p = 0.003$), but not latitude or substrate type. The best (BEST, PRIMER v.7) correlation of fish abundance and physical variables was with latitude, though it was extremely weak ($r = 0.125$); as the western Beaufort stations were in higher latitudes, it is very unlikely that latitude was contributed to increased fish abundance.

Fish biomass of catches was significantly affected by some of the physical factors that were tested. Catch biomass differed with bottom depth (ANOSIM, Global R = 0.345, $p = 0.001$). Fishes at stations >150 m were distinctly separate from stations shallower than 50 m ($p<0.001$) and 51–75 m ($p<0.002$). The shallowest stations of 1–25 m were separate from 26–75 m ($p<0.001$) and 76–100 m ($p<0.006$). Differences could be seen in fish biomass between water masses (Global R = 0.15, $p = 0.01$). Biomass of fishes in the warm, low salinity ACW (**Figure 3-2 and Figure 3-3**) were not different from SSW ($p = 0.46$), but they were different from those in AW ($p<0.001$), and SWW ($p<0.001$). The fish biomasses in AW differed from SSW ($p<0.001$) and SWW ($p = 0.012$), but those in SSW and SWW were not significantly different. Catch biomasses differed with bottom water temperature (Global R = 0.162, $p<0.001$), bottom salinity (Global R = 0.436, $p<0.001$), and longitude (Global R = 0.096, $p = 0.015$), but not latitude or substrate type.

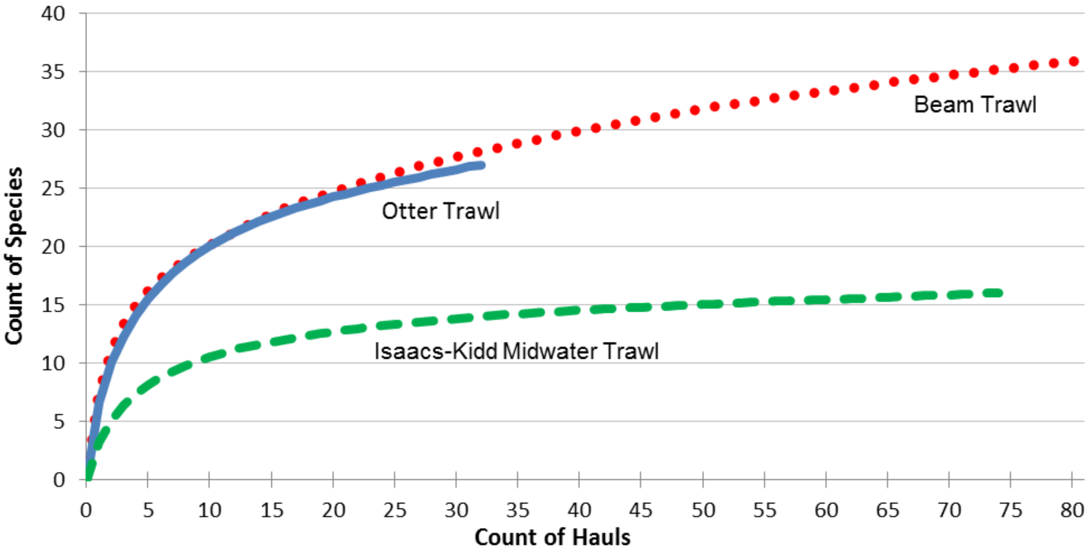
3.3.4 Fish Diversity

Distribution of species richness (**Figure 3-9**) mimicked the patterns of abundance for the BT (**Figure 2-10**). There were as many as 16 species caught in a single haul in the western Beaufort Sea and as few as three species in a haul in the east. Taxa richness was highest west of 152.5°W and at depths shallower than 150 m (**Figure 3-10**). Richness was lowest ~152–149°W and increased somewhat east of there. In contrast to richness, there was a much higher percentage of stations at which evenness was high; most of the evenness indices were >0.68 (**Figure 3-11**). Evenness was inversely related to richness at the outermost western stations, i.e., evenness was high when richness was low, though there was not a consistent pattern. There were high indices of Simpson’s diversity for almost all of the hauls, with diversity the lowest in the central US Beaufort Sea north of Nuiqsut (**Figure 3-12**).

Distribution of numbers of fish species captured by OT (**Figure 3-13**) was similar to the patterns of abundance in the west, but more species were caught in the east despite low abundances (**Figure 2-8**). There were as many as 13 species caught in a single haul in the western Beaufort Sea and as few as two species in a haul in the east. High taxa richness was found at individual stations spread across the whole sample area, but not at the shelf break stations in the west (**Figure 3-14**). Evenness was high (≥0.80) at most stations east of Prudhoe Bay (**Figure 3-15**). The pattern of evenness indices across sample stations was similar to that of Simpson’s diversity indices (**Figure 3-16**); the diversity of fishes caught by OT was very low in the west and highest in the east.

Distribution of numbers of fish species captured by IKMT was highest in the west (**Figure 3-17**), but the abundance was higher in the east (**Figure 2-3**). There were as many as 10 species caught in a single haul in the western Beaufort Sea and as few as one species in a haul in the east. The stations west of 152.5°W, including those at the shelf break, had high taxa richness (**Figure 3-18**). Evenness was high (≥0.69) at western stations and at some central and eastern stations (**Figure 3-19**). Simpson’s diversity indices were highest in the western Beaufort and quite low at most stations in the central and eastern sample areas (**Figure 3-20**).

The species accumulation curves showed the number of species captured to still be increasing for all gears, indicating that the additional hauls may increase the number of species captured (**Figure 3-8**). The species accumulation curve for OT overlays the BT curve closely while the IKMT captured fewer species.



Plot is based on presence of taxa in quantitative hauls by plumb staff beam trawls, otter trawl and Isaacs-Kidd midwater trawl. Taxon aggregates (see Table 3-1) are excluded.

Figure 3-8 Cumulative Count of Species for Bottom and Midwater Trawl Hauls in the Beaufort Sea during 2011

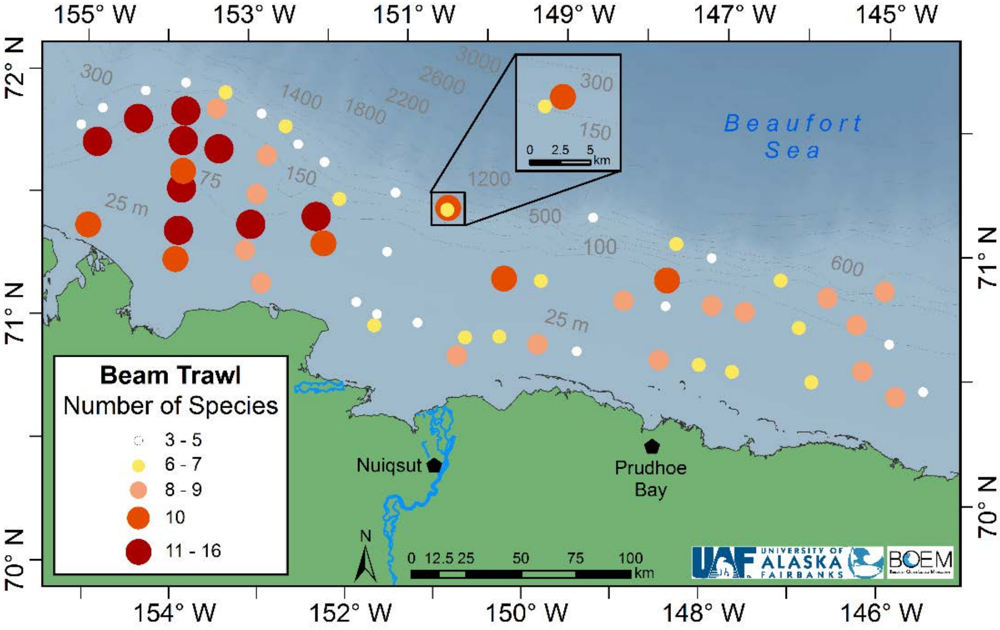


Figure 3-9 Numbers of Fish Taxa Captured at Each Station in the Beaufort Sea in 2011 by Beam Trawl

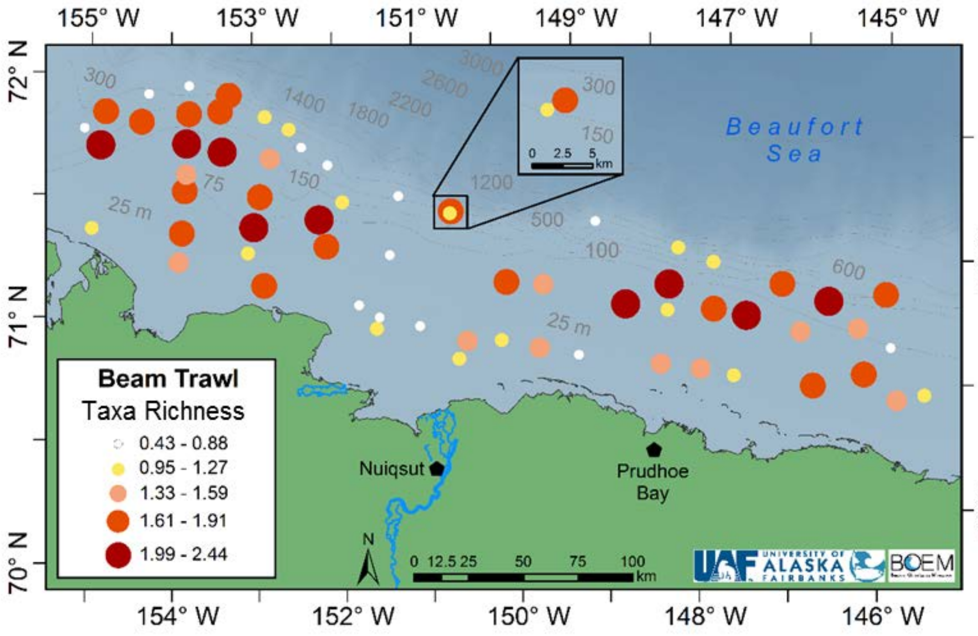


Figure 3-10 Margalef Index of Fish Species (taxa) Richness at Each Station in the Beaufort Sea in 2011 for Beam Trawl

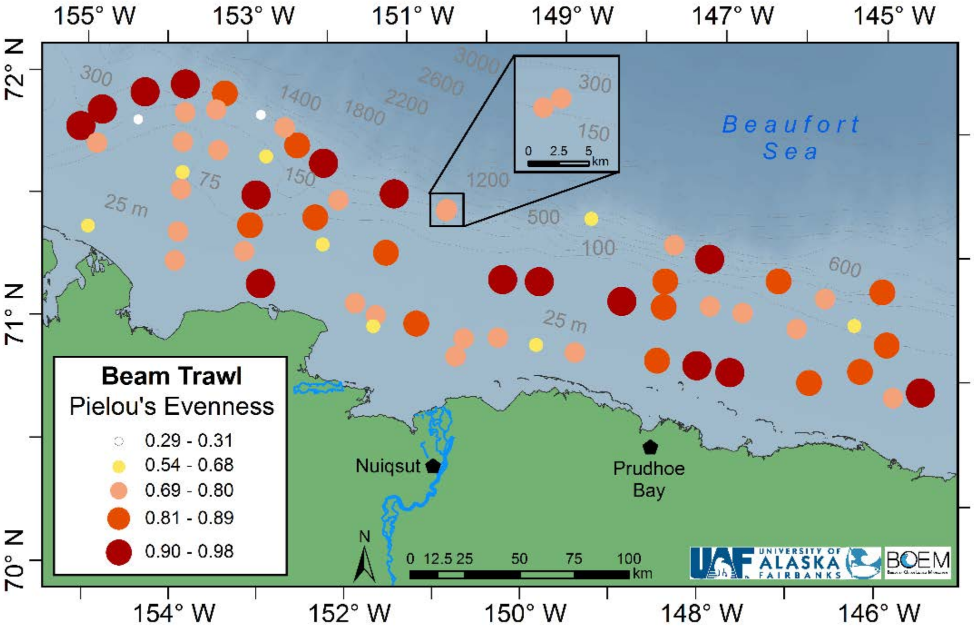


Figure 3-11 Pielou's Index of Fish Species Evenness at Each Station in the Beaufort Sea in 2011 for Beam Trawl

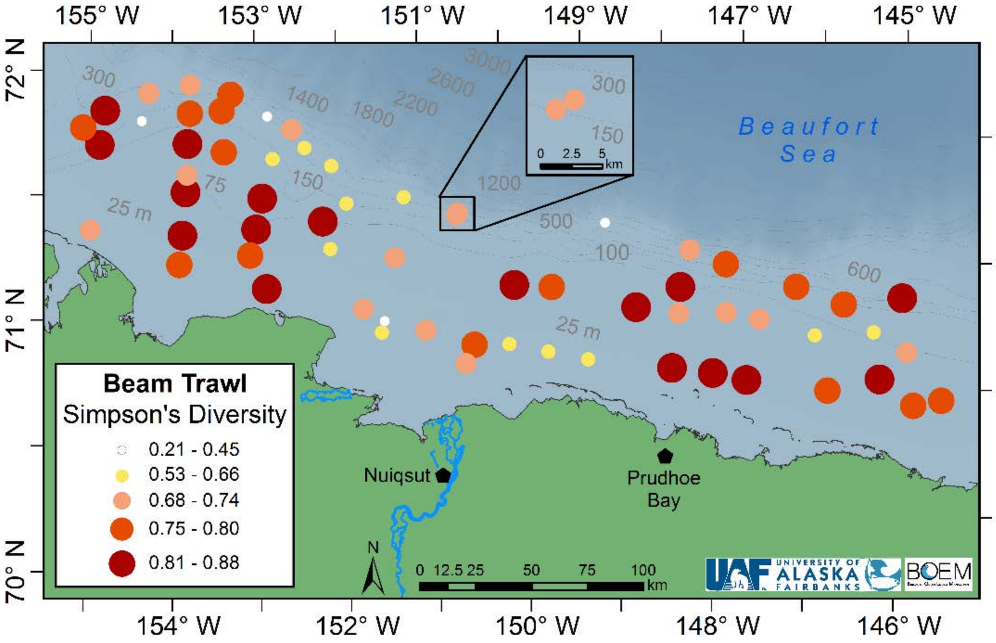


Figure 3-12 Simpson's Index of Fish Diversity at Each Station in the Beaufort Sea in 2011 for Beam Trawl

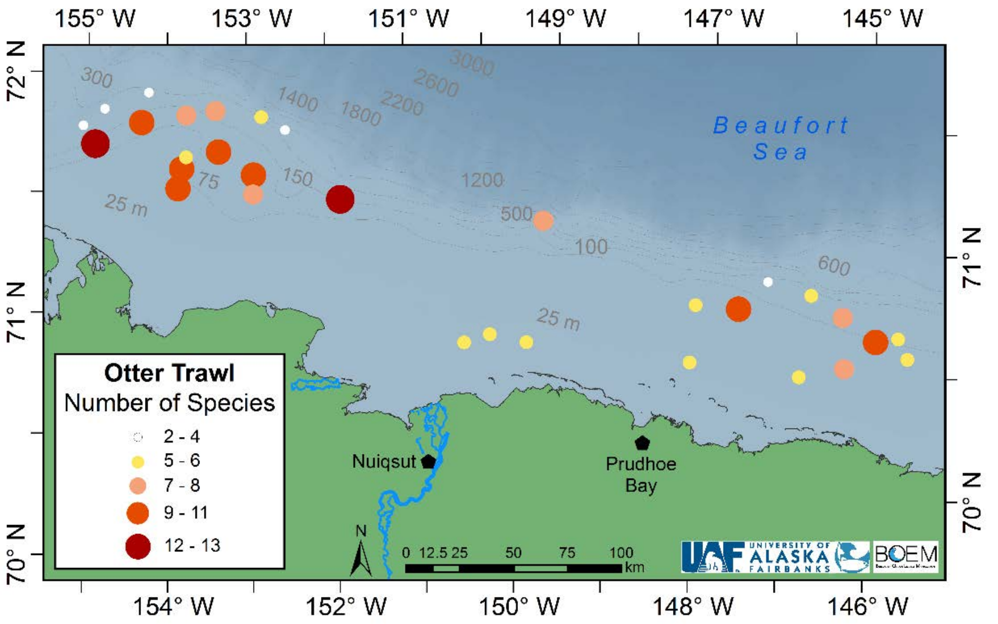


Figure 3-13 **Numbers of Fish Taxa Captured at Each Station in the Beaufort Sea in 2011 by Otter Trawl**

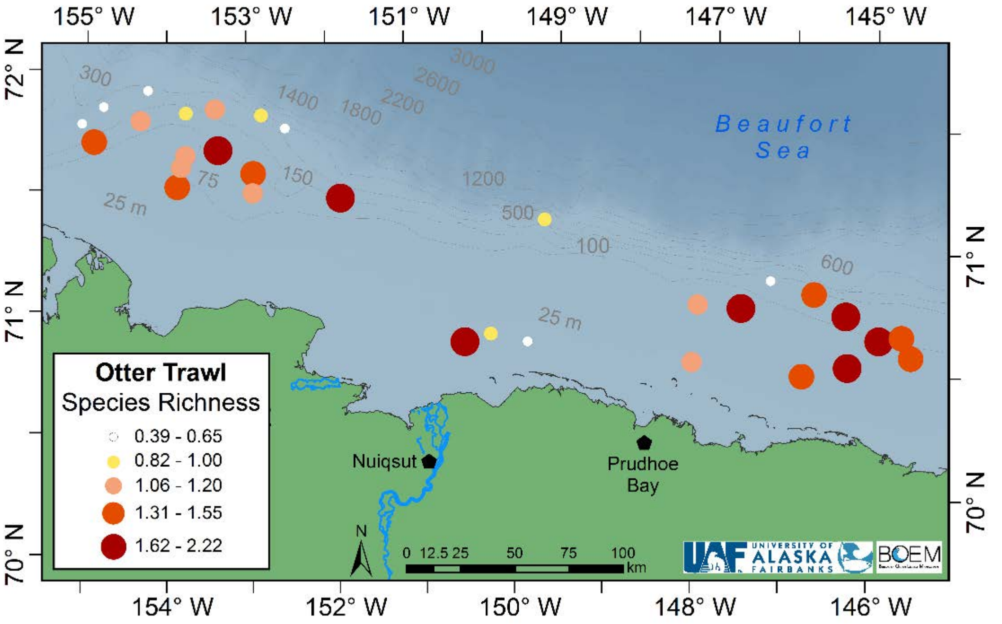


Figure 3-14 **Margalef Index of Fish Species Richness at Each Station in the Beaufort Sea in 2011 for Otter Trawl**

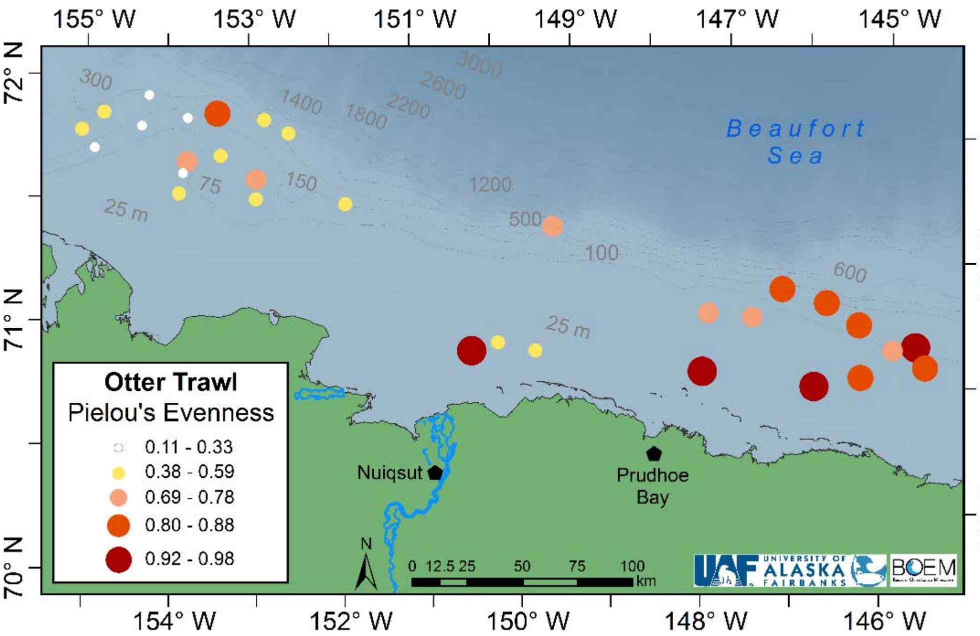


Figure 3-15 Pielou's Index of Fish Species Evenness at Each Station in the Beaufort Sea in 2011 for Otter Trawl

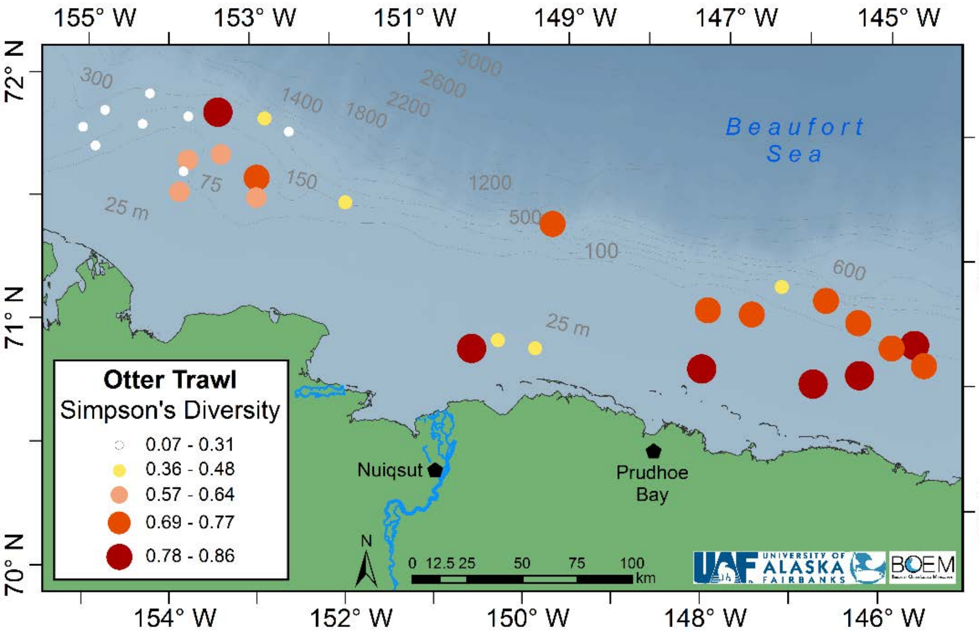


Figure 3-16 Simpson's Index of Fish Diversity at Each Station in the Beaufort Sea in 2011 for Otter Trawl

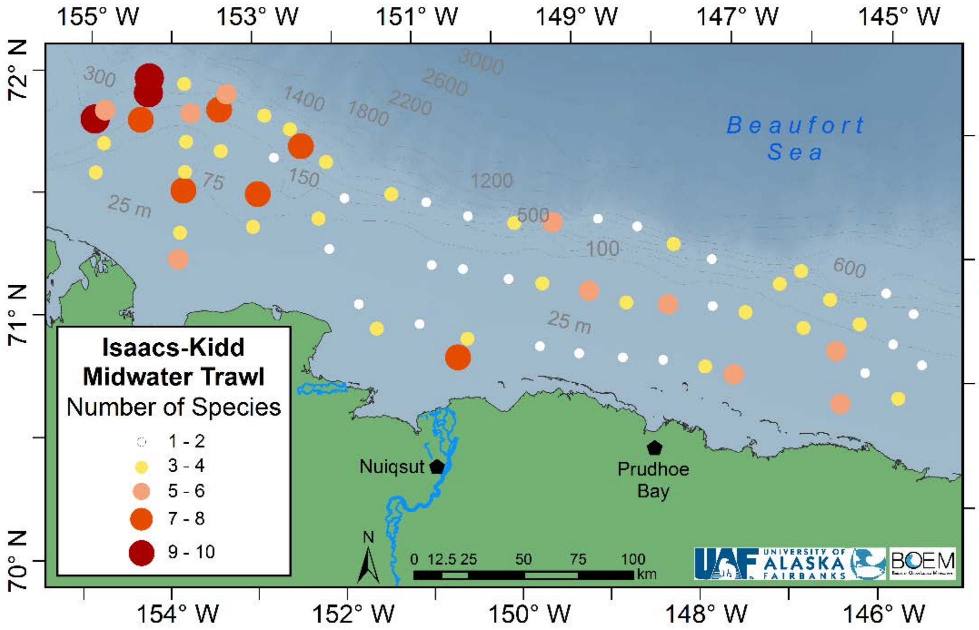


Figure 3-17 **Numbers of Fish Taxa Captured at Each Station in the Beaufort Sea in 2011 by Isaacs-Kidd Midwater Trawl**

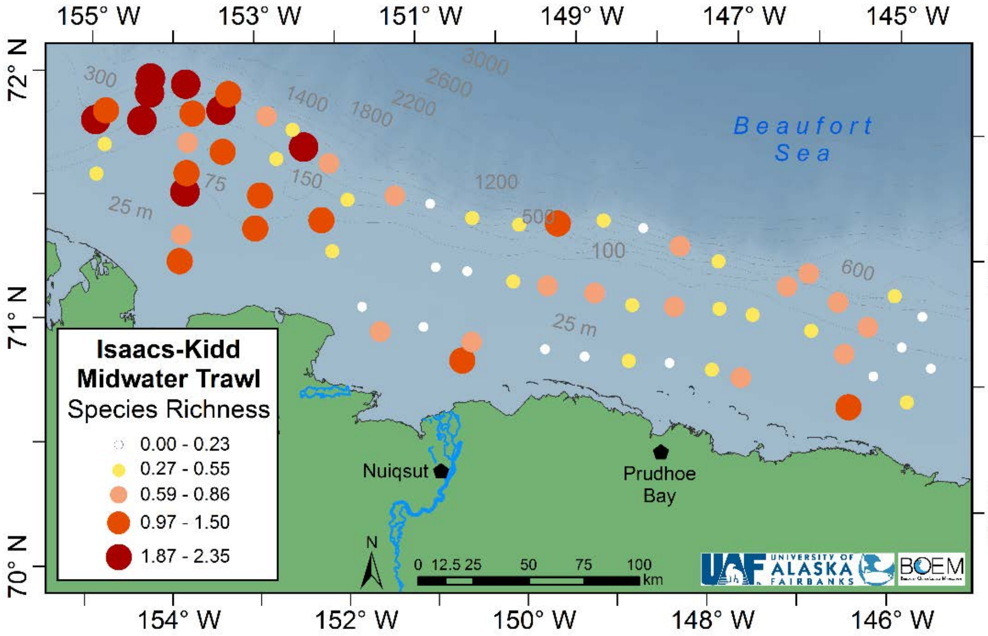


Figure 3-18 **Margalef Index of Fish Species Richness at Each Station in the Beaufort Sea in 2011 for Isaacs-Kidd Midwater Trawl**

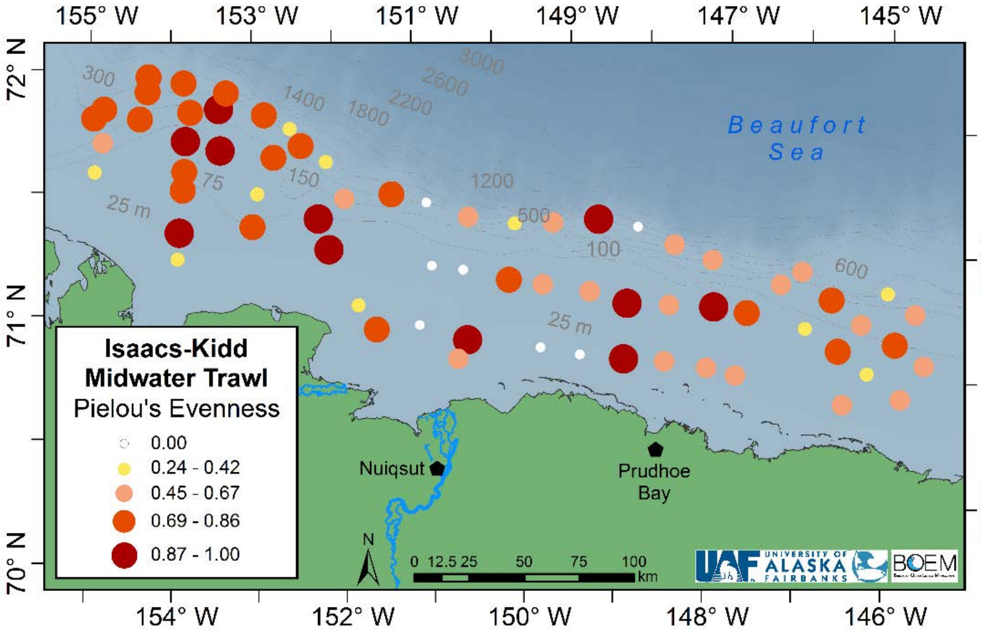


Figure 3-19 Pielou's Index of Fish Species Evenness at Each Station in the Beaufort Sea in 2011 for Isaacs-Kidd Midwater Trawl

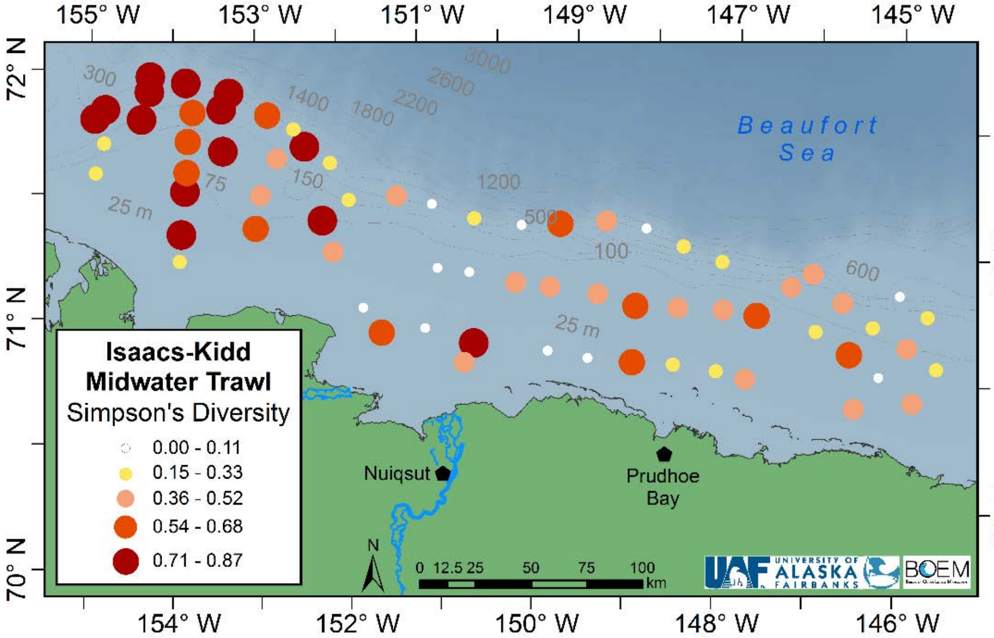


Figure 3-20 Simpson's Index of Fish Diversity at Each Station in the Beaufort Sea in 2011 for Isaacs-Kidd Midwater Trawl

3.4 Discussion

The extensive sampling of fishes across 200 km of the US Beaufort Sea coast (**Figure 3-1**) allowed us to discern richness, evenness, and diversity of taxa. Sampling with three different types of nets limited quantitative comparisons, but patterns and indices could be compared. The abundance and biomass of fishes captured by both BT (**Figure 2-10**) and OT (**Figure 2-8**) were greater in the western, and lower in the central and eastern, US Beaufort Sea. BTs caught 3 to 5 times more species in the west (**Figure 3-9**) than other stations. OTs also caught more individuals in the west (**Figure 3-13**). Richness of BT catches was lowest in the central Beaufort Sea (**Figure 3-10**). Evenness from BT catches was high at the shelf break in the west and at many stations across the whole sampling area (**Figure 3-11**). Diversity was fairly high at most stations, with lowest diversity apparent in the central Beaufort Sea (**Figure 3-12**). OT catches had lower indices of richness, evenness, and diversity (**Figure 3-14 and Figure 3-16**) in the west than in the east, despite having higher numbers of species in the west. The pattern for abundance of bottom fishes was not the same for larval and small juvenile fishes captured by midwater trawls; there was a cluster of stations in the eastern Beaufort with high abundance (**Figure 2-3**) due to these catches. However, the number of species of midwater fishes was similar to that of BT caught fishes, i.e., there were 2 to 5 times more in the west (**Figure 3-17**). That was reflected in the species richness (**Figure 3-18**) and diversity (**Figure 3-20**) indices, but not in evenness (**Figure 3-19**). These indices are all helpful in understanding the ecology of the Beaufort Sea fish communities, and continued research into interspecies associations is periodically needed to evaluate future Beaufort Sea trends.

To be useful for temporal comparisons, individual fish assemblages should be characterized by (1) taxa that co-occur together with few other species, and (2) taxa that co-occur at high frequencies, regardless of abundance (Fossheim et al. 2006). Our assignment of fish communities meets these criteria. We used taxa presence, dominance, associations, and communities that comprised a minimum of three stations to biologically characterize the communities, a technique that is commonly used (Ellis et al. 2000). Regardless of the type of net, all but one community was numerically dominated by *B. saida*. The interspecies association of abundance characterized the communities. There was one community in common between beam and otter trawl catches made up of three species (*B. saida–G. tricuspus–Liparus* spp.). Beam trawl communities ranged from simple with only two species (*B. saida–Lycodes* spp.), four species (*B. saida–Icelus* spp.*–Aspidophoroides olrikki–Liparis* spp.), and the most complex with seven species (*B. saida–G. tricuspus–Artediellus scaber–M. scorpius–Liparis* spp.*–Lycodes* spp.*–Lumpenus fabricii*). There were two simple two-species otter trawl communities (*B. saida–Artediellus scaber, B. saida–Liparis* spp.), and the most complex was four species (*B. saida–Artediellus scaber–Icelus* spp.*–Liparis* spp.). One IKMT community was the same as one of the two-species otter trawl (*B. saida–Liparis* spp.), and one was much more complex having five species (*B. saida–E. gracilis–Aspidophoroides olrikki–Liparis* spp.*–S. Punctatus*).

Spatial differentiation of fish communities was not consistent across gear types. Consistency would not be expected between bottom and midwater fishes because they represent very different life stages. Because of the low number of species and low indices of richness and diversity in all but the far western stations, it is not surprising that there is one large community of midwater fishes spread over most of the study area and a much smaller community in the west (IKMT CPUE, **Figure 3-28**). However, for bottom fishes, spatial structure of those indices was not as clear-cut; hence, neither was the structure of the communities. BT abundance (BT CPUE, **Figure 3-21**) and biomass (BT BPUE, Figure 3-23) communities loosely formed west, central, east, and shelf break aggregations. Unfortunately, there is little pattern in the spatial structure of OT abundance (OT CPUE, **Figure 3-26**) or biomass (OT BPUE, **Figure 3-27**), likely because only 32 OT (vs. 64 BT) stations were sampled over 200 km. We used the criteria described in the previous paragraph for BT CPUE and IKMT CPUE to create those fish communities that can be used in future comparisons.

Depth is often associated with demersal fish shelf communities (Colvocoresses and Musick 1984; Mahon et al. 1998; Mueter and Norcross 2002). On the US Beaufort Sea shelf, BT fish abundance grouped by depth increment. Fishes at the shallowest (<25 m) and deepest (>150 m) depths grouped separately with little mixing with other depths (**Figure 3-30**); whereas, fishes captured from 26 to 127 m formed a mixed group. These depth associations indicate habitat changes across the shelf. Shallow, nearshore waters are influenced by river runoff and have lower salinities. There is a rapid change in depth at the continental shelf break. Though the commonly accepted metric for a shelf break in the Beaufort Sea is 200 m, the break begins as shallow as 50 m (Pickart 2004); in the area we sampled it was roughly 100–150 m. These physical features, in part, explain the association of fish communities with depth. Often depth and substrate are related (Norcross et al. 1999; Ellis et al. 2000), making it difficult to determine which of the factors is affecting fish distribution. In this study, it was clear that depth was the important factor, as sediment was not related to fish abundance or community. However, depth is likely related to the other significant factors: salinity because of river runoff and distance from shore, longitude because the shelf is wider and shallower in the west, and bottom temperature because water masses change from shallow to deep.

Water masses are indicative of current patterns that affect zoogeographical boundaries (Bergstad and Isaksen 1987; Bergstad et al. 1987). Fronts separate water masses and associated distinct fish assemblages in the Barents Sea (Fossheim et al. 2006) and Chukchi Sea (Norcross et al. 2010). Similarly, in the Beaufort Sea, the four water masses loosely define the spatial patterns of the six demersal fish communities. The three water masses had overlapping ranges of salinity in 2011, but were separated by 3°C and -1°C bottom water isotherms (**Figure 3-8**). Comparison of horizontal bottom water mass structure (**Figure 3-3**) with fish distributions shows the BT CPUE community “c” to be associated with warm ACW, “d” associated with somewhat cooler SSW, and “e” associated with the coldest bottom temperatures of SWW (**Figure 3-21**). Because community “f” was at the northwest edge of the shelf break, we considered that it might be within upwelled AW (Pickart et al. 2009); however, despite having salinities 1 to 3 times higher than those of community “c”, most of these stations were still within the range of the SSW (**Figure 3-2**). The SSW bottom water temperatures encompassed those of AW, but AW had higher salinities. A clearer relationship might have been revealed if fish were trawled at all of the AW locations at the shelf edge between 147.5 and 152°W; unfortunately, maximum sampling depth was limited by length of the trawl wire. Despite statistical differences of abundance of fish in AW and SSW, they overlap in nMDS space (**Figure 3-30**).

The combination of physical characteristics that were statistically related to demersal species abundance and community composition (depth, bottom temperature, and salinity; **Table 3-4**) differentiated the prominent communities. The habitat of community “c” is shallow, warm, low salinity, ACW, and located in the far western Beaufort Sea. Community “d” is very shallow, cooler, low salinity, SSW, and in the central Beaufort. Community “e” has wide depth range, and is very cold, high salinity, and SWW. Habitat of community “f” is very deep, cold, high salinity, and AW or SWW. These descriptions may be useful for future comparisons.

The pelagic communities are not as easily described; they are composed of fewer and less abundant species than demersal fish communities and were collected throughout the water column (**Figure 3-28**). Community “b” habitat is warm (**Figure C1.10**), low salinity (**Figure C1.11**), and near the shelf break in the western Beaufort Sea. Community “c” covers the whole shelf from shallow to deep, thus encompassing the whole range of temperatures and salinities. Community “d” is very small, has mid-range temperatures and salinities, and is nearshore in the central Beaufort. These broad descriptions are unlikely to be helpful for future comparisons.

As “useful assemblage” criteria direct co-occurring species (Fossheim et al. 2006), the presence of *B. saida* alone is seldom sufficient to describe distinct fish assemblages on the Beaufort Sea shelf. That species was present in most of the communities that we assigned. However, the percent contribution of *B.*

saida to a community and the taxa that were or were not associated with *B. saida* illustrate distinctive assemblages. The prominent demersal fish communities all contained *B. saida* (**Table 3-2**). Community "c" is the most diverse, including seven dominant species, and yet still has very high within-community similarity. It is unique in that it contains *Myoxocephalus scorpius* and *Lumpenus fabricii*. Inclusion of *Gymnocanthus tricuspis* and *Liparis* spp. as dominant taxa in community "d" is not unique; what is characteristic is their roughly similar representation with *B. saida*. Community "e" is characterized by the inclusion of *Icelus* spp. and *Aspidophoroides olrikii.* Lastly, community "f" is exceptional in that it is mainly *B. saida*, but *Lycodes* spp. help characterize it. There is no pelagic community that duplicates the composition of any demersal community. Community "b" has *Eleginus gracilis* and *Stichaeus punctatus.* Community "c" is mainly *B. saida*, but *Liparis* spp. help characterize it. Lastly, the most unique community is "d" because *Liparis* spp. solely dominates, with no significant contribution from *B. saida.*

Monitoring fish communities should be useful to detect ecosystem responses to changes over time (Fossheim et al. 2006). For that purpose, community composition must be stable over time (Mahon et al. 1998). Communities might change geographical distribution (Dulvey et al. 2008), but the characteristic taxa should still be similarly grouped (Fossheim et al. 2006). As fish are within the same community and apparently react to the same environmental cues, a shift in group location should be indicative of a change in underlying physical setting such as temperature, salinity, and water mass. However, if some of the variables that define the assemblage are unalterable e.g., depth, latitude, and longitude, the assemblage composition itself may be altered. This project represents a snapshot in time, i.e., only one year, and the demersal and pelagic fish communities that we describe by representative taxa and associated physical characteristics existed in the US Beaufort Sea in 2011. Multiple years of sampling are needed to determine if these communities have temporal consistency. It is important to note that sampling must be comparable in terms of trawl gear and spatial and temporal distribution of collections in order to make valid comparisons.

Once the temporal and spatial consistency of fish communities in the Beaufort Sea has been established through repeated sampling, monitoring for changes in those communities would be feasible. It should be possible to reduce monitoring costs by basing the sample plan on knowledge of those assemblages. The number of stations to sample could be reduced by focusing on key locations that consistently have the same community attributes, i.e., the composition and relative proportions of characteristic fish taxa (Weslawski and Kwasniewski 1983). The intensity of the field and lab work could be reduced by focusing only on the specific fish taxa that are indicative of an identified assemblage. Monitoring the fish assemblages could be used to measure the biological response to factors such as oil and gas exploration, climate change, and fisheries.

Ecosystem stability is related to richness and diversity (Hillebrand et al. 2008). Diversity is a univariate index that combines components of richness (the number of taxa captured in one trawl haul) and evenness (the inverse of dominance) to produce a statistical measure (Frosini 2006). High stability in a community is characterized by high richness and high evenness (Hillebrand et al. 2008). Anthropogenic changes in an ecosystem might be seen in evenness indices, which often respond more rapidly than richness (Hillebrand et al. 2008). Because dominance and evenness are inverse indices of the same measure, an increase in evenness means a loss of dominance by one or more taxa, which is not necessarily good. Change in dominance structure will precede change in community composition, which in turn may cause changes in ecosystem function (Shackell and Frank 2003). For example, as a result of overfishing, Atlantic Cod (*Gadus morhua*) abundance and area occupied decreased on the Scotian Shelf (Zwanenburg 2000). As a result, food for cod increased and species that previously competed with cod increased to fill the niche previously occupied by cod. Thus, changes in evenness can reveal changes in distribution, with consequences for species interactions. In 1990 *B. saida* was the single dominant species on the northeast Chukchi Sea shelf (Barber et al. 1997), and by 2004 through 2008, species dominance was shared by sculpins, pricklebacks, cods, and flatfishes (Norcross et al. 2013 a or b). Communities with higher species richness are thought to be more resistant to disturbance and more stable than those with low richness and low diversity; higher diversity of species means more redundancy of function (Frank et al. 2006). In this study, none of the pelagic communities comprise more than five taxa; communities “c” and “d”, with only two and one taxa, respectively, are unlikely to be stable. The demersal community was more diverse. There, community “c”, with 22 species, seven of which are dominant, should be more stable than community “f”, with only seven total species and two dominant species (**Table 3-2**). Finally, the majority of the hauls on the US Beaufort Sea shelf comprised communities with high richness and diversity indices, which suggests that the Beaufort Sea shelf may be fairly stable and resistant to anthropogenic and climate changes.

Large-scale sampling with closely spaced collection locations is critical to be able to discern geographical and environmental patterns of fish communities. In-depth and seasonal knowledge of Arctic Ocean ecology is needed (Wassman 2011) to address potential changes from oil and gas exploration and climate change. What we presented here is a snapshot in time, i.e., summer 2011, but the density of this sampling provided a detailed examination of the US Beaufort Sea shelf.

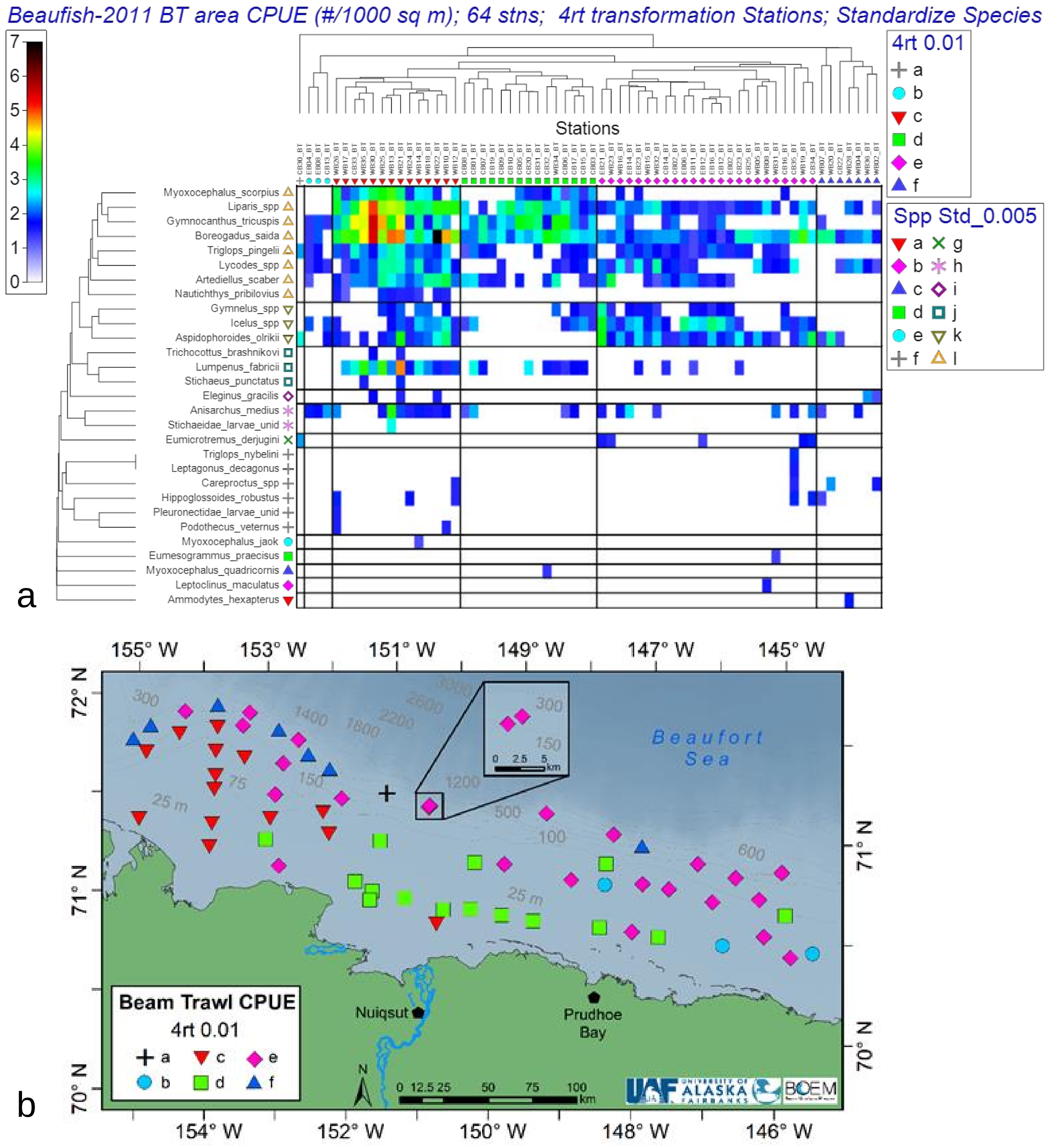
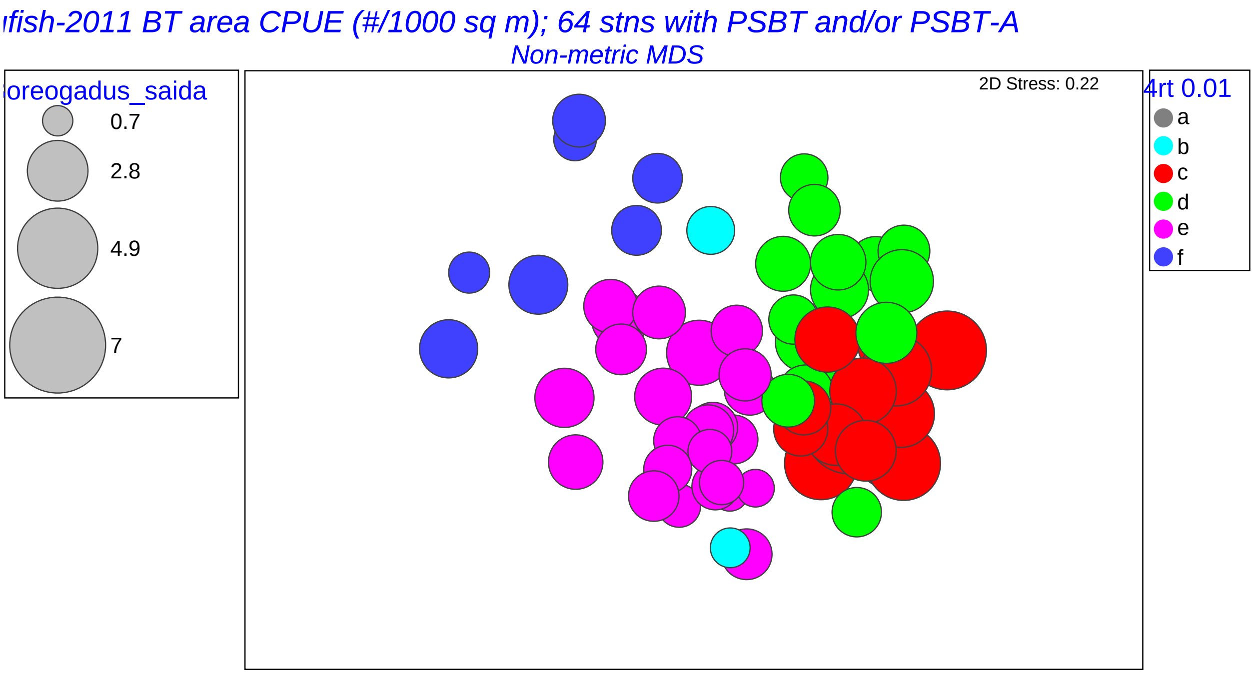


Figure 3-21 Beam Trawl CPUE (Catch) Six Fish Communities Formed by 4RT Transformation at p<0.01: a) Shade Plot, b) Distribution Map



4RT transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 3-22 Non-metric Multidimensional Scaling of Beam Trawl CPUE (Catch) Fish Communities (Colors) Formed by 4RT Transformation

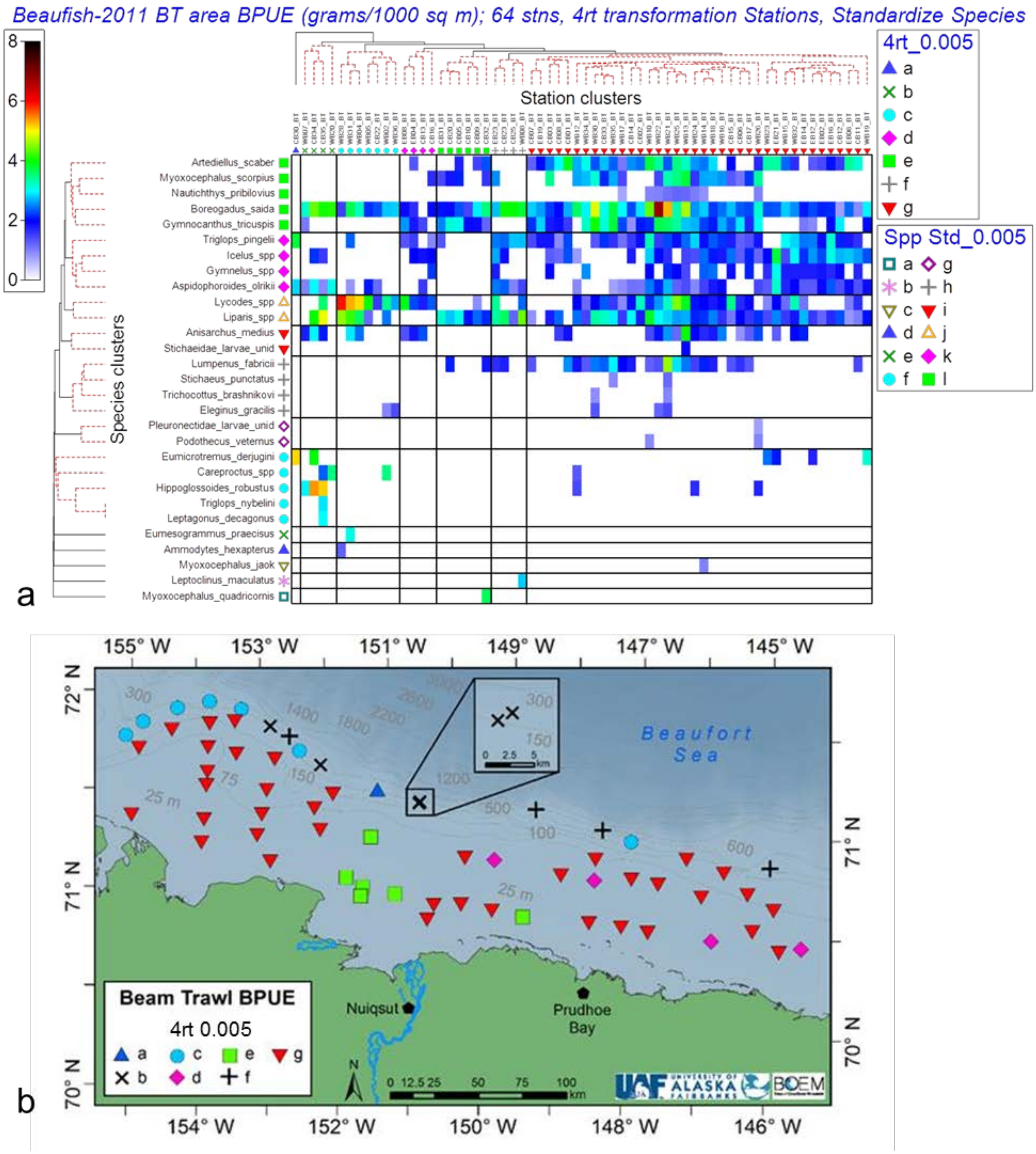
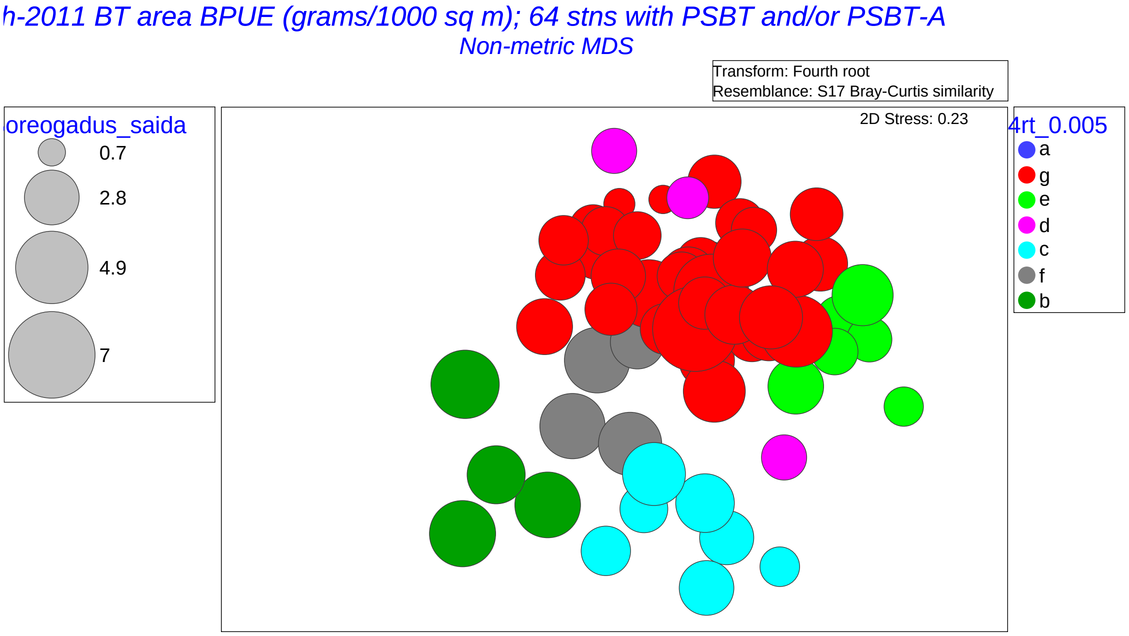


Figure 3-23 Beam Trawl BPUE (Biomass) Seven Fish Communities Formed by 4RT Transformation at p<0.005: a) Shade Plot, b) Distribution Map



4RT transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 3-24 Non-metric Multidimensional Scaling of Beam Trawl BPUE (Biomass) Fish Communities (Colors) Formed by 4RT Transformation

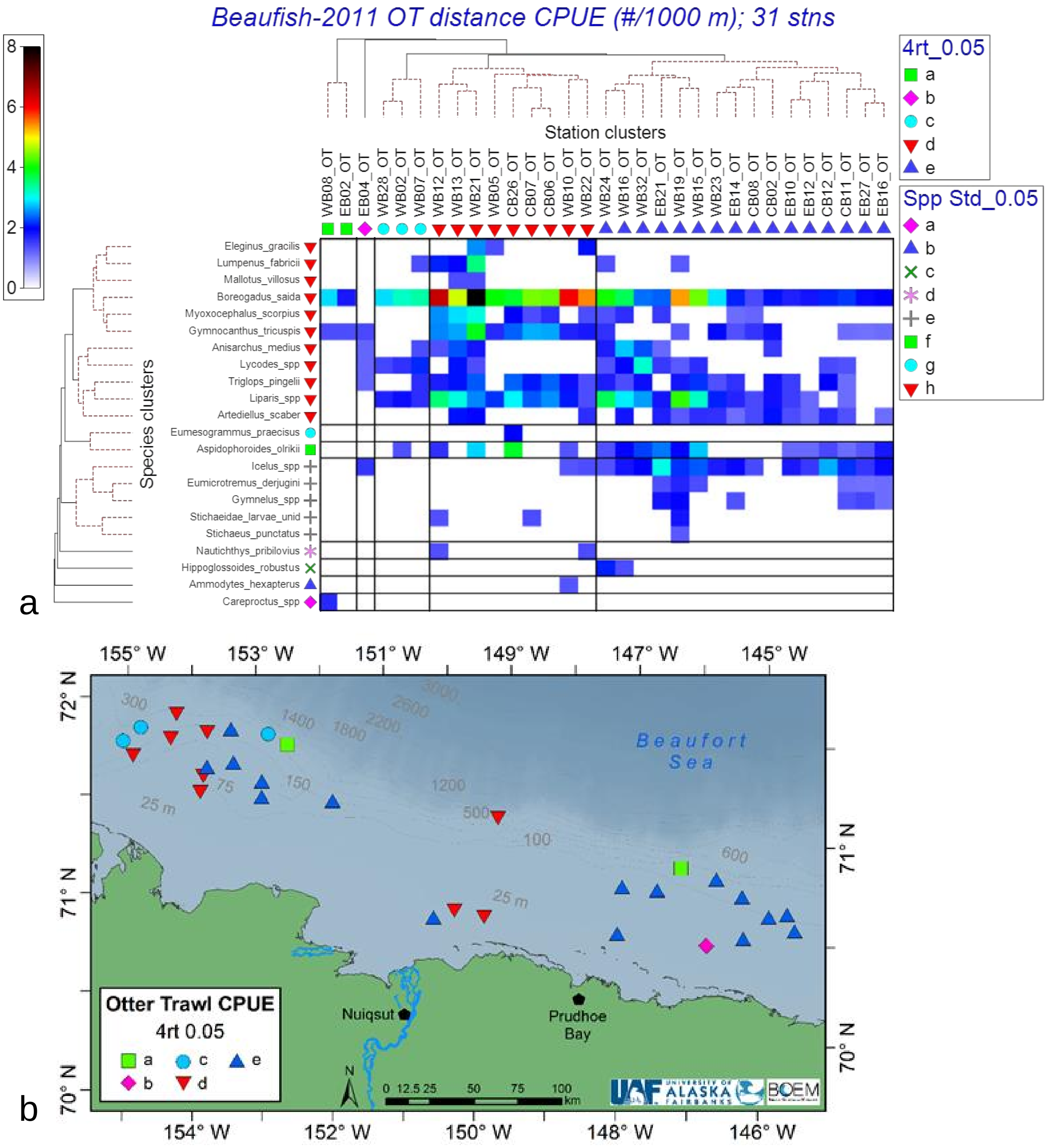
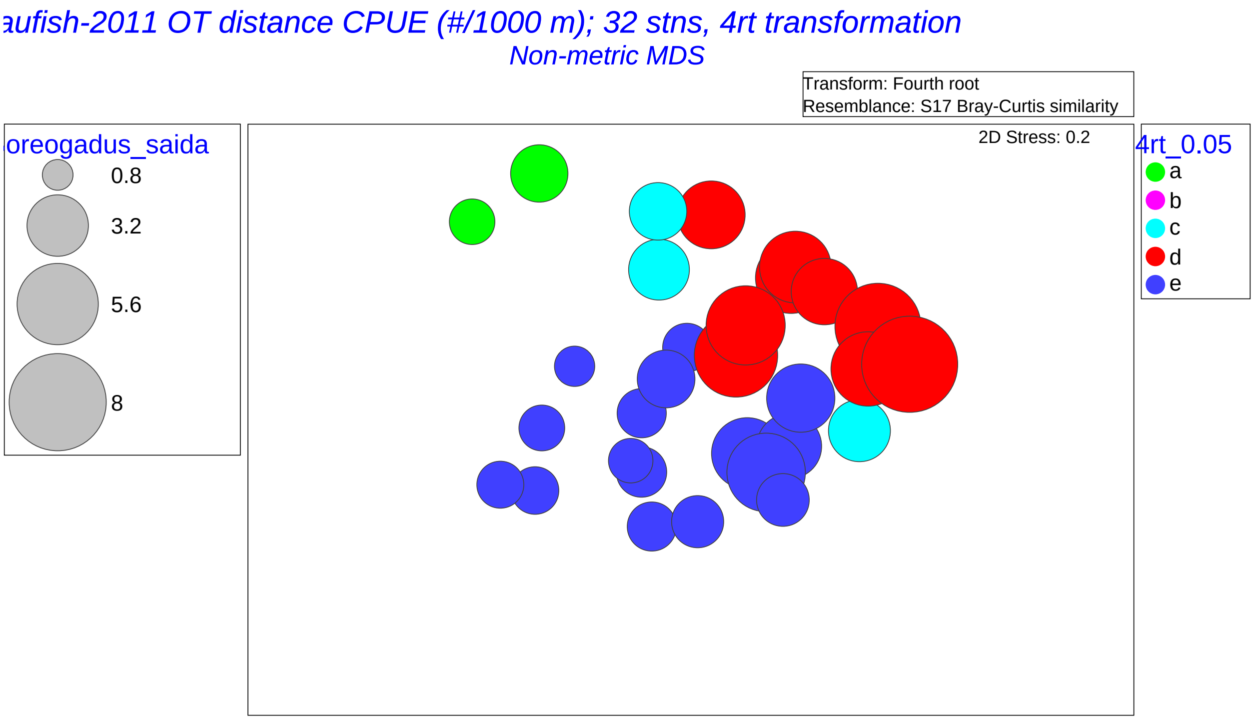


Figure 3-25 Otter Trawl CPUE Five Fish Communities Formed by 4RT Transformation at p<0.05: a) Shade Plot, b) Distribution Map



4RT transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 3-26 Non-metric Multidimensional Scaling of Otter Trawl CPUE (Catch) Fish Communities (Colors) Formed by 4RT Transformation

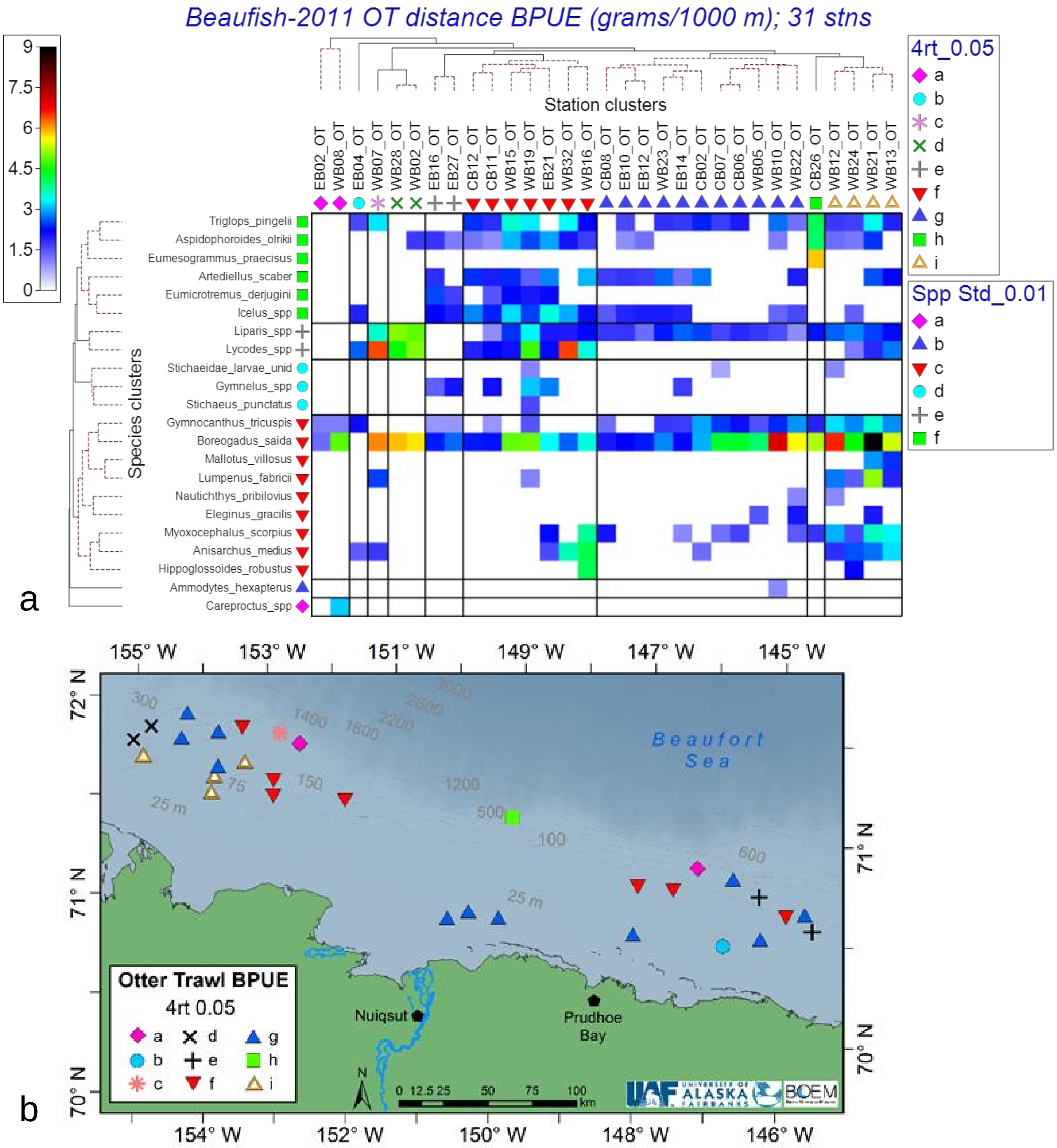


Figure 3-27 Otter Trawl BPUE Nine Fish Communities Formed by 4RT Transformation at $p<0.05$: a) Shade Plot, b) Distribution Map

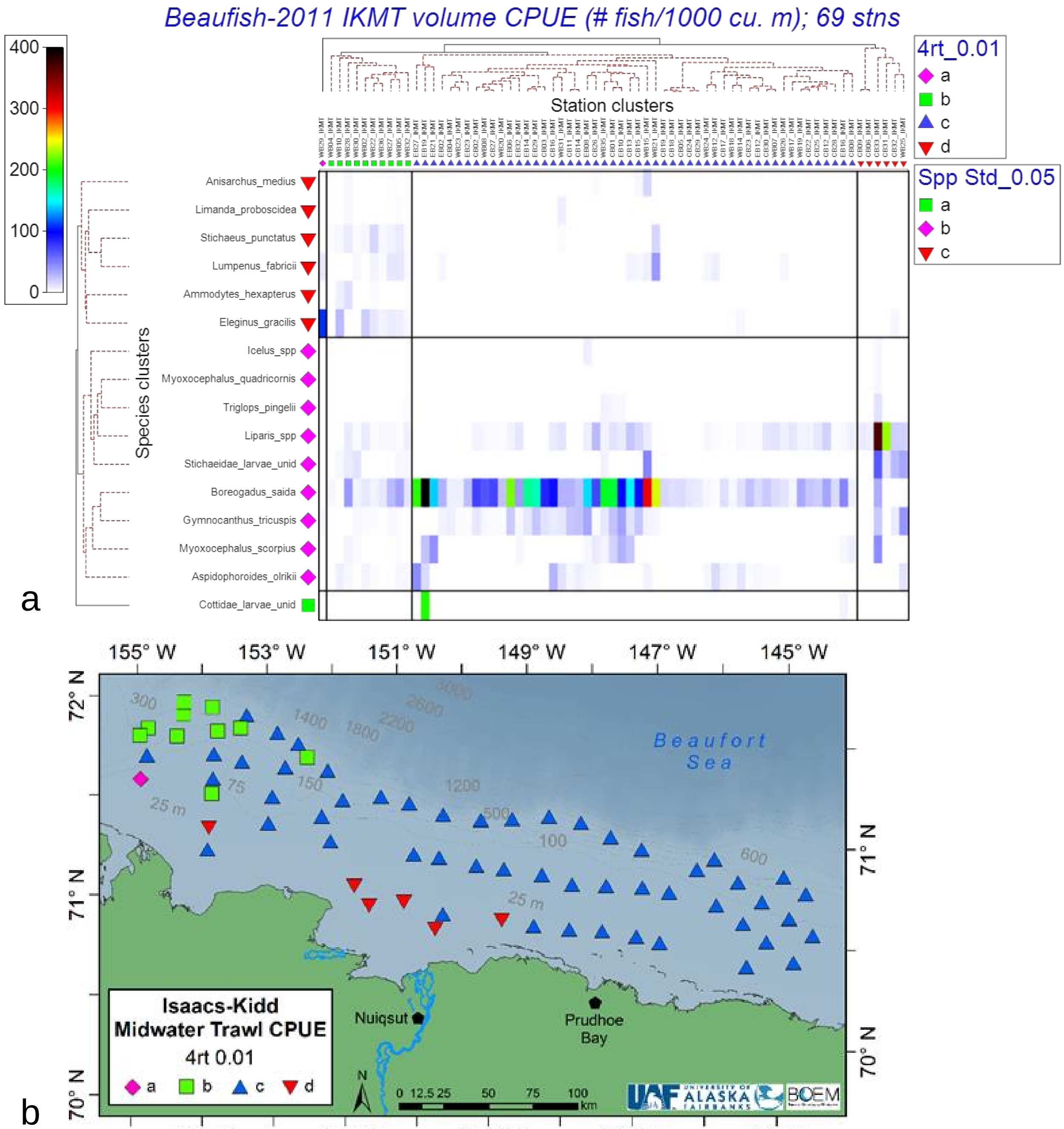
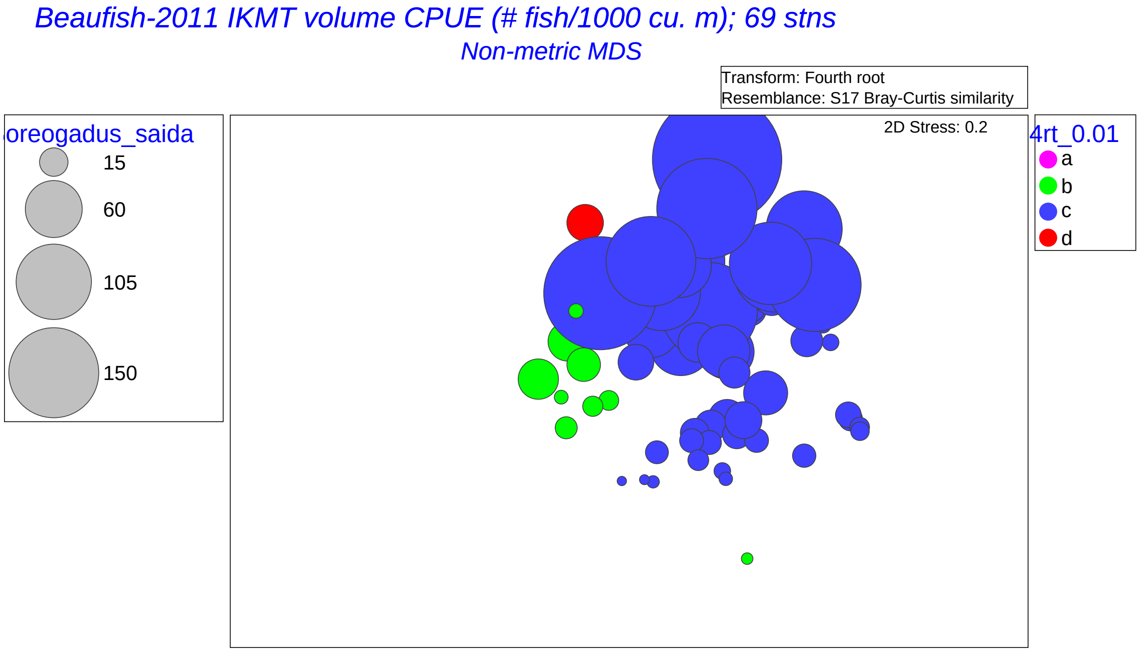


Figure 3-28 Isaacs-Kidd Midwater Trawl CPUE Four Fish Communities Formed by 4RT Transformation at p<0.01: a) Shade Plot, b) Distribution Map



4RT transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 3-29 Non-metric Multidimensional Scaling of Isaacs-Kidd Midwater Trawl CPUE (Catch) Fish Communities (Colors) Formed by 4RT Transformation

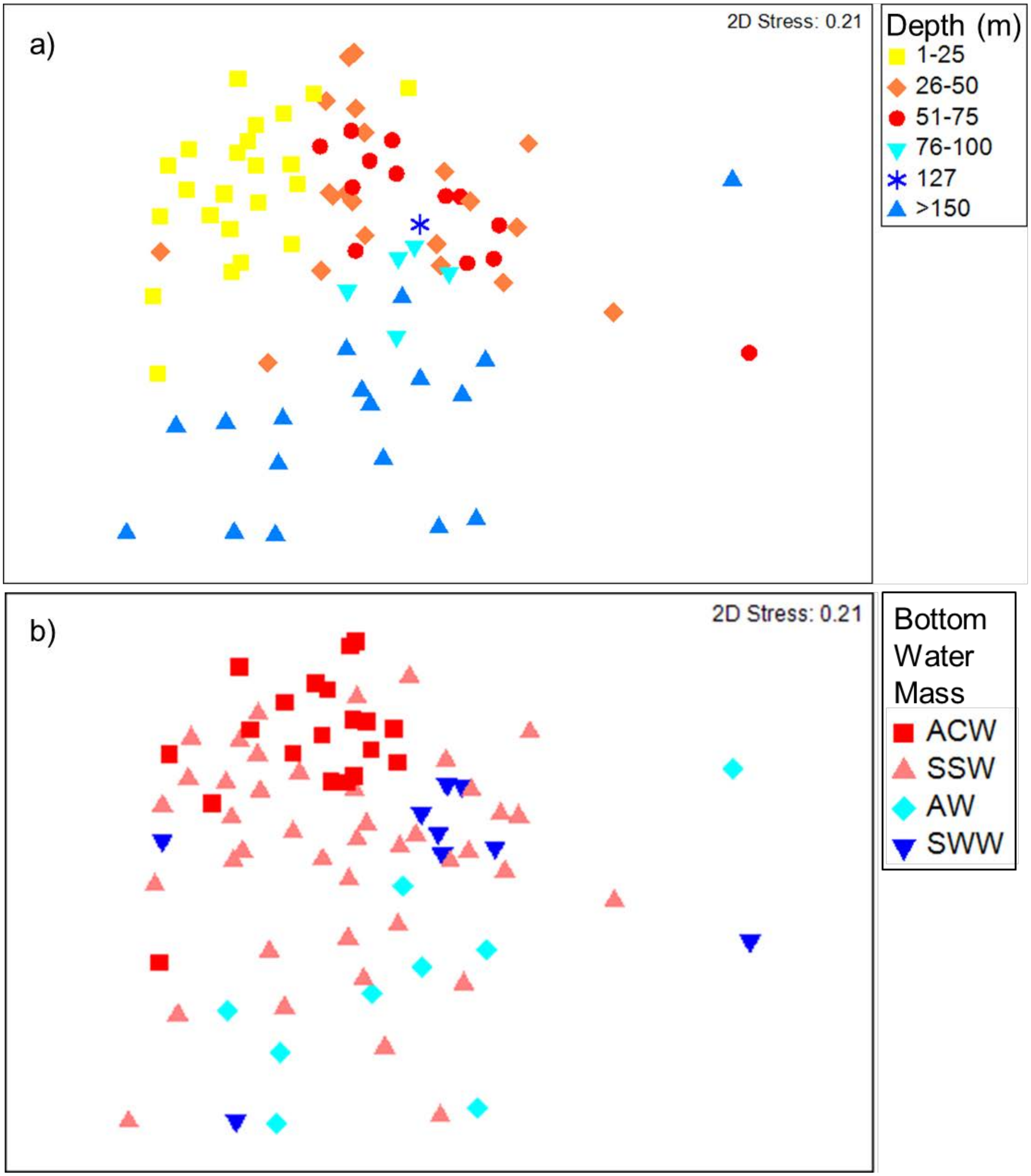


Figure 3-30 **Non-metric Multidimensional Scaling of Beam Trawl 4RT Transformed CPUE (Catch) in Relation to Depth Increments (Top) and Bottom Water Mass (Bottom)**

4 Length-Weight-Age Relationships of Demersal Fishes on the Shelf of the Alaskan Beaufort Sea

4.1 Introduction

The current interest regarding fishes in Arctic waters of the United States is primarily due to the importance of establishing a baseline of data against which future environmental changes can be interpreted. Many historic (Frost and Lowry 1983; Barber et al. 1997) and recent (Norcross et al. 2010; Rand and Logerwell 2011; Norcross et al. 2013b; Norcross et al. 2017) investigations in the Alaskan Arctic have focused on fish distribution and community analyses. While that type of information forms an excellent foundation for future investigations in the Arctic, it is equally important to establish basic life history parameters for individual species. Length at age and weight at age relationships would greatly complement fish distribution studies in that they could allow for a biomass estimate of captured fishes, along with the ability to estimate population age structure (Pauly 1993; Goncalves et al. 1997; Binohlan and Pauly 1998). At present, this type of baseline data is absent from the literature for many Arctic fish species.

Here we contribute information about length, weight, and age of ten fish species in the offshore and shelf waters of the central Beaufort Sea. These fishes are from seven families and represent taxa accounting for much of the abundance of demersal fishes in the western Arctic (Norcross et al. 2013b). Species include *Boreogadus saida*, *Eleginus gracilis*, *Gymnocanthus tricuspis*, *Myoxocephalus scorpius*, *Aspidophoroides olrikii*, *Liparis fabricii*, *Lycodes polaris*, *Anisarchus medius*, *Lumpenus fabricii*, and *Hippoglossoides robustus*.

Detailed life history information is only available for *B. saida*, *E. gracilis*, *G tricuspis*, and *H. robustus*. Of these species, length and weight at age of *B. saida* has been documented throughout the Arctic because of its circumpolar distribution, numeric abundance, and importance in Arctic marine food webs (Mecklenburg et al. 2011). Few studies document parameters for *E. gracilis*, *G. tricuspis*, and *H. robustus*, with all taking place in either the northern Bering Sea (*E. gracilis*, Helser et al. 2016) or northeastern Chukchi Sea (*E. gracilis*, Helser et al. 2016; *G. tricuspis*, Smith et al. 1997a; *H. robustus*, Smith et al. 1997b). Currently all other species do not have published length and weight at age information, which adds to the importance of this research. This study adds to the current knowledge of *B. saida*, *E. gracilis*, *G. tricuspis*, and *H. robustus* length-weight-age parameters, while providing baseline data for all remaining fish species. Both outputs serve to increase our knowledge of Arctic demersal fish communities.

4.2 Methods

Fishes were processed at the University of Alaska Fisheries Oceanography Laboratory in Fairbanks, Alaska. Each fish was thawed and blotted dry. Total length (TL) was measured to the nearest mm, and wet weight was measured to the nearest 0.1 g for larger fish and to the nearest 0.0001 g for smaller fish. It must be noted that between ours and other studies, there are three different standards of measure used for fish length. We report fish total length, which is the length of the fish from snout tip to the end of the tail. Other studies used either TL, fork length (FL), or standard length (SL). Fork length measures from the tip of the snout to the fork of the tail, while SL measures from the snout tip to the end of the scale cover at the tail. For the purpose of this study, measurements are reported as TL unless otherwise noted.

Otoliths from a subset of the fish that had been weighed were prepared for aging. The target quantity of specimens from each species was 20 individuals from each 10 mm length bin; in many cases, an insufficient number of fish was available to reach this target. Both sagittal otoliths were removed from the fish, cleaned of tissue, and stored dry in a centrifuge vial. One otolith was mounted to the center of a 1” x 3” glass slide using Crystalbond^{TM} thermoplastic glue. The otolith was polished (transversely sectioned) on a Buehler rotating wheel using 1200 grit sandpaper. The otolith was polished down to the center and flipped onto its flattened edge and polished to the proper thickness for aging (i.e., 300–400 µm). Using a compound scope at 100 x magnification, the otolith was checked during the polishing process to ensure over-polishing did not occur. If over-polishing or other damage caused the first otolith to be unreadable, a second otolith was processed for aging.

Transverse cross sections of otoliths were photographed under transmitted light using a Leica DM1000 dissecting scope mounted on a digital camera using 5x magnification. Otoliths were aged by two independent readers using an image of each otolith. Ages were assigned by counting each full year of growth on the otolith. One full year, or annual mark, consists of one opaque zone of faster summer growth and one translucent zone of slower winter growth (Matta and Kimura 2012). After each reader assigned an age to each otolith, the ages in which readers disagreed were re-read collaboratively by the same readers and assigned an agreed-upon age. These ages were used for constructing plots for data visualization and quality control.

The present analysis pooled catches across gear types, regardless of region of water column sampled, as parameters of entire fish communities were of primary interest. Statistical and graphic analyses were performed using SigmaPlot 12.5 software (Systat 2013). To exert control over the quality of the data for each fish species, an initial weight-at-length relationship was estimated by polynomial linear regression using the standard fisheries allometric equation (Ricker 1975) as:

$$W = a\,L^{b},$$

Where: W = total weight (g), L = total length (mm), *a* = the y-intercept, and *b* = the slope.

The fishes were generally small and lengths were measured in mm instead of cm, with the resulting *a* parameter expressed as 10^{-5}. Following the methods outlined by Giacalone et al. 2010, scatter plots of weight-at-length and age-at-length were visually examined for each fish species. Otoliths initially aged at >3 standard deviations outside of the mean were examined again by two readers because repetition of aging could reduce reader error if the originally assigned age was incorrectly estimated. Age-at-length observations that still occurred >3 standard deviations outside of the mean were assigned as outliers (**Table 4-1; Appendix C3**) and eliminated from other tables and figures. Using the standardized residuals obtained from the initial weight-at-length regressions, we assigned points >3 standard deviations from the mean as “outliers” and eliminated these points from other tables and figures (**Table 4-1; Appendix C3**). Because few data exist for these Arctic species, we use the term “outlier” without certainty that these data were necessarily incorrect. Outliers were excluded from length-weight-age tables and figures, but included as a record in **Table 4-1**.

For each fish species, a final length-at-age regression was calculated. A length-frequency histogram was plotted as the percentage of fishes in 10 mm length classes, and age-at-length data were plotted on the same x-axis. Length-frequency histograms were composed of fishes caught by all gears and were not adjusted for CPUE. Finally, length ranges and mean length-at-age were calculated for the assigned ages of each species.

Table 4-1 Number of Fishes Measured, Weighed, and with Ages Estimated

Family	Species	Fish Measured	Fish Weighed	Length-Weight Outliers	Age Estimates	Length-Age Outliers
Gadidae	*Boreogadus saida*[1]	2,880	2,807	59	353	7
	Eleginus gracilis	89	83	2	54	0
Cottidae	*Gymnocanthus tricuspis*	1,170	1,146	5	143	0
	Myoxocephalus scorpius	279	264	3	61	1
Liparidae	*Liparis fabricii*	104	93	4	57	2
Zoarcidae	*Lycodes polaris*	182	171	3	115	1
Stichaeidae	*Anisarchus medius*	240	232	8	167	1
	Lumpenus fabricii	356	351	3	138	1
Pleuronectidae	*Hippoglossoides robustus*	18	15	0	15	0
Total Number		5,839	4,641	92	1,217	14

[1] Two specimens were outliers in both length-weight and length-age categories.

The number of fishes >3 standard deviations from the mean are indicated as outliers.

4.3 Results

In 2011, sufficient numbers of fishes were available to develop length-weight relationships for 10 species from seven families (**Table 4-2**). The number of available specimens per species ranged over two orders of magnitude (**Table 4-2**) as they were dependent on the quantity of specimens captured. All weight-at-length regressions fit the data closely, with r^2 values between 0.93 (*A. olrikii*) and 0.99 (*H. robustus*) (**Table 4-2**). All weight-at-length intercepts (a) were near zero except for *H. robustus* ($a = 8.9$), while the range of slopes (b) was between 2.60 (*H. robustus*) and 3.56 (*Liparis fabricii*) (**Table 4-2**). A b value close to 3 indicates isometric growth, with values ~0.3 below or above 3 indicating negative or positive allometric growth, respectively (Andreu-Soler et al. 2005; Froese 2006). Therefore, the b value can be an indicator of body shape, with negative allometric growth indicating a decrease in body thickness or plumpness with increasing fish length, while positive allometric growth indicates an increase in these characteristics (Froese 2006). All but three species exhibited b values of 3 ± 0.3, i.e., relatively isometric growth. The flatfish *H. robustus* was the only species that exhibited an apparent negative allometric growth ($b = 2.60$, $r^2 = 0.99$), however the small sample size and wide range of lengths lead to limited confidence in this assessment (n = 15, 50–300 mm; **Table 4-2**). The sculpin, *G. tricuspis* ($b = 3.39$, $r^2 = 0.98$), and snailfish, *Liparis fabricii* ($b = 3.56$, $r^2 = 0.99$), were the only species to exhibit positive allometric growth.

Table 4-2 Weight-at-Length Relationships

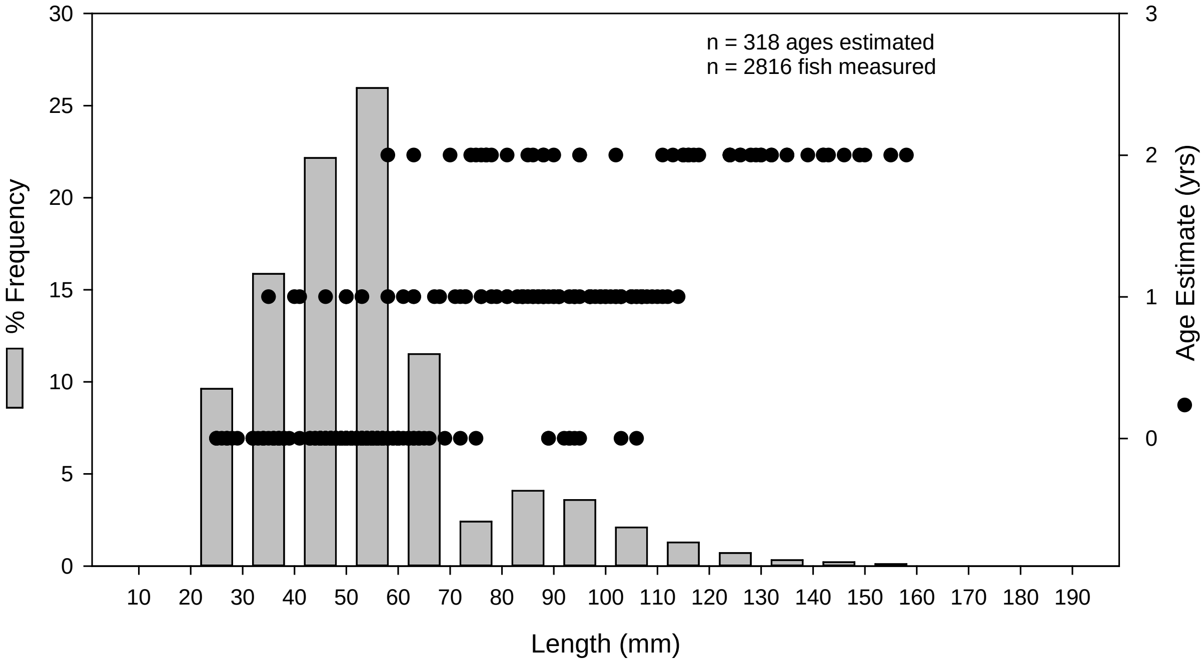
Species	n	Length Range (mm)	Weight Range (g)	a * 10^{-5} (95% CI)	B (95% CI)	r^2
Boreogadus saida	2,743	20-158	0.03-29.51	0.3063 (0.2784-0.3342	3.1748 (3.1555-3.1941)	0.9764
Eleginus gracilis	81	24-57	0.06-1.43	0.3235 (0.1203-0.5268	3.2167 (3.0522-3.3812	0.9498
Gymnocanthus tricuspis	1,141	22-127	0.08-36.15	0.2535 (0.2213-0.2857	3.3916 (3.3638-3.4194)	0.9821
Myoxocephalus scorpius	260	31-89	0.22-10.14	0.9564 (0.6728-1.2400)	3.0929 (3.0213-3.1644)	0.9324
Aspidophoroides olrikii	473	22-75	0.05-3.35	0.2612 (0.1636-0.3588)	3.2541 (3.1626-3.3456)	0.9368
Liparis fabricii	93	8-139	0.02-32.42	0.0759 (0.0094-0.1425)	3.5629 (3.3829-3.7430)	0.9872
Lycodes polaris	167	39-182	0.17-32.26	0.2853 (0.1306-0.4399)	3.1183 (3.0105-3.2262)	0.9618
Anisarchus medius	223	47-145	0.26-9.78	0.2041 (0.1181-0.2902)	3.0976 (3.0089-3.1863)	0.9767
Lumpenus fabricii	347	45-173	0.21-12.27	0.9715 (0.7597-1.1832)	2.7565 (2.7118-2.8011)	0.9842
Hippoglossoides robustus	15	50-300	0.84-244.80	8.8877 (-7.2745-0.0003)	2.6017 (2.2765-2.9269)	0.9905

$W = a L^{b}$, where W = total weight (g), L = total length (mm), *a* = the y-intercept, and *b* = the slope.
Outliers are excluded. Ranges of lengths and weights are of fishes where both measurements were recorded.

For each species, age-at-length values were superimposed on length-frequency plots (**Figure 4-1 through Figure 4-10**). Age-0 specimens were observed for all species except *H. robustus*. Despite the small size of *H. robustus* (**Figure 4-10**), otolith readings clearly indicated that *H. robustus* ≤60 mm were age-1 (**Table 4-3**). Over all species (**Table 4-3**), maximum ages ranged 0 to 16, with *E. gracilis* being the youngest (age-0, 24– 57 mm; **Figure 4-2**) and *Aspidophoroides olrikii* (age-13 at 75 mm; **Figure 4-5**), *A. medius* (age-16 at 145 mm; **Figure 4-8),** and *H. robustus* (age-11 at 300 mm; **Figure 4-10**) being the oldest. Within some species, length ranges at ages overlapped considerably; such patterns were most notable in ages 0 to 2 of *B. saida* (**Figure 4-1)**, ages 2 to 4 of *G. tricuspis* (**Figure 4-3)**, and ages 1 to 3 of *M scorpius* (**Figure 4-4**). Three or more sequential ages overlapped for *A. olrikii* (**Figure 4-5**), *Lycodes polaris* (**Figure 4-7**), *Anisarchus medius* (**Figure 4-8**), and *Lumpenus fabricii* (**Figure 4-9**). Age-at-length of some other species exhibited no overlap, such as *Liparis fabricii and H. robustus* (**Figure 4-6 and Figure 4-10**, respectively).

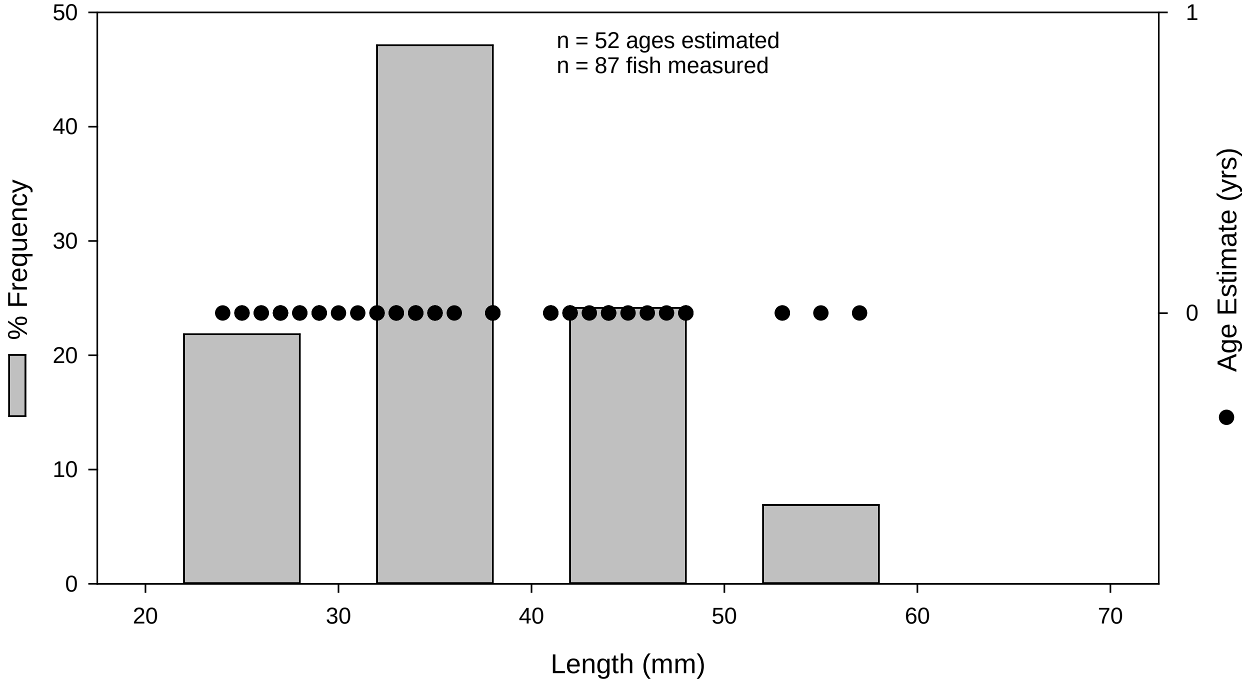
Table 4-3 Assigned Ages, Range of Total Length, Mean, and Standard Deviation (SD) of Length for Each Species and Age

Species	Age	n fish	Min-Max (mm)	Mean ±SD
Boreogadus saida	**all**	**2,816**	**20-162**	
	aged	**318**	**25-158**	
	0	192	25-106	51.9±13
	1	78	35-114	86.8±19.3
	2	48	58-158	112±27.2
Eleginus gracilis	**all**	**87**	**24-57**	
	aged	**52**	**24-57**	
	0	52	24-57	37.1±8.6
Gymnocanthus triscuspis	**all**	**1,165**	**22-127**	
	aged	**138**	**25-127**	
	0	50	25-47	36.7±5.4
	1	15	47-63	56±3.9
	2	38	54-90	67.1±10.1
	3	28	64-109	86.9±10.7
	4	6	85-127	104.3±16.7
	5	1	108	108
Myoxocephalus Scorpius	**all**	**275**	**31-162**	
	aged	**58**	**31-89**	
	0	46	31-56	47.3±5.3
	1	7	55-88	73.4±10.7
	2	4	60-89	75.8±13.6
	3	1	86	86
Aspidophoroides olrikii	**all**	**515**	**22-75**	
	aged	**111**	**28-75**	
	0	19	28-43	37.4±3.5
	1	32	32-53	42.6±4.3
	2	11	49-60	53.3±3.7
	3	23	46-64	57.2±5.1
	4	5	57-68	60.6±4.5
	5	5	54-69	62.4±5.7
	6	2	66-67	66.5±0.7
	7	6	65-72	68.2±3.1
	8	1	74	74
	9	1	68	68
	10	1	70	70
	12	4	65-75	71±4.2
	13	1	73	73
Liparis fabricii	**all**	**98**	**8-160**	
	aged	**52**	**21-139**	
	0	43	21-45	30.7±5.5
	1	8	54-79	67.3±8.7
	2	1	139	139
Lycodes polaris	**all**	**178**	**39-333**	
	aged	**111**	**39-177**	
	0	29	39-60	47±5.2
	1	9	39-66	51.7±7.2
	2	8	62-99	74±11.7
	3	26	66-106	77.4±7.9
	4	14	69-142	95.5±20.6
	5	13	76-160	103.5±22.2
	6	8	89-172	113.4±29.8
	7	1	121	121
	8	1	176	176
	9	2	142-177	159.5±24.7
Anisarchus medius	**all**	**231**	**47-145**	
	aged	**159**	**51-145**	
	0	47	51-81	59.8±5.3
	1	18	57-85	71.9±7.5
	2	21	72-108	90.4±10.5
	3	22	83-104	95±6.1
	4	6	97-127	107.7±11.3
	5	19	100-128	115.1±6.7
	6	8	109-127	119.3±5.8
	7	9	104-135	120.4±8.9
	8	3	120-139	127.7±10
	9	2	113-123	118±7.1
	10	1	130	130
	12	2	130-135	132.5±3.5
	16	1	145	145
Lumpenus fabricii	**all**	**352**	**45-173**	
	aged	**135**	**50-173**	
	0	41	50-86	61.4±7.7
	1	32	64-106	80.5±11.4
	2	25	83-148	113.2±21
	3	35	102-173	128.9±18.1
	4	2	135-162	148.5±19.1
Hippoglossoides robustus	**all**	**18**	**50-300**	
	aged	**15**	**50-300**	
	1	8	50-60	54.0±3.0
	6	1	159	159
	7	1	157	157
	8	2	170-247	208.5±54.4
	10	2	245-272	258.5±19.1
	11	1	300	300



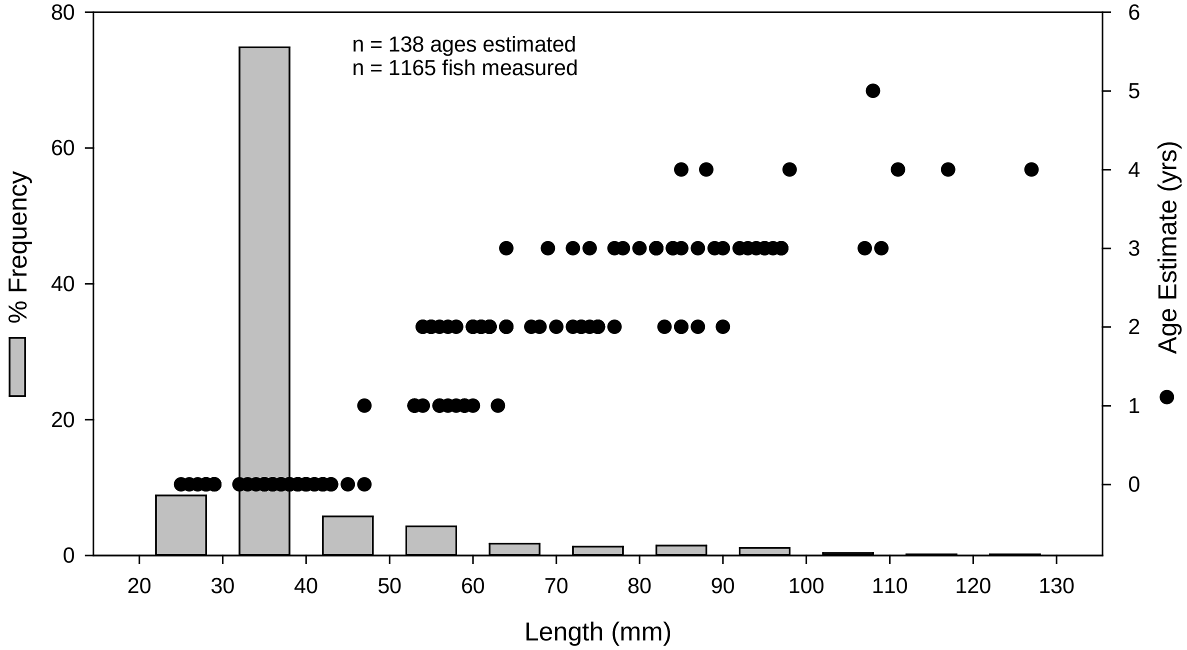
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-1 Length-Frequency and Age-at-Length of *Boreogadus saida*



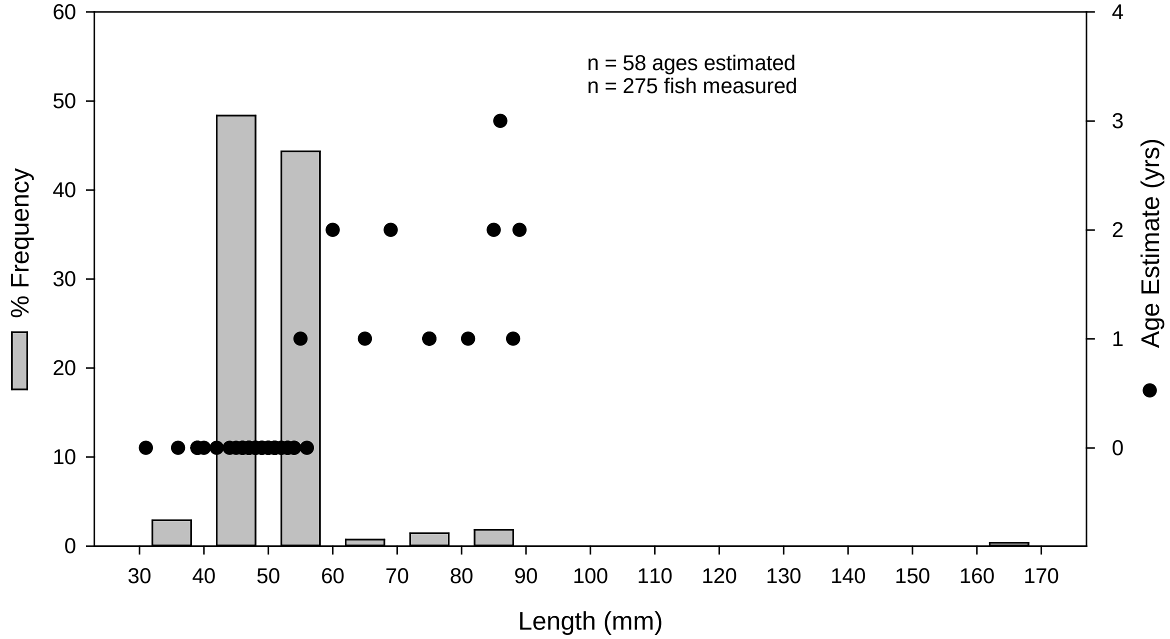
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-2 Length-Frequency and Age-at-Length of *Eleginus gracilis*



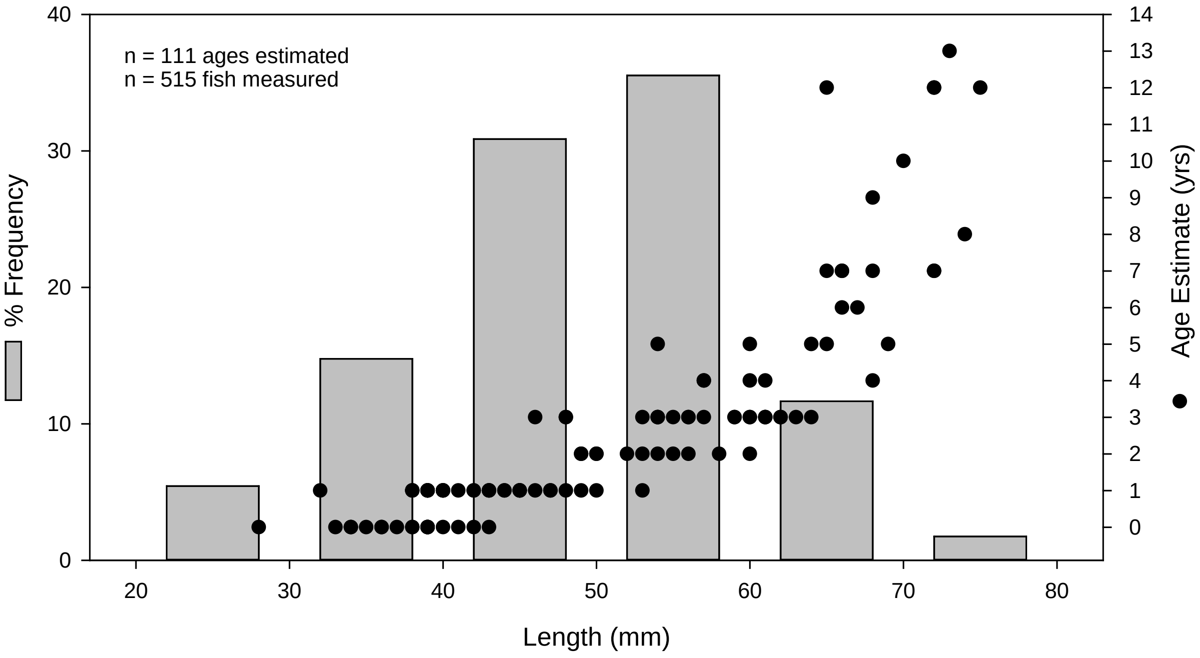
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-3 Length-Frequency and Age-at-Length of *Gymnocanthus tricuspis*



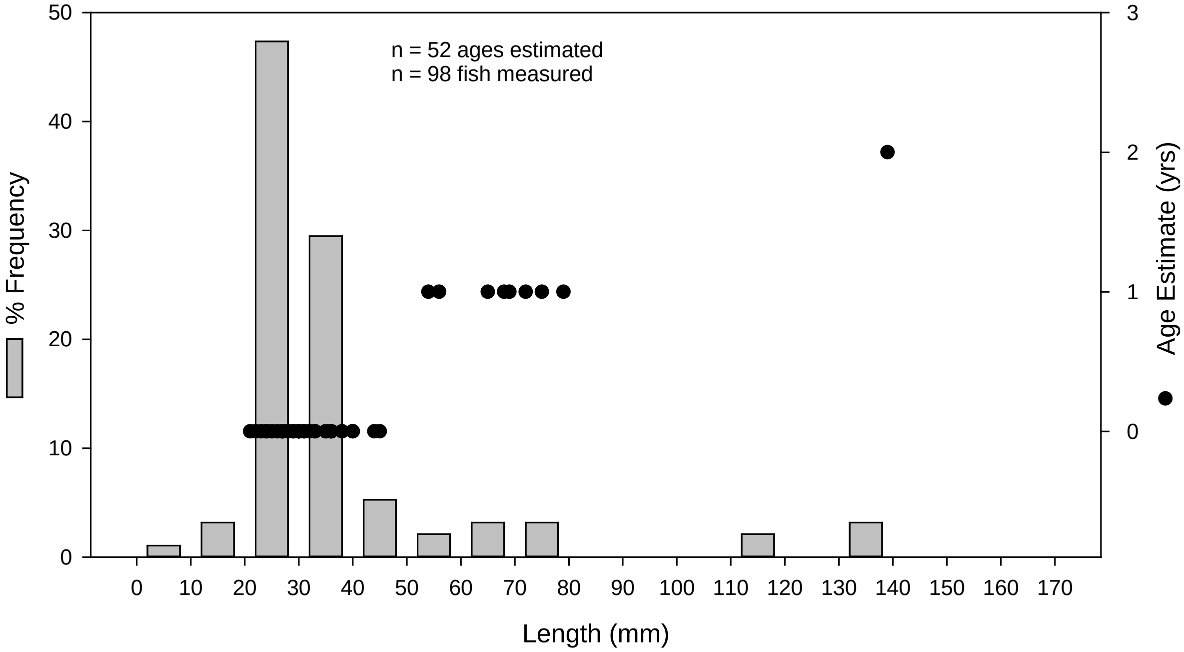
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-4 Length-Frequency and Age-at-Length of *Myoxocephalus scorpius*



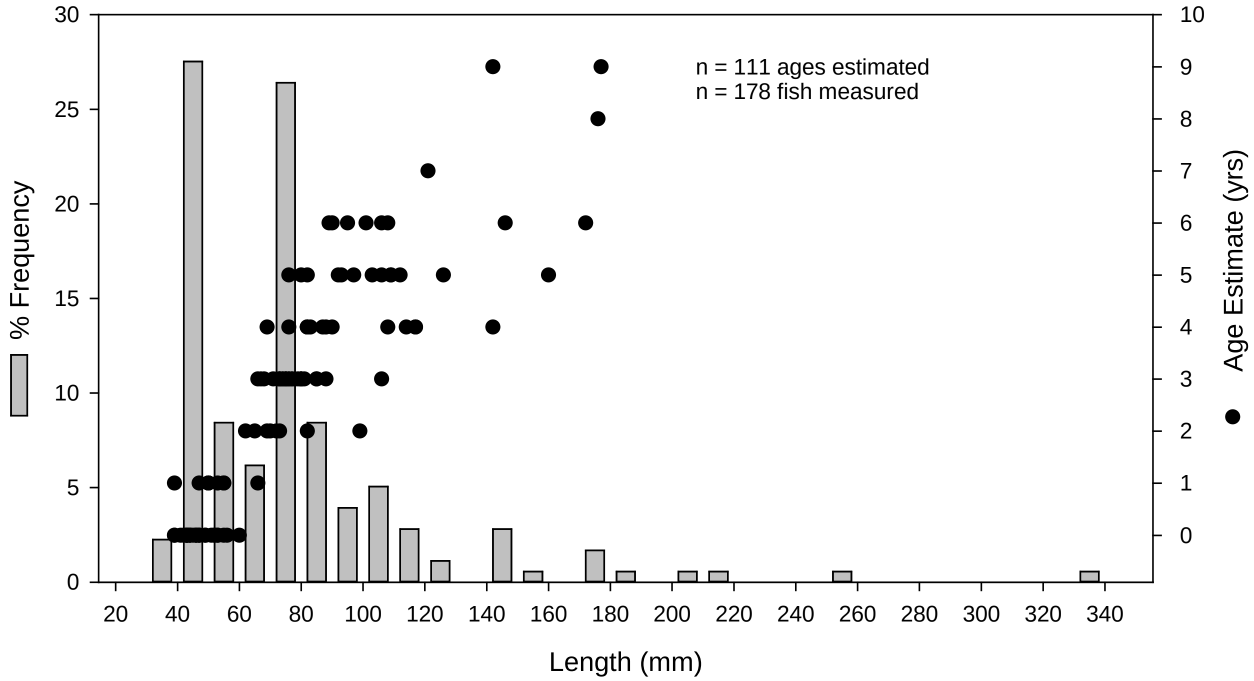
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-5 Length-Frequency and Age-at-Length of *Aspidophoroides olrikii*



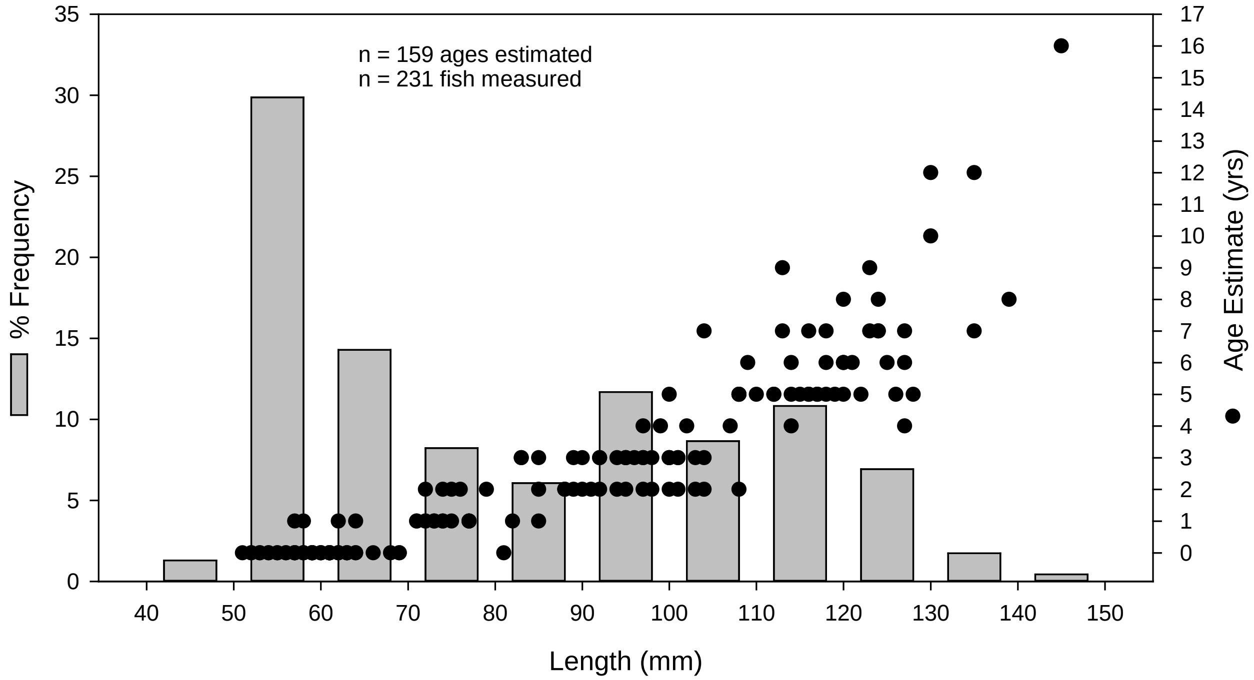
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-6 Length-Frequency and Age-at-Length of *Liparis fabricii*



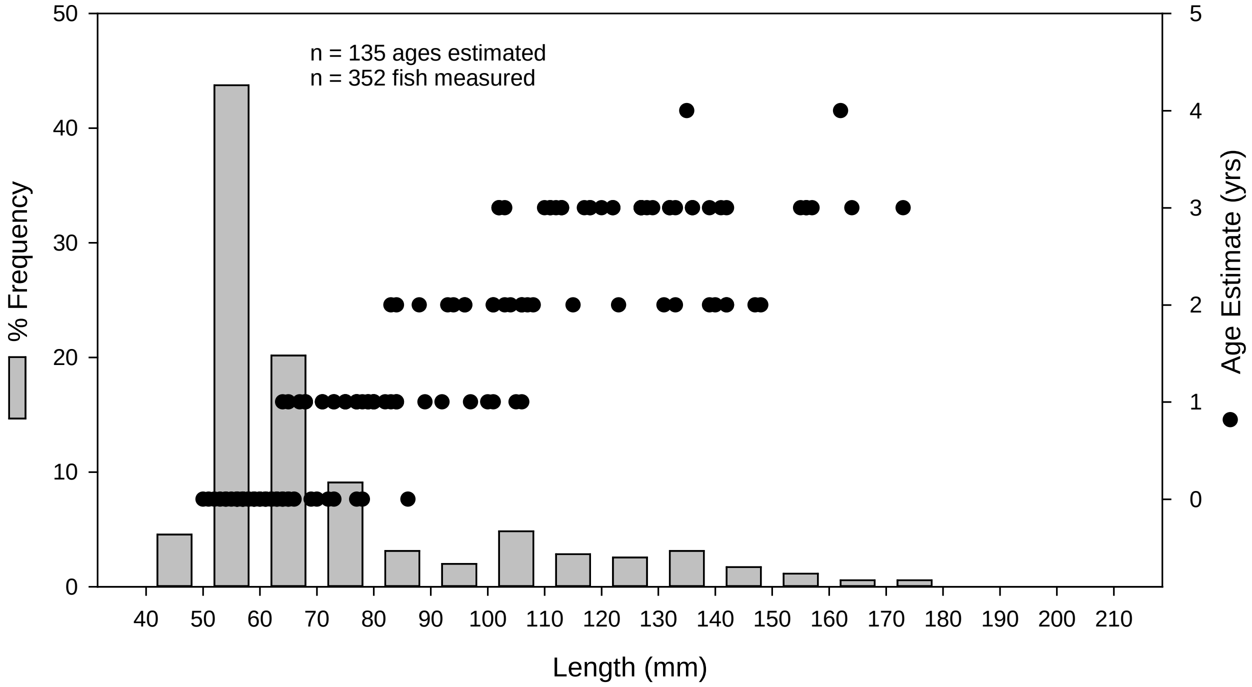
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-7 Length-Frequency and Age-at-Length of *Lycodes polaris*



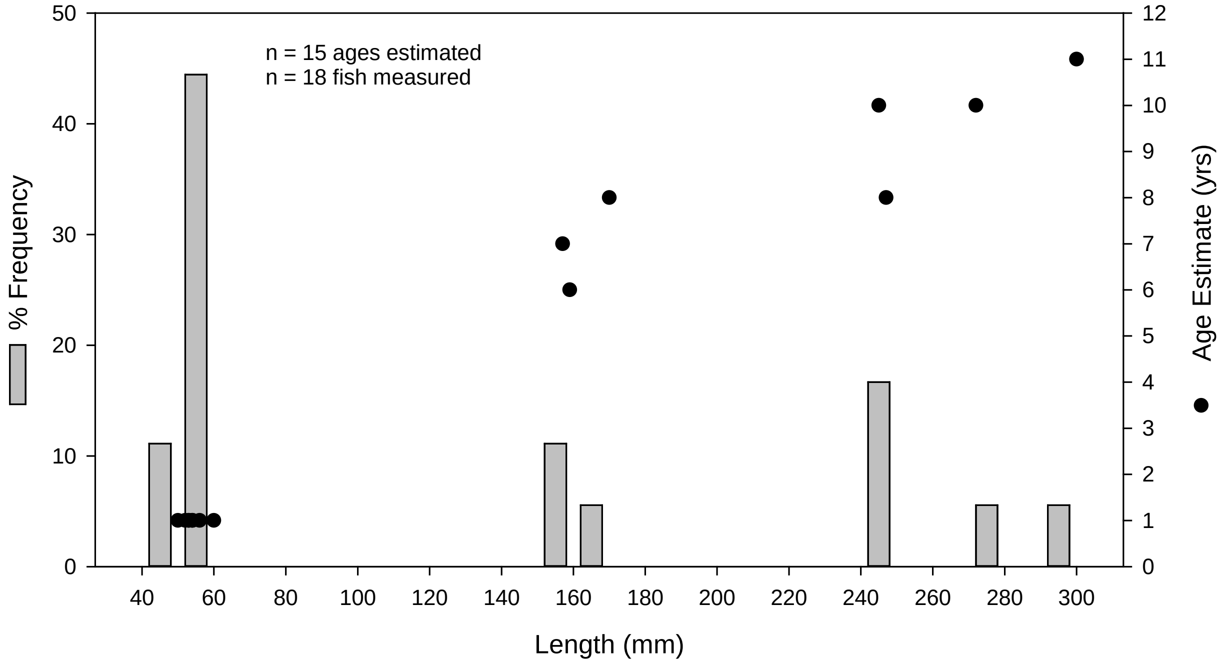
Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-8 Length-Frequency and Age-at-Length of *Anisarchus medius*



Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-9 Length-Frequency and Age-at-Length of *Lumpenus fabricii*



Length frequency includes measured fishes caught by all gears and is not adjusted for catch per unit effort.

Figure 4-10 Length-Frequency and Age-at-Length of *Hippoglossoides robustus*

4.4 Discussion

To the best of our knowledge, this is the first account of length-weight-age data for representative species of families Agonidae, Cottidae, Liparidae, Pleuronectidae, Stichaeidae, and Zoarcidae in the Central Beaufort Sea. In our study area, length-weight-age data has been examined for *B. saida* (family Gadidae) by Craig et al. (1982) and Rand and Logerwell (2011); but they did not examine these relationships for the gadid *E. gracilis* or any of the other species we present here. The majority of research with which to compare our findings was conducted in regions outside of the western Beaufort Sea and was primarily limited in scope to families Gadidae, Cottidae, and Pleuronectidae. This means the majority of comparisons between our study and previous literature are limited to *B. saida*, *E. gracilis*, *G. tricuspis*, *M. scorpius* (age-at-length only), *and H. robustus*. Where possible, we compare the remaining five species with life history information from other published research.

Comparisons between our findings and others were most possible for *B. saida* given the considerable amount of research on this species. In our study, all *B. saida* specimens followed an isometric growth strategy ($b = 3.17$), were ages 0–2, and ranged in length from 20–158 mm. These findings generally reflected those of other studies that reported all or some of these values. The majority of studies that reported b values were near our study area, e.g., the northern Bering and Chukchi seas (Helser et al. 2016), northeastern Chukchi Sea (Gillespie et al. 1997), western Beaufort Sea (Craig et al. 1982; Rand and Logerwell 2011), or the Canadian High Arctic (Elliot and Gaston 2008). Each of these studies supported *B. saida* following an isometric growth strategy (i.e., all reported b values ranged from 2.83–3.06). Considering age structure, a pattern emerged between ours and other studies in that the majority of *B. saida* collected were 2 years old or younger. This pattern is evident throughout many collection years and Arctic regions, e.g., the northern Bering and Chukchi seas (Helser et al. 2016), northeastern Chukchi Sea (Frost and Lowry 1983; Gillespie et al. 1997), the western Beaufort Sea (Frost and Lowry 1983; Parker-Stetter et al. 2011; Rand and Logerwell 2011), Canadian Beaufort Sea (Walkusz et al. 2013), Canadian Basin of the Arctic Ocean (Melnikov and Chernova 2013), and the Barents Sea (Lønne and Gulliksen 1989). Of these studies that included length ranges of *B. saida* at ages 2 years or younger, regional variability in length-at-age was apparent. Keeping in mind that TL>FL>SL, the greater lengths-at-age for *B. saida* were typically collected in warmer regions, for example the northern Bering Sea (ages 0–2, ~30–200 mm FL, Helser et al. 2016) and northeastern Chukchi Sea (ages 1–2, 75–193 mm FL; Gillespie et al. 1997). Smaller sizes at this age range were reported throughout the northeastern Chukchi Sea/western Beaufort Sea (ages 1–2, 45–144 FL; Frost and Lowry 1983), inshore western Beaufort Sea (ages 1–2; 54–177 FL; Craig et al. 1982), Canadian Beaufort Sea (ages 0–2, ~40–100 mm SL; Walkusz et al. 2013), the Barents Sea (ages 1–2, 59–168 mm TL; Lønne and Gulliksen 1989), and with the smallest collected in the Canadian Basin of the Arctic Ocean (ages 1–2, 72–89 mm SL; Melnikov and Chernova 2013). Some of these cruises did collect *B. saida* age 3 or older, which were larger than the ranges we discuss here. *B. saida* are documented as reaching age 8 (Gillespie et al. 1997) and attaining sizes >400 mm (Cohen et al. 1990); however, it is considered quite rare to encounter *B. saida* age 5 or greater (Helser et al. 2016).

In our study, length-weight-age data for *E. gracilis* was limited to age 0, ≤57 mm individuals, limiting comparisons between *E. gracilis* and *B. saida* and making comparisons with other *E. gracilis* studies difficult. We determined that both gadids follow isometric growth strategies in the western Beaufort Sea, with *B. saida* and *E. gracilis* exhibiting b values of 3.17 and 3.22, respectively. Our results resemble those found by Helser et al. (2016), with *B. saida* and *E. gracilis* in the northern Bering Sea and Chukchi Sea exhibiting b values of 2.90 and 3.10, respectively. Although both species exhibit isometric growth, *E. gracilis* in the northern Bering and northeastern Chukchi Sea exhibit a wider range of greater lengths than *B. saida* at a similar age (Helser et al. 2016). Throughout their range, *E. gracilis* may live up to 14 years of age and attain lengths of 550 mm (Cohen et al. 1990), although, like *B. saida*, individuals older than age 5 are rarely collected in surveys (Helser et al. 2016). Knowing this, we would predict that if there were larger *E. gracilis* present in the western Beaufort Sea that they would also follow a similar pattern and therefore be larger at age on average than *B. saida*.

The two sculpin species, *G. tricuspis* and *M. scorpius*, exhibited different weight-at-length relationships. The elevated *b* value we determined for *G. tricuspis* (*b* = 3.39) is similar to that determined by Smith et al. (1997a), *b* = 3.29, meaning this species is close to exhibiting positive allometric growth. In contrast, we found that *M. scorpius* generally followed isometric growth (*b* = 3.09). These findings are consistent with our laboratory observations of western Beaufort Sea cottids in that *G. tricuspis* exhibits a generally thicker body structure than *M. scorpius* at similar lengths. The importance of these findings are relatively unknown and could be an indicator of different growth strategies, or could be because we collected a wider range of sizes of *G. tricuspis* (22–127 mm) than *M. scorpius* (31–89 mm), i.e., we may have only documented length-weight parameters of a small subsample of *M. scorpius* life history.

Life history data indicates *G. tricuspis* can live up to 9 years of age throughout their distribution and attain lengths of 300 mm in warmer areas (western Greenland; Andriyashev 1964). The *G. tricuspis* we collected were much smaller and younger, with individuals older than age 4 being very rare. Our age-at-length estimates generally agreed with those from 1990–1991 catches in the Chukchi Sea (Smith et al. 1997a). Their analysis of mean length-at-age showed age 1 was ~50 mm (ours = 56 mm), age 2 ~65 mm (ours = 67 mm), age 3 ~80 mm (ours = 87 mm), age 4 ~105 mm (ours = 104 mm), and age 5 ~110 mm (ours = 108 mm). This appears to indicate larger mean length-at-age for age 1–3 *G. tricuspis* in the western Beaufort Sea with lengths at age 4–5 becoming larger in the Chukchi Sea; however, the difference is small and the age structure determined by the Smith et al. (1997a) study compared to ours is quite different. We collected much more age 0 individuals than Smith et al. (1997a) and they collected much higher proportions of age 1+ which would no doubt influence mean length-at-age.

Life history information for *M. scorpius* indicates they can live up to 15 years throughout their distribution and attain a maximum size of 500 mm (Newfoundland waters, Ennis 1970). Similar to *G. tricuspis*, *M. scorpius* individuals collected here were much smaller and younger than reported maxima. The ages 1–3 *M. scorpius* we observed ranged from 56–89 mm, in contrast, age 1–3 conspecifics in Newfoundland waters ranged from ~110–200 mm in length (Ennis 1970). This large discrepancy is likely due to better growth conditions in Newfoundland waters, which may include higher mean temperatures and possibly a better prey field.

Although there were few (n = 18) *H. robustus* captured in the present study, we examined this species' life history parameters because it was the most numerous pleuronectid collected. Our weight-at-length data indicated negative allometric growth (*b* = 2.60), a finding that did not agree with Smith et al. (1997b) which calculated *b* = 3.25 from a more representative sample size (n = 135) and age structure. Therefore, it is likely our *b* estimates would have been different were a similar sample size and age structure available in the Beaufort Sea. The maximum length-at-age we observed was 300 mm at age 11, which is similar to the reported maximum size (i.e., 324 mm at age 11; Smith et al. 1997b). *H. robustus* captured in the Chukchi Sea with a large NMFS 83-112 net, for which the smallest mesh of 38 mm were an average of age 8 for males and age 11 for females; >40% of the 133 fish examined were age 5 (Barber et al. 1997; Smith et al. 1997b). *H. robustus* of comparable size and age were caught in the Beaufort Sea during the present research with smaller mesh (4 mm or 19 mm).

For most all other species examined, i.e., the agonid (*A. olrikii*), liparid (*Liparis fabricii*), zoarcid (*L. polaris*), and stichaeids (*A. medius, Lumpenus fabricii*), there was a lack of published information regarding length-weight-age data with which to compare our findings. Records of the agonid, *A. olrikii*, indicate a maximum length of 86 to 89 mm, but no age information has been provided (Andriyashev 1986; Holladay and Norcross 2013). Our largest *A. olrikii* collected from the Beaufort Sea was 75 mm at age 12 and our oldest fish was 75 mm and age 13. It was possible to compare weigh-at-length values for *Liparis fabricii* with other snailfishes (i.e., *Liparis* spp.) from the Canadian Arctic (Elliot and Gaston

2008). We documented *Liparis fabricii* as exhibiting positive allometric growth (*b* = 3.56) as did Elliot and Gaston (2008), *b* = 3.73. There is no published age-at-length data for *Liparis fabricii*, but there is a record of maximum size (200 mm; Nielsen and Bertelsen 1992). The maximum size reported here for *Liparis fabricii* is smaller (139 mm at age 2). For the zoarcid, *L. polaris*, we observed individuals ranging in lengths from 39–333, of which the largest specimen aged was 177 mm at age 9. Our length-at-age distributions of *L. polaris* showed marked peaks at the smallest sizes indicating distinct age 0–1 year classes, which was confirmed by age assessments; a second peak was a mix of ages 2–5. The maximum sizes of previous records of *L. polaris* are 244 to 250 mm (Andriyashev 1986; Mecklenburg et al. 2007), lengths which are 83–89 mm smaller than the largest specimen we captured; however in the Barents Sea they can be 550 mm (Wienerroither et al. 2013) *A. medius* and *L. fabricii* are stichaeids that have somewhat different length and age maxima. The largest *A. medius* we captured was 145 mm and age 8, though maximum size is reported to be 300 mm (Novikov et al. 2002). The largest *L. fabricii* we caught was larger than *A. medius*, 205 mm and age 5, and the recorded size maximum is 365 mm at age 6 (Coad and Reist 2004).

The length, weight, and age parameters reported here give valuable insight into the life histories of 10 of the most commonly encountered demersal fishes in the western Beaufort Sea. The data we used to estimate our parameters were limited to the length, weight, and age of available specimens. Therefore, we suggest that the prediction intervals reported here be used only within the length ranges on which they are based. We posit that aging a larger number of fish specimens, particularly at the upper and lower ends of the length distributions, would decrease the number of outliers, thereby improving the regressions. Additional collections of fish from research conducted in the Beaufort Sea at depths of 20–1,000 m (Norcross et al. 2017) complement the present analyses of fishes from the Beaufort Sea shelf. Ultimately, length, weight, and age parameters could aid in determining the age structure and relative biomass of demersal fish species throughout Arctic regions. This type of information would certainly contribute important baseline data with which to compare future changes, and thus, greatly enhance our current and future knowledge of Arctic demersal fishes.

5 Region, Depth, and Size-based Comparisons of Three Fish Species' Diets between the Chukchi and Beaufort Seas

5.1 Introduction

The accurate description of fish diets and feeding habits provides the foundation for understanding their place in aquatic food webs (Garvey et al. 1998, Chipps and Garvey 2007). Fish diet composition represents the combination of several ecological factors including habitat use, prey availability, prey selectivity, morphological constraints due to body size, and inter- and intraspecific interactions (Chipps and Garvey 2007). In some cases, fish diet information has direct management implications for commercially and recreationally valuable species and may be used to manage prey resources, increase fish production, or accomplish other goals (Chipps and Garvey 2007). However, diet composition knowledge of non-commercially or recreationally valuable fish species is also important as agencies continue to implement ecosystem-based management strategies (Francis et al. 2007, Zimmerman and Krueger 2009). Further, the diet analysis of fishes of lesser importance has contributed to the parameterization of ecosystem and bioenergetics models (Christensen 1995, Hanson et al. 1997). As many smaller Arctic fish species are not directly important to humans, less is known about their roles in the Arctic food web. Because fishes are efficient samplers of the prey available in their immediate environments (Hinz et al. 2006), quantifying their diets over a large spatial scale in the Arctic could elucidate differences in feeding, and broaden our understanding of Arctic marine ecology.

Fishes in the Arctic ecosystem provide an important link between lower and higher trophic level organisms (Lowry and Frost 1981, Bradstreet and Cross 1982, Craig et al. 1982, Atkinson and Percy 1992). This study focuses on the diets of three Arctic fish species: Arctic Cod (*Boreogadus saida*), Arctic Staghorn Sculpin (*Gymnocanthus tricuspis*), and Shorthorn Sculpin (*Myoxocephalus scorpius*). *B. saida* is one of the most abundant forage fishes in the Arctic and is considered a key prey species for marine mammals, seabirds, and other fish species (Lowry and Frost 1981, Craig et al. 1982, Lønne and Gulliksen 1989, Welch et al. 1992). *G. tricuspis* is also numerous throughout the Arctic and is occassional prey for seals and whales in the Chukchi and Beaufort seas (Frost and Lowry 1981, Lowry and Frost 1981, Smith et al. 1997a). Less is known about *M. scorpius* in the Arctic; however, it is present in middle and inner shelf areas throughout the Arctic, including the Chukchi (Norcross et al. 2013b) and Beaufort seas (Mecklenburg et al. 2011; Norcross et al. 2017), and as prey for *B. saida* (Rand et al. 2013) and likely some marine mammals. The abundance of each of these fishes makes them important as both predators and prey throughout the Chukchi and Beaufort seas.

The diets of these three fish species may differ from one another in the Chukchi and Beaufort seas due to prey availability in the area each fish inhabits. Throughout the Chukchi and Beaufort seas, *B. saida* is primarily a pelagic predator (Lowry and Frost 1981, Lacho 1986, Chiperzak et al. 2003) that consumes ice-associated amphipods and various zooplankton in the winter months (Coyle et al. 1997) and mostly calanoid copepods in the summer months (Lowry and Frost 1981, Craig et al. 1982, Coyle et al. 1997). Its diet varies, however, and may consist of other pelagic prey, such as hyperiid amphipods, euphausiids, fishes, and shrimps (Lowry and Frost 1981, Coyle et al. 1997, Rand et al. 2013) along with some benthic and epibenthic prey including benthic amphipods, cumaceans, and mysids (Lowry and Frost 1981, Craig et al. 1982, Coyle et al. 1997). *G. tricuspis* is a benthic species and generalist feeder whose diet may differ depending on region of inhabitance and depth (Atkinson and Percy 1992, Coyle et al. 1997). Its diet throughout regions of the Chukchi (Coyle et al. 1997) and Beaufort seas (Atkinson and Percy 1992) primarily consists of benthic and epibenthic prey, including polychaetes, benthic amphipods, cumaceans, and bivalve siphons. Prior to this study no published diet information existed for *M. scorpius* in the Chukchi and Beaufort seas; elsewhere it is defined as a benthic, generalist predator that mainly consumes benthic crustaceans, decapods, and polychaetes in regions of the Labrador Sea (Moore and Moore 1974, Atkinson and Percy 1992), and crabs and benthic amphipods in the Bering Sea (Cui et al. 2012). There are differences within each species' diets; however, the sources of prey (i.e., mainly pelagic prey for *B. saida* and benthic prey for sculpin species) appear to be constant across all Arctic regions sampled.

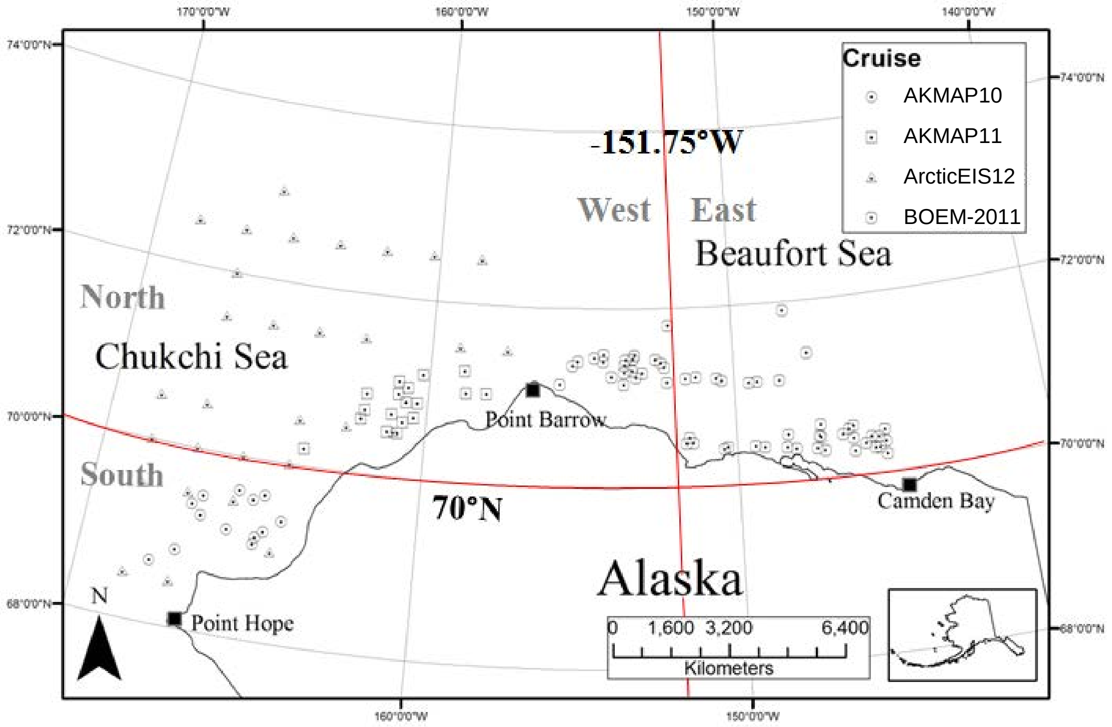
Historical diet descriptions indicate the potential for intraspecific variability in these fishes' diets between seas, regions, depth categories, and size classes; however, the process of determining the significant factors responsible for that variability is absent from Chukchi and Beaufort Sea fish studies. *B. saida*, *G. tricuspis*, and *M. scorpius* diets are expected to differ between the Chukchi and Beaufort seas due to large-scale differences in biological productivity and physical oceanography. The Chukchi Sea is a highly productive ecosystem (Grebmeier 2012) that supports a high biomass of benthic organisms (Grebmeier and Dunton 2000, Hunt et al. 2013). In contrast, regions of the Beaufort Sea have been described as oligotrophic (Belkin et al. 2009) and do not have the same nutrient-rich inputs as the Chukchi Sea. These differences alone likely influence the amount and type of prey taxa available for fish consumption in either sea, though regional and depth differences within seas may also drive differences in fish diets. In addition, fish size class is often a very important factor influencing diet composition and likely creates diet variability (Werner and Gilliam 1984, Rand et al. 2013). For example, smaller *B. saida* consume smaller prey like calanoid copepods, while larger *B. saida* consume larger prey such as fishes or shrimps in the Bering, Chukchi, or Beaufort seas (Lowry and Frost 1981). *G. tricuspis* and *M. scorpius* diets have not been examined by size classes in Arctic regions; however, Longhorn Sculpin (*Myoxocephalus octodecemspinosus*) along the northeast US coast, consume a wider range of prey taxa and sizes with an increase in body size (Scharf et al. 2000). We expected a similar pattern for *G. tricuspis* and *M. scorpius* in this study.

Many studies of Arctic fish diets are from small, isolated regions or small sample sizes; as a result, they do not account for variation in prey proportions due to habitat or fish size. A goal of this project was to sample a very large area throughout the Chukchi and Beaufort seas and collect an adequate sample size of each species to offer a comprehensive characterization and comparison of same-species fish diets. The objectives were to 1) determine the factors (seas, regions, depth categories, and size classes) that contributed most to intraspecific diet variability in *B. saida*, *G. tricuspis*, and *M. scorpius* between the Chukchi and Beaufort seas, and 2) to relate fish diet variation to descriptions of physical and biological oceanographic characteristics of the study areas. We accomplished the first objective through stomach contents analysis of fish specimens and by determining the mean percent weight (%MW) of prey items in the stomachs. These data were statistically analyzed to determine which factors created the most variability in diets and the specific prey types that created the most variability within comparisons. The second objective was accomplished by comparing the results of our data analysis with peer-reviewed literature focusing on the oceanographic characteristics of our broad study area.

5.2 Methods

5.2.1 Sampling Areas and Collection Methods

Sampling took place during ice-free months (August–September) in both the Chukchi and Beaufort seas (**Figure 5.1**). In the Chukchi Sea, fishes were collected over three cruises, two that were a part of the Alaska Monitoring and Assessment Program (AKMAP) in both 2010 (August 23 through September 03), and 2011 (September 05 through September16), and one cruise that was a part of the Arctic Ecosystem Integrated Survey (ArcticEIS) in 2012 (August 13 through September 20). These cruises covered the area between Point Hope and the western side of Point Barrow (**Figure 5.1**). The AKMAP 2010 cruise transects were set south of 70°N latitude (68.43°−69.96°N) and between longitudes 167.82° and 163.80°W, whereas the AKMAP 2011 cruise occurred north of 70°N (70.05°−71.30°N) and between longitudes 163.75° and 157.20°W (**Figure 5.1**). Both AKMAP cruises were relatively nearshore surveys (17−60 m water depth). The ArcticEIS cruise surveyed about the same latitudinal extent as both AKMAP cruises (**Figure 5.1**). Transects were set both south and north of 70°N (68.50°−73.00°N) and between latitudes 168.50° and 157.18°W and included both nearshore and further offshore stations (20−90 m water depth). For comparison purposes, Chukchi Sea stations falling below the 70˚N latitude were considered south Chukchi Sea (SCS) stations, and those stations north of this latitude were considered north Chukchi Sea (NCS) stations. In the Beaufort Sea, fishes were collected on the BOEM-2011 cruise as described in **Chapter 2**. For comparison purposes, stations to the west of the 151.75˚W longitude were considered west Beaufort Sea (WBS) stations, while all stations east of this longitude were considered east Beaufort Sea (EBS) stations (**Figure 5.1**).



Regions are divided into the south and north Chukchi Sea, and the east and west US Beaufort Sea; all Beaufort Sea samples were collected during BOEM-2011.

Figure 5-1 Chukchi and Beaufort Sea Stations where Fishes were Taken for Stomach Content Analyses during the 2010−2012 Open Water Seasons

5.2.1.1 Laboratory Methods

In the laboratory, all *B. saida*, *G. tricuspis*, and *M. scorpius* to be included in stomach contents analyses were thawed, individually weighed to the nearest 0.01 g, and measured for total length in mm. Whole stomachs (defined here as esophagus to pyloric valve) of all fishes were removed, placed in petri dishes, and frozen in water until examined. Each stomach was dissected and prey items were identified using a dissecting microscope. At 6 to 100x magnification, all recognizable prey was identified to species, genus, family, or order depending on the condition of the stomach contents. If prey items were identifiable, the use of taxonomic keys or personal communication with invertebrate specialists helped to achieve this desired taxonomic clarity. Once identified, the wet weight value of each prey item was recorded to the nearest 0.0001 g. Because there were 100 prey types identified in this analysis, including different species, genera, families, and orders, all prey were grouped into 13 broad categories (**Appendix A**). Within these 13 prey types, we included an ‘other prey’ category for prey that weighed <0.0001 g (harpacticoid copepods or barnacle cyprids), were rare (e.g., *Apherusa* spp., an ice-associated, pelagic amphipod), or was unidentifiable. Four selected diet indices were calculated for each of these 13 prey categories.

5.2.1.2 Data Analysis Methods

To broadly summarize same-species fish diets in the Chukchi and Beaufort seas, we used the indices mean percentage by weight (%MW), mean percentage by number (%MN), percent occurrence (%O), and percent index of relative importance (%IRI). Mean proportion by weight was calculated as follows:

$$\%MW = \frac{1}{P}\sum\left[\frac{W_{ij}}{\Sigma W_{ij}}\right]x100$$

where %MW is the mean percentage by weight of prey consumed by a predator, Wij is the weight of prey i eaten by a single predator j, and ΣWij is the sum of all prey weights in the stomach of a single predator j. The sums of this calculation for each prey item over the entire sample are then divided by the number of fish with prey in their stomachs (P). Mean percentage by number (%MN) was calculated similarly. We calculated percent occurrence using the formula:

$$\%O = \left[\frac{O_i}{\Sigma P}\right]x\ 100$$

where %O is defined as the occurrence of a prey group *i* divided by the sum of non-empty stomachs (ΣP). To calculate percent index of relative importance (%IRI), it was necessary to first calculate the index of relative importance (IRI). We used the Pinkas et al. (1971) formula and substituted %MN and %MW values for %N and %W resulting in the equation:

$$IRI = \%O\ x\ (\%MN + \%MW)$$

Because raw IRI values are difficult to compare to one another due to a large range of possible values for each item, the IRI of each prey item was converted to a percentage (%IRI) using the equation:

$$\%IRI = \left[\frac{IRI_i}{\Sigma IRI}\right] \text{----------}\ x\ 100$$

where IRI_i is the IRI value for a specific prey category *i* and ΣIRI is the sum of all IRI values for all prey items eaten by a predator (Pinkas 1971). We characterized the diets of *B. saida*, *G. tricuspis*, and *M. scorpius*, using each of these indices. However, only %MW was used for statistical comparisons because prey weight is a good indicator of energetic importance (Chipps and Garvey 2007).

By comparing *B. saida*, *G. tricuspis*, and *M. scorpius* diets between the Chukchi and Beaufort seas by regions, depth categories, and size classes we determined which factor (or factors) and prey created the most intraspecific variability in fish diet compositions. Percent mean weight information for each fish species' diet was sorted depending on Chukchi or Beaufort Sea residence, then into two regions within both seas, and by three depth levels and two size classes. Because *M. scorpius* were scarce in the Beaufort Sea, the WBS and EBS regions were combined into the west and east Beaufort region (hereafter, WEBS) for intraspecific comparisons. We evaluated the effect of depth on fish diets by separating %MW data into three depth categories (≤30 m, >30–50 m, and >50 m) and comparing each within and between seas and all regions. The effect of fish body size on diets was evaluated by calculating the mean, species-specific size for *B. saida*, *G. tricuspis*, and *M. scorpius* caught during all four cruises. Size class one (SC1) was defined as all fishes that fell below the species-specific mean size and size class two (SC2) were all fishes above the mean. These divisions were made to even the distribution of fishes for statistical comparisons because there were not enough fishes available to compare diets over multiple size classes within all factors of this study. Size classes for each species were as follows: for *B. saida*, SC1 = ≤60 mm and SC2 = ≥61 mm; for *G. tricuspis*, SC1 = ≤50 mm and SC2 = ≥51 mm; and for *M. scorpius*, SC1 = ≤53 mm and SC2 = ≥54 mm.

To statistically evaluate the differences in fish diets between seas, regions, depth categories, and size classes, it was necessary to use multivariate methods. Multivariate techniques are needed to simultaneously evaluate differences in prey proportions (Chipps and Garvey 2007). However, the stricter assumptions of parametric multivariate analysis of variance (MANOVA), such as multivariate normality and a similar variance-covariance structure among samples, are not met when using diet composition data (Chipps and Garvey 2007). Further, proportional diet data sets contain a multitude of zeroes, which make it difficult to meet distributional assumptions and affects model interpretation (Quinn and Keough 2002). Because of these issues, we used a permutation-based version of MANOVA based on a Bray-Curtis distance matrix using the function *adonis* in the vegan package of R, version 2.15.2. This method is considered to be a robust alternative to parametric MANOVA as well as to ordination methods (Legendre and Anderson 1999). The output of this method is an F and *p*-value analogous to that of MANOVA, and an R^2 value that indicates the amount of variance a specific factor or interaction of factors accounts for in the model of interest. We used the F and *p*-values to evaluate our hypotheses that there would be significant, intraspecific differences in fish diets within and between seas and regions by depth categories and size classes. We also used the R^2 value to determine which factor or factors accounted for the most variability in fish diets between the Chukchi and Beaufort seas. If a there was a significant difference found in the sea and region models, we used the same *adonis* function to facilitate multiple comparisons. To account for the increased likelihood of type 1 error rate, the resulting *p*-values from multiple comparisons were compared to corresponding sequential Bonferroni-adjusted α values to determine significance. Prey groups that contributed most to the differences between each significant comparison were determined using the SIMPER function in Primer version 6.1.6, which gives an output of dissimilarity percentages between each comparison.

5.3 Results

A total of 1,416 fishes with prey in their stomachs were used for this diet analysis (*B. saida* = 608, *G. tricuspis* = 443, and *M. scorpius* = 365). First, we pooled all fish diets by species and used the indices %MW, %MN, %O, and %IRI to determine differences in prey use between the Chukchi and Beaufort seas. *B. saida* consumed a very high proportion of calanoid copepods in both seas (**Table 5-1**; with taxa described in **Appendix C**), with all remaining prey being of little importance by %MW except hyperiid amphipods in the Beaufort Sea and other prey in the Chukchi Sea. *G. tricuspis* consumed large proportions of benthic amphipods, polychaetes, and other prey in the Chukchi and Beaufort seas, but in differing amounts (**Table 5-2**). Chukchi Sea *G. tricuspis* consumed a richer amount of taxa (**Appendix C**) and higher proportion of benthic amphipods by all indices than that of Beaufort Sea conspecifics, while more polychaetes were consumed by fish in the Beaufort Sea by %MW and %O, but not %MN. Other prey was slightly more important by %MW for fish in the Beaufort Sea. *M. scorpius* diet varied widely between the Chukchi and Beaufort seas, with benthic amphipods, crabs, fish prey, hyperiid amphipods, shrimps, and other prey being important by all indices (**Table 5-3**). Taxa richness and proportions of benthic amphipods, fish prey, and shrimps were much higher in the diets of Chukchi Sea *M. scorpius* (**Table 5-3; Appendix C**) than that of Beaufort Sea conspecifics, where hyperiid amphipods were of great importance. Relative to *B. saida* and *G. tricuspis*, ‘other prey’ was much less important for *M. scorpius*. This %MN, %MW, %O, and %IRI analysis indicated conspecific diets were more similar than heterospecific diets. However, diets varied within species between the Chukchi and Beaufort seas, and statistical methods were necessary to determine which factors were most responsible for that variability.

We developed two separate *adonis* (permutational MANOVA) models that used the %MW data of the 13 prey categories (**Table 5-1, Table 5-2, and Table 5-3**) to determine diet differences within and between seas and regions, by depth categories and size classes. The output of the *adonis* analysis model highlighted that seas, depth categories, size classes, and their interactions were significant, except for the interaction between seas and size classes for *M. scorpius* (**Table 5-3**). Although this interaction for *M. scorpius* was not significant, it was included in further analyses because %MW figures indicated some differences in prey proportions **(Figure 5-2e and Figure 5-2f**). The majority of variance in all fish species' diets by sea analysis was attributed to seas (4%−5%) or size classes (2%−8%), with less variance being explained by interactions (**Table 5-4**). When the *adonis* model was used to analyze regions, depth categories, size classes, and their interactions, each was found significantly different except for *G. tricuspis* diet by depth categories (**Table 5-5**). Regions alone explained the majority of variance in each species fish diets (8%−10%) when compared to either size classes or interactions, although size class accounted for slightly more variance in *B. saida* diets (10% vs. 9.7%) than that of regions. Additionally, the interaction between regions and depth categories accounted for about as much variance (2%−3%) as did size class alone (2%–4%) for *G. tricuspis* and *M. scorpius*. Although the individual factors of seas, regions, or size classes explained more variance than did the interactions, most interactions were significant, therefore, these interactions were looked at further using figures, multiple comparisons, and SIMPER dissimilarity percentages.

Using separate *adonis* models for multiple comparisons, we analyzed fish diets by two size classes (SC1 and SC2) and three depth categories (<30 m, 31(i.e., 30−50 m), and >50 m) within and between the Chukchi and Beaufort seas (**Table 5-6**). *B. saida* diet within and between both seas by size classes and depth categories was most dissimilar due to calanoid copepod proportions, followed by varying percentages of hyperiid amphipods, euphausiids, and benthic amphipods (**Table 5-6; Figure 5-2 and Figure 5-3**). *B. saida* in the Chukchi Sea by size classes (**Figure 5-2a**) and depth categories (**Figure 5-3a**) consumed the higher proportion of benthic amphipods and other prey, while *B. saida* in the Beaufort Sea by size classes (**Figure 5-2b**) and depth categories (**Figure 5-3b**) consumed a larger proportion of calanoid copepods, hyperiid amphipods, and euphausiids. All size class comparisons were significant in *G. tricuspis* diet; additionally, there were more significant differences at similar depths between seas than within seas at different depths (**Table 5.6**). These dissimilarities were mainly driven by varying proportions of benthic amphipods, polychaetes, and other prey (**Figure 5-2, Figure 5-3c and Figure 5-3d**). Chukchi Sea fish ate more benthic amphipods between size classes (**Figure 5-2c**) and depth categories (**Figure 5-3c**), while Beaufort Sea fish consumed higher proportions of polychaetes and other prey by size classes (**Figure 5-2d**) and depth categories (**Figure 5-3d**). Prey groups that contributed most to dissimilarities in *M. scorpius* diet between both seas by size classes and depth categories were benthic amphipods and hypecriid amphipods, followed by fish prey, crabs, and other prey (**Table 5-6**). *M. scorpius* diets also differed more between seas at similar depths than within seas at different depths, but only slightly so (**Table 5-6**). Within seas, all size class comparisons were significantly different except for large and small fish in the Beaufort Sea, with more diet differences present among depth categories in the Chukchi Sea than the Beaufort Sea (**Table 5-6**). *M. scorpius* in the Chukchi Sea consumed higher proportions of benthic amphipods and fish prey by size classes (**Figure 5-2e**) and depth categories (**Figure 5-3e**), while Beaufort Sea conspecifics ate considerably more hyperiid amphipods by size classes (**Figure 5-2f**) and depth categories (**Figure 5-3f**). Because *M. scorpius* sample sizes were low in the Beaufort Sea for some depths and size classes (i.e., >30–50 m, n = 24, >50 m, n = 17, and SC2, n = 14), comparisons between these depths and size classes were meant to be more descriptive than quantitative.

When analyzing regions and size classes, the majority of *B. saida* diets again differed mainly by calanoid copepod proportions, with hyperiid and benthic amphipods, euphausiids, and other prey making up the remainder of the dissimilarities (**Table 5-7**). When looking at diet within the same region, each SC1 group consumed a higher proportion of calanoid copepod prey when compared to SC2 conspecifics, while SC2 fish throughout all regions and sizes consumed a more varied diet (**Figure 5-4a through Figure 5-4d**). Between regions at similar size classes, SC1 fish in the SCS drove the differences with other SC1 fish in the WBS, and EBS (**Table 5-7**). This was largely due to a high proportion of other prey (18%) in the diets of fish in the SCS region (**Figure 5-3a**). SC2 *B. saida* diets were more variable than SC1 diets. Most differences among SC2 by regions were due to a high amount of other prey (36%) in the SCS, benthic amphipods in the NCS (17%), hyperiid amphipods in the WBS (37%), and calanoid copepods in the EBS (86%; **Figure 5-4a through Figure 5-4d**).

Diets differed less by size classes within regions for *G. tricuspis* than for *B. saida* or *M. scorpius*, with differences only in EBS SC1 and SC2 because of higher proportions of polychaete prey in SC2 diets (49% vs SC1 = 23%) and higher proportions of other prey in SC1 diets (52% vs SC2 = 22%; **Table 5-7; Figure 5-5d**). All other significant differences were between regions at similar size classes (**Table 5-7**). Each difference was due to SC1 and SC2 fish in the NCS having a very high proportion of benthic amphipods (62%–72%) in their respective diets (**Figure 5-5b**) compared to all other regions and size classes (12%–33%; **Figure 5-5a, Figure 5-5c, and Figure 5-5d**). *M. scorpius* diet was compared between the SCS, NCS, and WEBS. Within regions, diets differed between sizes in both the SCS and NCS (**Table 5-7**). Within the SCS region, diets were very different from SC1 to SC2; SC1 fish ate high proportions of hyperiid amphipods (36%) whereas larger fish did not eat much of this prey type (**Figure 5-6a**). Conversely, SC2 fish in the SCS ate large proportions of fish prey and shrimps (both 29%) while smaller fish did not consume much of these prey types (**Figure 5-6a**). In the NCS region, SC1 and SC2 diets differed mainly due to benthic amphipods, crabs, and fish prey **(Table 5-7**). A larger proportion of benthic amphipods (57%) and crabs (27%; mostly crab zoea) were found in SC1 diets, while higher proportions of fish prey (23%) were present in SC2 *M. scorpius* diets (**Figure 5-6b**). Between seas at similar size classes, SC1 diets differed mostly by proportions of benthic and hyperiid amphipods. Smaller, SC1 fish inhabiting the SCS and WEBS regions had similar diets that greatly differed from SC1 fish in the NCS. This was due to NCS fish consuming a large amount of benthic amphipods (57%), while SCS and WEBS fish consumed higher amounts of hyperiid amphipods (36% and 52% respectively; **Figure 5-6a through Figure 5-6c**). All SC2 fish diets differed by mainly benthic and hyperiid amphipods, fish prey, and shrimp proportions, with SCS fish eating higher proportions of fish and shrimps (both 29%), NCS fish eating more benthic amphipods (31%), and WEBS fish eating more hyperiid amphipods (38%; **Figure 5-6a through Figure 5-6c**).

For all three species, diets differed more between regions at a specific depth category (e.g., NCS vs. SCS at ≤30 m) than within regions at different depth categories (e.g., SCS≤30 m vs SCS>50 m; **Table 5-8**). Of the three species, *B. saida* showed the most significant differences within and between regions by depth categories, followed by *M. scorpius*; while there were only significant differences between regions at similar depth categories for *G. tricuspis* diet (**Table 5-8**). Within regions, *B. saida* diet differed in the SCS at depths of ≤30 m and >30–50 m, the NCS at depths of ≤30 m and >50 m, and among all depths in the WBS (**Table 5-8**). These differences were primarily due to variation in calanoid copepod proportions, although high proportions of other prey in the SCS at ≤30 m (51%) and euphausiids in the WBS at >30–50 m (27%), created some differences within regions (**Table 5-8; Figure 5-7a and Figure 5-7c**). When diets were examined between regions at similar depth categories, differences in *B. saida* diet were driven mainly by calanoid copepod proportions, although hyperiid amphipods, euphausiids, benthic amphipods, and other prey also contributed slightly. A few regions and depth categories created the most diet differences for *B. saida*, including fish in the SCS at ≤30 m and at >50 m, which had high proportions of other prey (51% and 30%, respectively) and lower proportions of calanoid copepods (30% and 36%, respectively; **Figure 5-7a**), fish in the NCS at ≤30 m, which had a low proportion of calanoid copepods (28%) and a relatively higher amount of benthic amphipods (23%; **Figure 5-7**), and fish in the WBS at >30–50 m which had a low proportion of calanoid copepods (27%) and a higher proportion of euphausiids (27%) and hyperiid amphipods (24%; **Figure 5-7c**). Most other regions and depths, especially those in the EBS (**Figure 5-7d**), had much higher proportions of calanoid copepods (53%–100%) in the diets.

For *G. tricuspis*, fish diets in all depths of the NCS region were significantly different from all other regions at similar depths (**Table 5-8**). This dissimilarity between comparisons was primarily due to benthic amphipod proportions in the diets, followed by other prey, and polychaetes. In the NCS, benthic amphipod prey proportions ranged from 57%–74% of total diet (**Figure 5-8b**) compared to 6%–30% throughout all other regions and depths (**Figure 5-8a, Figure 5-8c, and Figure 5-8d**). Because benthic amphipod proportions were high in the NCS, amounts of other prey (8%–11%) and polychaetes (5%–

17%) in NCS diets were much lower than all other regions. These differences in other prey and polychaetes accounted for the remaining majority of the dissimilarity among groups (**Table 5-8, Figure 5-8a through Figure 5-8d**).

M. scorpius diets were more variable among regions and depth categories than that of *G. tricuspis*. Depending on the region and depth category, benthic amphipods, hyperiid amphipods, or fish prey accounted for the highest percentage dissimilarity between comparisons, followed by crabs, other prey, and shrimps (**Table 5-8**). Only *M. scorpius* diets within the NCS region differed between depth categories. This was between fish at depths of >30–50 m and >50 m; with higher proportions of benthic amphipods consumed by fish in >50 m depths (66%) while NCS >30–50 m fish fed on higher amounts of crabs (26%) and fish prey (30%; **Figure 5-9b**). Out of all regions, benthic amphipod consumption was highest in the NCS region at ≤30 m and >50 m depths (40% and 66%, respectively), while hyperiid amphipod consumption was highest in the WEBS region at all depths (35%–74%; **Figure 5-9b and Figure 5-9c**). Consequently, the NCS and WEBS regions created the most significant differences by depth categories in diets when compared amongst themselves or to depths in the SCS region (**Table 5.8**).

Table 5-1 Boreogadus saida Diet Summarized between the Chukchi and Beaufort Seas by Mean Percent Weight (%MW), Mean Percent Number (%MN), Percent Occurrence (%O), and Percent Index of Relative Importance (%IRI)

Arctic Cod Prey Category	Chukchi Sea				Beaufort Sea			
	%MW	%MN	%O	%IRI	%MW	%MN	%O	%IRI
Benthic amphipods	9.20	6.50	21.80	3.37	0.67	0.51	1.42	0.01
Calanoid copepods	52.19	60.18	71.28	78.92	73.25	75.13	83.81	94.45
Crabs	2.02	1.79	4.84	0.18	1.46	1.02	4.26	0.08
Cumaceans	3.10	4.71	16.96	1.31	0.61	0.42	1.99	0.02
Euphausiids	3.46	3.25	6.92	0.46	5.29	4.84	8.24	0.63
Fish prey	3.31	2.13	4.15	0.22	1.42	0.65	2.84	0.04
Hyperiid amphipods	3.77	2.64	8.65	0.55	11.85	9.04	20.45	3.25
Isopods	-	-	-	-	-	-	-	-
Mollusks	-	0.08	0.35	-	0.02	0.10	0.57	-
Mysids	0.73	0.52	0.69	0.01	1.23	0.63	2.27	0.03
Polychaetes	1.22	0.68	3.11	0.06	0.30	0.10	0.57	-
Shrimps	1.11	1.11	3.81	0.08	0.02	0.16	0.57	-
Other prey	19.89	16.40	41.52	14.85	3.87	7.40	17.33	1.48
Total stomachs	273				335			
Total number of prey	7,000				4,558			
Total prey weight (g)	13.57				15.57			

Table 5-2 ***Gymnocanthus tricuspis*** **Diet Summarized for the Chukchi and Beaufort Seas by Mean Percent Weight (%MW), Mean Percent Number (%MN), Percent Occurrence (%O), and Percent Index of Relative Importance (%IRI)**

Arctic Staghorn Sculpin	**Chukchi Sea**				**Beaufort Sea**			
Prey Category	**%MW**	**%MN**	**%O**	**%IRI**	**%MW**	**%MN**	**%O**	**%IRI**
Benthic amphipods	45.48	41.75	66.43	59.41	21.11	20.20	34.29	16.73
Calanoid copepods	0.43	0.62	3.93	0.04	0.75	1.67	2.86	0.08
Crabs	4.63	4.61	9.29	0.88	4.91	5.17	9.52	1.13
Cumaceans	1.20	1.29	5.00	0.13	6.02	4.39	12.86	1.58
Euphausiids	-	-	-	-	0.37	0.24	0.48	-
Fish prey	1.87	1.23	3.21	0.10	0.54	0.48	0.48	0.01
Hyperiid amphipods	1.19	0.70	1.43	0.03	0.98	1.33	4.29	0.12
Isopods	0.42	0.54	0.71	0.01	0.38	0.16	0.48	-
Mollusks	2.42	3.22	10.36	0.60	0.99	0.71	2.38	0.05
Mysids	-	-	-	-	-	-	-	-
Polychaetes	17.81	11.93	28.21	8.60	28.75	19.53	36.19	20.63
Shrimps	1.91	1.20	3.21	0.10	0.21	0.14	0.48	0.00
Other prey	22.64	32.91	52.86	30.10	34.99	45.99	62.38	59.66
Total stomachs	257				186			
Total number of prey	1,666				630			
Total prey weight (g)	22.34				5.83			

Table 5-3 ***Myoxocephalus scorpius*** **Diet Summarized for the Chukchi and Beaufort Seas by Mean Percent Weight (%MW), Mean Percent Number (%MN), Percent Occurrence (%O), and Percent Index of Relative Importance (%IRI)**

Shorthorn Sculpin	**Chukchi Sea**				**Beaufort Sea**			
Prey Category	**%MW**	**%MN**	**%O**	**%IRI**	**%MW**	**%MN**	**%O**	**%IRI**
Benthic amphipods	24.36	26.88	43.53	41.40	11.29	11.41	18.28	5.87
Calanoid copepods	0.51	1.26	2.52	0.08	2.30	2.43	5.38	0.36
Crabs	14.98	16.57	30.22	17.69	16.52	19.16	25.81	13.03
Cumaceans	0.98	1.50	4.68	0.22	0.13	0.10	1.08	-
Euphausiids	1.26	1.30	2.52	0.12	0.98	0.54	1.08	0.02
Fish prey	15.91	10.01	21.58	10.38	2.28	1.88	3.23	0.19
Hyperiid amphipods	11.76	9.96	14.39	5.80	49.86	43.04	54.84	72.09
Isopods	0.66	0.42	1.08	0.02	0.12	0.57	2.15	0.02
Mollusks	0.89	2.66	6.47	0.43	0.04	0.11	1.08	-
Mysids	-	-	-	-	-	-	-	-
Polychaetes	4.55	4.05	10.07	1.61	3.95	2.76	7.53	0.71
Shrimps	12.95	10.23	19.42	8.36	2.57	2.38	4.30	0.30
Other prey	11.19	15.16	28.42	13.90	9.97	15.62	20.43	7.40
Total stomachs	276				89			
Total number of prey	1,020				243			
Total prey weight (g)	67.69				3.3			

Table 5-4 *Adonis* Output Used to Compare Diet Proportions for each Fish Species within and between the Chukchi and Beaufort Seas

Predator	Sea	Depths	Size Classes	Sea* Depths	Sea* Size Classes
Arctic Cod	***df=1***	df=2	***df=1***	df=2	df=1
	F=33.372	F=4.627	***F=56.747***	F=8.964	F=8.237
	R^2=0.04615	R^2=0.01280	***R^2=0.07848***	R^2=0.02479	R^2=0.01139
	p<0.001	**p=0.002**	***p<0.001***	**p<0.001**	**p=0.002**
Arctic staghorn sculpin	***df=1***	df=2	***df=1***	df=2	df=1
	F=17.5032	F=2.4009	***F=10.2865***	F=2.9013	F=3.5087
	R^2=0.03685	R^2=0.01011	***R^2=0.02166***	R^2=0.01222	R^2=0.00739
	p<0.001	**p=0.023**	***p<0.001***	**p<0.008**	**p=0.014**
Shorthorn sculpin	***df=1***	df=2	***df=1***	df=2	df=1
	F=20.5993	F=3.1124	***F=15.3205***	F=3.1627	F=1.3902
	R^2=0.05112	R^2=0.01545	***R^2=0.03802***	R^2=0.01570	R^2=0.00345
	p<0.001	**p<0.001**	***p<0.001***	**p<0.001**	**p=0.210**

Mean percentage weight of each prey item was included in the model. Significant *p*-values are in bold, and factors that contributed the most to variance in diet (R^2) are bolded and italicized.

Table 5-5 *Adonis* Output Used to Compare Diet Proportions for each Fish Species within and between Regions of the Chukchi and Beaufort Seas

Predator	Sea	Depths	Size Classes	Sea* Depths	Sea* Size Classes
Arctic Cod	***df=3***	df=2	***df=1***	df=6	df=3
	F=26.797	F=4.329	***F=83.315***	F=7.006	F=6.981
	R^2=0.09740	R^2=0.01049	***R^2=0.10095***	R^2=0.05093	R^2=0.02537
	p<0.001	**p<0.001**	***p<0.001***	**p<0.001**	**p<0.001**
Arctic staghorn sculpin	***df=3***	df=2	***df=1***	***df=6***	df=3
	F=18.5716	F=1.7655	***F=10.1503***	***F=1.9485***	F=2.3295
	R^2=0.10910	R^2=0.00691	***R^2=0.01988***	***R^2=0.02289***	R^2=0.01369
	p<0.001	p=0.109	***p<0.001***	***p<0.015***	**p=0.008**
Shorthorn sculpin	***df=2***	df=2	***df=1***	***df=4***	df=2
	F=17.3303	F=2.4523	***F=16.4887***	***F=3.3542***	F=3.5585
	R^2=0.08185	R^2=0.01158	***R^2=0.03894***	***R^2=0.03168***	R^2=0.01681
	p=0.001	**p=0.011**	***p<0.001***	***p<0.001***	**p<0.001**

Significant *p*-values are bolded, and factors that contributed the most to variance in diet (R^2) are bolded and italicized.

Table 5-6 F and *p*-value Results from *Adonis* Explaining the Variation in Diet Proportions Due to Seas and Depth Categories

	Arctic Cod		**Arctic staghorn sculpin**		**Shorthorn sculpin**	
Sea-depth	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**
Chukchi-Beaufort.30m	F=38.9 p<0.001	Cc=43.9, Ot=26.4, Ba=8.65	F=5.732 p=0.002	Ba=30.8, Ot=25.2, Pl=24.1	F=6.196 p<0.001	Ha=21.1, Ba=19.6, Ot=15.4
Chukchi Beaufort.31m	NS	n/a	F=14.12 p<0.001	Ot=32.5, Ba=28.9, Pl=25.2	F=5.996 p<0.001	Ha=33.7, Ba=15.3, Fi=13.4
Chukchi-Beaufort.50m	F=5.376 p=0.002	Cc=42.0, Ha=19.0, Ot=15.5	F=4.924 p<0.001	Ba=34.2, Ot=24.9, Pl=18.5	F=16.87 p<0.001	Ha=41.1, Ba=20.7, Cr=15.8
Chukchi30v31	F=11.19 p<0.001	Cc=33.1, Ot=27.2, Ba=13.4	NS	n/a	F=3.306 p=0.005	Ba=20.1, Fi=14.9, Cr=14.0
Chukchi31v50	NS	n/a	NS	n/a	F=4.031 p=0.003	Ba=24.6, Fi=17.2, Cr=15.72
Chukchi30v50	F=13.06 p<0.001	Cc=36.3, Ot=27.5, Ba=13.5	NS	n/a	NS	n/a
Beaufort30v31	F=14.69 p<0.001	Cc=45.8, Eu=16.9, Ha=16.2	F=5.982 p<0.001	Ot=33.6, Ba=20.5	NS	n/a
Beaufort31v50	NS	n/a	NS	n/a	NS	n/a
Beaufort30v50	F=12.15 p<0.001	Cc=47.3, Ha=24.1, Ot=7.50	NS	n/a	F=5.004 p=0.003	Ha=42.6, Cr=22.8, OT=12.8
Sea-size	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**
Chukchi-Beaufort.SC1	F=4.779 p=0.007	Cc=43.0, Ot=22.8, Ba=12.3	F=13.07 p<0.001	Ba=33.2, Ot=25.7, Pl=20.2	F=7.352 p<0.001	Ha=32.2, Ba=19.8, Cr=19.3
Chukchi-Beaufort.SC2	F=23.57 p<0.001	Cc=34.4, Ot=18.4, Ha=14.1	F=7.510 p<0.001	Pl=30.3, Ba=29.8, Ot=20.8	F=3.920 p=0.004	Ha=22.1, Ba=18.3, Fi=16.2
ChukchiSC1vSC2	F=28.67 p<0.001	Cc=47.4, Ot=25.9, Ha=7.07	F=2.845 p=0.036	Ba=35.2, Ot=25.7, Pl=20.2	F=13.20 p<0.001	Ba=21.1, Fi=15.1, Cr=14.8
BeaufortSC1vSC2	F=29.85 p<0.001	Cc=47.4, Ha=22.2, Eu=10.6	F=10.64 p<0.001	Ot=30.3, Pl=29.6, Ba=21.6	NS	n/a

Comparisons were made within and between the Chukchi and Beaufort seas by depths (≤30 m, 31 (i.e., >30-50 m), and >50 m) and size classes (SC1 and SC2). Significant *p*-values that were less than the sequential Bonferroni-adjusted α are listed along with prey items that contributed most to the percent dissimilarity (SIMPER) between each comparison.

Prey abbreviations are as follows: Ba = Benthic amphipods, Cc = Calanoid copepods, Cr = Crabs, Cu = Cumaceans, Eu = Euphausiids, Fi = Fish prey, Ha = Hyperiid amphipods, Pl = Polychaetes, Sh = Shrimps, and Ot = Other prey.

Table 5-7 F and *p*-value Results from *Adonis* Explaining the Variation in Diet Proportions due to Regions and Size Classes

	Arctic Cod		Arctic staghorn sculpin		Shorthorn sculpin	
Regions-size classes	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**
SCS1vSCS2	F=17.70 p<0.001	Cc=42.9, Ot=21.8, Cu=4.97	NS	n/a	F=16.12 p<0.001	Ha=19.4, Sh=16.9, Fi=15.4
NCS1vNCS2	F=15.24 p<0.001	Cc=43.8, Ba=19.1, Ot=15.7	NS	n/a	F=4.892 p=0.003	Ba=34.3, Cr=22.0, Fi=15.8
WBS1vWBS2	F=49.95 p<0.001	Cc=45.4, Ha=25.0, Eu=10.7	NS	n/a	NS	n/a
EBS1vEBS2	F=4.327 p=0.007	Cc=52.3, Ha=15.3, Ot=12.2	F=6.548 p=0.003	Ot=34.5, Pl=33.4, Ba=17.0	NS	n/a
WEBS1vWEBS2	NS	n/a	NS	n/a	NS	n/a
SCS1vNCS1	NS	n/a	F=20.10 p<0.001	Ba=40.2, Ot=30.8, Pl=14.1	F=14.07 p<0.001	Ba=31.8, Ha=20.9, Cr=18.9
SCS1vWBS1	F=5.96 p=0.006	Cc=46.4, Ot=33.1, Eu=6.41	NS	n/a	NS	n/a
SCS1vEBS1	F=10.91 p<0.001	Cc=49.8, Ot=43.1, n/a	NS	n/a	NS	n/a
SCS1vWEBS1	NS	n/a	NS	n/a	NS	n/a
SCS2vNCS2	F=8.021 p<0.001	Cc=27.3, Ot=27.3, Ba=14.3	F=16.59 p<0.001	Ba=35.4, Pl=22.9, Ot=22.3	F=5.673 p<0.001	Fi=21.8, Ba=21.1, Sh=20.2
SC2vWBS2	F=14.64 p<0.001	Ot=24.1, Ha=20.8, Cc=20.8	NS	n/a	NS	n/a
SCS2vEBS2	F=61.92 p<0.001	Cc=43.7, Ot=25.7, Fi=5.78	NS	n/a	NS	n/a
SCS2vWEBS2	NS	n/a	NS	n/a	F=4.919 p<0.001	Ha=21.4, Sh=18.4, Fi=16.7
NCS1vWBS1	NS	n/a	F=21.51 p<0.001	Ba=40.2, Ot=27.7, Pl=13.0	NS	n/a
NCS1vEBS1	NS	n/a	F=26.08, p<0.001	Ba=39.6, Ot=30.2, Pl=14.9	NS	n/a
NCS1vWEBS1	NS	n/a	NS	n/a	F=21.23 p<0.001	Ba=32.0, Ha=29.8, Cr=20.5
NCS2vWBS2	F=14.30 p<0.001	Cc=27.7, Ha=22.4, Ot=13.2	F=5.735 p<0.001	Ba=36.5, Pl=27.2, Ot=15.0	NS	n/a
NCS2vEBS2	F=30.94 p<0.001	Cc=43.9, Ba-17.3, Ot=14.9	F=20.05 p<0.001	Ba=35.7, Pl=30.8, Ot=17.3	NS	n/a
WBS2vEBS2	F=54.47 p<0.001	Cc=46.0, Ha=25.2, Eu=10.1	NS	n/a	NS	n/a
NCS2v WEBS2	NS	n/a	NS	n/a	F=3.393 p=0.005	Ha-22.7, Ba=21.7, Fi=15.7

Comparisons were made within and between regions (SCS, NCS, WBS, EBS, and WEBS) of the Chukchi and Beaufort seas by size classes (SC1 and SC2). Significant *p*-values that were less than the sequential Bonferroni-adjusted α are listed along with prey items that contributed most to the percent dissimilarity (SIMPER) between each comparison.

Prey abbreviations are as follows: Ba = Benthic amphipods, Cc = Calanoid copepods, Cr = Crabs, Cu = Cumaceans, Eu = Euphausiids, Fi = Fish prey, Ha = Hyperiid amphipods, Pl = Polychaetes, Sh = Shrimps, and Ot = Other prey.

Table 5-8 F and p-value Results from Adonis Explaining the Variation in Diet Proportions due to Regions and Depths

	Arctic Cod		Arctic staghorn sculpin		Shorthorn sculpin	
Regions-depths	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**	**Adonis (F,p)**	**Simper Dissimilarity (%)**
SCS.30vSCS.50	NS	n/a	NS	n/a	NS	n/a
SCS.30vSCS.31	F=15.09 p<0.001	Ot=35.6, Cc=35.5, Cu=8.10	NS	n/a	NS	n/a
SCS.31vSCS.50	NS	n/a	NS	n/a	NS	n/a
NCS.30vNCS.50	F=8.499 p<0.001	Cc=36.7, Ba=22.3, Ot=15.3	NS	n/a	NS	n/a
NCS.30vNCS.31	NS	n/a	NS	n/a	NS	n/a
NCS.31vNCS.50	NS	n/a	NS	n/a	F=6.831 p<0.001	Ba=36.4, Cr=19.8, Fi=19.6
WBS.30vWBS.50	F=9.152 p<0.001	Cc=44.6, Ha=26.3, My=8.70	NS	n/a	NS	n/a
WBS.30vWBS.31	F=21.76 p<0.001	Cc=43.3, Eu=18.0, Ha=16.3	NS	n/a	NS	n/a
WBS.31vWBS.50	F=8.620 p<0.001	Cc=35.8, Ha=24.2, Eu=19.0	NS	n/a	NS	n/a
EBS.30vEBS.50	NS	n/a	NS	n/a	NS	n/a
EBS.30vEBS.31	NS	n/a	NS	n/a	NS	n/a
EBS.31vEBS.50	F=5.155 p<0.001	Cc=54.3, Ha=14.5, Ot=13.0	NS	n/a	NS	n/a
WEBS.30vWEBS.50	NS	n/a	NS	n/a	F=5.004 p=0.004	Ha=42.6, Cr=22.8, Ot=12.8
WEBS.30vWEBS.31	NS	n/a	NS	n/a	NS	n/a
WEBS.31vWEBS.50	NS	n/a	NS	n/a	NS	n/a
SCS30vNCS30	F=7.151 p<0.001	Ot=29.8, Cc=24.0, Ba=16.0	F=26.47 p<0.001	Ba=40.9, Ot=29.3, Pl=17.3	F=4.231 p<0.001	Ba=24.7, Ot=16.0, Cr=12.9
SCS30vWBS30	F=35.86 p<0.001	Cc=43.5, Ot=34.8, Cu=7.40	NS	n/a	NS	n/a
SCS30vEBS30	F=62.54 p<0.001	Cc=45.7, Ot=35.4, Cu=7.50	NS	n/a	NS	n/a
SCS30vWEBS30	NS	n/a	NS	n/a	NS	n/a
SCS31vNCS31	NS	n/a	F=6.967 p<0.001	Ba=34.2, Ot=23.5, Pl=22.4	F=4.987 p<0.001	Fi=20.2, Cr=17.4, Ha=16.6
SCS31vWBS31	F=9.281 p<0.001	Cc=34.5, Eu=18.3, Ha=15.7	NS	n/a	NS	n/a
SCS31vEBS31	F=10.30 p<0.001	Cc=47.2, Ot=19.7, Fi=14.6	NS	n/a	NS	n/a
SCS31vWEBS31	NS	n/a	NS	n/a	F=4.629 p<0.001	Ha=34.0, Ba=14.1, Sh=11.9
SCS50vNCS50	F=6.218 p<0.001	Cc=39.7, Ot=26.1, Ba=12.6	NS	n/a	F=9.828 p<0.001	Ba=35.3, Fi=18.1, Cr=16.2
SCS50vWBS50	F=6.261 p=0.002	Cc=34.7, Ot=20.9, Ha=16.9	NS	n/a	NS	n/a
SCS50vEBS50	F=14.82 p<0.001	Cc=45.2, Ot=23.0, Ba=8.40	NS	n/a	NS	n/a
SCS50vWEBS50	NS	n/a	NS	n/a	F=15.11 p<0.001	Ha=41.4, Cr=17.1, Fi=16.0
NCS30vWBS30	F=15.45 p<0.001	Cc=41.1, Ba=19.5, Ot=12.7	F=9.056 p<0.001	Ba=41.0, Ot=19.0, Pl=16.9	NS	n/a
NCS30vEBS30	F=28.10 p<0.001	Cc=43.6, Ba=19.8, Ot=12.7	F=20.58 p<0.001	Ba=40.3, Pl=23.9, Ot=17.4	NS	n/a
NCS30vWEBS30	NS	n/a	NS	n/a	F=8.656 p<0.001	Ba=24.0, Ha=20.4, Cr=16.5
NCS31vWBS31	F=7.843 p<0.001	Cc=31.2, Eu=18.1, Ha=15.7	F=13.63 p<0.001	Ba=34.4, Ot=30.1, Pl=22.7	NS	n/a
NCS31vEBS31	F=15.40 p<0.001	Cc=48.2, Ba=17.9, Ot=15.6	F=17.57 p<0.001	Ba=33.1, Ot=31.7, Pl=23.1	NS	n/a
NCS31vWEBS31	NS	n/a	NS	n/a	F=9.072 p<0.001	Ha=33.1, Fi=18.1, Ba=17.4
NCS50vWBS50	F=6.028 p=0.003	Cc=41.3, Ha=25.4, Ot=11.8	F=7.009 p=0.002	Ba=39.1, Ot=22.8, Cr=15.6	NS	n/a
NCS50vEBS50	NS	n/a	F=9.382 p<0.001	Ba=37.9, Pl=26.9, Ot=24.3	NS	n/a
NCS50vWEBS50	NS	n/a	NS	n/a	F=25.51 p<0.001	Ha=40.8, Ba=34.8, Cr=14.4
WBS30vEBS30	NS	n/a	NS	n/a	NS	n/a
WBS31vEBS31	F=32.82 p<0.001	Cc=49.9, Eu=18.6, Ha=16.5	NS	n/a	NS	n/a
WBS50vEBS50	F=9.110 p=0.002	Cc=46.9, Ha=27.4, Ot=8.30	NS	n/a	NS	n/a

Comparisons were made within and between regions (SCS, NCS, WBS, EBS, and WEBS) of the Chukchi and Beaufort seas by depths (≤30 m, 31 (i.e., >30–50 m), and >50 m).
Significant *p*-values that were less than the sequential Bonferroni-adjusted α are listed along with prey items that contributed most to the percent dissimilarity (SIMPER) between each comparison.
Prey abbreviations are as follows: Ba = Benthic amphipods, Cc = Calanoid copepods, Cr = Crabs, Cu = Cumaceans, Eu = Euphausiids, Fi = Fish prey, Ha = Hyperiid amphipods, Pl = Polychaetes, Sh = Shrimps, and Ot = Other prey.

5.4 Discussion

Overall, this analysis highlights many differences in prey use by *B. saida*, *G. tricuspis*, and *M. scorpius* within and between the Chukchi and Beaufort seas. In general, all three species' diets were more different between seas or regions than within seas or regions for both the depth and size class. This indicates that each of these fishes is likely a generalist that consume some combination of the prey available in their immediate environments, which is consistent with previous accounts of these fish species in the literature (i.e., Moore and Moore 1974; Atkinson and Percy 1992; Coyle et al. 1997; Renaud et al. 2012). Therefore, each species' diet is likely strongly influenced by the physical and biological oceanographic characteristics of the sea or region each inhabits. These abiotic and biotic characteristics probably dictate the amount and type of prey available for consumption.

The large-scale, oceanographic differences between the Chukchi and Beaufort seas should influence prey availability for *B. saida*, *G. tricuspis*, and *M. scorpius*. The Chukchi Sea is relatively shallow, encompasses a vast amount of area (Weingartner et al. 2005), is supplemented by nutrients and zooplankton from the Bering Sea (Weingartner 1997), and supports a high amount of primary productivity (Grebmeier and Dunton 2000; Hunt et al. 2013). Nutrients and primary productivity are strongly coupled with the benthos in many areas of the Chukchi Sea, thereby supplementing secondary, benthic production (Feder et al. 1994; Grebmeier et al. 2006). In contrast to the wide Chukchi Sea shelf, that of the Beaufort Sea is much narrower. The Beaufort Sea is less productive due to lower nutrient inputs (Belkin et al. 2009; Crawford et al. 2012); only about 1%–10% of primary productivity is estimated to reach the benthos (Carey and Ruff 1977; Carey 1987), meaning benthic-pelagic coupling processes are not as strong as they are in the Chukchi Sea. The Beaufort Sea is a pelagically dominated ecosystem (Carey and Ruff 1977; Carey 1987). These broad oceanographic differences appear to affect the diets of *B. saida* and *M. scorpius* more than *G. tricuspis*.

G. tricuspis diet was much more consistent between both seas by depths and size classes, with benthic prey, e.g., benthic amphipods and polychaetes, making up the bulk of identifiable prey throughout the majority of comparisons. Conversely, *B. saida* and *M. scorpius* consumed more benthic taxa in the Chukchi Sea relative to conspecifics in the Beaufort Sea. Because *G. tricuspis* fed exclusively on benthic prey in both seas, it is obvious that benthic prey is available in the Beaufort Sea for consumption; however, *B. saida* and *M. scorpius* did not eat much benthic prey in the Beaufort Sea. This could be due to some oceanographic processes that enhance benthic production in the regions of the Chukchi Sea, thus making benthic prey more abundant.

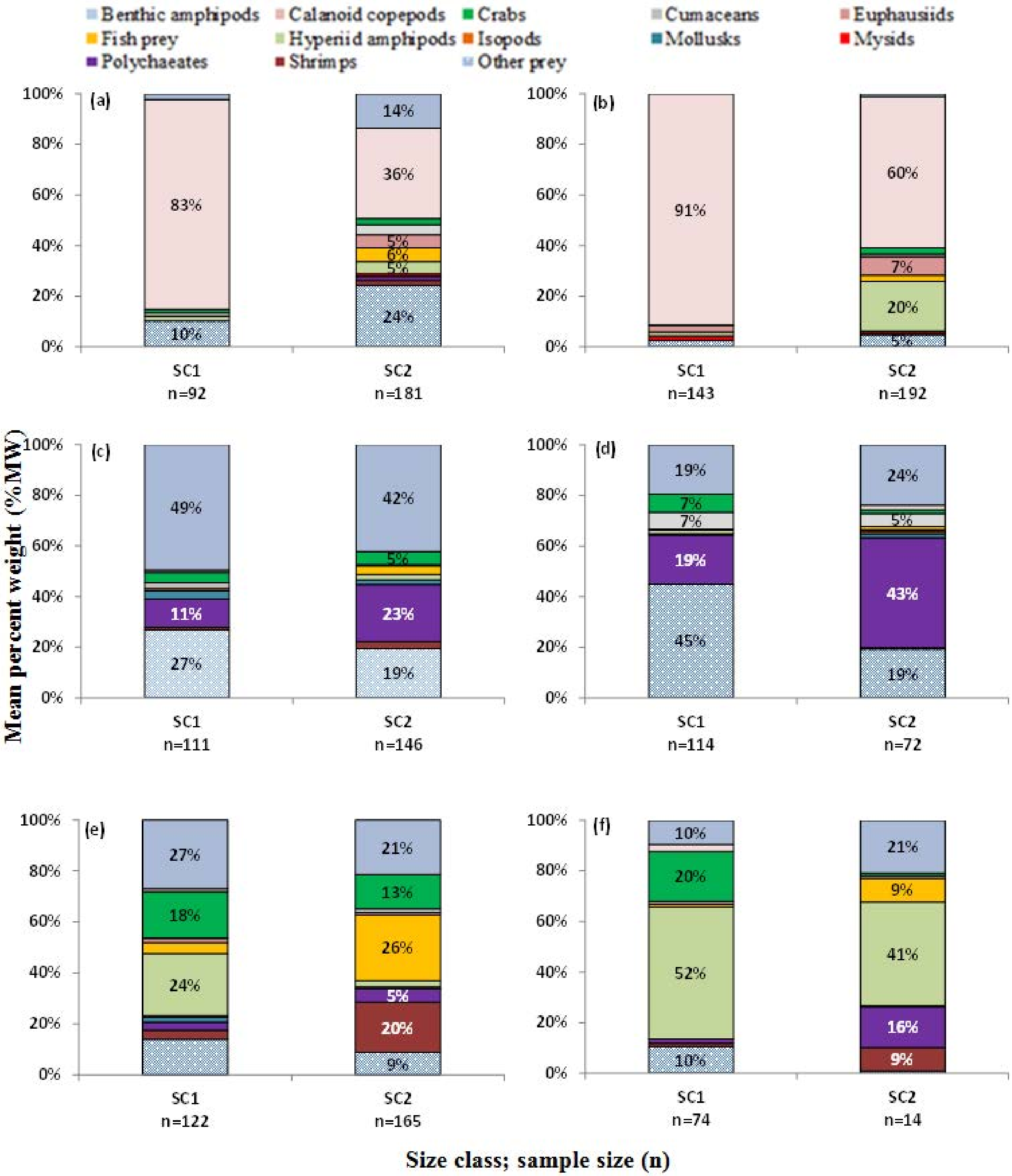
Differences in regional oceanography were most likely responsible for the diet variability noticed between all regional comparisons. This variability was most noticeable when considering each species' diets in the NCS region. In this region, benthic amphipods were consumed in greater amounts by all species, especially by *G. tricuspis* and *M. scorpius*. This increase in benthic amphipod consumption in the NCS is possibly due to the presence of a productive, semi-permanent front located near Point Franklin (Weingartner 1997) which supports benthic production and a high abundance of benthic taxa (Feder et al. 1994). Another contributing factor may be enhanced organic carbon deposition in areas of the NCS caused by the inflow of dense water from Hanna Shoal (Weingartner et al. 2013). These factors could be part of what is driving an apparent regional increase in benthic amphipod consumption by these fish species. However, confirming this would involve determining the benthic amphipod density within the NCS region relative to that throughout the Chukchi and Beaufort seas, which was outside the scope of this project. The WBS and EBS regions were not divided by any particular oceanographic process; they were divided to even the distribution of fishes to facilitate statistical comparisons.

Factors other than regional oceanography, including depth of inhabitance and fish body size, likely influence the type of prey taxa consumed by *B. saida*, *G. tricuspis*, and *M. scorpius* in regions of the

Chukchi and Beaufort seas. Unfortunately, the effect of depth on fish diets was confounded by fish size; therefore, we focus on the effect of fish size here. As diets were compared between smaller and larger size classes, *B. saida* and *M. scorpius* diet became increasingly varied in both prey taxa and prey size consumed; while *G. tricuspis* diet remained relatively similar in content, but included larger prey. These ontogenetic shifts in diet associated with larger body sizes are a wide-ranging occurrence among fishes (Labropoulou and Eleftheriou 1997) because as individuals grow they become more proficient at handling larger, more profitable prey (Werner and Hall 1974). Of the three fish species considered in this project, *B. saida* is the only species documented to feed on different prey types throughout ontogeny in the Arctic. Smaller, age 0 (~<70 mm TL) *B. saida* consume nearly exclusively younger stages of calanoid copepods throughout their distribution (Bradstreet et al. 1986; Walkusz et al. 2011), while larger individuals may eat larger prey such as benthic amphipods, euphausiids, fishes, mysids, and shrimps in the Bering (Lowry and Frost 1981; Cui et al. 2012), Chukchi (Lowry and Frost 1981) and Beaufort seas (Lowry and Frost 1981; Craig et al. 1982). This pattern is similar in our study. In both seas, the smallest fish consumed mostly calanoid copepods; however, larger individuals shifted their diet from only calanoid copepods to eating larger benthic and pelagic crustaceans, and ultimately fish prey at the upper end of the body size spectrum.

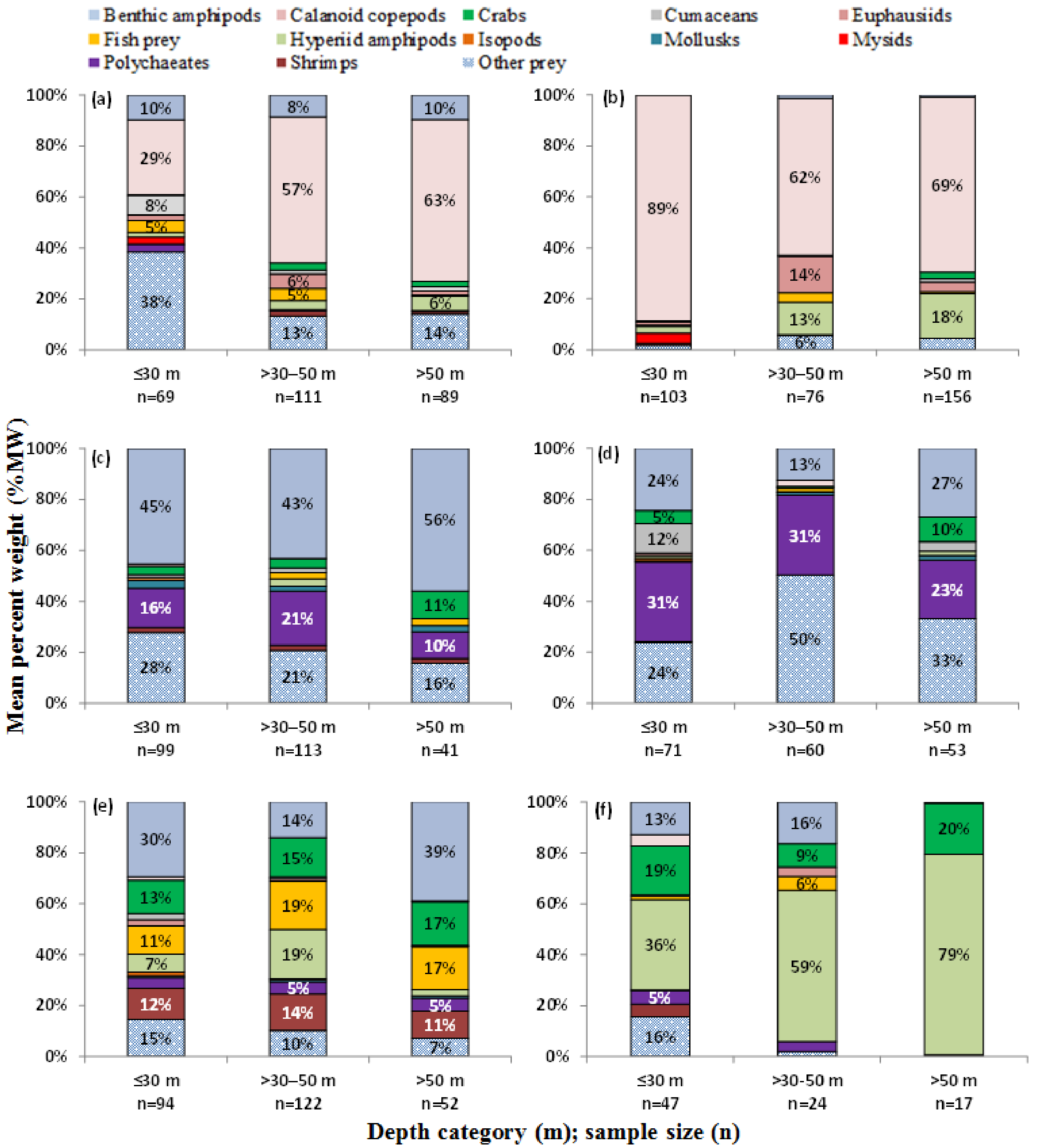
There is no size-related diet information available for sculpin species in the Arctic. Both *G. tricuspis* and *M. scorpius* included larger prey in their diets with increasing body size; however, the most noticeable differences, whether by sea, region, or depth, was the comparison between *M. scorpius* diet in the Chukchi and Beaufort seas. The large discrepancy between benthic and pelagic prey sources between fish inhabiting either sea is most likely due to the size distribution of the *M. scorpius* available for diet analysis in the Beaufort Sea. *M. scorpius* is documented as growing up to 600 mm TL, but usually is less than 350 mm TL (Mecklenburg et al. 2002). A more representative size range of this species was available for stomach contents analysis in the Chukchi Sea (28–223 mm) compared to conspecifics in the Beaufort Sea (31–89 mm), meaning we cannot make definitive claims as to whether or not this species feeds differently in the Beaufort Sea. Though it is possible, especially when considering the diet of smaller *M. scorpius* in the Beaufort Sea and the SCS region, that in the absence of high benthic production, such as seen in the NCS, juvenile *M. scorpius* may supplement their diets with similar pelagic prey types. However, further study would be needed to confirm this.

We have shown that the oceanographic characteristics of the Chukchi and Beaufort seas, along with what is likely a combination of fish body size and depth of capture, account for intraspecific diet variability in *B. saida*, *G. tricuspis*, and *M. scorpius*. Documenting this variation gives information on the position of each of these species as predators in the Arctic, and how the importance of similar prey to similar predators may vary depending on habitat. This information would prove useful in modeling the foraging impacts of *B. saida*, *G. tricuspis*, or *M. scorpius* in regions of the Chukchi and Beaufort seas. While our study is a step in the right direction for Arctic fish ecology, other research could enhance these findings. In this analysis, it was apparent that fish were feeding most differently between regions rather than within regions. This was most likely due to differences in prey availability. The next logical step is to relate prey abundance data to our diet data to determine whether these fish species are eating what is available, or selecting similar prey differently between the Chukchi and Beaufort seas. This would allow for an even more in-depth look at these fishes' feeding ecologies, including feeding behavior, and to better document their places in regional food webs throughout the Chukchi and Beaufort seas.



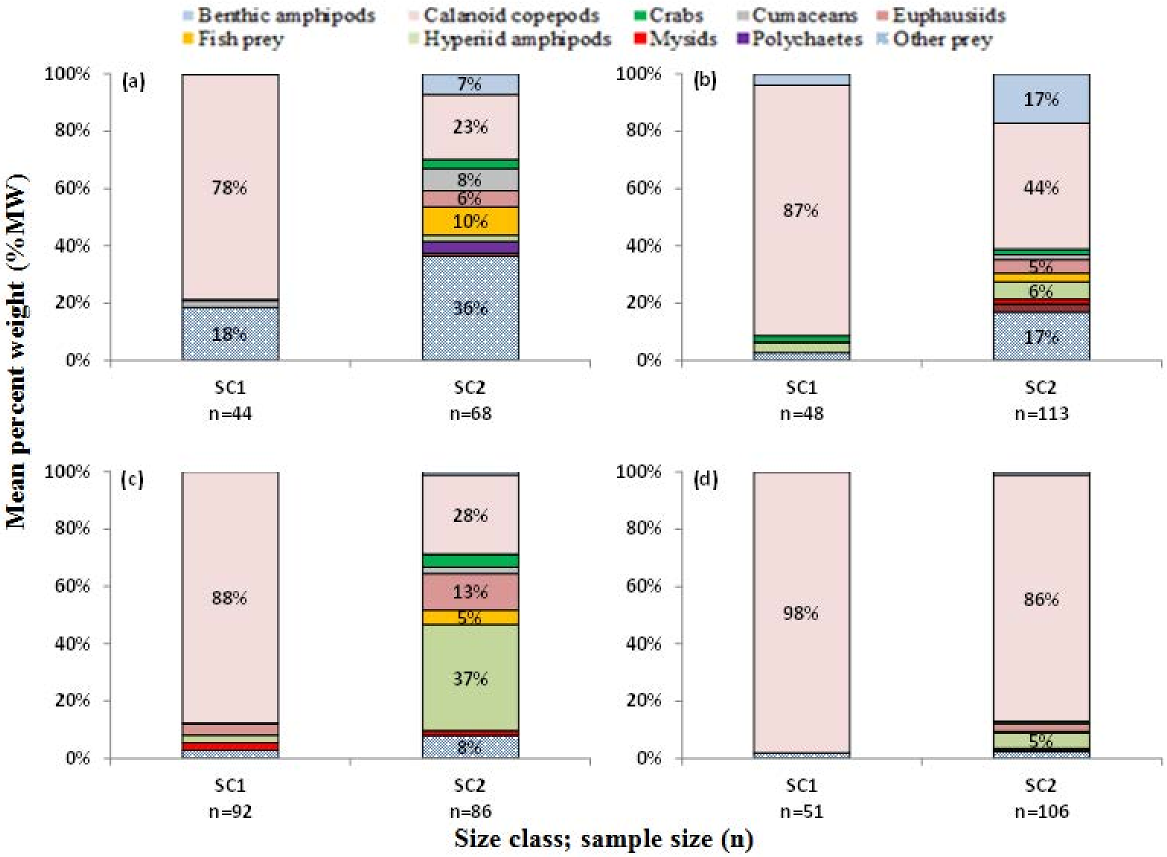
Figures a, c, and e represent fish species' diets in the Chukchi Sea, while figures b, d, and f represent those in the Beaufort Sea.

Figure 5-2 Diets of *Boreogadus saida* (a and b), *Gymnocanthus tricuspis* (c and d), and *Myoxocephalus scorpius* (e and f) Summarized by Size Classes (SC1 and SC2) Throughout the Chukchi and Beaufort Seas



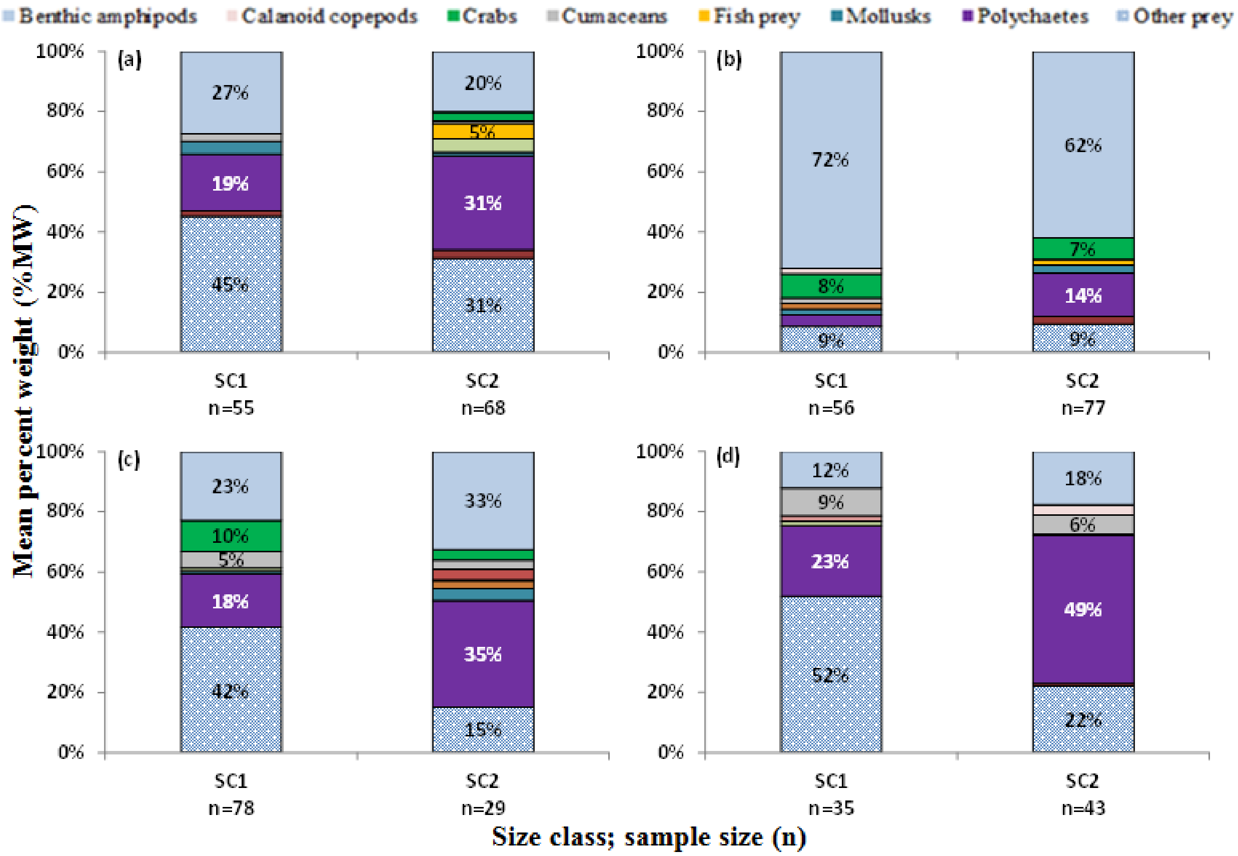
Figures a, c, and e represent fish species' diets in the Chukchi Sea, while figures b, d, and f represent those in the Beaufort Sea.

Figure 5-3 Diets of *Boreogadus saida* (a and b), *Gymnocanthus tricuspis* (c and d), and *Myoxocephalus scorpius* (e and f) Summarized by Depth Categories (≤30 m, >30–50 m, and >50 m) throughout the Chukchi and Beaufort Seas



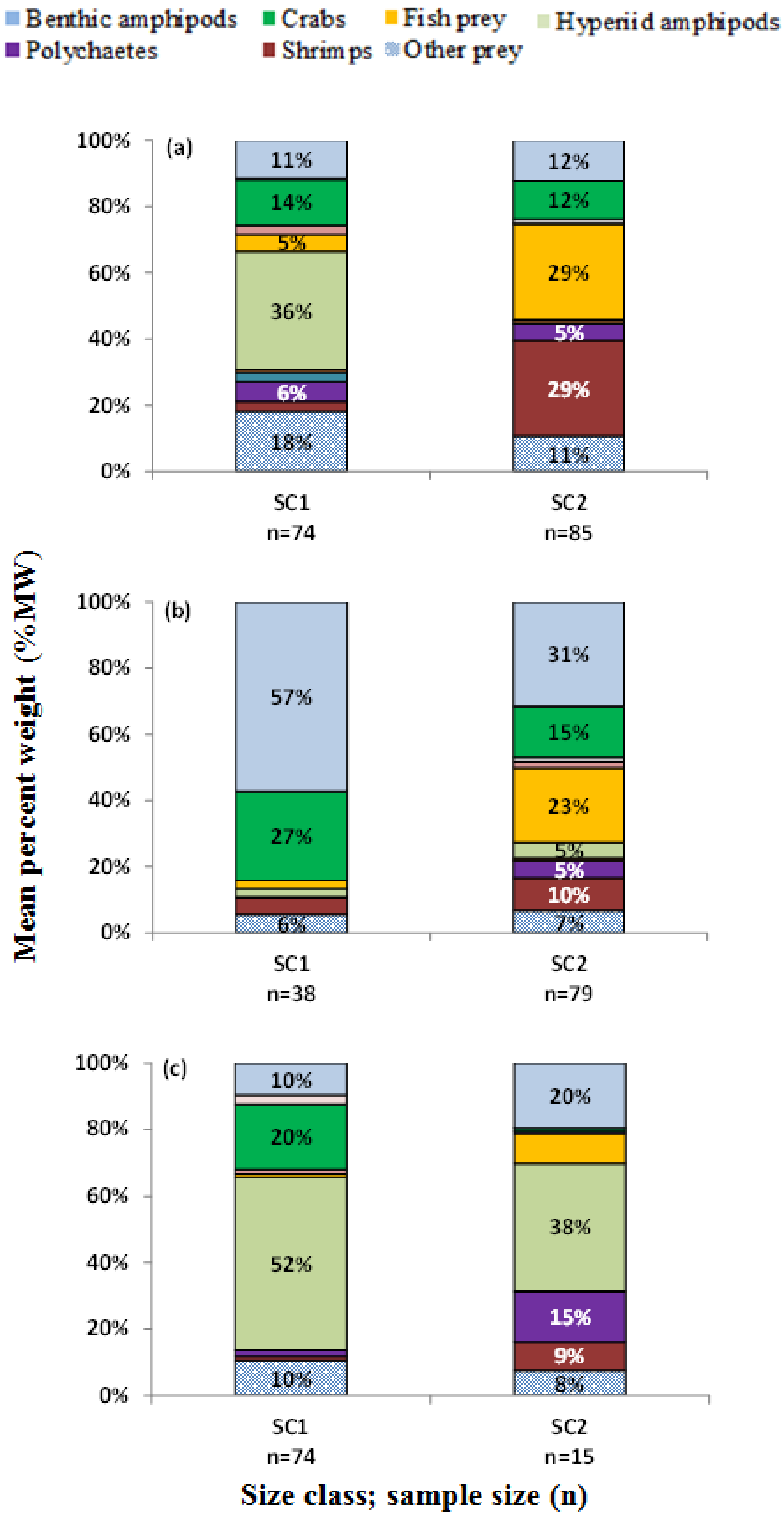
a) South Chukchi Sea b) North Chukchi Sea c) west Beaufort Sea d) east Beaufort Sea
size classes (SC1 and SC2)

Figure 5-4 ***Boreogadus saida*** **Diets Summarized by Region**



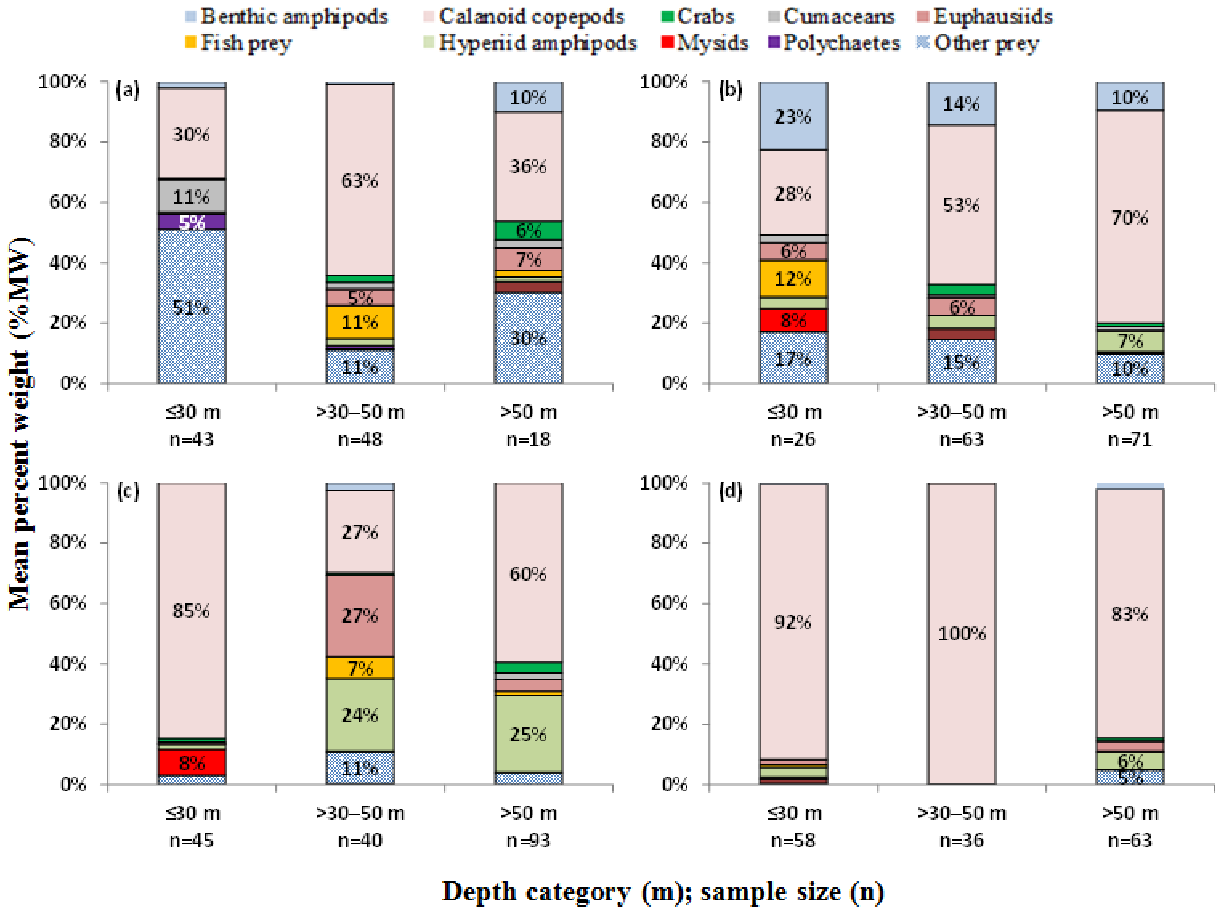
a) South Chukchi Sea b) North Chukchi Sea c) West Beaufort Sea d) East Beaufort Sea
Size classes (SC1 and SC2)

Figure 5-5 *Gymnocanthus tricuspis* Diets Summarized by Region



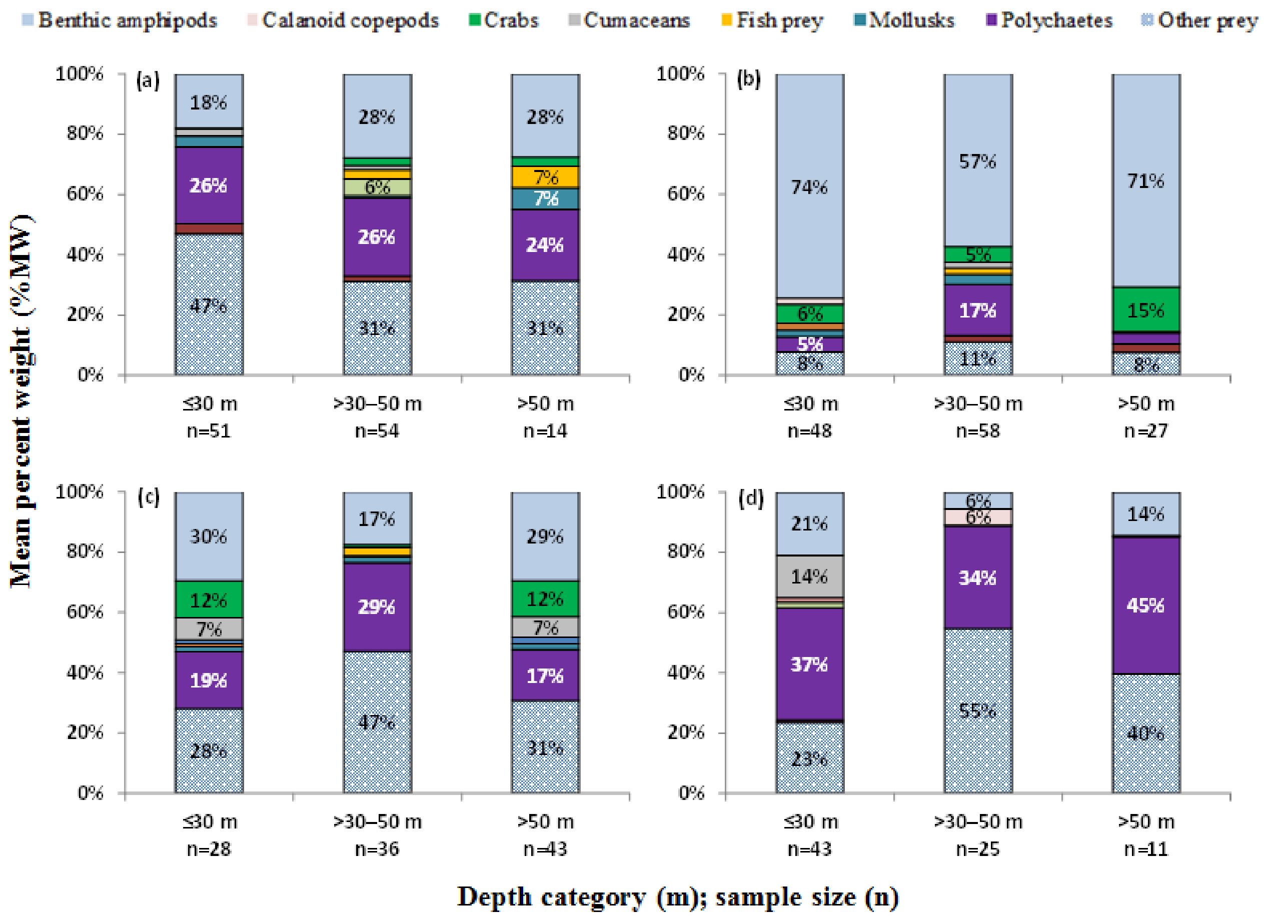
a) South Chukchi Sea b) North Chukchi Sea c) West Beaufort Sea d) East Beaufort Sea
Size Classes (SC1 and SC2)

Figure 5-6 *Myoxocephalus scorpius* Diets Summarized by Region



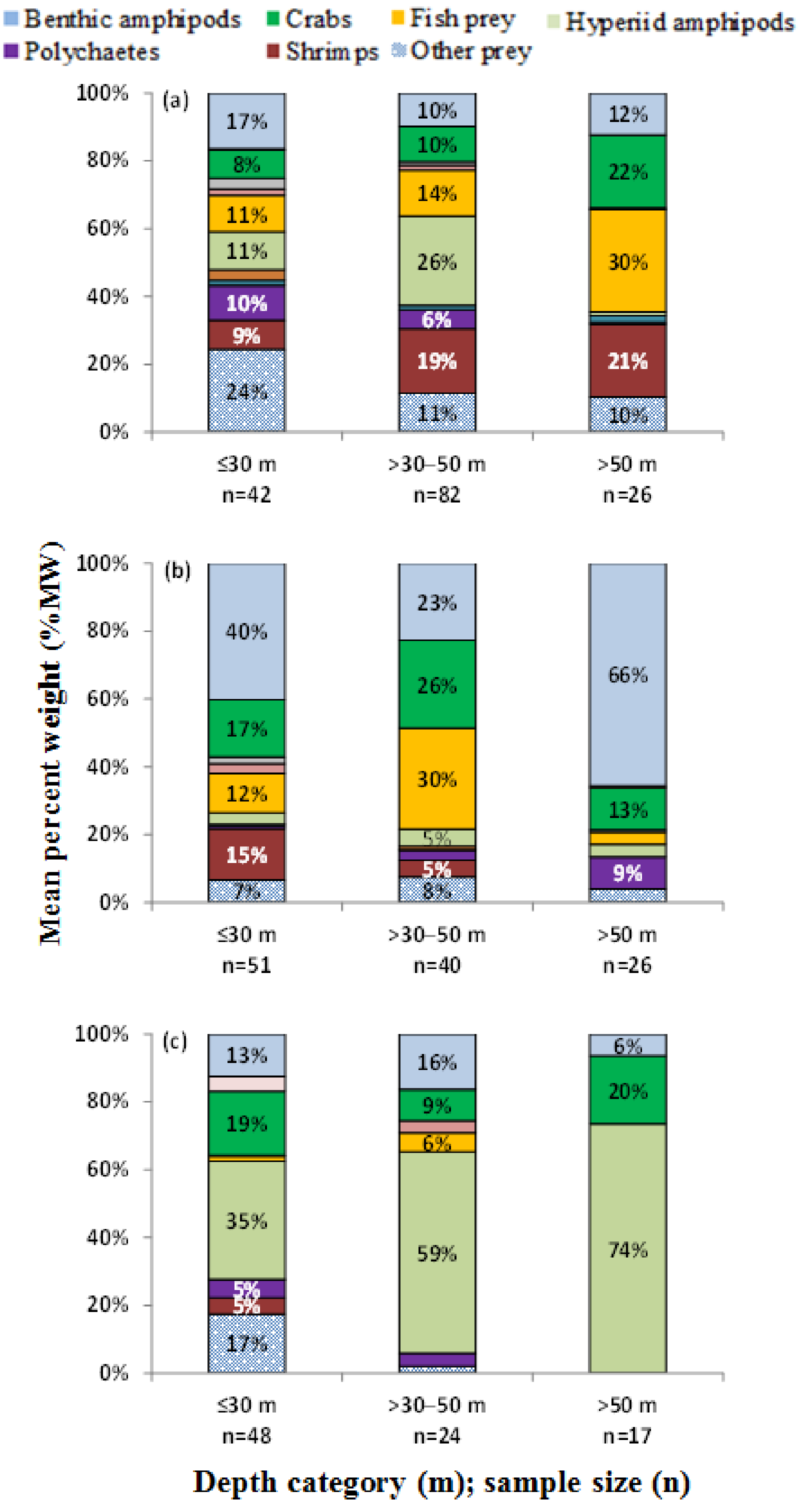
a) South Chukchi Sea b) North Chukchi Sea c) West Beaufort Sea d) East Beaufort Sea) Depth Categories (<30 m, >30-50 m, and >50 m)

Figure 5-7 *Boreogadus saida* Diets Summarized by Region



a) South Chukchi Sea b) North Chukchi Sea c) West Beaufort Sea d) East Beaufort Sea) Depth Categories (<30 m, >30-50 m, and >50 m)

Figure 5-8 *Gymnocanthus tricuspis* Diets Summarized by Region



a) South Chukchi Sea b) North Chukchi Sea c) West Beaufort Sea d) East Beaufort Sea) Depth Categories (<30 m, >30-50 m, and >50 m)

Figure 5-9 ***Myoxocephalus scorpius*** **Diets Summarized by Region**

6 Stable Isotope Contrasts Across the Beaufort Sea – An Examination of *Boreogadus saida*, *Gymnocanthus tricuspis* and *Myoxocephalus scorpius*

6.1 Introduction

There are significant gaps in existing knowledge about the feeding and trophic ecology of Beaufort Sea fishes. Understanding the trophic ecology of arctic fishes is critical, as fish are important ecological links between high and low trophic levels of the food web (Atkinson and Percy 1991, Craig et al. 1982, Lowry and Frost 1981). One technique that is widely used and extremely useful in deciphering trophic relationships between organisms is stable isotope analysis. Analysis of stable nitrogen and carbon isotopes can reveal a consumer's relative trophic level as well as habitat type and carbon source of the diet (Kelly 2000, Dehn et al. 2007). Stable isotope analysis has been used in the arctic on a range of organisms, including marine mammals, birds, and fish (Dehn et al. 2007, Hobson 1993, Kline et al. 1998). Developing a thorough understanding of arctic food web structure is becoming more urgent as the rate of environmental change increases across the arctic (Hopcroft et al. 2008). Potential abiotic and biotic changes have elicited an urgent need to collect baseline ecological data for abundant fish species in the arctic.

One tool to analyze food web ecology of fishes is stable isotope analysis. Nitrogen is taken into an organism via its food as ^{14}N and the heavier and less common ^{15}N form (Peterson and Fry 1987). The lighter nitrogen isotope is used up by metabolic processes while the heavier nitrogen isotope persists in an organism's tissue, and accumulates in the tissues of higher trophic level organisms with an expected 3% enrichment of a consumer's tissue versus its prey (Peterson and Fry 1987). Therefore, higher ^{15}N to ^{14}N ratio (expressed as δ^{15}N) in an organism's tissues indicates that organism has consumed food of a higher trophic level than another organism with a lower nitrogen isotopic ratio. Stable carbon isotope ratios (^{13}C/^{12}C expressed as δ^{13}C) can indicate consumer habitat and carbon source (Dehn et al. 2007). Factors such as the origin of the carbon, where terrestrial in origin, will generally have a lower stable carbon isotope ratio than carbon that is marine in origin, (Dunton et al. 2006). Benthic organisms generally consume greater amounts of recycled material, so their tissue is generally more enriched in the heavier carbon isotope than pelagic consumers (Iken et al. 2005). Stable isotope analysis can give information on diet over a longer timeframe than diet content analysis. The time period covered by stable isotope can vary, based on tissue type and cellular turnover (Tieszen et al. 1983, Trudel et al. 2010). For example, soft tissues in gerbils were found to have a carbon isotope turnover rate of 6.4 days versus 47.5 days for hair (Tieszen et al. 1983). For fish tissue, isotopic turnover rates of muscle can vary among species (Weidel et al. 2011). Isotopic turnover rates of carbon and nitrogen for muscle have been found to range from 49 to 107 for Summer Flounder (*Paralichthys dentatus*) (Trudel et al. 2010), 49.5 days for carbon isotopes in Red Drum (*Sciaenops ocellatus*), and 157.5 days for carbon in European Sea Bass muscle tissue (*Dicentrarchus labrax*) (Weidel et al. 2011). In contrast, stomach content analysis may only represent a time window of hours to days depending on the predator species, prey species and digestion rates (Hyslop 1980). However, unlike stomach content analysis, stable isotope analysis has little resolution of prey species being consumed. Utilizing stable carbon and nitrogen isotopes in conjunction with other diet analysis techniques gives a more complete picture of a consumer's diet and how that consumer fits into the greater ecological framework of a system.

Understanding the current trophic relations of three abundant and ecologically important arctic fish species, Arctic Cod (*Boreogadus saida*), Arctic Staghorn Sculpin (*Gymnocanthus tricuspis*), and Shorthorn Sculpin (*Myoxocephalus scorpius*), is essential as the arctic environment continues to change. The objective of this chapter is to examine differences in diet of these fishes integrated over time as opposed to viewing snapshots revealed by stomach contents in **Chapter 5**.

6.2 Methods

B. saida, G. tricuspis and *M. scorpius* were chosen for stable isotope analyses for comparison with diet information (**Chapter 5**) to gain a thorough understanding of feeding ecology of these species. When analyzing stable carbon and nitrogen isotopes, we used the same stratification of locales into western and eastern regions (**Figure 5-1**) and depth categories (**Table 6-1**) as for stomach analysis. Ontogenetic shifts can occur during the life history of many fish species resulting in large and small fish having differing diets (Schael et al. 1991). Because the fish size at which ontogenetic change occurs is not known for these species of fish, fishes were grouped in size classes to assure statistically robust results for stomach content analysis (**Table 6-1**). For stable isotope analysis a sample size of n = 10 was chosen as the target number of fish to be analyzed when all four variables of interest were applied (species, size class, depth, and region). Actual sample size was determined by the total number of individuals captured.

Two tissue samples were collected for stable isotope analysis from the upper lateral muscles, making sure not to include bones or skin tissue, as different tissue groups can have different isotope signatures (Tieszen et al. 1983). Lipids were extracted from one of these samples (LE) to remove the stable carbon signature of fats, leaving behind the $\delta^{13}C$ ratios of the tissue (DeNiro and Epstein 1977). This process can alter the stable nitrogen isotope ratios in the tissue, so the other tissue sample was left untreated (non-LE) (Pinnegar and Polunin 1999). Tissues were stored frozen at -20°C until they were processed at the Alaska Stable Isotope Facility (ASIF) on the University of Alaska Fairbanks campus.

Frozen tissues were freeze dried at ASIF for 24 to 48 hours. Samples were then pulverized using a metal spatula, which was wiped with a clean kimwipe between samples to prevent cross-contamination. Samples to be lipid extracted for $\delta^{13}C$ ratios were processed with a 2:1 chloroform methanol solution as follows. Pulverized tissue samples were placed in labeled scintillation vials and 5 ml of chloroform methanol solution was added. Vials were capped with a urea lid and agitated for 30 seconds. The samples were allowed to sit for 1 hour before the resulting solution was removed using a glass pipet. Extractions were repeated a minimum of three times, or until the resulting solution was clear (on average 3–4 extractions). After extraction, LE samples were dried overnight in a fume hood and then freeze dried again for 24 to 48 hours.

Subsamples (0.2 to 0.4 mg) of LE and non-LE fish tissue were weighed in tin crucibles and stable $\delta^{15}N$ and $\delta^{13}C$ isotope ratios were measured using Elemental Analysis-Isotope Ratio Mass Spectrometry (EA-IRMS). This method utilizes a Costech Elemental Analyzer (ECS 4010) and ThermoScientific Conflo III (Conflo IV after Nov 18, 2013) interfaced with a ThermoScientific DeltaV Mass Spectrometer. Stable nitrogen and carbon ratios were reported in conventional delta (δ) notation relative to atmospheric N_2 (atm) and Vienna Pee Dee Belemnite (VPDB). Peptone was used as a control, and working standards were analyzed every ten samples.

The stable nitrogen isotopes ratios from non-LE samples ($\delta^{15}N$) and stable carbon isotopes from LE samples ($\delta^{13}C$) were plotted against one another in standard bi-plots. One-way analysis of variance (ANOVA) was used to test for differences in mean stable carbon and nitrogen isotopes between the three fish species ($\alpha = 0.05$). One-way ANOVA was also used to test for differences in mean stable nitrogen and carbon isotopes between size classes of fish. If differences in mean isotope ratios were detected between the groups, the Holm-Sidak method (t) was used to test all pairwise comparisons. If the data violated assumptions of normality or equal variance, a Kruskal-Wallis one-way ANOVA was used. If differences were detected between groups, the Dunn's Method (Q) was then used to test for differences between groups. Two-way ANOVA's were used to test for interactions between species and depth, and species and region for $\delta^{13}C$ and $\delta^{15}N$ for all three fish species. Finally, an ANOVA was used to test for three-way interaction between the variables region (east vs. west), size class (small vs. large), and species, for both stable carbon and nitrogen isotopes. Any differences in mean values among the three variables were further tested using the Holm-Sidak method with an overall significance level of $\alpha = 0.05$. Graphs were generated and statistical tests were conducted in SigmaPlot 12.5 (Systat 2013). The map was generated using ArcMap 10.2.1 for Desktop (ESRI 2013).

Table 6-1 Fishes Examined by Stable Isotope Analysis

	Region	Length Class	Depth (m)	n	Length Range (mm)	Average Length (mm)
GADIDAE (COD)						
Boreogadus saida	East	Small (≤60 mm)	>50	10	29-54	40.1
Arctic Cod			>30-50	8	35-60	47.1
			≤30	13	26-59	49.9
		Large (>60 mm)	>50	32	70-168	101.3
			>30-50	12	67-109	80.8
			≤30	16	61-114	82.4
	West	Small (≤60 mm)	>50	10	48-60	55.1
			>30-50	10	49-60	55.7
			≤30	11	40-60	53.0
		Large (>60 mm)	>50	28	63-171	117.1
			>30-50	11	61-130	90.2
			≤30	8	62-106	75.8
		Total		169	26-171	80.0
COTTIDAE (SCULPINS)						
Gymnocanthus triscuspis	East	Small (≤50 mm)	>50	3	31-35	33.0
Arctic Staghorn Sculpin			>30-50	9	28-40	32.5
			≤30	9	26-41	34.7
		Large (>50 mm)	>50	7	56-98	81.1
			>30-50	10	53-108	74.9
			≤30	12	54-80	64.0
	West	Small (≤50 mm)	>50	10	31-39	37.3
			>30-50	10	35-42	38.8
			≤30	10	25-47	36.8
		Large (>50 mm)	>50	10	53-109	77.9
			>30-50	7	63-127	89.9
			≤30	7	53-113	71.7
		Total		104	25-127	55.9
Myoxocephalus scorpius	East	Small (≤53 mm)	>50	0	-	-
Shorthorn Sculpin			>30-50	2	48-49	48.5
			≤30	9	39-50	44.1
		Large (>53 mm)	>50	0	-	-
			>30-50	0	-	-
			≤30	4	55-89	67.3
	West	Small (≤53 mm)	>50	9	44-53	49.8
			>30-50	12	42-53	48.0
			≤30	10	36-52	45.8
		Large (>53 mm)	>50	5	54-57	54.6
			>30-50	5	56-88	75.8
			≤30	3	69-74	72.0
		Total		59	36-89	52.8
	Grand Total of All Species			332		

Sample sizes and total lengths (min, max, and mean) of arctic fishes analyzed for stable nitrogen and carbon isotope ratios. Stratifications of stations by longitude and depth, and of species by length class, are as defined in Chapter 5.

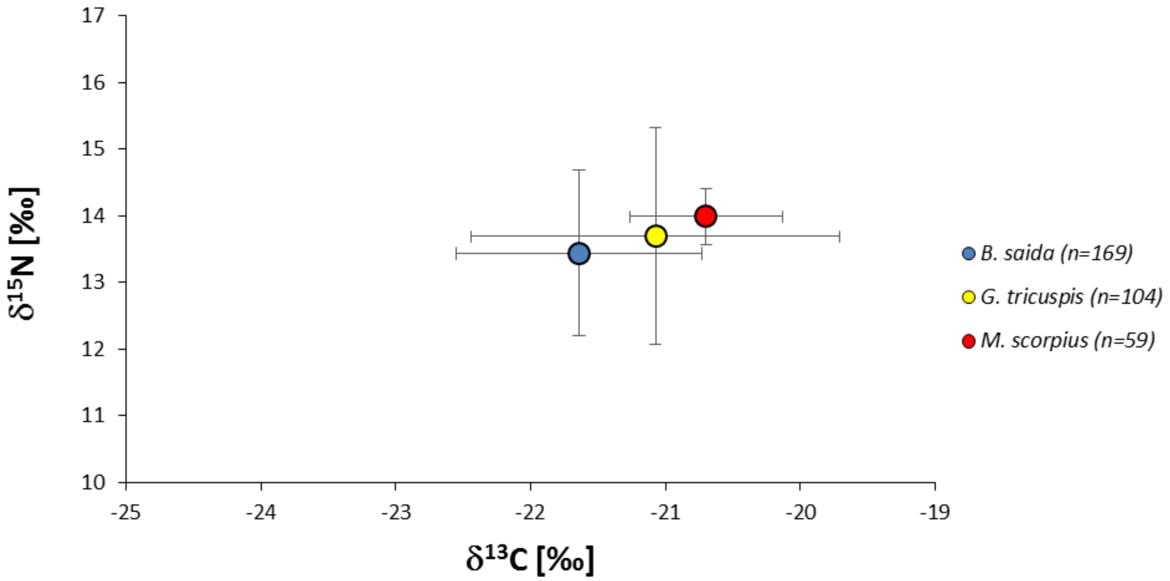
6.3 Results

6.3.1 Stable Carbon and Nitrogen Isotope Comparison between Fish Species

One-way ANOVA between fish species for stable carbon and nitrogen isotopes revealed $\delta^{13}C$ differed significantly between *B. saida* and each of the sculpin species, *G. tricuspis* (Q = 5.248) and the *M. scorpius* (Q = 6.556, **Table 6-2**). No significant difference in mean $\delta^{13}C$ was detected between the two sculpin species (Q = 2.069). Statistically significant differences in mean stable nitrogen isotope ($\delta^{15}N$) were only detected between *B. saida* and the *M. scorpius* (Q = 3.03). Significant differences in nitrogen isotopes were not detected between *B. saida* and the *G. tricuspis* (Q = 1.954), nor between the *G. tricuspis* and the *M. scorpius* (Q = 1.137). The bi-plot of mean stable nitrogen and carbon isotope ratios for the three species shows that Arctic *M. scorpius* had the highest average $\delta^{13}C$ and $\delta^{15}N$ ratio values followed in decreasing order by *G. tricuspis* and *B. saida* (**Figure 6-1**).

Table 6-2 One-way ANOVA for Stable Isotope Ratios between Fish Species

Species	$\delta^{13}C$		$\delta^{15}N$	
	Q	*p* value	Q	*p* value
Myoxocephalus scorpius vs. *Boreogadus saida*	6.56	<0.05	3.03	<0.05
Myoxocephalus scorpius vs. *Gymnocanthus tricuspis*	2.07	>0.05	1.32	>0.05
Gymnocanthus tricuspis vs. *Boreogadus saida*	5.25	<0.05	1.95	>0.05

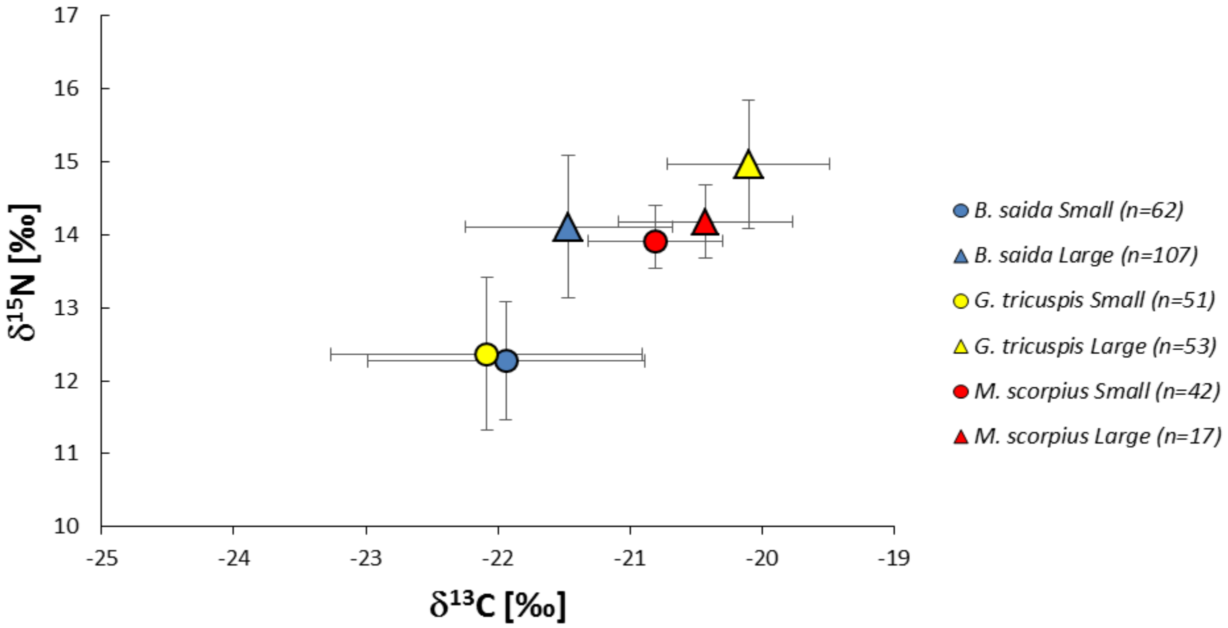


Mean and standard deviation (bars) are illustrated for each species. Sample size (n) is number of individuals.

Figure 6-1 Stable Isotope Signatures of *Boreogadus saida*, *Gymnocanthus tricuspis*, and *Myoxocephalus scorpius*

6.3.2 Stable Carbon and Nitrogen Isotope Comparisons between Fish Size Classes

Conspecific pairwise comparisons of stable carbon and nitrogen isotope ratios between size classes were found to be significant for all three fish species (**Table 6-3**). Significant differences in $\delta^{13}C$ (Q = 2.530) and $\delta^{15}N$ (Q = 9.407) were found between small and large *B. saida*. Significant differences were found for both isotopes between small (≤50mm) and large (>50mm) *G. tricuspis*: $\delta^{13}C$ Q = 8.216, $\delta^{15}N$ t = 13.777). Differences in size classes for *M. scorpius* were found to be significant for both $\delta^{13}C$ (t = 2.406) and $\delta^{15}N$ (t = 2.297). The bi-plot of stable carbon and nitrogen isotope ratios for each species size class further supported that there were significant differences in mean isotope signatures between size classes (**Figure 6-2**). From visual inspection, it appears that the greatest differences in $\delta^{13}C$ and $\delta^{15}N$ between small and large size classes of fish are for *G. tricuspis*, followed by *B. saida*. The differences for $\delta^{13}C$ and $\delta^{15}N$ in *M. scorpius* look to be smaller than for the two other fish species.



The mean and standard deviation (bars) are of stable nitrogen and carbon isotope ratios for the size classes defined for each species in Chapter 5.

Small and large size classes are as follows:

Boreogadus saida (small ≤60 mm, large >60 mm)
Gymnocanthus tricuspis (small ≤50 mm, large >50 mm)
Myoxocephalus scorpius (small ≤53 mm, large >53 mm)

Figure 6-2 Stable Isotope Signatures of Fish Species by Small and Large Size Classes

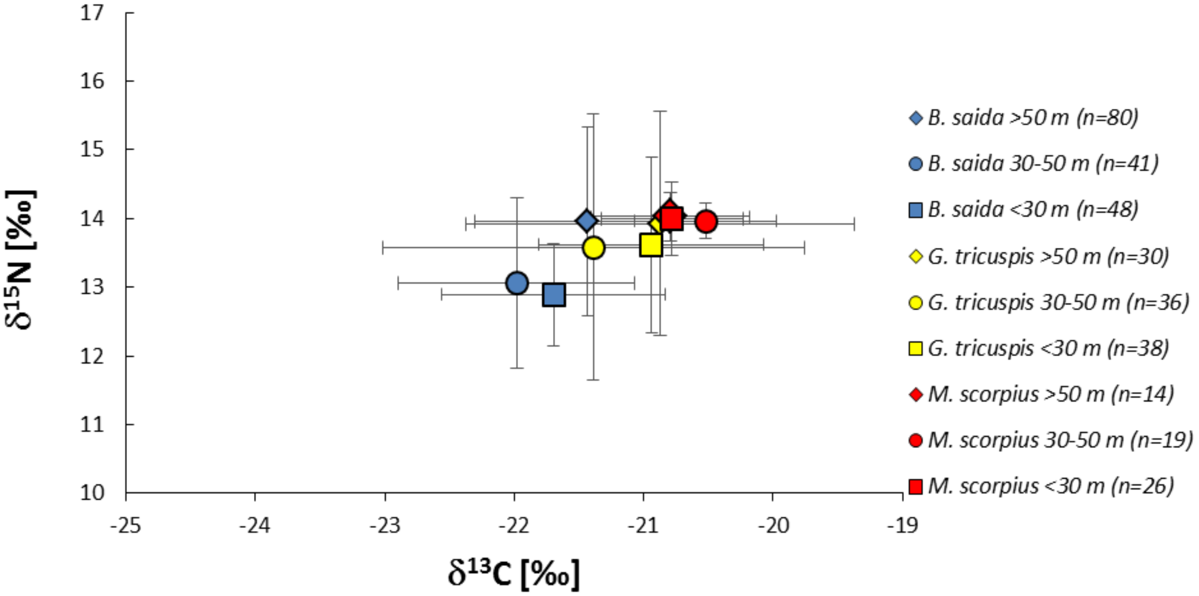
Table 6-3 One-way ANOVA for Stable Isotope Ratios between Small and Large Size Classes within a Species

Species	δ^{13}C		δ^{15}N	
Boreogadus saida	Q = 2.53	p<0.05	Q = 9.50	p<0.05
Gymnocanthus tricuspis	Q = 8.22	p<0.05	t = 13.78	p<0.05
Myoxocephalus scorpius	t = 2.41	p<0.05	t = 2.30	p<0.05

Pairwise comparisons were conducted using either Holm-Sidak Method (t) or Dunn's Method (Q).

6.3.3 Comparisons of Stable Carbon and Nitrogen Isotopes between Depths

Depth was not a significant factor in influencing mean stable nitrogen and carbon isotopes. The results of the two-way ANOVA indicated a non-significant interaction between fish species and size class for carbon ($p = 0.237$) and nitrogen ($p = 0.102$). Because of the lack of evidence of significant interaction between the two factors, further pairwise comparisons were not conducted. However, a bi-plot of depth and species (**Figure 6-3**) shows that *B. saida* at depths ≤50 m appear to have lower mean δ^{13}C signatures than *G. tricuspis* and *M. scorpius*; δ^{13}C signatures were quite similar for *B. saida* at depths >50 m and *G. tricuspis* at depths of 30-50 m. The δ^{15}N signature was lower for *B. saida* at depths ≤50 m than for the other species and depth combinations. The standard deviations represented by vertical and horizontal bars (**Figure 6-3**) appear to overlap, and may explain why depth was not found to be a significant influencing factor.



The mean and standard deviation (bars) are of stable nitrogen and carbon isotope ratios for the depth strata definfed in Section 4.2 as <30 m, 30-50 m, and >50 m.

Figure 6-3 Stable Isotope Signatures of Fish Species by Depth Category

6.3.4 Comparisons of Stable Carbon and Nitrogen Isotopes between Region, Size Class, and Species

Tests of interactions of multiple variables on stable isotope signatures indicated regional variations in stable nitrogen isotopes, but not carbon stable isotopes. An ANOVA investigating a two-way interaction between region and fish species showed a significant interaction for $\delta^{15}N$, but not $\delta^{13}C$ (**Table 6-4**). Regional differences in $\delta^{15}N$ were significant for *G. tricuspis* and *M. scorpius*, but not *B. saida* (**Table 6-5**). Adding size class as a third factor further reinforced these results as a significant interaction between region, size class, and fish species was not detected for stable carbon isotopes but were detected for stable nitrogen isotopes (**Table 6-6**). This indicated that the effect of one factor was not consistent at all combinations of the two other factors for $\delta^{15}N$. Significant differences were found between east and west for small *B. saida* (**Table 6-7**), but not for small *G. tricuspis* or small *M. scorpius* between regions. There was not a significant difference within regions for large *B. saida*. However, there were significant differences for large *G. tricuspis* and large *M. scorpius*. Bi-plots of stable carbon and nitrogen isotope ratios for the three fish species between regions show that eastern *B. saida* have the lowest mean stable nitrogen and carbon isotope signatures, while western Staghorn Sculpin, western *M. scorpius* and eastern *M. scorpius* all appear to have the highest relative stable carbon and nitrogen isotope signatures (**Figure 6-4**). Incorporating the variable size class into the bi-plot (**Figure 6-5**), shows a broad spread of mean stable nitrogen and carbon isotopes for both *B. saida* and *G. tricuspis*, and a tighter grouping for *M. scorpius*, which indicates more similar values over region and size class.

Table 6-4 ANOVA of Two-Way Interaction between Species and Region for Carbon and Nitrogen Isotopes

	$\delta^{13}C$		$\delta^{15}N$	
Interaction	F	*p* value	F	*p* Value
Species, Region	1.52	0.221	3.27	0.039

Table 6-5 Pairwise Comparisons between Regions for Stable Nitrogen Isotope Ratios

δ15N Within Species: East vs. West	t	*p* value
Boreogadus saida	1.89	0.060
Gymnocanthus tricuspis	2.88	0.004
Myoxocephalus scorpius	3.81	<0.001

The Holm-Sidak method was used for all pairwise comparisons.

Table 6-6 ANOVA of Three-way Interaction between Species, Region, and Size Class for Stable Carbon and Nitrogen Isotopes

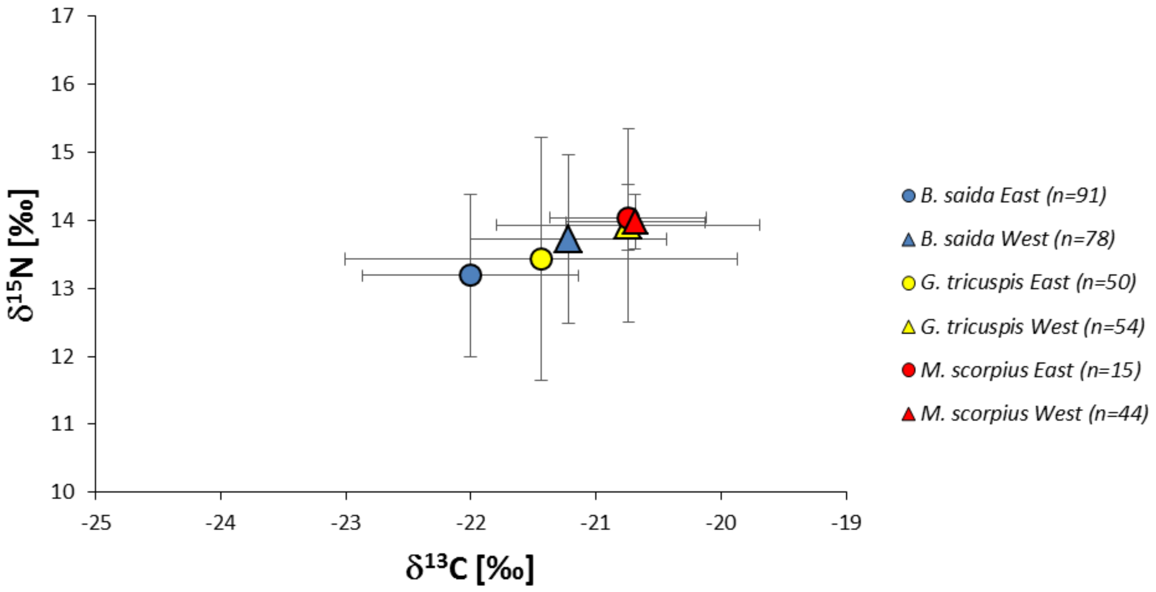
	$\delta^{13}C$		$\delta^{15}N$	
Interaction	F	*p* value	F	*p* value
Species, Region, Size Class	0.0324	0.968	3.913	**0.021**

Bold values indicate statistical significance.

Table 6-7 Pairwise Comparisons between Species, Region, and Size Class for Stable Nitrogen Isotopes

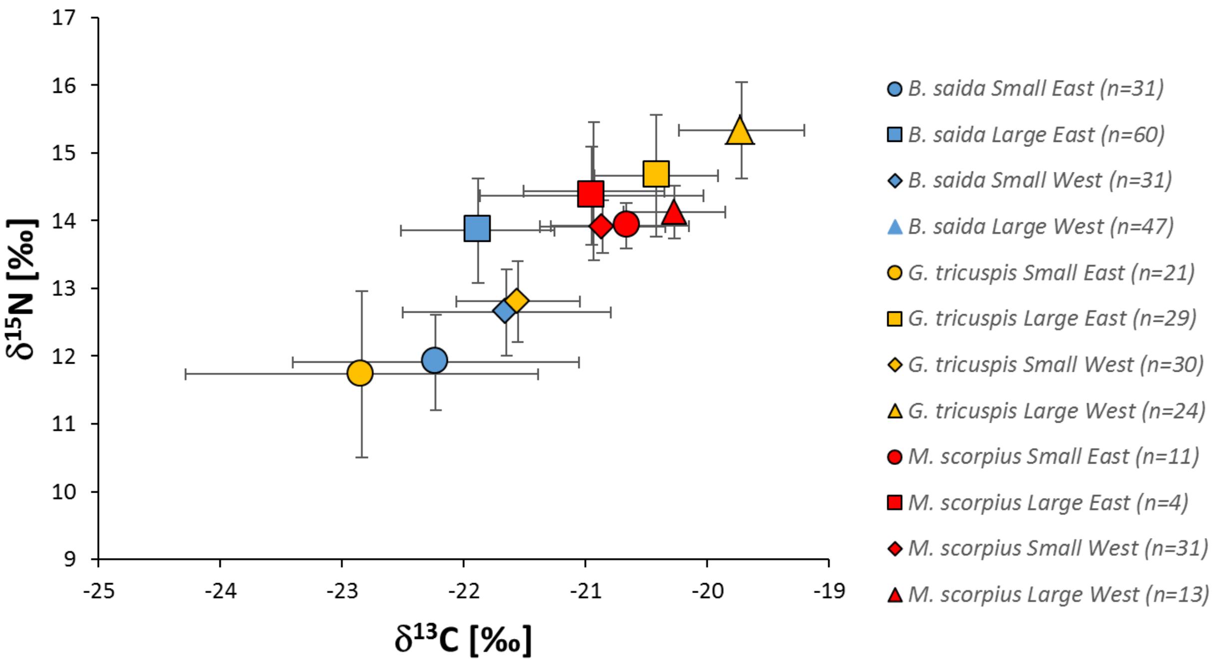
$\delta^{15}N$ Within Species: East vs. West		
Small Fish	t	p
Boreogadus saida	5.41	**<0.001**
Gymnocanthus tricuspis	--	0.369
Myoxocephalus scorpius	--	0.152
Large Fish	t	p
Boreogadus saida	--	0.981
Gymnocanthus tricuspis	3.34	**<0.001**
Myoxocephalus scorpius	2.94	**0.004**

All pairwise comparisons were conducted using the Holm-Sidak method (t) with an overall significance level of $p<0.05$. Values in bold indicate statistical significance.



Mean values and standard deviation (bars) are illustrated. As defined in Section 4.2, the sampling area in the Beaufort Sea is divided into east and west regions at 151.75°W.

Figure 6-4 Stable Isotope Signatures of Fish Species by Region



Standard deviations are illustrated by bars.

Figure 6-5 Stable Isotope Signatures by Region (West vs. East) and Fish Size Class (Small vs. Large)

6.4 Discussion

Lower $\delta^{13}C$ signatures are generally reflective of diets whose carbon sources are more pelagic or have more terrestrial influence. *B. saida* had lower average stable carbon isotopic signatures than either the *G. tricuspis* or *M. scorpius* (**Figure 6-1, Table 6-2**). This is supported by what is known about *B. saida* ecology (Lowry and Frost 1981, Rand et al. 2013) and the more pelagic diet found in *B. saida* in this study (**Chapter 5**). *B. saida* frequently consumed pelagic copepods and amphipods, whereas sculpins were noted to consume benthic amphipods, polychaetes, and crabs (**Chapter 5**). Lower $\delta^{13}C$ can also be indicative of terrestrial versus marine sources of carbon (Dunton et al. 2006). Rivers and coastal erosion are major sources of terrestrial carbon input in the Beaufort Sea and across the arctic (Dunton et al. 2006, Raymond et al. 2007). $\delta^{13}C$ found in *B. saida* potentially suggest that the basis of their food chain is influenced more strongly by the input of terrestrial carbon than for the two sculpin species. This may have interesting implications as terrestrial sources of carbon (river discharge and coastal erosion) are expected to increase in the near future due to climate change (Hopcroft et al. 2008). Lower isotopic carbon sources are generally more representative of feeding patterns farther from shore and food webs whose primary producers consist of phytoplankton versus ice algae (Iken et al. 2005). Overall, $\delta^{13}C$ suggests that the food chain of *B. saida*, when averaged over region and size class, has a very different carbon source than that of the two sculpin species. This difference in carbon source indicates differences in habitat usage (pelagic vs. benthic, offshore vs. nearshore) and influences of different carbon sources (terrestrial vs. marine, phytoplankton vs. ice algae) between *B. saida* and both sculpin species. No differences in $\delta^{13}C$ was found between the two sculpin species (**Figure 6-1, Table 6-2**), indicating that they likely occupy a similar more benthic habitat and that their diets are based on similar more nearshore carbon sources with a greater ice algae influence.

Stable nitrogen signatures for *B. saida* were found to be significantly lower than for *M. scorpius*, but not significantly different from *G. tricuspis* (**Figure 6-1, Table 6-2**). Higher $\delta^{15}N$ in a consumer's tissue generally indicates higher trophic level feeding and vice versa (Kelly 2000). In particular, benthic organisms like polychaetes and benthic amphipods tend to have higher $\delta^{15}N$ because they consume more recycled material due to a general trend of low primary production in the high Arctic (Iken et al. 2005). Therefore, it appears that the stable nitrogen isotope analysis reinforces the findings of **Chapter 5** in that *B. saida* are consuming a lower trophic level (primarily calanoid copepods) than *M. scorpius* (benthic amphipods and polychaetes) in the Beaufort Sea. Due to the lack of statistically significant difference in $\delta^{15}N$ between *B. saida* and *G. tricuspis*, it appears that these two species are feeding more similarly than *B. saida* and *M. scorpius*. A lack of significant differences in $\delta^{15}N$ between sculpin species over the entire study region suggests similar trophic level feeding for both species across the study region and for both small and large fishes.

Significant differences in $\delta^{13}C$ and $\delta^{15}N$ were found within each fish species between size classes (**Figure 6-1, Table 6-3**). These major shifts in fish diets between size classes provide evidence of ontogenetic change, or a significant shift in feeding of a fish species over its lifetime (Scharf et al. 2000). As a fish increases in length, morphological changes such as gape size allow consumers to exploit new prey items (Scharf et al. 2000, Thompson and Simon 2014). Increase in length is also often related to swimming ability, which would allow access to different prey items (Scharf et al. 2000). The results of mean stable nitrogen isotope comparisons of this study indicate that larger fish are consuming prey at a higher trophic level than are smaller fish of the same species. $\delta^{13}C$ was found to differ significantly, suggesting possible change in habitat type or carbon source (Dehn et al. 2007). Evidence of substantial shifts in both $\delta^{13}C$ and $\delta^{15}N$ found in these fish species is strong evidence of ontogenetic change and potentially indicates that different size classes occupy different ecological niches (Bearhop et al. 2004).

Depth was not found to be a significant factor on mean stable nitrogen and carbon isotopes in this study. It is possible that differences were not observed between depth ranges, because sampling ranges for this study were too narrow. Fish for this study were only collected to a maximum depth of 183 m, meaning most sampling took place on the continental shelf. Differences may be observed if sampling was conducted at depths greater than 183 m. The Beaufort Sea shelf is characterized by complex layering of water masses and is strongly influenced by freshwater runoff (Crawford et al. 2012). Arctic basin water is influenced by Atlantic and Pacific water masses that have very different characteristics than shelf water (Crawford et al. 2012). Stable isotope signatures in fish tissue may reflect these differences in water masses, especially carbon, which can show influences of freshwater (Dunton et al. 2006). Exchange of water masses and nutrients occurs between the shelf and slope; however, this exchange is variable and depends on wind conditions and seasonal ice extent (Carmack and Chapman 2003). Mixing of water masses could potentially mute carbon isotope signatures. Though this particular analysis did not show depth to be a significant factor in determining isotope signatures, the influence of depth as a factor could be of interest in future studies that incorporate greater ranges of depth.

In our inter-regional analysis, the ANOVA of a three-way interaction did not provide evidence of a statistically significant regional difference in stable carbon isotope ratios when size class and species interactions were taken into account (**Table 6-6**). A two-way ANOVA also did not show significant differences in $\delta^{13}C$ between regions for any of the three fish species (**Table 6-4**). Previous studies that analyzed stable isotope ratios of epibenthic fauna and suspended particulate organic matter in the Beaufort region have shown evidence of eastward decrease in $\delta^{13}C$ content of invertebrate and vertebrate consumers (Dunton et al. 2006). In addition, regional differences in $\delta^{13}C$ have been found in the neighboring Chukchi Sea (Iken et al. 2010). It is possible that the region covered by our study does not cover enough longitudinal distance for this gradient in carbon isotopes to be apparent. Potentially, with a larger extent, a shift in $\delta^{13}C$ in fish tissue could become apparent. Major sources of terrestrial carbon in the Beaufort Sea come from erosion and river outputs, most notably the Mackenzie River near the Canada-US border (Dunton et al. 2006). Investigation of fish diets further east toward the output of the Mackenzie River may show a stronger shift in $\delta^{13}C$. Unlike $\delta^{13}C$, $\delta^{15}N$ was found to differ regionally when size class and species were considered (**Table 6-6**). Further analysis through pairwise comparisons revealed statistically significant regional differences between small and large *B. saida* (**Table 6-7**). Small *B. saida* in the east consumed a lower trophic level than in the West. *B. saida* in this size range may be consuming prey differently due to differing regional prey availability and localized oceanographic conditions. No such differences were found for small *M. scorpius* or *G. tricuspis*. However, the reverse was found for large fish; there were no regional differences for *B. saida* but there were for the two sculpin species. Again, this may be due to differing prey availability between regions, which in turn may be related to local oceanographic conditions and habitat types. Differing $\delta^{15}N$ between regions may also indicate that fish are occupying differing ecological niches across the region (Bearhop et al. 2004). Overall, the comparisons between regions based on species and size class indicates that some consumers feed at differing trophic levels depending on region, but habitat type and carbon sources do not appear to be as strongly influenced.

7 Under-Ice Pilot Study

7.1 Introduction

Virtually nothing is known about fish species' presence in the Beaufort Sea during the ice-covered season. Most data to date are from the ice-free season. However, Arctic Cod (*Boreogadus saida*) have been observed among crevices and ridges under ice (Gradinger and Bluhm 2004). Therefore, we used a wide array of gear in an attempt to find, identify, and estimate fishes inhabiting the Beaufort Sea during the ice-covered season.

The objective of this pilot study was to design and test field logistics to support the use of under-ice observations and under-ice fish collections in arctic winter conditions. Under-ice observations were sophisticated, including self-contained underwater breathing apparatus (SCUBA) divers, divers using rebreathers to eliminate bubbles, dual-frequency identification sonar (DIDSON), remotely operated vehicle (ROV), and CTD observations. All of these methods were intended to directly observe the presence of and quantify abundance of marine fishes and their habitat in the nearshore area around Barrow, Alaska during the ice-covered season. For under-ice collections, we used quantitative gill net sets for fish and qualitative vertical plankton net hauls for ichthyoplankton and zooplankton.

7.2 Methods

Because of the critical need for logistical support for on-ice fieldwork, our pilot field sampling was dependent upon local support in Utqiaġvik. Unfortunately, the Barrow Arctic Science Consortium that supported arctic logistics for decades went out of business between the start of negotiations (October 2011) and implementation (planned for March 2012) of this under-ice pilot project. That caused a one year delay from spring 2012 to spring 2013 because of the need to work with the new logistics company, UMIAQ Science, a holding of Ukpeaġvik Iñupiat Corporation. Working with the logistics company was time-consuming, but vital to ensure a safe working environment on and under the ice north of Barrow in the winter. Through multiple phone conversations and meetings we were able to determine that UMIAQ could provide the logistical and safety support that we needed. A detailed sampling and safety plan was received from UMIAQ in February 2013 (**Appendix D.1**) and amended immediately prior to the start of the fieldwork because Barrow had been experiencing a blizzard for a week prior to the scheduled start of the under-ice field sampling. UMIAQ provided all the necessary logistical support including cutting holes, setting up heated weather ports over holes, supplying snow machines, providing bear guards, and housing scientists (**Appendix D.1**).

To accomplish the objective of observing fish under ice, Brenda Konar prepared by becoming certified to use a rebreather (as suggested). It was unknown how the bubbles produced by scuba might influence the results, especially for fish like *B. saida* that are associated with the underside of the ice. Bubbles may scare or attract fishes and could alter the rugosity of the under-ice structure, thought to be the habitat of *B. saida*. The use of rebreathers should have no effect on the fish habitat. However, a study was needed to compare results achieved through traditional scuba and rebreathers. Along with the question of how scuba bubbles impact scuba results, it was unknown if the cold conditions found under the ice would cause equipment failures of rebreathers (i.e., freeze-ups and free-flows). Because of this, a feasibility study was conducted in Antarctica in November 2010 and demonstrated that rebreathers could be used in cold water, winter conditions of the Alaskan Arctic.

Six people made up the scientific crew for the under-ice pilot study: 1 Chief scientist/ fish expert, 3 divers, 1 DIDSON operator, and 1 ROV operator. Personnel arrived in Barrow the morning of 28 February and departed on 4 March. We attempted to sample three sites, each ~10 m depth, with a minimum distance of 100 m between holes (**Figure 7-1**). The holes were sampled in reverse numerical order, 3, 2, and lastly 1. An acoustic Doppler current profiler (ADCP) was not available until the second day of sampling and was used only at Hole #2. At Hole #1, sampling was cut short due to a crack that had developed overnight at this hole, making sampling unsafe. In addition, the weather had come up significantly since the morning travel and was at the limit where UMIAQ personnel were comfortable being on the ice. The CTD was deployed at Hole #1 before safety concerns about the status of the ice and weather conditions required vacating the site.

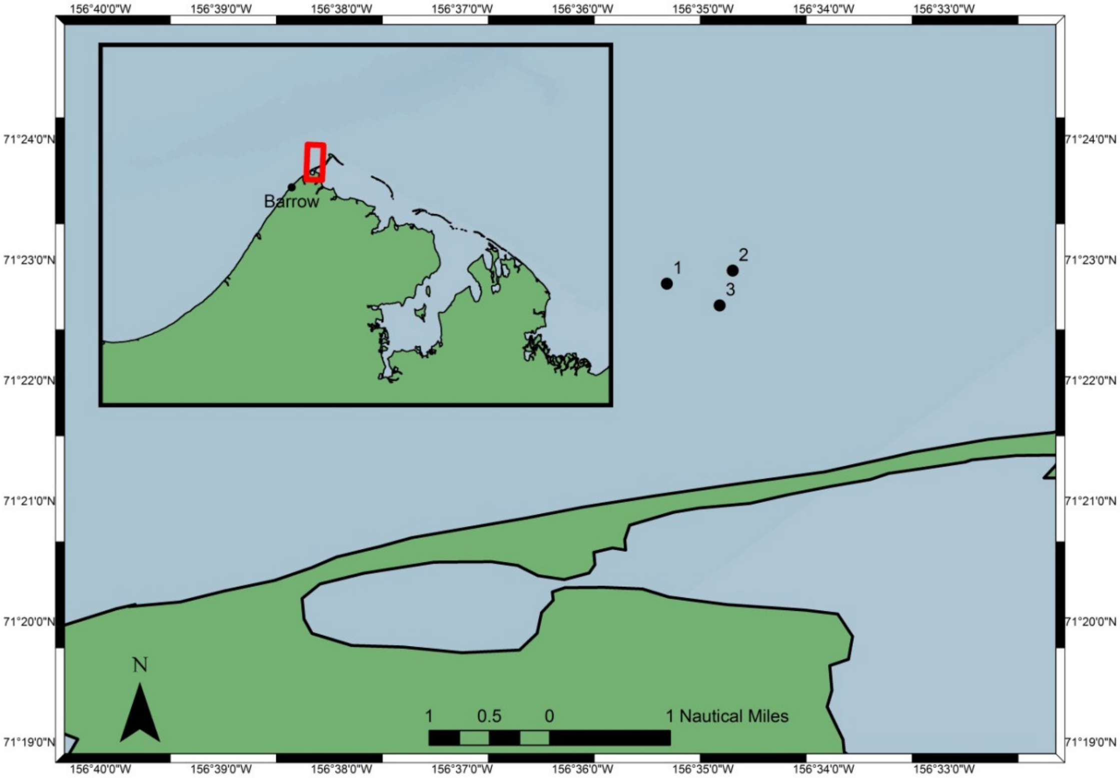


Figure 7-1 Sample Locations (Holes 1–3) Examined March 2013 during Under-Ice-2013

Upon arrival at each site, a YSI EXO sonde CTD (reading DO, TSS, temperature, conductivity, and depth) was deployed by hand through the water column vertically.

After the CTD was retrieved, two divers entered the water to conduct a habitat dive along three random compass headings and to measure rugosity along a 10 m transect. One diver used a rebreather while the other diver used scuba. Habitat dives lasted approximately 10-13 minutes.

The habitat dive was followed by the ROV deployment. The ROV, a Video Ray Pro 3 GTO (**Appendix D.2**) was manipulated in real time by an operator on the surface of the ice. The path of the ROV observation followed the transects completed by divers as much as possible based on the trail of bubbles left on the under surface of the ice by the diver who was not using the rebreather. The ROV compass and depth readings were not functioning properly, so exact headings were not followed. Because the ROV was able to travel farther away from the hole than the divers were, the ROV operator and the chief scientist watched the live display and determined possible areas of interest for further exploration. Footage was recorded at Hole #2, but there was a software malfunction and Hole #3 ROV deployment was not recorded properly.

An ARIS (adaptive resolution imaging sonar) acoustic video camera, the DIDSON device, was deployed through the hole in the ice to collect under-ice imagery of fish and invertebrates in the water column and associated with the bottom (**Appendix D.2**). The sonar was mounted to a rotating pipe, rotated in approximately 15 minute intervals to allow for panning and tilting with real-time viewing of collected data via the connected computer which was controlled from the surface by the ARIS operator.

The ADCP was deployed (**Appendix D.3**) at the same time as the ARIS to collect information about the vertical profiles of the velocity vector field under the ice and determine the variation during time of observations. ADCP deployment lasted approximately one hour. Longer deployments were not possible due to conflicts with other sampling gears. Unfortunately, the ADCP was not set up and working properly the first day and thus was not used until day #2.

One sample of zooplankton was collected prior to setting the gill net by towing a 25 cm ring zooplankton net with 200 µm codend by hand through the water column vertically. Upon retrieval, nets were rinsed with saltwater to wash the sample into the cod-end. Samples were preserved in molecular-grade ethanol and transported to the University of Alaska Fairbanks.

Prior to leaving the sample location (hole) for the day, a monofilament floating gill net 20 m (L) x 2.4 m (H) with 13 mm mesh was set by the divers. Centering the net across the hole proved to be very difficult for the divers, as they struggled with the weights and becoming entangled with the tethering line. Therefore, the net deployment procedure was modified so that one diver swam the entire net out from the hole, with the other diver swimming alongside the ice holding the transect tape. The diver holding the net dropped the net and used the transect tape as a guide/tether to the hole. Then, both divers stretched the other end of the net as much as possible. The net was tethered at one end to the hole and was set just above the substrate. Retrieval of the gill net occurred after it had set overnight. Scientists on the surface of the ice pulled the gill net by hand.

7.3 Results

Divers, ROV, CTD, ARIS, vertical net, and gill nets were successfully deployed at Holes #2 and #3 (**Table 7-1**).

At Hole #2, the gill net entangled approximately 20 jellyfish ranging in size from 50-400 mm and three ~50 mm isopods. At this site, the ROV observed what appeared to be an under-ice ridge with organisms moving around it. We were unable to get close enough to identify them, however. Due to the issues with the heading readings, we can say only that this ice ridge was within 25 m linear distance from Hole #2. The video feed from this site recorded isopods and shrimps.

At Hole #3, divers observed a jellyfish. Two ~50 mm isopods were retrieved in the net. The ROV display did not show any organisms at this site. Due to a software malfunction, the ROV footage was not successfully recorded at this site. One fish was observed in Hole #3 by scientists on top of the ice, but capture and species identification were not possible.

In general, CTD casts showed no turbidity and relatively constant temperatures ranging from -0.4°C to -1.8°C throughout the water column (**Appendix D.4**). No fish were captured in gill nets or observed by the divers, ROV, or DIDSON at any of the sites. At both sites which were safe to sample with divers, the under ice habitat was characterized as very flat with muddy substrate. The vertical zooplankton tows did not capture any fish and very few zooplankton were visually observed in the cod-end. Those zooplankton samples are preserved and stored by Dr. Russell Hopcroft at the University of Alaska Fairbanks until funding is procured to process them.

Table 7-1 Sampling Effort of Under-ice Pilot Study

Hole #	Latitude (°N)	Longitude (°W)	Depth (m)	CTD	Dive	ROV	ARIS	ADCP	Plankton tow	Gill net
1	71.38	156.5883	8.5	X						
2	71.3818	156.5792	9.1	X	X	X	X	X	X	X
3	71.377	156.581	9.7	X	X	X	X		X	X

7.4 Summary

Though no fish were seen or captured, this project was very important in that it answered questions about logistics, gear deployment, and feasibility for sampling under the ice in the Arctic. We successfully deployed a variety of gears, gill nets, ROV, DIDSON, and CTD through the ice. We reaffirmed our initial thoughts that to undertake any under-ice sampling in the Arctic, it is essential to have strong logistical support.

One reason we did not catch or see fish in this study is that the under-ice structure surrounding the dive holes was very smooth. This is because our support team, UMIAQ, chose to drill holes in locations that were flat on the surface as adequate flat area was needed for the windbreaks and equipment staging. In future studies, we recommend having a scientist on site during site selection to ensure that an area with adequate under-ice habitat is selected. We believe that holes located closer to jumble ice would have been more representative of fish and invertebrate habitat and therefore better for scientific observations. Under-ice rugosity, which was low in this study, probably would increase the likelihood of observing fishes in shallow depths.

8 Synthesis and Recommendations

The 200 km of the Alaskan Beaufort Sea shelf sampled in 2011 was the most comprehensive effort of that time. This project yielded many results that addressed the project objectives and went beyond them. The local communities have subsistence bowhead whale hunts each autumn starting about 25 August and continuing until quotas are reached for each community. During this time, communities request that all operations cease within 50 nmi of a village. The in-place Conflict Avoidance Agreement (CAA) requires any sampling to be performed west of 150°W or east of the US-Canada border (or 50 nmi from Kaktovik) starting 25 August. For this cruise, our sampling operations were west of 150°W by 23 August 2011 and did not interfere with local whaling operations. Each year following sampling, Norcross made a presentation at an Alaska Eskimo Whaling Commission meeting to present the previous year's results and the upcoming year's field plan. Complying with the CAA is critical and communicating with local people is essential.

The sample design for 2011 was based on three areas: west, central, and east Beaufort Sea (**Figure 1-1**). Station locations were designed to replicate sites that had been previously sampled and to maximize coverage of the shelf within the time allotted (21 days). The western portion of the area had 30 fishing stations from which 9,290 fish were captured between August 26 and September 2, 2011, between longitudes 155.25°W and 152.01°W. The sampling plan for the western area attempted to sample as many of the sites as possible that were trawled in 2008 (Rand and Logerwell 2011). Because the cruise in 2011 experienced extraordinarily good weather, extra stations were added to fill in between the 2008 sites and to create transects (i.e., ~155°W, ~154°W, ~153°W). The central area (151.84°W to 147.13°W) was sampled with a grid pattern to maximize spatial coverage of the area. Stations were spaced at approximately 0.5° latitude and 0.25° longitude. Due to good weather, additional stations were added between 151.8°W and 150.1°W. Between August 20, and September 3, 2011, 34 stations were fished and 2,576 fish were captured. Stations in the eastern area were located at the same grid pattern sampled during the WWW1004 cruise in 2010 (LGL and Norcross, unpublished) between longitudes 146.65°W and 145.09°W. In 15 complete stations 1,242 fish were captured between August 16 and 20, 2011.

Determining the appropriate bottom sampling gear was significant. Though we used a PSBT, the PSBT-A was used at stations where a regular PSBT would have been impractical (i.e., dense mud or boulders). There was no significant difference in quantitative catch between the bottom PSBT and PSBT-A gears. There was, however, some variability of catch between hauls of the two types of plumb staff beam trawls, but that variability was not greater nor more frequent than hauls repeated with a single trawl type. This is an extremely applicable result because one of the two versions of this trawl was used to sample the Chukchi Sea for 16 cruises:

- RUSALCA (Russian-American Long-term Census of the Arctic) in 2004 (Norcross et al. 2010), 2009, and 2012;
- BOEM-funded sampling aboard the *Oshoro-Maru* in 2007 and 2008, and the RV *Oscar Dyson* in 2007 (Norcross et al. 2013a);
- CSESP (Chukchi Sea Environmental Studies Program) in 2009 and 2010 (Norcross et al. 2013b);
- AKMAP (Alaska Monitoring and Assessment Program) in 2010 and 2011;
- ArcticEIS (Arctic Ecosystem Integrated Survey) in 2012;
- SHELZ (Shelf Habitat and Ecology of Fish and Zooplankton) in 2013;
- AMBON (Arctic Marine Biodiversity Observing Network) in 2015 and 2017; and
- two Arctic IERP (Arctic Integrated Ecosystem Research Program) cruises in 2017.

This net also will be used for Arctic IERP in 2018 and 2019. Of the 18 cruises on which the net was or will be used to sample bottom fishes, 13 were under Norcross's direction. Additionally the PSBT-A was used to sample in the Beaufort Sea for three TB (US-Canada Transboundary Fish and Lower Trophic Community) cruises in 2012, 2013 and 2014 (Norcross et al. 2017), and one ArcticEIS II station in 2017.

It will be used for ArcticEIS II in 2019. Therefore, this project has shown that demersal fish collections from 22 cruises in the Chukchi and Beaufort seas can be quantitatively compared to each other and that demersal fish communities are analogous. The PSBT-A is sturdier than the PSBT and thus less susceptible to damage and loss. As the two plumb staff beam trawls produce equivalent results, it is recommended that the sturdier PSBT-A be used for all future sampling efforts in the Arctic.

Including the present research, at least 74 marine and anadromous fish species have been found in the US Beaufort Sea. Nineteen species were captured in 2011 that were not collected in previous Beaufort Sea fish sampling. Overall, the most abundant taxa were *Boreogadus saida*, *Gymnocanthus tricuspis*, *Liparis* spp., *Aspidophoroides olrikii*, *Icelus spatula*, and *Lumpenus fabricii*. *B. saida* was the single most abundant taxa captured in every gear type and accounted for slightly over one-third of the fish captured. For demersal catches, there was an east-west pattern in abundance and biomass in the Beaufort Sea. Gadidae (cods, primarily *B. saida*) dominated abundance and biomass of fish catches in the west, including at the shelf break. Cottidae (sculpins) density and biomass were greatest in the west, with only a few sculpins at the shelf break. Though Liparidae (snailfishes) were caught across most of the Beaufort Sea, the greatest density was in the west. Zoarcidae (eelpouts) density was highest in the west and at two stations in the east, whereas biomass was greatest at the shelf break. For all fish taxa combined, demersal abundance was greatest west of ~153°W. In contrast, midwater catches of larval and juvenile fishes did not display the same east-west pattern as bottom trawl catches; abundance was highest in east. Gadidae dominated midwater catches. Cottidae density was high at a few stations in the east. Liparidae density was highest at a few nearshore stations of the central coast. There was no center of density of larvae and early juveniles; they were found in both eastern and western portions of the sampling region, and both nearshore and at the shelf break.

Demersal and pelagic communities were spatially grouped as west, coastal, and shelf, and somewhat related to spatial patterns of physical variables. However, there were differences in numbers of demersal and pelagic communities (as was expected) because more taxa were captured demersally than pelagically. Six demersal fish communities were characterized by 2–7 taxa, and three pelagic fish communities (and one lone station) were characterized by 1–5 taxa. Analysis of multiple transformation for demersal fish communities showed that fourth root transformation (4RT) most clearly spatially defined the communities because it provides more equitable information on very abundant and very sparse fishes as found for these collections. When the density differences are less than the three orders of magnitude found in this study, a square root transformation (2RT) could potentially be used; though some expert statisticians such as Dr. Franz Mueter (University of Alaska Fairbanks) still prefer a fourth root transformation. Demersal fish abundance was correlated with depth, bottom temperature, bottom salinity and water mass (which is a combination of temperature and salinity). The relationships were the same between physical variables and either abundance or biomass. It is important to know persistence of community structure, density of fish, and associated physical variables over time in order to be able to detect natural and anthropogenic changes. This study provides a benchmark against which fish abundance, biomass, and communities can be compared in the future.

Length-weight relationships are basic life history parameters of fishes that have been poorly documented for the Pacific Arctic. Now there are known length-weight relationships for an additional six demersal fish species in the Central Beaufort Sea: *Aspidophoroides olrikii*, *Myoxocephalus scorpius*, *Liparis fabricii*, *Lycodes polaris*, *Anisarchus medius*, and *Lumpenus fabricii*. Isometric growth (consistent proportional growth throughout development) is documented for five species, - all except *Liparis fabricii* which was positively allometric (an increase in body thickness with an increase in length). Additional information is also available on smaller sizes of fish to supplement earlier length and weight-at-age relationships for four more species: *B. saida*, *Eleginus gracilis*, *G. tricuspis*, *and Hippoglossoides robustus*. As in previous research in the Pacific Arctic, growth of *B. saida* and *E. gracilis* was isometric, and growth of *G. tricuspis* was positively allometric. However, unlike an earlier growth-type assessment

(Smith et al. 1997b), in this study, growth of *H. robustus* is negatively allometric, i.e., a proportional decrease in body thickness with an increase in length. The difference may be because the *H. robustus* specimens in this study were smaller than those of the earlier study, or because the earlier study was in the warmer Chukchi Sea. In light of this contradiction and because environmental conditions in the Central Beaufort Sea are likely to change, it is recommended that length-weight relationships of demersal fishes be used as a metric against which to measure natural and anthropogenic changes.

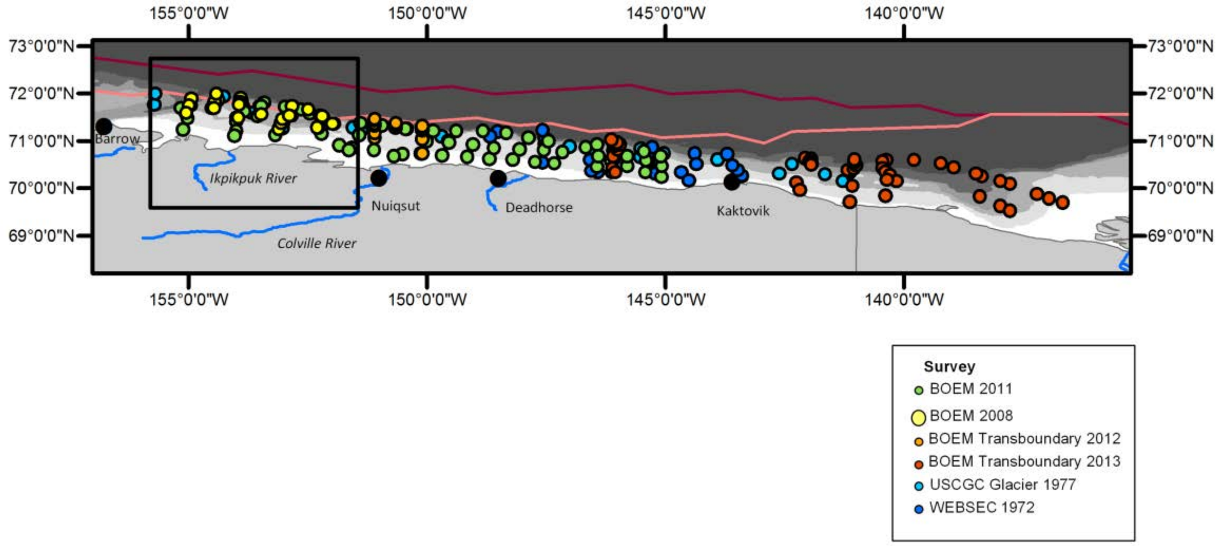
Analysis of diets and stable carbon and nitrogen isotope signatures of three of these abundant and ecologically important fish species, *B. saida*, *G. tricuspis*, and *M. scorpius*, elucidates aspects of their prey, trophic interaction, habitat, and carbon source of their diets. *B. saida* feed lower trophically, i.e., pelagic copepods, than both *G. tricuspis* and *M. scorpius* which feed on benthic amphipods. The carbon source of the *B. saida* diet is phytoplankton and terrestrial influenced, indicating an offshore habitat. The carbon source for both sculpin species was more ice algae, indicating an inshore habitat. Ontogenetic change in food consumed is evident for all three fish species. Evidence of different feeding types throughout ontogeny in the arctic has only been observed previously in *B. saida* (Lowry and Frost 1981, Walkusz et al. 2011). Diet studies show *B. saida* <70 mm consumed calanoid copepods, while larger specimens also eat hyperiid amphipods, fish, and shrimps. *G. tricuspis'* diet is similar across size classes, including benthic amphipods and polychaetes; larger prey can be consumed by large individuals. *M. scorpius* has a distinct ontogenetic diet shift such that larger individuals consume more fish and shrimps.

While fish body size determined the size and type of prey consumed, regional oceanographic differences likely affected prey availability. In the Beaufort Sea small *B. saida* are trophically lower in the east than west. Large *G. tricuspis* are trophically lower in east and large *M. scorpius* are trophically higher in east. On a larger scale of the Beaufort Sea compared to the Chukchi Sea, there are also regional differences. A more diverse spectrum of benthic prey taxa was found in the diets of all three species in the Chukchi Sea regions than in the Beaufort Sea. In the Beaufort Sea, *B. saida* fed on pelagic prey not on benthic amphipods as it does in the Chukchi Sea, especially in the northern Chukchi Sea region. Sculpin diets were less diverse in the Beaufort than in the Chukchi Sea. *G. tricuspis'* diet was consistent across regions as well as fish sizes; it consumed an exclusively benthic diet in all regions of the Beaufort and Chukchi seas. In contrast, *M. scorpius* exhibited both benthic and pelagic feeding, more pelagic in the Beaufort Sea and more benthic in the Chukchi Sea. Regional differences in diet and trophic level feeding may indicate some differences in prey availability, or that fish of the same species and size class occupy different ecological niches between seas and across the Beaufort Sea, both which could be explained by the oceanography. The Beaufort Sea is less productive than the Chukchi Sea due to lower nutrient inputs (Belkin et al. 2009; Crawford et al. 2012). Benthic-pelagic coupling processes are not as strong in the Beaufort Sea as they are in the Chukchi Sea. The narrow Beaufort Sea shelf is a pelagically dominated ecosystem (Carey and Ruff 1977; Carey 1987) that has more riverine input in the east from the Mackenzie River. The Chukchi Sea has a wide, shallow shelf area (Weingartner et al. 2005) with nutrients transported from the Bering Sea (Weingartner 1997); the high primary productivity (Grebmeier and Dunton 2000; Hunt et al. 2013) is strongly coupled with the benthos (Feder et al. 1994; Grebmeier et al. 2006). Understanding of the spatial complexity of local food webs will be increasingly important in formulating an ecologically sound management plan for the arctic as regional development increases and the impacts of climate change become more apparent. Therefore, it is recommended that regional variability and body size of fish be considered in diet and stable isotope studies.

As offshore oil exploration interest expands, more information about the sparsely documented fish species inhabiting the US Beaufort Sea is required. Minimal historical data exist for shelf and slope marine fish populations in the US Beaufort Sea in the open water season. What does exist comes from fish surveys on the shelf that were conducted sporadically in 1977 (USCGC *Glacier*, Frost and Lowry 1983), 1990 (nearshore survey, Thorsteinson et al. 1992), and 2008 (Logerwell et al. 2011, Rand and Logerwell 2011; **Figure 8-1**). The area previously sampled ranged from Barrow to the Alaska – Canada border, though no sites were sampled in multiple years. Contemporary data were absent east of 145°W to the border until

2013 (Norcross et al. 2017). To get a complete picture of the ecosystem in which fishes live, it is recommended that the physical environment and other trophic levels, e.g., epibenthos, benthic infauna, and zooplankton, be simultaneously investigated. As physical oceanographic characteristics change on slope and Atlantic Water may upwell onto shelf (Pickart et al. 2009), sampling on both the shelf and the slope is recommended. Additionally, because this study found regional differences in demersal and pelagic fishes, it is recommended that future sampling occur between Pt. Barrow and the US-Canada border.

Though sampling in open water season was successful, sampling under ice was not. We did not learn anything about fishes under ice from the pilot project as part of this study, though we learned several things that do not work such as sampling in flat ice, too close to shore, and with a limited sampling time. Under-ice rugosity, not found in this study, probably would increase the likelihood of observing fishes in shallow depths. We suggest sampling be conducted 20 to 100 miles from shore, which will require large-scale support. Wintertime sampling will always be more difficult due to the dark, cold, and wind. Windows of opportunity are small and staffing a crew to take advantage of them is difficult. Launching a study for sampling fishes in the winter will be extremely expensive.



The average August and September sea ice extents from 1979–2000 are pink and red, respectively (from Bluhm et al. 2014).

Figure 8-1 Historic, BOEM-2008 (black box) and 2010+ Sampling Efforts in the Beaufort Sea

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COLLABORATIVE RESEARCH DURING BEAUFISH-2011:

APPENDIX A
TO THE FINAL REPORT FOR
CENTRAL BEAUFORT SEA MARINE FISH MONITORING,
BOEM 2014-33

August 2018

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APPENDIX A1 PHYSICAL HYDROGRAPHY

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Summary

We conducted 84 conductivity-temperature-depth (CTD) casts over 16 August – 3 September 2011 on Beaufort Sea cruise Beaufish-2011, herein called AKBE11, using Sea-Bird SBE19 (5 casts) and SBE25 (79 casts) instruments (**Figure A1-1**). Factory calibrations of the CTD sensors were made in May 2011 for the SBE25 instrument and August 2009 for the SBE19. Upon examination of the SBE19 data, large offsets were found in the salinity data with respect to nearby SBE25 casts and so were discarded. Four of the SBE25 profiles did not capture the entire water column and were also discarded. Therefore, the analyses and accompanying figures are based on the remaining 75 SBE25 CTD profiles. Given typical SBE sensor drifts, we assign expected accuracy of ~ 0.02 for the SBE25 salinity measurements and 0.01°C for the temperatures. Data were processed and averaged to 1 decibar (dbar) bins following the manufacturer's recommended procedures. All profiles were individually visually inspected for data errors (e.g., density inversions, spikes) that can be caused by contact with the bottom sediment, ship drift in regions of strong horizontal property gradients, bubbles in the near-surface layer, or bio-fouling (e.g., jellyfish). Identified problems were removed near the bottom, extrapolated near the surface, or linearly interpolated in the water column.

Sampling began over the eastern Alaskan Beaufort shelf near 145 °W and progressed westward toward Barrow Canyon (**Figure A1-1: Transect T6 to Transect T1; Figure A1-2**). Just prior to the cruise, winds (recorded at the Barrow airport and taken to be representative of the Alaskan Beaufort as a whole) were moderately strong, exceeding 10 m/s on August 12, 13, and 14, and blowing toward the west (**Figure A1-3**). Other notable wind events of > 8 m/s occurred on August 16, 20, 24, and 29 but the mean wind speed for the entire cruise was a moderately weak 4.2 m/s. In general, winds blew toward the quadrant between southwest and northwest, with the exception of more variable directions that occurred in the presence of low wind speeds (< 4 m/s).

We define here five water masses that encompass the observed water types and mixing end-members (**Figure A1-4**). Alaska Coastal Water (ACW, T > 3°C, S > 30) and Chukchi-Beaufort Shelf Summer Waters (SSW, -1°C < T < 3°C, 30 < S < 33.5) together comprise the bulk of the shelf and upper slope water types. Shelf Winter Waters (SWW, T < -1°C, 31 < S < 34) are cold waters remnant from the previous winter's freezing and found primarily over the outer shelf, the slope, and within the Canada Basin halocline. Temperature-salinity (T-S) diagrams (**Figures A1-5 through A1-8**) and vertical profiles **(Figures A1-9a through A1-9f)** show that the shelf break CTD casts sampled halocline waters, but did not extend into to the temperature maximum associated with the core of the underlying Atlantic Water (AW, defined here as T > 0°C, S > 34.4). We note that full separation and/or identification of the proportions of AW vs. SSW/SWW is not possible without additional geochemical tracer measurements such as silicate. Summer Melt Waters (SMW, S < 30) are near-surface low-salinity waters that we found along the shelf break and across the shelf just west of Harrison Bay. Meteoric waters from Alaskan North Slope and Canadian rivers (Colville, Sagavanirktok, Kuparuk, and Mackenzie) and shelf waters from the Canadian Beaufort also contribute in portions that we cannot fully delineate here.

Near-surface temperatures as high as 7.8°C were observed in the western Beaufort Sea near Barrow Canyon and as low as 0.6°C on the inner shelf in the eastern Beaufort (**Figure A1-10**). Near-surface salinities varied from 28 to 31.7, with a SMW minimum located between Smith Bay and Harrison Bay that extended across the shelf and along much of the shelf break (**Figure A1-11**). These low-salinity waters were usually associated with local temperature minima, which we interpret as a local ice melt signature, rather than meteoric waters from the Colville River (on the shelf) or Mackenzie River (along the shelf break).

Near the seafloor, temperatures of 4–5°C were found over the western Beaufort shelf while sub-zero temperatures were found near the bottom along the shelf break and across the entire shelf east of 148°W (**Figure A1-12**). These cold near-bottom waters in the east were associated with slightly elevated shelf salinities (31< S < 32.5), suggesting that the near-bottom shelf waters here may be remnant from the previous winter and/or the result of waters upwelled from the slope region (**Figure A1-13**). In the west, warmer near-bottom temperatures and lower near-bottom salinities (< 31.5) likely reflect advection of Alaskan Coastal Water (ACW) and other Pacific-origin waters from the eastern Chukchi Sea (Weingartner et al. 1998, Shimada et al. 2001, Steele et al. 2004, Woodgate et al. 2005).

Highest salinities were found in Barrow Canyon and between 148°W and 151°W. Upper Halocline Water (UHW, 32.25 < S < 33.5), and Lower Halocline Water (LHW, T < 0°C, 33.5 < S < 34.6) are not well separable by strict T-S limits because of water column differences observed between the western and the eastern sides of the survey grid. In particular, the S = 33 isohaline was at ~140 m for stations west of 152°W, whereas we found it at ~ 104 m depth for stations east of this. This zonal difference in the S = 33 isohaline depth suggests the possible influence of upwelling in the east that could have been triggered by the wind event that occurred over 12–14 August. The presence of relatively cool surface waters on the inner eastern shelf along with elevated near-bottom salinities on the outer shelf is also consistent with a possible upwelling event.

The linear character of the T-S properties close to the bottom and within Barrow Canyon shows that we also sampled through a water mass resultant from direct mixing of water types lying on the line passing through (-1°C, 33) and (0°C, 34.4). End-members of this mixing appear to be associated with AW and SSW or possibly SWW (Mountain et al. 1976, Aagaard and Roach 1990). The three stations most strongly exhibiting this character are CTD stations 78, 81 and 82, which lie along the northwestern edge of the sampling grid.

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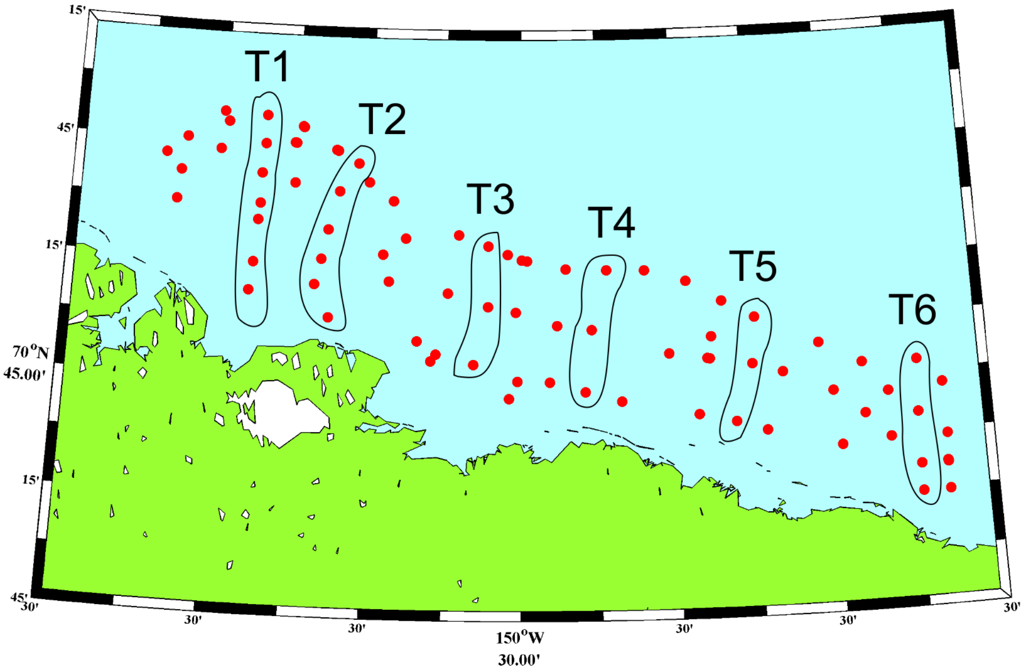


Figure A1-1. Station and transect locations during cruise AKBE11.

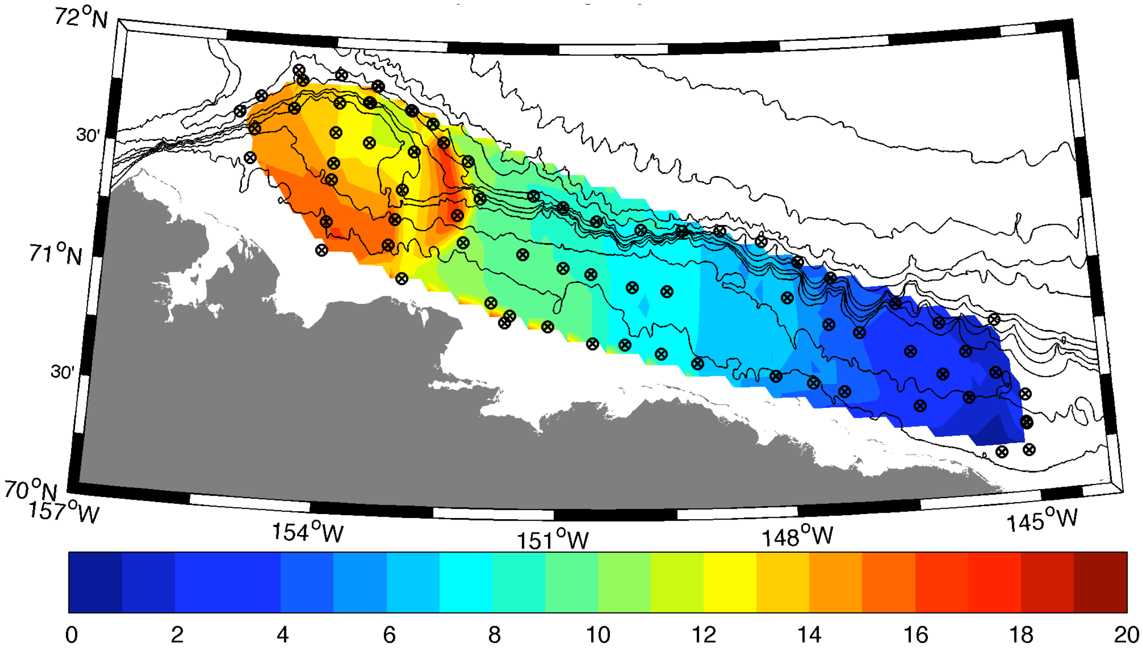
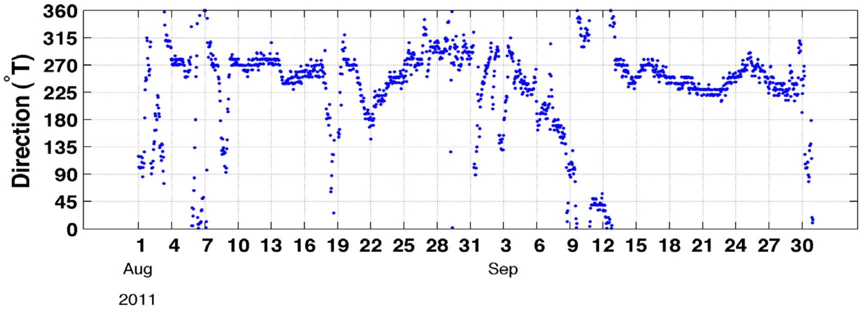


Figure A1-2. AKBE11 station occupation timing: days after start of cruise.



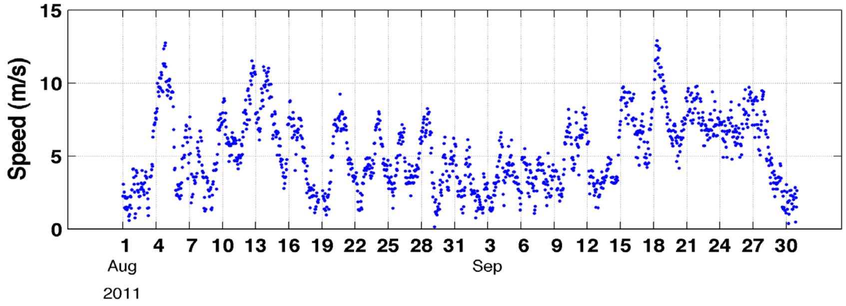


Figure A1-3 Barrow wind direction and speed (August–September 2011).

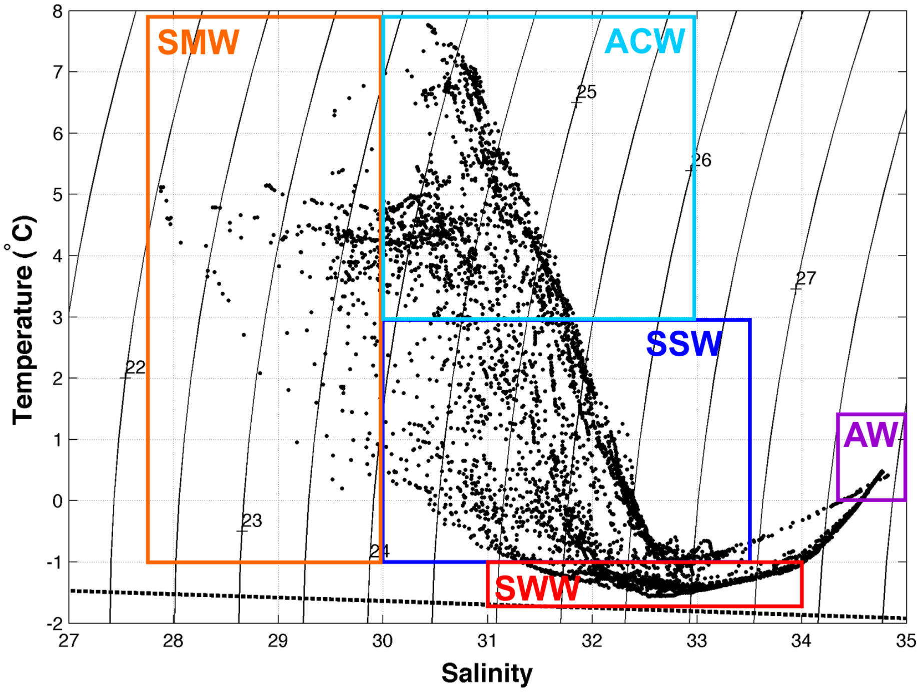


Figure A1-4. Scatter plot of potential temperature and salinity data during AKBE11; isopycnals are shown. Colored outlines indicate five water masses: Summer Melt Waters (SMW), Alaska Coastal Water (ACW), Chukchi-Beaufort Shelf Summer Waters (SSW), Shelf Winter Waters (SWW), and Atlantic Water (AW). The dotted line denotes the freezing point of seawater for the range of salinities.

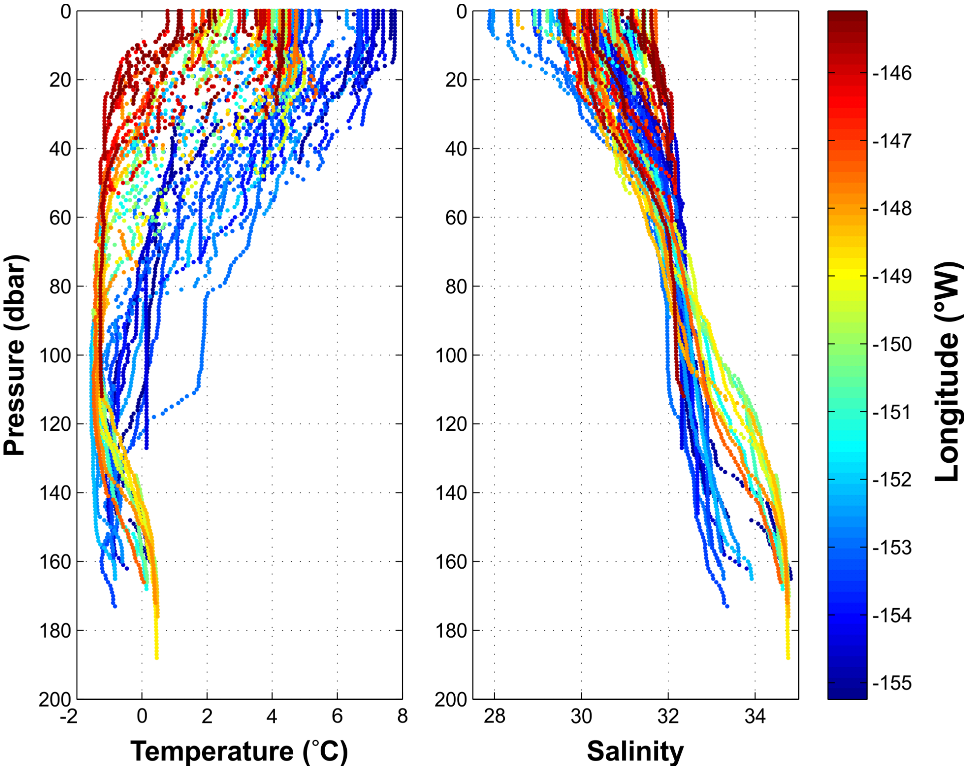


Figure A1-5. Scatter plots of temperature and salinity vs. pressure. Data are colored by longitude of station.

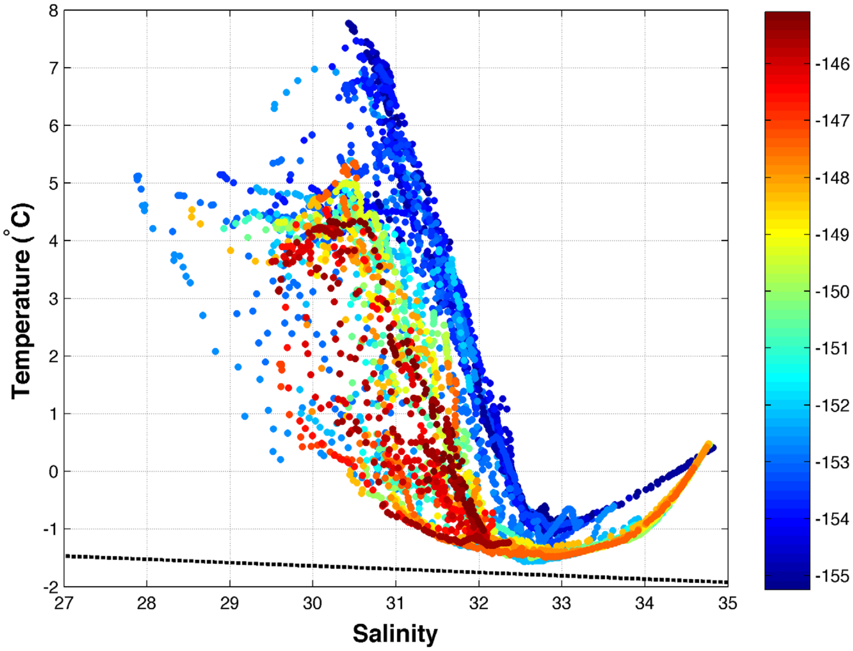


Figure A1-6. Temperature-salinity scatterplot; color indicates longitude (°W) of station.

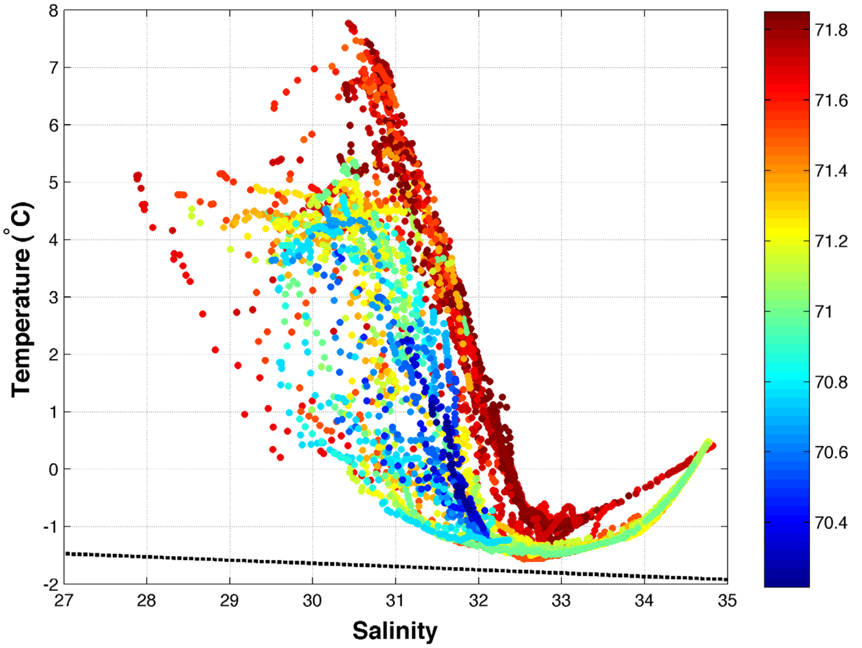


Figure A1-7. Temperature-salinity scatterplot; color indicates latitude (°N) of station.

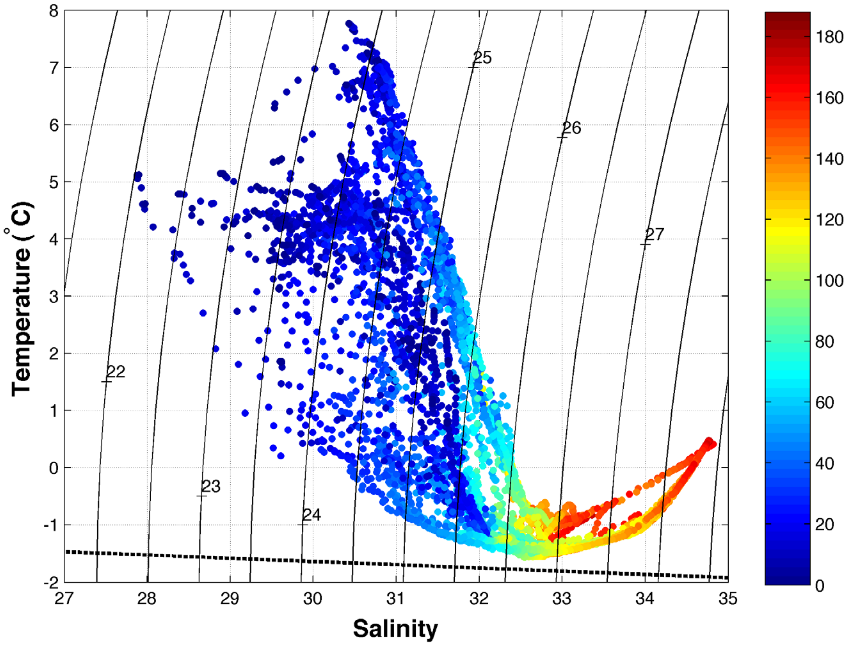


Figure A1-8. Temperature-salinity scatterplot; color indicates pressure (dbar).

NEXT SIX FIGURES

Figures A1-9a–f. Vertical contours of physical parameters along six offshore to onshore transects during Beaufish-2011. Parameters included temperature (°C), salinity, density, and geostrophic velocity.

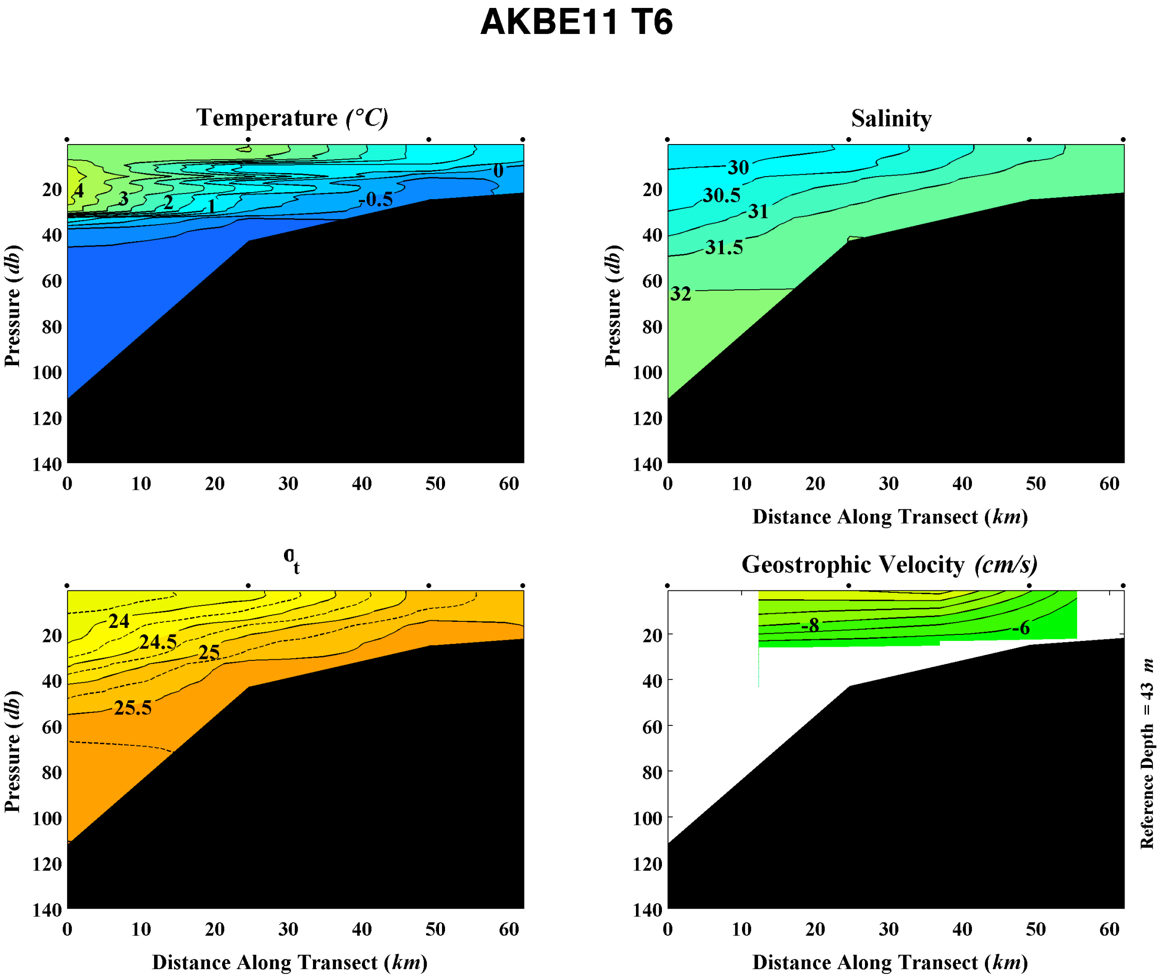


Figure A1-9a. Vertical contours of temperature, salinity, density and geostrophic velocity along the easternmost transect T6, from offshore (north, 0 km) to onshore (south, 60 km).

AKBE11 T5

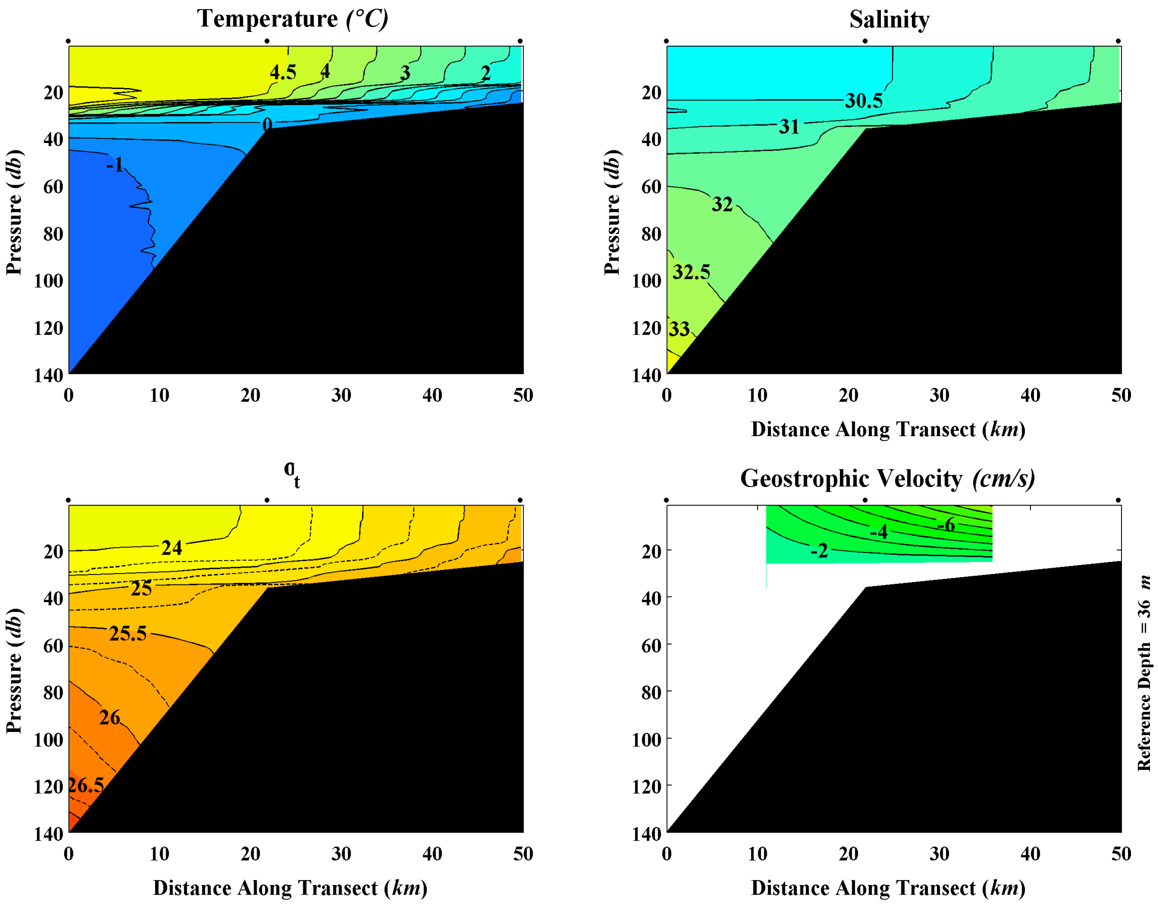


Figure A1-9b. Vertical contours of temperature, salinity, density and geostrophic velocity along transect T5, from offshore (north, 0 km) to onshore (south, 50 km).

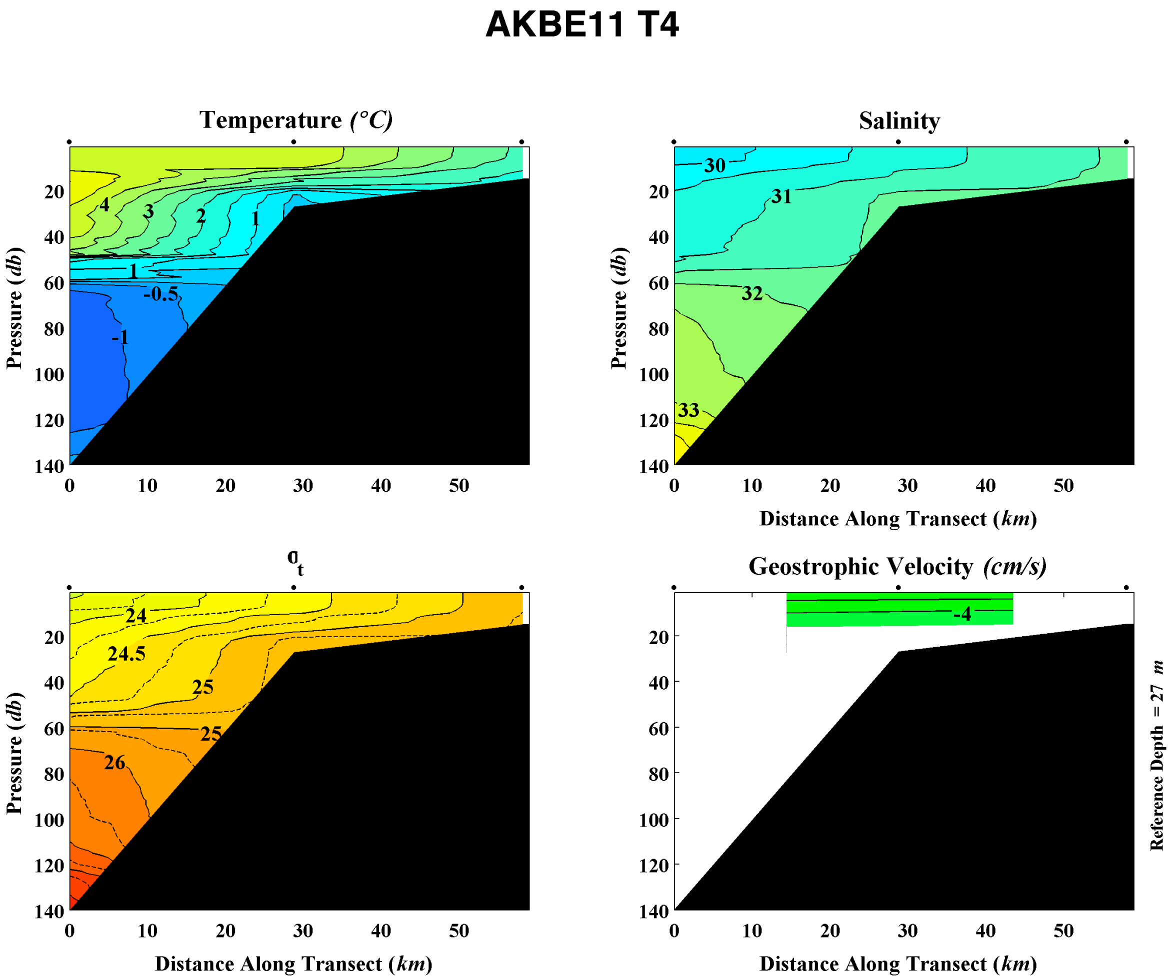


Figure A1-9c. Vertical contours of temperature, salinity, density and geostrophic velocity along transect T6, from offshore (north, 0 km) to onshore (south, 55 km).

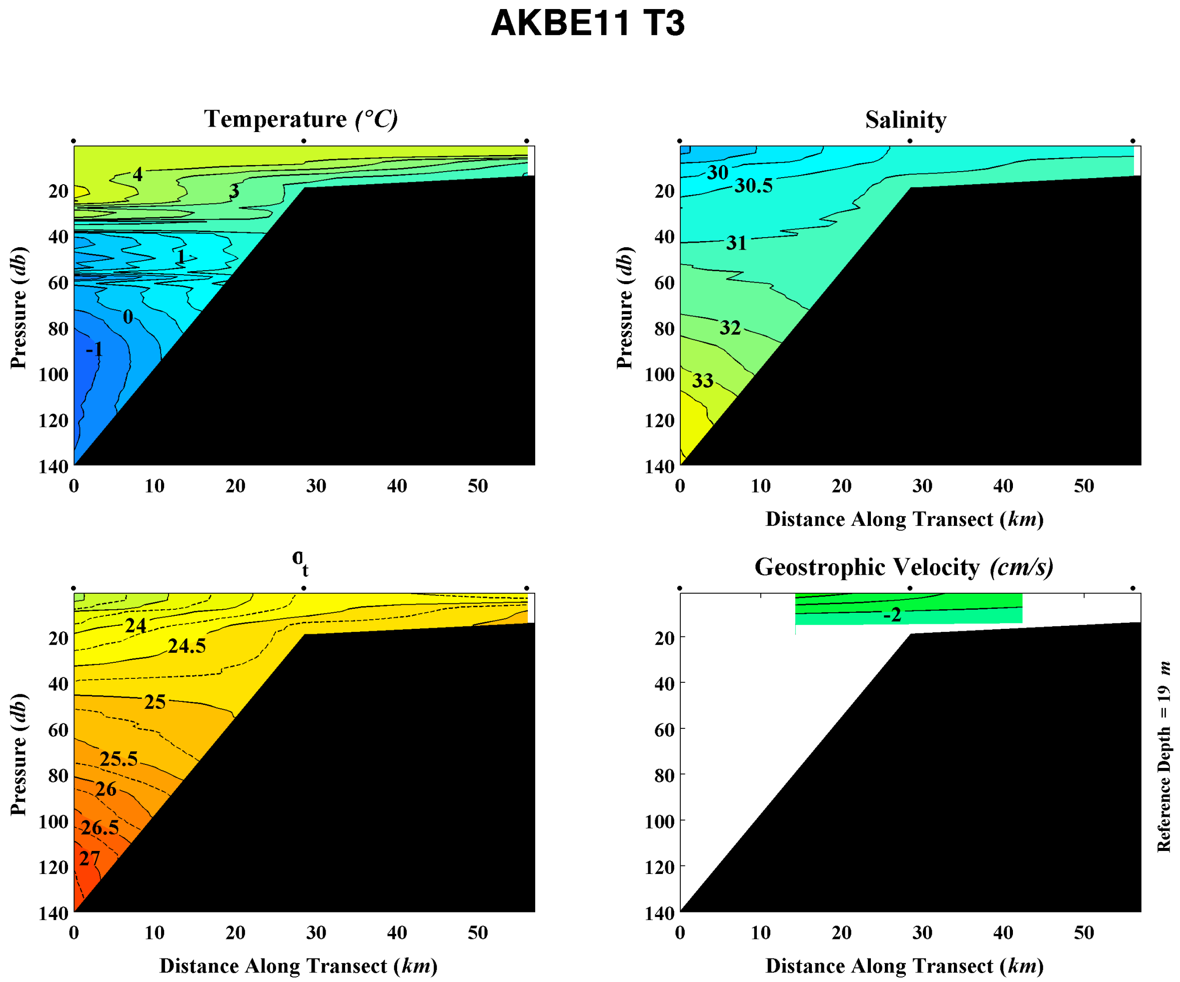


Figure A1-9d. Vertical contours of temperature, salinity, density and geostrophic velocity along transect T3, from offshore (north, 0 km) to onshore (south, 55 km).

AKBE11 T2

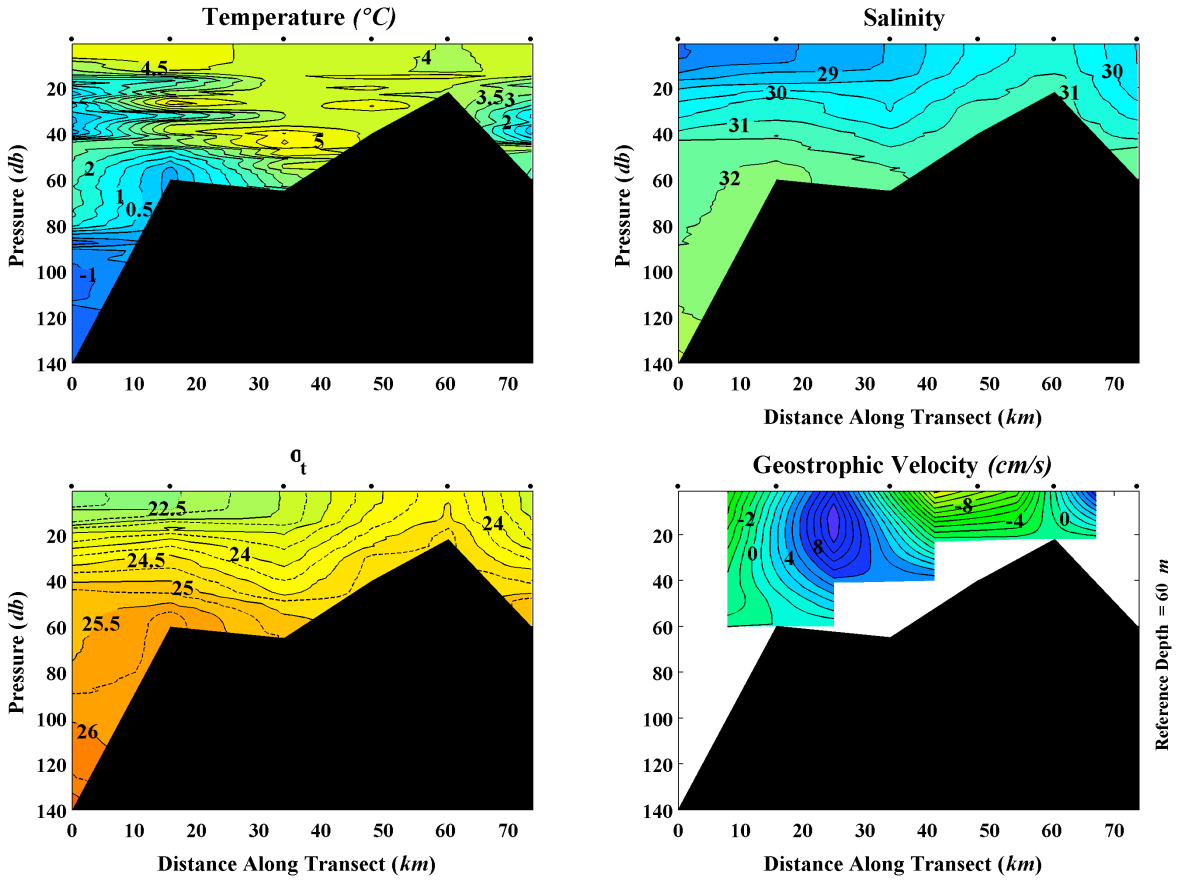


Figure A1-9e. Vertical contour of Vertical contours of temperature, salinity, density and geostrophic velocity along transect T2, from offshore (north, 0 km) to onshore (south, 70 km).

AKBE11 T1

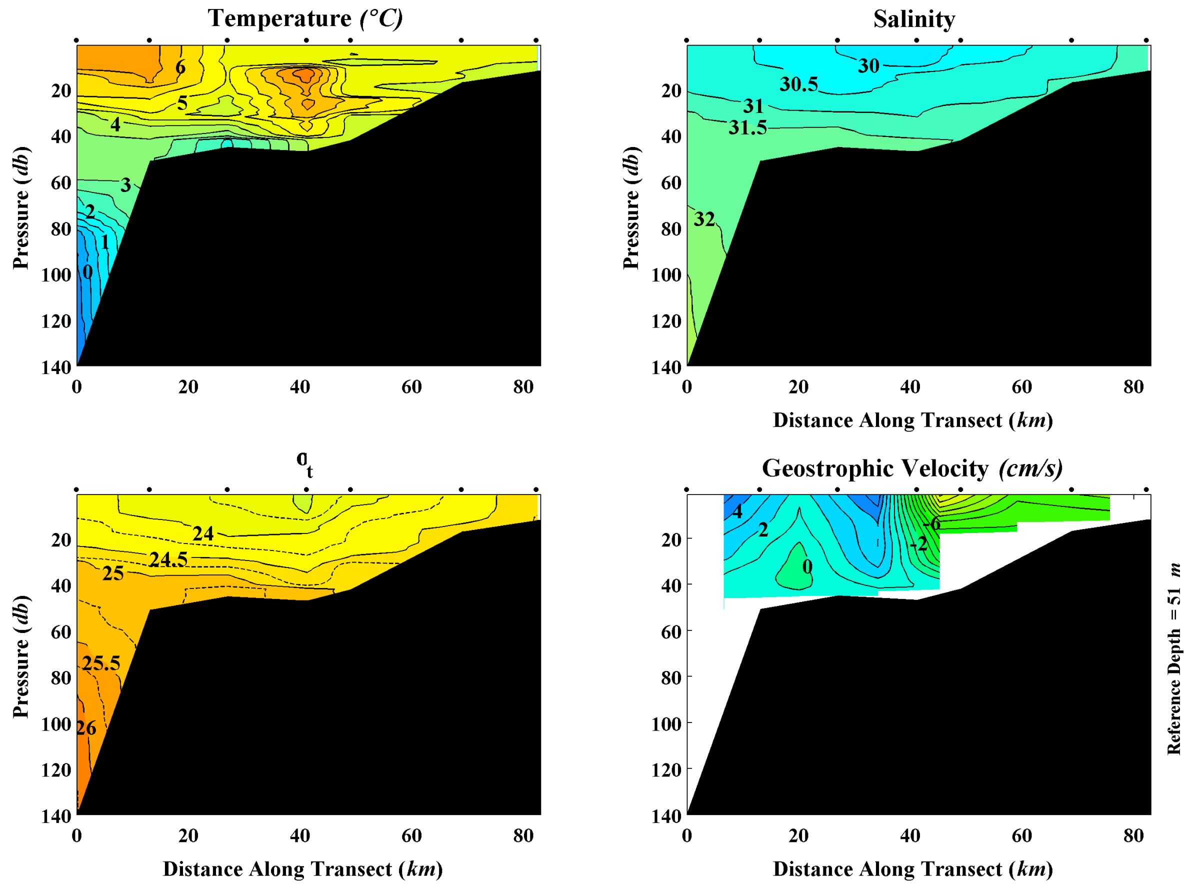


Figure A1-9f. Vertical contours of temperature, salinity, density and geostrophic velocity along the westernmost transect T1, from offshore (north, 0 km) to onshore (south, 80 km).

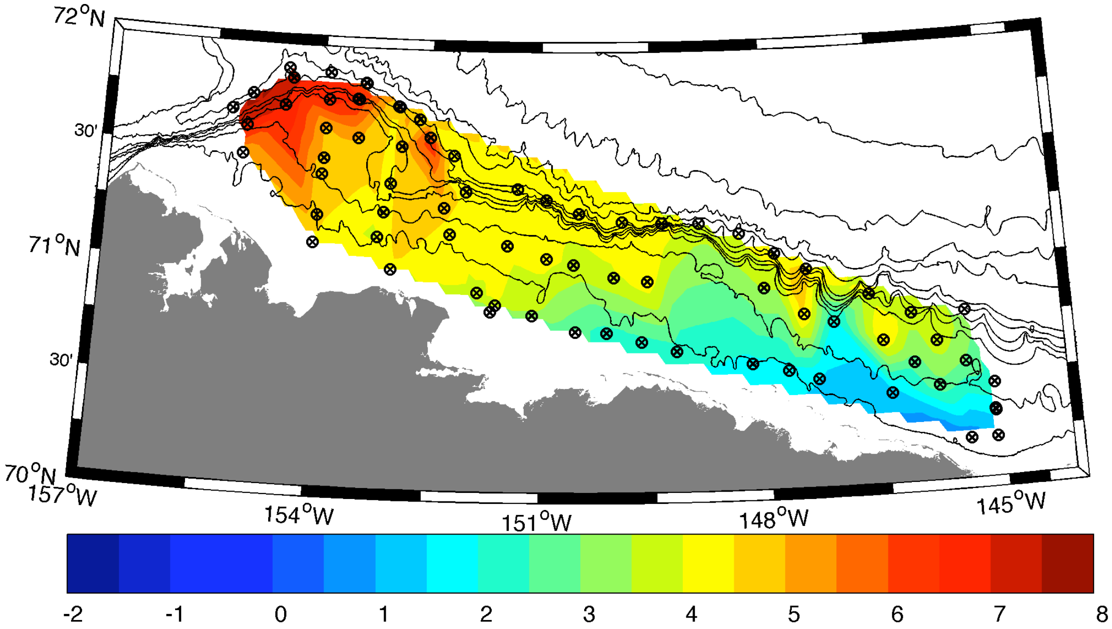


Figure A1-10. Contour map of near-surface temperature (°C).

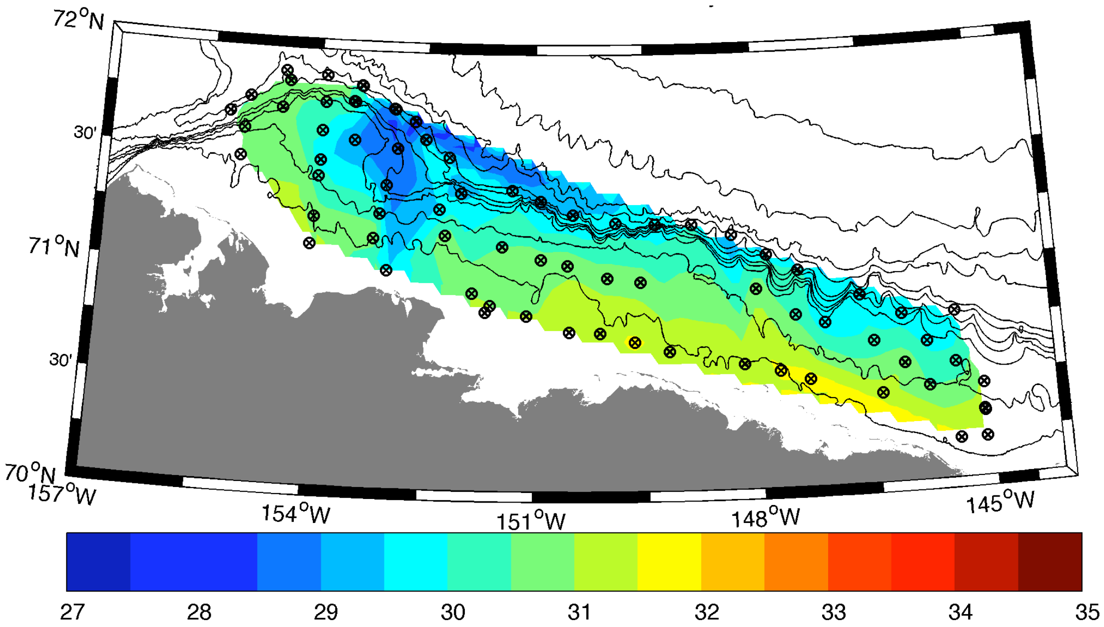


Figure A1-11. Contour map of near-surface salinity.

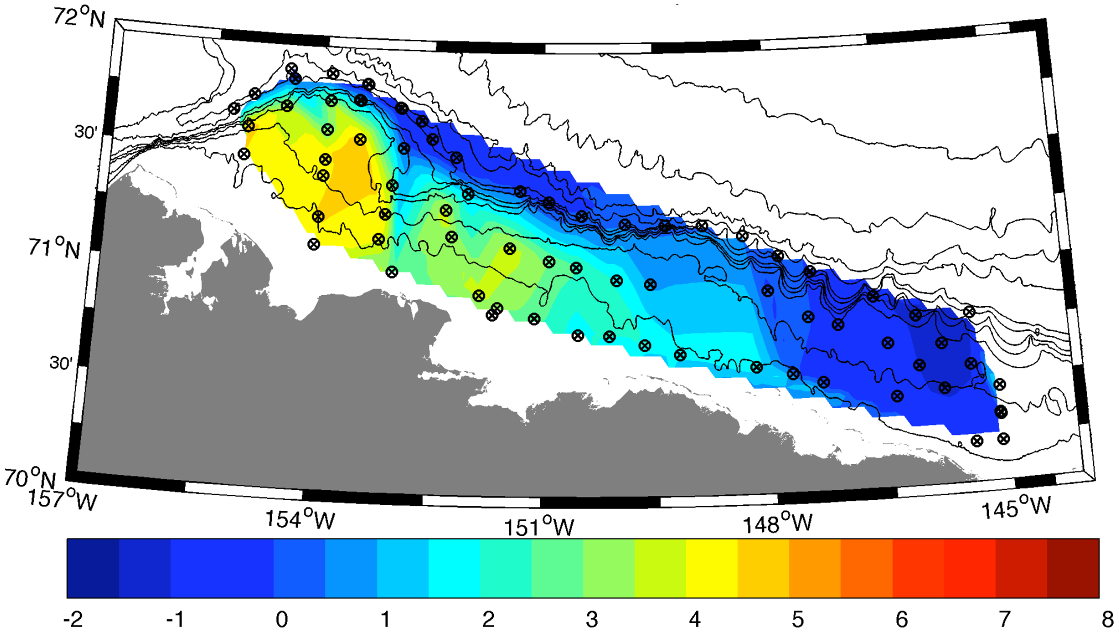


Figure A1-12. Contour map of near-bottom temperature (°C).

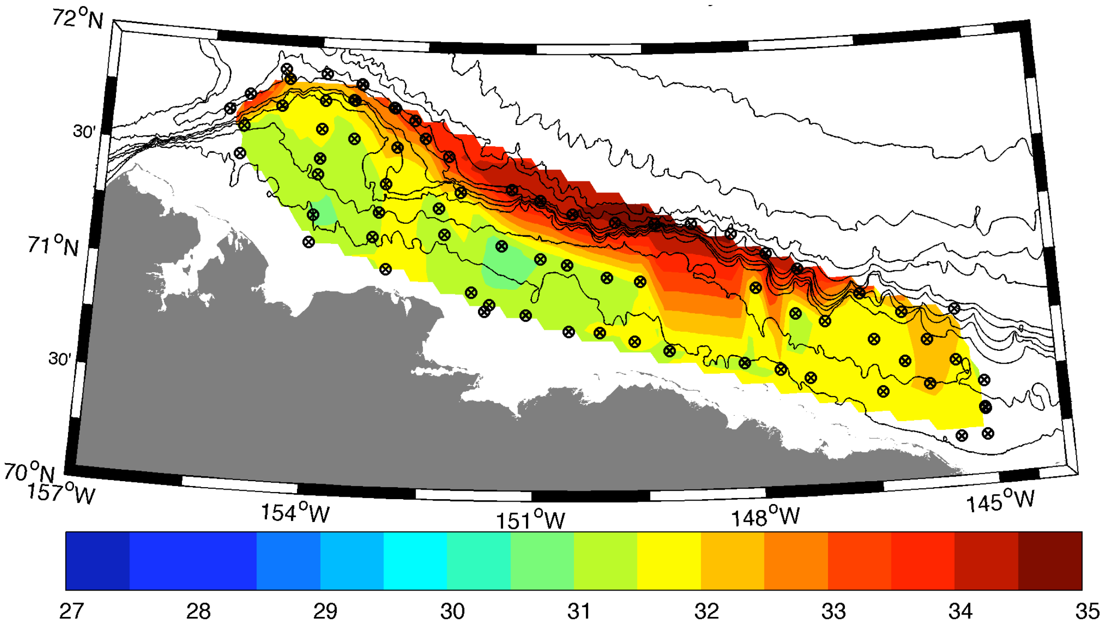


Figure A1-13. Contour map of near-bottom salinity.

APPENDIX A2 ZOOPLANKTON AND CHLOROPHYLL

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Funding Source for Planktonic Work: Shell Exploration and Production Company

Summary

Mesozooplankton surveys were completed in the American Beaufort Sea as part of the multidisciplinary Beaufish-2011 project during August and September 2011. A total of 79 taxonomic categories of zooplankton were found. This included 68 holozooplankton and 11 meroplankton categories. The greatest diversity was found in the copepods (26 species), followed by the cnidarians (9 species). Overall, sites were dominated by copepods, larvaceans, and cnidarians, although relative importance varied by site. Generally, species were characteristic of the Arctic, with a mixture of neritic species, such as *Pseudocalanus* spp. and oceanic species, such as *Calanus hyperboreus*.

Introduction

Zooplankton are important trophic links, yet have been poorly characterized in the Beaufort Sea. The Beaufort Sea serves as a foraging ground for fish, birds, and whales that feed on zooplankton resources (Gradinger et al. 2010). In addition to its importance as a foraging ground for upper trophic levels, the Beaufort Sea is particularly vulnerable to the impacts of global climate change (Fabry et al. 2009). Historically, sampling in this region has been constrained by sea ice cover. Recent reductions in sea ice extent provide a new opportunity to collect critical biological data in this sensitive area. An improved understanding of the composition, spatial distribution, and seasonal and inter-annual variability of the zooplankton community of the Beaufort Sea is needed to understand trophic linkages and establish a modern reference point from which any long term change may be gauged. This work contributes to efforts to fill the knowledge gap of contemporary zooplankton communities of the Beaufort Sea.

Study Area and Methods

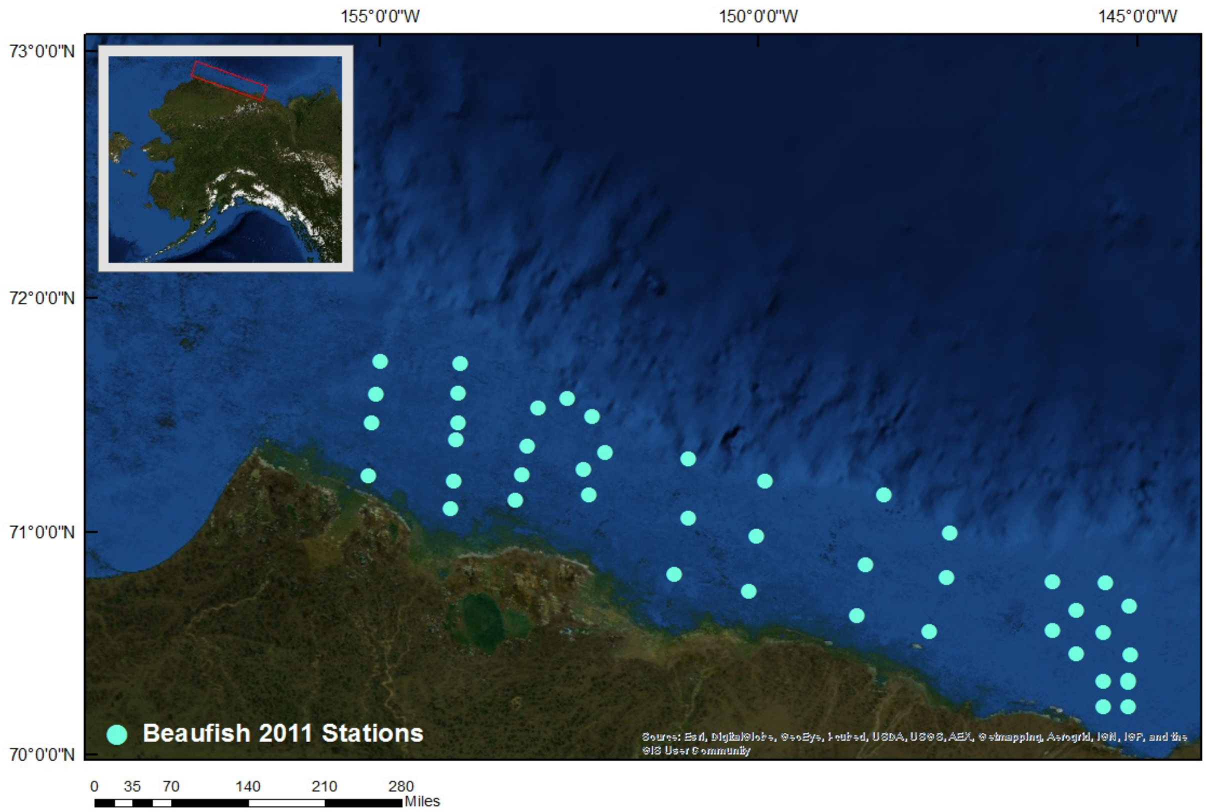
PHYSICAL OCEANOGRAPHY AND CHLOROPHYLL

Physical oceanographic data, including temperature, salinity, fluorescence, and PAR profiles, were collected using a Sea-Bird SBE25 CTD attached to an SBE55 water sampler. Water samples were collected to assess phytoplankton in the study area using chlorophyll-*a* concentration as a proxy. Water samples were collected in Niskin bottles during CTD up-casts. Water samples were filtered under low pressure onto Whatman GF/F filters and immediately frozen for post-cruise analysis. In the laboratory, chlorophyll was extracted using 95% acetone and analyzed fluorometrically.

ZOOPLANKTON

Mesozooplankton were collected in the American Beaufort Sea during August and September 2011 (**Figure A2-1**). Zooplankton were targeted using nets fitted with two different mesh sizes. Small zooplankton were targeted with a vertically hauled 60 cm diameter paired net fitted with 150 µm mesh. Larger, more mobile zooplankton were targeted with a 60 cm diameter net fitted with paired 500 µm mesh hauled obliquely from a vessel moving at approximately two knots. Each type of net was fitted with flowmeters to estimate the volume of water filtered. Collected samples were preserved in 10% buffered formalin and returned to the laboratory for further processing.

In the laboratory samples were split with a Folsom splitter until approximately 100 of the most abundant taxa were contained in a split. Increasingly larger splits were examined for less abundant taxa. Organisms were identified, enumerated, measured, and staged when appropriate to determine community composition, abundance, and biomass. The weight of measured animals was predicted from measurements of length using species-specific relationships. Typically, 400–600 animals were measured in each sample.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure A2-1. Beaufish-2011 Study Region, showing stations.

Results

PHYSICAL OCEANOGRAPHY AND CHLOROPHYLL

Integrated chlorophyll concentrations were highest in the eastern region of the study area (**Figure A2-2**).The average temperature over the study area during the Beaufish-2011 cruise was 1.56°C, with highest temperatures occurring in the western portion of the study area (**Figure A2-3**). The average salinity in the study area during the cruise was 31.75. The highest salinities were generally observed in inshore regions of the study area (**Figure A2-4**).

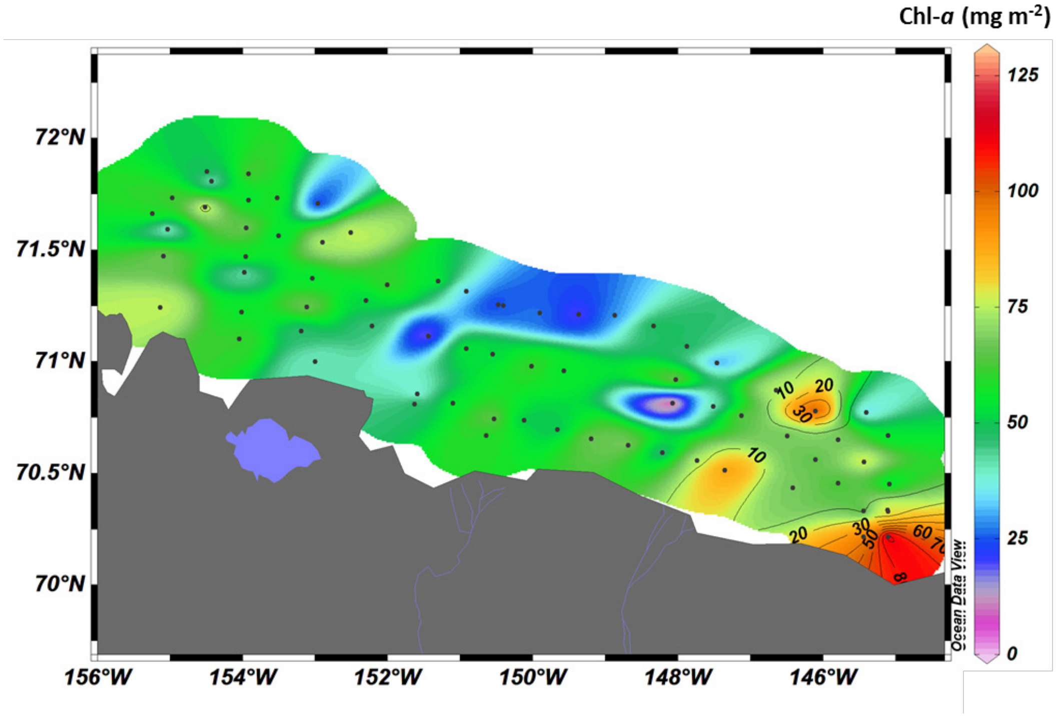


Figure A2-2. Integrated chl-*a* (mg m^{-2}) in the study area during the Beaufish-2011 cruise.

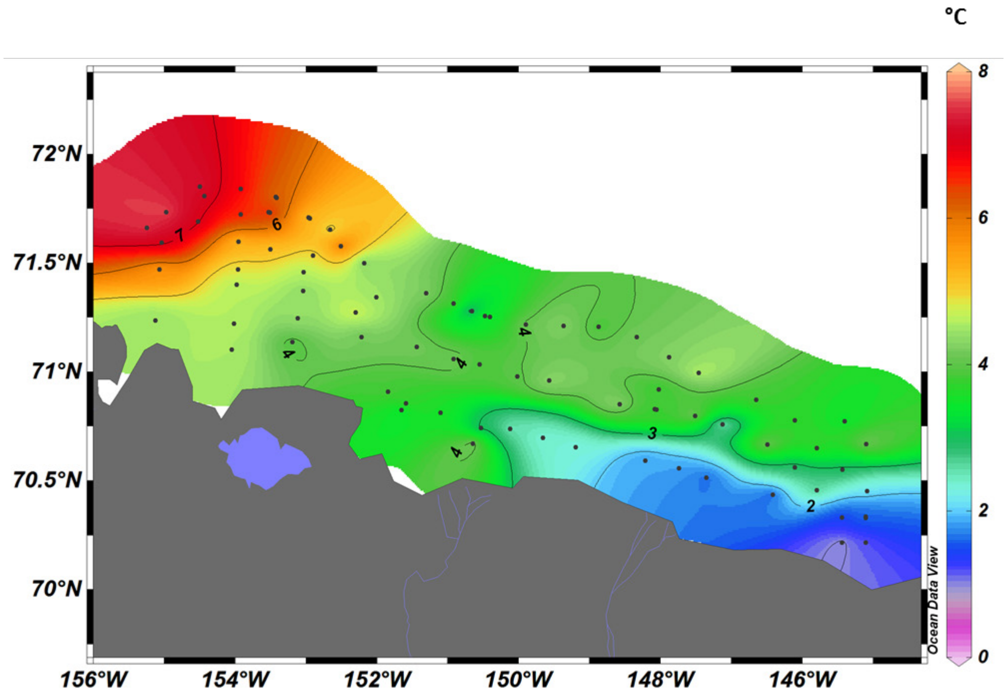


Figure A2- 3. Averaged upper 10 m temperature in study area during Beaufish-2011 cruise.

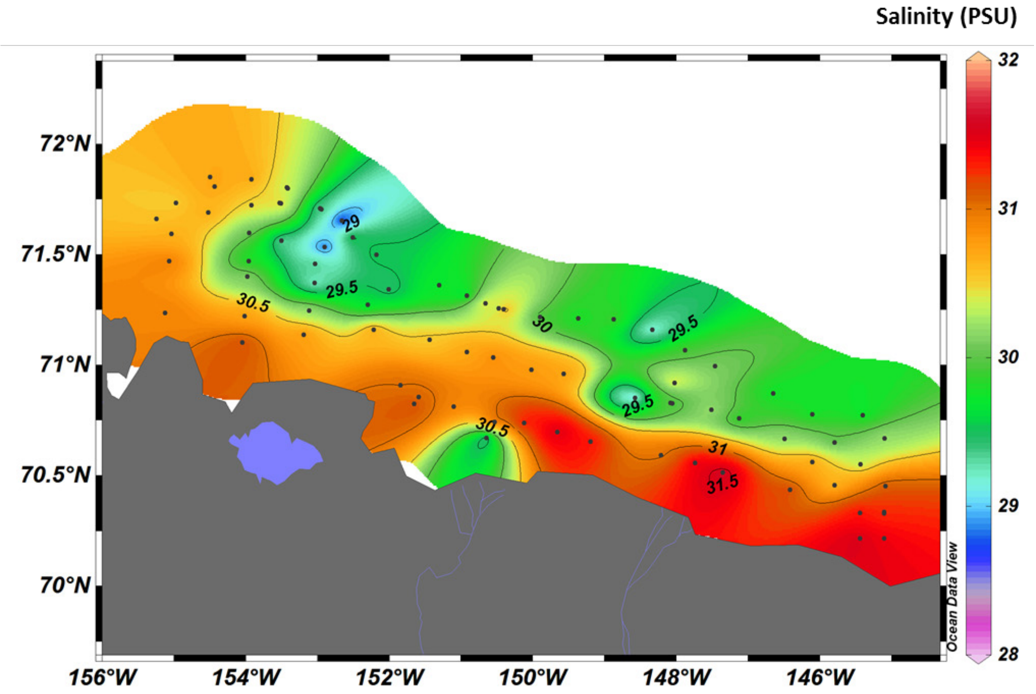


Figure A2-4. Averaged upper 10 m salinity in study area during Beaufish-2011 cruise.

ZOOPLANKTON

An average of 1811 individuals m^{-3} and 19.8 mg DW m^{-3} was found in the 150 µm net and an average of 107 individuals m^{-3} and 17.2 mg DW m^{-3} was found in the 500 µm net in the study area during the sampling period. A total of 79 taxonomic categories were observed (**Table A2-1**). Copepods and cnidarians exhibited the greatest diversity, with 27 and 9 species, respectively. Eleven taxonomic categories of meroplankton were observed in the study area. The 150 µm net was numerically dominated by copepods and larvaceans, although the relative importance of each group varied by site (**Figure A2-5**). The larvacean *Fritillaria borealis*, calanoid copepod nauplii, and the copepods *Pseudocalanus* spp. and *Oithona similis* were major contributors. The biomass in the 150 µm was dominated by *Calanus* spp., the chaetognath *Parasagitta elegans*, and the cnidarian *Aglantha digitale.* The 500 µm net was also numerically dominated by copepods and larvaceans, although cnidarians were also relatively important contributors at some sites (**Figure A2-6**). The copepods *Calanus glacialis* and *Calanus hyperboreus* and the larvacean *Oikopleura vanhoeffeni* were dominant contributors. These taxa were large contributors to biomass in the 500 µm net, with the addition of *Parasagitta elegans.*

Spatial distribution patterns were observed for some species (**Figures A2-7 & A2-8**), likely reflecting the physical oceanographic conditions of the region around the time of sampling.

Table A2-1 Observed zooplankton taxa and respective average abundance and biomass for each mesh size net. Trace refers to a taxa observed once or twice during processing and generally of insignificant biomass.

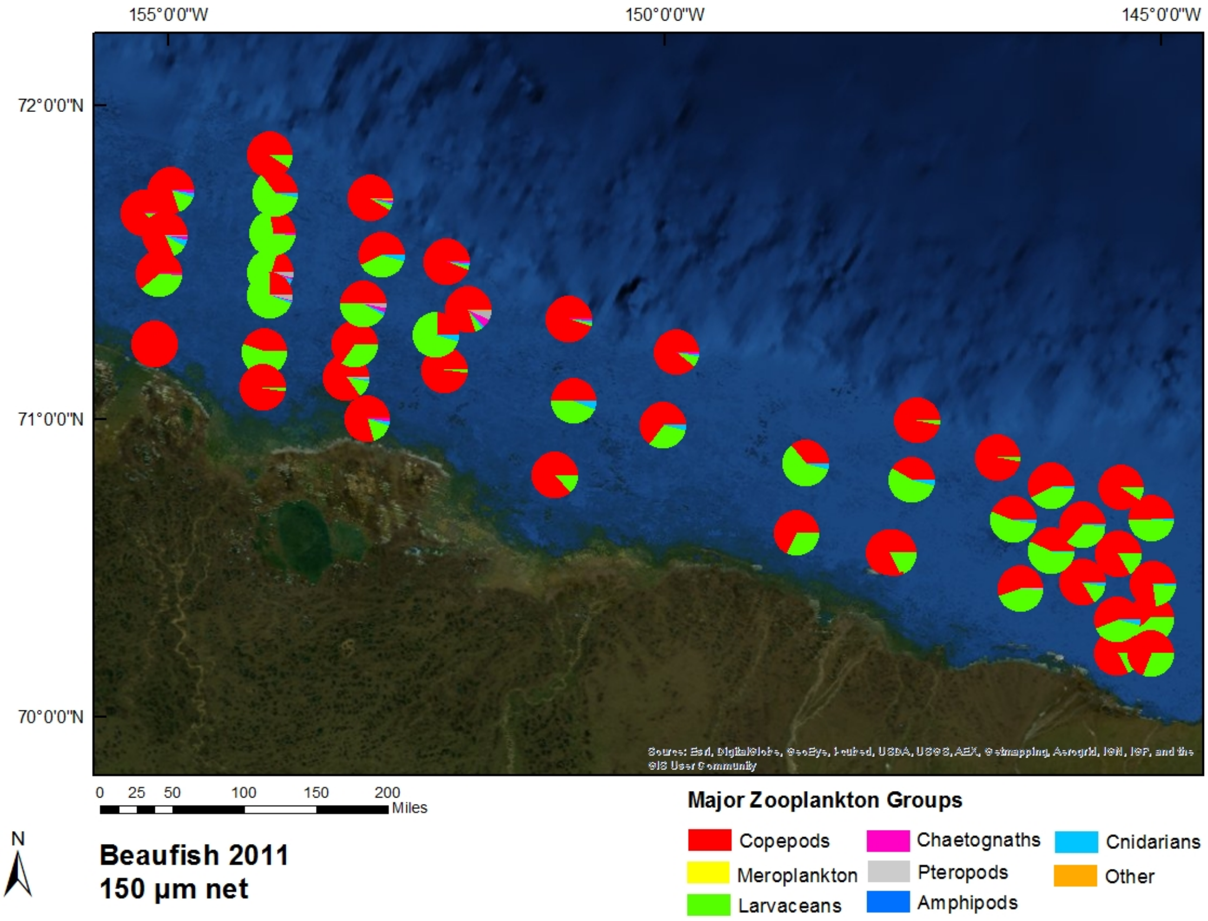
	150 µm net		**500 µm net**	
	Abundance (Ind. m^{-3})	Biomass (mg DW m-3)	Abundance (Ind. m^{-3})	Biomass (mg DW m-3)
Copepods				
Acartia longiremis	11.922	0.024	0	0
Calanus hyperboreus	7.824	8.276	6.48	6.573
Calanus glacialis	92.193	5.407	21.43	3.384
Centropages abdominalis			Trace	Trace
Chiridius obtusifrons	0.006	0.000	0.01	0.001
Epilabidocera amphitrites	0.000	0.000	Trace	Trace
Eucalanus bungii	0.125	0.002	Trace	Trace
Paraeuchaeta glacialis	0.599	0.758	0.35	0.43
Heterorhabdus norvegicus	0.106	0.058	0	0
Limnocalanus macrusus	0.000	0.000	Trace	Trace
Jashnovia tolli	0.000	0.000	0	0
Metridia spp.	2.041	0.010	0	0
Metridia longa	1.296	0.340	0.73	0.204
Metridia pacifica	0.325	0.010	0.17	0.008

Table A.2-1 Continued.

	150 µm net		500 µm net	
	Abundance (Ind. m^{-3})	Biomass (mg DW m-3)	Abundance (Ind. m^{-3})	Biomass (mg DW m-3)
Neocalanus plumchrus	0.009	0.006	0	0
Neocalanus cristatus	0.015	0.038	Trace	0.016
Pseudocalanus spp. (juvenile)	561.730	1.037	0.28	0.005
Pseudocalanus minutus	6.753	0.105	0.7	0.014
Pseudocalanus acuspes	0.338	0.003	0	0
Pseudocalanus newmanii	2.593	0.017	0	0
Pseudocalanus mimus	0	0	Trace	Trace
Pseudocalanus spp. (male)	2.752	0.021	0	0
Scolecithricella minor	0.072	0.001	Trace	Trace
Tortanus discaudatus	0.007	0.000	Trace	Trace
Oithona similis	254.175	0.337		
Oncaea borealis	24.437	0.034		
Microsetella norvegica	0.742	Trace	0	0
Calanoid nauplii	424.749	0.310	0.02	0
Cyclopoid nauplii	0.795	Trace		
Harpacticoida	0.204	0.001		
Harpacticoid nauplii	0.037	Trace		
Larvaceans				
Oikopleura vanhoeffeni	55.562	0.734	11.39	0.714
Fritillaria borealis	524.868	0.006	1.23	Trace
Cladocerans				
Podon leuckartii	0.274	Trace	0	0
Pteropods				
Limacina helicina	15.288	0.061	0.39	Trace
Clione limacina	0.006	0.019	0.01	0.016
Euphausiids				
Euphausiid nauplii	0.002	Trace	0	0
Euphausiid calyptopis	0.468	0.001	0.04	0
Euphausiid furcillia	0.067	0.005	0.073	0.002
Euphausiid juvenile	0.372	0.044	0.431	0.054
Thysanoessa longipes	0	0	0.007	0
Thysanoessa inermis	0	0	0.016	0
Thysanoessa raschii	0.016	0.065	0.001	0.388
Shrimps and Mysids				
Mysis oculata	0.014	0.133	0.016	0.099
Hippolytidae (juvenile)	0.050	0.041	0.1	0.007
Pandalidae (juvenile)	0.011	0.001	0.011	0.001

Table A.2-1 Continued.

	150 µm net		500 µm net	
	Abundance (Ind. m^{-3})	Biomass (mg DW m-3)	Abundance (Ind. m^{-3})	Biomass (mg DW m-3)
Amphipods				
Themisto abyssorum	0.107	0.079	0.114	0.082
Themisto libellula	0.214	0.121	0.014	0.18
Gammaridae	0.162	0.129	0.003	0.002
Apherusa glacialis	0	0	Trace	Trace
Onisimus spp.	0	0	Trace	Trace
Chaetognaths				
Parasagitta elegans	13.799	1.860	0.94	0.6
Cnidarians				
Aglantha digitale	24.412	1.643	1.159	0.721
Aeginopsis laurentii	0.322	0.990	0.202	0.352
Catablema vesicarium	0.002	Trace	0.001	0.003
Halitholus cirratus	0	0	Trace	Trace
Melicertum octopunctata	0.015	0.015	0.007	0.004
Ptychogena lactea	0	0	Trace	Trace
Cyanea capillata	0	0	Trace	Trace
Dimophyes arctica	0	0	Trace	Trace
Obelia longissima	0.201	0.009	0.004	0.001
Miscellaneous Cnidaria	4.491	0.038	0.006	0.005
Ctenophores				
Mertensia ovum	0.086	0.353	0.001	0.003
Ctenophora	0.020	0.197	Trace	Trace
TOTAL Holozooplankton	**2048.2**	**23.4**	**46.4**	**13.9**
Meroplankton				
Gastropoda larvae	4.916	Trace		
Echinoid larvae	60.360	Trace		
Polychaeta larvae	43.336	0.134		
Asteroid bipinnara	7.759	0.005		
Ophiuroid larvae	2.791	Trace		
Decapoda zoea	0.186	Trace	0.229	0.002
Paguriidae zoea	0.051	Trace	0.064	Trace
Barnacle cyprid	12.253	0.340	0.019	Trace
Barnacle nauplii	2.451	Trace	0.042	Trace
Decapoda megalopa	0.008	Trace	0.023	0.003
Bivalvia larvae	66.384	0.017		
TOTAL Meroplankton	**200.5**	**0.5**	**0.4**	**0.005**



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure A2-5. Relative contributions of major zooplankton groups in the 150 µm net during the Beaufish-2011 cruise.

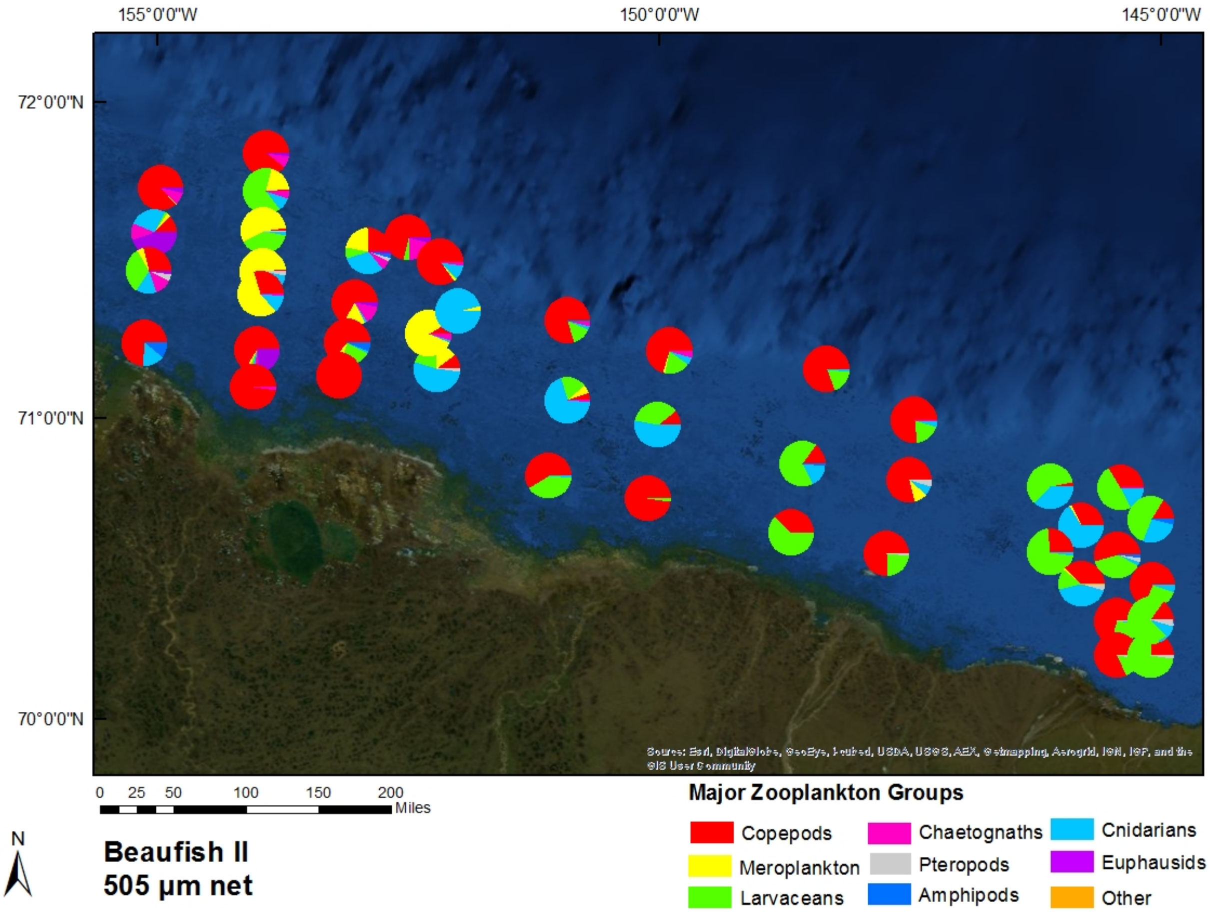


Figure A2-6. Relative contributions of major zooplankton groups in the 505 μm net during the Beaufish-2011 cruise.

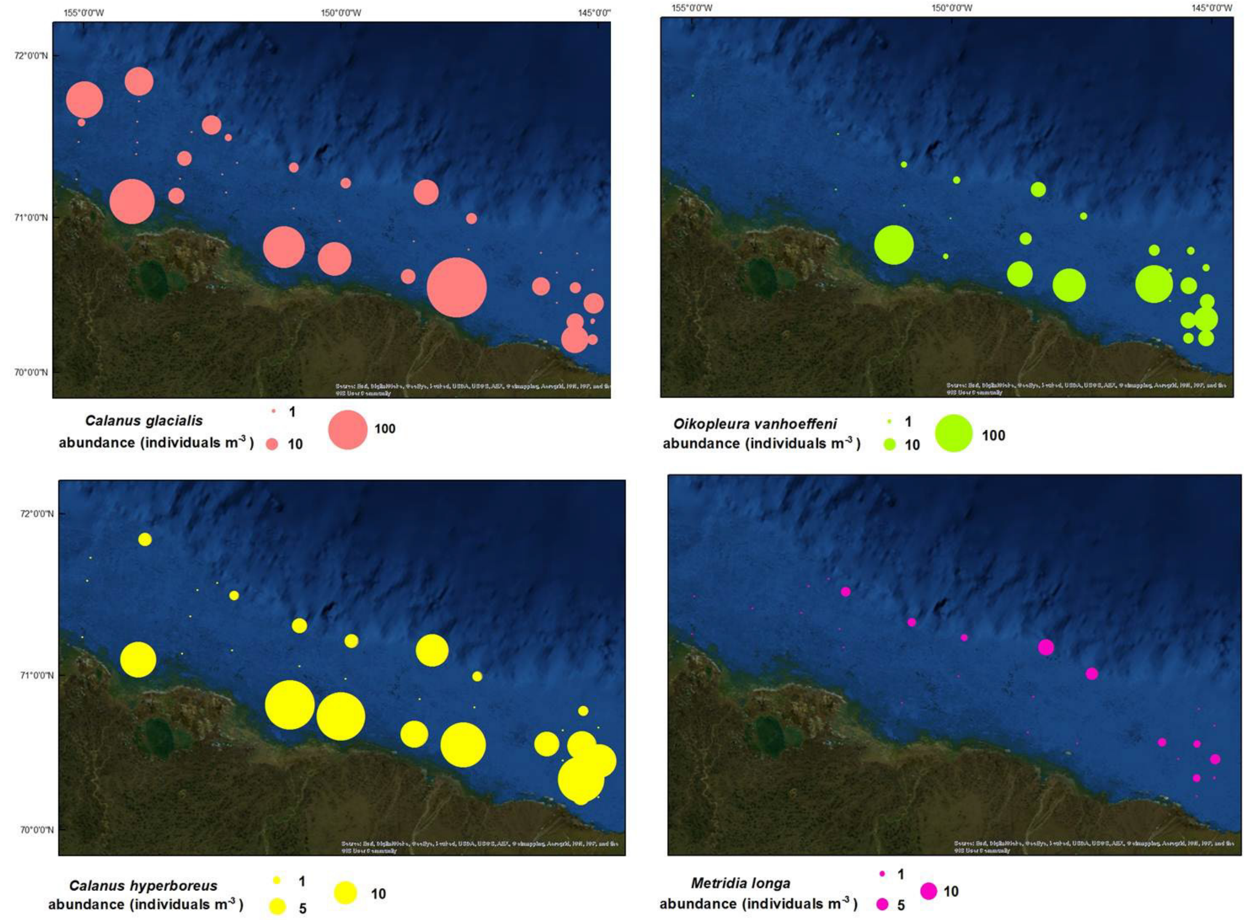


Figure A2-7. Abundance (individuals m^{-3}) of selected zooplankton species found in the 505 µm net during the Beaufish-2011 cruise.

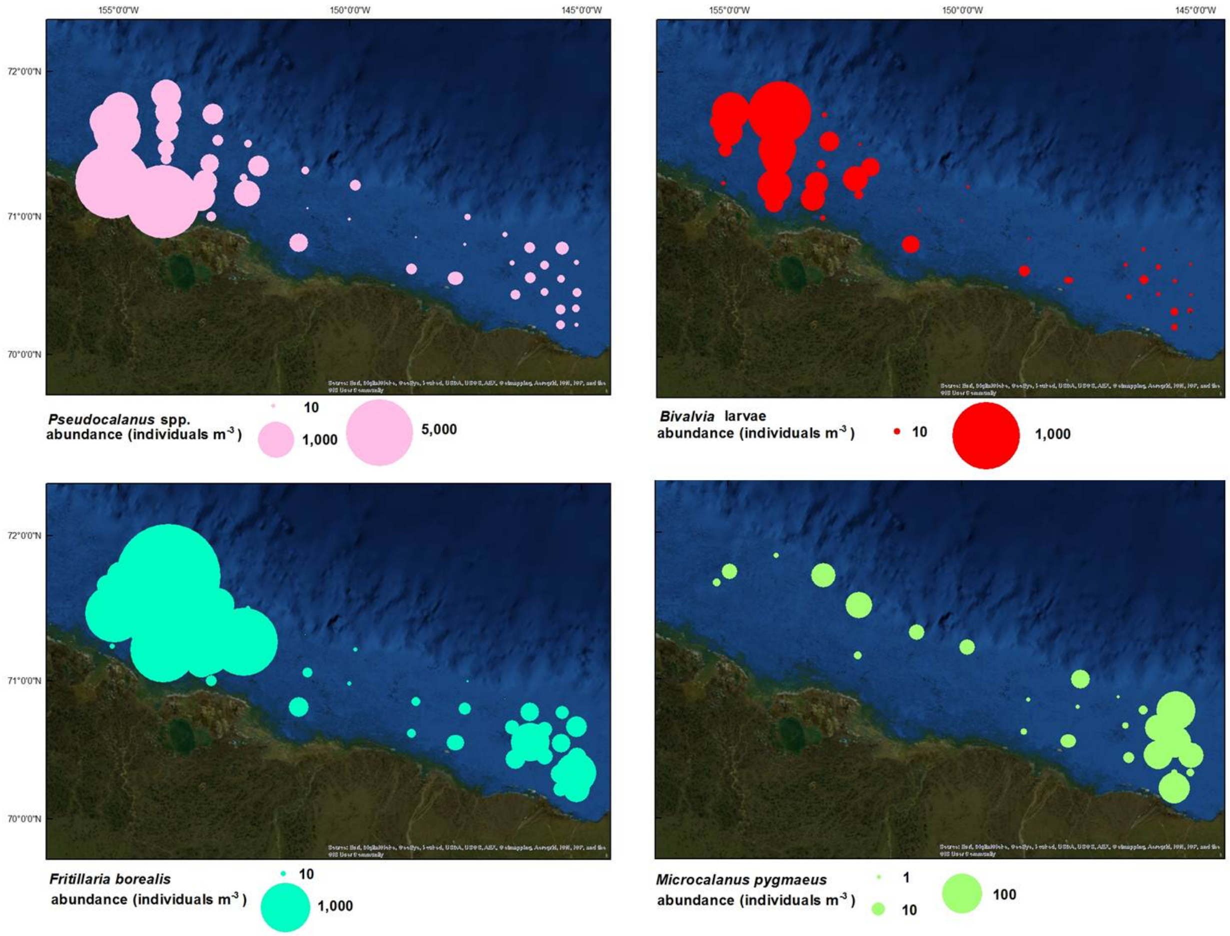


Figure A2-8. Abundance (individuals m^{-3}) of selected zooplankton species found in the 150 µm net during the Beaufish-2011 cruise.

Discussion

Generally, species were characteristic of the Arctic, with a mixture of neritic species, such as *Pseudocalanus* spp. and oceanic species, such as *Calanus hyperboreus*. Although small-bodied genera such as *Oithona, Pseudocalanus* and *Fritillaria* dominated numerically, biomass was dominated by later-stage *Calanus* species, as illustrated by the similarity in catch between the two mesh sizes of nets employed. Meroplankton was a relatively minor component of the community, representing less than 10% of the community abundance and less so in terms of biomass.

These results show similar species composition to both historic (Horner et al. 1981) and more recent (Hopcroft et al. 2012, Lane et al. 2008, Walkusz et al. 2008) research efforts in this general region, exhibiting an assemblage of characteristically Arctic species. These data, combined with past efforts in Camden Bay (2010) and data collected in conjunction with the US-Canada Transboundary Fish and Lower Trophic Communities project will provide broad spatial coverage of the modern zooplankton communities of the Beaufort Shelf.

Conclusions

These results demonstrate the spatial variability in physical oceanographic conditions and zooplankton communities of the Beaufort Shelf, and are an important step towards a modern baseline zooplankton dataset for the Beaufort Sea. This work also provides valuable information about zooplankton resources that are available for higher trophic levels.

Publications and Presentations

2014

Smoot CA, Hopcroft RR. Toward a contemporary baseline for zooplankton communities in the American Beaufort Sea. Alaska Marine Science Symposium, Anchorage, AK, January 2014 (student oral presentation)

Smoot & Hopcroft. Toward a contemporary baseline for zooplankton communities in the American Beaufort Sea. Ocean Sciences Meeting, Honolulu, HI, February 2014 (poster)

2013

Smoot CA, Hopcroft RR. Toward a contemporary baseline for zooplankton communities in the American Beaufort Sea. Alaska Marine Science Symposium, Anchorage, AK, January 2014 (poster)

Data Archive

Data will be archived with the Alaska Ocean Observing System, www.aoos.org

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APPENDIX A3 EPIBENTHIC COMMUNITY VARIABILITY ON THE ALASKAN BEAUFORT SEA CONTINENTAL SHELF

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Funding Sources: BOEM; Prince William Sound Oil Spill Recovery Institute

Significant Findings

The main objective of this study was to characterize the epibenthic communities along the Alaskan Beaufort Sea shelf in terms of abundance, biomass, species composition and diversity; also to link the changes in epibenthic communities with relevant environmental variables. In particular our objectives were to: 1) describe how the epibenthic community varies along the Alaskan Beaufort Sea shelf; 2) identify the environmental parameters that best describe the epibenthic community variability; 3) test for differences between samples collected using the plumb staff beam trawl (PSBT) and the modified version (PSBT-A) at the same site; and 4) test for differences between replicate samples collected using the same gear type (PSBT-A) at the same site within a short time frame.

Epibenthic samples were collected at 71 stations in an area extending from 70.45° N and 145.09° W to 71.66°N and 155.25°W in August 2011 (**Figure A3-1**). Stations ranged in water depth from 10 to 220 m. Prior to the cruise and for logistic purposes, the study area was divided into three regions (Eastern, Central and Western Beaufort). Two gear types were used, a plumb staff beam trawl (PSBT) designed after Gunderson and Ellis (1986) and a modified version of the former (PSBT-A) similar to the one developed by Abookire and Rose (2005). Both gear types were 3.05 m plumb staff beam trawls with a 7 mm mesh and a 4 mm codend liner. A rigid 3 m pipe forward of the net held the mouth open for an effective swath of 2.26 m. The vertical opening of the net was approximately 1.2 m. The modification of the PSBT-A gear consisted of the addition of rubber rollers on the bottom of the net following the design of Abookire and Rose (2005). The area trawled ranged from 63 m to 383 m. A comparison was done at five opportunistically chosen stations (WB13, WB14, WB18, WB21 and CB33) to determine the variability in the performance of the two gear types (from here on called “gear comparison”). Also, opportunistically six stations were resampled (WB07, WB31, WB32, CB33, CB34 and CB35) no more than five days apart using the PSBT-A to determine the variability in samples collected at the same site (from here on called “site variability comparison”). To characterize the physical environment and define the environmental variables that best explained the variability in epibenthic community abundance and biomass, the following environmental variables were collected at each station:

- Sediment chlorophyll *a* and phaeopigment concentration, percent organic matter in surface sediments, surface sediments percent total organic carbon (TOC) and nitrogen (TON) content, and carbon to nitrogen ratio (C/N) as indicators of food supply and quality.
- Bottom water chlorophyll *a* and phaeopigment concentrations were included as indirect indicators of food supply and quality.

- Sediment grain size including percent gravel, percent sand, percent mud (silt and clay) and percent sediment water content were included as habitat descriptors; coarser substrates were grouped in four categories (0: only fine sediments, 1: cobbles, 2: boulders, 3: cobbles and boulders) based on the Wentworth scale (1922). These were included as a proxy for habitat complexity and availability of hard substrate for taxa that require it for attachment.
- Bottom water salinity, temperature and pH were included as hydrographic descriptors.

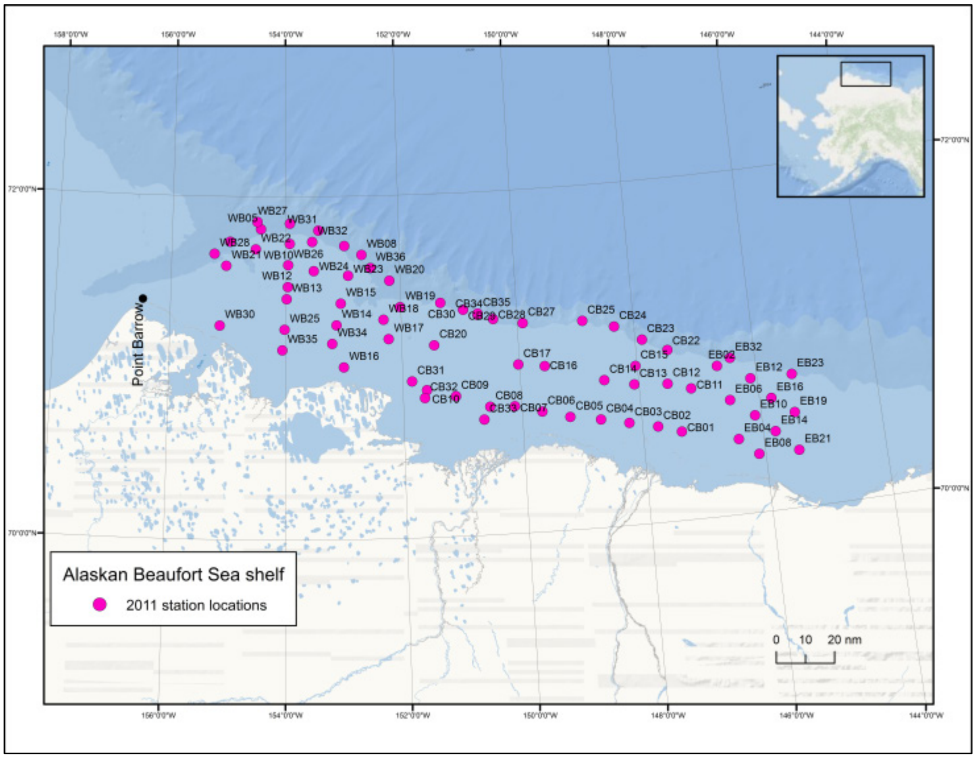

Figure A3-1. Stations sampled for epibenthos. Labels defined *a priori* for cruise logistics.

Across all stations, 154 taxa in nine phyla were identified including 55 molluscans, 30 echinoderms, 24 arthropods, 14 cnidarians, 14 bryozoans, nine chordates, six poriferans, one platyhelminthes, and one brachiopod. The mean total abundance per station was 2,527 ind./100 m² (s.d. 5,337) ranging from a total abundance of 4 ind./100 m² at station WB30 to 27,433 ind./100 m² at station WB04. The mean total biomass amounted to 3,656.54 gr/100 m² (s.d. 7,854) ranging from a total biomass of 5.75 gr/100 m² at station CB07 to 50,103.1 gr/100 m² at station WB04 (**Figure A3-2**).

Nine taxa best represented the abundance of epibenthos across all stations, including (in order of importance) the brittle star *Ophiura sarsii,* the shrimp category other Caridea, the brittle star *Ophiocten sericeum,* Amphipoda, the shrimp *Sabinea septemcarinata*, the brittle star *Ophiacantha bidentata*, the hermit crab *Pagurus* spp., the isopod *Saduria entomon*, and the snail *Boreotrophon* spp. (BVSTEP Primer v6, Spearman correlation coefficient: 0.953 with 0.1% significance level). Using biomass data, 11 taxa best represented the epibenthos in the study area. These taxa included (in order of importance) the brittle star *Ophiura sarsii,* the shrimp *Sabinea septemcarinata*, the hermit crab *Pagurus* spp., the brittle star *Ophiacantha bidentata,* Amphipoda, the snail *Buccinum elatior*, the isopod *Saduria entomon*, the brittle star *Ophiocten sericeum,* the shrimp category other Caridea, the sea star *Ctenodiscus crispatus*, and the sea urchin *Strongylocentrotus pallidus* (BVSTEP Primer v6, Spearman correlation coefficient: 0. 910 with 0.1% significance level; **Figure A3-3**).

The BIOENV analysis (Primer v6 statistical software) resulted in a moderate to low correlation of the environmental variables examined with the relative abundance and biomass of all taxa in the trawls. For abundance, the combination of five variables had the highest correlation coefficient of 0.46 and a significance level of 0.1%. These variables were (in order of importance), bottom water salinity, sediment phaeopigments, bottom water temperature, percent organic matter and sediment C/N; with the option of bottom water pH as an alternative for the last variable at the same correlation value. For biomass, the variables selected were (in order of importance) sediment phaeopigments, sediment C/N, percent sand, bottom water salinity and bottom water temperature at a correlation value of 0.43 and 0.1% significance level.

The PERMANOVA analysis (Primer v6 statistical software) of the five stations trawled for gear comparison, using both gear types (PSBT and PSBT-A) showed no significant difference in gear performance for abundance and biomass data (**Tables A3-1 and A3-2**). This result allowed for the inclusion of all stations in the community analysis, regardless of the gear type used. Epifaunal abundance and biomass at the six revisited stations for site variability comparison were not significantly different (**Tables A3-3 and A3-4**).

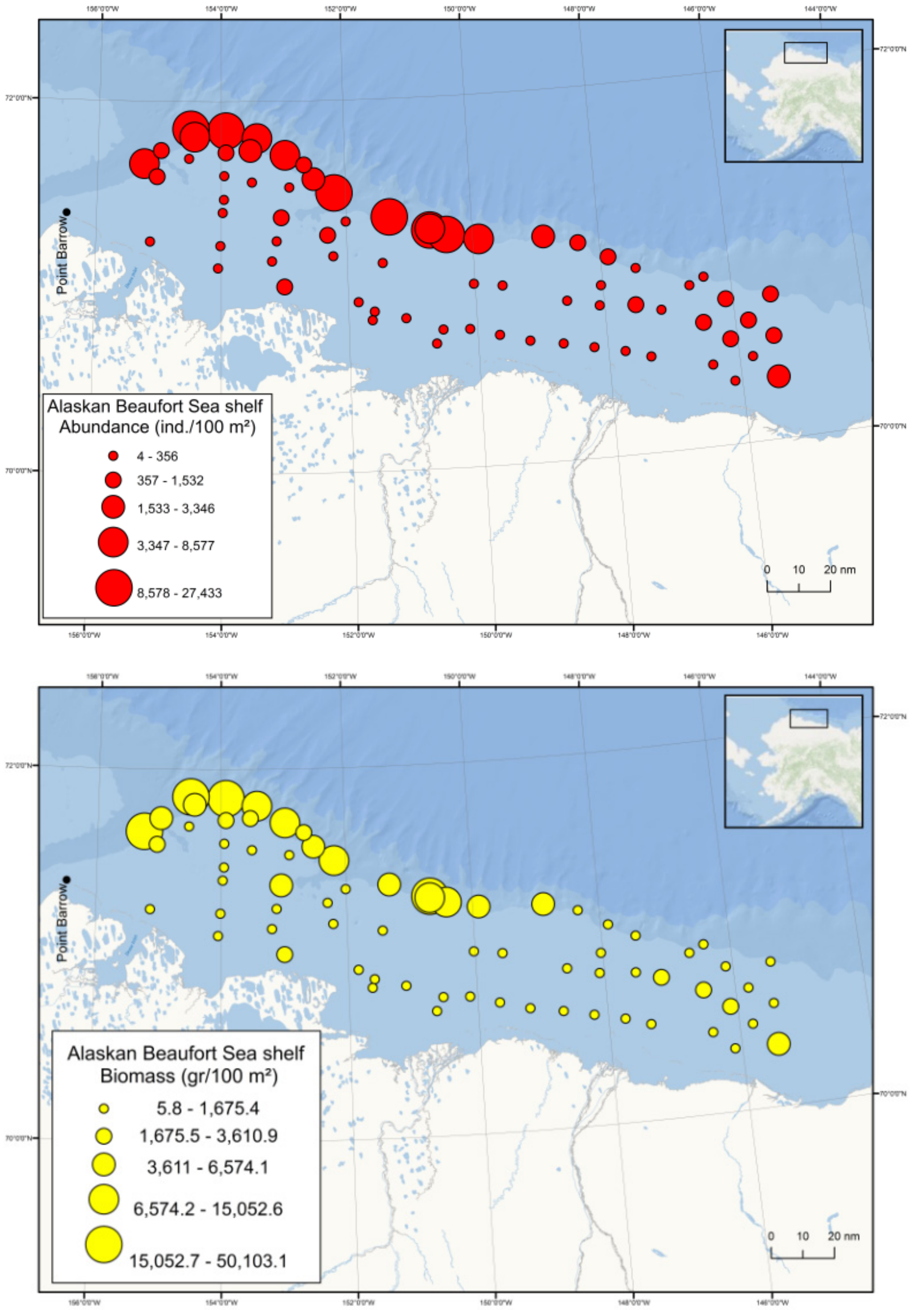

Figure A3-2. Abundance (upper) and biomass (lower) of epibenthos. Stations represented by scaled circles of total abundance (ind./100 m²) or total biomass (gr/100m²).

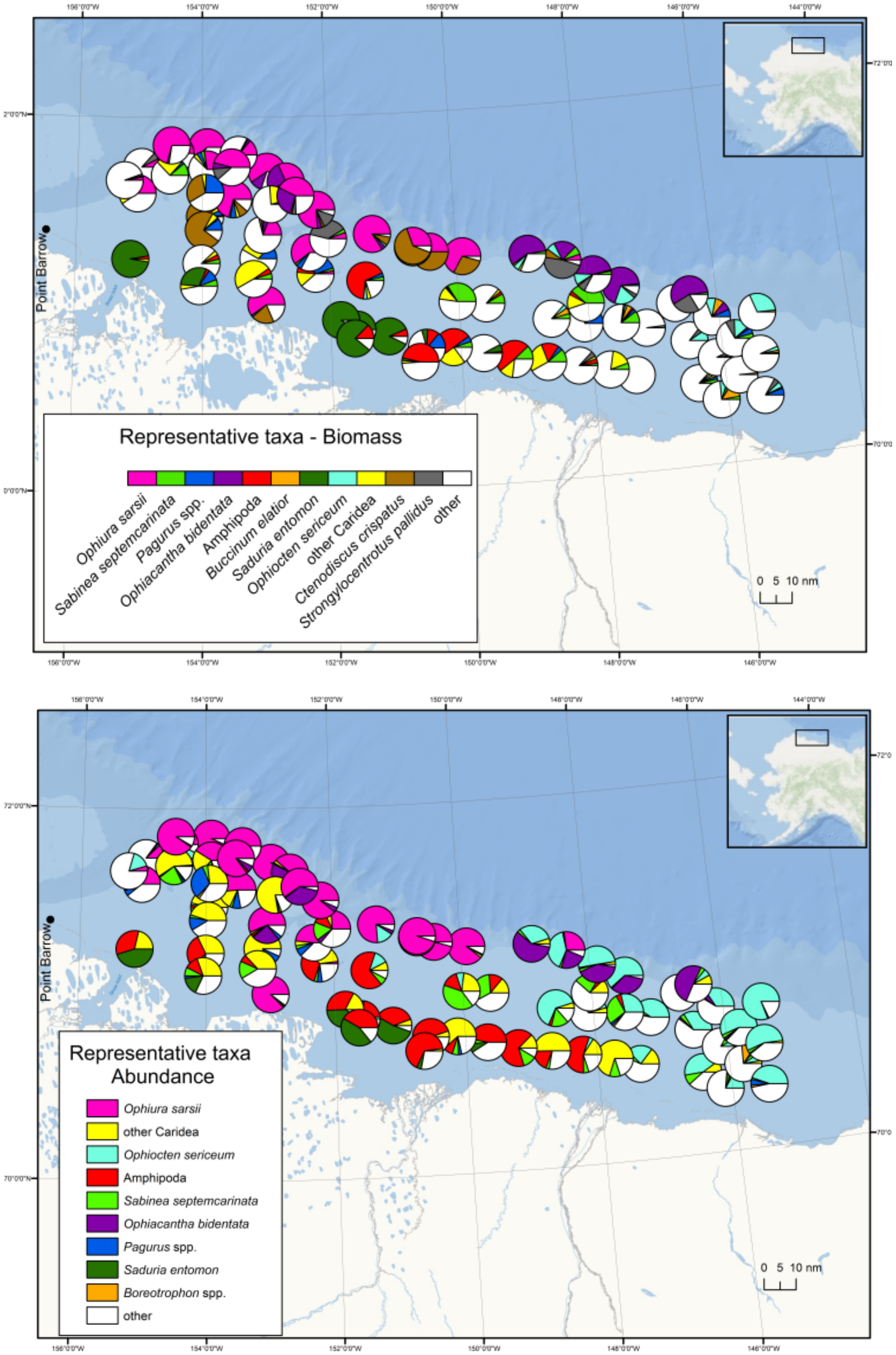

Figure A3-3 Relative abundance (upper) and biomass (lower) of representative taxa. Taxa were selected by BVSTEP procedure.

Table A3-1. PERMANOVA analysis of the epibenthic abundance collected for gear comparisons. The term P(perm) is showing significant evidence to not reject the null hypothesis of no difference between samples collected using the plumb staff beam trawl and the modified version. df: degrees of freedom, SS: sum of squares, MS: mean squares, Pseudo-F, P(perm): permutation p value.

Source	df	SS	MS	Pseudo-F	P(perm)
Gear Comparison	1	394.33	394.33	0.16294	0.9922
Residuals	8	19360	2420.1		

Table A3-2. PERMANOVA analysis of the epibenthic biomass collected for gear comparisons. The term P(perm) is showing significant evidence to not reject the null hypothesis of no difference between samples collected using the plumb staff beam trawl and the modified version. df: degrees of freedom, SS: sum of squares, MS: mean squares, Pseudo-F, P(perm): permutation p value.

Source	df	SS	MS	Pseudo-F	P(perm)
Gear Comparison	1	723.25	723.25	0.24642	0.9908
Residuals	8	23480	2935		

Table A3-3. PERMANOVA analysis of the epibenthic abundance collected at revisited stations for site variability analysis. The term P(perm) is showing significant evidence to not reject the null hypothesis of no difference between samples collected using the same gear types at the same site. df: degrees of freedom, SS: sum of squares, MS: mean squares, Pseudo-F, P(perm): permutation p value.

Source	df	SS	MS	Pseudo-F	P(perm)
Site variability	1	434.02	434.02	0.21073	0.8679
Residuals	10	20596	2059.6		

Table A3-4. PERMANOVA analysis of the epibenthic biomass collected at revisited stations for site variability analysis. The term P(perm) is showing significant evidence to not reject the null hypothesis of no difference between samples collected using the same gear types at the same site. df: degrees of freedom, SS: sum of squares, MS: mean squares, Pseudo-F, P(perm): permutation p value.

Source	df	SS	MS	Pseudo-F	P(perm)
Site variability	1	645.03	645.03	0.23959	0.9856
Residuals	10	26922	2692.2		

Publications and Presentations

Ravelo AM, Konar B (in prep.) Epibenthic community variability on the Alaska Beaufort Sea shelf.

2013

Konar B. Ravelo AM (2013) Epibenthic Community Variability on the Alaskan Beaufort Sea Continental Shelf. Final Report to the UAF Coastal Marine Institute. Report number 2013-01148, 44 pp.

Ravelo A, Konar B (2013) Alaskan Arctic epibenthic communities: A tale of two seas. 6th Annual Western Alaska Interdisciplinary Science Conference, Nome, AK, March 2013 (oral presentation)

Ravelo A, Konar B (2013) Alaskan Arctic epibenthic communities: A tale of two seas. Alaska Marine Science Symposium, Anchorage, AK, January 2013 (poster)

2012

Ravelo A, Konar B (2012) Epibenthic community variability on the Alaskan Beaufort Sea shelf. Alaska Marine Science Symposium, Anchorage, AK, January 2012 (oral presentation)

2011

Ravelo A, Konar B (2011) Epibenthic community variability on the Alaskan Beaufort Sea shelf, preliminary results. UAF Coastal Marine Institute Annual Research Review, Fairbanks, AK (oral presentation)

Data Archive

A copy of all data files will be delivered to BOEM and a copy will be archived with the National Oceanographic Data Center (NODC).

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APPENDIX A4 SNOW CRAB POPULATION ASSESSMENT AND BEAUFORT SEA BENTHIC FOOD WEB

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Institute of Marine Science
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Sources of Funding:
BOEM: ship time, PI Norcross
Coastal Marine Institute: snow crab project (M11AC00003), PI Bluhm, Co-PI Iken
North Pacific Research Board: food web project (12-27), PI Iken, Co-PI Bluhm

Student using material collected: Lauren Divine, UAF-MESAS PhD student

Background and Objectives

Benthic invertebrate communities contribute substantially to secondary production, carbon cycling and remineralization of nutrients on Pacific Arctic shelves (Grebmeier 2012). These communities are potentially affected by current and planned oil and gas exploration in large areas of the Beaufort Sea that are leased for exploration and drilling activities. Sensitivity of marine organisms to oil and gas-related chemicals is related to their trophic level, with high bioaccumulation and biomagnification potential of persistent petroleum pollutants for higher trophic level organisms (Borgå et al. 2004). Knowledge of trophic structure of dominant shelf fauna is therefore important, but was poorly studied in the US Beaufort Sea until now. We, therefore, took the opportunity to collect tissue samples for food web studies during Beaufish-2011.

One of the omnivorous predatory invertebrate in the Beaufort Sea is the snow crab, *Chionoecetes opilio,* which contributes a large fraction to epibenthic biomass in the western Beaufort Sea (Rand and Logerwell 2011). Its abundance and distribution in the remaining US Beaufort Sea remained undocumented and stock structure in the entire Beaufort Sea was unknown until now. The recent northward contraction of the species in the Bering Sea (Orensanz et al. 2004), the assumed biomass increase in the Chukchi Sea (Bluhm et al. 2009), and the increased interest in the Chukchi and Beaufort Seas for oil and gas-related exploration activities motivated further study of the species. Recently, a number of research cruises to the Chukchi and Beaufort Seas afforded the possibility to collect new snow crab population data and Beaufish was one of those.

The primary objectives of the Beaufish 2011 cruise for Bluhm and Iken (and later PhD student Divine) were:

1. to determine stock structure, female fecundity and diet of snow crab, *Chionoecetes opilio* and
2. to determine food web structure of benthic invertebrates using stable isotope analysis.

Objective 1 is part of an ongoing CMI-funded project (M11AC00003) entitled “Population assessment of snow crab, *Chionoecetes opilio*, in the Chukchi and Beaufort Seas including oil and gas lease areas” (2011–2014). Objective 2 was an *ad hoc* opportunistic sampling at the time of the cruise which subsequently provided leverage for one objective of a NPRB project (12-27) entitled "Benthic lower trophic level food webs in the Chukchi and Beaufort Seas – baselines and relevance of sea ice algal production" (2012–2015). The following paragraphs outline abbreviated methods and select results so far for each of the two main objectives of our activities during the Beaufish-2011 cruise. More detail can be found in reports provided to CMI and NPRB.

Brief Material and Methods

Between 16 August and 3 September 2011, a total of 79 stations were sampled onboard the Norseman II in the Alaskan Beaufort Sea between 70.22–71.85°N and 145.09–155.85°W. All sampling was conducted between 14 and 220 m. For both above outlined objectives, epibenthic invertebrates were collected from trawl catches, washed on deck and sorted to the lowest practical taxonomic level. Details about trawl collections are in the fish team report.

Snow crab sampling and processing. All crabs collected were sexed, sizes measured (carapace width, chela height for males), wet weights taken and shell conditions determined. Stomachs were dissected and preserved in formalin for later stomach content analysis. Muscle tissue was dissected for later stable C and N isotope analysis (see food web sampling). Ovary color and fullness were noted, egg flaps were frozen for later analysis and spermathecae were dissected and preserved for later analysis. For fecundity estimates, the dry weight of an egg sub-sample was determined, eggs were dried and remaining eggs removed from the pleopods and dried also. Analysis of spermathecal load is ongoing with fullness of spermathecae estimated on a categorical scale and spermathecal load to be recorded to the nearest mg. Data from the 64 crabs were later combined with crabs collected during the BOEM-funded 2008 Ocean Explorer expedition and will eventually be integrated with those collected during the Transboundary expeditions (2012–2014).

Food web sampling. Niskin bottles on a CTC rosette were sampled for the stable carbon ($\delta^{13}C$) and nitrogen isotope signatures ($\delta^{15}N$) of water column particular organic matter (POM) as the basis of estimating trophic levels of the fauna. Samples from van Veen grabs were taken for sediment POM $\delta^{15}N$ and $\delta^{13}C$ signatures. Over 1000 tissue samples of over 150 invertebrate taxa were collected for $\delta^{13}C$ and $\delta^{15}N$ analysis. Voucher specimens from each taxon sampled were preserved in 4% buffered formalin for later detailed identification or verification. Upon return to the lab, inorganic carbonates were removed from all samples and lipids were removed from tissue samples. Samples were measured at the Alaska Stable Isotope Facility at the University of Alaska Fairbanks on a Thermo Finnigan Delta Isotope Ratio Mass-Spectrometer with V-PDB and atmospheric N_2 as standards for carbon and nitrogen, respectively.

Selected Results

Snow crabs. Snow crabs occurred at 19 of the Beaufish-2011 stations at water depths between 40 and 220 m, with mature female crabs found at only three stations. Of the 64 collected *Chionoecetes opilio*, 50 were males, nine were immature females, and five were mature females. The size range of all crabs was between 32.6 and 129.6 mm carapace width (CW) with most crabs measuring between 40 and 70 mm CW. The size range of immature females was very similar to that of mature females, suggesting that maturity may occur over a wide range of body sizes. All but two females had deep orange ovaries suggesting they would have produced a clutch in the next season. To our knowledge, this study documented the first occurrence of large (or any) snow crab in the Central Alaskan Beaufort Sea as far east as 148°W. During the 2008 Western Beaufort Sea Fish Survey, large snow crabs were first documented ever for the Western Beaufort Sea to ~152°W (Rand and Logerwell 2011).

The combined 2008 and 2011 data reveal insights into the spatial segregation of sexes of *C. opilio* in the Beaufort Sea. Large males (>80 mm CW) only occurred at deeper than ~180 m (**Figure A4-1**). Mature females were only found deeper than 160 m (with one exception). Immature females and smaller crabs (to about 50 mm CW) were primarily found shallower than 200 m. The combined size-frequency-distribution of the 2008 and 2011 crab shows that a large range of crab sizes occurs in the Beaufort Sea with about a third of the crabs larger than reported previously from the Chukchi Sea (Paul et al. 1997). The full results from the Chukchi and Beaufort Sea will form the basis for a manuscript led by the PIs.

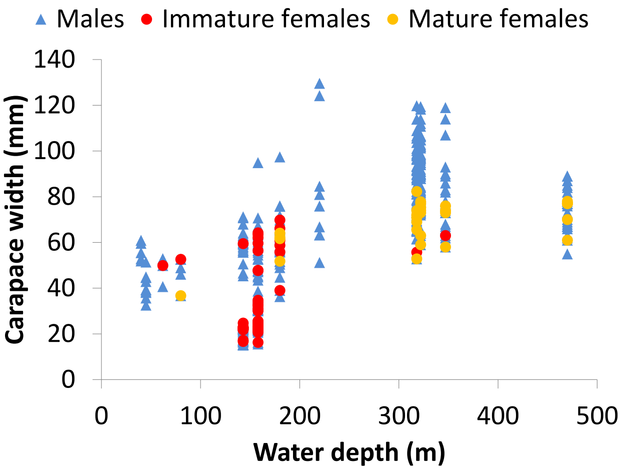

Figure A.4-1 Distribution of *C. opilio* collected in the Beaufort Sea in 2008 and 2011 (Beaufish) by water depth.

Stomach content analysis for 2011 and 2013 has recently been completed. A wide variety of prey items were present in the stomachs including polychaetes, bivalves, crustaceans, echinoderms and other taxa in addition to detritus and unidentifiable tissue parts. Crab stomach fullness ranged from completely empty to completely full. The crab stomach content and crab stable isotope data (not reported) will form a chapter of PhD student Lauren Divine's thesis.

Food web. Mean $\delta^{13}C$ and $\delta^{15}N$ of five feeding guilds differed across regions. Feeding guilds in the central and east shallow regions were depleted in $\delta^{13}C$ and $\delta^{15}N$ relative to corresponding guilds within the west shallow and deep and central deep regions (**Figure A4-2**). In each region, suspension feeders, surface deposit feeders and subsurface deposit feeders had lower $\delta^{15}N$ ratios than predator/scavengers and predators. Suspension feeders in all regions were most depleted in $\delta^{13}C$ compared to all other feeding guilds, while all other feeding guilds were relatively similar in $\delta^{13}C$. The central shallow area overall had the shortest food-web length (calculated as difference between trophic level (TL) of top consumer relative to mean POM) with a top TL of 4.1. The sea star *Urasterias lincki* was the top

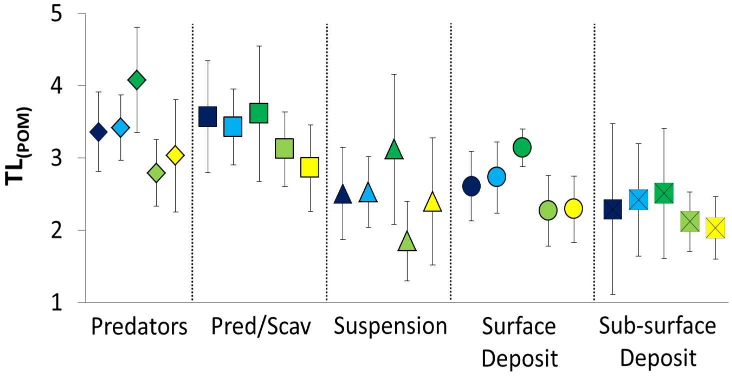

Figure A.4-2 Mean trophic level occupied by each feeding guild across regions. All values are standardized to regional POM as the baseline food source. Dark blue: West deep, light blue: west shallow, dark green: central deep, light green: central shallow, yellow: east. (data: L. Divine, PhD student) consumer. The central deep area had the longest food-web and the only region with five TL. The amphipod *Stegocephalus sp.* at TL 5.2 and the sea star *Crossaster papposus* at TL 5.1 were the top consumers of the fauna measured. Trophic structure also varied among regions. East and central shallow regions had most consumers in the first and second TL with few in TL4 (**Figure A4-3**). In the western regions similar proportions of taxa contributed to all four TL. The central deep region had the lowest proportion of second level consumers and many consumers occupying the fourth TL. This was the only region with a fifth TL. A manuscript describing the full results is currently in progress and forms the first chapter of PhD student Divine's thesis project.

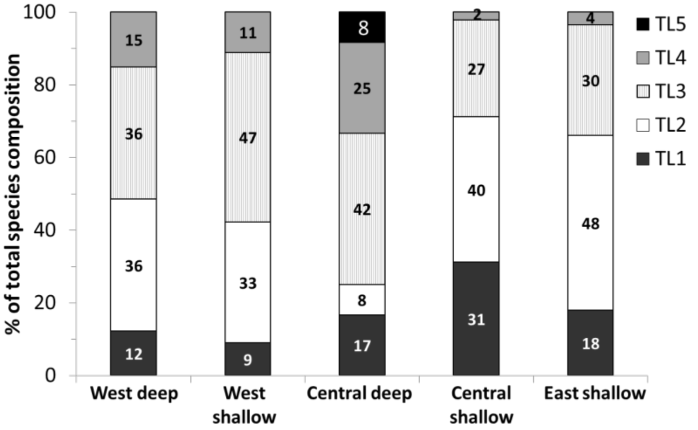

Figure A.4-3 Trophic structure across regions with particulate organic matter as the baseline. Values within each bar indicate the percent of total species within each region occupying each trophic level (TL). (data: L. Divine, PhD student)

Conference and Seminar presentations

2014

Divine L, Aydin K, Bluhm B, Foy R, Gray B, Iken K, Lauth R, Norcross B, Whitehouse A. Snow crab ecology in the Chukchi Sea. Arctic Eis project PI meeting, Juneau, AK, 16–19 June 2014 (oral)

Divine LM, Bluhm BA, Iken K. Arctic snow crab diets: comparison of δ ^{13}C and δ ^{15}N stable isotope and stomach content analyses. Alaska Marine Science Symposium, Anchorage, AK, January 2014 (poster)

Divine L, Bluhm B, Iken K. *Chionoecetes opilio* population assessment in the Chukchi and Beaufort Seas: Trophic ecology. Coastal Marine Institute Annual Review, Fairbanks, AK, January 2014 (oral)

2013

Divine L, Iken K, Bluhm B. Arctic snow crab (*Chionoecetes opilio*) diets: a comparison of stomach content and stable δ ^{13}C and δ ^{15}N isotope analysis. American Fisheries Society Meeting, Alaska Chapter, Fairbanks, AK, 7–11 October 2013 (oral)

Bluhm BA, Iken K. Population assessment of snow crab, *Chionocetes opilio*, in the Chukchi and Beaufort Seas: preliminary findings. 28th Lowell Wakefield Symposium, Anchorage, AK, 26–29 March 2013 (oral)

Bluhm BA, Iken K. Population assessment of snow crab, *Chionoecetes opilio*, in the Chukchi Sea: preliminary findings. Alaska Marine Science Symposium, Anchorage, AK, 21–24 January 2013 (poster)

Divine L, Iken K, Bluhm B. Can you stomach it? Regional diet and stable isotope analysis of snow crab (*Chionoecetes opilio*) in the Alaskan Arctic. Lowell Wakefield Symposium. Anchorage AK, March 2013 (poster – won student poster award)

Divine LM, Iken K, Bluhm BA. Regional benthic food-web structure on the Alaskan Beaufort Sea shelf. Alaska Marine Science Symposium, Anchorage, AK, January 2013 (poster)

2012

Divine L, Iken K, Bluhm B. Snow crabs (*C. opilio*) in the Alaskan Arctic: contributing to stock assessment data for the AFMP. Interagency Crab Meeting. Kodiak, AK, December 2012 (oral)

Bluhm BA, Iken K. *Chionoecetes opilio* population structure in the Pacific Arctic: preliminary results. CMI Annual Review, November 2012 (oral)

Bluhm BA, Iken K. Population assessment of snow crab, *Chionoecetes opilio*, in the Chukchi and Beaufort Seas: preliminary findings. Institute of Marine Science Seminar Series, Fairbanks, AK, 7 November 2012 (oral)

Divine L, Iken K, Bluhm B. Population structure and trophic positioning of snow crabs (*Chionoecetes opilio*) in the Alaskan Arctic. Alaska Chapter of the American Fisheries Society. Kodiak, AK, October 2012 (oral)

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Bluhm BA, Iken K. Population assessment of snow crab, *Chionoecetes opilio*, in the Beaufort Sea: preliminary findings. Alaska Marine Science Symposium, Anchorage, January 2012 (poster)

Divine L, Iken K, Bluhm B. Fitting snow crabs (*Chionoecetes opilio*) into the benthic food web of the central Alaskan Beaufort Sea. Alaska Marine Science Symposium. Anchorage, AK, January 2012 (poster)

Data Archive

Snow crab data will be archived with BOEM and in a University of Alaska Coastal Marine Institute (CMI) report, because the Beaufish-2011 activities are part of an ongoing CMI project. The food web data will be archived with the North Pacific Research Board.

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APPENDIX A5 SEABIRD AND MARINE MAMMAL OBSERVATIONS AND PRELIMINARY RESULTS

Author: Kathy Kuletz
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Sources of Funding: Seabird surveys were conducted as part of the 'Seabird Distribution and Abundance in the Offshore Environment' project funded by BOEMRE (Agreement Number M10PG00050) with in-kind support from the U.S. Fish and Wildlife Service (USFWS).

Methods

Seabird surveys were conducted by USFWS observer David Pavlik while the vessel was transiting between fish sampling stations during daylight hours when conditions were in accordance with the USFWS protocol. The observer, stationed on the port side of the bridge, used strip transect methodology and counted all birds and marine mammals within a 300-m, 90° arc from the bow to the beam of the ship. The observer used10x binoculars for species identification when necessary and identified animals to species unless otherwise noted. Birds on the water or on ice were counted continuously and flying birds were counted during quick 'snapshots' (scans), the frequency of which varied with vessel speed (typically ~1^{-1}min). Data were entered directly into a laptop computer with a GPS interface using Dlog3 software (R.G. Ford Consulting, Portland, OR). Location and selected environmental conditions (weather, seas, ice and glare) were automatically written to the program at 20 sec intervals. We recorded behavior (on water, flying, foraging, on ice) and distance to the animal in 100-m bins. Unusual species or large groups of birds or mammals beyond 300 m were recorded as 'off transect' for distributional information. A transect was initiated when the ship began a new transit between fish stations or if environmental conditions changed drastically. For each transect, we recorded wind speed, wind direction, ship speed, surface water and air temperature as obtained from the ship's console on the bridge. The weather was sufficient for conducting surveys on most days, although fog hampered visibility on a few days. When fog limited visibility, transect width was reduced to 200 m or 100 m, with surveys terminated when visibility was < 100 m.

Results

We surveyed 1,117 km of transects, with the majority of that effort (970 km) on the shelf in waters < 100 m deep (**Figure A5-1**). Ice was not encountered during the seabird surveys. We recorded 2,207 marine birds on transect and an additional 15,210 birds off transect (**Table A5-1**). Short-tailed shearwaters comprised the majority (72% of total) of both on and off transect birds, and they were concentrated on the western end of study area (**Figure A5-1**). A large flock of at least 15,000 short-tailed shearwaters was observed off transect in the western Beaufort and thus not included in density estimates, but was indicative of the importance of the region for these highly migratory species and of their dominance in these pelagic waters in the fall.

The number of marine bird species was highest in the central Beaufort and densities were highest in the western Beaufort, whereas relatively few birds were observed in the eastern Beaufort Sea. Black-legged kittiwakes (4% of total) were widespread and were the most abundant birds in the eastern Beaufort (**Figure A5-2**). In the shallower regions (~8–35 km from shore) the main species included red and red-necked phalaropes (**Figure A5-3**), eiders (primarily king eiders), and long-tailed ducks (**Figure A5-4**). Arctic terns were the main birds observed over deeper waters farther from shore (40–80 km offshore; **Figure A5-5**). Three species of non-marine birds, pine sisken, common redpoll, and pectoral sandpiper landed on the ship and were photographed to confirm species identification.

Notably, there were multiple sightings of Kittlitz's murrelets within 8–30 km from shore in the western and central Beaufort. These included four single birds in alternate plumage, two separate pairs in basic plumage, and one group of four birds all in alternate plumage. These sightings are of interest because little is known about the post-breeding distribution or timing of molt for these rare birds (currently a Candidate Species for listing under the Endangered Species Act). Given the rarity of pelagic sightings for Kittlitz's murrelets, these records suggest that the region is a post-breeding foraging and possible molting area for the species.

We recorded a total of 56 marine mammals, including off transect sightings of four unidentified whales and three pinnipeds (**Table A5-2**). On transect mammals included spotted seals (45%) and bearded seals (16%), with the remaining being unidentified seal species.

Products and Data Archive

The data will be used to examine seabird distribution relative to oceanographic and biological features of the northern Bering, Chukchi, and Beaufort seas. Survey data will be submitted to BOEMRE and will be archived in the North Pacific Pelagic Seabird Database (NPPSD; *http://alaska.usgs.gov/science/biology/nppsd/index.php*). Additionally, these data have been integrated into analyses for a publication titled "Seasonal spatial patterns in marine bird & mammal densities, distribution, and community structure in the Pacific Arctic: A comparison of biologically important pelagic areas." This article is part of the Synthesis of Arctic Research (SOAR) and will be submitted to the SOAR Special Issue in the journal *Progress in Oceanography.* Early versions were presented at the 2013 Alaska Marine Science Symposium (Anchorage, Alaska) and the 2013 Pacific Seabird Group (Portland, OR).

Table A5-1.Summary of marine birds observed during Beaufish-2011, August 16 – September 4.

			On Transect		Off Transect	
Family	**Common Name**	**Scientific Name**	Count	Percent of Total	Count	Total Count
Loons	Yellow-billed Loon	*Gavia adamsii*	2	0.09		2
	Pacific Loon	*Gavia pacifica*	18	0.82	11	29
	Unid. Loon	*Gavia* spp.	3	0.14		3
Fulmars	Northern Fulmar	*Fulmarus glacialis*	30	1.36	8	38
Shearwaters	Short-tailed Shearwater	*Puffinus tenuirostris*	1,594	72.22	15,006	16,600
	Unid. Shearwater	*Puffinus* spp.		0.00	6	6
Seaducks	Brant	*Branta bernicla*	7	0.32		7
	Common Eider	*Somateria mollissima*		0.00	2	2
	King Eider	*Somateria spectabilis*	42	1.90		42
	Long-tailed Duck	*Clangula hyemalis*	124	5.62	11	135
	White-winged Scoter	*Melanitta fusca*	1	0.05		1
	Unid. Eider	*Somateria* spp	65	2.95	46	111
	Unid. Duck	*Anatinae* spp.		0.00	55	55
Alcids	Kittlitz's Murrelet	*Brachyramphus brevirostris*	6	0.27	6	12
	Common Murre	*Uria aalge*	3	0.14		3
	Thick-billed Murre	*Uria lomvia*	2	0.09		2
	Unid. Murre	*Uria* spp.	2	0.09		2
	Horned Puffin	*Fratercula corniculata*	1	0.05		1
	Tufted Puffin	*Fratercula cirrhata*	1	0.05		1
	Unid. Small Dark Alcid	*Aethia* spp.		0.00	1	1
Larids	Arctic Tern	*Sterna paradisaea*	67	3.04	3	70
	Black-legged Kittiwake	*Rissa tridactyla*	84	3.81	6	90
	Glaucous Gull	*Larus hyperboreus*	8	0.36		8
	Sabine's Gull	*Xema sabini*		0.00	4	4
Jaegers	Long-tailed Jaeger	*Stercorarius longicaudus*	1	0.05		1
	Parasitic Jaeger	*Stercorarius parasiticus*	2	0.09	3	5
	Pomarine Jaeger	*Stercorarius pomarinus*	6	0.27	2	8
Shorebirds	Pectoral Sandpiper	*Calidris melanotos*	1	0.05		1
	Red Phalarope	*Phalaropus fulicarius*	44	1.99		44
	Red-necked Phalarope	*Phalaropus lobatus*	36	1.63		36
	Unid. Phalarope	*Phalaropus* spp.	44	1.99	40	84
	Unid. Shorebird	*Family Scolopadidae*	13	0.59		13
Total			**2,207**		**15,210**	**17,417**

Table A5-2. Summary of marine mammal observations during Beaufish-2011, August 16 – September 4.

		On Transect		Off Transect	
Common Name	**Scientific Name**	Count	Percent of Total	Count	Total Count
Bearded Seal	*Erignathus barbatus*	8	16.33		8
Spotted Seal	*Phoca largha*	22	44.90		22
Unid. Seal	*Family Otariidae or Pinnipedia*	19	38.78	2	21
Unid. Pinniped	*Suborder Pinnipedia*			1	1
Unid. Whale	*Order Cetacea*			4	4
Total		**49**		**3**	**52**

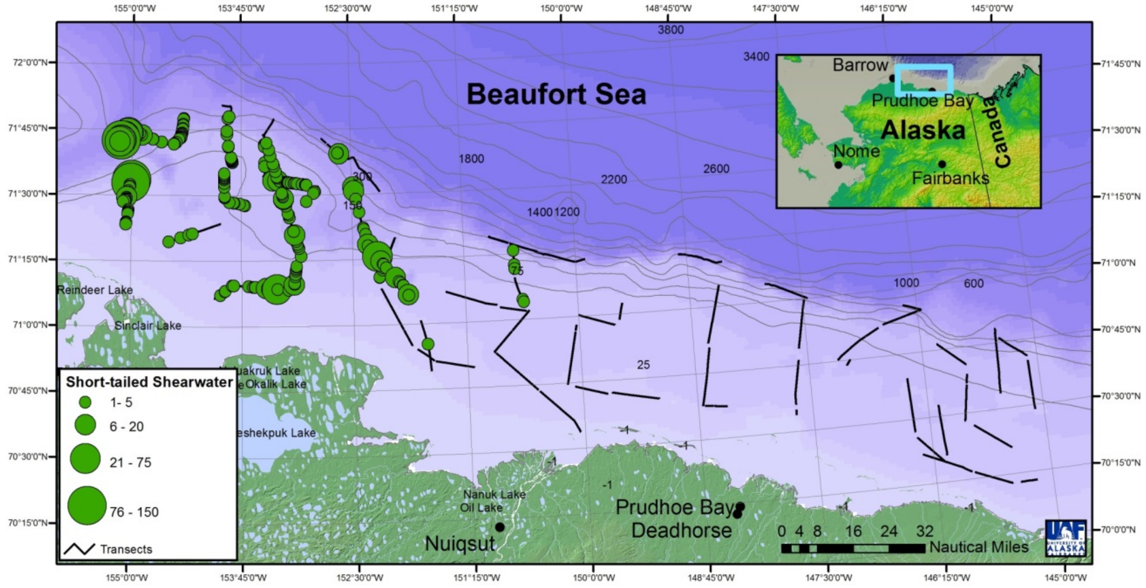

Figure A5-1. Distribution of short-tailed shearwaters during Beaufish surveys, August – September 2011. The black lines indicate where seabird and marine mammal surveys were conducted.

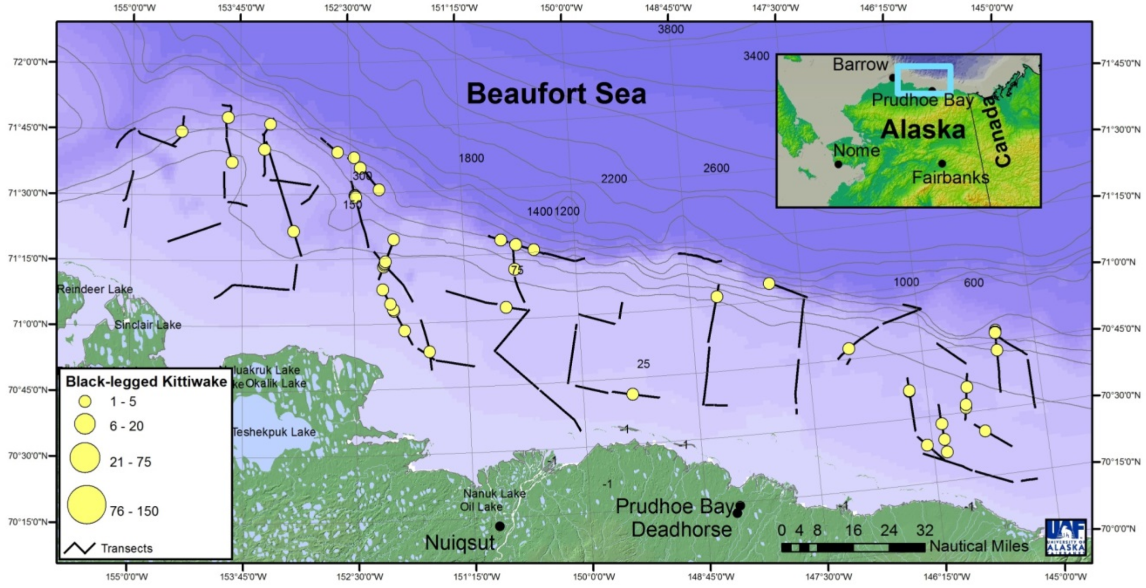

Figure A5-2. Distribution of black-legged kittiwakes during Beaufish surveys, fall 2011.

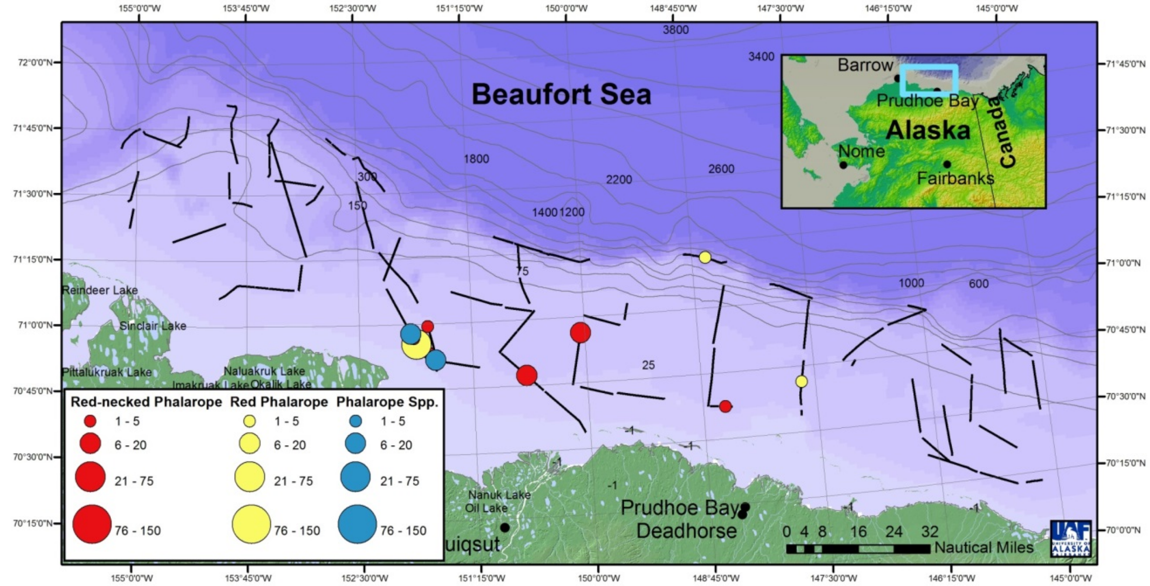

Figure A5-3. Distribution of phalaropes during Beaufish surveys, fall 2011.

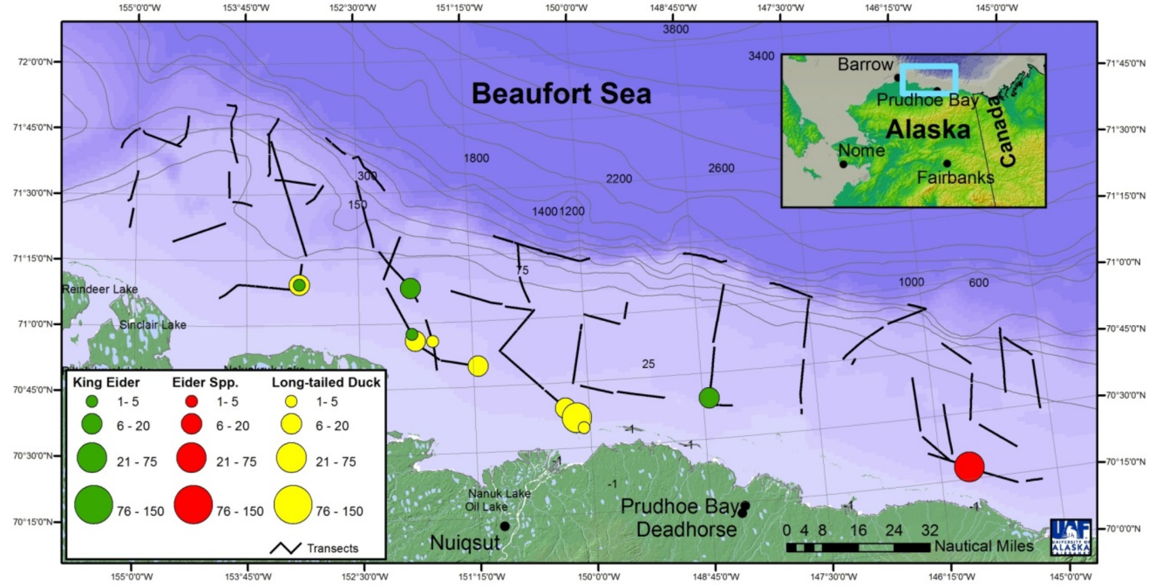

Figure A5-4. Distribution of eiders and long-tailed ducks during Beaufish surveys, fall 2011.

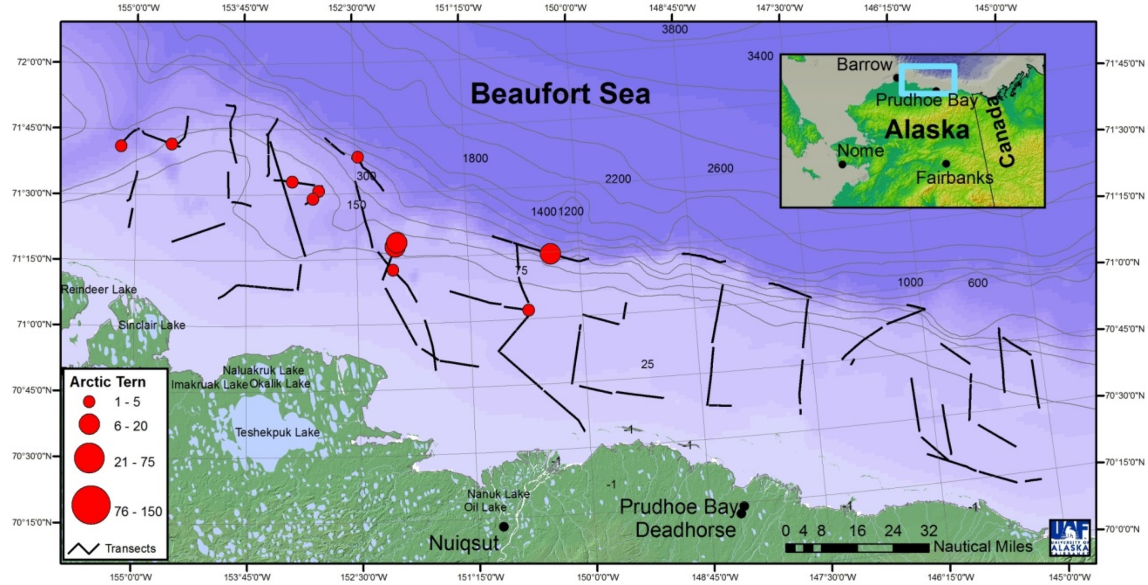

Figure A5-5. Distribution of arctic terns during Beaufish surveys, fall 2011.

BOEM-2011 M10AC20004 BOEM-2011 DATABASE DESCRIPTION

APPENDIX B
TO THE FINAL REPORT FOR
CENTRAL BEAUFORT SEA MARINE FISH MONITORING,
BOEM 2014-33

August 2018

Central Beaufort Sea Marine Fish Monitoring

BOEM Agreement Number M10AC20004

BOEM 2017-033 Appendix B

Database Description

Institute of Marine Science
College of Fisheries and Ocean Sciences
University of Alaska Fairbanks
PO Box 757220
Fairbanks AK 99775

9 August 2018

OVERVIEW

The database for the Central Beaufort Sea Marine Fish Monitoring project consists of 15 data tables in Microsoft Excel format. Tables report station collection and environmental data, catch data for pelagic and demersal fishes, and data about individual specimens of fishes. Data about subsets of fish specimens include length, weight, age, diet and stable isotope ratios in muscle tissues. Environmental data include conductivity, temperature, density vertical profiles and sediment grain size data. Data are provided as Microsoft Excel files, with each Excel file having one worksheet of data and one worksheet of metadata that describe the data fields.

This project was funded by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Alaska Outer Continental Shelf Region, Anchorage Alaska, through Cooperative Agreement Award No. M10AC00004 between BOEM and the University of Alaska Fairbanks, as part of the MMS Alaska Environmental Studies Program.

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OVERVIEW

Table 1. Fields that appear in multiple data tables of database from the BOEM-2011 survey in the U.S. Beaufort Sea.

Event	Text	Unique identifier for each deployment of gear; includes Cruise Station Gear and Haul separated by underscore symbols. E.g., BOEM-2011_CB35_PSBT-A_89
Region	Text	E.g., U.S. Beaufort Sea, Canadian Beaufort Sea
Cruise	Text	Name associating a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Station	Text	Name identifying the site (location) of Event; usually assigned during cruise to associate multiple deployments of gear
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple events at station
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number indicating the consecutive deployment of Gear during Cruise; "no data" indicates deployment sequence unknown
Year	Number	Year of haul
Date	yyyy-mm-dd	Local date of haul or "no data" indicating precise date unknown
Latitude	Number	Latitude of vessel at start of haul in decimal degree; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Comment	Memo	Blank cell or comment about row of data
SpecimenNum	Text	Identifier for an individual fish specimen in the UAF Fisheries Oceanography Lab database. An integer was assigned to each fish whose tissues were sampled or information was recorded specific to that individual. Entries beginning with "LW" and “F” were measured only for length and weight and processed fish bodies were not individually labeled. Processed fishes with integer and “LW-“ SpecimenNums were retained for several years after project end; “F-“ SpecimenNums were discarded
Midpoint_10mm	Number	Midpoint of 10-mm increment of fish total length, e.g. 25 for 21-30 mm, 35 for 31-40 mm. Blank cell indicates total length not available
Weight_g	Number	Weight in grams, after blotting to remove excess water. Blank cell indicates no data

Table 2. tblCruise. One row for each type of gear deployed on open-water cruise BOEM-2011 and under-ice cruise BOEM-2013-Ice. Each combination of Cruise and Gear is unique.

Field	Type	Description
Cruise	Text	Name that associates a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
CruiseAlt	Text	Populated only where alternate names have been used to identify Cruise. Blank indicates no data
Regions	Text	E.g., U.S. Beaufort Sea, Canadian Beaufort Sea
Vessel	Text	Sampling base. E.g., name of vessel from which gear was deployed, shore-based
Year	Number	Year of cruise
DateStart	yyyy-mm-dd	Local date of start of cruise, i.e., vessel leaves dock. Where no vessel was utilized, DateStart is date of first deployment of any Gear during cruise
DateEnd	yyyy-mm-dd	Local date of end of cruise, i.e., vessel returns to dock
LatLongComment	Text	E.g., vessel Global Positioning System (GPS); celestial navigation; one position per deployment
MeshSmallest_mm	Number	Populated only for net gear. Smallest mesh size in the gear in millimeters; usually from codend or codend liner or sieve. NA indicates not applicable
DeploymentMethod	Text	Description of the typical deployment method for this gear during cruise
DurationReported	Text	Availability in database of duration of deployment: yes, no, not applicable (NA), or comment
DistanceReported	Text	Availability in database of distance of deployment: yes, no, not applicable (NA), or comment
SwathReported	Text	Availability in database of horizontal swath (width of haul track or observation): yes, no, not applicable (NA), or comment
CountReported	Text	Availability in database of count data: yes, no, not applicable (NA), or comment
WeightReported		Availability in database of weight data: yes, no, not applicable (NA), or comment
CPUEReported	Text	Availability in database of abundance (catch-per-unit-effort) data: yes, no, not applicable (NA), or comment
BiomassReported	Text	Availability in database of biomass data: yes, no, not applicable (NA), or comment
VoucherCollections	Text	Location of voucher collections, not applicable (NA), or comment
Comment	Memo	Blank cell or comment about row of data

15 rows

Table 3. tblEvent. Details about each overboard deployment of gear during the BOEM-2011 survey in the U.S. Beaufort Sea. Each Event is a unique combination of Cruise, Station, Gear and Haul.

Field	Type	Description
Event	Text	Unique identifier for each deployment of gear; includes Cruise, Station, Gear and Haul separated by underscores. E.g., TB-2012-US_B1-500_IKMT_6. "x" is a placeholder for a missing gear or haul
Region	Text	E.g., U.S. Beaufort Sea, Canadian Beaufort Sea
Cruise	Text	Name associating a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Stratum_BOEM-2011	Text	The study region of cruise BOEM-2011 was divided into three geographical strata: Western BOEM-2011 (WB), Central BOEM-2011 (CB), Eastern BOEM-2011 (EB)
Station	Text	Name identifying the site (location) of Event; usually assigned during cruise to associate multiple deployments of gear
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple events at station
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number identifying the particular deployment of Gear. Usually assigned consecutively for each gear throughout the cruise. Blank cell indicates Haul not assigned
Year	Number	Year of haul
Date	yyyy-mm-dd	Local date of haul or "no data" indicating precise date unknown
Time	hh:mm	Local time of start of haul. For oblique hauls by gear IKMT this is time IKMT is at surface of water at beginning of deployment. For hauls by bottom trawls this is time gear was fully deployed on the sea floor (wire out). Blank indicates missing value
Duration_min	Number	Number of minutes the gear was deployed. For bottom trawls, Duration_min is the number of minutes the gear was on the sea floor. “No data” indicates missing value. NA indicates not applicable
DepthMin_m	Number	Minimum depth of the haul in meters. NA indicates not applicable.
DepthMax_m	Number	Maximum depth of the haul in meters; for bottom trawl hauls this is equal to DepthStn_m. NA indicates not applicable
DepthPredom_m	Number	Predominant depth of haul in meters; for bottom trawl hauls this is equal to DepthMax_m; for pelagic hauls that did not pause at a particular depth this is equal to average of DepthMin_m and DepthMax_m. NA indicates not applicable
DepthStn_m	Number	Depth of station in meters
Latitude	Number	Latitude of vessel at start of haul in decimal degrees; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
LatitudeEnd	Number	Latitude of vessel at the end of haul in decimal degrees; xx.xxxx. Blank indicates no data

Field	Type	Description
LongitudeEnd	Number	Longitude of vessel at the end of haul in negative decimal degrees to indicate western hemisphere; -xxx.xxxx. Blank indicates no data
DistanceTowed_m	Number	Distance between start and end positions of haul in meters. Blank indicates no data
NetSwath_m	Number	Effective horizontal opening of the gear in meters. Blank indicates no data
AreaTowed_sqm	Number	Area towed in square meters; calculated as NetSwath_m x DistanceTowed_m. Blank indicates no data
CPUE_Quality	Text	CPUE area; CPUE distance; CPUE volume; Presence. CPUE area: catch data are quantitative per unit area & can be compared with hauls of same gear. CPUE distance and CPUE volume: catch data can be compared within a gear type. Presence (not quantitative): analysis should be limited to taxon presence; examples: specimens recorded or retained from haul that was incompletely sorted; deployment unsuccessful. NA indicates field is not applicable for the Haul
Comment	Memo	Comment about row of data or blank cell

477 rows

Table 4. tblFish_Catch. Presence, count and weight of each fish taxon at each Event (haul) during the BOEM-2011 survey in the U.S. Beaufort Sea. Where appropriate includes factors by which to multiply count and weight to calculate abundance and biomass standardized to time (10 min; Gears = IKMT, PSBT, PSBT-A, OT), distance (1000 m; Gears = IKMT, PSBT, PSBT-A, OT), area (1000 square m of water surface or sea floor; Gears = IKMT, PSBT, PSBT-A) and volume (1000 cubic m water; Gears = Bongo, IKMT). Each combination of Event and NameScientific is unique.

Field	Type	Description
Event	Text	Unique identifier for each deployment of gear; includes Cruise, Station, Gear and Haul separated by underscores. E.g., TB-2012-US_B1-500_IKMT_6. "x" is a placeholder for a missing gear or haul.
Cruise	Text	Name associating a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Stratum_BOEM-2011	Text	The study region of cruise BOEM-2011 was divided into three geographical strata: Western BOEM-2011 (WB), Central BOEM-2011 (CB), Eastern BOEM-2011 (EB)
Station	Text	Name identifying the site (location) to associate multiple deployments of gear. Transboundary station names indicate Stratum (transect) and target station depth, e.g., A1-50 indicates transect A1 and 50 m
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used for associating data from multiple events at station.
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number indicating the consecutive deployment of Gear during Cruise
Mesh_Smallest _mm	Text	Smallest mesh size in the gear; usually from codend, codend liner of net, or mesh of sieve. NA indicates not applicable
Swath	Number	Effective opening of the gear in meters (e.g., bottom trawls) or sq m (e.g., plankton nets, sediment grab); units are indicated. "No data" is assigned to nets without fixed opening and "NA" indicates not applicable
Date	yyyy-mm-dd	Local date of Event
Time	hh:mm:ss	Local time at start of Haul. For oblique hauls by Bongo and IKMT, Time_StartHaul when net is at surface of water at beginning of deployment. For midwater hauls targeting a particular depth range, Time_StartHaul is when net arrives at target depth. For bottom trawls hauls, Time_StartHaul is when net is on the seafloor with wire fully deployed
Duration_min	Number	Number of minutes the gear was deployed. For bottom trawls, Duration_min is the number of minutes the gear was on the sea floor. “No data” indicates missing value and "NA" indicates not applicable
GearDepthMin_m	Number	Minimum depth of the Haul in meters
GearDepthMax_m	Number	Maximum depth of the Haul in meters

Field	Type	Description
GearDepthPredom_m	Number	Predominant depth of Haul in meters; for bottom trawl hauls this is equal to DepthMax_m; for pelagic hauls that did not pause at a particular depth this is equal to average of DepthMin_m and DepthMax_m
DepthStn_m	Number	Depth of station in meters; for bottom trawl hauls this is equal to DepthMax_m
Latitude	Number	Latitude of vessel at start of Haul in decimal degrees; if only one latitude was reported for the haul that latitude is assigned in this field. xx.xxxx
Longitude	Number	Longitude of vessel at start of Haul; negative decimal degrees indicate western hemisphere; if only one longitude was reported for the haul that longitude is assigned in this field; -xxx.xxxx
DistanceTowed_m	Number	Distance between start and end positions of haul in meters, not applicable (NA) or "no data"
CPUE_Quality	Text	CPUE area, CPUE distance, CPUE volume, CPUE proportional, Presence or "no data". CPUE area: catch data are quantitative per unit area & can be compared with hauls of same gear. CPUE distance and CPUE volume: catch data can be compared within a gear type. CPUE proportional: area, distance and time on bottom not known: analyze by proportional catch; Presence: analysis should be limited to taxon presence (e.g., specimens collected from haul that was incompletely sorted, gear deployment unsuccessful, haul not quantitative)
PercentSorted	Text	Set as a number between 0 and 100 if a portion of the haul was sorted quantitatively; 0 indicates none of haul was sorted; "NQ" indicates haul was not sorted in a quantitative fashion
Family	Text	Scientific name of family
AnalysisLevel	Text	Taxonomic level at which taxa were aggregated for some analyses; some taxa are also divided into ranges of total length, e.g., Icelus spp. ≤40 mm and Icelus spp. 41-87 mm
NameScientific	Text	Genus and species, or the most precise level of taxonomy available; set as "None captured" at hauls where no fishes were captured and CPUE_Quality is other than "NonQuant"
Presence	Number	1 indicates the taxon was present at a haul of any CPUE_Quality
Count_per_Haul	Number	Count of individuals in entire haul; where only part of haul was sorted, count was extrapolated to 100% of the haul. Where CPUE_Quality = presence, this field is blank to discourage standardization of nonquantitative data.

Field	**Type**	**Description**
Wt_per_Haul_g	Number	Demersal gears only. Weight of taxon in the entire haul in grams, rounded to 6 digits; where only part of haul was sorted, this weight is extrapolated to 100% of the haul. Where CPUE_Quality = presence, this field is blank to discourage standardization of nonquantitative data.
Count_per_10_min	Number	Count of individuals standardized to 10 minute haul or "no data". (Count_per_Haul / Duration in minutes) * 10 min.
Weight_per_10_min_g	Number	Demersal gears only. Weight of taxon standardized to 10 minute haul in grams or "no data". (Weight_per_Haul_g / Duration in minutes) * 10 min
Count_per_1000_m	Number	Count of individuals standardized to 1000 m distance or "no data". (Count_per_Haul / DistanceTowed_m) * 1000
Weight_per_1000_m_g	Number	Demersal gears only. Weight of taxon standardized to 1000 m distance. (Weight_per_Haul_g / DistanceTowed_m) * 1000
Count_per_1000_sq_m	Number	Count of individuals standardized to 1000 sq m of sea floor (benthic nets), water surface (pelagic nets), or "no data". PSBT and PSBT-A: (Count_per_Haul / (DistanceTowed_m * 2.257 m NetSwath_m) * 1000; IKMT: (Count_per_Haul / DistanceTowed_m * 1.5 m) * 1000, where 1.5 m is horizontal swath of IKMT
Weight_per_1000_sq_m_g	Number	Demersal gears only. Weight of taxon standardized to 1000 sq m of sea floor. PSBT and PSBT-A: (Weight_per_Haul_g / (DistanceTowed_m * 2.257 m NetSwath_m) * 1000
Count_per_1000_cu_m	Number	Count of individuals standardized to 1000 cubic meters volume. Bongo: calculated based on flowmeter revolutions during haul and 0.6 m diameter mouth of net. IKMT: (Count_per_Haul / DistanceTowed_m * 2.137 sq m) * 1000. Mouth of IKMT is 2.137 sq m when net is fished at 45 degree angle.
Comment	Memo	Comment about row of data or blank cell

Table 5 tblFish_TLength_Increment. Count and weight of fishes at each haul by fishing gear during the BOEM-2011 survey in the U.S. Beaufort Sea, by 10-mm increment of fish total length. Abundance and biomass are reported for hauls that are quantitative for area or volume fished. Fishing gears include Isaacs-Kidd midwater trawl (IKMT), and benthic nets otter trawl (OT), plumb staff beam trawl (PSBT) and modified plumb staff beam trawl (PSBT-A). Biomass (grams per 1000 sq m) and abundance (number individuals per 1000 sq m) are reported for quantitative PSBT and PSBT-A. Abundance (number individuals per 1000 cu m) is reported for quantitative IKMT hauls. Data rows are sorted by Cruise, Gear, Haul, NameScientific and Midpoint_10mm. Each combination of Event, NameScientific and Midpoint_10mm is unique.

Field	Type	Description
Event	Text	Unique identifier for each deployment of gear; includes Cruise, Station, Gear and Haul separated by underscores. E.g., TB-2012-US_B1-500_IKMT_6. "x" is a placeholder for a missing gear or haul.
Cruise	Text	Name associating a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Stratum_BOEM-2011	Text	The study region of cruise BOEM-2011 was divided into three geographical strata: Western BOEM-2011 (WB), Central BOEM-2011 (CB), Eastern BOEM-2011 (EB)
Station	Text	Name identifying the site (location) of Event; usually assigned during cruise to associate multiple deployments of gear
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used for associating data from multiple events at station.
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Mesh_Smallest _mm	Text	Smallest mesh size in the gear; usually from codend, codend liner of net, or mesh of sieve. NA indicates not applicable
Swath	Number	Effective opening of the gear in meters (e.g., bottom trawls) or sq m (e.g., plankton nets, sediment grab); units are indicated. "No data" is assigned to nets without fixed opening and "NA" indicates not applicable
Haul	Text	Name or number indicating the consecutive deployment of Gear during Cruise
Date	yyyy-mm-dd	Local date of Event
Time_StartHaul	hh:mm:ss	Local time at start of Haul or "no data". For oblique hauls by Bongo and IKMT, Time_StartHaul when net is at surface of water at beginning of deployment. For midwater hauls targeting a particular depth range, Time_StartHaul is when net arrives at target depth. For bottom trawls hauls, Time_StartHaul is when net is on the seafloor with wire fully deployed
Duration_min	Number	Number of minutes the gear was deployed. For bottom trawls, Duration_min is the number of minutes the gear was on the sea floor. “No data” indicates missing value and "NA" indicates not applicable
GearDepthMin_m	Number	Minimum depth of the Haul in meters
GearDepthMax_m	Number	Maximum depth of the Haul in meters

Field	Type	Description
DepthStn_m	Number	Depth of station in meters; for bottom trawl hauls this is equal to DepthMax_m
Latitude	Number	Latitude of vessel at start of Haul in decimal degrees; xx.xxxx
Longitude	Number	Longitude of vessel at start of Haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
DistanceTowed_m	Number	Distance between start and end positions of haul in meters, not applicable (NA) or "no data"
CPUE_Quality	Text	CPUE area, CPUE distance, CPUE volume, CPUE proportional, Presence or "no data". CPUE area: catch data are quantitative per unit area & can be compared with hauls of same gear. CPUE distance and CPUE volume: catch data can be compared within a gear type. CPUE proportional: area, distance and time on bottom not known: analyze by proportional catch; Presence: analysis should be limited to taxon presence (e.g., specimens collected from haul that was incompletely sorted, gear deployment unsuccessful, haul not quantitative)
NameScientific	Text	Genus and species, or the most precise level of taxonomy available; set as "None captured" at hauls where no fishes were captured and CPUE_Quality is other than "NonQuant"
Midpoint_10mm	Number	Midpoint of 10-mm increment of total length, e.g. 25 for 21-30 mm, 35 for 31-40 mm. Field is set to "0" at hauls where no fishes were captured
Count_per_Haul	Number	Count of individuals in entire haul or "no data"; where only part of haul was sorted, count was extrapolated to 100% of the haul. Where CPUE_Quality = presence, this field is set to "no data" to discourage standardization of nonquantitative data
Wt_per_Haul_g	Number	Demersal gears only. Weight of taxon in the entire haul in grams; where only part of haul was sorted, this weight is extrapolated to 100% of the haul. Where CPUE_Quality = presence, field is set to "no data" to discourage standardization of nonquantitative data
Count_per_1000_sq_m	Number	Count of individuals standardized to 1000 sq m of sea floor (benthic nets), water surface (pelagic nets), or "no data". PSBT and PSBT-A: (Count_per_Haul / (DistanceTowed_m * 2.257 m NetSwath_m) * 1000; IKMT: (Count_per_Haul / DistanceTowed_m * 1.5 m) * 1000, where 1.5 m is horizontal swath of IKMT
Weight_per_1000_sq_m_g	Number	Demersal gears only. Weight of taxon standardized to 1000 sq m of sea floor or "no data". PSBT and PSBT-A: (Weight_per_Haul_g / (DistanceTowed_m * 2.257 m NetSwath_m) * 1000
Count_per_1000_cu_m	Number	Count of individuals standardized to 1000 cubic meters volume or "no data". IKMT: (Count_per_Haul / DistanceTowed_m * 2.137 sq m) * 1000. Mouth of IKMT is 2.137 sq m when net is fished at 45 degree angle.
Comment	Memo	Comment about row of data or blank cell

Table 6. tblFish_Specimen. Length, weight and list of analyses applied to individual fish specimens captured during the BOEM-2011 survey in the U.S. Beaufort Sea. No fishes were captured during BOEM-2013-Ice. Not all captured fishes are in this table. Fields indicate length, weight, sex, age and whether the specimen was used in analyses of diet, length-frequency, length-weight or stable isotopes. Fields indicate where tissues were provided to other researchers for genetics analysis and specimens are archived in a voucher collection. Rows are sorted by Event, NameScientific, LengthTotal_mm. Each SpecimenNum is unique.

Field	Type	Description
SpecimenNum	Text	Identifier for an individual fish specimen in the UAF Fisheries Oceanography Lab database. An integer was assigned to each fish whose tissues were sampled or information was recorded specific to that individual. Entries beginning with "LW" and “F” were measured only for length and weight, and processed fish bodies were not individually labeled. Processed fishes with integer and “LW-“ SpecimenNums were retained for several years after project end; “F-“ SpecimenNums were discarded
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple gear deployments at Station
Event	Text	Unique identifier for each deployment of gear; includes Cruise Station Gear and Haul separated by underscore symbols. Example: BOEM-2011_CB35_PSBT-A_89
Cruise	Text	Name that associates a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Station	Text	Name identifying the site to associate multiple deployments of gear
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number indicating the consecutive deployment of Gear during Cruise; "no data" indicates deployment sequence unknown
Latitude	Number	Latitude of vessel at start of haul in decimal degrees; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Date	yyyy-mm-dd	Local date of haul or "no data" indicating precise date unknown
DepthStn_m	Number	Depth of station in meters
NameScientific	Text	Genus and species, or the most precise level of taxonomy available
LengthTotal _mm	Text	Total length is the preferred measure of fishes. Straight-line measure from the tip of the snout to the tip of the longer lobe of the caudal fin; measured with the lobes compressed along the midline. Where exact length was not measured, value is assigned as 10-mm length range (e.g., 11-20, 21-30, 31-40) or "no data"
Midpoint_10mm	Number	Midpoint of 10-mm increment of fish total length, e.g. 25 for 21-30 mm, 35 for 31-40 mm. Blank cell indicates total length not available
LengthFork _mm	Text	Fork length is measured from the most anterior part of head to the deepest point of notch in the caudal fin. Blank cell indicates no data
LengthStandard _mm	Text	Standard length is the typical measure of larval fishes because caudal fin may not be fully developed and is often damaged. Straight-line measure from the most anterior part of head to the end of caudal peduncle. Blank cell indicates no data
Weight_g	Number	Weight in grams, after blotting to remove excess water.

Field	**Type**	**Description**
Sex	Text	Male, female. Blank cell indicates sex was not assessed
LifeStage	Text	Mature, juvenile, larvae, egg. Blank cell indicates LifeStage was not assessed
Age	Number	Assigned based on analysis of otoliths; 0 = young of the year, 1 = age-1, 2 = age-2, etc. Blank cell indicates age was not assessed
Diet_Analyzed	Text	Set as "x" where stomach contents of SpecimenNum were examined and reported in tblFish_Diet. Blank cell indicates diet was not assessed
LengthFrequency _Analyzed	Text	Set as "x" where fish was used in length frequency histograms in project final report. Blank cell indicates fish was excluded from analysis
LengthWeight _Analyzed	Text	Set as "x" where fish was used in length-weight regression analyses in project final report. Blank cell indicates fish was excluded from analysis
StableIsotopes _Analyzed	Text	Set as "x" where muscle tissue of SpecimenNum was analyzed for carbon and nitrogen stable isotopes. Blank cell indicates stable isotopes not assessed
GeneticsSample _SandyTalbot	Text	Set as "x" where tissue was provided to Sandy Talbot of United States Geological Survey/Anchorage/AK <stalbot@usgs.gov>. Blank cell indicates not provided
GeneticsSample _JohnNelson	Text	Set as "x" where tissue was provided to R. John Nelson of University of Victoria/British Columbia/Canada <jnelson@uvic.ca>. Blank cell indicates not provided
Voucher	Text	Indicates repository of archived specimens location where specimen is archived as voucher per http://researcharchive.calacademy.org/research/ichthyology/catalog/collections.asp; blank cell indicates not in voucher collection
Comment	Memo	Blank cell or comment about row of data

Table 7. tblFish_SpecimenBongo. Standard length and body depth for fish specimens identified from hauls by Bongo net during the BOEM-2011 survey in the U.S. Beaufort Sea. Each SpecimenNum is unique. Original identifications were under the responsibility of Principal Investigator Prof. Louis Fortier, Canada Research Chair/Département de Biologie/Université Laval/Québec -louis.fortier@bio.ulaval.ca. Some identifications were revised to a less precise taxon by Brenda Holladay, College of Fisheries and Ocean Sciences/University of Alaska Fairbanks based on observation of a subset of specimens and knowledge of taxa caught in other gears during cruise BOEM-2011.

Field	**Type**	**Description**
SpecimenNum	Text	Identifier for an individual fish specimen in the UAF Fisheries Oceanography Lab database. An integer was assigned to each fish whose tissues were sampled or information was recorded specific to that individual. Entries beginning with "LW" and “F” were measured only for length and weight, and processed fish bodies were not individually labeled. Processed fishes with integer and “LW-“ SpecimenNums were retained for several years after project end; “F-“ SpecimenNums were discarded
Larva_SampleID	Text	Identifier for an individual fish caught by Bongo net, as assigned by Fortier lab
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple gear deployments at Station
Event	Text	Unique identifier for each deployment of gear; includes Cruise Station Gear and Haul separated by underscore symbols. E.g., BOEM-2011_CB35_PSBT-A_89
Cruise	Text	Name associating a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Station	Text	Name identifying the site to associate multiple deployments of gear
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number indicating the consecutive deployment of Gear during Cruise
Latitude	Number	Latitude of vessel at start of haul in decimal degrees; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Date	yyyy-mm-dd	Local date of haul
DepthStn_m	Number	Depth of station in meters
NameScientific	Text	Genus and species, or the most precise level of taxonomy available
LengthStandard_mm	Text	Standard length is the typical measure of larval fishes because caudal fin may not be fully developed and is often damaged. Straight-line measure from the most anterior part of head to the end of caudal peduncle. Blank cell indicates no data
Comment	Memo	Blank cell or comment about row of data

157 rows

Table 8. tblFish_Diet. Stomach contents of fishes examined from the BOEM-2011 survey in the Beaufort Sea. All predators were captured with demersal fishing gears: otter trawl, plumb staff beam trawl or modified plumb staff beam trawl. One row for each prey taxon identified from one predator's stomach or one row that reports predator's empty stomach. Each combination of SpecimenNum and PreyTaxon_MostPrecise is unique.

Field	Type	Description
SpecimenNum	Text	Identifier for an individual fish specimen in the UAF Fisheries Oceanography Lab database. An integer was assigned to each fish whose tissues were sampled or information was recorded specific to that individual. Entries beginning with "LW" and “F” were measured only for length and weight, and processed fish bodies were not individually labeled. Processed fishes with integer and “LW-“ SpecimenNums were retained for several years after project end; “F-“ SpecimenNums were discarded
Cruise	Text	Name that associates a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple gear deployments at Station
Sea	Text	E.g., Beaufort, Chukchi
StrataDiet	Text	The BOEM-2011 study region was divided into two geographic regions to stratify diet analysis: West B was west of 151.75 W; East B was east of 151.75 W
Pelagic_Demersal	Text	Gear used to collect predator (SpecimenNum) was assigned as pelagic, demersal or "no data"
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number indicating the consecutive deployment of Gear during Cruise; "no data" indicates deployment sequence unknown
Station	Text	Name identifying the site to associate multiple deployments of gear
DepthStn_m	Number	Depth of station in meters
Latitude	Number	Latitude of vessel at start of haul in decimal degree; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Year	Number	Year of haul
Date	yyyy-mm-dd	Local date of haul; no data = precise date unknown
PredatorSpecies	Text	Genus and species of the fish SpecimenNum
LengthTotal_mm	Text	Length of SpecimenNum. Total length is the preferred measure of fishes: straight-line measure from the tip of the snout to the tip of the longer lobe of the caudal fin, measured with the lobes compressed along the midline.
Weight_g	Text	Weight of fish specimen after blotting to remove excess water (grams) or "no data"
StomachFullness	Text	Visual estimate of fish stomach fullness on a scale of 0–100% or "no data"

Field	Type	Description
StomachWeight_Full_g	Text	Weight of fish stomach measured to the nearest 0.0001 g or "burst" indicating stomach wall ruptured and stomach not weighed
StomachWeight_Empty_g	Text	Empty stomach weights measured to the nearest 0.0001 g. If it was not possible to assign an empty stomach weight the weight value was listed as "na" (not available).
PreyTaxon_Coarse	Text	Prey taxonomic groups used for summary purposes
PreyTaxon_MostPrecise	Text	Most precise taxonomic nomenclature assigned to a respective prey item
PreyTotalLength_mm	Text	Length of body of prey in mm or "no data" indicating unmeasured. Invertebrates: length does not include antennae or setae
PreySize	Text	Small ≤5 mm; Med >5 to <10 mm; Large >10 mm; Frags = fragmented prey (no measurements); na = no measurement available.
PreyCount	Text	When non-fragmented prey were present, PreyCount was based on counts of each prey item. When prey were fragmented, PreyCount was on presence of distinguishable body parts (heads; tails; other) or if no distintuisable parts, PreyCount was assigned as 1. Due due to prey fragmentation the number of prey length values in PreyTotalLength_mm does not always match the PreyCount
PreyWeight_g	Text	Prey weights were measured to the nearest 0.0001 g. If a prey item did not register a value at 0.0001 g, it was assigned as 0.00005 g. Excluded prey and empty stomachs were assigned "no data".
Comment	Text	Blank cell or comment about row of data

2129 rows

Table 9. tblFish_StableIsotopes. Results of carbon and nitrogen stable isotope analyses of muscle tissue of fishes collected during cruise BOEM-2011. Each SpecimenNum is unique.

Field	Type	Description
SpecimenNum	Text	Identifier for an individual fish specimen in the UAF Fisheries Oceanography Lab database. An integer was assigned to each fish whose tissues were sampled or information was recorded specific to that individual. Entries beginning with "LW" and "F" were measured only for length and weight, and processed fish bodies were not individually labeled. Processed fishes with integer and "LW-" SpecimenNums were retained for several years after project end; "F-" SpecimenNums were discarded
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple events at station
Event	Text	Unique identifier for each deployment of gear; includes Cruise, Station, Gear and Haul separated by underscores; Example: BOEM-2011_WB10_PSBT-A_56
Latitude	Number	Latitude of vessel at start of haul in decimal degrees; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Year	Number	Year of field collection
Date	yyyy-mm-dd	Local date of haul
DepthStn_m	Number	Depth of station in meters
Sea	Text	E.g., Beaufort or Chukchi
Pelagic_or_ Demersal	Text	Pelagic or demersal Gear used to collect SpecimenNum; "no data" if unknown
NameScientific	Text	Genus and species, or the most precise level of taxonomy available
LengthTotal_mm	Text	Total length is the preferred measure of fishes. Straight-line measure from the tip of the snout to the tip of the longer lobe of the caudal fin; measured with the lobes compressed along the midline. 10-mm length range is reported where exact length was not measured, e.g., 11-20, 21-30, 31-40. Blank cell indicates no data
Weight_g	Text	Weight of fish specimen after blotting to remove excess water (grams). "No data" indicates missing value
TissueType	Text	E.g., muscle, liver, whole animal homogenate
Del_15N	Text	Stable isotope ratio of 15N/14N; run on tissue that was not lipid-extracted. "No data" indicates missing value
Del_13C	Text	Stable isotope ratio of 13C/12C; fish tissues are lipid-extracted and invertebrate tissues are not lipid-extracted. "No data" indicates missing value
Comment	Memo	Blank cell or comment about row of data

303 rows

Table 10. tblArcticCod_Otolith_Microstructure. Otolith microstructure data of juvenile Arctic Cod *Boreogadus saida* captured during the BOEM-2011 survey in the U.S. Beaufort Sea. Data include age in days, hatch date, radius of otolith and distances in micrometers between daily increments of age. Analyses were under the responsibility of Principal Investigator Prof. Louis Fortier, Canada Research Chair/Département de Biologie/université Laval/Québec -*louis.fortier@bio.ulaval.ca*

Field	Type	Description
SpecimenNum	Text	Identifier for an individual fish specimen in the UAF Fisheries Oceanography Lab database. An integer was assigned to each fish whose tissues were sampled or information was recorded specific to that individual. Entries beginning with "LW" and “F” were measured only for length and weight, and processed fish bodies were not individually labeled. Processed fishes with integer and “LW-“ SpecimenNums were retained for several years after project end; “F-“ SpecimenNums were discarded
Larva_SampleID	Number	3-digit code pertaining to a single larva; assigned in lab of Professor Louis Fortier (Universite Laval/Quebec/Canada)
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple gear deployments at Station
Event	Text	Unique identifier for each deployment of gear; includes Cruise Station Gear and Haul separated by underscore symbols. Example: BOEM-2011_CB35_PSBT-A_89
Cruise	Text	Name that associates a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Station	Text	Name identifying the site to associate multiple deployments of gear
Latitude	Number	Latitude in decimal degrees
Longitude	Number	Longitude in decimal degrees; longitude is negative to indicate eastern hemisphere
DateAtCapture	Date	Local date of field collection
StationDepth_m	Number	Bottom depth at station in meters
LengthStandard_mm	Text	Standard length is the typical measure of larval fishes because caudal fin may not be fully developed and is often damaged. Straight-line measure from the most anterior part of head to the end of caudal peduncle. "No data" assigned where not measured
OtolithLapillus	Text	Code LL is left lapillus; RL is right lapillus
Age_Days	Number	Number of days post-hatch. Blank cell indicates age not determined
HatchDate	yyyy-mm-dd	HatchDate = DateAtCapture minus Age_Days. Blank cell indicates HatchDate was not determined
OtolithRadius	Number	Radius of otolith in micrometers. Blank cell indicates no data
Center	Number	Set as 0 for each aged SpecimenNum. Blank cell indicates age not determined

Field	Type	Description
HatchMark	Number	Distance from center of otolith to distinctive mark in the otolith indicating date of hatch from egg to larva in micrometers. Blank cell indicates not aged
Comment	Memo	Blank cell or comment about row of data
Increment1	Number	Distance from hatch mark to first daily increment in micrometers (I day old). Blank cell indicates no data
Increment2	Number	Distance from Increment1 to Increment2 in micrometers (2 days old). Blank cell indicates no data
Increment3	Number	Distance from Increment 2 to Increment 3 in micrometers (3 days old). Blank cell indicates no data
one field for each increment assigned to any SpecimenNum		
Increment232	Number	Distance from Increment 231 to Increment 232 in micrometers (232 days old). Blank cell indicates no data
99 rows		

Table 11. tblSediment. Grain size and substrate description from sediment samples collected by Van Veen sediment sampler during cruise BOEM-2011. No replicate substrate samples were collected during this cruise. Therefore, each Event and each CruiseStation are unique.

Field	Type	Description
Event	Text	Unique identifier for each deployment of gear. Concatenation of Cruise, Station, Gear, and Haul, separated by underscore symbols. Example: BOEM-2011_CB35_PSBT-A_89
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate multiple events at station
Cruise	Text	Name associating a series of field sampling events that are in physical and temporal proximity. E.g., BOEM-2011, BOEM-2013-Ice, TB-2012-US
Station	Text	Name or number identifying the site (location); usually assigned during cruise to associate multiple deployments of gear
Latitude	Number	Latitude of vessel when Gear was deployed in decimal degrees; xx.xxxx
Longitude	Number	Longitude of vessel when Gear was deployed; negative decimal degrees indicate western hemisphere; if only one longitude was reported for the haul that longitude is assigned in this field; -xxx.xxxx
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Text	Name or number identifying the particular deployment of Gear. Usually assigned consecutively for each gear throughout the cruise. Blank cell indicates no data
GravelPercent	Number	Percent weight of gravel in dried substrate (>2–64 mm); x.xx%. Blank cell indicates no data
SandPercent	Number	Percent weight of sand in dried substrate (0.0625–2 mm); x.xx%. Blank cell indicates no data
MudPercent	Number	Percent weight of mud in dried substrate (<0.0625 mm); x.xx%; silt + clay = mud. Blank cell indicates no data
SiltPercent	Number	Percent weight of silt in dried substrate (3.90625–62.5 µm). Blank cell indicates no data
ClayPercent	Number	Percent weight of clay in dried substrate (< 3.90625 µm). Blank cell indicates no data
Substrate	Text	Qualitative description of substrate textural group with standardized terminology; as assigned by GRADISTAT v.8.0 software (Blott 2010 as modified from Folk 1954) Blott, S.J. and K. Pye. 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms 26(11):1237–1248. Folk RL (1954) The distinction between grain size and mineral composition in sedimentary-rock nomenclature. J Geology 62:344–359
SubstrAbbr	Text	Abbreviation of Substrate that indicates primary sediment with a capital letter and lesser sediments with lowercase letters. Examples: sM=sandy mud; mS=muddy sand; M=mud; S=Sand; sgsM=slightly gravelly sandy mud
PhiMean	Number	Mean phi size. Folk and Ward method as calculated using GRADISTAT v.8.0 software
PhiMean Description	Text	Qualitative description of the mean phi size. Folk and Ward method as assigned using GRADISTAT v.8.0 software

Field	Type	Description
PhiMean DescriptionAbbr	Text	Abbreviation of "PhiMeanDescription". Examples: CSi=Coarse Silt; MS=Medium Sand; MSi=Medium Silt; VFS=Very Fine Sand; VCSi=Very Coarse Silt; FS=Fine Sand
Comment	Memo	Blank cell or comment about row of data

75 rows

Table 12. tblCTD_Cast. Record of each deployment (cast) of the Conductivity Temperature Density measuring device during cruise BOEM-2011. Each Event or combination of CruiseStation, Gear and Haul is unique.

Field	Type	Description
Event	Text	Unique identifier for a CTD deployment
Cruise	Text	BOEM-2011
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate Events
Station	Text	Name or number identifying the site (location); usually assigned during cruise to associate multiple deployments of gear
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Number	Deployment of profiler; numbered consecutively throughout cruise
Region	Text	U.S. Beaufort Sea
Date_UTC	yyyy-mm-dd	UTC Date of deployment
Time_UTC	HH:MM	UTC Time of deployment
Date_Local	yyyy-mm-dd	Local Date of deployment
Time_Local	HH:MM	Local Time of deployment
Latitude	Number	Latitude of vessel during CTD deployment in decimal degrees; xx.xxxx
Longitude	Number	Latitude of vessel during CTD deployment; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Depth_Stn_m	Number	Bottom depth of the station in meters
Datafile	Text	Example: CAST021AKBE11-EB02.hex.cnv
Instrument	Text	Examples: Seabird Electronics models SBE 25 and SBE 19
Vessel	Text	Name of vessel from which gear was deployed
Agency	Text	Funding agency
PI	Text	Principal Investigator
Project	Text	Research project
CTD_Operator	Text	Name of person responsible for CTD data collection
DataRestrictions	Text	Example: describe problems with data
Comment	Memo	Blank cell or comment about row of data

Table 13. tblCTD_Data. Environmental profile data collected by Conductivity Temperature Density (CTD) measuring device during cruise BOEM-2011. One datum reported per vertical meter of CTD deployment. Each combination of Event and Depth_m is unique.

Field	Type	Description
Event	Text	Unique identifier for each deployment of gear; includes Cruise Station Gear and Haul separated by underscore symbols. Example: BOEM-2011_CB35_PSBT-A_89
CruiseStation	Text	Concatenation of Cruise and Station separated by underscore. Used to associate Events
Cruise	Text	Examples: Beaufish-2011; TB-2012-US; TB-2013-US
Station	Text	Name identifying the site (location) of Event; usually assigned during cruise to associate multiple deployments of gear
Latitude	Number	Latitude of vessel at start of haul in decimal degree; xx.xxxx
Longitude	Number	Longitude of vessel at start of haul; negative decimal degrees indicate western hemisphere; -xxx.xxxx
Date	yyyy-mm-dd	Local date of haul
Gear	Text	Abbreviated description of gear. Gear is described more completely in table luGear
Haul	Number	Name or number identifying the particular deployment of Gear. Usually assigned consecutively for each gear throughout the cruise. "No data" indicates data are not available
Depth_m	Number	Depth of sample in meters
Temp_C	Number	Temperature at sample depth in degrees Celcius. "No data" indicates data are not available
Salinity	Number	Salinity at sample depth. "No data" indicates data are not available
Density	Number	Density at sample depth (kg/m^3). "No data" indicates data are not available
pH	Number	pH at sample depth. "No data" indicates data are not available
Fluorescence	Number	Fluorescence at sample depth (mg/m^3). "No data" indicates data are not available
PAR/Irradiance	Number	Photosynthetically Available Radiation at sample depth. "No data" indicates data are not available
DissolvedO2	Number	Dissolved oxygen at sample depth. "No data" indicates data are not available
Count_Bins	Number	Count of data points averaged at sample depth. "No data" indicates data are not available
Flag	Number	Numerical code indicating data processing; 0 = data untouched; 1 = data extrapolated (typically at top; or bottom of water column); 2 = primary temperature and salinity data are interpolated (typically at mid-water column depth). "No data" indicates data are not available
Level	Text	Indicates "surface" or "deepest" depth of each cast. Blank at other depths
DataRestriction	Text	Example: indicate that CTD data at "deepest" Level should not be associated with sea floor. Blank indicates no restriction

5474 rows

Table 14. luSpecies. Look up table that indicates taxonomy of species reported in Fish and FishDiet data of cruise BOEM-2011. Taxonomy is per the World Register of Marine Species (WoRMS) unless otherwise noted. Most columns are direct output from "match taxa" query at http://www.marinespecies.org; access date 9-Aug-2018. Each combination of DataSet and NameScientific is unique.

Field	Type	Description
DataSet	Text	Fish or FishDiet
NameScientific	Text	Genus and species, or the most precise level of taxonomy available
WoRMS_MatchType	Text	Two sources: 1) output from WoRMS (e.g., exact, exact subgenus), or where no match in WoRMS 2) note by researcher on source of TSN etc.
AphiaID	Text	Output from WoRMS: Number representing NameScientific; blank if not assigned
TSN	Text	Taxonomic Serial Number; output from WoRMS species match function if available and from www.ITIS.gov if not available via WoRMS. Blank if not assigned
QualityStatus	Text	Output from WoRMS: quality of name; blank if not assigned
TaxonStatus	Text	Output from WoRMS: status of taxon; blank if not assigned
ScientificName _accepted	Text	Output from WoRMS: accepted scientific name; blank if not assigned
Authority_accepted	Text	Output from WoRMS: authority for scientific name; blank if not assigned
Kingdom	Text	Taxonomic classification of kingdom; blank if not assigned
Phylum	Text	Taxonomic classification of phylum; blank if not assigned
Class	Text	Taxonomic classification of class; blank if not assigned
Order	Text	Taxonomic classification of order; blank if not assigned
Family	Text	Taxonomic classification of family; blank if not assigned
Genus	Text	Taxonomic classification of genus; blank if not assigned
Subgenus	Text	Taxonomic classification of subgenus; blank if not assigned
Species	Text	Taxonomic classification of species; blank if not assigned
Subspecies	Text	Taxonomic classification of subspecies; blank if not assigned
isMarine	Text	Output from WoRMS: 1 if known and 0 if not known to be in marine ecosystem. Blank if not assigned in WoRMS
isBrackish	Text	Output from WoRMS: 1 if known and 0 if not known to be in brackish water. Blank if not assigned in WoRMS
isFresh	Text	Output from WoRMS: 1 if known and 0 if not known to be in fresh water. Blank if not assigned in WoRMS
isTerrestrial	Text	Output from WoRMS: 1 if known and 0 if not known to be in terrestrial ecosystem. Blank if not assigned in WoRMS

Field	Type	Description
FamilyCommon	Text	Populated only for fishes - common name of taxonomic family; blank if not assigned. Standard used for fishes is the American Fisheries Society's (AFS) Book of Scientific and Common Names (Page et al. 2013). Page LM, Espinosa-Pérez H, Findley LT, Gilbert CR, Lea RN, Mandrak NE, Mayden RL, Nelson JS (2013) Common and scientific names of fishes from the United States, Canada, and Mexico, 7th edition. American Fisheries Society, Special Publication 34, Bethesda MD.
NameCommon	Text	Populated only for fishes - common name of species. Common names for fishes are primarily from Page et al. (2013); if the fish has no common name in that source, an English vernacular name reported by WoRMS (2017) or other source may be listed. Blank if not assigned Page LM, Espinosa-Pérez H, Findley LT, Gilbert CR, Lea RN, Mandrak NE, Mayden RL, Nelson JS (2013) Common and scientific names of fishes from the United States, Canada, and Mexico, 7th edition. American Fisheries Society, Special Publication 34, Bethesda MD. 384 pp. WoRMS Editorial Board (2017). World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2017-06-17. doi:10.14284/170
Comment	Memo	Blank cell or comment about row of data

159 rows

Table 15. luGear. Detailed description of field sampling gears used during cruise BOEM-2011 and BOEM-2013-Ice. Each Gear is unique.

Field	Type	Description
Gear	Text	Abbreviated description of gear
Mesh_Smallest_mm	Text	Smallest mesh size in the gear; usually from codend, codend liner of net, or mesh of sieve. NA indicates not applicable
Horizontal_Opening_m	Text	Horizontal opening of the sampling gear while being deployed, e.g., of net while fishing or mouth of sediment grab. NA indicates not applicable
Vertical_Opening_m	Text	Vertical opening of the sampling gear while being deployed. NA indicates not applicable
Description	Memo	Full and detailed description of gear

13 rows

Table 16. tblRevisions. Notation to track revisions of data after submission to BOEM on DATE, e.g., errors repaired, taxon identification revised. RevisionNum is unique.

Field	**Type**	**Description**
RevisionNum	Autonumber	Assigned sequentially as changes are made to database
Table_Affected	Text	Name of affected database table
Global	yes or no	Does the change affect all rows of table?
Scope	Text	E.g., all, many, cruise BOEM-2011, or list the particular Event(s) affected
Original_Data	Text	Text of the original data
Comment_from _Reviewer	Memo	Comments from Reviewer
Reviewer	Text	Name and affiliation of person reviewing data
Review_Date	Date	Date of review
Response_to _Review	Memo	Response to Reviewer’s comment
Responder	Text	Name and affiliation of person responding to Requester’s comment
Response_Date	Date	Date of Response_to_Request

FISHES: SUPPLEMENTAL INFORMATION

APPENDIX C
TO THE FINAL REPORT FOR
CENTRAL BEAUFORT SEA MARINE FISH MONITORING, BOEM 2017-33

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APPENDIX C1. BEAUFISH-2011 (BOEM-2011) CRUISE REPORT

Appendix C1 is taken from the cruise report submitted to the Bureau of Energy Management in January 2012. Appendices, tables, figures and text summaries that are present in updated form in other chapters or appendices of the project Final Report are omitted from **Appendix C1.** Updated and supplementary information can be found as follows:

- **Appendix C2**. Fishes
    - **Appendix C2.1** Isaaks-Kidd midwater trawl
    - **Appendix C2.2** Otter trawl
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- **Appendix A** Collaborative Collections
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    - **Appendix A3** Epibenthic Community Variability
    - **Appendix A4** Snow Crab Population and Benthic Food Web
    - **Appendix A5** Seabird and Marine Mammal Observations

Central Beaufort Sea Fish Monitoring

Cooperative Agreement Award # M10AC20004

2011 Annual report

2011 BeauFish cruise report

Brenda L. Norcross, Principal Investigator
Lorena E. Edenfield, Assistant Project Manager
University of Alaska Fairbanks
January 2012

Citation: Norcross BL, Edenfield LE (2012) Central Beaufort Sea Fish Monitoring. 2011 Annual report provided to Bureau of Ocean Energy Management. 62 p + appendices.

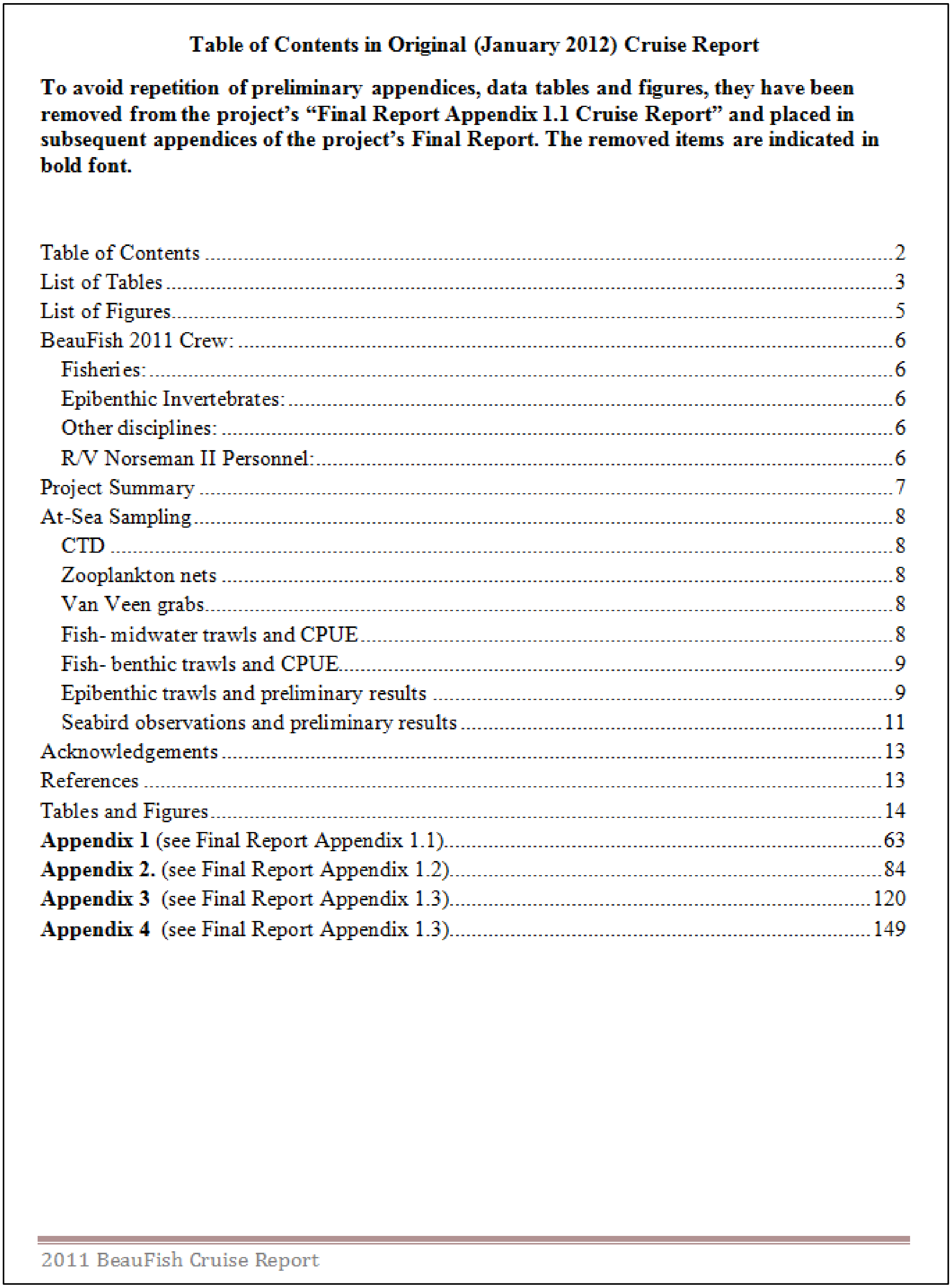

Table of Contents in Original (January 2012) Cruise Report

To avoid repetition of preliminary appendices, data tables and figures, they have been removed from the project's "Final Report Appendix 1.1 Cruise Report" and placed in subsequent appendices of the project's Final Report. The removed items are indicated in bold font.

List of Tables in Original (January 2012) Cruise Report

To avoid repetition of preliminary data tables, they have been removed from Appendix 1.1 Cruise Report and placed in subsequent appendices of the project's Final Report as indicated in bold font.

List of Figures in Original (January 2012) Cruise Report

To avoid repetition of preliminary data tables and figures, they have been removed from Appendix 1.1 Cruise Report and placed in subsequent appendices of the project's Final Report as indicated in bold font

2011 CENTRAL BEAUFORT SEA SURVEY (BOEM-2011) CRUISE REPORT

Report prepared by Lorena Edenfield, with contributions from Bodil Bluhm, Katrin Iken, Kathy Kuletz, Elizabeth Labunski, and Alexandra Ravelo

BOEM-2011 Crew:

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PROJECT SUMMARY

A team of scientists from the University of Alaska Fairbanks (UAF), the United States Bureau of Ocean Energy (BOEM), the United States Fish and Wildlife Service (USFWS) and the Alaska Department of Conservation (ADEC) conducted the work specified in the BOEM Agreement Number M10AC2004, "Central Beaufort Sea Marine Fish Monitoring." In addition to the BOEM CESU work, there were collaborative studies on epibenthos (University of Alaska Coastal Marine Institute, UAF CMI), snow crabs (UAF CMI), zooplankton (Shell Exploration and Production Company), and ichthyoplankton (LGL Ecological Research Associated, Inc.)

The Beaufort Sea August-September 2011 cruise (BOEM-2011) generated data comparable to, but broader in geographic scope than, previous fish surveys in this area. In addition to fisheries gear, a suite of plankton, sediment, and water samplers were deployed to collect physical and biological data. The data collected on this cruise, coupled with information gathered during a second phase of sampling during the ice covered season (2012), will provide a baseline data set that encompasses summer and winter seasons in the Beaufort Sea.

The R/V *Norseman II* left Prudhoe Bay on 15 August 2011 and returned to Prudhoe Bay on 4 September 2011. A total of 81 stations were sampled between longitudes 155.25 W and 145.09 W (**Figure 1**). Out of all 81 stations, 79 of those were sampled using fishing (bottom and midwater trawls), sediment (sediment grabs), plankton (plankton nets), and oceanographic gears (CTD to collect and temperature, depth, and salinity data with a rosette for water samples), while two were sampled using only plankton and oceanographic gears. Fishing gears used included both bottom and midwater trawls. The smallest fish was in the 11-20 mm size class and was from the family Cottidae, while the largest fish was in the 331-340 mm size class and was in the family Zoarcidae. A total of 13,108 fish were captured during this cruise, from 32 species representing 11 families (Tables 1 and 2).

Three areas in the central Beaufort Sea were sampled. The eastern portion was bounded by longitudes 146.65^{o} W and 145.09^{o} W and contained 15 complete stations and two stations sampled for only zooplankton (1,242 total fish captured, **Figure 2, Tables 3**, 4, 5, 6, and 7). Midwater trawls in this area captured mostly Gadidae (Figure 3), while bottom trawls captured primarily Cottidae, Gadidae, and Agonidae (Figure 4). Sampling occurred in the eastern area from 16 August 2011 and 20 Aug 2011. The central area was bounded by longitudes 151.84^{o} W and 147.13^{o} W and contained 34 stations (**Figure 5, Table 8**). Sampling occurred between 20 Aug 2011 and 3 September 2011 and 2,576 fish were captured (Tables 9, 10, 11, and 12). Midwater trawls in this area captured mostly Gadidae (Figure 6), while bottom trawls captured primarily Cottidae and Gadidae (Figure 7). The vessel and sampling operations were west of 150.00^{o} W by 23 August 2011 and did not interfere with local whaling operations. The mate or captain of the *Norseman II* conducted daily check-in calls with local native communication centers to provide updated vessel operation information. The western portion of the sampling area was bounded by 155.25° W and 152.01° W and contained 30 fishing stations (**Figure 8, Table 13**). Fishing occurred in this area from 26 August 2011 and 2 September 2011 and captured 9,290 fish (Tables 14, 15, 16, and 17). Gadidae were the majority of fish captured in both midwater and bottom trawls (Figures 9 and 10).

At-Sea Sampling

CTD

A SeaBird 25 CTD with rosette was used to measure water quality, including temperature, conductivity (salinity), pressure (depth), dissolved oxygen, pH, Fluorescence (Turner Fluorometer), and PAR (Biospherical Par sensor; if sensor is available). The smart wire was not functioning, so collections for water chemistry and stable isotopes were manually fired. In addition, the live-display depths from the CTD were not correct, and that problem was magnified at deep stations. The ship's fathometer was used at deeper stations to determine the appropriate time to fire the bottles. A few stations were sampled using a SBE Profiler 19 due to high seas. The data from this gear is still being proofed and analyzed and is unavailable.

Zooplankton nets

Zooplankton was collected using bongo and vertical nets (**Table 18**). The bongo net had 505µm mesh in the codends and was deployed from the stern at a speed of approximately 40-45m/min. This net was towed in a single oblique haul at 2 kts, and fished from the surface to a maximum depth of 5-10 m above the bottom. The vertical net had 505µm mesh in the codend and was deployed vertically from the stern. Ichthyoplankton will be retained and identified from one side of the bongo net.

Van Veen grabs

A double Van Veen was used to collect sediments at 69 stations (**Table 19**). The top 2-3 cm of the sediment from the Van Veen sampler was retained for the following analyses: sediment grain size, surface sediment chlorophyll a, organic matter, and stable isotope. Sediment analysis is currently in process.

Fish- midwater trawls and CPUE

Pelagic fishes were collected using an Isaacs-Kidd Midwater Trawl (IKMT, 73 quantitative hauls out of 84 hauls at 72 stations, captured 2312 fish, **Tables** 4, 9, 14, **20**), which fished from the surface to 10 m above the substrate. The IKMT had 3 mm mesh throughout body and codend with mouth dimensions of 1.5 m wide by 1.8 m high, with an effective fishing area of 2.137 m^2 when fished at 45° angle. A rigid diving vane kept the mouth of the net open during towing and exerted a depressing force to stabilize the net vertically. The IKMT was deployed from the stern and towed with the current at approximately 4 kts speed over ground in a double oblique tow. During the haul, the towing cable was continuously released or retrieved at the rate of approximately 30 m/min; rate was modified to maintain the target 45º wire angle. Photographs were taken of each catch. Catch-per-unit-effort (CPUE) of IKMT hauls is calculated as (# fish x 1000) / (haul distance in m x 2.137 m^2 net opening) and reported as # fish per 1000 m^3 (Tables 21 and 22). Distribution maps for CPUE of fish species and families collected in IKMT trawls can be found in Appendix 1.

Fish- benthic trawls and CPUE

A combination of otter trawls (OT), plumb staff beam trawls (PSBT), and modified plumb staff beam trawls (PSBT-A) were used to capture benthic and demersal fishes and invertebrates. The otter trawl had 32 quantitative hauls out of 43 hauls at 36 stations, and captured 4556 fish (**Tables** 5, 10, 15, and **23**). The 9.1 m OT had 38 mm stretch mesh on the codend and 19 mm stretch mesh on the codend liner. It was deployed from the stern and towed at a speed of 2 kt. Photographs were taken of each catch. Catch-per-unit-effort (CPUE) of OT hauls is calculated as (# fish x 1000) / (haul distance in m) and is reported as # fish per 1000 m (Tables 24 and 25). Distribution maps for CPUE of fish species and families collected in OT trawls can be found in Appendix 2. Both the PSBT and PSBT-A had a 4.7 m headrope, 4.6m footrope, 7mm mesh in body, and 4mm mesh as codend liner. A rigid 3-m pipe forward of the net held the mouth open for an effective swath of 2.26 m, allowing for accurate quantifications of trawl effort by area swept or by duration of tow. The PSBT-A was modified according to Abookire and Rose (2005) by adding rollers to the footrope to exclude boulders and rocky substrate and by securing the headrope to the beam in several places in order to prevent fish escapement. The modified plumb staff was used at stations where a regular PSBT would have been impractical (i.e., dense mud or boulders). Both the PSBT and PSBT-A were deployed from the stern at 30 m/min with a ratio of 2.5-5 m of towing cable to 1 m of water depth. These nets were towed with the current at approximately 1-1.5 kts speed. Photographs were taken of each catch. The PSBT had 13 quantitative hauls out of 23 hauls at 15 stations and captured 1572 fish (**Tables** 6, 11, 16, and **26**), while the PSBT-A had 68 quantitative hauls out of 89 hauls at 64 stations and captured 4938 fish (**Tables** 7, 12, 17, and **27**). Haul distance is calculated between the positions of the vessel when scope is fully deployed and when the haul back begins. CPUE of PSBT catch was calculated as (# fish x 1000) / (haul distance in m x 2.26 m net swath) and reported as # fish per 1000 m^2 (Tables 28, 29, 30, and 31). Distribution maps for CPUE of fish species and families collected in PSBT and PSBT-A trawls can be found in Appendices 3 and 4, respectively.

Epibenthic trawls and preliminary results

Epibenthic samples were collected from PSBT and PSBT-A trawls. Of the total number of trawls sampled, 72 were original stations and12 trawls corresponded to revisited stations. Revisited stations were sampled with the purpose of comparing gear types (7 sites) or assessing the variability in trawl performance using the same gear type (5 sites). After the trawl was brought on board, catches were cleaned and organisms sorted to the lowest taxonomic level (in most cases to genus). All groups were individually counted and their damp biomass determined.

Voucher specimens were fixed in either 4% or 10% buffered formalin for further taxonomic identification. Table 19 shows the stations sampled for epibenthos, time trawled and percent sampled; however, the total biomass and abundance values are standardized to the total catch and 2.5 minutes of trawl time. The revisited stations have a –R added to the station name and gear comparison stations have a -GC. In the sediment sample column, NS represents stations in which sediments were not collected due to high seas. Abundance and biomass data will be standardized to the percent of the total catch by station. Preliminary analysis show that the epibenthic communities throughout the study area vary considerably in species composition, abundance and biomass. Throughout the study area amphipods, shrimp and ophiuroids were the groups most represented. Gastropods showed the highest diversity (Figure 11).

Snow crab counts were recorded per station and will later be used to calculate gross abundance per unit area. Each of the total 64 crabs collected was sexed and measured for size (carapace width for all crabs, chela height for males) and wet weight taken. Shell condition was determined after Jadamec et al. (1999). Stomachs were dissected and preserved in formalin to identify stomach content at the home lab. Muscle tissue was frozen and then dried at 60°C for later stable C and N isotope analysis at the Alaska Stable Isotope Facility. Out of the 79 stations, 76 were sampled for the stable carbon and nitrogen isotope signatures of water column, and 75 were sampled for sediment particular organic matter, to provide context for estimating the trophic level of snow crabs. Mature females were sampled for egg counts and spermathecal load. Ovary color and fullness were noted and egg flaps were frozen for later analysis. Spermathecae were dissected, their fullness determined, the presence of fresh ejaculate noted, and then intact spermathecae were preserved in formalin. Muscle tissue was frozen from all crabs for collaborators interested in caloric value and fatty acid profiles. Muscle tissue was preserved in ~80% ethanol for collaborators performing molecular analyses. Additional samples collected from epibenthic trawls include: (1) a total of 1167 tissue samples (frozen and later dried) of over 150 invertebrate taxa for food web studies via stable C and N isotopes, (2) 42 invertebrate taxa (multiple specimens) for the frozen tissue collection at the UA Museum of the North, (3) 84 invertebrate taxa (multiple specimens) in ethanol for DNA barcoding, (4) 61 invertebrate taxa (frozen, multiple specimens) for fatty acid profiles and caloric content, (5) over 20 invertebrate taxa (frozen) for experiments on the chemical ecology of those taxa, and (6) several samples of isopods of the genus *Saduria* from different locations, preserved in ethanol (Table 32).

Snow crabs occurred at 19 stations (Table 32) at water depths between 40 and 220 m, with mature female crabs found at only three stations. We found between one and six crabs per trawl haul with a total of 64 crabs. Of these 64 collected Chionoecetes opilio, 50 were males, nine were immature females, and five were mature females (Figure 12). The size range of all crabs was between 32.6 and 129.6 mm carapace width with most crabs measuring between 40 and 70 mm (Figure 13). The size range of immature females was very similar to that of mature females, suggesting that maturity may occur over a wide range of body sizes (Table 33). Five males were larger than 78 mm in carapace width, the size limit for commercial harvest in the southeastern Bering Sea. Crabs larger than 70 mm exclusively occurred in water depths of 180 and 220 m (Figure 14). Body weight ranged from 14 to 1105 g (Table 33).

All crabs were categorized as shell condition 2 (new shell), except for three males that were considered shell condition 3 (old shell) based on the worn dactyl tips and chelae, dull color of the carapace and the presence of scratches and abrasions. All but two females (including mature and immature females) had deep orange ovaries suggesting they would have produced a clutch in the next season. The two immature females with white ovaries measured 39.0 and 49.9 mm in carapace width. Three of seven crabs at station WB21 likely had bitter crab disease, based on the milky (rather than clear) coloration of the hemolymph and the opaque rather than slightly translucent appearance of the leg shell. In addition, one of five crabs at station CB35 may have had bitter crab disease.

To our knowledge, this study documented the first occurrence of legal size snow crab in the Central Alaskan Beaufort Sea as far east as 148°W. During the 2008 Western Beaufort Sea Fish Survey, legal size snow crab were first documented ever for the Western Beaufort Sea to ~152°W (Rand and Logerwell 2011). In terms of other commercially interesting crab species, we found a total of three blue king crabs, *Paralithodes platypus*, at two stations (Figure 15). Two were females (91.8 and 94.1 mm carapace length) and one was a male (102.8 mm carapace length). All three individuals were caught at 180 m water depth. To our knowledge, the only other records of blue king crab from the Beaufort Sea are from the 2008 Western Beaufort Sea fish survey where two specimens were caught. Two of our king crabs were caught in the central Beaufort Sea, i.e. farther west than the 2008 records.

Seabird observations and preliminary results (see Appendix C5)

Acknowledgements

We are grateful for the support and hard work of the captain and crew of the Norseman II and members of the science team who collected our samples. Funding for different elements of this cruise was provided by BOEM, the Coastal Marine Institute, and LGL.

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Table A1-1; Cruise Report Table 3. Location of 2011 Eastern Beaufort station locations.

Station	Station Depth (m)	Date	Latitude	Longitude	Notes
EB02	64	08/20/11	70.8725	-146.6500	
EB04	35	08/19/11	70.4360	-146.4200	
EB06	45	08/19/11	70.6667	-146.4938	
EB08	30	08/19/11	70.3367	-146.1104	
EB10	41	08/19/11	70.5619	-146.1066	
EB12	68	08/18/11	70.7782	-146.1099	
EB14	39	08/18/11	70.4561	-145.7967	
EB16	56	08/18/11	70.6503	-145.7977	
EB18	20	08/16/11	70.2165	-145.4433	Zooplankton Only
EB19	33	08/18/11	70.5520	-145.4381	
EB21	52	08/18/11	70.3315	-145.4430	
EB23	127	08/17/11	70.7739	-145.4070	
EB25	27	08/16/11	70.2163	-145.1065	
EB26	30	08/17/11	70.3304	-145.1053	Zooplankton Only
EB27	43	08/17/11	70.4521	-145.0877	
EB29	58	08/17/11	70.6698	-145.1038	
EB32	126	08/20/11	70.9101	-146.4159	

Table A1-2; Cruise Report Table 8. Location of 2011 Central Beaufort station locations.

Station	Station Depth (m)	Date Sampled	Latitude	Longitude	Notes
CB01	23	08/21/11	70.5145	-147.3533	
CB02	28	08/21/11	70.5570	-147.7415	
CB03	23	08/22/11	70.5928	-148.2158	
CB04	13	08/22/11	70.6262	-148.6868	
CB05	19	08/23/11	70.6548	-149.1974	
CB06	19	08/23/11	70.6970	-149.6623	
CB07	19	08/23/11	70.7384	-150.1203	
CB08	19	08/25/11	70.7432	-150.5349	
CB09	18	08/26/11	70.8136	-151.1057	
CB10	17	08/26/11	70.8556	-151.5946	
CB11	48	08/20/11	70.7583	-147.1254	
CB12	41	08/21/11	70.7989	-147.5143	
CB13	43	08/22/11	70.8133	-148.0767	
CB14	36	08/22/11	70.8528	-148.5788	
CB15	33	08/23/11	70.9201	-148.0300	
CB16	33	08/23/11	70.9602	-149.5722	
CB17	30	08/23/11	70.9791	-150.0197	
CB18	13	08/25/11	71.0344	-150.5549	
CB19	13	08/25/11	71.0585	-150.9187	
CB20	20	08/25/11	71.1149	-151.4424	
CB22	184	08/21/11	70.9950	-147.4627	
CB23	183	08/21/11	71.0686	-147.8788	
CB24	180	08/22/11	71.1592	-148.3365	
CB25	179	08/22/11	71.2073	-148.8749	
CB26	183	08/23/11	71.2111	-149.3684	
CB27	163	08/24/11	71.2184	-149.9031	
CB28	103	08/24/11	71.2520	-150.4104	
CB29	103	08/24/11	71.3151	-150.9197	
CB30	183	08/25/11	71.3610	-151.3092	
CB31	17	08/26/11	70.9089	-151.8422	
CB32	16	09/02/11	70.8096	-151.6320	
CB33	16	09/03/11	70.6700	-150.6458	
CB34	183	09/03/11	71.2805	-150.6733	
CB35	223	09/03/11	71.2883	-150.6699	

Table A1-3; Cruise Report Table 13. Location of 2011 Western Beaufort station locations.

Station	Station Depth (m)	Date	Latitude	Longitude	Notes
WB02	183	08/30/11	71.7344	-154.9747	
WB04	184	08/29/11	71.8418	-153.9206	
WB05	155	08/30/11	71.8086	-154.4321	
WB07	183	08/27/11	71.7085	-152.9630	
WB08	183	08/27/11	71.6546	-152.6614	
WB10	53	08/29/11	71.7238	-153.9227	
WB12	52	08/29/11	71.4710	-153.9570	
WB13	43	08/31/11	71.4000	-153.9770	
WB14	41	09/01/11	71.2457	-153.1169	
WB15	79	08/29/11	71.3723	-153.0386	
WB16	65	08/28/11	71.0000	-153.0000	
WB17	24	08/26/11	71.1594	-152.2214	
WB18	51	09/02/11	71.2730	-152.3036	
WB19	90	08/26/11	71.3442	-152.0087	
WB20	184	08/27/11	71.5000	-152.1833	
WB21	48	08/31/11	71.5933	-155.0366	
WB22	51	08/30/11	71.6912	-154.5217	
WB23	60	08/28/11	71.5343	-152.9027	
WB24	53	08/28/11	71.5634	-153.5034	
WB25	23	09/01/11	71.2221	-154.0137	
WB26	49	08/29/11	71.5988	-153.9508	
WB27	178	08/30/11	71.8512	-154.4951	
WB28	183	08/30/11	71.6624	-155.2461	
WB29	15	08/31/11	71.4726	-155.0913	
WB30	13	08/31/11	71.2433	-155.1354	
WB31	183	08/28/11	71.8005	-153.4167	
WB32	83	08/28/11	71.7340	-153.5261	
WB34	25	09/01/11	71.1379	-153.1948	
WB35	18	09/01/11	71.1017	-154.0514	
WB36	154	09/02/11	71.5773	-152.5094	

Table A1-4; Cruise Report Table 18. Stations sampled with bongo and vertical nets.

Western	Bongo	Vertical	Notes	Central	Bongo	Vertical	Notes	Eastern	Bongo	Vertical	Notes
WB02	1	1		CB01	1	1		EB02	1	1	
WB04	1	1		CB02	1	1		EB04	1	1	
WB05	1	0	High seas	CB03	1	1		EB06	1	1	
WB07	1	1		CB04	1	1		EB08	1	1	
WB08	1	1		CB05	1	1		EB10	1	1	
WB10	1	1		CB06	1	1		EB12	1	1	
WB12	1	1		CB07	1	1		EB14	1	1	
WB13	1	1		CB08	1	1		EB16	1	1	
WB14	1	1		CB09	1	1		EB18	1	1	
WB15	1	1		CB10	1	1		EB19	1	1	
WB16	1	1		CB11	1	1		EB21	1	1	
WB17	1	1		CB12	1	1		EB23	1	1	
WB18	1	1		CB13	1	0	High seas	EB25	1	1	
WB19	1	1		CB14	1	1		EB26	1	1	
WB20	1	1		CB15	1	1		EB27	1	1	
WB21	1	1		CB16	1	1		EB29	1	1	
WB22	1	1		CB17	1	1		EB32	1	0	High seas
WB23	1	1		CB18	1	1					
WB24	1	1		CB19	1	1					
WB25	1	1		CB20	2	1					
WB26	1	1		CB22	1	1					
WB27	1	0	High seas	CB23	1	0	High seas				
WB28	1	1		CB24	1	0	High seas				
WB29	1	1		CB25	1	1					
WB30	1	1		CB26	1	1					
WB31	1	1		CB27	1	1					
WB32	1	1		CB28	1	1					
WB34	1	1	Double bongo	CB29	1	1					
WB35	1	1		CB30	1	1					
WB36	1	1		CB31	1	1					
				CB32	1	1					
				CB33	1	1	Double bongo				

Table A1-5; Cruise Report Table 19. Standardized biomass and abundance of epibenthic invertebrates collected in benthic trawls.

Station	Gear type/ Number	Date	Time trawled (min)	Percent sampled	Standardized total biomass (kg)	Standardized total abundance	Number of taxa	VanVeen sample	Station	Gear type/ Number	Date	Time trawled (min)	Percent sampled	Standardized total biomass (kg)	Standardized total abundance	Number of taxa	VanVeen sample
EB23	PSBT-1	17-Aug	2	100%	5.15	3406	22	X	WB20	PSBT-A-45	27-Aug	2.517	2%	44.2	50566	20	X
EB21	PSBT-4	17-Aug	2.033	25%	28.89	8377	42	X	WB07	PSBT-A-47	28-Aug	2	10%	55.23	28566	33	X
EB16	PSBT-7	18-Aug	2.167	100%	3.09	3093	32	X	WB23	PSBT-A-51	28-Aug	2.167	100%	0.86	683	29	X
EB19	PSBT-A-2	18-Aug	2.283	50%	3.18	1312	23	X	WB24	PSBT-A-50	28-Aug	2.067	100%	3.36	1164	29	X
EB12	PSBT-8	18-Aug	2.083	25%	3.75	4363	31	X	WB31	PSBT-A-48	28-Aug	2.033	10%	40.16	25930	27	X
EB14	PSBT-6	18-Aug	5.283	50%	5.64	576	30	X	WB10	PSBT-A-56	29-Aug	2.517	50%	9.93	3127	38	X
EB08	PSBT-11	19-Aug	1.5	100%	1.2	720	26	X	WB12	PSBT-A-54	29-Aug	2.183	100%	1.93	635	32	X
EB04	PSBT-12	19-Aug	1.717	100%	2.2	1076	30	X	WB15	PSBT-A-53	29-Aug	2.233	33.33%	13.43	3684	44	X
EB06	PSBT-A-5	19-Aug	3.283	50%	9.21	1358	26	X	WB16	PSBT-A-52	29-Aug	2.033	50%	8.2	5854	31	X
EB10	PSBT-10	19-Aug	2.067	100%	13.18	2165	35	X	WB26	PSBT-A-55	29-Aug	2.167	50%	3.05	959	26	X
EB02	PSBT-A-7	20-Aug	5.05	100%	0.5	627	23	X	WB04	PSBT-A-58	30-Aug	1.05	5%	190.82	104383	41	X
EB32	PSBT-15	20-Aug	1.167	100%	4.3	1284	20	X	WB05	PSBT-A-60	30-Aug	1.7	12.50%	17.37	25966	27	NS
CB11	PSBT-A-8	20-Aug	5.3	50%	6.78	620	26	X	WB22	PSBT-A-61	30-Aug	2.1	100%	0.85	706	32	X
CB01	PSBT-16	21-Aug	1.067	50%	4.82	480	27	X	WB27	PSBT-A-59	30-Aug	1.9	4%	24.33	85493	31	NS
CB02	PSBT-A-9	21-Aug	3.017	100%	0.44	157	15	X	WB02	PSBT-A-63	31-Aug	4.533	8.33%	19.79	6360	35	NS
CB12	PSBT-A-11	21-Aug	5	100%	1.23	771	31	X	WB13	PSBT-A-69	31-Aug	2.35	100%	1.67	405	29	X
CB22	PSBT-A-12	21-Aug	5.183	100%	0.57	819	20	X	WB21	PSBT-17	31-Aug	2.683	33.33%	7.53	2502	30	X
CB03	PSBT-A-15	23-Aug	3.183	100%	1.12	335	27	X	WB28	PSBT-A-64	31-Aug	1	12.50%	116.19	35050	31	X
CB04	PSBT-A-16	22-Aug	3.017	100%	0.11	118	15	X	WB30	PSBT-A-68	31-Aug	1.05	100%	0.09	21	3	X
CB13	PSBT-A-14	22-Aug	3	25%	1.44	1267	25	X	WB14	PSBT-20	1-Sep	1.217	100%	0.8	766	26	X
CB14	PSBT-A-17	22-Aug	2.7	100%	0.53	321	19	X	WB25	PSBT-A-70	1-Sep	2.017	100%	0.47	166	15	X
CB23	PSBT-A-13	22-Aug	2.883	25%	5.27	5689	26	X	WB32	PSBT-A-74	1-Sep	2.017	25%	12.77	8006	34	X
CB24	PSBT-A-18	22-Aug	4.833	5%	2.86	3301	17	X	WB34	PSBT-A-72	1-Sep	1.617	100%	0.16	59	12	X
CB05	PSBT-A-22	23-Aug	2.95	100%	0.05	151	6	X	WB35	PSBT-A-71	1-Sep	2.2	100%	0.4	164	15	X
CB06	PSBT-A-23	23-Aug	1.333	100%	1.94	124	10	X	CB32	PSBT-A-80	2-Sep	2.967	100%	0.1	35	6	X
CB15	PSBT-A-20	23-Aug	3.117	100%	0.12	113	18	X	WB18	PSBT-A-79	2-Sep	1.6	25%	6.56	3669	27	X
CB25	PSBT-A-19	23-Aug	2.033	12.50%	16.99	9402	24	X	WB36	PSBT-A-78	2-Sep	1.15	12.50%	15.77	14539	30	X
CB07	PSBT-A-25	24-Aug	2.033	100%	0.02	45	7	X	CB33	PSBT-A-83	3-Sep	2.083	100%	0.1	56	5	X
CB17	PSBT-A-26	24-Aug	1.583	100%	0.15	117	12	X	CB34	PSBT-A-87	3-Sep	1	8.33%	50.36	58723	26	X
CB27	PSBT-A-31	24-Aug	2	2.78%	34.65	36093	15	X	CB35	PSBT-A-88	3-Sep	1.183	6.67%	85.35	29768	16	X
CB28	PSBT-A-32	24-Aug	2.117	2.50%	67.98	57686	12	X	WB32-R	PSBT-A-49	28-Aug	2.117	12.50%	24.92	28885	39	--
CB29	PSBT-A-34	24-Aug	2.233	8.33%	11.06	13194	26	X	WB21-GC	PSBT-17	31-Aug	2.083	25%	9.93	3293	26	--
CB08	PSBT-A-36	25-Aug	2.1	100%	0.35	137	11	X	WB32-R2	PSBT-A-75	1-Sep	2.9	16.67%	15.32	22350	33	--
CB16	PSBT-A-28	23-Aug	3.033	100%	0.64	195	20	X	WB13-GC	PSBT-18	1-Sep	2.25	16.67%	7.47	1647	26	--
CB20	PSBT-A-35	25-Aug	2.15	100%	0.03	152	11	X	WB14-GC	PSBT-20	1-Sep	1.65	25.00%	9.98	4558	33	--
CB09	PSBT-A-38	26-Aug	2.65	100%	0.29	120	6	X	WB31-R	PSBT-A-76	1-Sep	2.083	2.78%	67.92	11236	28	--
CB10	PSBT-A-39	26-Aug	2.083	100%	0.22	58	4	X	WB18-GC	PSBT-21	2-Sep	1.617	33.33%	8.54	1568	26	--
CB31	PSBT-A-40	26-Aug	2.1	100%	0.19	54	4	X	WB07-R	PSBT-A-77	2-Sep	2.067	5%	33.54	10695	33	--
WB17	PSBT-A-42	26-Aug	2	100%	0.25	330	12	X	CB33-GC	PSBT-23	3-Sep	0.833	100%	1.13	234	8	--
WB19	PSBT-A-43	26-Aug	2.6	100%	4.47	680	38	X	CB33-R	PSBT-A-82	3-Sep	1.983	100%	0.05	59	6	--
CB30	PSBT-A-44	27-Aug	2.4	4%	19.56	43255	23	X	CB34-R	PSBT-A-85	3-Sep	1.133	6.67%	37.98	48214	13	--
WB08	PSBT-A-46	27-Aug	2.167	50%	7.27	4508	32	X	CB35-R	PSBT-A-89	3-Sep	1.117	3.33%	70.46	63210	17	--

Table A1-6; Cruise Report Table 20. Table of fishing effort using Isaacs-Kidd midwater trawl (IKMT).

Date Sampled	Station	Haul	Station Depth (m)	Start Latitude	Start Longitude	End Latitude	End Longitude	Tow Distance (m)	Start Time	Duration (Minutes)	Quantitative (Y/N)	Haul Notes
8/16/2011	EB25	1	14.5	70.2023	-145.1502	-	-	-	21:08	-	N	Problems with winch
8/16/2011	EB25	2	7.5	70.2081	-145.1442	-	-	-	21:18	-	N	Problems with winch
8/16/2011	EB25	3	14.5	70.2126	-145.1426	-	-	-	21:28	-	N	Problems with winch
8/16/2011	EB25	4	12	70.2237	-145.1265	-	-	-	21:45	-	N	Irregular deployment
8/17/2011	EB27	5	43	70.4562	-145.1062	70.4594	-145.0881	759	7:10	6.48	Y	
8/17/2011	EB29	6	58	70.6723	-145.1237	70.6834	-145.1192	1243	11:30	19.25	Y	
8/17/2011	EB23	7	125	70.7730	-145.4203	70.7717	-145.4727	1925	16:08	27.38	Y	
8/17/2011	EB21	8	118	70.5583	-145.4156	70.5646	-145.4055	796	22:07	8.00	Y	
8/18/2011	EB19	9	23	70.3315	-145.4387	70.3305	-145.4543	593	6:07	8.53	Y	
8/18/2011	EB14	10	39	70.4543	-145.7945	70.4595	-145.7955	581	12:20	7.85	Y	
8/18/2011	EB16	11	32	70.6607	-145.7868	70.6693	-145.8030	1130	17:37	15.13	Y	
8/18/2011	EB12	12	26	70.7769	-146.1059	70.7872	-146.0754	1601	21:27	13.13	Y	
8/19/2011	EB10	13	41	70.5620	-146.1045	70.5617	-146.1352	1138	3:26	12.68	Y	
8/19/2011	EB08	14	20	70.3400	-146.1297	70.3435	-146.1481	790	9:04	8.25	Y	
8/19/2011	EB04	15	28	70.4476	-146.4443	-	-	-	14:52	-	N	Net hit bottom
8/19/2011	EB06	16	44.5	70.6699	-146.4733	-	-	-	22:29	-	N	Problems with winch
8/19/2011	EB06	17	33	70.6727	-146.4666	70.6672	-146.4586	683	22:46	8.95	Y	
8/20/2011	EB32	18	126	70.9101	-146.4159	70.9179	-146.4106	887	3:31	13.30	Y	
8/20/2011	EB02	19	53	70.8668	-146.6944	70.8741	-146.6779	1010	11:26	16.65	Y	
8/20/2011	CB11	20	38	70.7646	-147.0605	-	-	-	18:30	-	N	Net hit bottom
8/20/2011	CB11	21	48	70.7630	-147.0866	-	-	-	19:06	-	N	Problems with winch
8/20/2011	CB11	22	38	70.7641	-147.1445	70.7651	-147.1647	749	19:21	7.30	Y	
8/21/2011	CB01	23	23	70.5121	-147.3601	70.5132	-147.3387	803	1:56	8.50	Y	
8/21/2011	CB02	24	18	70.5553	-147.6944	70.5552	-147.7097	567	5:49	4.65	Y	
8/21/2011	CB12	25	28	70.8034	-147.5344	70.8020	-147.5336	162	11:54	8.08	Y	
8/21/2011	CB22	26	143	70.9988	-147.4913	70.9958	-147.4402	1879	16:54	23.08	Y	
8/21/2011	CB23	27	53	71.0780	-147.9403	71.0737	-147.9076	1270	21:03	10.65	y	
8/22/2011	CB13	28	33	70.8300	-148.0729	70.8289	-148.0864	508	1:33	8.42	Y	
8/22/2011	CB03	29	13	70.5902	-148.1934	-	-	-	5:46	-	N	Irregular deployment
8/22/2011	CB03	30	13	70.5986	-148.1941	70.6025	-148.2002	489	5:59	4.23	Y	
8/22/2011	CB04	31	13	70.6222	-148.6753	70.6224	-148.6872	436	9:01	6.95	Y	
8/22/2011	CB14	32	23	70.8512	-148.5806	70.8543	-148.5893	466	12:14	7.12	Y	
8/22/2011	CB24	33	180	71.1647	-148.3697	71.1577	-148.3155	2093	16:28	33.32	Y	
8/22/2011	CB25	34	173	71.2101	-148.8456	71.2151	-148.8494	570	19:58	34.63	Y	
8/23/2011	CB15	35	23	70.9133	-149.0216	70.9203	-149.0330	875	2:59	8.83	Y	
8/23/2011	CB05	36	9	70.6538	-149.1866	70.6561	-149.1784	246	7:04	3.28	Y	Estimated distance using average speed for gear
8/23/2011	CB06	37	11	70.6942	-149.6676	70.6978	-149.6732	451	10:16	5.70	Y	
8/23/2011	CB07	38	11	70.7358	-150.1208	70.7366	-150.1285	296	13:44	3.92	Y	
8/23/2011	CB17	39	18	70.9837	-149.9982	70.9886	-149.9896	636	17:11	8.92	Y	
8/23/2011	CB16	40	23	70.9566	-149.5855	70.9587	-149.5653	768	20:17	6.43	Y	
8/24/2011	CB26	41	173	71.2112	-149.4081	71.2067	-149.3476	2222	1:01	43.75	Y	
8/24/2011	CB27	42	163	71.2172	-149.8839	71.2058	-149.8810	1275	7:25	41.53	Y	
8/24/2011	CB28	43	103	71.2565	-150.4551	71.2490	-150.3323	4467	13:03	52.82	Y	
8/24/2011	CB29	44	103	71.3234	-150.9649	71.3195	-150.9505	677	17:30	51.42	Y	
8/25/2011	CB20	45	8	71.1112	-151.4769	-	-	-	6:15	-	N	Low catch, did not retow
8/25/2001	CB19	46	13	71.0590	-150.9314	71.0570	-150.9448	527	11:17	6.25	Y	
8/25/2001	CB18	47	13	71.0354	-150.5512	71.0365	-150.5558	208	13:01	5.48	Y	
8/25/2011	CB08	48	13	70.7437	-150.5386	70.7404	-150.5334	419	23:22	4.48	Y	
8/26/2011	CB09	49	8	70.8139	-151.1147	70.8133	-151.1051	355	4:42	3.25	Y	
8/26/2011	CB10	50	11	70.8576	-151.6209	70.8577	-151.6100	398	8:38	4.82	Y	
8/26/2011	CB31	51	11	70.9067	-151.8464	70.9022	-151.8389	568	11:41	11.13	Y	
8/26/2011	WB17	52	14	71.1420	-152.1886	71.1475	-152.1931	633	15:33	7.02	Y	
8/26/2011	WB19	53	76	71.3537	-151.9819	71.3581	-151.9688	677	19:21	22.47	Y	
8/26/2011	CB30	54	173	71.3640	-151.3946	71.3589	-151.4260	1255	23:05	59.37	Y	
8/27/2011	WB20	55	173	71.5078	-152.1978	71.4935	-152.2125	1669	6:32	52.92	Y	
8/27/2011	WB08	56	173	71.6495	-152.6441	71.6434	-152.6636	962	11:42	50.10	Y	
8/27/2011	WB07	57	173	71.7090	-152.9661	71.6984	-152.9587	1212	18:18	67.80	Y	
8/28/2011	WB31	58	173	71.8026	-153.4420	71.7901	-153.4296	1448	6:16	56.82	Y	
8/28/2011	WB32	59	73	71.7360	-153.5365	71.7362	-153.4751	2139	9:15	28.78	Y	
8/28/2011	WB24	60	43	71.5620	-153.5197	71.5579	-153.4896	1156	14:33	16.62	Y	
8/28/2011	WB23	61	61.5	71.5303	-152.8530	71.5277	-152.8182	1258	18:11	14.85	Y	
8/28/2011	WB16	62	53	71.4572	-153.0317	-	-	-	22:40	-	N	Irregular deployment
8/29/2011	WB15	63	68	71.3788	-153.0619	71.3876	-153.0350	1364	3:10	20.47	Y	
8/29/2011	WB12	64	41	71.4747	-153.9710	71.4829	-153.9983	1330	8:53	16.85	Y	
8/29/2011	WB26	65	36	71.6021	-153.9559	71.5962	-153.9431	798	11:47	13.00	Y	
8/29/2011	WB10	66	52	71.7216	-153.8946	71.7278	-153.8809	837	15:30	16.40	Y	
8/29/2011	WB04	67	173	71.8452	-153.9793	71.8388	-153.8567	4306	20:00	47.72	Y	
8/30/2011	WB27	68	178	71.8706	-154.4235	71.8681	-154.3025	4198	2:20	49.35	Y	
8/30/2011	WB05	69	143	71.8073	-154.4350	71.7877	-154.5038	3239	6:47	39.00	Y	
8/30/2011	WB22	70	43	71.6934	-154.5298	71.6910	-154.4957	1217	11:39	12.80	Y	
8/30/2011	WB02	71	173	71.7335	-154.9817	71.7394	-154.9255	2064	16:28	62.75	Y	
8/31/2011	WB28	72	173	71.6952	-155.1087	71.6913	-155.0808	1065	0:15	43.62	Y	
8/31/2011	WB21	73	38	71.5932	-154.9941	71.5902	-155.0233	1079	5:55	12.77	Y	
8/31/2011	WB29	74	15	71.4695	-155.0917	71.4704	-155.0687	820	10:54	8.90	Y	
8/31/2011	WB30	75	8	71.2415	-155.1407	71.2370	-155.1244	770	14:25	7.53	Y	
8/31/2011	WB30	76	33	71.3964	-153.9910	71.3837	-153.9632	1726	19:25	13.77	Y	
9/1/2011	WB25	77	13	71.2194	-154.0342	71.2165	-154.0242	482	3:16	4.08	Y	
9/1/2011	WB35	78	8	71.1083	-154.0537	71.1130	-154.0583	544	6:22	12.50	Y	
9/1/2011	WB34	79	13	71.1350	-153.2080	71.1312	-153.1961	596	11:59	5.98	Y	
9/1/2011	WB14	80	31	71.2422	-153.1255	71.2329	-153.1150	1098	15:00	11.90	Y	
9/2/2011	WB36	81	143	71.5776	-152.5094	71.5490	-152.4294	4241	9:06	47.92	Y	
9/2/2011	WB18	82	38	71.2709	-152.3096	71.2811	-152.2815	1510	13:38	15.50	Y	
9/2/2011	CB32	83	10	70.8028	-151.6340	70.8091	-151.6408	740	19:31	6.87	Y	
9/3/2011	CB33	84	8	70.6679	-150.6653	70.6709	-150.6895	949	0:59	8.40	Y	

Table A1-7; Cruise Report Table 23. Table of fishing effort using 9-m otter trawl (OT).

Date Sampled	Station	Haul	Station Depth (m)	Start Latitude	Start Longitude	End Latitude	End Longitude	Tow Distance (m)	Start Time	Duration (Minutes)	Quantitative (Y/N)	Haul Notes
8/17/2011	EB25	1	27	70.2337	-145.0941	70.2389	-145.0917	586	0:10	10.05	Y	
8/17/2011	EB27	2	43	70.4634	-145.0757	70.4700	-145.0744	735	7:49	9.97	Y	
8/17/2011	EB29	3	65.3	70.6767	-145.1015	-	-	-	13:19	-	N	Did not hit bottom
8/17/2011	EB23	4	155	70.7917	-145.4436	-	-	-	18:27	-	N	Irregular deployment
8/18/2011	EB21	5	50.7	70.5537	-145.4312	70.5585	-145.4389	606	2:06	9.97	Y	
8/18/2011	EB14	6	39	70.4589	-145.8543	70.4650	-145.8531	680	14:40	10.25	Y	
8/18/2011	EB16	7	56	70.6761	-145.7929	70.6757	-145.7747	670	18:42	10.00	Y	
8/18/2011	EB12	8	65	70.7838	-146.1465	70.7822	-146.1308	602	21:43	10.00	Y	
8/19/2011	EB10	9	40.4	70.5537	-145.1527	70.5484	-145.1464	632	5:01	10.15	Y	
8/19/2011	EB08	10	30	70.3275	-146.1097	-	-	-	10:55	-	N	Lost net
8/19/2011	EB04	11	35.5	70.4464	-146.4159	70.4483	-146.4022	547	17:15	8.55	Y	
8/20/2011	EB02	12	63	70.8635	-146.6615	70.8640	-146.6530	314	14:57	5.53	Y	
8/20/2011	CB11	13	48	70.7622	-147.0601	70.7593	-147.0446	653	21:53	15.03	Y	
8/21/2011	CB02	14	28	70.5578	-147.7240	70.5572	-147.7191	190	7:29	3.13	Y	
8/21/2011	CB12	15	41.5	70.7984	-147.5834	70.7983	-147.5913	287	13:00	5.17	Y	
8/23/2011	CB06	16	19	70.6991	-149.7068	70.7003	-149.7148	321	11:40	4.98	Y	
8/23/2011	CB07	17	18.5	70.7418	-150.1480	70.7430	-150.1553	301	14:19	4.97	Y	
8/24/2011	CB26	18	183	71.2108	-149.3905	71.2107	-149.3885	72	3:44	1.52	Y	
8/24/2011	CB29	19	182	71.3171	-150.9311	-	-	-	20:10	-	N	Irregular deployment
8/25/2001	CB20	20	23	71.1190	-151.4511	-	-	-	8:33	-	N	Damaged net
8/26/2011	CB08	21	19	70.7134	-150.4720	70.7136	-150.4567	560	1:23	8.78	Y	
8/26/2011	CB10	22	17	70.8563	-151.5913	-	-	-	9:14	-	N	Damaged net
8/26/2011	CB31	23	17	70.9091	-151.8430	-	-	-	12:34	-	N	Unable to sort or subsample catch
8/26/2011	WB19	24	90	71.3451	-151.9443	71.3440	-151.9337	398	20:40	5.98	Y	
8/27/2011	CB30	25	183	71.3653	-151.3811	-	-	-	1:56	-	N	Irregular deployment
8/27/2011	WB08	26	183	71.6464	-152.6287	71.6448	-152.6218	298	15:02	4.97	Y	
8/28/2011	WB07	27	183	71.7041	-152.9316	71.7031	-152.9232	312	1:30	5.03	Y	
8/28/2011	WB32	28	84.5	71.7329	-153.5184	71.7319	-153.5086	357	11:54	5.02	Y	
8/28/2011	WB24	29	53	71.5562	-153.4857	71.5548	-153.4771	341	15:31	5.07	Y	
8/28/2011	WB23	30	60	71.5347	-152.9007	71.5343	-152.8909	346	19:12	5.12	Y	
8/28/2011	WB16	31	65.5	71.4563	-153.0409	71.4571	-153.0492	306	23:57	4.95	Y	
8/29/2011	WB15	32	79	71.3750	-153.0471	-	-	-	4:28	-	N	Did not hit bottom
8/29/2011	WB15	33	79	71.3738	-153.0492	71.3723	-153.0420	303	5:02	5.05	Y	
8/29/2011	WB12	34	51.5	71.4848	-153.9656	71.4849	-153.9561	336	9:47	5.10	Y	
8/29/2011	WB10	35	53	71.7146	-153.8965	71.7140	-153.9067	363	16:27	5.00	Y	
8/30/2011	WB05	36	155	71.8111	-154.3829	71.8104	-154.3913	299	8:38	4.83	Y	
8/30/2011	WB22	37	50.5	71.6830	-154.4716	71.6838	-154.4803	316	12:41	5.05	Y	
8/30/2011	WB02	38	183	71.7397	-154.9486	71.7417	-154.9410	342	19:31	5.15	Y	
8/31/2011	WB28	39	183	71.6678	-155.2232	71.6664	-155.2285	244	2:35	4.22	Y	
8/31/2011	WB21	40	47	71.5906	-155.0640	71.5904	-155.0729	312	7:07	5.13	Y	
8/31/2011	WB21	41	48	71.5912	-155.0344	-	-	-	7:43	-	N	Unable to sort or subsample catch
8/31/2011	WB13	42	43	71.4007	-154.0049	71.4022	-153.9972	315	22:51	4.75	Y	
9/1/2011	WB25	43	43	71.1085	-154.0713	-	-	-	7:15	-	N	Damaged net

Table A1-8; Cruise Report Table 26. Table of fishing effort using 3-m plumb staff beam trawl (PSBT).

Date Sampled	Station	Haul	Station Depth (m)	Start Latitude	Start Longitude	End Latitude	End Longitude	Tow Distance (m)	Start Time	Duration (Minutes)	Quantitative (Y/N)	Haul Notes
8/17/2011	EB23	1	127	70.7826	-145.4511	70.7835	-145.4493	120	17:09	2.00	Y	
8/17/2011	EB21	2	53	70.5645	-145.3907	-	-	-	23:06	-	N	Did not hit bottom
8/17/2011	EB21	3	53	70.5706	-145.3912	-	-	-	23:21	-	N	Did not hit bottom
8/17/2011	EB21	4	53	70.5782	-145.4090	70.5790	-145.4115	125	23:50	2.03	Y	
8/18/2011	EB19	5	33.5	70.3321	-145.4444	-	-	-	6:59	-	N	Problems with winch
8/18/2011	EB14	6	38	70.4561	-145.8068	70.4562	-145.8171	383	13:38	5.28	Y	
8/18/2011	EB16	7	56	70.6742	-145.8068	70.6758	-145.8064	180	18:10	2.17	Y	
8/18/2011	EB12	8	63	70.7867	-146.0878	70.7871	-146.0920	159	22:15	2.08	Y	
8/18/2011	EB12	9	75	70.7881	-146.0937	70.7891	-146.0914	143	22:41	2.15	Y	
8/19/2011	EB10	10	41	70.5610	-146.1418	-	-	-	na	-	N	Irregular deployment
8/19/2011	EB08	11	30.2	70.3391	-146.1232	70.3387	-146.1209	97	9:33	1.50	Y	
8/19/2011	EB04	12	35.6	70.4460	-146.4417	-	-	-	15:25	-	N	Damaged net
8/19/2011	EB06	13	45	70.6710	-146.4162	-	-	-	23:24	-	N	Damaged net
8/20/2011	EB32	14	207	70.9312	-146.4256	-	-	-	4:47	-	N	Irregular deployment
8/20/2011	EB32	15	183	70.9261	-146.4351	-	-	-	5:43	-	N	Damaged net
8/21/2011	CB01	16	23	70.5153	-147.3249	70.5153	-147.3229	74	2:18	1.07	Y	
8/31/2011	WB21	17	48	71.5943	-154.9852	71.5936	-154.9890	158	8:44	2.08	Y	
9/1/2011	WB13	18	43	71.3973	-153.9954	71.3978	-153.9922	128	23:33	2.25	Y	
9/1/2011	WB13	19	43	71.3966	-154.0001	-	-	-	0:15	-	N	Towed only for snow crab
9/1/2011	WB14	20	41	71.2467	-153.1024	71.2473	-153.0999	116	15:55	1.65	Y	
9/2/2011	WB18	21	51	71.2867	-152.2603	71.2854	-152.2608	146	14:28	1.62	Y	
9/2/2011	CB32	22	15	70.8258	-151.6615	-	-	-	20:27	-	N	Unable to sort or subsample catch
9/3/2011	CB33	23	16	70.6802	-150.6911	70.6799	-150.6892	77	1:49	0.83	Y	

Table A1-9; Cruise Report Table 27.Table of fishing effort using modified 3-m plumb staff beam trawl (PSBT-A).

Date Sampled	Station	Haul	Station Depth (m)	Start Latitude	Start Longitude	End Latitude	End Longitude	Tow Distance (m)	Start Time	Duration (Minutes)	Quantitative (Y/N)	Haul Notes
8/18/2011	EB19	1	34	70.3512	-145.4654	-	-	-	7:53	-	N	Did not hit bottom
8/18/2011	EB19	2	33	70.3357	-145.4272	70.3368	-145.4260	133	9:17	2.28	Y	
8/19/2011	EB04	3	40	70.4440	-146.4477	-	-	-	16:15	-	N	Low catch, retowed
8/19/2011	EB04	4	34.2	70.4429	-146.4381	70.4444	-146.4486	423	16:36	5.12	Y	
8/19/2011	EB06	5	45	70.6751	-146.4133	70.6749	-146.4079	197	23:57	3.28	Y	
8/20/2011	EB02	6	65	70.8689	-146.6689	-	-	-	12:52	-	N	Irregular deployment
8/20/2011	EB02	7	65	70.8653	-146.6765	70.8654	-146.6674	333	13:31	5.05	Y	
8/20/2011	CB11	8	47.5	70.7696	-147.1529	70.7698	-147.1439	327	20:28	5.30	Y	
8/21/2011	CB02	9	28	70.5544	-147.7398	70.5540	-147.7448	192	6:08	3.02	Y	
8/21/2011	CB12	10	41	70.8016	-147.5456	70.8010	-147.5497	165	12:16	3.03	Y	
8/21/2011	CB12	11	41	70.7990	-147.5654	70.7990	-147.5683	360	12:36	5.00	Y	Estimated distance using average speed for gear
8/21/2011	CB22	12	184	70.9949	-147.4670	70.9935	-147.4590	330	17:35	5.18	Y	
8/21/2011	CB23	13	183	71.0687	-147.8814	71.0691	-147.8865	190	21:40	2.88	Y	
8/22/2011	CB13	14	43	70.8265	-148.0629	70.8267	-148.0575	198	1:57	3.00	Y	
8/22/2011	CB03	15	23	70.6070	-148.2014	70.6088	-148.2013	200	6:15	3.18	y	
8/22/2011	CB04	16	23	70.6226	-148.6920	-	-	-	9:16	-	N	Boulder in net
8/22/2011	CB14	17	36	70.8558	-148.5888	70.8572	-148.5868	173	12:31	2.70	Y	
8/22/2011	CB24	18	182	71.1597	-148.3424	-	-	-	17:23	-	N	Damaged net
8/22/2011	CB25	19	179	71.2099	-148.8315	71.2099	-148.8279	127	20:58	2.03	Y	
8/23/2011	CB15	20	33	70.9253	-149.0406	70.9271	-149.0421	199	3:22	3.12	Y	
8/23/2011	CB05	21	19	70.6614	-149.1626	-	-	-	7:20	-	N	Irregular deployment
8/23/2011	CB05	22	19	70.6666	-149.1558	70.6677	-149.1539	144	7:32	1.95	Y	
8/23/2011	CB06	23	19	70.6941	-149.6780	70.6948	-149.6796	98	11:12	1.33	Y	
8/23/2011	CB06	24	19	70.6962	-149.6886	70.6975	-149.6932	219	11:23	3.03	Y	
8/23/2011	CB07	25	18.5	70.7382	-150.1366	70.7395	-150.1384	154	14:00	2.03	Y	
8/23/2011	CB17	26	29.5	70.9925	-149.9923	70.9932	-149.9933	87	17:31	1.58	Y	
8/23/2011	CB17	27	29.5	71.0004	-150.0019	-	-	-	17:53	-	N	Unable to sort or subsample catch
8/23/2011	CB16	28	33	70.9612	-149.5481	70.9622	-149.5433	211	20:35	3.03	Y	
8/24/2011	CB26	29	183	71.2106	-149.3799	-	-	-	2:10	-	N	Damaged net
8/24/2011	CB27	30	183	71.2139	-149.8459	-	-	-	8:36	-	N	Did not hit bottom
8/24/2011	CB27	31	183	71.2162	-149.8723	-	-	-	9:12	-	N	Overfull cod end
8/24/2011	CB28	32	183	71.2530	-150.4217	-	-	-	14:21	-	N	Overfull cod end
8/24/2011	CB29	33	183	71.3214	-150.9592	-	-	-	18:47	-	N	Did not hit bottom
8/24/2011	CB29	34	183	71.3201	-150.9501	-	-	-	19:20	-	N	Irregular deployment
8/25/2001	CB20	35	20	71.1186	-151.4259	71.1184	-151.4224	127	7:52	2.15	Y	
8/25/2011	CB08	36	19	70.7231	-150.5198	70.7220	-150.5178	145	0:27	2.10	Y	
8/26/2011	CB08	37	19	70.7193	-150.5014	70.7177	-150.4979	221	0:48	3.55	Y	
8/26/2011	CB09	38	17.5	70.8142	-151.1051	70.8134	-151.1020	144	5:28	2.65	Y	
8/26/2011	CB10	39	17	70.8567	-151.5893	70.8565	-151.5852	152	8:54	2.08	Y	
8/26/2011	CB31	40	17	70.9093	-151.8409	70.9081	-151.8428	146	12:06	2.10	Y	
8/26/2011	WB17	41	24	71.1551	-152.1985	71.1555	-152.2001	72	15:53	1.03	Y	
8/26/2011	WB17	42	24	71.1552	-152.2098	71.1529	-152.2059	289	16:04	4.20	Y	
8/26/2011	WB19	43	89	71.3515	-151.9643	71.3525	-151.9677	161	19:59	2.60	Y	
8/27/2011	CB30	44	183	71.3638	-151.3996	71.3636	-151.3956	141	0:31	2.40	Y	
8/27/2011	WB20	45	184	71.5015	-152.1839	71.5004	-152.1813	151	9:05	2.52	Y	
8/27/2011	WB08	46	183	71.6519	-152.6486	71.6512	-152.6456	133	14:13	2.17	Y	
8/28/2011	WB07	47	183	71.7110	-152.9747	71.7103	-152.9702	175	0:27	2.00	Y	
8/28/2011	WB31	48	183	71.7983	-153.4219	71.7975	-153.4194	125	7:41	2.03	Y	
8/28/2011	WB32	49	83	71.7329	-153.5032	71.7324	-153.5159	152	11:18	2.12	Y	Estimated distance using average speed for gear
8/28/2011	WB24	50	53	71.5069	-153.5584	71.5559	-153.5057	149	15:02	2.07	Y	Estimated distance using average speed for gear
8/28/2011	WB23	51	60.5	71.5298	-152.8473	71.5301	-152.8524	186	18:46	2.17	Y	
8/28/2011	WB16	52	65	71.4517	-153.0111	71.4510	-153.0077	145	23:20	2.03	Y	
8/29/2011	WB15	53	78.5	71.3785	-153.0231	71.3774	-153.0213	143	3:53	2.23	Y	
8/29/2011	WB12	54	51.5	71.4817	-153.9921	71.4820	-153.9877	160	9:22	2.18	Y	
8/29/2011	WB26	55	48.5	71.6180	-153.8449	71.6177	-153.8487	135	12:50	2.17	Y	
8/29/2011	WB10	56	53	71.7200	-153.8715	71.7186	-153.8712	158	16:00	2.52	Y	
8/29/2011	WB04	57	183	71.8407	-153.8933	-	-	-	21:11	-	N	Did not hit bottom
8/29/2011	WB04	58	184	71.8410	-153.9019	71.8407	-153.9001	70	21:53	1.05	Y	
8/30/2011	WB27	59	183	71.8586	-154.3691	-	-	-	3:43	-	N	Too much swell
8/30/2011	WB05	60	155	71.8096	-154.4085	71.8100	-154.4054	117	7:51	1.70	Y	
8/30/2011	WB22	61	50.5	71.6842	-154.4838	71.6848	-154.4871	134	12:06	2.10	Y	
8/30/2011	WB02	62	183	71.7411	-154.9400	-	-	-	17:48	-	N	Too much swell
8/30/2011	WB02	63	183	71.7382	-154.9574	71.7398	-154.9483	366	18:34	4.53	Y	
8/31/2011	WB28	64	183	71.6838	-155.1577	71.6831	-155.1607	72	1:23	1.00	Y	Estimated distance using average speed for gear
8/31/2011	WB21	65	47.5	71.5888	-155.0641	71.5883	-155.0681	151	6:25	2.68	Y	
8/31/2011	WB29	66	23.5	71.4718	-155.0228	-	-	-	11:18	-	N	Did not hit bottom
8/31/2011	WB29	67	24.5	71.4711	-155.0227	-	-	-	11:33	-	N	Unable to sort or subsample catch
8/31/2011	WB30	68	13	71.2370	-155.1262	71.2369	-155.1288	94	14:53	1.05	Y	
8/31/2011	WB13	69	43	71.3977	-153.9775	71.3964	-153.9819	212	19:50	2.35	Y	
9/1/2011	WB25	70	23	71.2121	-154.0052	71.2115	-154.0025	122	3:32	2.02	Y	
9/1/2011	WB35	71	18	71.1086	-154.0456	71.1078	-154.0430	135	6:48	2.20	Y	
9/1/2011	WB34	72	24.5	71.1295	-153.1861	71.1299	-153.1828	129	12:16	1.62	Y	
9/1/2011	WB14	73	41	71.2366	-153.1045	71.2382	-153.1044	183	15:24	2.22	Y	
9/1/2011	WB32	74	83	71.7307	-153.4883	71.7309	-153.4968	145	20:40	2.02	Y	Estimated distance using average speed for gear
9/1/2011	WB32	75	83	71.7322	-153.5149	71.7327	-153.5194	162	21:09	2.90	Y	
9/1/2011	WB31	76	183	71.7967	-153.4090	71.7958	-153.4062	139	22:56	2.08	Y	
9/2/2011	WB07	77	183	71.7137	-152.9786	71.7146	-152.9817	147	2:37	2.07	Y	
9/2/2011	WB36	78	154	71.5618	-152.4615	71.5621	-152.4638	88	10:15	1.15	Y	
9/2/2011	WB18	79	51	71.2834	-152.2699	71.2843	-152.2680	118	14:04	1.60	Y	
9/2/2011	CB32	80	13	70.8129	-151.6466	70.8144	-151.6341	214	19:46	2.97	Y	Estimated distance using average speed for gear
9/2/2011	CB32	81	19	70.8202	-151.6620	70.8229	-151.6665	338	20:03	4.97	Y	
9/3/2011	CB33	82	16	70.6732	-150.7012	70.6743	-150.7034	138	1:18	1.98	Y	
9/3/2011	CB33	83	17	70.6780	-150.7046	70.6788	-150.7017	144	1:31	2.08	Y	
9/3/2011	CB28	84	183	71.2552	-150.4463	-	-	-	7:10	-	N	Damaged net
9/3/2011	CB34	85	183	71.2782	-150.6530	-	-	-	9:56	-	N	Damaged net
9/3/2011	CB34	86	183	71.2784	-150.6556	-	-	-	11:09	-	N	Towed only for snow crab
9/3/2011	CB34	87	183	71.2798	-150.6658	71.2795	-150.6640	68	14:11	1.00	Y	
9/3/2011	CB35	88	223	71.2883	-150.6699	71.2880	-150.6680	77	16:27	1.18	Y	
9/3/2011	CB35	89	223	71.2875	-150.6599	71.2874	-150.6581	63	17:21	1.12	Y	

Table A1-10; Cruise Report Table 32. Overview of all stations sampled by the snow crab team. Light gray: Stations where snow crab were found. Dark gray: stations where invertebrate stable isotope (SI), fatty acid and barcoding samples were collected for snow crab only. Green: data from snow crab team notes. Red: data from CTD team. Other lat/long and depth data from fish team.

Consequ. #	Station	Lat N (dec deg)	Lat W (dec deg)	Water depth (m)	Trawl gear/ number	Water SI	Sediment SI	Crabs general	Crabs diet	Crabs SI	Crabs reproduction	Invert SI	Fatty acids, Calorimetry	Barcoding	Chemistry	Frozen tissue collection
1	EB25	70.234	145.094	24	OT-1	x	x	0	0	0	0	0	0	0	0	0
2	EB27	70.463	145.076		OT-2	x	x	0	0	0	0	x	0	0	x	0
3	EB29	70.677	145.101	62	OT-3	x	x	0	0	0	0	x	x	0	x	0
4	EB23	70.783	145.451	124	PSBT-1	x	x	0	0	0	0	x	x	0	x	0
5	EB21	70.578	145.409	49	PSBT-4	x	x	0	0	0	0	x	x	0	0	0
6	EB19	70.336	145.427	30	PSBT-A2	x	x	0	0	0	0	x	x	0	0	0
7	EB14	70.456	145.807	35	PSBT-6	x	x	0	0	0	0	x	x	0	x	0
8	EB16	70.674	145.807	53	PSBT-7	x	x	0	0	0	0	x	x	0	0	0
9	EB12	70.788	146.094	60	PSBT-9	x	x	0	0	0	0	x	x	0	0	0
10	EB10	70.561	146.142	38	PSBT-10	x	x	0	0	0	0	x	x	x	x	0
11	EB8	70.339	146.123	26	PSBT-11	x	x	0	0	0	0	x	x	x	x	0
12	EB4	70.443	146.438	31	PSBT-A4	x	x	0	0	0	0	x	0	x	0	0
13	EB6	70.675	146.413	42	PSBT-A5	x	x	0	0	0	0	0	0	x	0	0
14	EB32	70.926	146.435	180	PSBT-15	0	x	0	0	0	0	0	0	0	x	0
15	EB02	70.865	146.676	62	PSBT-A7	x	x	0	0	0	0	0	0	0	x	0
16	CB11	70.770	147.153	45	PSBT-A8	x	x	0	0	0	0	0	x	x	0	0
17	CB01	70.515	147.325	20	PSBT-16	x	x	0	0	0	0	0	0	x	0	0
18	CB02	70.554	147.740	25	PSBT-A9	x	x	0	0	0	0	x	0	x	x	0
19	CB12	70.802	147.546	38	PSBT-A10	x	x	0	0	0	0	x	x	0	0	0
20	CB22	70.995	147.467	180	PSBT-A12	x	x	0	0	0	0	x	x	0	0	0
21	CB23	71.069	147.881	180	PSBT-A13	x	x	x	x	x	0	0	x	x	x	0
22	CB13	70.827	148.063	40	PSBT-A14	x	x	0	0	0	0	0	x	x	0	0
23	CB03	70.607	148.201	20	PSBT-A15	x	x	0	0	0	0	0	x	0	x	0
24	CB04	70.623	148.692	20	PSBT-A16	x	x	0	0	0	0	0	0	0	x	0
25	CB14	70.856	148.589	33	PSBT-A17	x	x	0	0	0	0	0	x	0	0	0
26	CB24	71.160	148.342	180	PSBT-A18	x	x	x	x	x	0	0	x	x	x	0
27	CB25	71.210	148.831	176	PSBT-A19	x	x	x	x	x	0	0	x	x	x	0
28	CB15	70.925	149.041	30	PSBT-A20	x	x	0	0	0	0	x	0	0	x	0
29	CB05	70.661	149.163	16	PSBT-A21	x	x	0	0	0	0	0	0	0	0	0
30	CB06	70.696	149.689	16	PSBT-A23&24	x	x	0	0	0	0	x	x	x	0	0
31	CB07	70.738	150.137	16	PSBT-A25	x	x	0	0	0	0	x	x	0	0	0
32	CB17	71.000	150.002	30	PSBT-A27	x	x	0	0	0	0	x	0	0	x	0
33	CB16	70.961	149.548	30	PSBT-A28	x	x	0	0	0	0	x	x	x	x	0
34	CB26	71.211	149.380	180	PSBT-A29	x	x	x	x	x	0	x	x	x	x	0
35	CB27	71.216	149.872	180	PSBT-A31	x	x	x	x	x	x	x	x	x	x	0
36	CB28	71.253	150.422	180	PSBT-A32	x	x	x	x	x	x	x	x	x	0	0
37	CB29	71.320	150.950	180	PSBT-A34	x	x	x	x	x	0	x	x	x	x	0
38	CB30	71.364	151.400	180	PSBT-A44	x	x	0	0	0	0	(x)	0	0	0	0
39	CB20	71.119	151.426	17	PSBT-A35	x	x	0	0	0	0	x	0	0	0	0
40	CB19	71.058	150.919	18	no trawl	x	x	0	0	0	0	0	0	0	0	0
41	CB18	71.034	150.555	?	no trawl	x	x	0	0	0	0	0	0	0	0	0
43	CB08	70.723	150.520	16	PSBT-A36	x	x	0	0	0	0	0	x	x	0	0
44	CB09	70.814	151.105	14	PSBT-A38	x	x	0	0	0	0	0	0	0	0	0
45	CB10	70.857	151.589	14	PSBT-A39	x	x	0	0	0	0	0	x	0	0	0
46	CB31	70.909	151.841	14	PSBT-A40	x	x	0	0	0	0	0	0	0	0	0
47	WB17	71.155	152.210	21	PSBT-A42	x	x	0	0	0	0	x	0	0	0	0
48	WB19	71.352	151.964	86	PSBT-A43	x	x	0	0	0	0	x	0	x	x	0
49	WB20	71.501	152.184	181	PSBT-A45	x	x	x	x	x	0	x	0	x	x	0
50	WB08	71.652	152.649	180	PSBT-A46	x	x	0	0	0	0	x	0	x	x	0
51	WB07	71.711	152.975	180	PSBT-A47	x	x	x	x	x	0	x	x	x	x	0
52	WB31	71.798	153.422	180	PSBT-A48	x	x	0	0	0	0	x	x	x	x	0
53	WB32	71.733	153.503	80	PSBT-A49	x	x	x	x	x	x	x	x	x	x	0
54	WB24	71.507	153.558	50	PSBT-A50	x	x	0	0	0	0	x	0	x	0	0
55	WB23	71.530	152.847	58	PSBT-A51	x	x	0	0	0	0	x	0	0	0	0
56	WB16	71.452	153.011	62	PSBT-A52	x	x	x	x	x	0	x	0	x	x	0
57	WB15	71.379	153.023	78	PSBT-A53	x	x	0	0	0	0	x	0	x	x	0
58	WB12	71.482	153.992	49	PSBT-A54	x	x	0	0	0		x	0	0	x	0
59	WB26	71.618	153.845	46	PSBT-A55	x	x	x	x	x	0	x	x	x	0	0
60	WB10	71.720	153.871	50	PSBT-A56	x	x	0	0	0	0	x	x	x	x	0
61	WB04	71.841	153.902	180	PSBT-A58	x	x	x	x	x	0	x	x	x	0	x
62	WB27	71.859	154.369	180	PSBT-A59	x	0	0	0	0	0	x	0	0	0	0
63	WB05	71.810	154.409	152	PSBT-A60	x	x	x	x	x	0	0	x	x	0	0
64	WB22	71.684	154.484	48	PSBT-A61	x	x	0	0	0	0	x	0	0	0	0
65	WB02	71.738	154.957	180	PSBT-A63	x	0	0	0	0	0	x	x	x	0	x
66	WB28	71.684	155.158	180	PSBT-A64	x	x	x	x	x	x	x	x	0	0	0
67	WB21	71.589	155.064	45	PSBT-A65	x	x	x	x	x	0	x	x	0	0	x
68	WB29	71.471	155.023	21	PSBT-A67	x	x	0	0	0	0	0	0	0	0	0
69	WB30	71.237	155.126	10	PSBT-A68	x	x	0	0	0	0	0	0	(x)	0	0
70	WB13	71.397	153.995	40	PSBT-18	x	x	x	x	x	0	x	x	x	0	x
71	WB25	71.212	154.005	20	PSBT-A70	x	x	0	0	0	0	x	0	0	0	0
72	WB35	71.109	154.046	14	PSBT-A71	x	x	0	0	0	0	x	0	(x)	0	x
72	WB34	71.129	153.186	22	PSBT-A72	x	x	0	0	0	0	x	0	0	x	0
73	WB14	71.237	153.105	38	PSBT-A73	x	x	0	0	0	0	x	0	0	x	x
73	**WB32b**	71.731	153.488	80	PSBT-A74&75	0	0	x	x	x	0	x	x	x	x	x
73	**WB31b**	71.797	153.409	180	PSBT-A76	0	0	x	x	x	0	x	x	x	0	0
73	**WB07b**	71.714	152.979	180	PSBT-A77	0	0	x	x	x	0	x	x	x	0	0
74	WB36	71.562	152.462	151	PSBT-A78	x	x	x	x	x	0	x	x	x	x	0
75	WB18	71.283	152.270	48	PSBT-A79 & PSBT-21	x	x	0	0	0	0	0	0	0	x	0
76	CB32	70.813	151.647	10	PSBT-A80	x	x	0	0	0	0	0	0	0	0	x
77	CB33	70.680	150.691	13	PSBT-23	x	x	0	0	0	0	0	0	0	0	0
77	**CB28b**	71.255	150.446	**180**	PSBT-A84	0	0	x	x	x	0	x	x	x	0	x
78	CB34a	71.278	150.653	180	PSBT-A85	0	0	x	x	x	0	0	x	x	x	0
78	**CB34b**	71.278	150.656	**180**	PSBT-A86	0	0	x	x	x	0	0	x	x	0	0
79	CB35a	71.288	150.670	220	PSBT-A88	0	0	x	x	x	0	x	x	x	0	0
79	**CB35b**	71.287	150.660	**220**	PSBT-A89	0	0	x	x	x	0	x	x	x	0	x

Table A1-11; Cruise Report Table 33. Size and weight range of the 64 snow crab collected during the BOEM-2011 cruise at 40-220 m water depth.

	Males	Females	
		Mature	Immature
Min. CW (mm)	32.6	36.7	39.0
Max. CW (mm)	129.6	64.08	69.8
Min. wet weight (g)	14	54	30
Max. wet weight (g)	1105	125	115
Min. chela height (mm)	4.8		
Max. chela height (mm)	37.3		

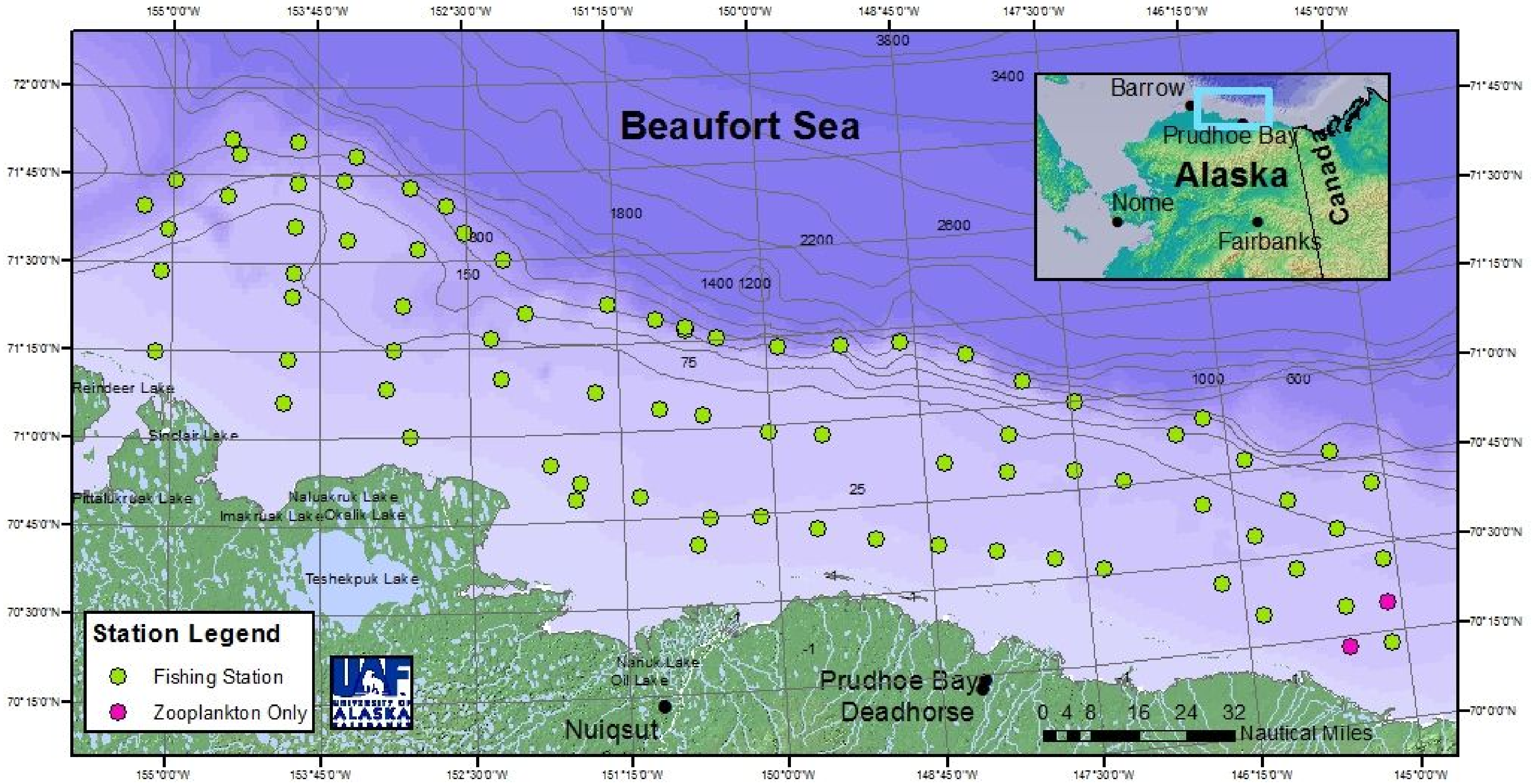


Figure C1-1; Cruise Report Figure 1. Map of stations sampled during BOEM-2011 cruise.

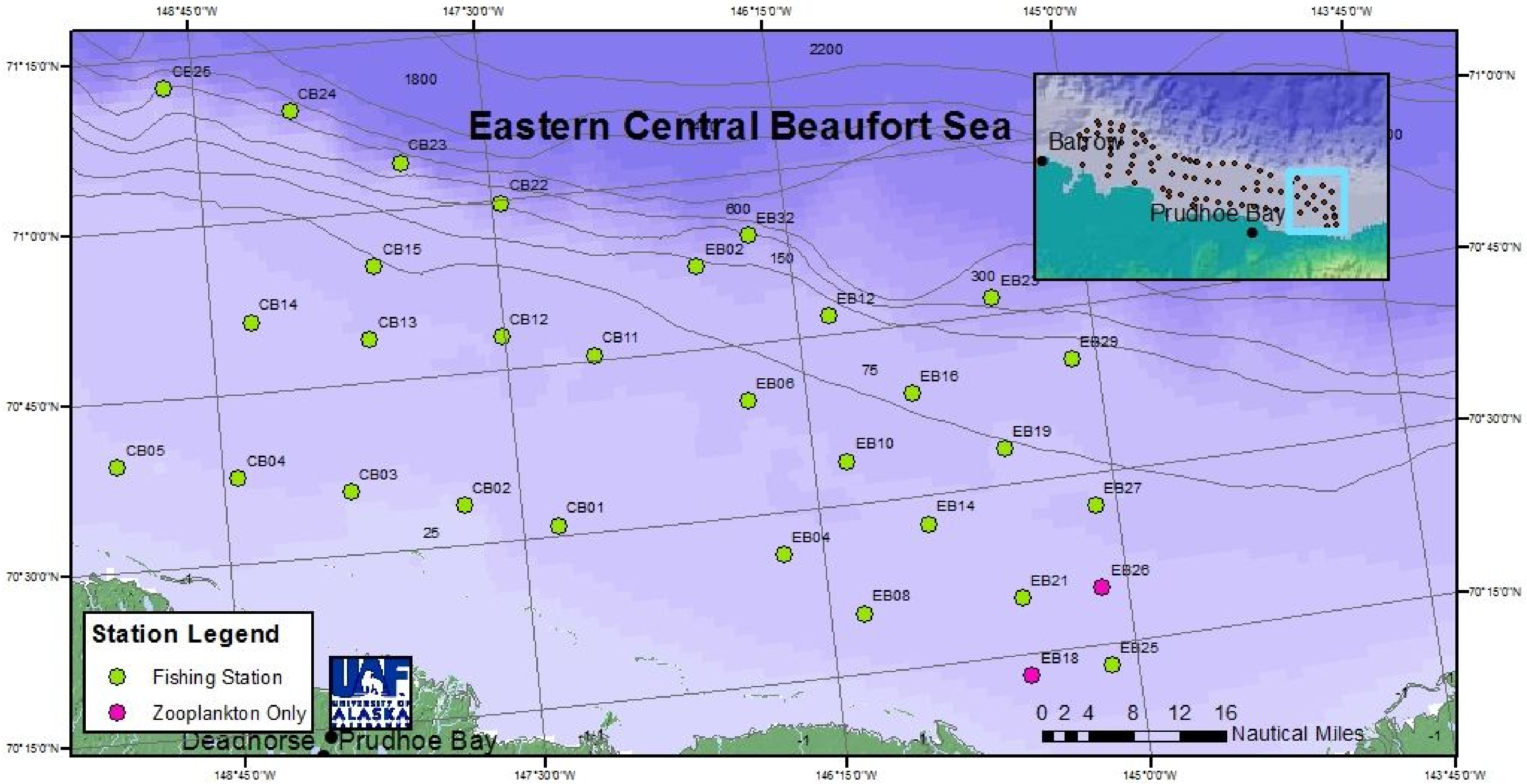


Figure C1-2; Cruise Report Figure 2. Map of Eastern Beaufort station sampled during BOEM-2011 cruise.

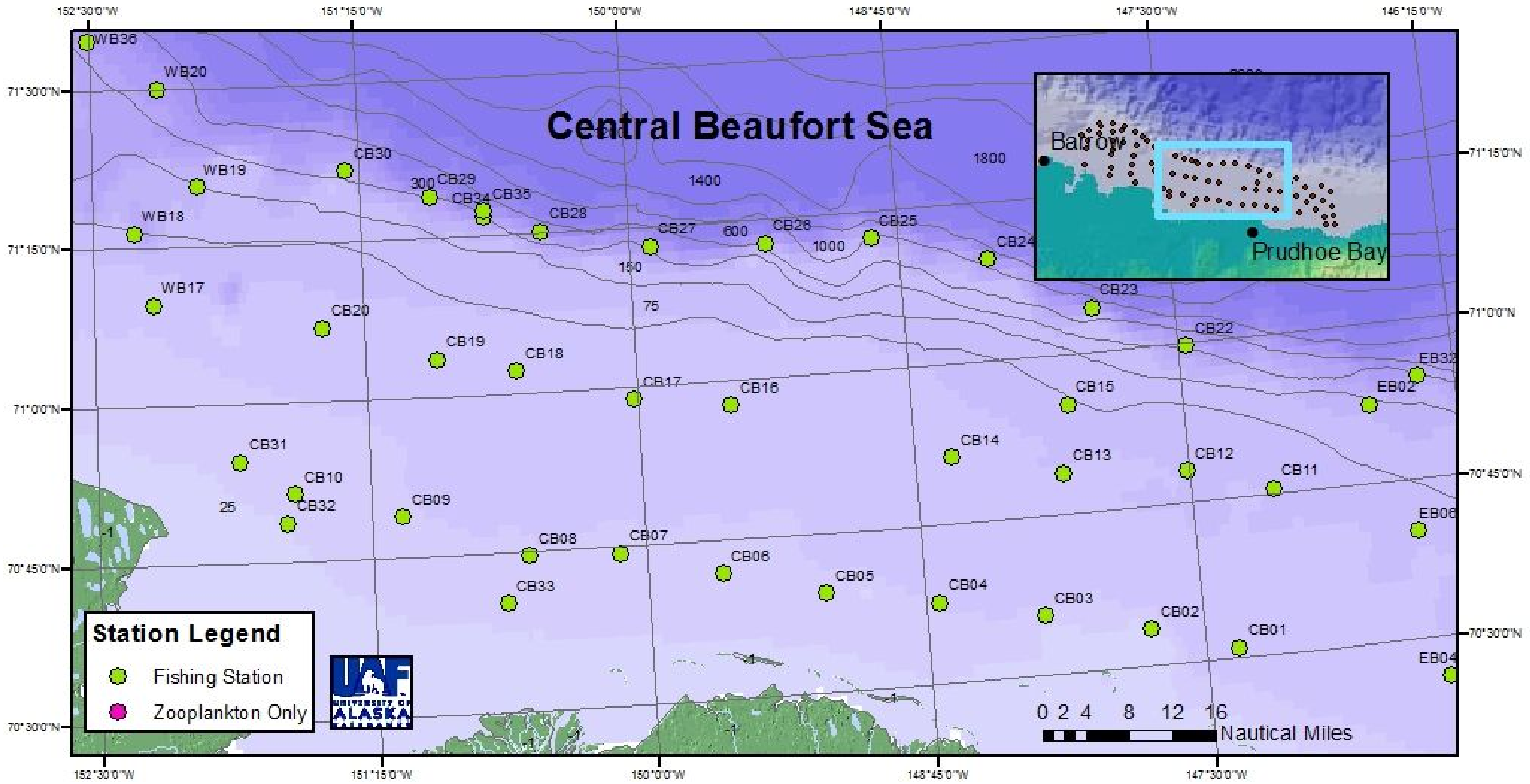


Figure C1-3; Cruise Report Figure 5. Map of Central Beaufort station sampled during BOEM-2011 cruise.

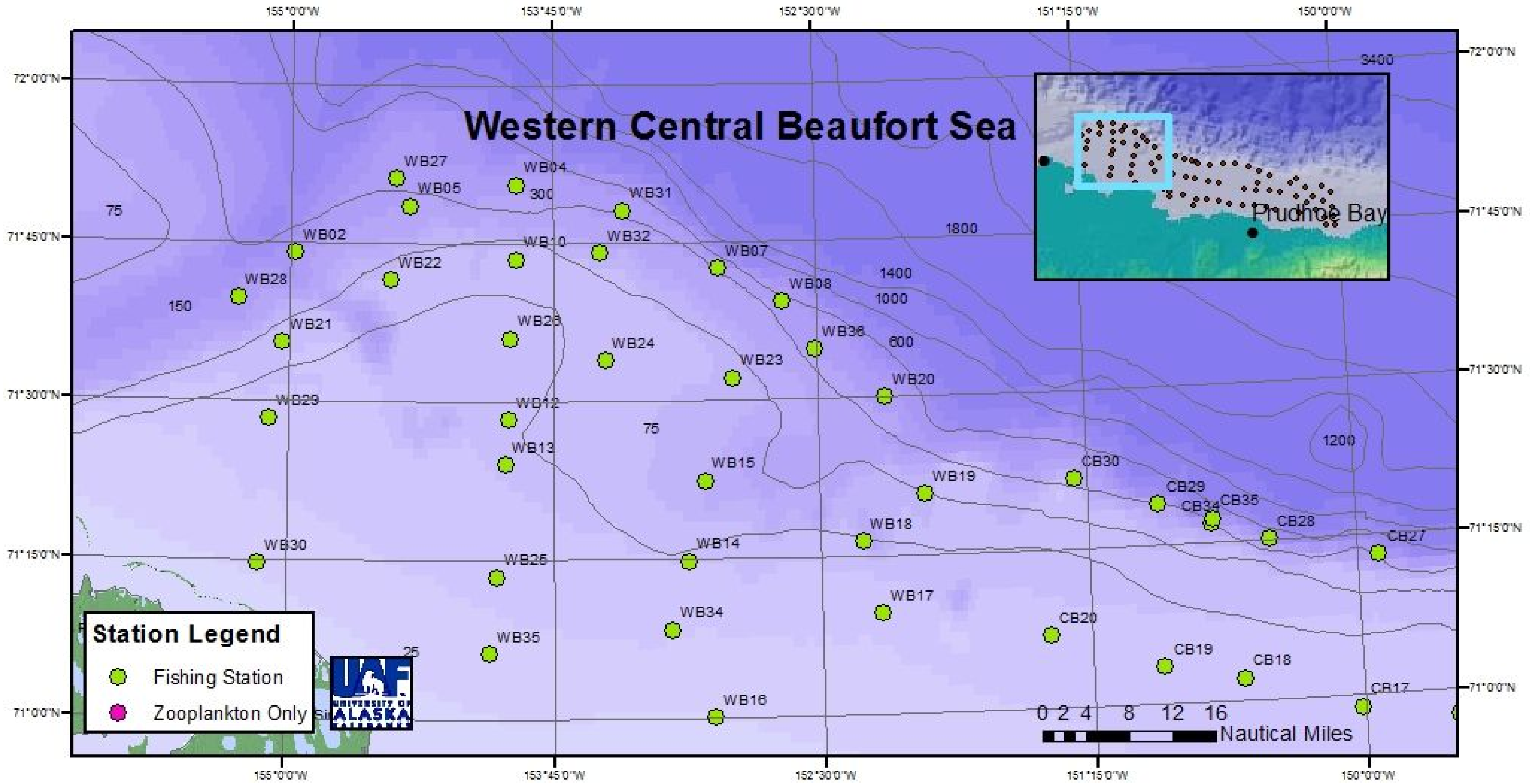


Figure C1-4; Cruise Report Figure 8. Map of Western Beaufort station sampled during BOEM-2011 cruise.

Figure C1-5; Cruise Report Figure 12. Examples of mature (left) and immature (center) female and male (right) snow crab collected during the BOEM-2011 survey.

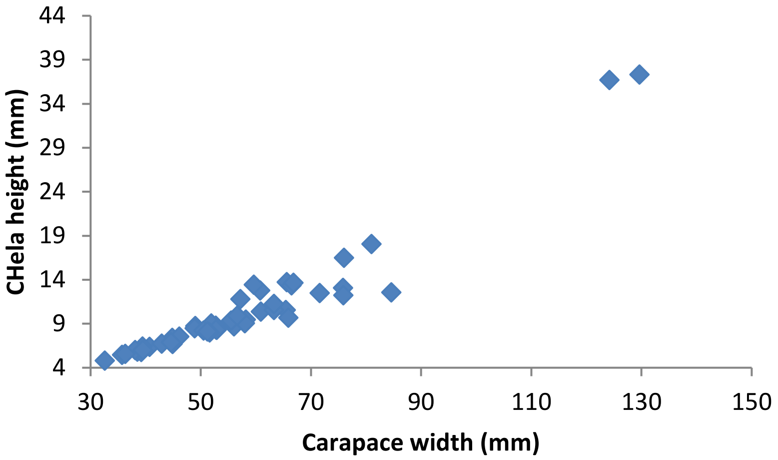


Figure C1-6; Cruise Report Figure 13. Size frequency distribution of the 64 snow crab collected during the BOEM-2011 cruise at 40-220 m water depth.

Figure C1-7; Cruise Report Figure 15. One of the three blue king crabs collected during the BOEM-2011 cruise.

APPENDIX C2. DATA TABLES AND FIGURES SUPPLEMENTARY TO "CHAPTER 2.1. FISH DISTRIBUTION AND ABUNDANCE

Appendix C2 consists of tables and maps that report standardized fish catches by each type of fishing gear: Isaacs-Kidd midwater trawl (IKMT), otter trawl (OT) and beam trawl (BT). Fish taxa are aggregated into groups that were used in analyses as described in **Chapter 2.1 Table 2.1-2.** In tables, taxa are in phylogenetic order by family, and within family taxa are in alphabetical order by genus and species. Tables for each gear report abundance (catch-per-unit-effort, CPUE); for the demersal gears OT and BT, biomass-per-unit-effort (BPUE) is also reported. Maps report abundance and biomass data averaged over quantitative hauls at each station. Maps were created using ArcMap 10.2.1 for Desktop (ESRI 2013) and datum D_WGS_1984. To create bubble maps of CPUE and BPUE, data were classified into 1–4 groups using the Natural Breaks (Jenks) function in ArcMap.

Appendix C2.1 contains a table and maps for pelagic catches by Isaacs-Kidd midwater trawl: CPUE is ## fish/1000 cu. m. **Tables C2.1; Figures C2.1-1 through C2.1-20.**

Appendix C2.2 contains tables and maps for demersal catches by otter trawl: BPUE is grams fish/1000 m; CPUE is # fish/1000 m. **Tables C2.2-1 and C2.2-2; Figures C2.2-1 through C2.2-28.**

Appendix C2.3 contains tables and maps for demersal catches of plumb staff beam trawl and modified plumb staff beam trawl: CPUE is # fish / 1000 sq. m, BPUE is grams/1000 sq. m. **Tables C2.3-1 and C2.3-2; Figures C2.3-1 through C2.3-36**.

APPENDIX C2.1. PELAGIC FISH DISTRIBUTION AND ABUNDANCE

Table C2.1- 1 Density of fishes caught in each quantitative Isaacs-Kidd midwater trawl haul during BOEM-2011 (# fish/1000 m^3, volume).). Fishes are aggregated as in Table 2.1-2 and are presented in phylogenetic order; stations are in alphabetic order within west to east regions. Replicate quantitative hauls were collected at WB30.

Station-IKMT haul	***All fishes combined***	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 taxa)**	Cottidae larvae unid.	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae (6 taxa)**	*Aspidophoroides olrikii* = ***Agonidae***	*Liparis* spp. = **Liparidae**	*Anisarchus medius*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (4 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Limanda proboscidea* = **Pleuronectidae**
Western Beaufish																				
WB02-71	34.2	7.2	14.5	21.7	-	1.0	-	-	-	-	1.0	3.1	6.2	-	-	-	2.1	2.1	-	-
WB04-67	5.0	2.5	-	2.5	-	-	-	-	-	-	-	0.5	-	-	-	-	1.5	1.5	-	0.5
WB05-69	56.1	28.4	4.6	33.0	-	1.3	-	-	0.7	-	2.0	2.6	0.7	-	7.3	2.6	6.6	16.5	-	1.3
WB07-57	21.2	10.6	-	10.6	-	-	-	-	-	-	-	1.8	8.8	-	-	-	-	-	-	-
WB08-56	55.5	51.1	-	51.1	-	2.2	-	-	-	-	2.2	-	2.2	-	-	-	-	-	-	-
WB10-66	35.8	-	20.4	20.4	-	-	-	-	-	-	-	5.1	-	-	-	2.6	2.6	5.1	5.1	-
WB12-64	19.3	1.6	-	1.6	-	-	-	-	-	-	-	11.2	1.6	-	4.8	-	-	4.8	-	-
WB14-80	21.4	9.7	1.9	11.7	-	-	-	-	-	-	-	7.8	1.9	-	-	-	-	-	-	-
WB15-63	302.3	236.5	-	236.5	-	3.1	-	-	-	-	3.1	3.1	6.3	12.5	4.7	36.0	-	53.3	-	-
WB17-52	10.1	3.4	-	3.4	-	-	-	-	-	-	-	-	6.8	-	-	-	-	-	-	-
WB18-82	8.5	2.8	1.4	4.2	-	-	-	-	-	-	-	2.8	1.4	-	-	-	-	-	-	-
WB19-53	28.4	25.3	-	25.3	-	-	-	-	-	-	-	-	3.2	-	-	-	-	-	-	-
WB20-55	20.5	17.9	-	17.9	-	1.3	-	-	-	-	1.3	-	1.3	-	-	-	-	-	-	-
WB21-73	229.8	186.2	-	186.2	-	2.0	-	-	-	-	2.0	-	-	-	29.7	-	11.9	41.6	-	-
WB22-70	33.4	3.5	7.0	10.5	-	1.8	-	-	-	-	1.8	1.8	1.8	-	3.5	-	12.3	15.8	1.8	-
WB23-61	6.8	5.1	-	5.1	-	1.7	-	-	-	-	1.7	-	-	-	-	-	-	-	-	-
WB24-60	7.4	1.8	-	1.8	-	-	-	-	-	-	-	1.8	1.8	-	1.8	-	-	1.8	-	-
WB25-77	79.7	-	-	-	-	31.0	-	-	-	-	31.0	8.9	13.3	-	-	26.6	-	26.6	-	-
WB26-65	16.1	8.0	-	8.0	-	-	-	-	-	-	-	-	5.4	-	2.7	-	-	2.7	-	-
WB27-68	44.8	20.9	6.1	27.0	-	2.0	-	-	-	-	2.0	0.5	2.0	1.0	7.6	-	4.1	12.7	-	0.5
WB28-72	68.2	30.1	-	30.1	-	-	-	-	4.0	-	4.0	2.0	6.0	2.0	-	6.0	6.0	14.0	10.0	2.0
WB29-74	93.8	-	83.4	83.4	-	2.6	-	-	-	-	2.6	-	-	-	7.8	-	-	7.8	-	-
WB30-75	19.4	2.8	-	2.8	-	-	-	-	-	-	-	-	-	-	-	16.6	-	16.6	-	-
WB30-76	17.3	5.0	-	5.0	-	3.7	-	-	1.2	-	5.0	-	1.2	-	5.0	-	1.2	6.2	-	-
WB31-58	54.6	23.6	-	23.6	-	7.4	-	-	-	-	7.4	8.9	8.9	-	-	-	1.5	1.5	-	4.4
WB32-59	25.0	9.0	3.0	12.0	-	-	-	-	-	1.0	1.0	2.0	5.0	-	2.0	2.0	1.0	5.0	-	-
WB35-78	172.8	149.2	-	149.2	-	7.9	-	-	3.9	3.9	15.7	-	3.9	-	-	3.9	-	3.9	-	-
WB36-81	19.7	7.6	4.0	11.6	-	0.5	-	-	-	-	0.5	0.5	3.0	-	1.5	-	2.0	3.5	0.5	-

Table C2.1-1 Density of fishes caught by IKMT (continued).

Station-IKMT haul	***All fishes combined***	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 taxa)**	Cottidae larvae unid.	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae (6 taxa)**	*Aspidophoroides olrikii* = ***Agonidae***	*Liparis* spp. = **Liparidae**	*Anisarchus medius*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (4 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Limanda proboscidea* = **Pleuronectidae**
Central Beaufish																				
CB01-23	188.9	146.4	-	146.4	-	18.6	-	-	13.3	2.7	34.6	-	8.0	-	-	-	-	-	-	-
CB02-24	67.8	56.5	-	56.5	-	7.5	-	-	-	-	7.5	-	3.8	-	-	-	-	-	-	-
CB03-30	74.3	65.6	-	65.6	-	8.7	-	-	-	-	8.7	-	-	-	-	-	-	-	-	-
CB04-31	9.8	4.9	-	4.9	-	4.9	-	-	-	-	4.9	-	-	-	-	-	-	-	-	-
CB05-36	10.4	10.4	-	10.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB06-37	4.7	-	-	-	-	-	-	-	-	-	-	-	4.7	-	-	-	-	-	-	-
CB07-38	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB08-48	15.3	5.1	-	5.1	-	-	-	-	5.1	-	5.1	-	5.1	-	-	-	-	-	-	-
CB09-49	6.0	-	-	-	-	-	-	-	-	-	-	-	6.0	-	-	-	-	-	-	-
CB11-22	42.8	22.8	-	22.8	-	17.1	-	-	-	-	17.1	2.9	-	-	-	-	-	-	-	-
CB12-25	39.5	26.4	-	26.4	-	-	-	-	-	-	-	-	13.2	-	-	-	-	-	-	-
CB13-28	159.9	113.6	-	113.6	-	8.4	-	-	16.8	-	25.2	-	16.8	-	4.2	-	-	4.2	-	-
CB14-32	41.3	18.4	-	18.4	-	18.4	-	-	-	-	18.4	4.6	-	-	-	-	-	-	-	-
CB15-35	107.5	73.3	-	73.3	-	17.1	-	-	-	-	17.1	-	12.2	2.4	2.4	-	-	4.9	-	-
CB16-40	105.7	72.3	-	72.3	-	5.6	-	-	-	-	5.6	22.2	5.6	-	-	-	-	-	-	-
CB17-39	13.4	10.1	-	10.1	-	-	-	-	-	-	-	3.4	-	-	-	-	-	-	-	-
CB18-47	10.3	10.3	-	10.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB19-46	12.2	12.2	-	12.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB22-26	20.5	17.1	-	17.1	-	-	-	-	-	-	-	-	3.4	-	-	-	-	-	-	-
CB23-27	21.9	18.5	-	18.5	-	-	-	-	-	-	-	1.7	1.7	-	-	-	-	-	-	-
CB24-33	7.1	7.1	-	7.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB25-34	22.5	15.0	-	15.0	-	-	-	-	-	-	-	-	7.5	-	-	-	-	-	-	-
CB26-41	87.5	55.8	-	55.8	-	1.0	-	-	5.8	-	6.7	2.9	21.2	1.0	-	-	-	1.0	-	-
CB27-42	58.6	55.3	-	55.3	-	1.7	-	-	-	-	1.7	-	1.7	-	-	-	-	-	-	-
CB28-43	12.0	10.5	-	10.5	-	-	-	-	-	-	-	-	1.4	-	-	-	-	-	-	-
CB29-44	6.4	6.4	-	6.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB30-54	23.8	15.3	-	15.3	-	-	-	-	-	-	-	1.7	6.8	-	-	-	-	-	-	-
CB31-51	184.3	-	-	-	-	-	-	-	-	-	-	-	176.8	-	-	7.5	-	7.5	-	-
CB32-83	43.3	-	2.9	2.9	-	5.8	-	-	-	-	5.8	-	14.4	-	-	20.2	-	20.2	-	-
CB33-84	423.2	24.8	-	24.8	-	15.8	2.3	2.3	33.8	9.0	63.0	-	285.9	-	-	49.5	-	49.5	-	-

Table C2.1-1 Density of fishes caught by IKMT (continued).

Station-IKMT haul	***All fishes combined***	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 taxa)**	Cottidae larvae unid.	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae (6 taxa)**	*Aspidophoroides olrikii* = ***Agonidae***	*Liparis* spp. = **Liparidae**	*Anisarchus medius*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (4 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Limanda proboscidea* = **Pleuronectidae**
Eastern Beaufish																				
EB02-19	29.6	23.3	-	23.3	-	4.2	-	-	-	-	4.2	-	-	-	2.1	-	-	2.1	-	-
EB06-17	191.0	172.2	-	172.2	-	15.7	-	-	-	-	15.7	-	3.1	-	-	-	-	-	-	-
EB08-14	154.1	110.8	-	110.8	-	27.0	5.4	-	2.7	-	35.1	2.7	5.4	-	-	-	-	-	-	-
EB10-13	135.3	77.0	-	77.0	-	28.2	-	-	22.5	1.9	52.6	-	5.6	-	-	-	-	-	-	-
EB12-12	14.7	10.7	-	10.7	-	-	-	-	-	-	-	2.7	1.3	-	-	-	-	-	-	-
EB14-10	139.7	132.4	-	132.4	-	7.4	-	-	-	-	7.4	-	-	-	-	-	-	-	-	-
EB16-11	43.5	35.9	-	35.9	3.8	-	-	-	1.9	-	5.7	-	1.9	-	-	-	-	-	-	-
EB19-9	497.7	310.2	-	310.2	158.7	-	-	-	18.0	-	176.7	10.8	-	-	-	-	-	-	-	-
EB21-8	139.7	107.5	-	107.5	-	-	-	-	32.2	-	32.2	-	-	-	-	-	-	-	-	-
EB23-7	20.0	18.9	-	18.9	-	1.1	-	-	-	-	1.1	-	-	-	-	-	-	-	-	-
EB27-5	194.2	160.5	-	160.5	-	-	-	-	-	-	-	33.8	-	-	-	-	-	-	-	-
EB29-6	142.7	125.5	-	125.5	-	17.2	-	-	-	-	17.2	-	-	-	-	-	-	-	-	-
EB32-18	41.0	28.9	-	28.9	-	2.4	-	-	2.4	-	4.8	-	7.2	-	-	-	-	-	-	-

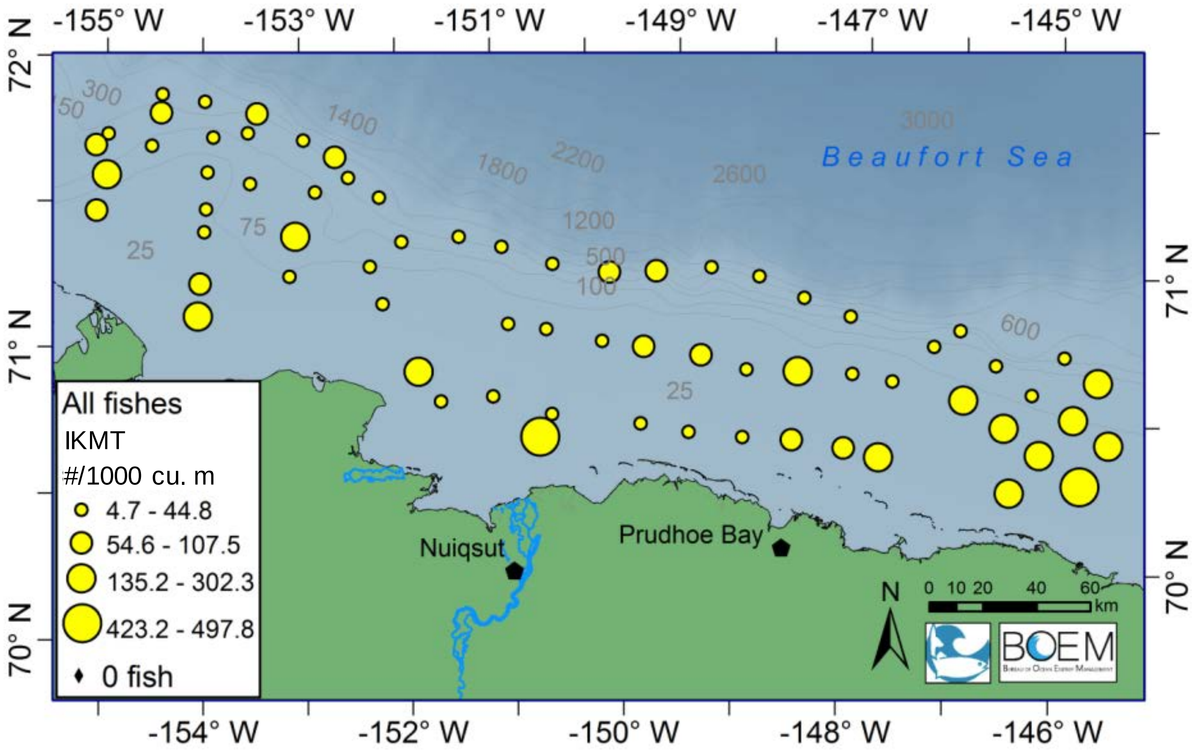


Figure C2.1- 1. All fishes combined – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

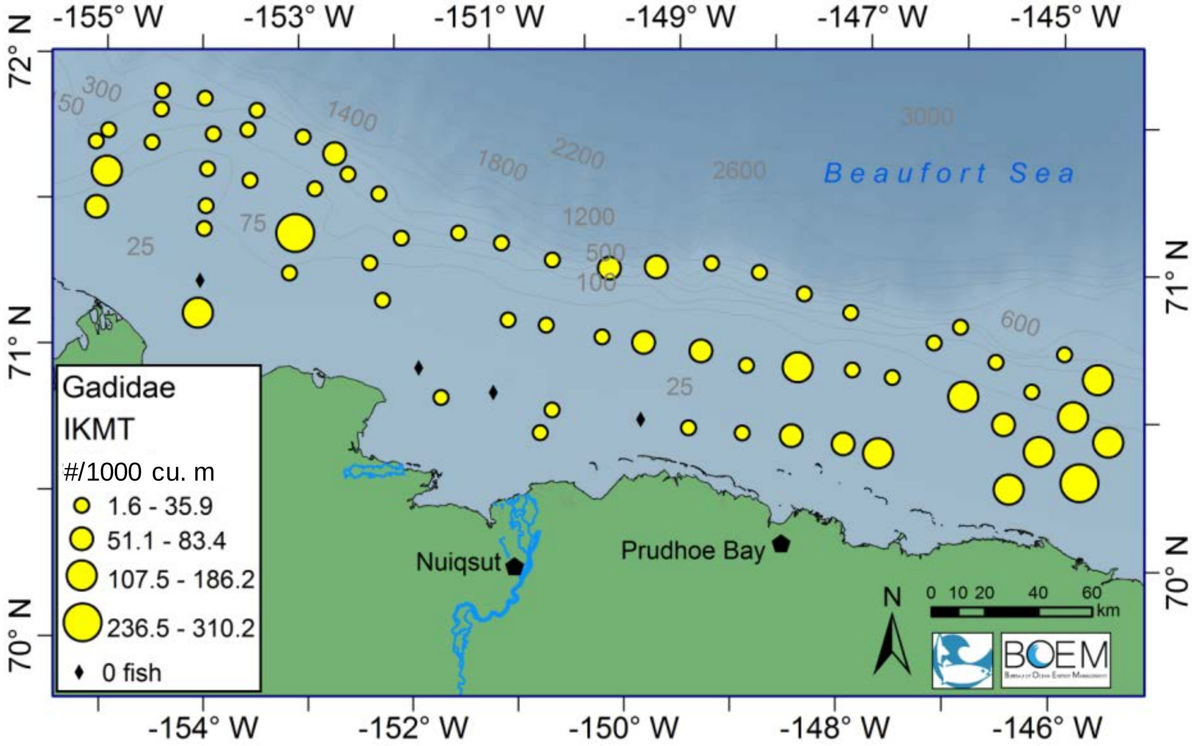


Figure C2.1- 2. Gadidae – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

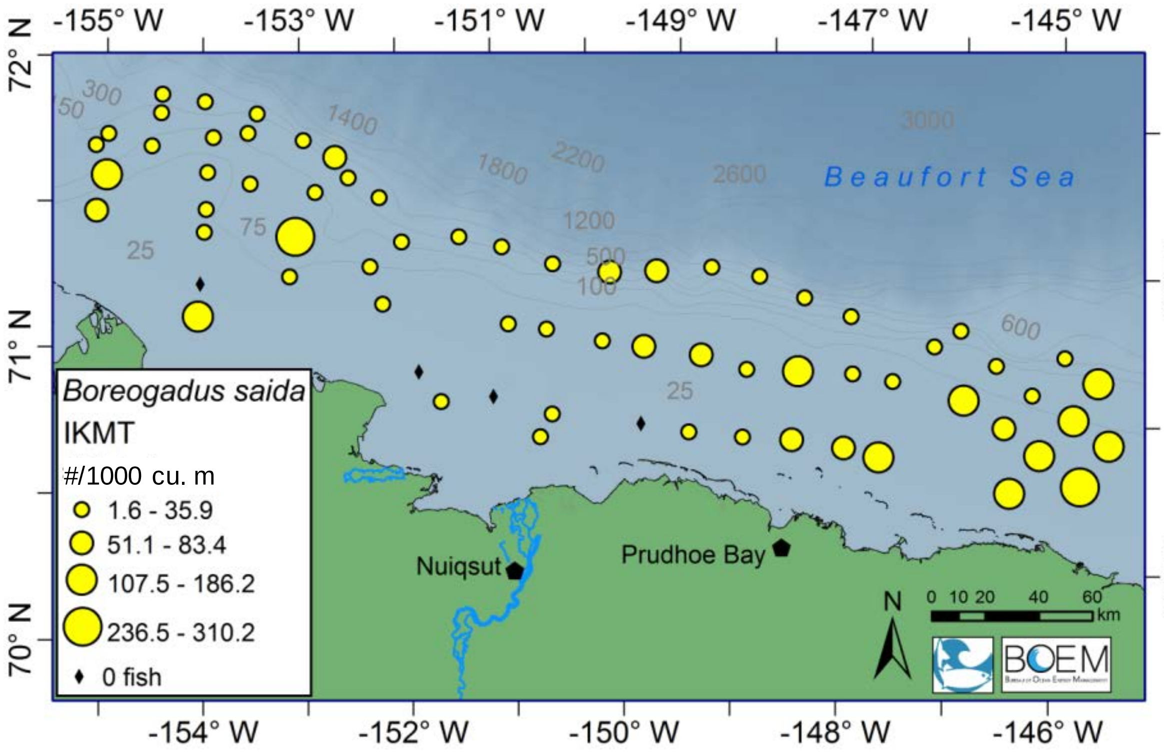


Figure C2.1- 3. Gadidae: *Boreogadus saida* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

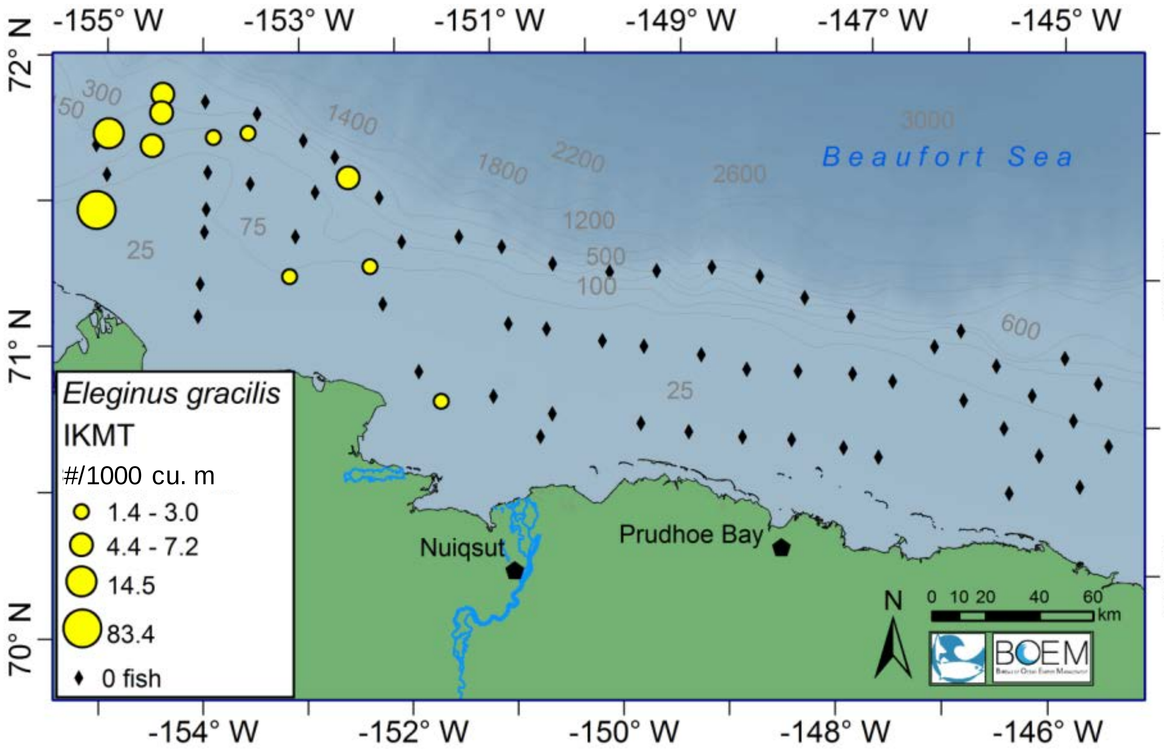


Figure C2.1- 4. Gadidae: *Eleginus gracilis* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

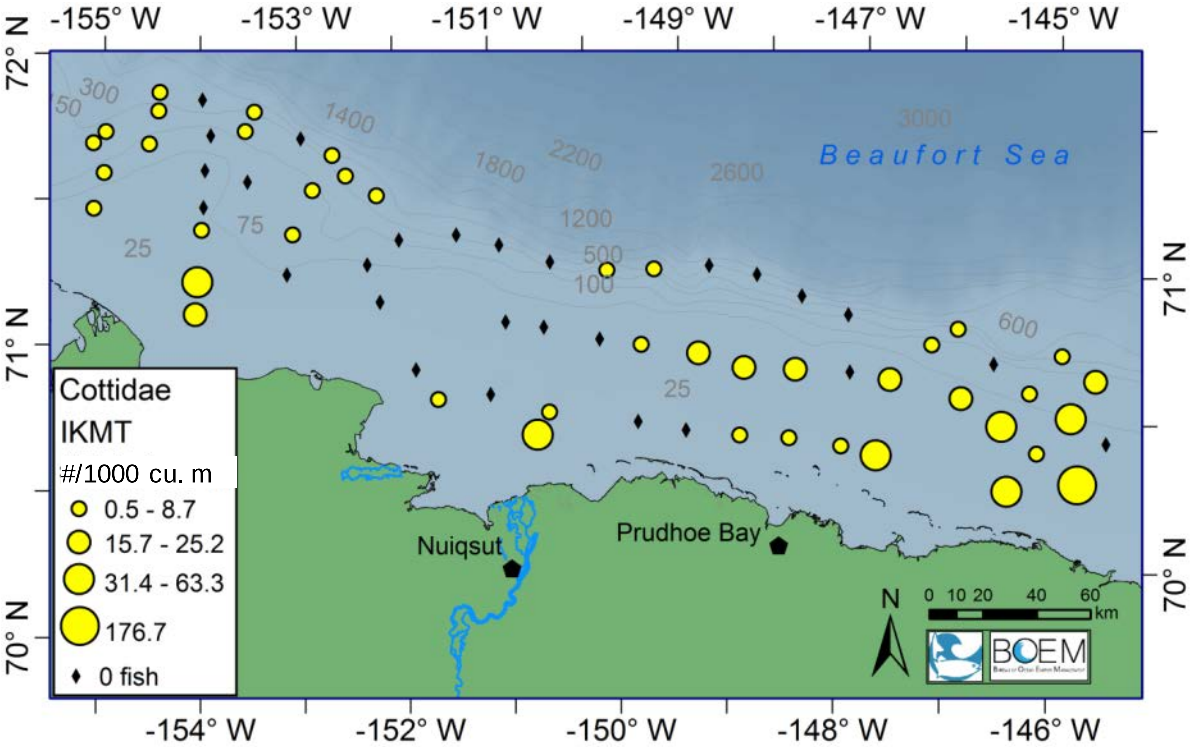


Figure C2.1- 5. Cottidae – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

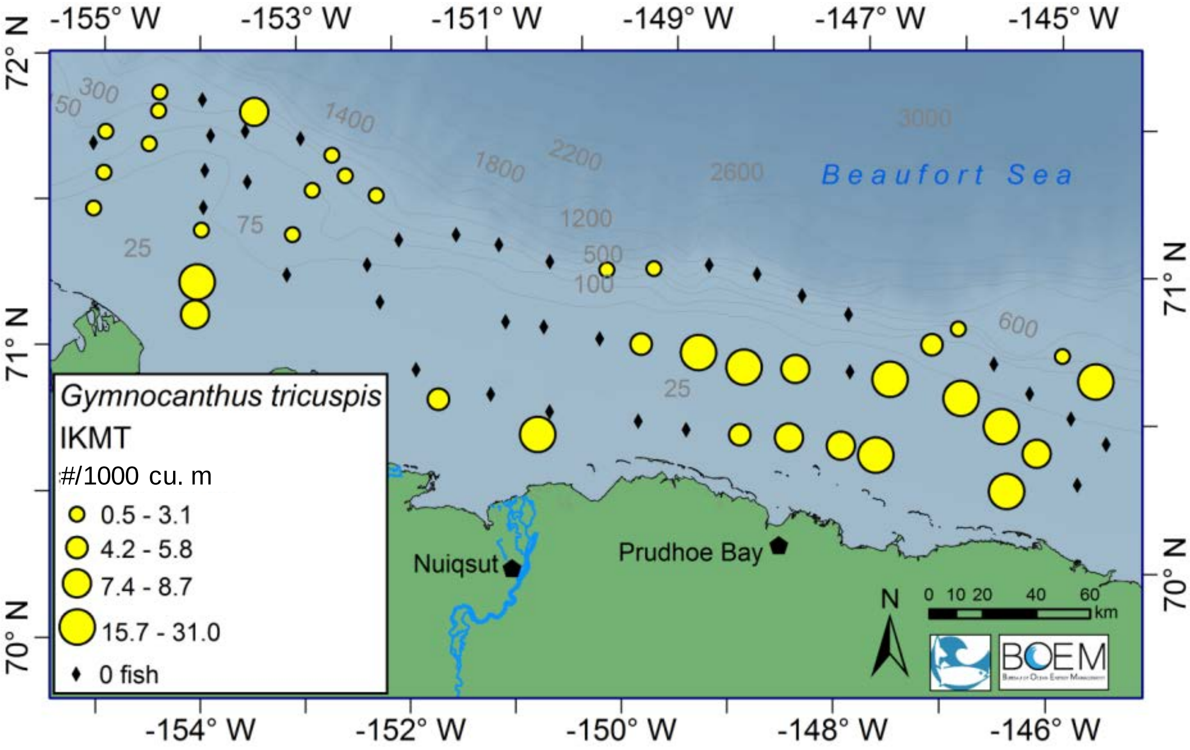


Figure C2.1- 6. Cottidae: *Gymnocanthus tricuspis* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

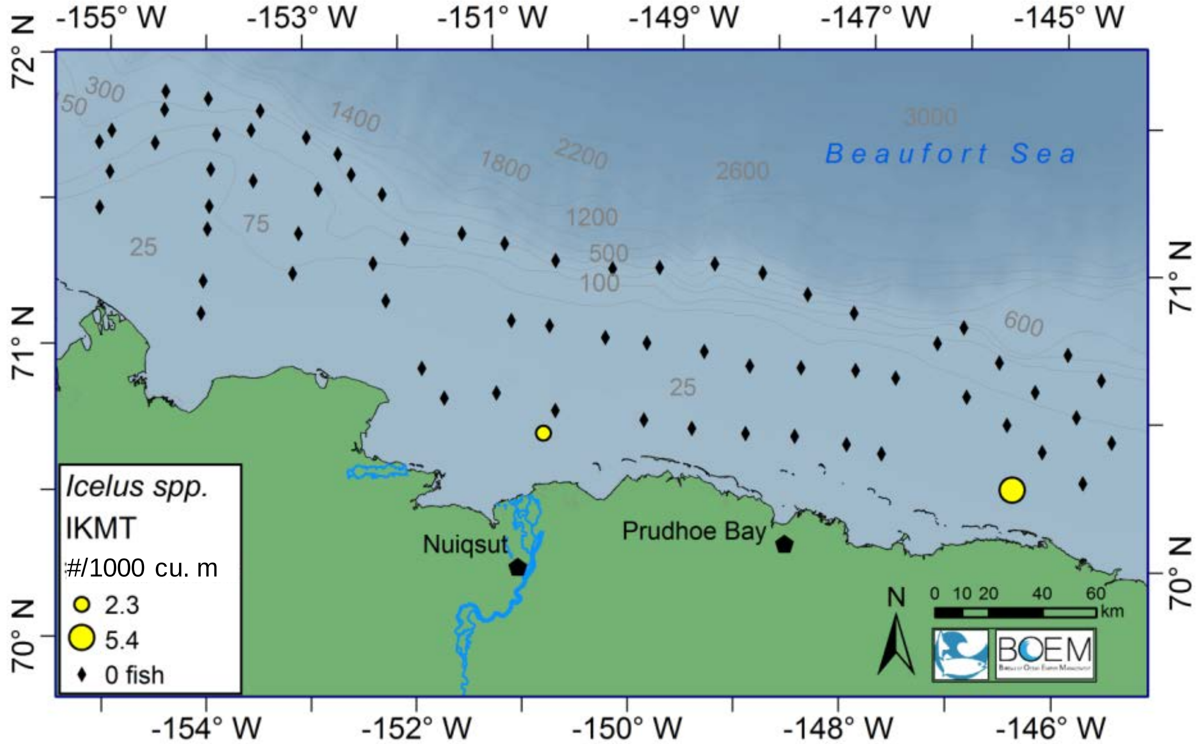


Figure C2.1- 7. Cottidae: *Icelus spp.* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

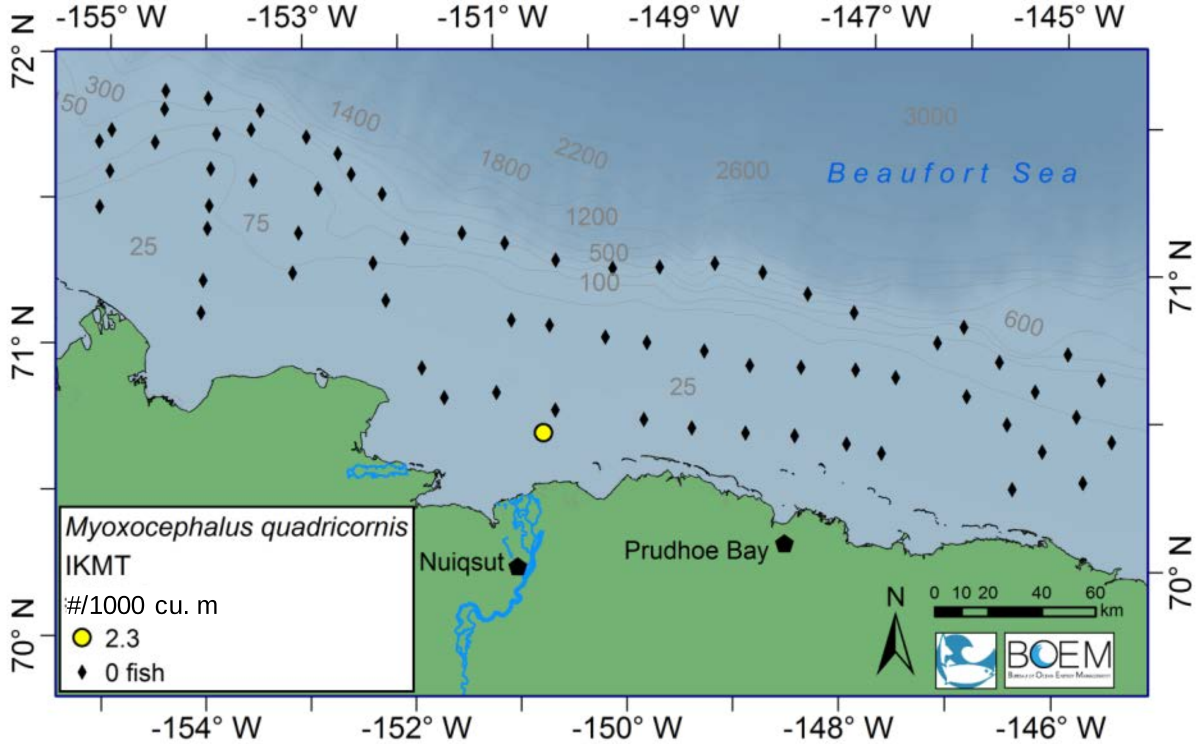


Figure C2.1- 8. Cottidae: *Myoxocephalus quadricornis* density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

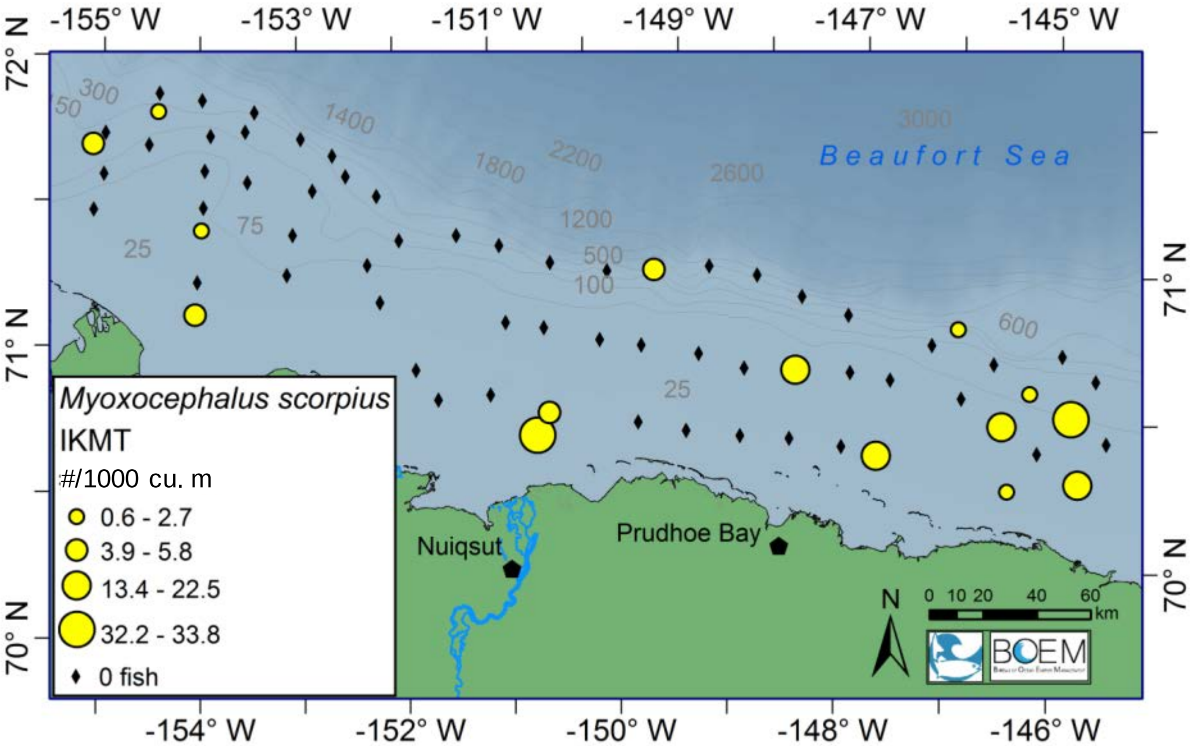


Figure C2.1- 9. Cottidae: *Myoxocephalus scorpius* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

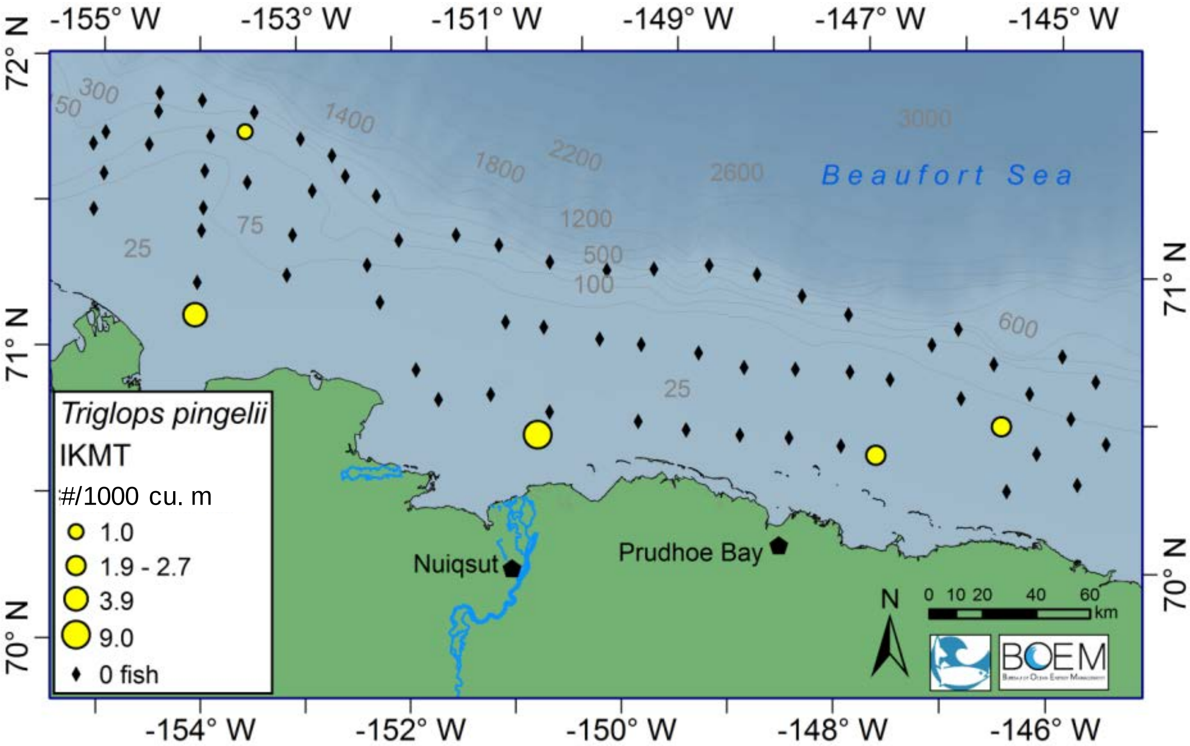


Figure C2.1- 10. Cottidae: *Triglops pingelii* density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

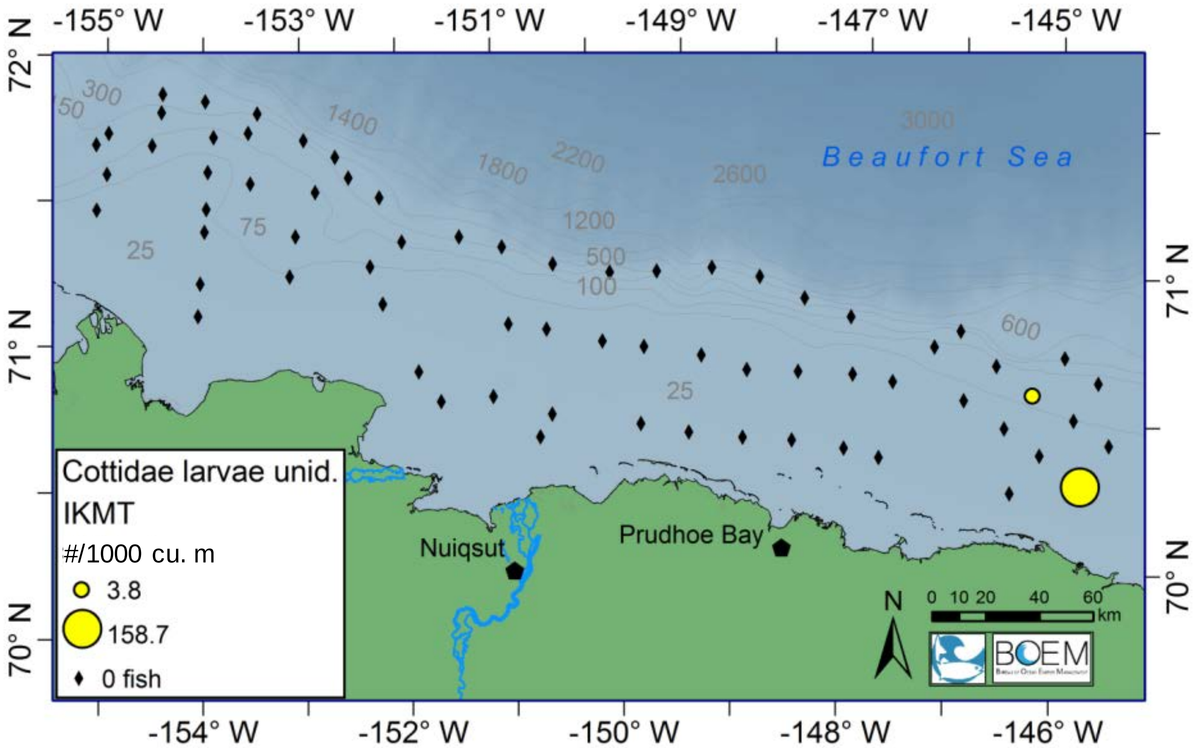


Figure C2.1- 11. Cottidae larvae (unidentified) – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

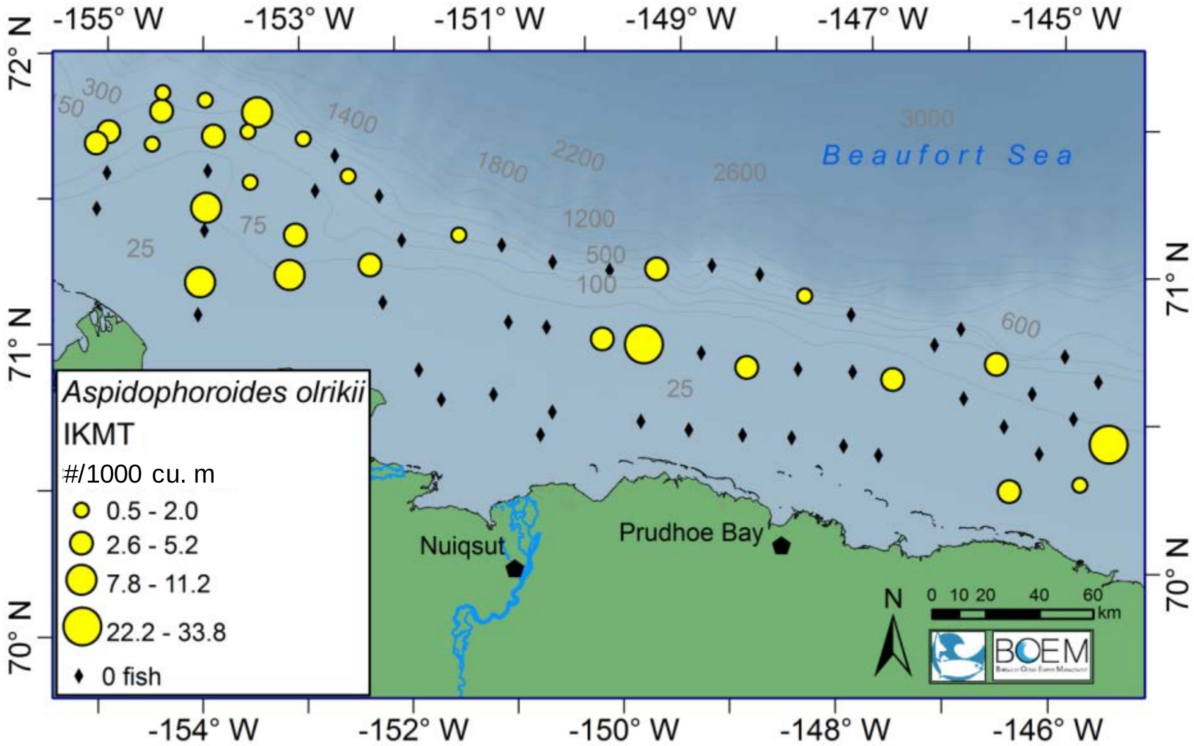


Figure C2.1- 12. Agonidae: All were *Aspidophoroides olrikii* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

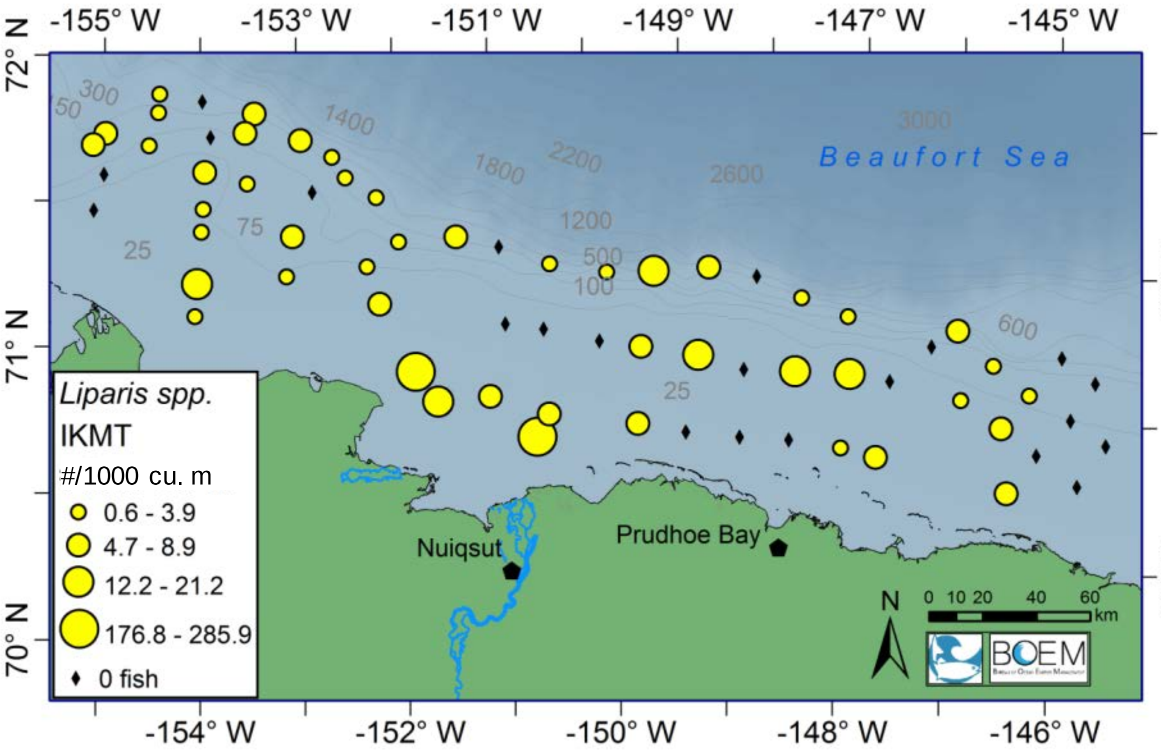


Figure C2.1- 13. Liparidae: All were *Liparis* spp. – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

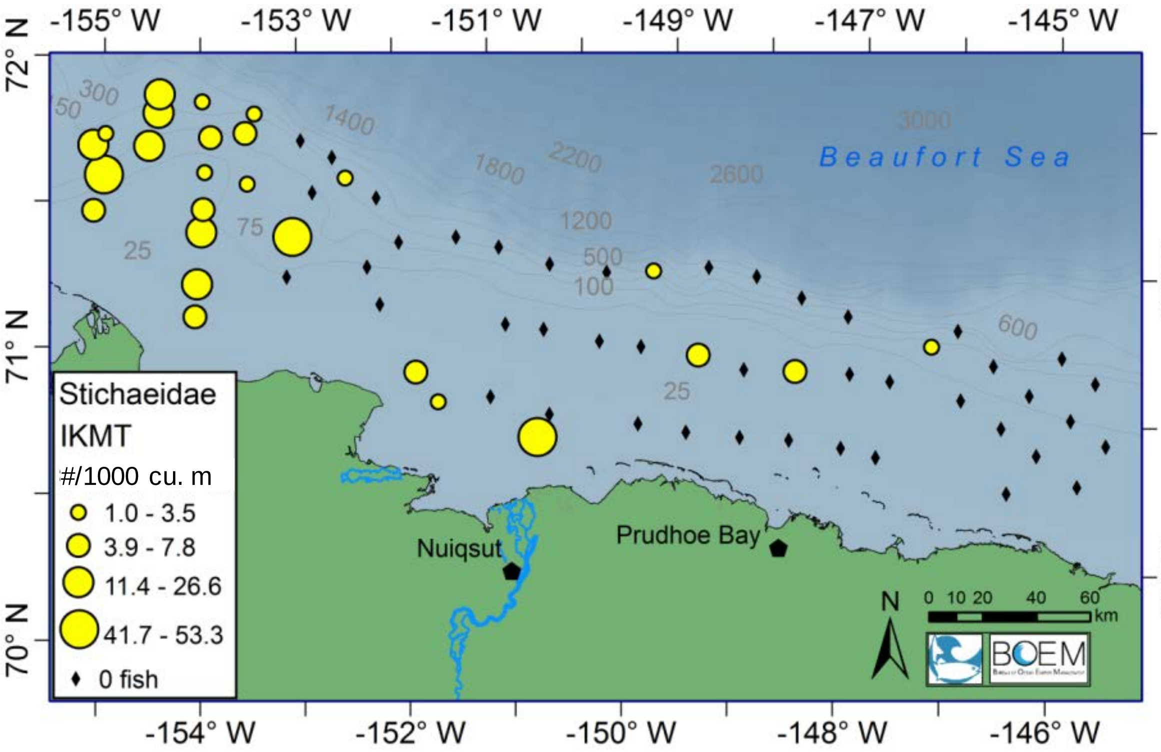


Figure C2.1- 14. Stichaeidae – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

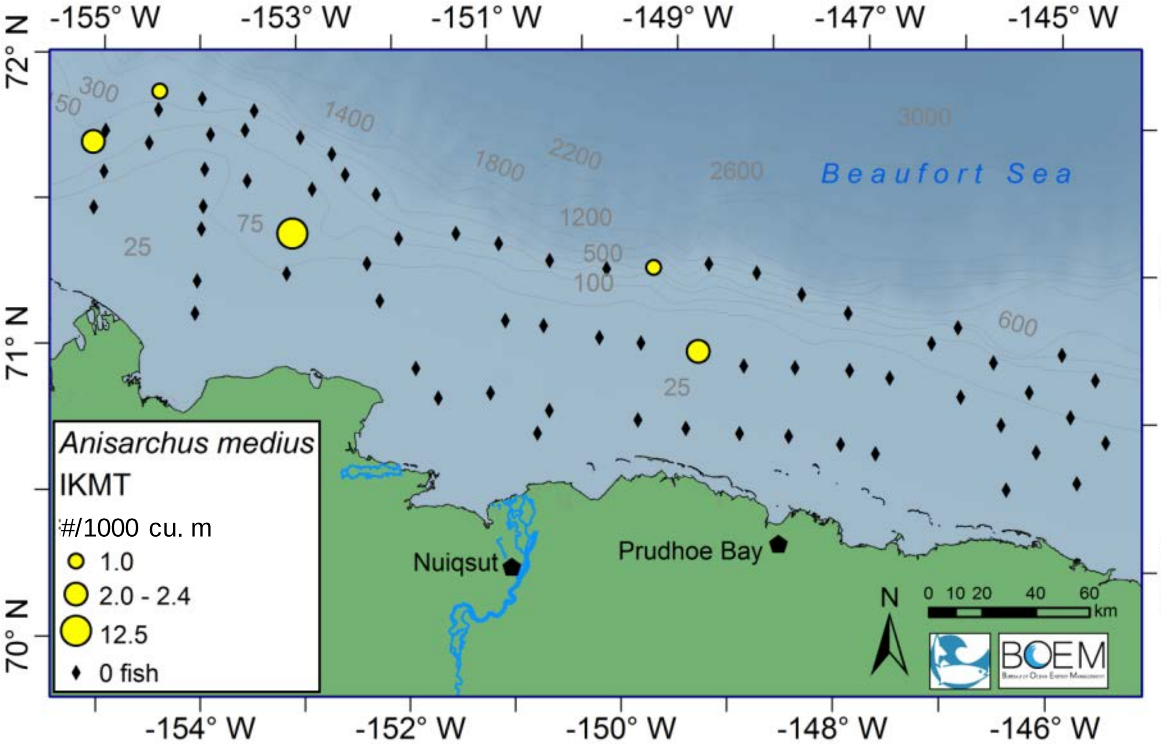


Figure C2.1- 15. Stichaeidae: *Anisarchus medius* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

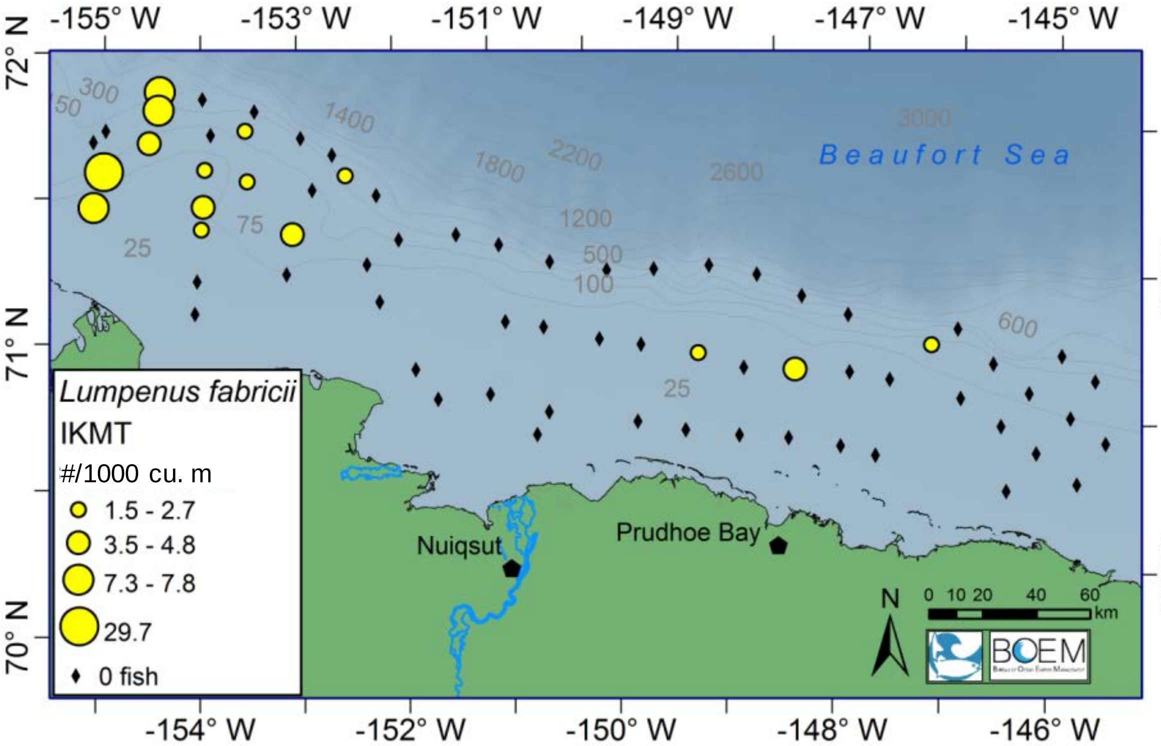


Figure C2.1- 16. Stichaeidae: *Lumpenus fabricii* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

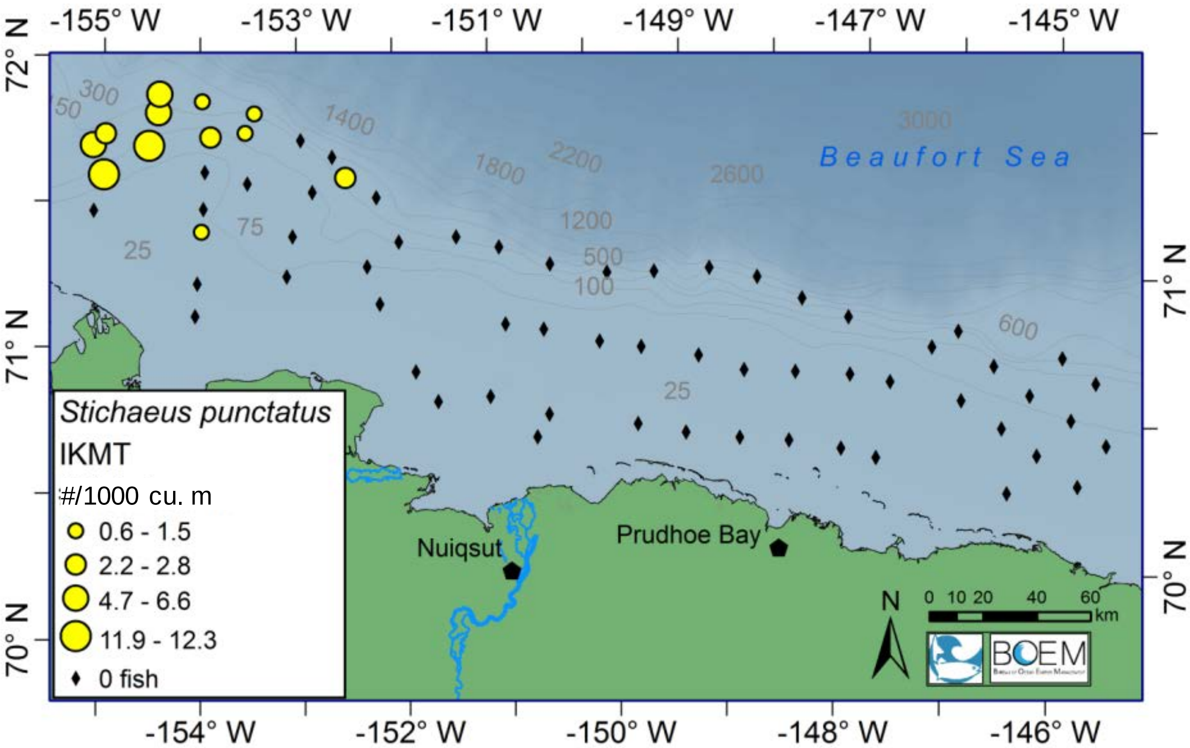


Figure C2.1- 17. Stichaeidae: *Stichaeus punctatus* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

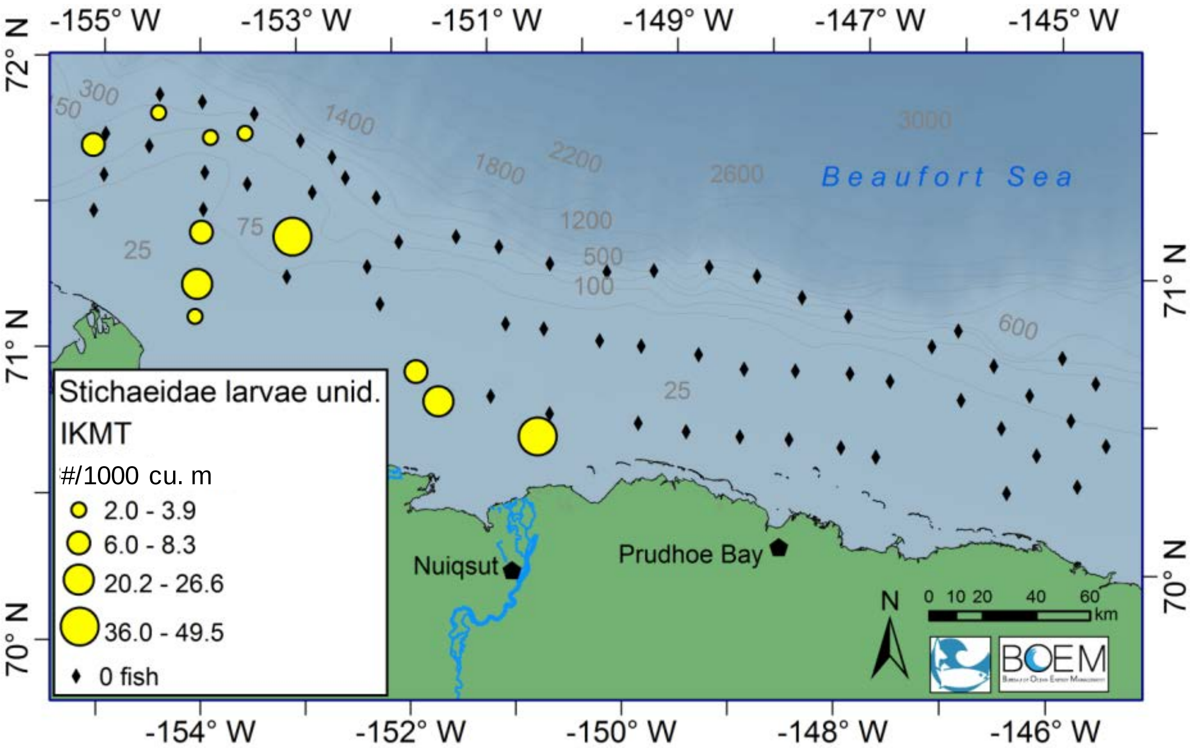


Figure C2.1- 18. Stichaeidae larvae (unidentified) – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

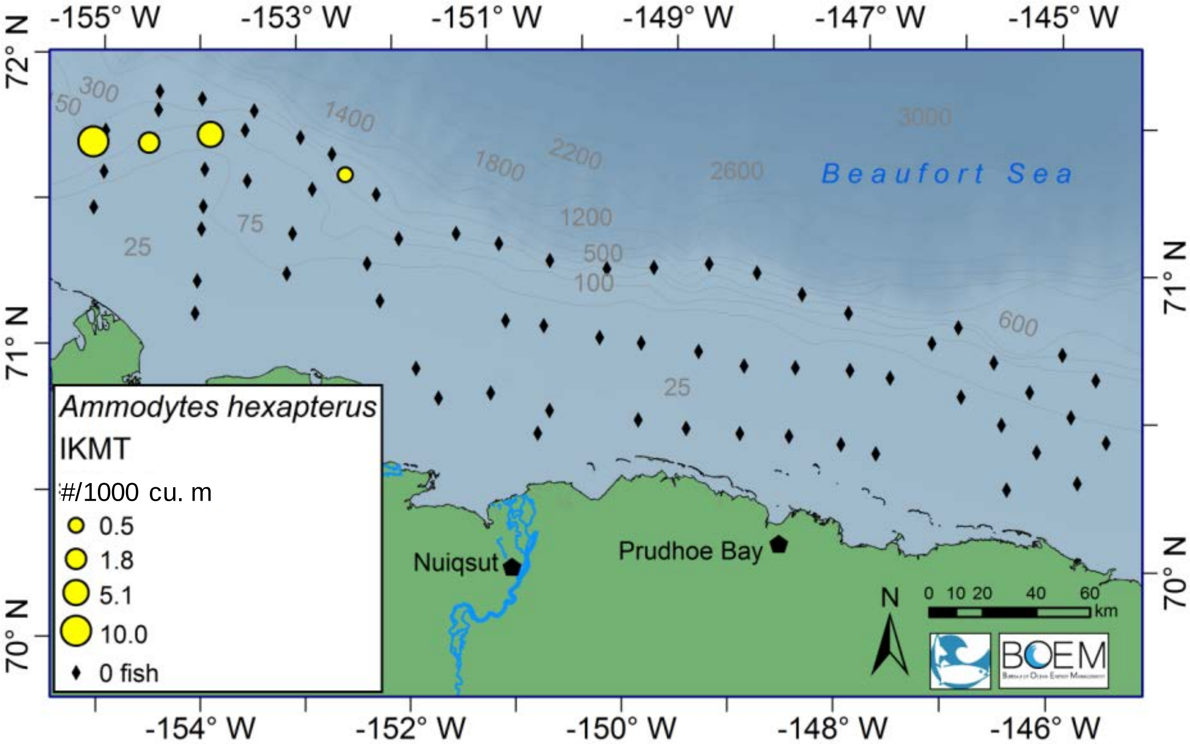


Figure C2.1- 19. Ammodytidae: All were *Ammodytes hexapterus* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

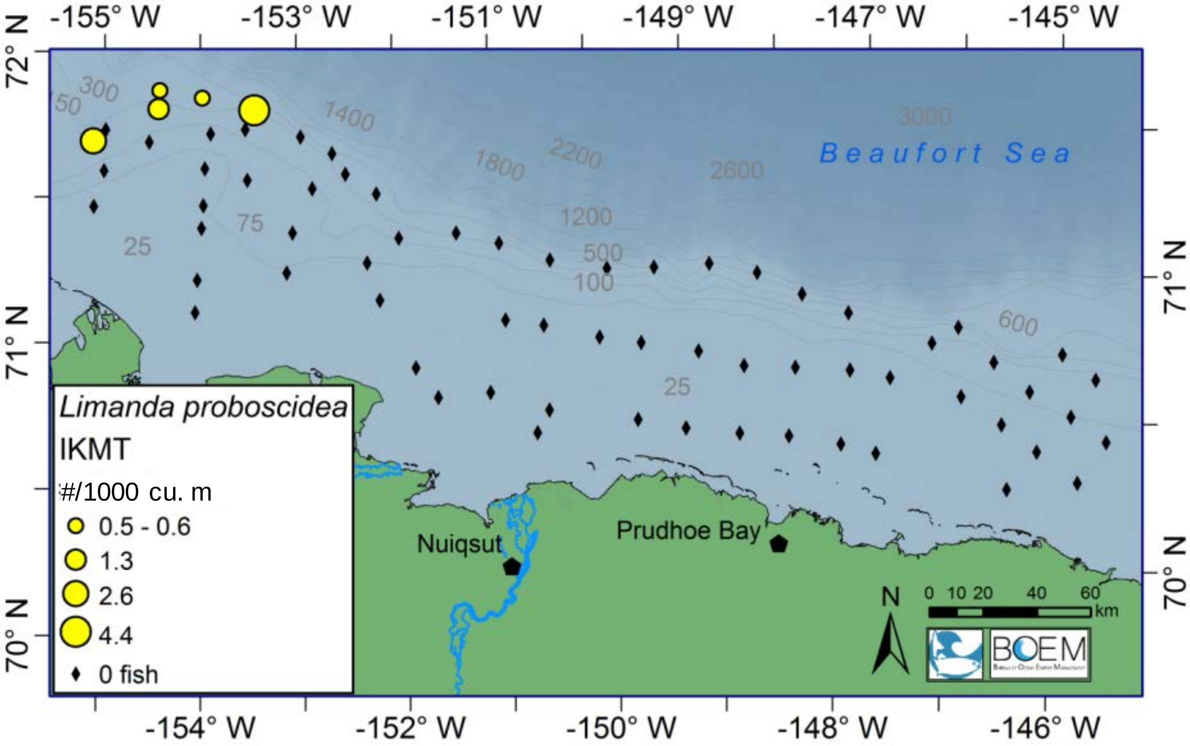


Figure C2.1- 20. Pleuronectidae: All were *Limanda proboscidea* – density in catches by Isaacs-Kidd midwater trawl during BOEM-2011.

APPENDIX C2.2 TABLES AND MAPS OF CATCHES BY OTTER TRAWL: BIOMASS AND DENSITY OF FISH FAMILIES AND SPECIES

Table C2.2- 1 Biomass of fishes caught in each quantitative otter trawl haul during BOEM-2011 (grams fish/1000 m, distance).). Fishes are aggregated as in Table 2.1-2 and are presented in phylogenetic order; stations are in alphabetic order within west to east regions. No replicate hauls were collected.

Station- OT haul	All fishes	*Mallotus villosus* = **Osmeridae**	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae** (5 taxa)	*Nautichthys pribilovius* = **Hemitripteridae**	*Aspidophoroides olrikii* = **Agonidae**	*Eumicrotremus derjugini* = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Lumpenus fabricii*	Stichaeidae larvae unid	*Stichaeus punctatus*	**Stichaeidae** (5 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus* = **Pleuronectidae**
Western Beaufish																												
WB02-38	2148.6	-	990.6	-	990.6	-	-	-	-	-	-	-	8.2	-	-	535.1	535.1	-	614.8	614.8	-	-	-	-	-	-	-	-
WB05-36	253.1	-	235.3	4.4	239.7	-	4.8	-	-	-	4.8	-	-	-	-	8.6	8.6	-	-	-	-	-	-	-	-	-	-	-
WB07-27	3227.9	-	1323.1	-	1323.1	-	-	-	-	103.5	103.5	-	-	-	-	152.7	152.7	-	1602.1	1602.1	8.4	-	37.9	-	-	46.4	-	-
WB08-26	614.4	-	523.8	-	523.8	-	1.6	-	-	-	1.6	-	-	-	89.1	-	89.1	-	-	-	-	-	-	-	-	-	-	-
WB10-35	2378.5	-	2285.6	-	2285.6	-	30.9	3.2	-	50.9	84.9	-	1.6	-	-	5.4	5.4	-	-	-	-	-	-	-	-	-	1.0	-
WB12-34	2090.1	-	1788.4	-	1788.4	-	99.0	-	76.9	8.3	184.3	1.0	2.5	-	-	47.1	47.1	-	-	-	11.0	-	54.7	1.1	-	66.8	-	-
WB13-42	1226.6	33.1	796.7	-	796.7	21.2	62.1	-	112.9	12.1	208.3	-	-	-	-	24.4	24.4	-	53.5	53.5	98.1	-	12.5	-	-	110.6	-	-
WB15-33	981.4	-	544.2	-	544.2	31.7	-	98.9	-	153.2	283.8	-	79.0	24.0	-	32.9	32.9	-	17.5	17.5	-	-	-	-	-	-	-	-
WB16-31	1174.4	-	142.0	-	142.0	79.3	-	18.3	194.0	23.5	315.2	-	7.6	-	-	24.0	24.0	-	139.5	139.5	279.8	-	-	-	-	279.8	-	266.2
WB19-24	1462.9	-	569.1	-	569.1	3.7	4.6	36.0	-	110.7	154.9	-	39.0	15.8	-	112.4	112.4	88.6	474.6	563.2	-	-	1.3	1.1	6.0	8.4	-	-
WB21-40	7563.1	64.2	6234.9	15.4	6250.3	41.4	149.3	-	161.4	129.8	481.9	-	33.7	-	-	36.2	36.2	-	11.8	11.8	50.8	-	634.2	-	-	685.0	-	-
WB22-37	1043.3	-	931.9	16.6	948.5	13.8	67.0	6.0	4.0	2.1	92.8	1.1	-	-	-	0.9	0.9	-	-	-	-	-	-	-	-	-	-	-
WB23-30	166.1	-	59.3	-	59.3	47.6	8.1	14.7	-	9.5	79.9	-	-	-	-	26.9	26.9	-	-	-	-	-	-	-	-	-	-	-
WB24-29	584.2	-	378.4	-	378.4	-	60.0	3.4	5.7	7.0	76.0	-	1.7	-	-	60.3	60.3	-	1.5	1.5	41.0	-	3.8	-	-	44.8	-	21.3
WB28-39	2116.6	-	1117.1	-	1117.1	-	-	-	-	-	-	-	-	-	-	612.3	612.3	-	387.2	387.2	-	-	-	-	-	-	-	-
WB32-28	2078.0	-	45.8	-	45.8	-	-	76.8	-	123.4	200.2	-	16.9	-	-	14.8	14.8	-	1632.1	1632.1	168.3	-	-	-	-	168.3	-	-
Central Beaufish																												
CB02-14	268.8	-	76.4	-	76.4	52.6	72.2	-	-	28.5	153.2	-	-	-	-	36.6	36.6	-	-	-	2.5	-	-	-	-	2.5	-	-
CB06-16	368.7	-	317.2	-	317.2	-	19.4	-	6.3	14.8	40.4	-	-	-	-	11.2	11.2	-	-	-	-	-	-	-	-	-	-	-
CB07-17	368.4	-	315.7	-	315.7	-	35.6	-	2.3	8.0	45.9	-	-	-	-	6.4	6.4	-	-	-	-	-	-	0.4	-	0.4	-	-
CB08-21	54.1	-	14.9	-	14.9	7.8	2.5	4.1	16.2	-	30.6	-	-	-	-	8.6	8.6	-	-	-	-	-	-	-	-	-	-	-
CB11-13	129.2	-	26.3	-	26.3	14.7	0.7	28.9	-	11.0	55.3	-	0.9	4.7	-	0.9	0.9	18.0	23.2	41.2	-	-	-	-	-	-	-	-
CB12-15	167.3	-	27.4	-	27.4	33.5	-	58.0	-	33.5	125.0	-	2.0	-	-	-	-	-	12.8	12.8	-	-	-	-	-	-	-	-
CB26-18	2374.2	-	706.4	-	706.4	-	12.8	-	9.4	272.3	294.5	-	245.9	-	-	26.2	26.2	-	-	-	-	1101.2	-	-	-	1101.2	-	-

Table C2.2- 1 Biomass of fishes caught by otter trawl (continued).

Station- OT haul	All fishes	*Mallotus villosus* = **Osmeridae**	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae** (5 taxa)	*Nautichthys pribilovius* = **Hemiptipteridae**	*Aspidophoroides olrikii* = **Agonidae**	*Eumicrotremus derjugini* = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Lumpenus fabricii*	Stichaeidae larvae unid	*Stichaeus punctatus*	**Stichaeidae** (5 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus* = **Pleuronectidae**
Eastern Beaufish																												
EB02-12	3.8	-	2.3	-	2.3	-	1.5	-	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EB04-11	87.9	-	-	-	-	-	19.2	13.1	-	6.0	38.4	-	-	-	-	-	-	-	45.9	45.9	3.6	-	-	-	-	3.6	-	-
EB10-9	59.7	-	22.5	-	22.5	9.2	-	12.1	-	6.1	27.4	-	0.9	-	-	8.9	8.9	-	-	-	-	-	-	-	-	-	-	-
EB12-8	54.4	-	27.8	-	27.8	8.0	-	14.1	-	-	22.1	-	2.1	-	-	2.4	2.4	-	-	-	-	-	-	-	-	-	-	-
EB14-6	106.7	-	21.6	-	21.6	2.2	7.6	12.7	1.0	8.3	31.8	-	-	-	-	45.7	45.7	7.7	-	7.7	-	-	-	-	-	-	-	-
EB16-7	111.4	-	26.9	-	26.9	10.6	0.7	21.4	-	-	32.6	-	9.3	39.2	-	-	-	3.3	-	3.3	-	-	-	-	-	-	-	-
EB21-5	537.3	-	122.5	-	122.5	59.3	-	136.9	25.0	-	221.1	-	71.8	20.6	-	15.2	15.2	56.2	23.8	80.0	6.1	-	-	-	-	6.1	-	-
EB25-1	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EB27-2	87.9	-	47.4	-	47.4	-	0.6	14.3	-	-	14.9	-	1.6	7.1	-	-	-	17.0	-	17.0	-	-	-	-	-	-	-	-

Table C2.2- 2 Density of fishes caught in each quantitative otter trawl haul during BOEM-2011 (# fish/1000 m, distance). Fishes are aggregated as in Table 2.1-2 and are presented in phylogenetic order; stations are in alphabetic order within west to east regions. No replicate hauls were collected.

Station- OT haul	All fishes	*Mallotus villosus* = **Osmeridae**	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae** (5 taxa)	*Nautichthys pribilovius* = **Hemiptipteridae**	*Aspidophoroides olrikii* = **Agonidae**	*Eumicrotremus derjugini* = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Lumpenus fabricii*	Stichaeidae larvae unid	*Stichaeus punctatus*	**Stichaeidae** (5 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus* = **Pleuronectidae**
Western Beaufish																												
WB02-38	117.0	-	96.6	-	96.6	-	-	-	-	-	-	-	2.9	-	-	11.7	11.7	-	5.9	5.9	-	-	-	-	-	-	-	-
WB05-36	260.8	-	230.8	3.3	234.1	-	6.7	-	-	-	6.7	-	-	-	-	20.1	20.1	-	-	-	-	-	-	-	-	-	-	-
WB07-27	150.7	-	112.2	-	112.2	-	-	-	-	6.4	6.4	-	-	-	-	6.4	6.4	-	19.2	19.2	3.2	-	3.2	-	-	6.4	-	-
WB08-26	70.5	-	60.4	-	60.4	-	3.4	-	-	-	3.4	-	-	-	6.7	-	6.7	-	-	-	-	-	-	-	-	-	-	-
WB10-35	1251.8	-	1207.8	-	1207.8	-	8.3	2.8	-	11.0	22.0	-	2.8	-	-	16.5	16.5	-	-	-	-	-	-	-	-	-	2.8	-
WB12-34	1806.5	-	1550.6	-	1550.6	-	35.7	-	38.7	8.9	83.3	3.0	6.0	-	-	139.9	139.9	-	-	-	3.0	-	17.9	3.0	-	23.8	-	-
WB13-42	761.8	3.2	482.5	-	482.5	15.9	44.4	-	60.3	15.9	136.5	-	-	-	-	85.7	85.7	-	15.9	15.9	25.4	-	12.7	-	-	38.1	-	-
WB15-33	561.5	-	350.1	-	350.1	6.6	-	26.4	-	19.8	52.8	-	52.8	3.3	-	95.8	95.8	-	6.6	6.6	-	-	-	-	-	-	-	-
WB16-31	336.9	-	160.3	-	160.3	9.8	-	9.8	6.5	3.3	29.4	-	13.1	-	-	65.4	65.4	-	13.1	13.1	52.3	-	-	-	-	52.3	-	3.3
WB19-24	1103.0	-	746.2	-	746.2	2.5	2.5	20.1	-	10.1	35.2	-	12.6	7.5	-	271.4	271.4	12.6	2.5	15.1	-	-	2.5	10.1	2.5	15.1	-	-
WB21-40	4379.4	3.2	3769.8	38.5	3808.3	12.8	208.6	-	83.4	25.7	330.5	-	57.8	-	-	35.3	35.3	-	3.2	3.2	9.6	-	131.5	-	-	141.2	-	-
WB22-37	844.4	-	796.9	15.8	812.8	6.3	9.5	3.2	3.2	3.2	25.3	3.2	-	-	-	3.2	3.2	-	-	-	-	-	-	-	-	-	-	-
WB23-30	112.7	-	63.6	-	63.6	5.8	14.5	8.7	-	2.9	31.8	-	-	-	-	17.3	17.3	-	-	-	-	-	-	-	-	-	-	-
WB24-29	460.1	-	243.2	-	243.2	-	5.9	2.9	2.9	8.8	20.5	-	2.9	-	-	161.2	161.2	-	2.9	2.9	8.8	-	2.9	-	-	11.7	-	17.6
WB28-39	73.8	-	61.5	-	61.5	-	-	-	-	-	-	-	-	-	-	8.2	8.2	-	4.1	4.1	-	-	-	-	-	-	-	-
WB32-28	235.3	-	30.8	-	30.8	-	-	14.0	-	11.2	25.2	-	22.4	-	-	42.0	42.0	-	89.6	89.6	25.2	-	-	-	-	25.2	-	-
Central Beaufish																												
CB02-14	68.3	-	15.8	-	15.8	15.8	10.5	-	-	10.5	36.8	-	-	-	-	10.5	10.5	-	-	-	5.3	-	-	-	-	5.3	-	-
CB06-16	454.9	-	339.6	-	339.6	-	43.6	-	6.2	28.0	77.9	-	-	-	-	37.4	37.4	-	-	-	-	-	-	-	-	-	-	-
CB07-17	455.5	-	359.1	-	359.1	-	46.5	-	3.3	16.6	66.5	-	-	-	-	26.6	26.6	-	-	-	-	-	-	3.3	-	3.3	-	-
CB08-21	21.4	-	3.6	-	3.6	3.6	5.4	3.6	1.8	-	14.3	-	-	-	-	3.6	3.6	-	-	-	-	-	-	-	-	-	-	-
CB11-13	58.2	-	21.4	-	21.4	3.1	1.5	19.9	-	1.5	26.0	-	1.5	1.5	-	1.5	1.5	3.1	3.1	6.1	-	-	-	-	-	-	-	-
CB12-15	90.7	-	17.4	-	17.4	7.0	-	45.4	-	14.0	66.3	-	3.5	-	-	-	-	-	3.5	3.5	-	-	-	-	-	-	-	-
CB26-18	539.3	-	193.6	-	193.6	-	27.7	-	13.8	27.7	69.1	-	193.6	-	-	69.1	69.1	-	-	-	-	13.8	-	-	-	13.8	-	-

Table C2.2- 2 Density of fishes caught by otter trawl (continued).

Station- OT haul	All fishes	*Mallotus villosus* = **Osmeridae**	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus scorpius*	*Triglops pingelii*	**Cottidae** (5 taxa)	*Nautichthys pribilovius* = **Hemiptipteridae**	*Aspidophoroides olrikii* = **Agonidae**	*Eumicrotremus derjugini* = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Lumpenus fabricii*	Stichaeidae larvae unid	*Stichaeus punctatus*	**Stichaeidae** (5 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus* = **Pleuronectidae**
Eastern Beaufish																												
EB02-12	12.7	-	9.5	-	9.5	-	3.2	-	-	-	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EB04-11	14.6	-	-	-	-	-	3.7	5.5	-	1.8	11.0	-	-	-	-	-	-	-	1.8	1.8	1.8	-	-	-	-	1.8	-	-
EB10-9	31.7	-	7.9	-	7.9	3.2	-	9.5	-	4.8	17.4	-	1.6	-	-	4.8	4.8	-	-	-	-	-	-	-	-	-	-	-
EB12-8	19.9	-	10.0	-	10.0	1.7	-	5.0	-	-	6.6	-	1.7	-	-	1.7	1.7	-	-	-	-	-	-	-	-	-	-	-
EB14-6	51.5	-	17.7	-	17.7	1.5	2.9	11.8	1.5	5.9	23.5	-	-	-	-	7.4	7.4	2.9	-	2.9	-	-	-	-	-	-	-	-
EB16-7	40.3	-	13.4	-	13.4	1.5	1.5	11.9	-	-	14.9	-	9.0	1.5	-	-	-	1.5	-	1.5	-	-	-	-	-	-	-	-
EB21-5	184.9	-	28.1	-	28.1	8.3	-	80.9	5.0	-	94.1	-	33.0	3.3	-	9.9	9.9	9.9	5.0	14.9	1.7	-	-	-	-	1.7	-	-
EB25-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EB27-2	27.2	-	12.2	-	12.2	-	1.4	5.4	-	-	6.8	-	2.7	1.4	-	-	-	4.1	-	4.1	-	-	-	-	-	-	-	-

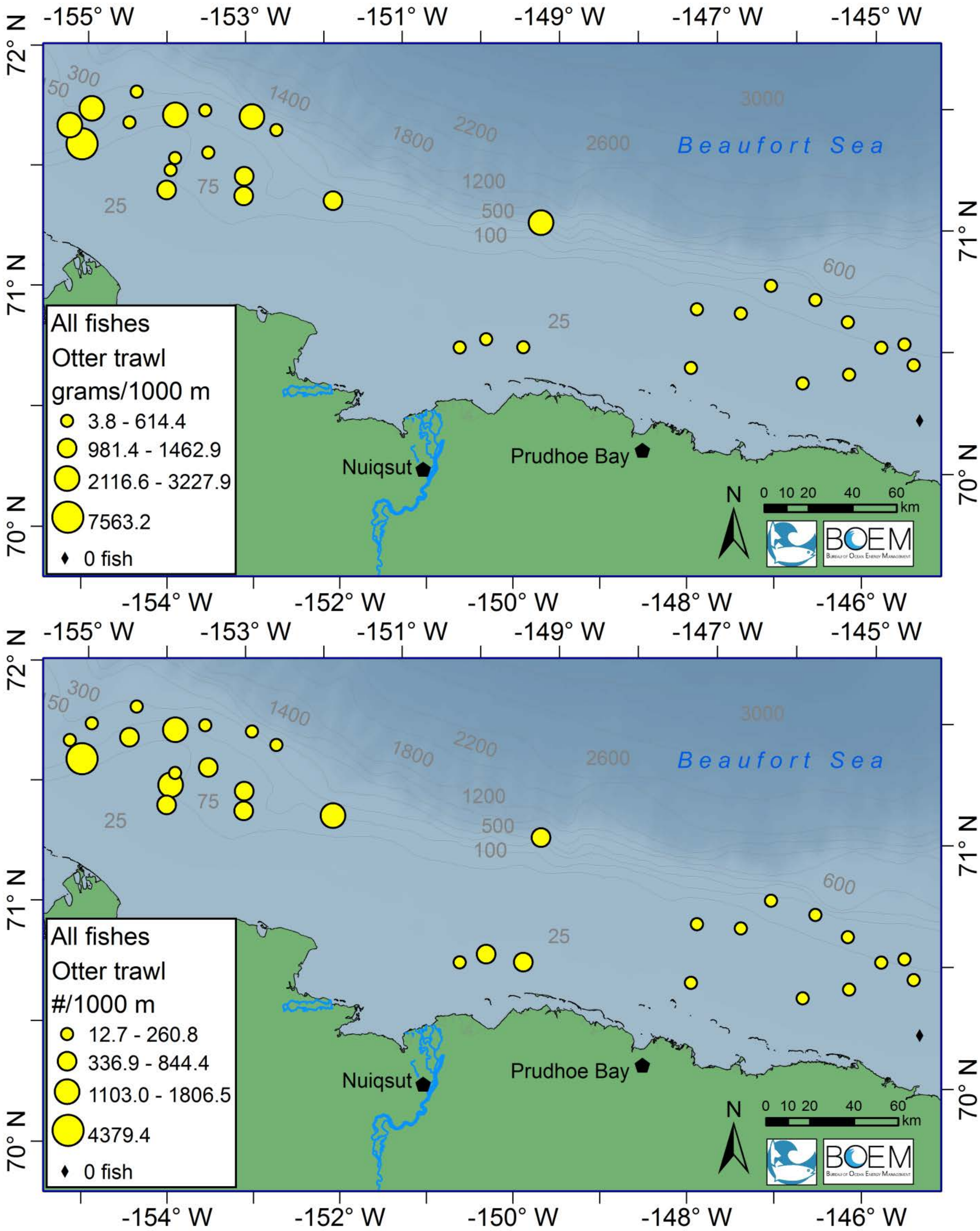


Figure C2.2- 1. All fishes combined – biomass and density in catches by otter trawl during BOEM-2011.

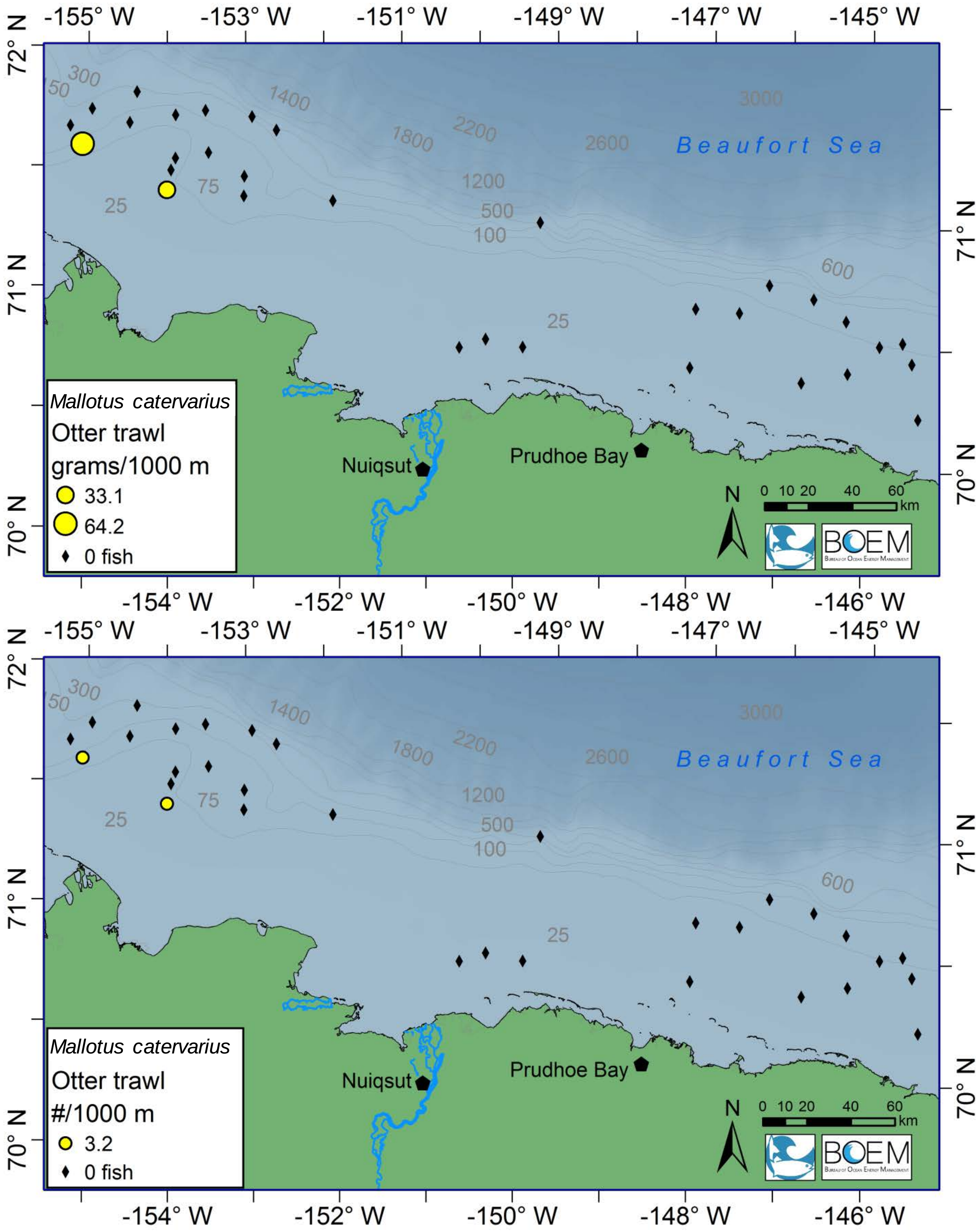


Figure C2.2- 2. Osmeridae (all were *Mallotus catervarius)* – density and biomass in catches by otter trawl during BOEM-2011.

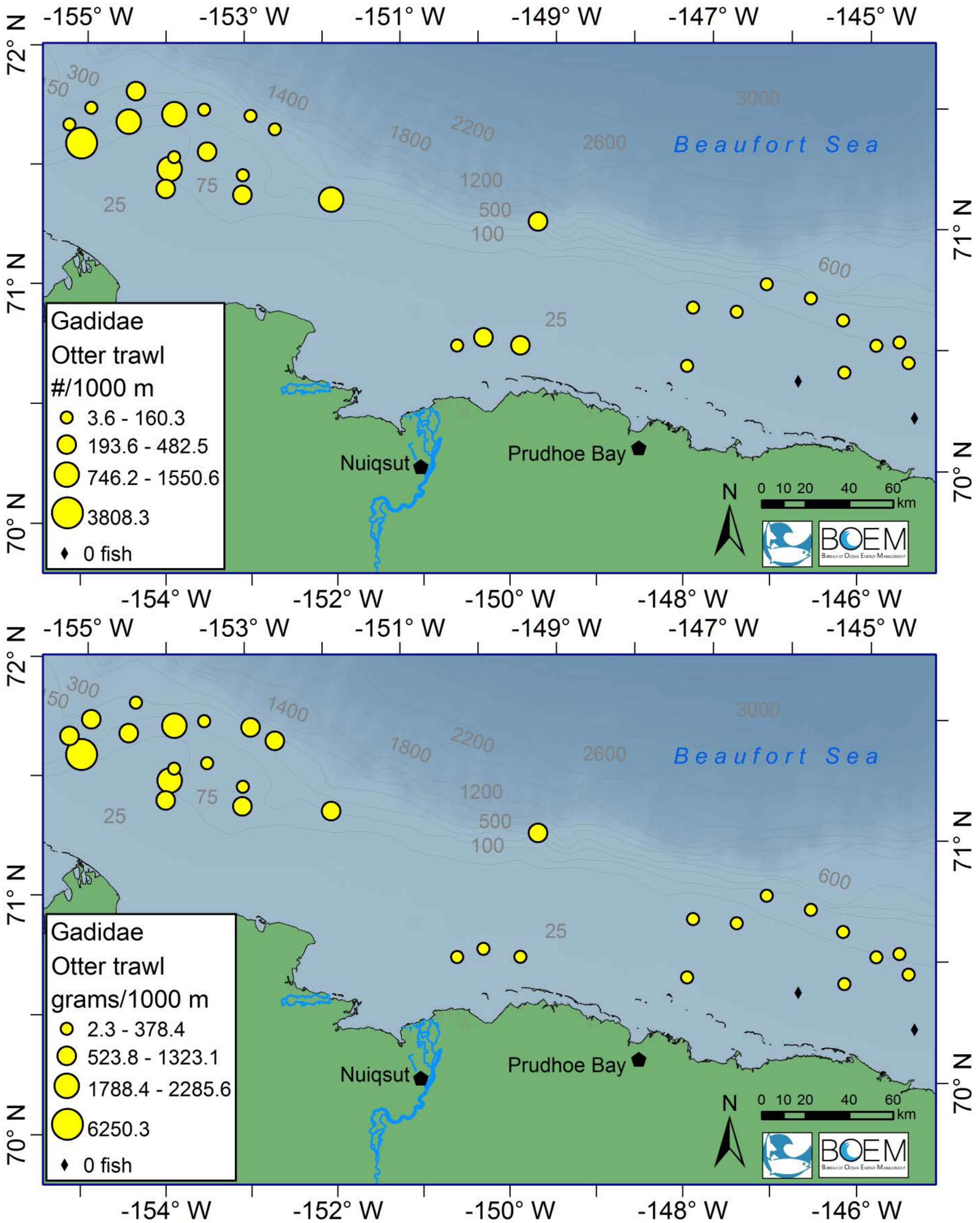


Figure C2.2- 3. Gadidae – biomass and density in catches by otter trawl during BOEM-2011.

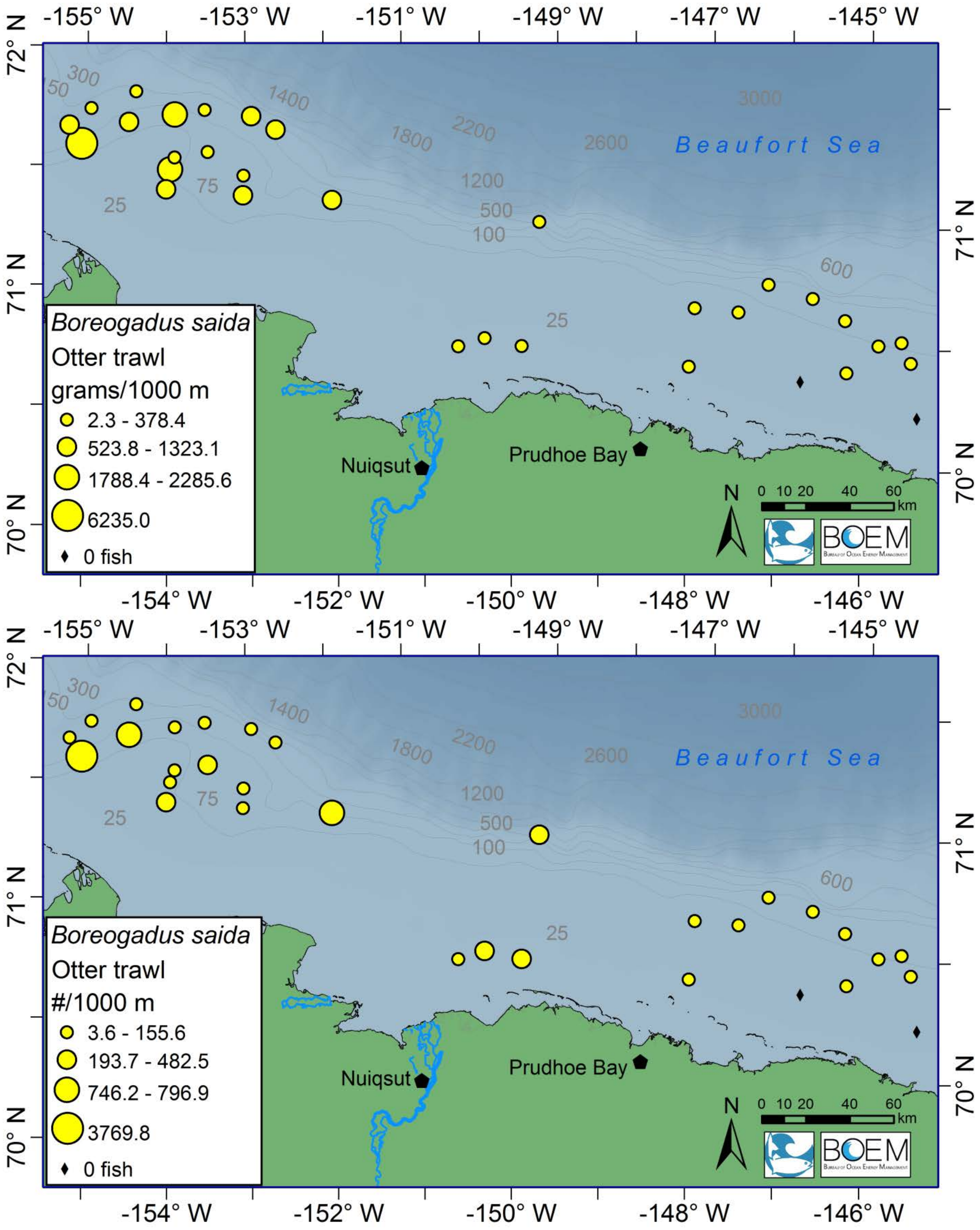


Figure C2.2- 4. Gadidae: *Boreogadus saida* biomass and density in catches by otter trawl during BOEM-2011.

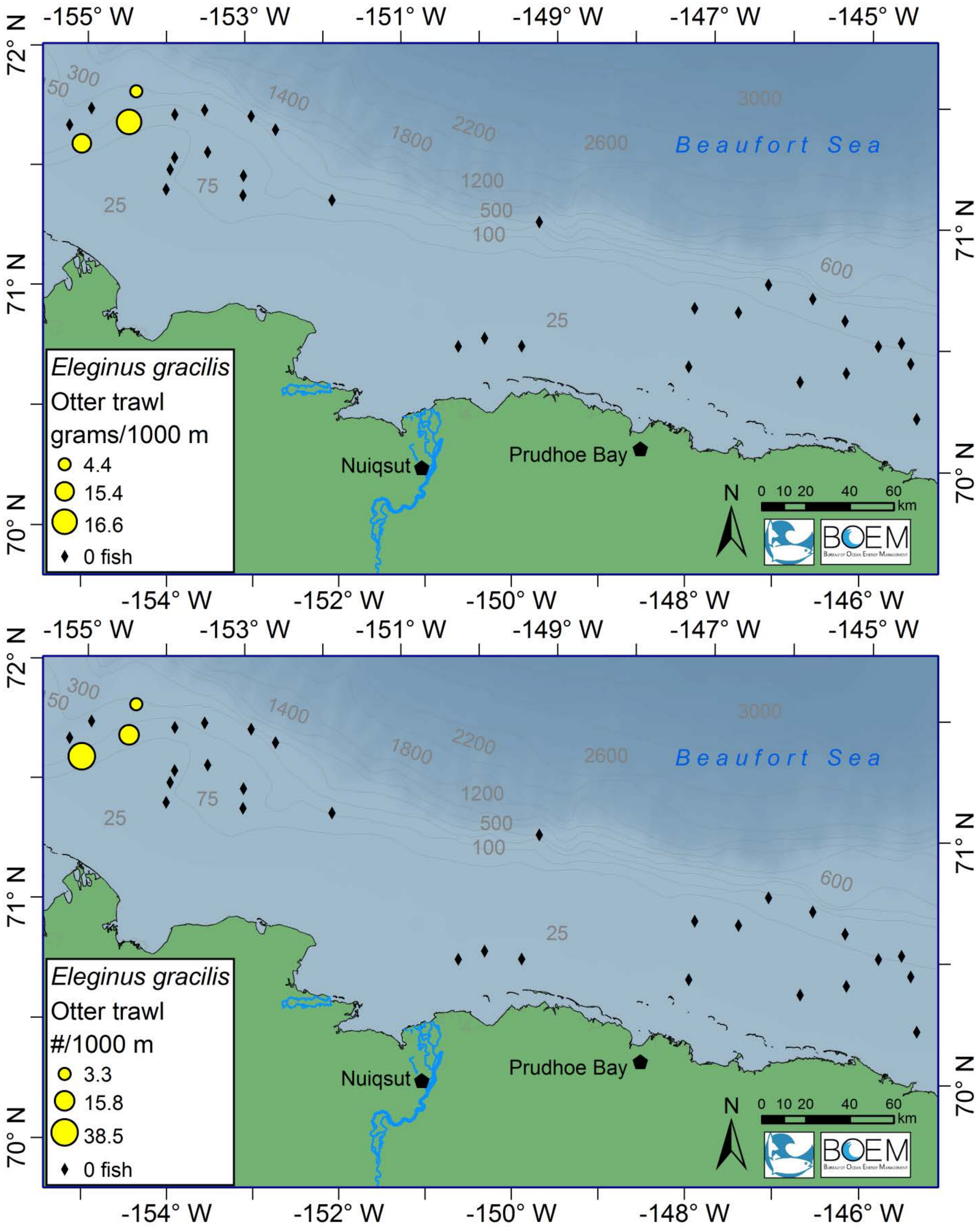


Figure C2.2- 5. Gadidae: *Eleginus gracilis* biomass and density in catches by otter trawl during BOEM-2011.

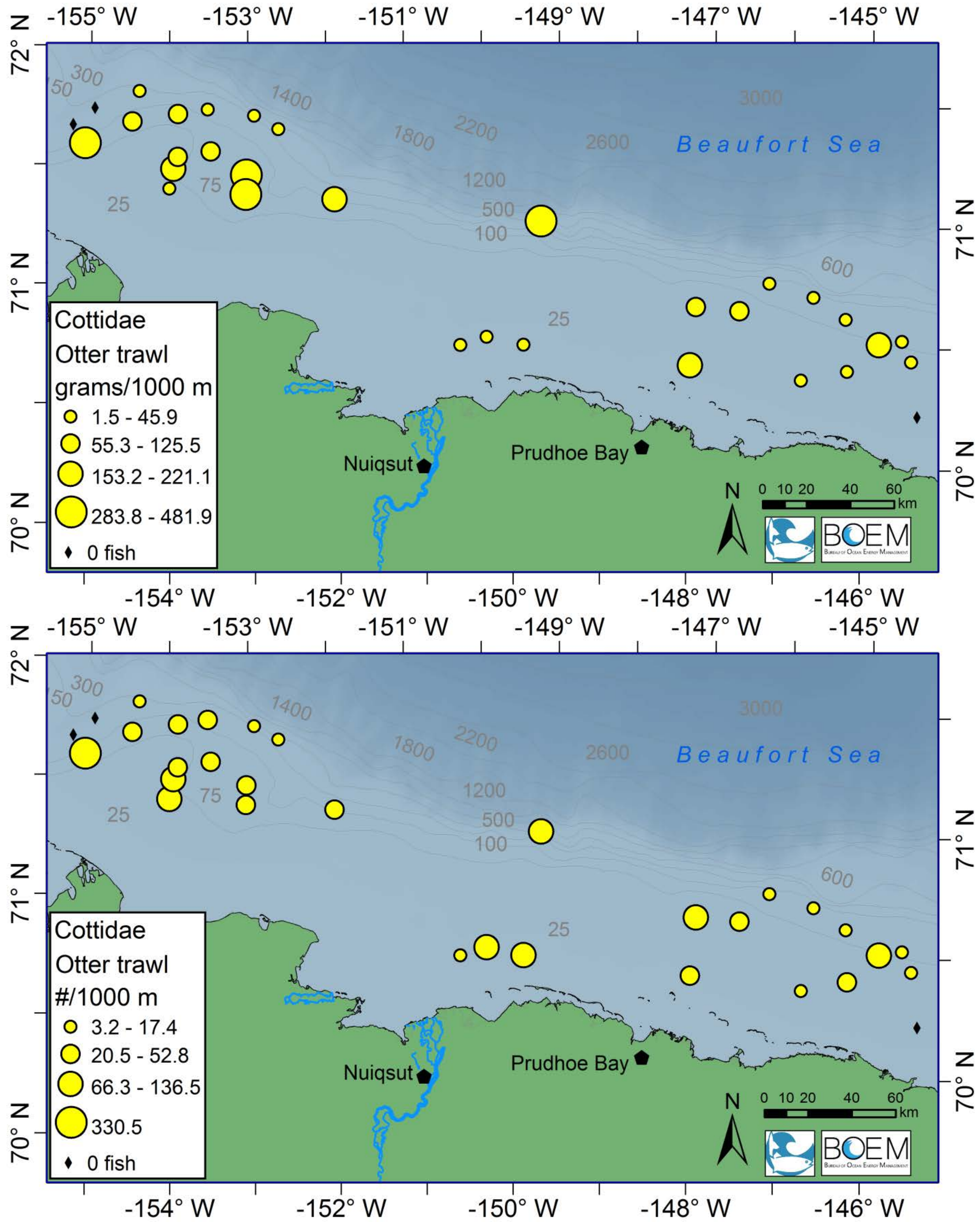


Figure C2.2- 6. Cottidae – biomass and density in catches by otter trawl during BOEM-2011.

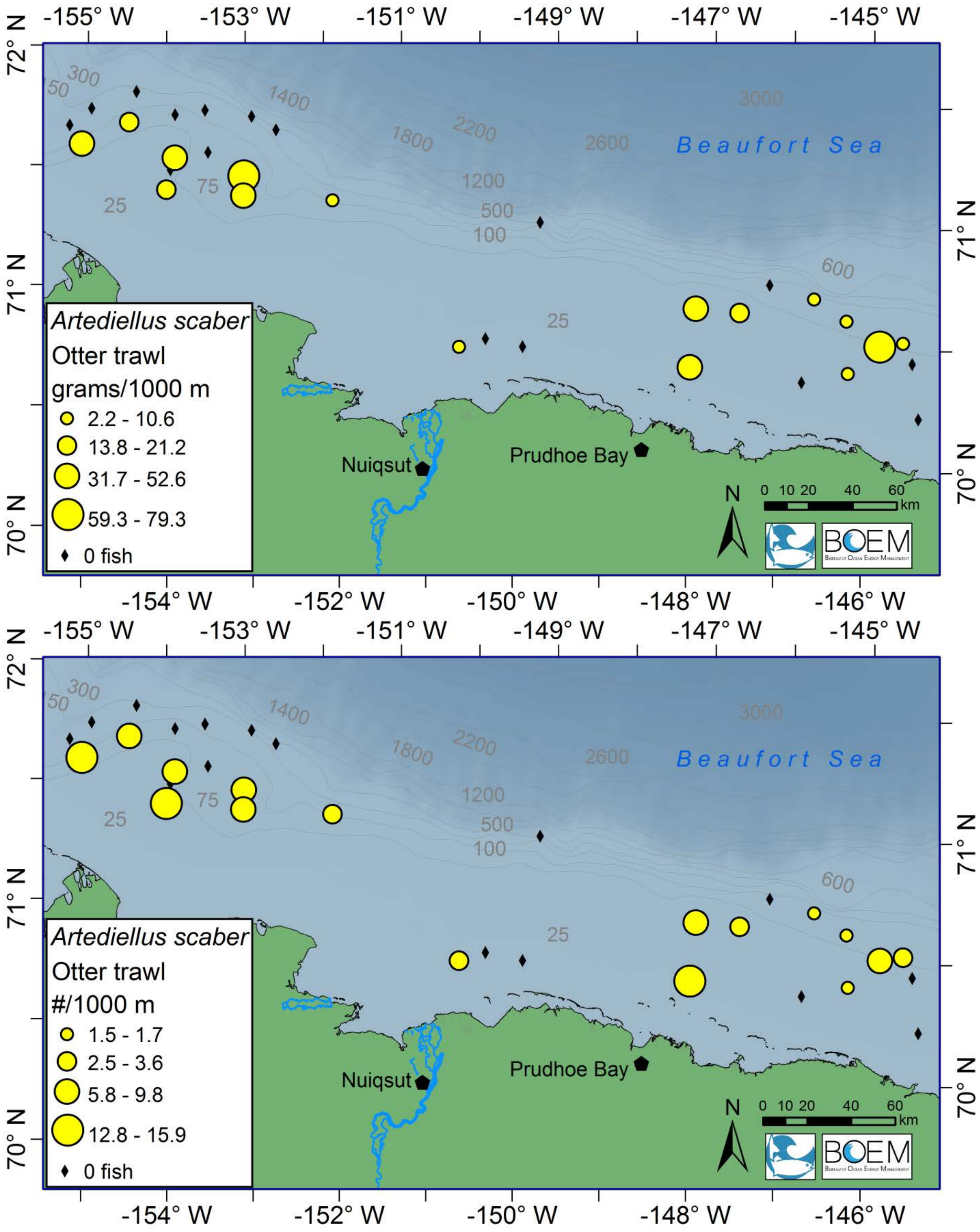


Figure C2.2- 7. Cottidae: *Artediellus scaber* biomass and density in catches by otter trawl during BOEM-2011.

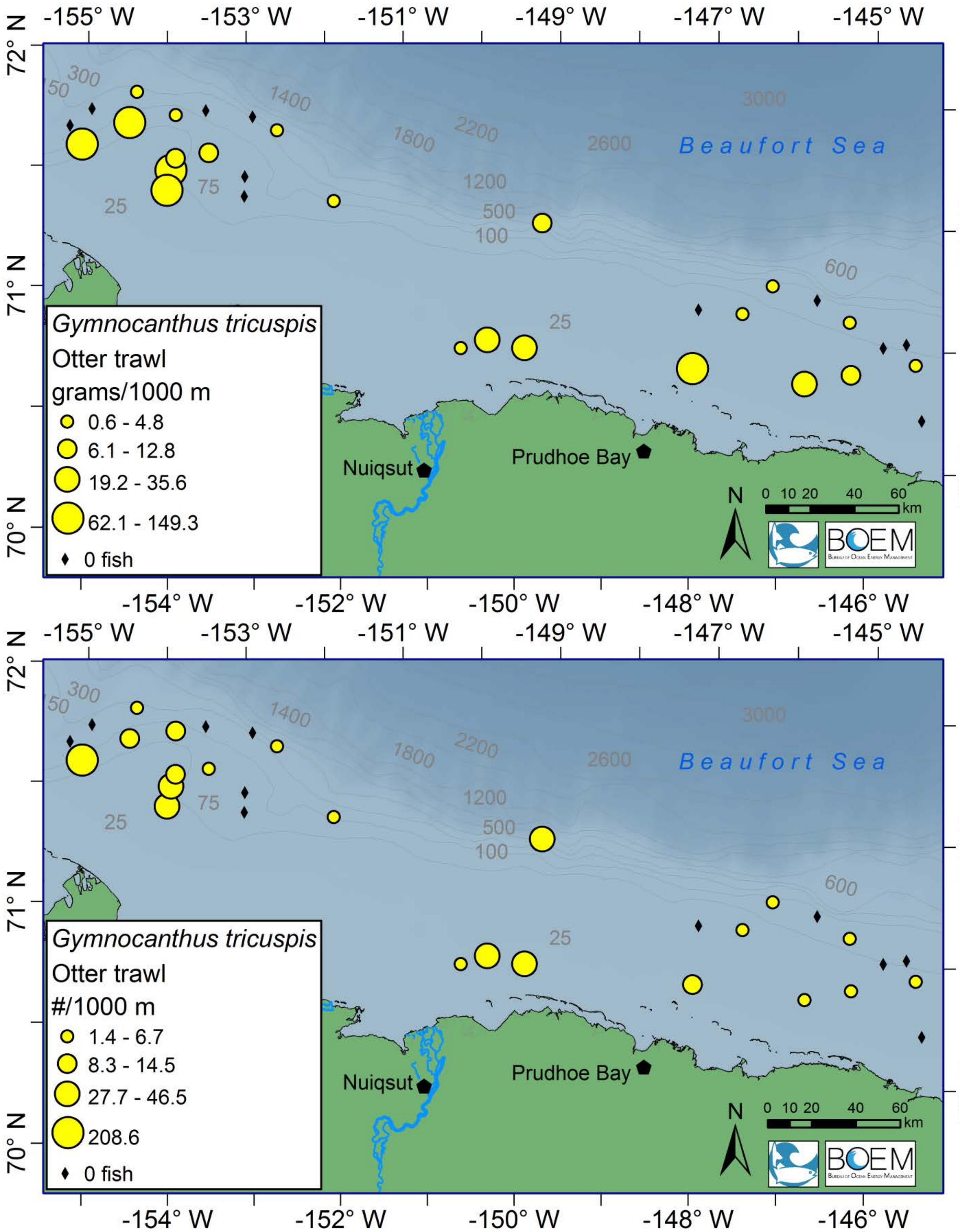


Figure C2.2- 8. Cottidae: *Gymnocanthus tricuspis* biomass and density in catches by otter trawl during BOEM-2011.

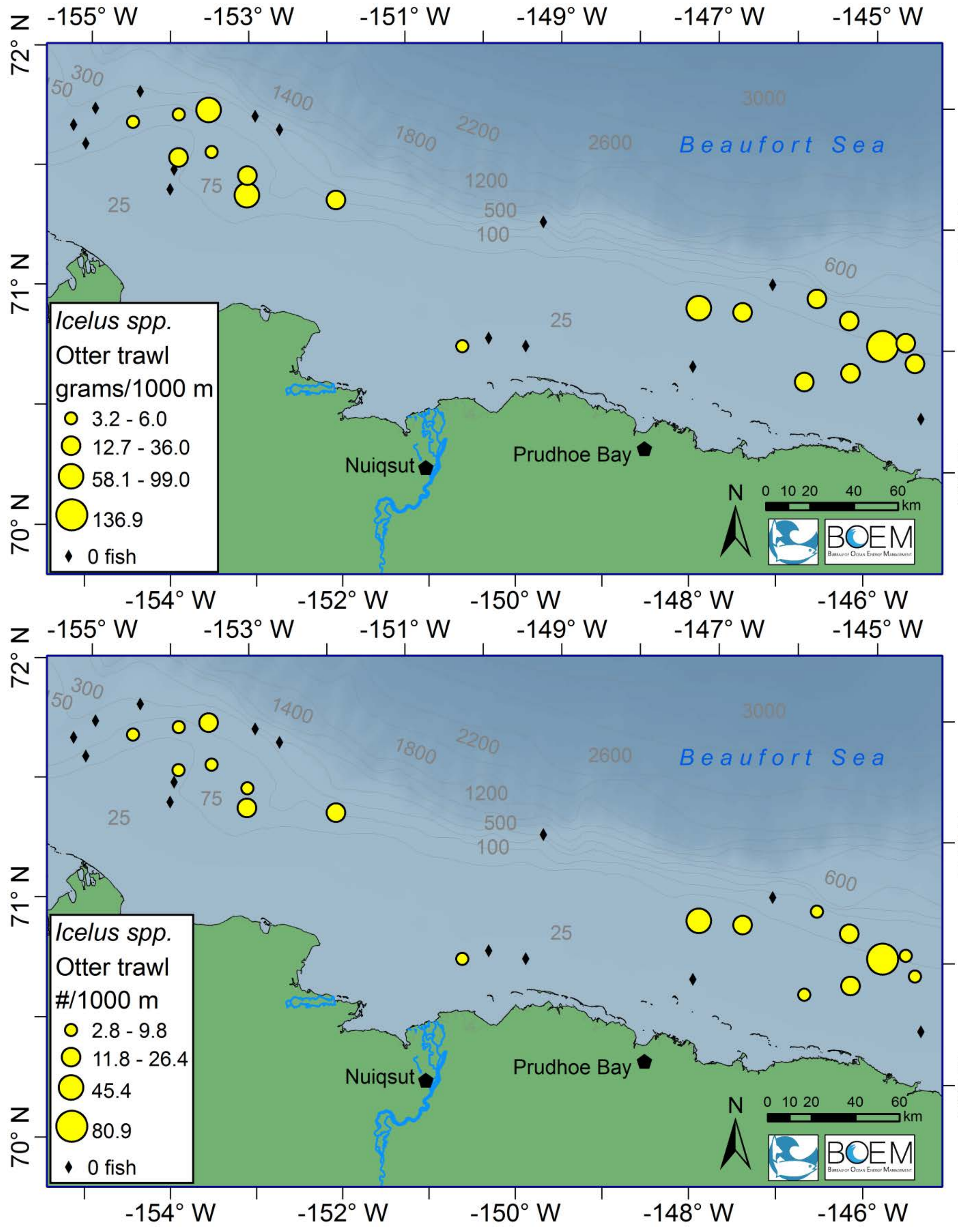


Figure C2.2- 9. Cottidae: *Icelus* spp. biomass and density in catches by otter trawl during BOEM-2011.

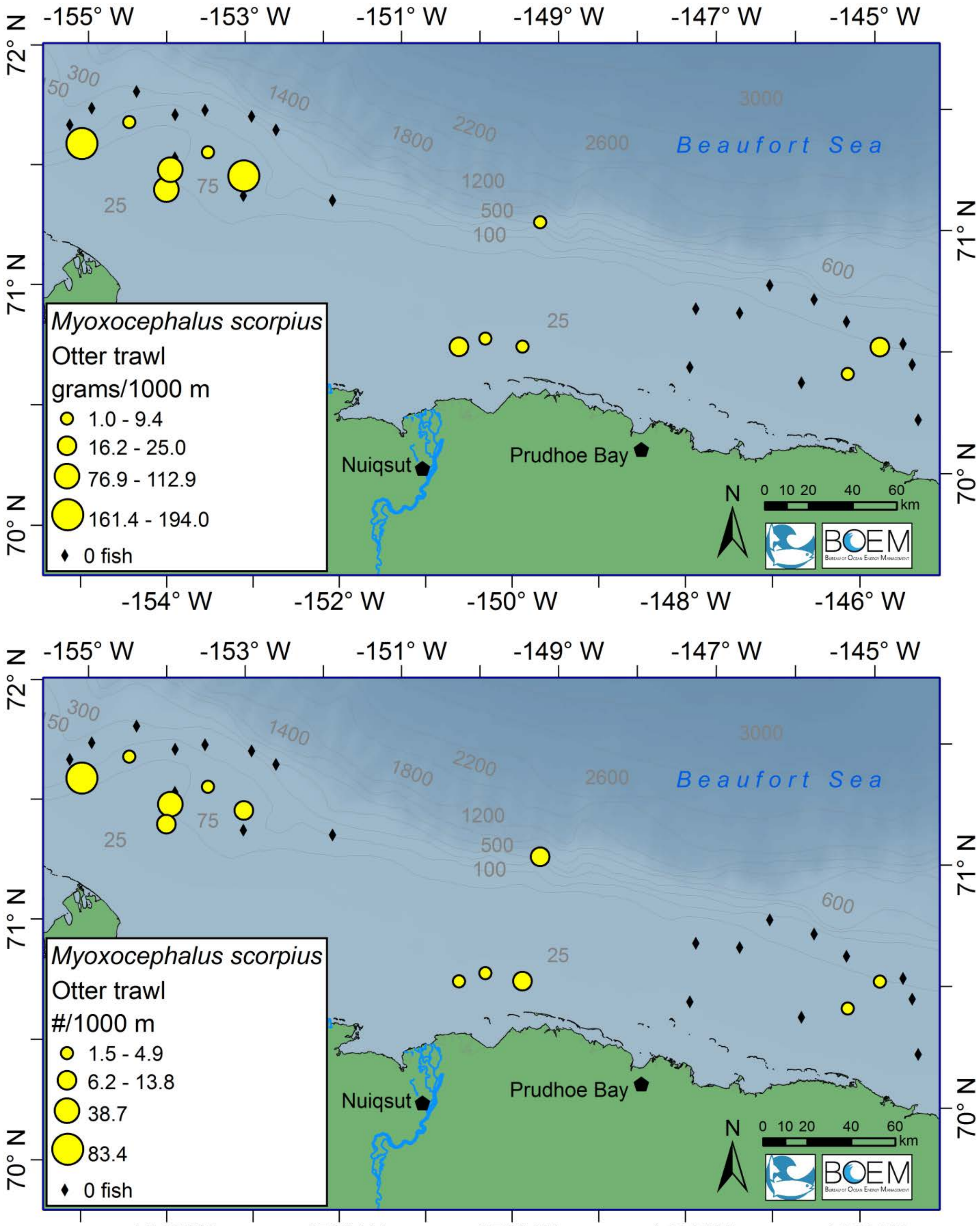


Figure C2.2- 10. Cottidae: *Myoxocephalus scorpius* biomass and density in catches by otter trawl during BOEM-2011.

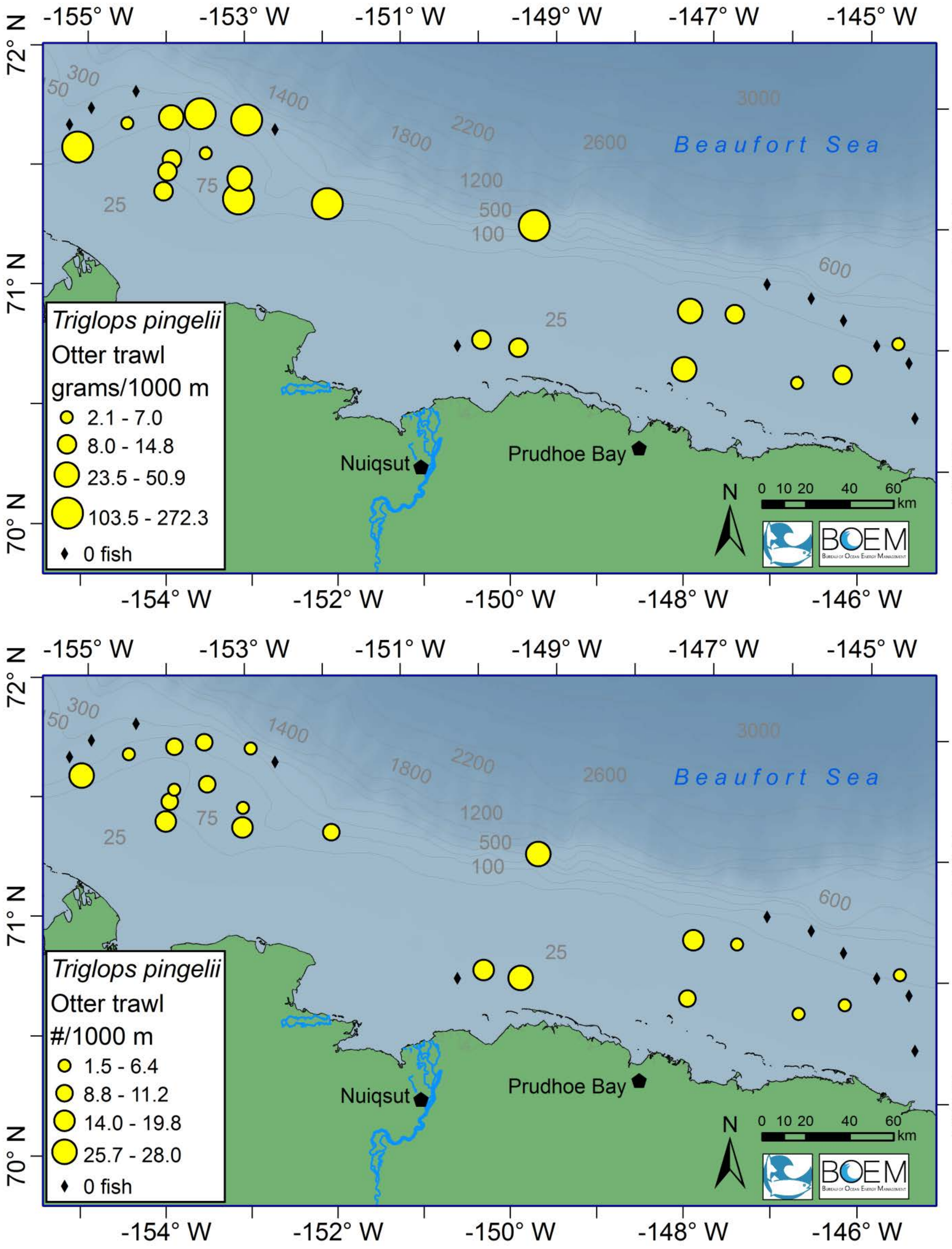


Figure C2.2- 11. Cottidae: *Triglops pingelii* biomass and density in catches by otter trawl during BOEM-2011.

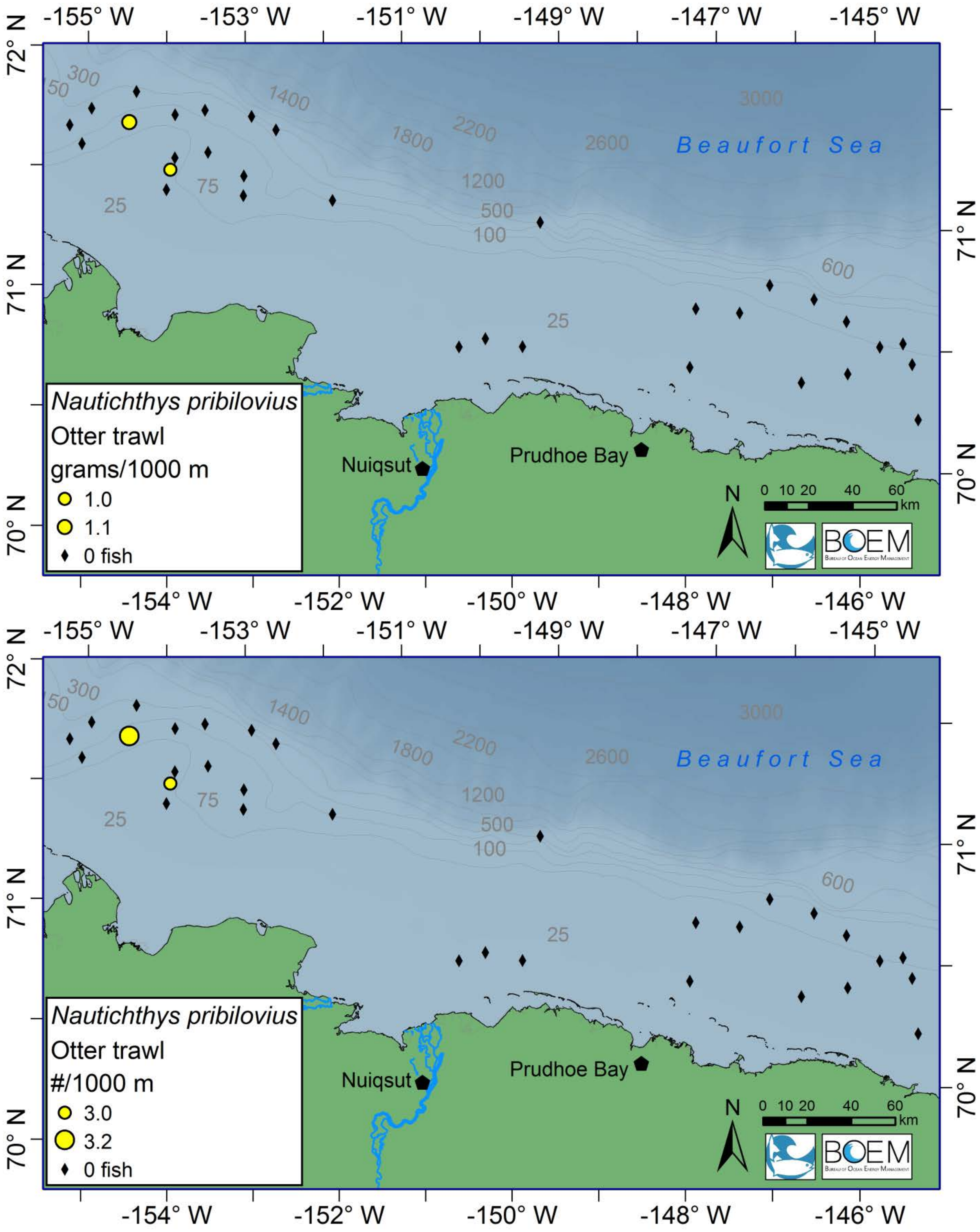
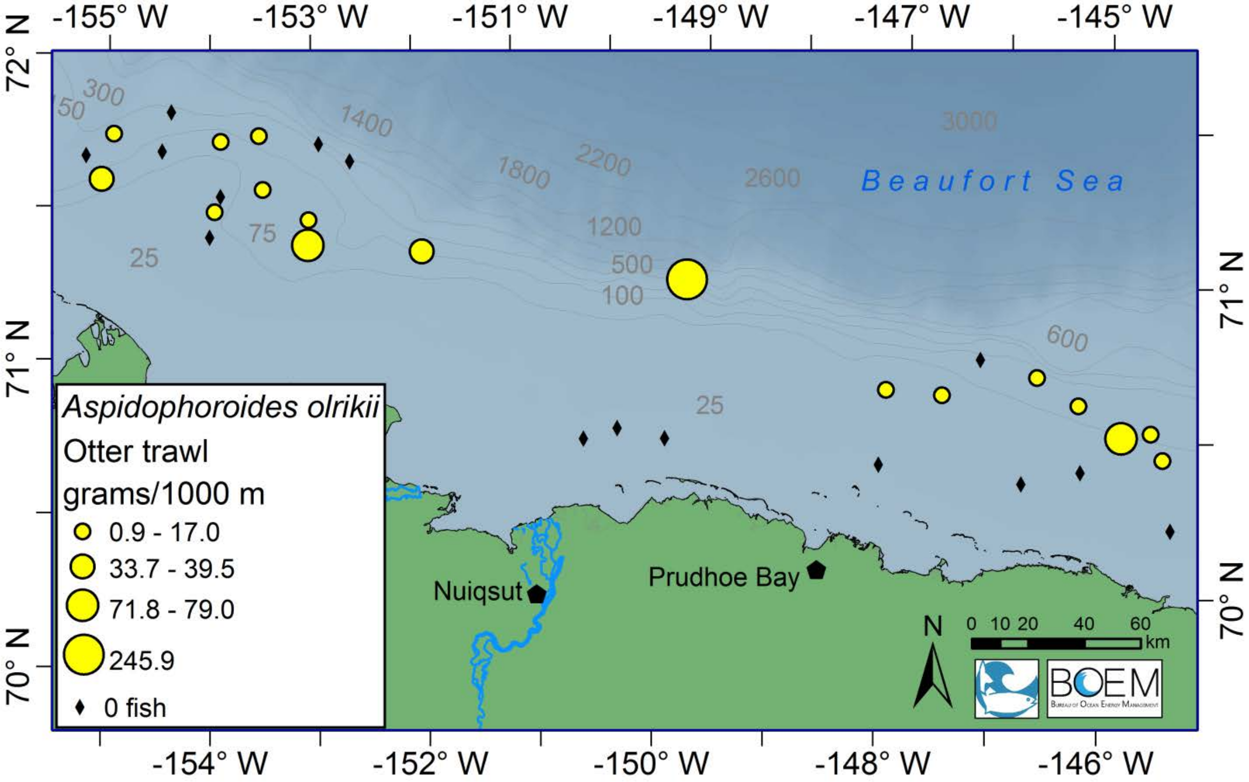


Figure C2.2- 12. Hemitripteridae (all were *Nautichthys pribilovius)* – biomass and density in catches by otter trawl during BOEM-2011



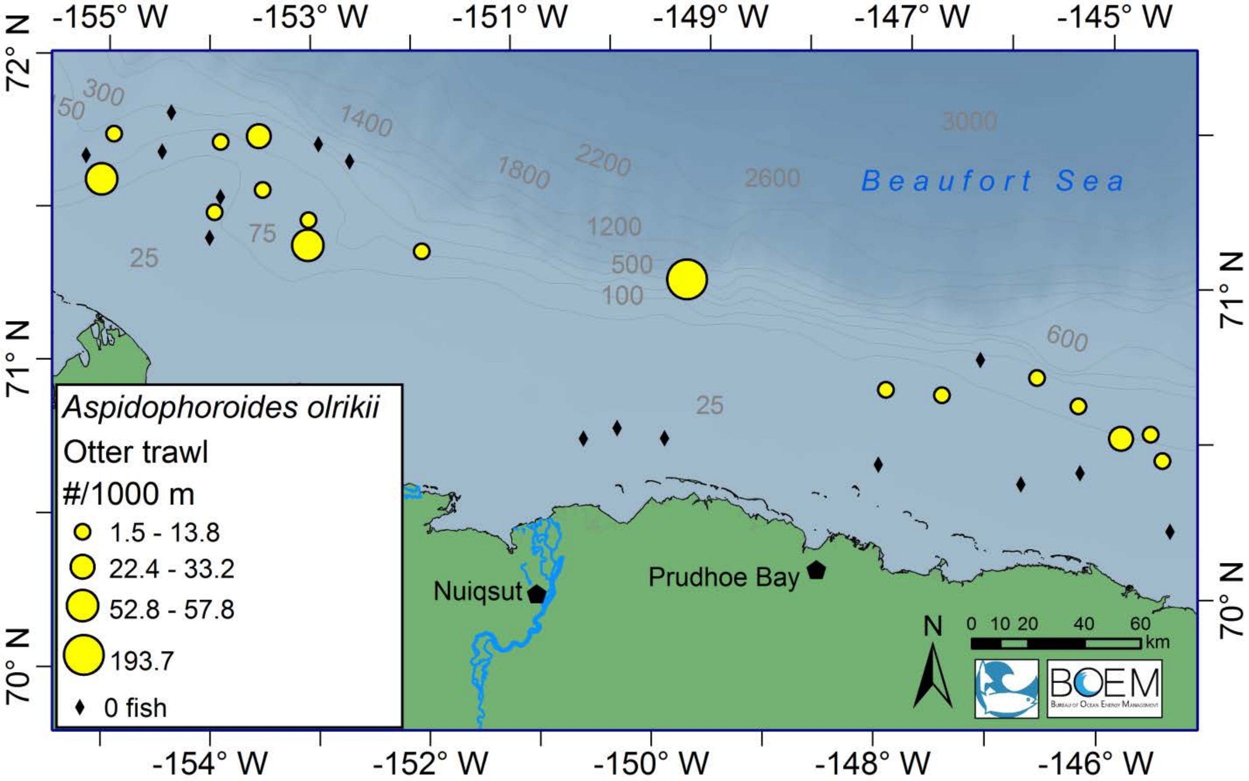


Figure C2.2- 13. Agonidae (all were *Aspidophoroides olrikii)* – biomass and density in catches by otter trawl during BOEM-2011

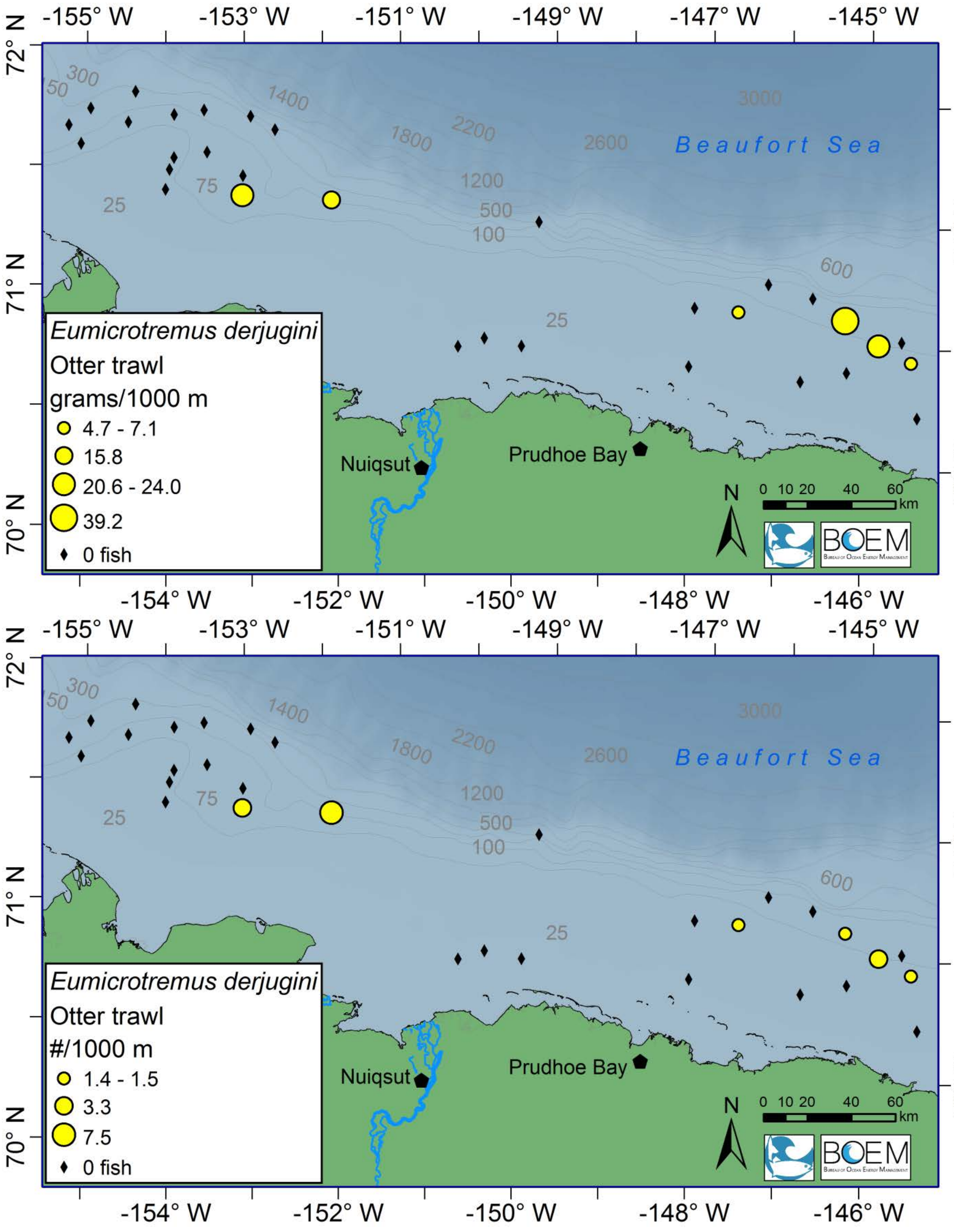


Figure C2.2- 14. Cyclopteridae (all were *Eumicrotremus derjugini)* – biomass and density in catches by otter trawl during BOEM-2011

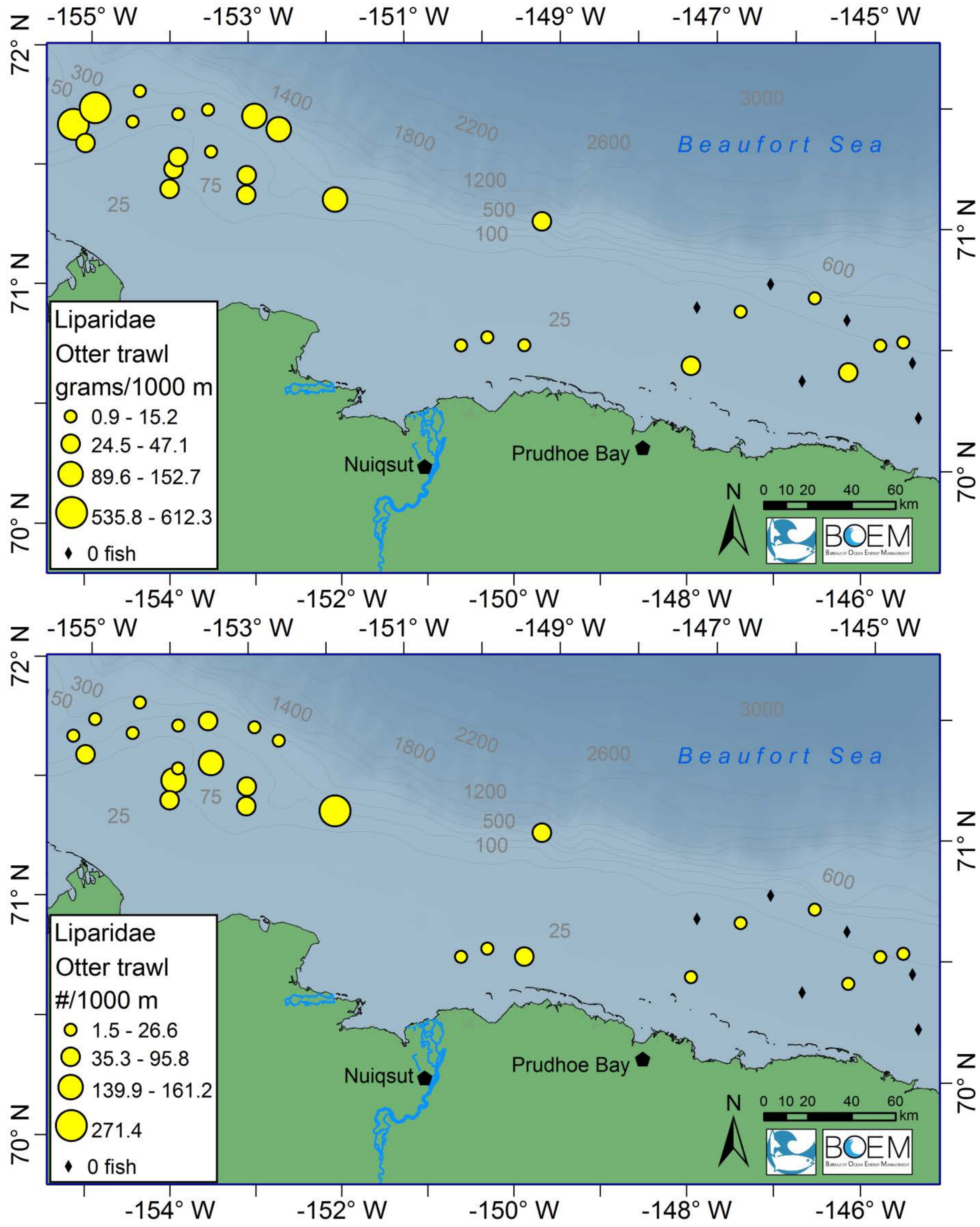


Figure C2.2- 15. Liparidae – biomass and density in catches by otter trawl during BOEM-2011.

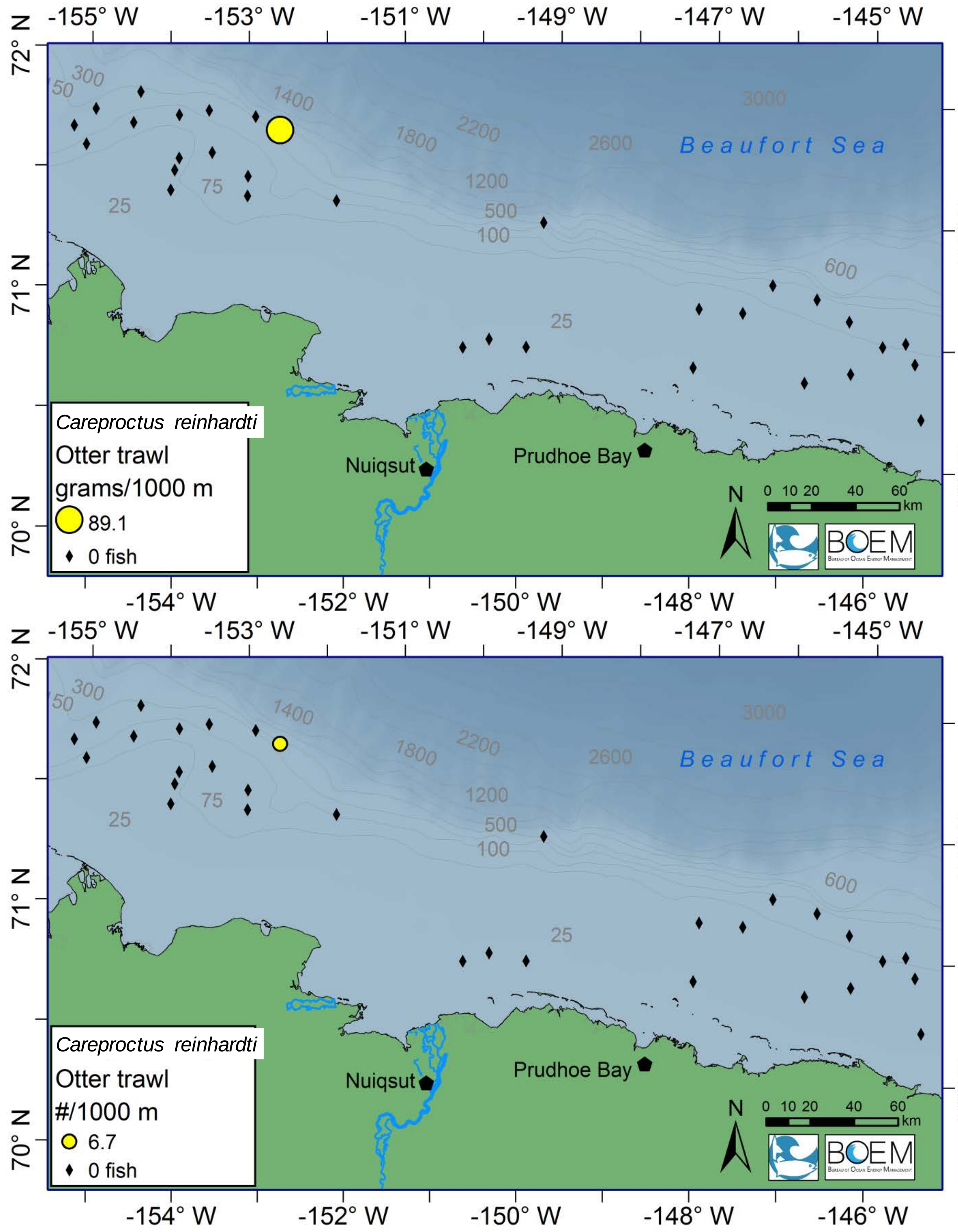


Figure C2.2- 16. Liparidae: *Careproctus reinhardti* biomass and density in catches by otter trawl during BOEM-2011.

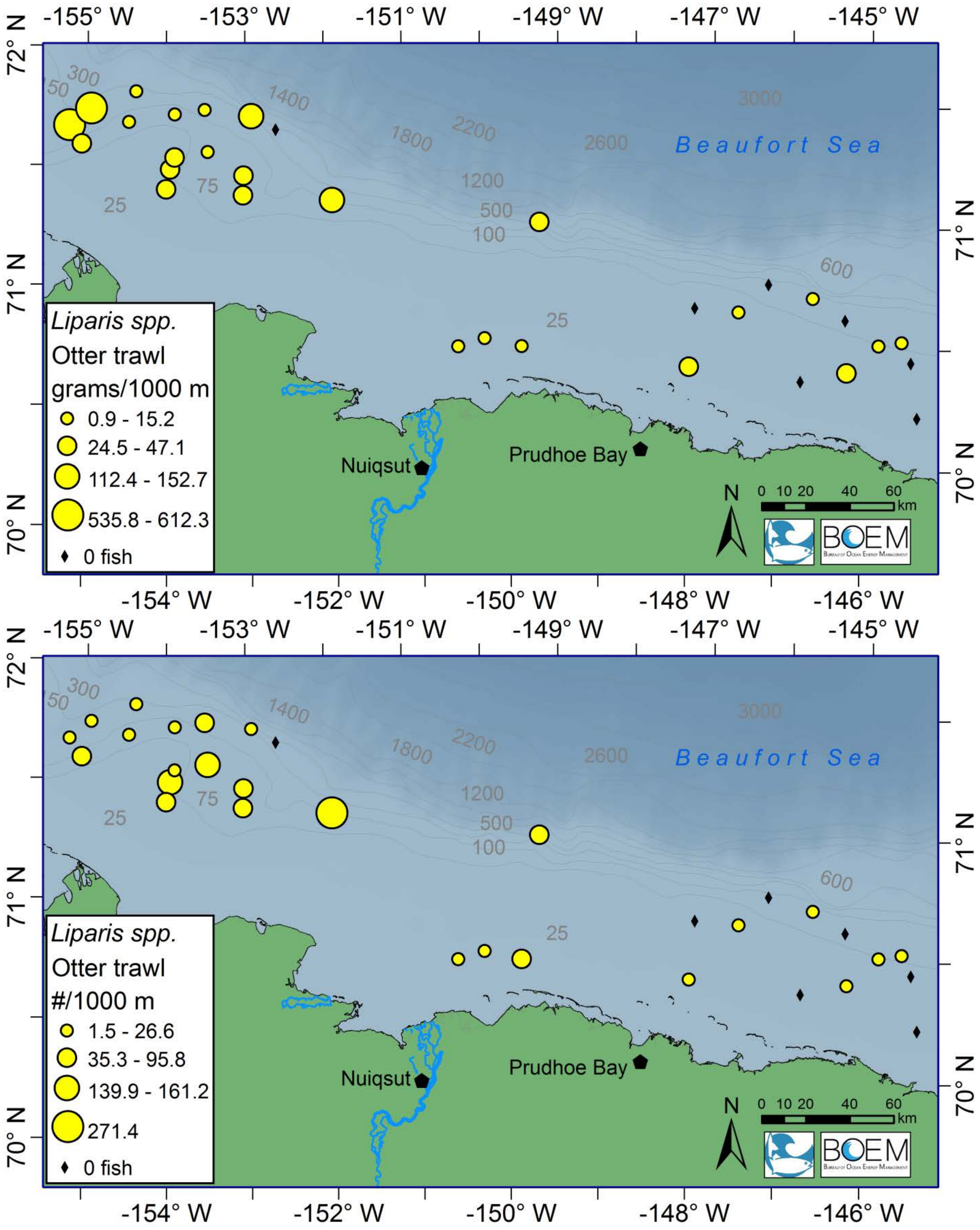


Figure C2.2- 17. Liparidae: *Liparis* spp. biomass and density in catches by otter trawl during BOEM-2011.

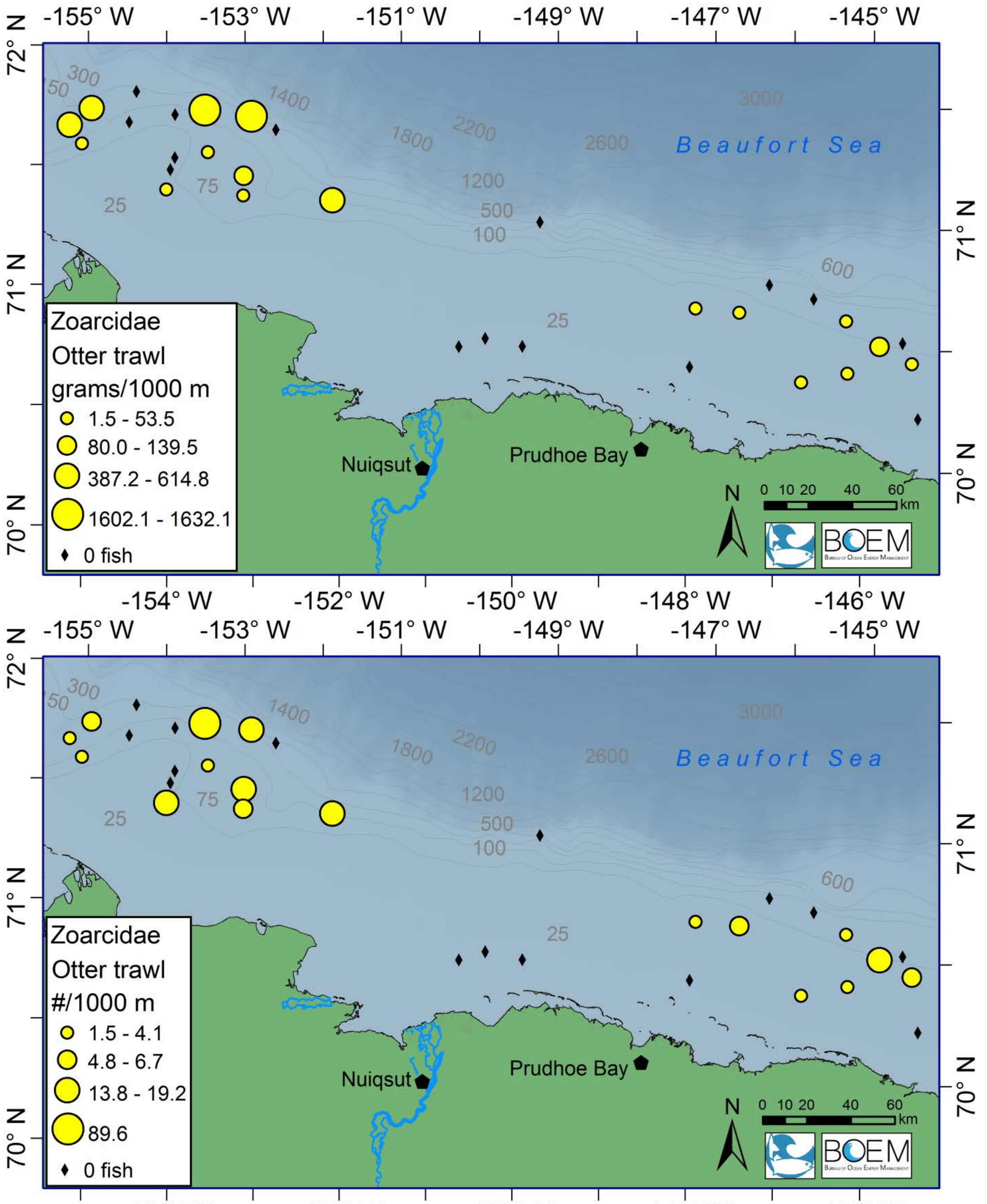


Figure C2.2- 18. Zoarcidae – biomass and density in catches by otter trawl during BOEM-2011.

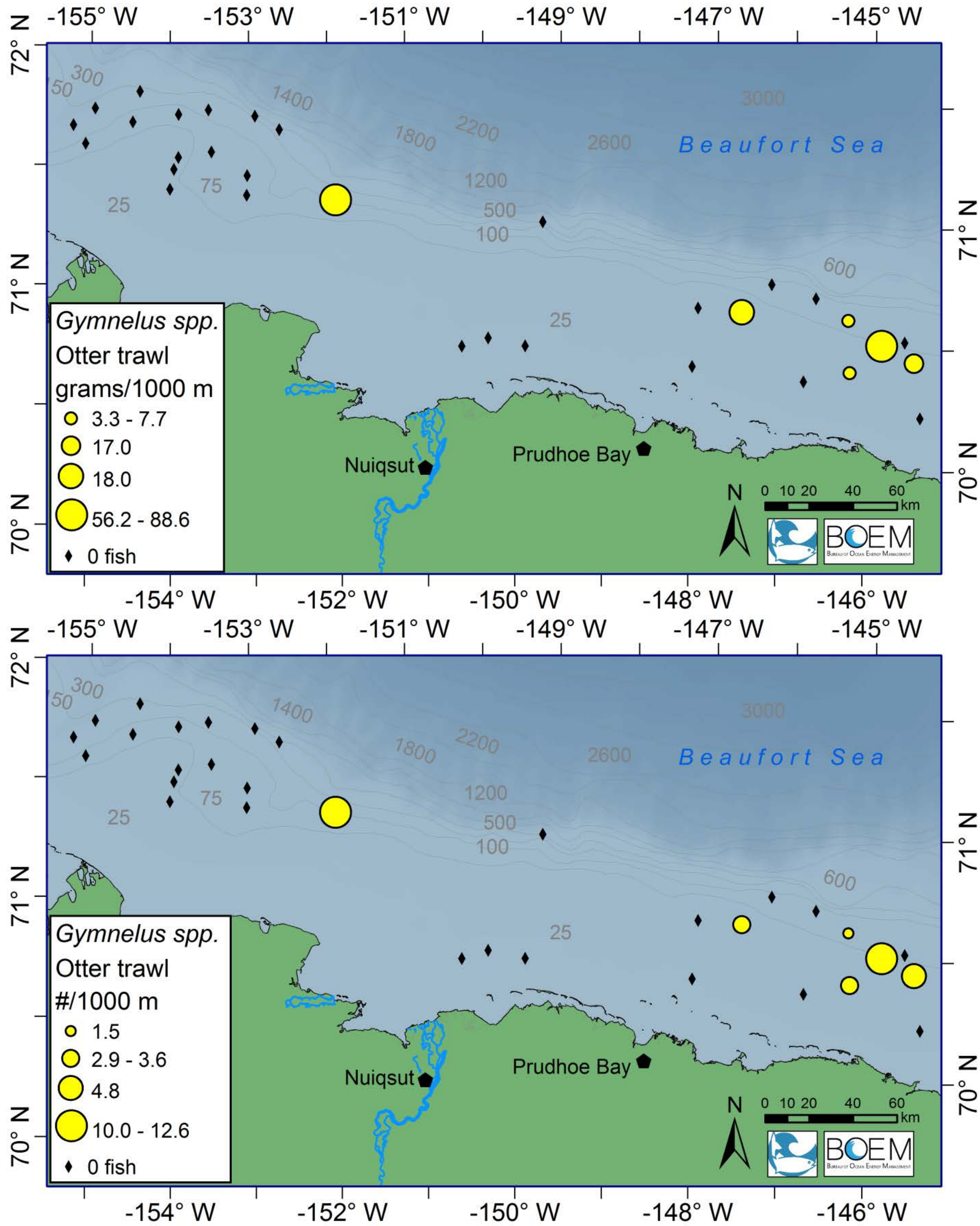


Figure C2.2- 19. Zoarcidae: *Gymnelus* spp. biomass and density in catches by otter trawl during BOEM-2011.

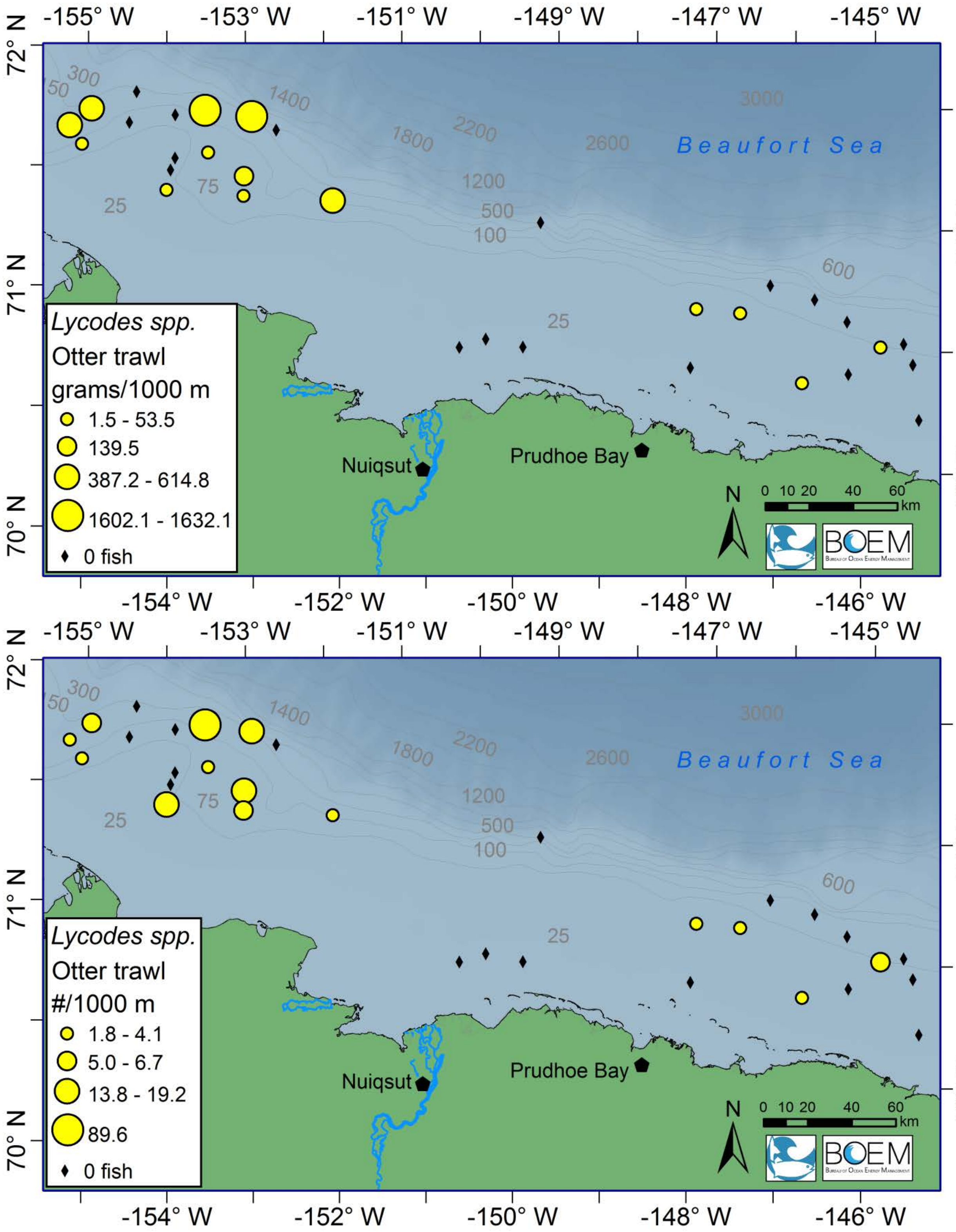


Figure C2.2- 20. Zoarcidae: *Lycodes* spp. biomass and density in catches by otter trawl during BOEM-2011.

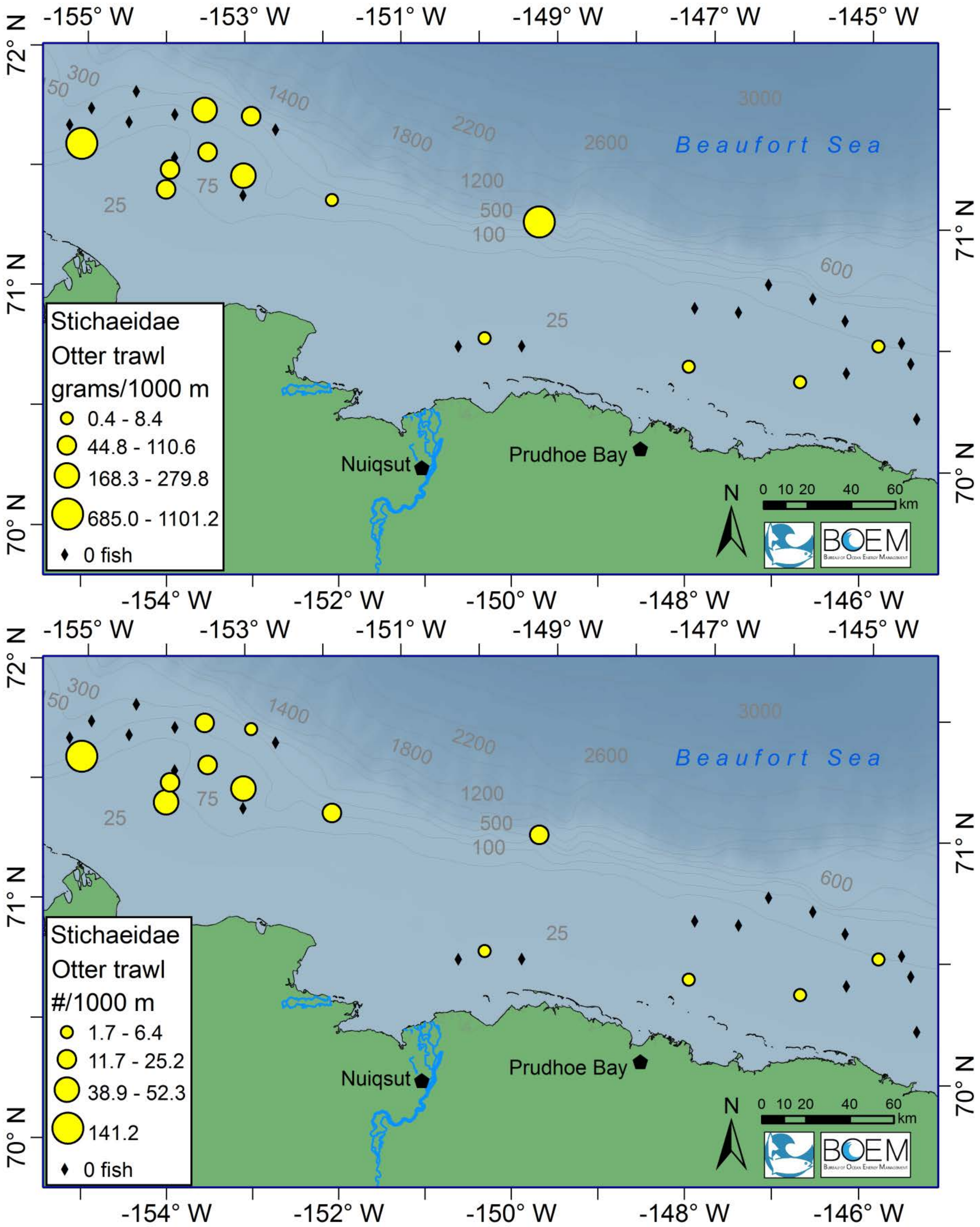


Figure C2.2- 21. Stichaeidae – biomass and density in catches by otter trawl during BOEM-2011.

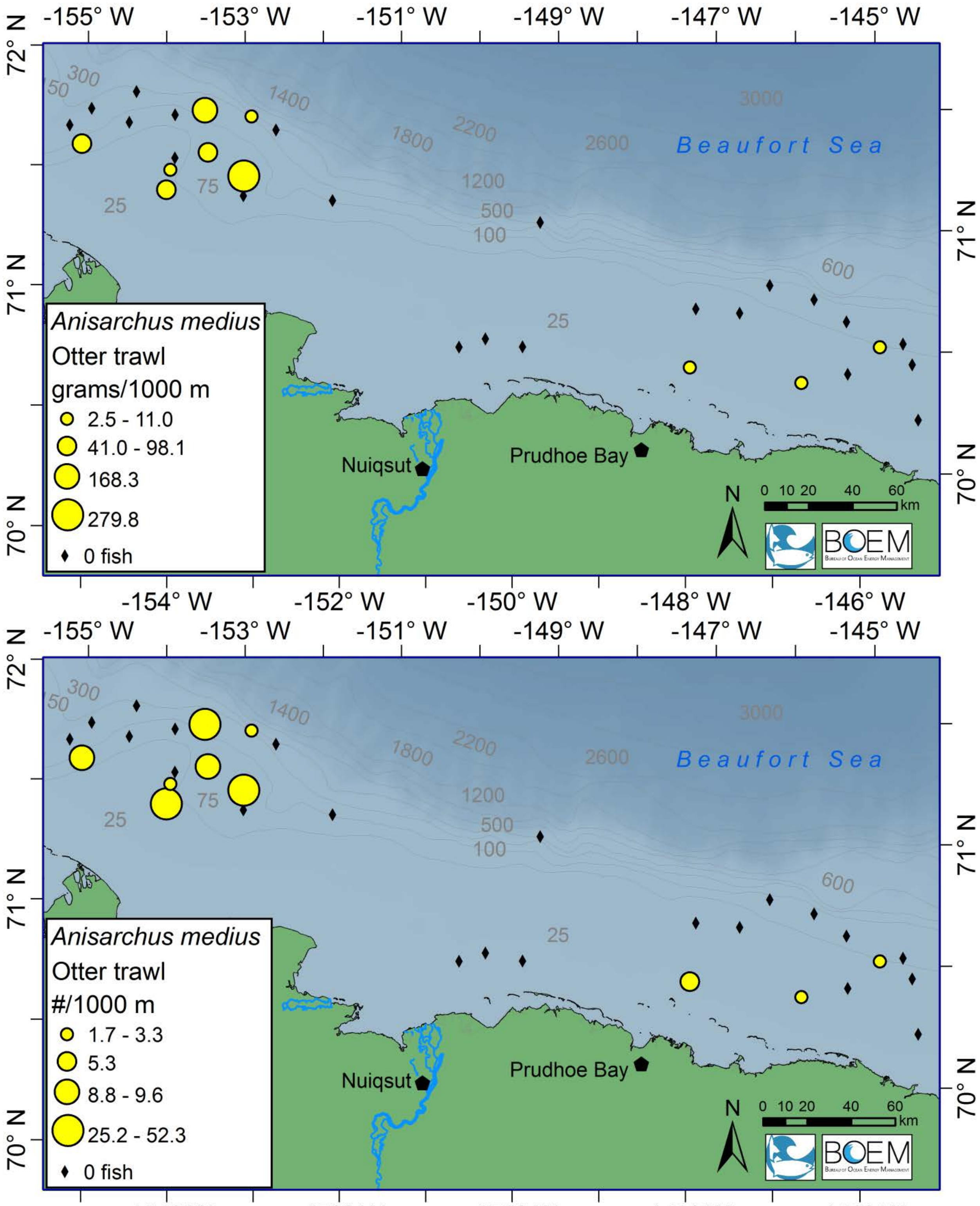


Figure C2.2- 22. Stichaeidae: *Anisarchus medius* biomass and density in catches by otter trawl during BOEM-2011.

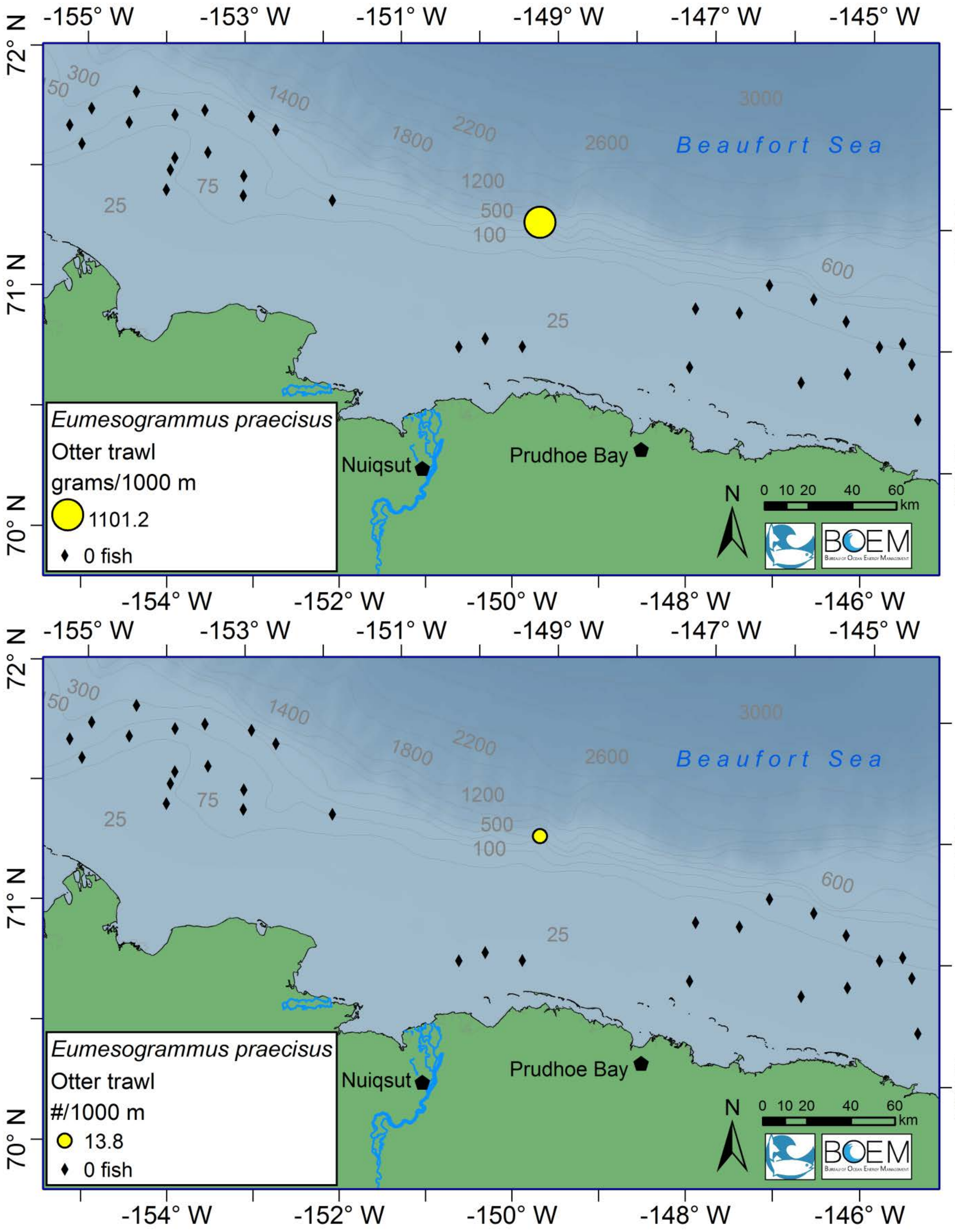


Figure C2.2- 23. Stichaeidae: *Eumesogrammus praecisus* biomass and density in catches by otter trawl during BOEM-2011.

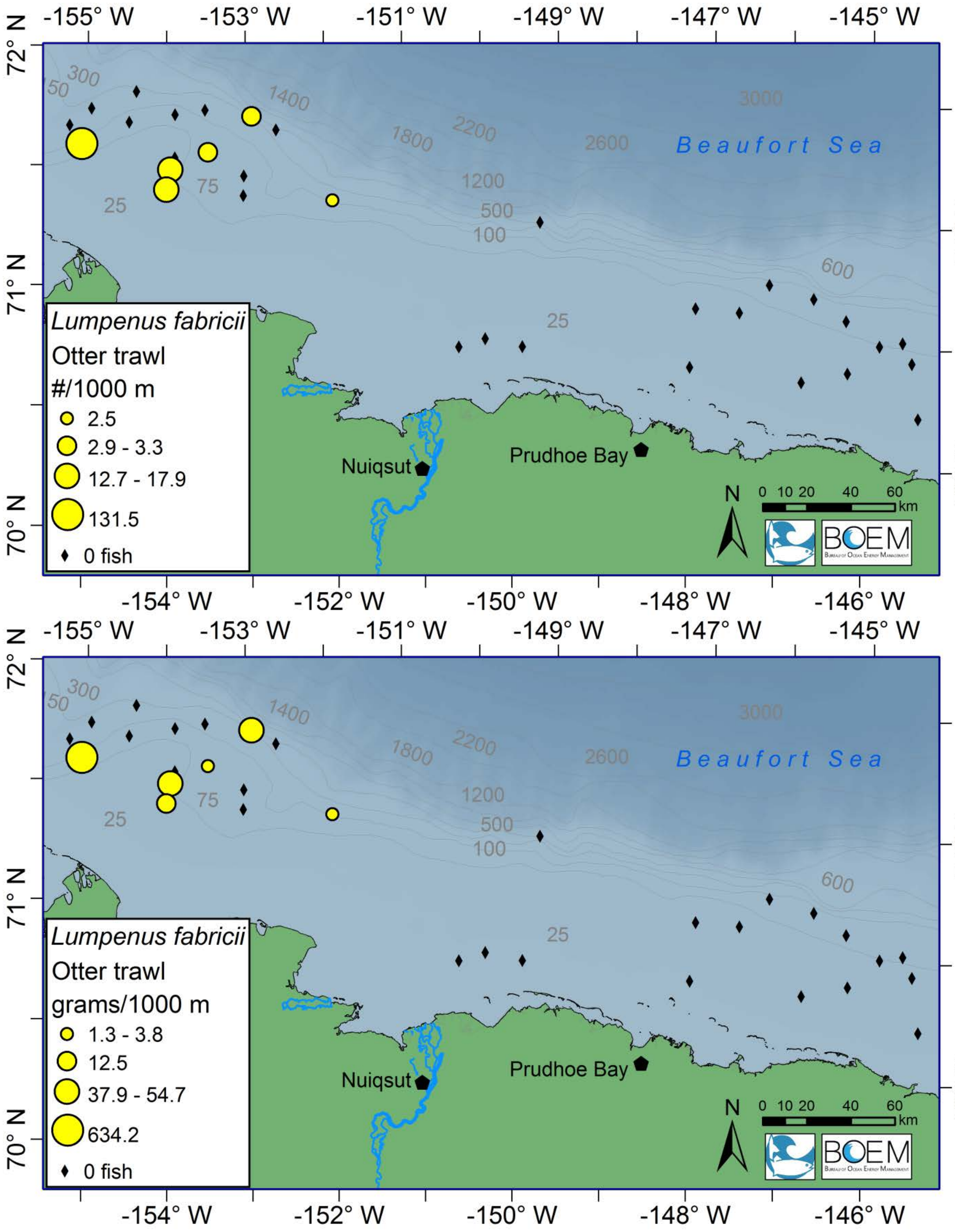


Figure C2.2- 24. Stichaeidae: *Lumpenus fabricii* biomass and density in catches by otter trawl during BOEM-2011.

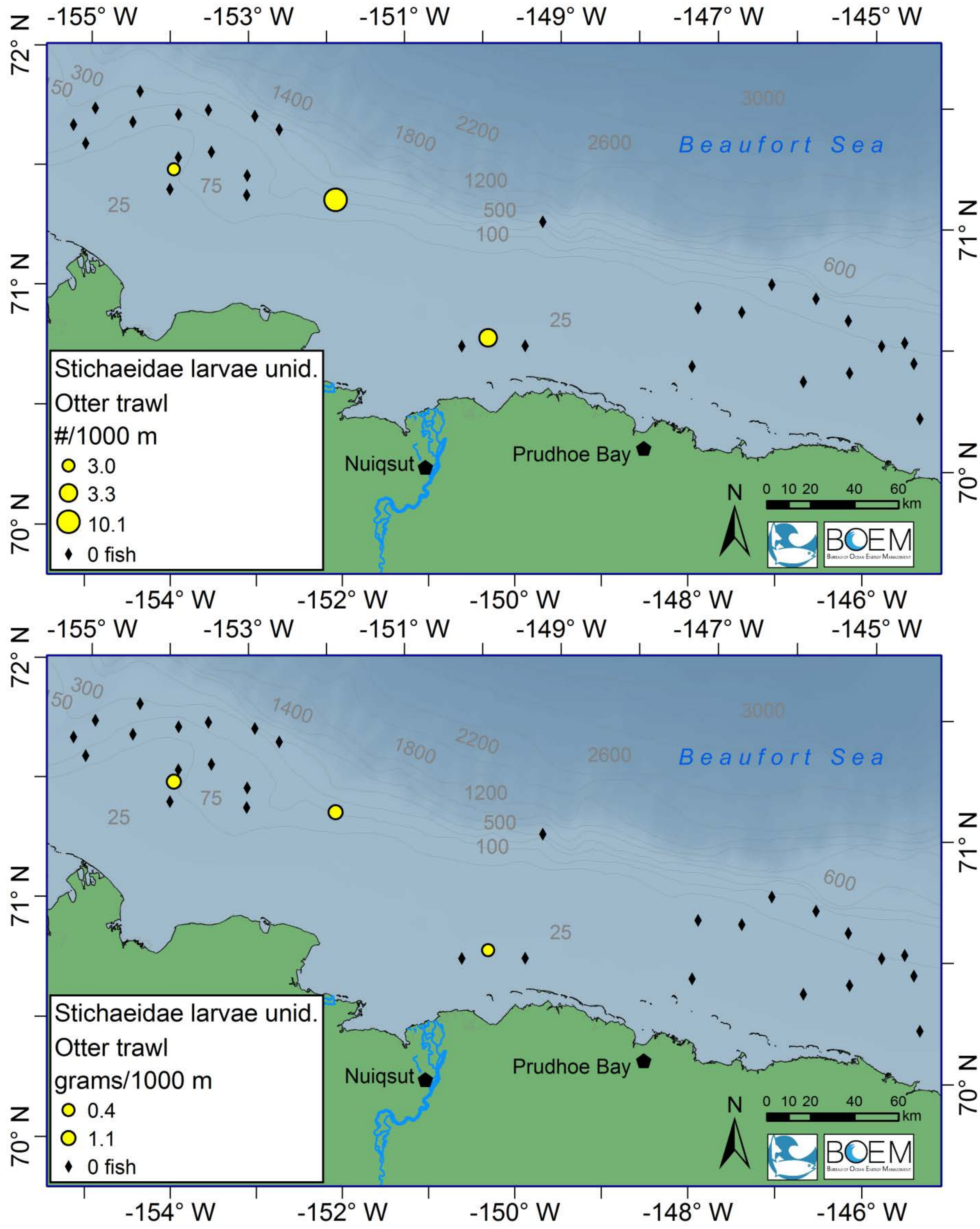


Figure C2.2- 25. Stichaeidae: unidentified larvae biomass and density in catches by otter trawl during BOEM-2011.

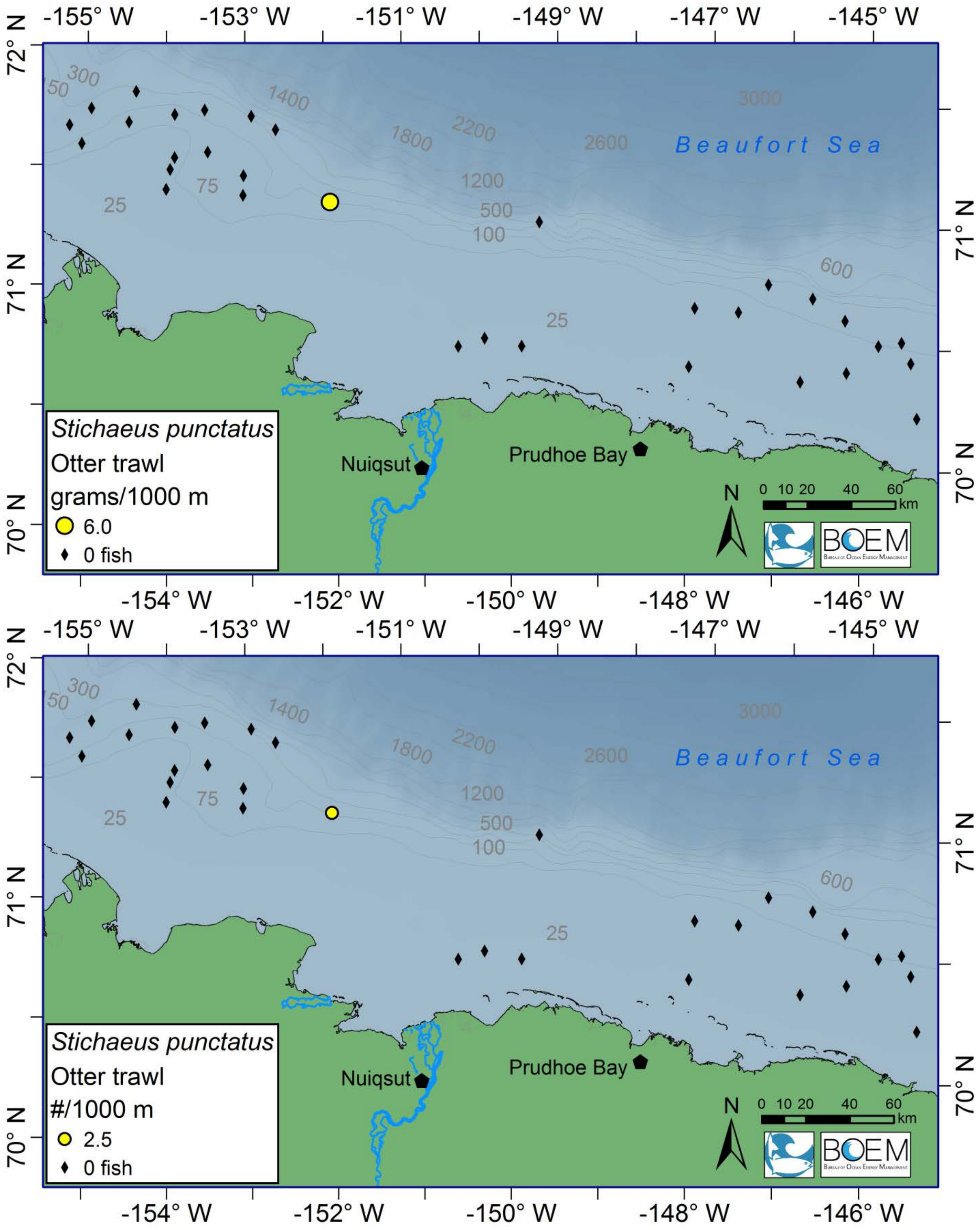


Figure C2.2- 26. Stichaeidae: *Stichaeus punctatus* biomass and density in catches by otter trawl during BOEM-2011.

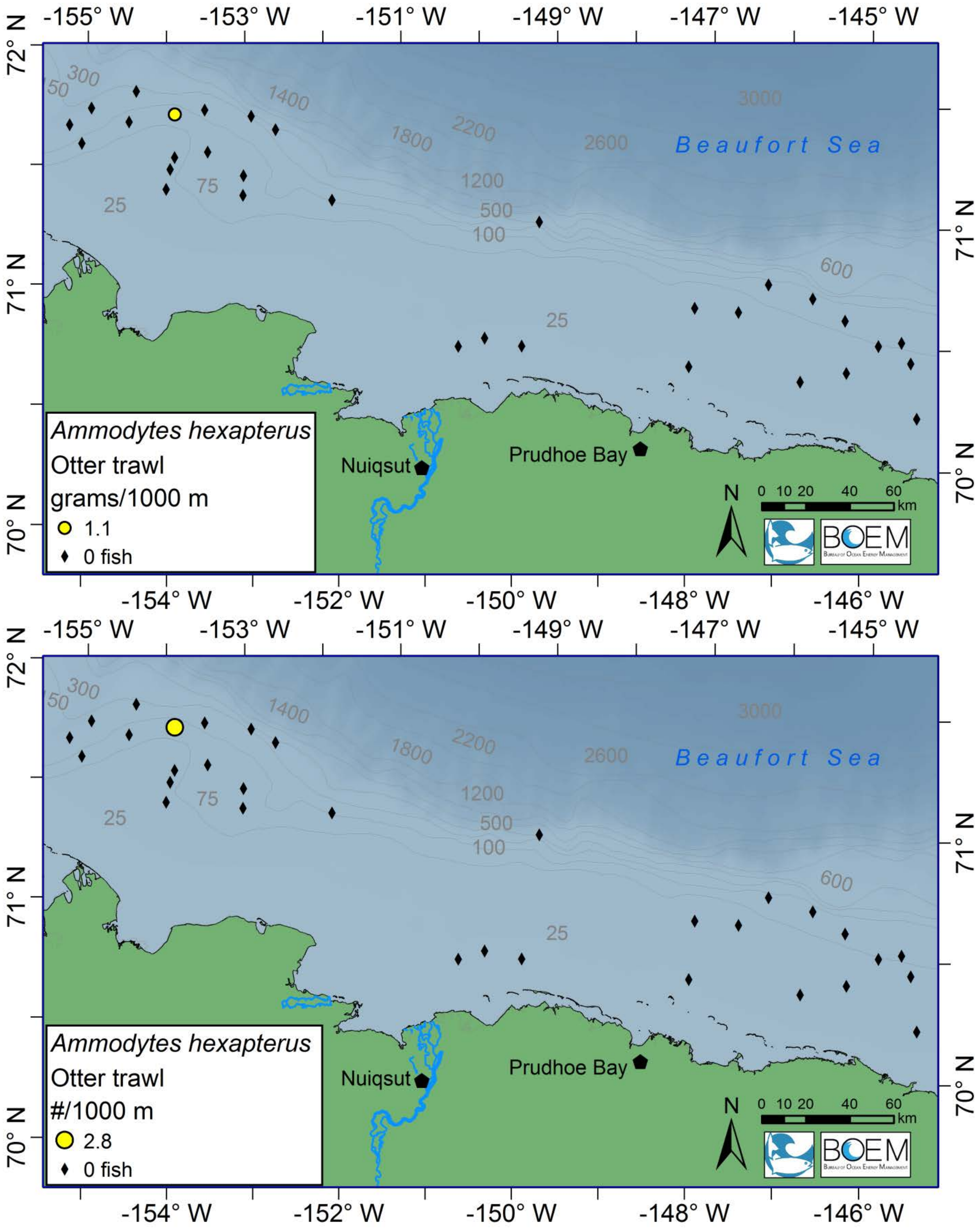


Figure C2.2- 27. Ammodytidae (all were *Ammodytes hexapterus)* – biomass and density in catches by otter trawl during BOEM-2011

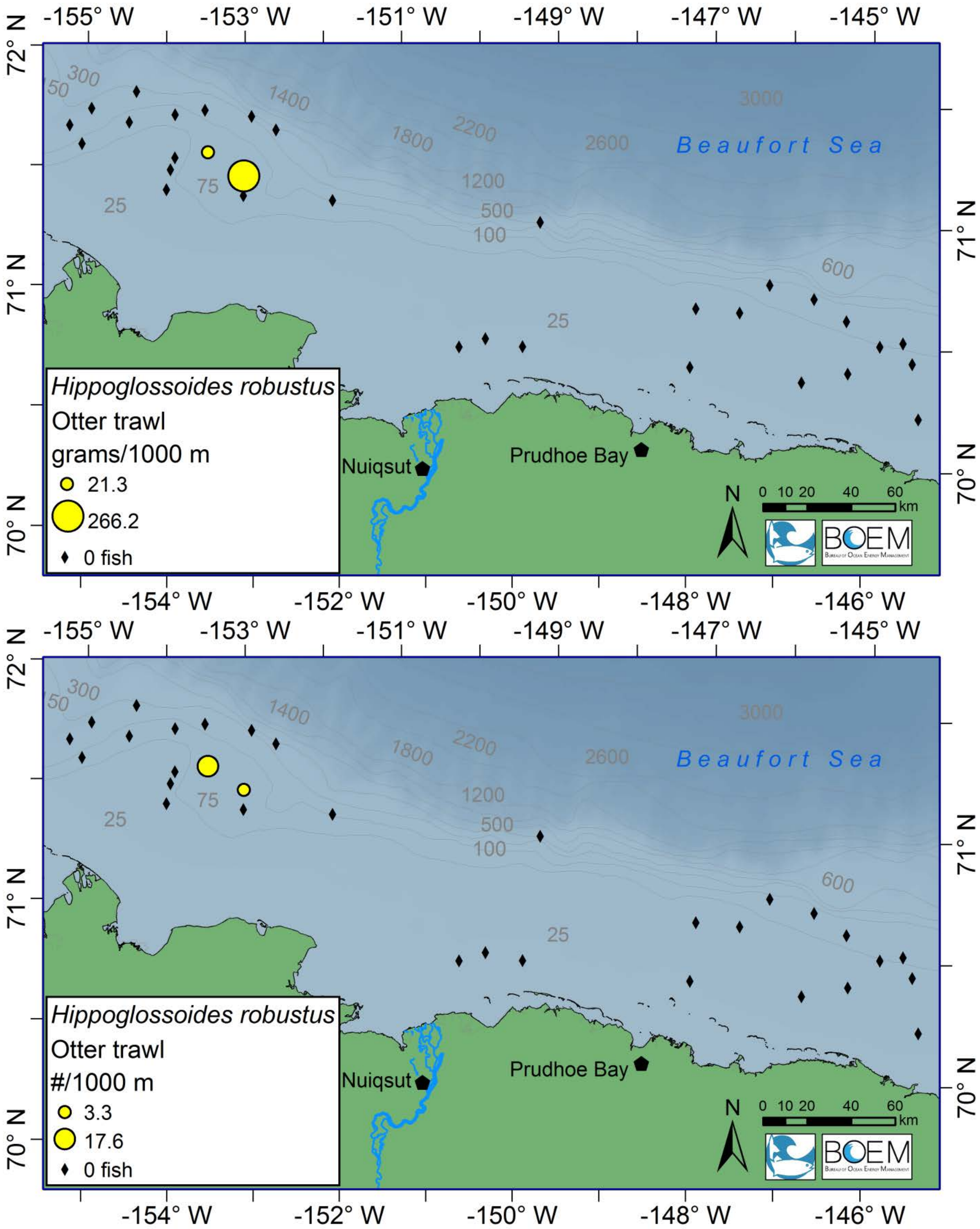


Figure C2.2- 28. Pleuronectidae (all were *Hippoglossoides robustus)* – biomass and density in catches by otter trawl during BOEM-2011

APPENDIX C2.3 TABLES AND MAPS OF CATCHES BY BEAM TRAWL: BIOMASS AND DENSITY OF FISH FAMILIES AND SPECIES

Table C2.3- 1 Biomass of fishes caught in quantitative beam trawl hauls during BOEM-2011 (# fish/1000 m², area), averaged by station. Fishes are aggregated as in **Table 2.1-2** and are presented in phylogenetic order; stations are in alphabetic order within west to east regions.

Station - *n* hauls	All fishes	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus jaok*	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Trichocottus brashnikovi*	*Triglops nybelini*	*Triglops pingeli*	**Cottidae** (9 spp.)	*Nautichthys pribilovius* = **Hemiptipteridae**	Aspidophoroides olrikii	Leptagonus decagonus	Podothecus veternus	**Agonidae** (3 spp.)	Eumicrotremus derjugini = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Leptoclinus maculatus*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (6 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus*	*Limanda* sp. (not *proboscide* a)	**Pleuronectidae** (2 species)
Western Beaufish																																					
WB02-1 haul	369.8	56.5	0.8	57.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	143.5	35.1	178.7	-	133.9	133.9	-	-	-	-	-	-	-	-	-	-	-
WB04-1 haul	984.5	107.0	-	107.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	164.6	164.6	-	680.2	680.2	32.7	-	-	-	-	-	32.7	-	-	-	-
WB05-1 haul	296.2	21.1	-	21.1	-	-	-	-	-	-	-	-	-	-	-	18.6	-	-	18.6	-	-	1.8	1.8	-	254.9	254.9	-	-	-	-	-	-	-	-	-	-	-
WB07-2 hauls	183.3	99.1	-	99.1	-	1.1	-	-	-	-	-	-	-	1.1	-	0.9	-	-	0.9	-	-	-	-	-	-	-	9.2	-	-	-	-	-	9.2	-	73.1	-	73.1
WB08-1 haul	712.2	195.1	-	195.1	-	-	-	-	-	-	-	-	55.8	55.8	-	4.2	-	-	4.2	-	-	365.2	365.2	-	32.4	32.4	-	-	59.6	-	-	-	59.6	-	-	-	-
WB10-1 haul	1046.3	354.4	-	354.4	199.1	20.1	59.4	-	-	-	-	-	115.5	394.1	0.8	34.8	-	0.7	35.5	-	-	219.9	219.9	14.6	20.9	35.5	4.0	-	-	2.1	-	-	6.2	-	-	-	-
WB12-1 haul	330.9	166.9	-	166.9	49.0	-	0.4	-	-	48.5	-	-	-	98.0	-	0.7	-	-	0.7	-	2.6	33.6	36.2	-	14.7	14.7	-	-	-	10.8	-	-	10.8	-	3.8	-	3.8
WB13-2 hauls	1440.4	458.4	-	458.4	106.4	56.0	4.3	-	-	194.7	-	-	31.6	392.9	1.8	3.5	-	-	3.5	-	-	50.1	50.1	3.9	227.0	230.9	253.6	-	-	34.7	14.5	-	302.8	-	-	-	-
WB14-2 hauls	313.1	60.7	-	60.7	36.2	24.7	31.9	0.9	-	48.2	-	-	12.1	153.9	0.5	4.8	-	-	4.8	-	-	21.0	21.0	29.7	15.1	44.8	7.8	-	-	19.6	-	-	27.4	-	-	-	-
WB15-1 haul	200.4	59.4	-	59.4	31.1	-	4.0	-	-	-	-	-	81.0	116.1	-	8.4	-	-	8.4	-	-	5.7	5.7	9.2	1.6	10.8	-	-	-	-	-	-	-	-	-	-	-
WB16-1 haul	231.1	34.2	-	34.2	-	49.2	10.1	-	-	43.8	-	-	21.9	125.0	-	13.6	-	-	13.6	-	-	6.5	6.5	-	14.8	14.8	37.1	-	-	-	-	-	37.1	-	-	-	-
WB17-2 hauls	132.0	78.1	-	78.1	1.1	25.5	-	-	-	3.9	-	-	1.5	32.0	0.2	0.6	-	-	0.6	-	-	5.7	5.7	-	0.7	0.7	-	-	-	14.8	-	-	14.8	-	-	-	-
WB18-2 hauls	311.5	23.5	-	23.5	64.9	17.9	17.7	-	-	49.1	-	-	28.0	177.6	-	10.4	-	-	10.4	-	-	38.0	38.0	33.5	10.1	43.6	9.9	-	-	8.5	-	-	18.4	-	-	-	-
WB19-1 haul	242.3	73.7	-	73.7	-	16.1	27.0	-	-	-	-	-	-	43.1	-	12.7	-	-	12.7	95.2	-	17.5	17.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WB20-1 haul	514.6	281.7	-	281.7	-	-	-	-	-	-	-	-	-	-	-	87.0	-	-	87.0	-	145.8	-	145.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WB21-2 hauls	1812.2	757.3	3.8	761.1	28.0	161.9	7.0	-	-	110.2	0.7	-	26.1	334.0	1.4	53.2	-	-	53.2	-	-	62.2	62.2	20.2	103.4	123.6	43.0	-	-	432.0	-	1.8	476.7	-	-	-	-
WB22-1 haul	2606.6	2109.0	2.1	2111.0	127.3	178.6	15.6	-	-	4.1	-	-	5.7	331.4	0.9	19.6	-	-	19.6	-	-	80.6	80.6	-	42.5	42.5	17.1	-	-	3.3	-	-	20.5	-	-	-	-
WB23-1 haul	209.3	27.5	-	27.5	119.6	-	13.7	-	-	-	-	-	-	133.3	-	2.8	-	-	2.8	33.9	-	4.0	4.0	7.1	0.8	7.9	-	-	-	-	-	-	-	-	-	-	-
WB24-1 haul	273.7	42.9	-	42.9	42.9	51.9	3.4	-	-	5.8	-	-	61.7	165.7	1.0	0.7	-	-	0.7	-	-	19.3	19.3	-	17.1	17.1	15.4	-	-	4.6	-	-	20.0	-	6.8	-	6.8
WB25-1 haul	1073.8	115.6	-	115.6	143.1	126.0	-	-	-	146.0	-	-	12.1	427.3	2.0	2.1	-	-	2.1	-	-	46.3	46.3	14.5	394.6	409.1	1.8	-	-	69.7	-	-	71.5	-	-	-	-
WB26-1 haul	385.9	98.0	-	98.0	7.4	80.0	2.0	-	-	125.8	-	-	10.6	225.8	0.9	3.8	-	0.8	4.6	-	-	21.7	21.7	-	-	-	26.3	-	-	-	-	-	26.3	-	8.2	0.3	8.5
WB28-1 haul	1635.3	4.6	-	4.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	420.7	420.7	-	1207.7	1207.7	-	-	-	-	-	-	-	2.2	-	-	-
WB30-1 haul	1120.6	552.6	3.0	555.5	27.4	265.4	-	-	-	96.7	0.6	-	3.1	393.2	-	-	-	-	-	-	-	121.1	121.1	-	15.0	15.0	-	-	-	35.8	-	-	35.8	-	-	-	-
WB31-2 hauls	1463.9	187.8	-	187.8	-	-	-	-	-	-	-	-	30.2	30.2	-	0.4	-	-	0.4	-	-	306.7	306.7	-	779.5	779.5	72.5	86.8	-	-	-	-	159.3	-	-	-	-
WB32-3 hauls	351.7	41.9	-	41.9	7.2	-	80.3	-	-	-	-	-	61.9	149.4	-	14.0	-	-	14.0	-	-	10.7	10.7	9.1	112.1	121.1	14.5	-	-	-	-	-	14.5	-	-	-	-
WB34-1 haul	371.6	75.3	-	75.3	87.6	103.0	-	-	-	55.7	-	-	-	246.3	-	-	-	-	-	-	-	4.4	4.4	41.2	1.8	43.0	-	-	-	2.6	-	-	2.6	-	-	-	-
WB35-1 haul	626.0	191.8	-	191.8	30.8	195.9	-	-	-	50.6	-	-	6.7	284.0	-	0.3	-	-	0.3	-	-	70.4	70.4	-	5.6	5.6	-	-	-	73.2	-	0.7	73.9	-	-	-	-
WB36-1 haul	113.0	60.9	3.5	64.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	48.5	48.5	-	-	-	-	-	-	-	-	-	-	-

Table C2.3- 1 Biomass of fishes caught by beam trawl (continued).

Station - *n* hauls	All fishes	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus jaok*	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Trichocottus brashnikovi*	*Triglops nybelini*	*Triglops pingelii*	**Cottidae** (9 spp.)	*Nautichthys pribilovius* = **Hemiptipteridae**	Aspidophoroides olrikii	Leptagonus decagonus	Podothecus veternus	**Agonidae** (3 spp.)	Eumicrotremus derjugini = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Leptoclinus maculatus*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (6 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus*	*Limanda* sp. (not *proboscide* a)	**Pleuronectidae** (2 species)
Central Beaufish																																					
CB01-1 haul	383.8	49.8	-	49.8	222.6	5.5	27.1	-	-	-	-	-	25.4	280.7	-	-	-	-	-	-	-	-	-	-	-	-	11.5	-	-	41.8	-	-	53.3	-	-	-	-
CB02-1 haul	250.4	68.0	-	68.0	32.7	18.3	-	-	-	-	-	-	12.1	63.1	-	1.3	-	-	1.3	-	-	9.4	9.4	-	108.5	108.5	-	-	-	-	-	-	-	-	-	-	-
CB03-1 haul	238.8	23.4	-	23.4	34.8	10.2	2.5	-	-	133.7	-	-	10.5	191.7	-	-	-	-	-	-	-	9.2	9.2	14.5	-	14.5	-	-	-	-	-	-	-	-	-	-	-
CB05-1 haul	230.1	27.5	-	27.5	9.0	85.4	-	-	-	19.7	-	-	-	114.1	-	-	-	-	-	-	-	88.5	88.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB06-2 hauls	132.6	29.0	-	29.0	-	67.9	2.6	-	-	1.3	-	-	2.1	73.9	-	-	-	-	-	-	-	15.2	15.2	-	7.8	7.8	0.5	-	-	6.3	-	-	6.8	-	-	-	-
CB07-1 haul	91.2	59.8	-	59.8	2.2	22.0	-	-	-	-	-	-	3.7	28.0	-	-	-	-	-	-	-	0.5	0.5	-	-	-	-	-	-	2.9	-	-	2.9	-	-	-	-
CB08-2 hauls	143.3	13.8	-	13.8	78.2	12.2	1.8	-	-	-	-	-	0.7	92.8	-	-	-	-	-	-	-	31.5	31.5	-	-	-	5.2	-	-	-	-	-	5.2	-	-	-	-
CB09-1 haul	119.6	70.5	-	70.5	4.5	12.2	-	-	-	-	-	-	-	16.7	-	-	-	-	-	-	-	31.8	31.8	-	0.6	0.6	-	-	-	-	-	-	-	-	-	-	-
CB10-1 haul	35.3	4.4	-	4.4	-	13.5	-	-	-	-	-	-	-	13.5	-	-	-	-	-	-	-	17.4	17.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB11-1 haul	168.6	0.7	-	0.7	94.1	-	44.3	-	-	-	-	-	6.2	144.7	-	3.3	-	-	3.3	-	-	1.0	1.0	8.3	6.8	15.1	-	-	-	3.8	-	-	3.8	-	-	-	-
CB12-2 hauls	192.9	0.3	-	0.3	5.5	71.0	52.2	-	-	-	-	-	19.4	148.1	-	3.7	-	-	3.7	-	-	27.4	27.4	13.4	-	13.4	-	-	-	-	-	-	-	-	-	-	-
CB13-1 haul	57.7	-	-	-	-	4.1	11.9	-	-	-	-	-	-	16.1	-	5.5	-	-	5.5	-	-	-	-	-	9.4	9.4	26.7	-	-	-	-	-	26.7	-	-	-	-
CB14-1 haul	185.3	25.4	-	25.4	41.9	0.5	9.7	-	-	-	-	-	5.4	57.5	-	1.5	-	-	1.5	-	-	79.4	79.4	-	12.1	12.1	-	-	-	9.4	-	-	9.4	-	-	-	-
CB15-1 haul	300.2	55.3	-	55.3	15.8	28.2	32.9	-	-	2.8	-	-	9.7	89.4	-	-	-	-	-	-	-	1.2	1.2	12.4	139.2	151.5	-	-	-	2.8	-	-	2.8	-	-	-	-
CB16-1 haul	85.9	13.2	-	13.2	-	-	14.3	-	-	6.7	-	-	0.8	21.9	-	-	-	-	-	-	-	-	-	22.5	28.4	50.9	-	-	-	-	-	-	-	-	-	-	-
CB17-1 haul	123.1	25.6	-	25.6	-	8.4	19.4	-	-	22.8	-	-	3.3	53.9	-	-	-	-	-	-	-	5.8	5.8	19.3	13.5	32.8	2.5	-	-	2.6	-	-	5.1	-	-	-	-
CB20-1 haul	195.8	12.9	-	12.9	-	94.9	-	-	-	11.1	-	-	-	106.0	-	-	-	-	-	-	-	57.2	57.2	-	-	-	-	-	-	19.6	-	-	19.6	-	-	-	-
CB22-1 haul	34.5	27.2	-	27.2	-	-	-	-	-	-	-	-	-	-	-	1.7	-	-	1.7	-	-	-	-	-	5.6	5.6	-	-	-	-	-	-	-	-	-	-	-
CB23-1 haul	507.9	258.1	-	258.1	-	-	12.6	-	-	-	-	-	32.4	45.0	-	29.8	-	-	29.8	-	-	166.4	166.4	-	-	-	-	-	-	8.6	-	-	8.6	-	-	-	-
CB25-1 haul	311.9	251.0	-	251.0	-	-	-	-	-	-	-	-	58.1	58.1	-	0.9	-	-	0.9	-	-	2.0	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB30-1 haul	945.5	-	-	-	-	-	-	-	-	-	-	-	196.4	196.4	-	63.7	-	-	63.7	685.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB31-1 haul	161.5	17.0	-	17.0	-	38.2	-	-	-	3.8	-	-	3.1	45.1	-	-	-	-	-	-	-	99.4	99.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB32-2 hauls	389.2	149.9	-	149.9	27.2	2.0	-	-	173.7	5.9	-	-	-	208.8	-	-	-	-	-	-	-	20.1	20.1	-	-	-	-	-	-	10.5	-	-	10.5	-	-	-	-
CB33-3 hauls	435.9	82.9	-	82.9	55.1	92.6	-	-	-	20.2	-	-	21.0	188.9	-	-	-	-	-	-	-	105.1	105.1	-	28.8	28.8	-	-	-	30.1	-	-	30.1	-	-	-	-
CB34-1 haul	1845.8	364.5	-	364.5	-	-	21.4	-	-	-	-	-	-	21.4	-	77.1	-	-	77.1	236.6	-	247.6	247.6	-	-	-	73.1	-	-	-	-	-	73.1	-	825.5	-	825.5
CB35-2 hauls	1895.1	265.2	-	265.2	-	-	5.4	-	-	-	-	69.4	-	74.9	-	0.7	76.7	-	77.4	-	29.8	574.9	604.7	-	152.8	152.8	18.3	-	-	-	-	-	18.3	-	701.8	-	701.8

Table C2.3- 1 Biomass of fishes caught by beam trawl (continued).

Station - *n* hauls	All fishes	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus jaok*	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Trichocottus brashnikovi*	*Triglops nybelini*	*Triglops pingelii*	**Cottidae** (9 spp.)	*Nautichthys pribilovius* = **Hemiptipteridae**	Aspidophoroides olrikii	Leptagonus decagonus	Podothecus veternus	**Agonidae** (3 spp.)	Eumicrotremus derjugini = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Leptoclinus maculatus*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (6 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus*	*Limanda* sp. (not *proboscide* a)	**Pleuronectidae** (2 species)
Eastern Beaufish																																					
EB02-1 haul	86.4	19.0	-	19.0	3.9	-	25.1	-	-	-	-	-	12.2	41.2	-	13.4	-	-	13.4	-	-	1.9	1.9	10.9	-	10.9	-	-	-	-	-	-	-	-	-	-	-
EB04-1 haul	76.3	7.2	-	7.2	3.0	10.0	14.6	-	-	-	-	-	5.2	32.8	-	-	-	-	-	-	-	-	-	-	25.6	25.6	10.7	-	-	-	-	-	10.7	-	-	-	-
EB06-1 haul	242.6	31.3	-	31.3	129.2	-	57.7	-	-	-	-	-	10.3	197.3	-	12.5	-	-	12.5	-	-	0.4	0.4	-	1.0	1.0	-	-	-	-	-	-	-	-	-	-	-
EB08-1 haul	286.2	13.3	-	13.3	-	43.6	-	-	-	-	-	-	3.0	46.6	-	-	-	-	-	-	-	-	-	-	223.0	223.0	3.3	-	-	-	-	-	3.3	-	-	-	-
EB12-2 hauls	134.7	25.4	-	25.4	2.6	0.7	43.7	-	-	-	-	-	37.0	83.9	-	2.8	-	-	2.8	8.0	-	5.4	5.4	9.2	-	9.2	-	-	-	-	-	-	-	-	-	-	-
EB14-1 haul	159.9	17.7	-	17.7	-	1.1	21.0	-	-	-	-	-	35.0	57.1	-	2.8	-	-	2.8	-	-	52.7	52.7	9.4	1.3	10.7	18.9	-	-	-	-	-	18.9	-	-	-	-
EB16-1 haul	278.6	20.5	-	20.5	17.4	14.3	86.3	-	-	-	-	-	97.6	215.6	-	27.9	-	-	27.9	-	-	7.3	7.3	7.3	-	7.3	-	-	-	-	-	-	-	-	-	-	-
EB19-1 haul	133.8	45.7	-	45.7	16.0	61.4	-	-	-	-	-	-	10.7	88.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EB21-1 haul	621.2	29.4	-	29.4	127.1	-	195.7	-	-	-	-	-	-	322.8	-	104.2	-	-	104.2	18.4	-	40.0	40.0	88.5	15.2	103.8	2.5	-	-	-	-	-	2.5	-	-	-	-
EB23-1 haul	483.6	55.6	-	55.6	-	-	46.7	-	-	40.4	-	-	35.0	122.1	-	34.7	-	-	34.7	-	-	126.2	126.2	9.7	128.3	138.0	-	-	-	7.0	-	-	7.0	-	-	-	-

Table C2.3- 2 Abundance of fishes caught in quantitative beam trawl hauls during BOEM-2011 (# fish/1000 m², area), averaged by station. Fishes are aggregated as in **Table 2.1-2** and are presented in phylogenetic order; stations are in alphabetic order within west to east regions.

Station - *n* hauls	All fishes	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus jaok*	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Trichocottus brashnikovi*	*Triglops nybelini*	*Triglops pingelii*	**Cottidae** (9 spp.)	*Nautichthys pribilovius* = **Hemitripteridae**	Aspidophoroides olrikii	Leptagonus decagonus	Podothecus veternus	**Agonidae** (3 spp.)	Eumicrotremus derjugini = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Leptoclinus maculatus*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (6 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus*	*Limanda* sp. (not *proboscidea*)	**Pleuronectidae** (2 species)
Western Beaufish																																					
WB02-1 haul	10.9	3.6	1.2	4.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6	1.2	4.8	-	1.2	1.2	-	-	-	-	-	-	-	-	-	-	-
WB04-1 haul	44.1	12.6	-	12.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.3	6.3	-	18.9	18.9	6.3	-	-	-	-	-	6.3	-	-	-	-
WB05-1 haul	72.1	22.8	-	22.8	-	-	-	-	-	-	-	-	-	-	-	19.0	-	-	19.0	-	-	7.6	7.6	-	22.8	22.8	-	-	-	-	-	-	-	-	-	-	-
WB07-2 hauls	54.6	48.5	-	48.5	-	1.5	-	-	-	-	-	-	-	1.5	-	1.5	-	-	1.5	-	-	-	-	-	-	-	1.5	-	-	-	-	-	1.5	-	1.5	-	1.5
WB08-1 haul	56.8	20.1	-	20.1	-	-	-	-	-	-	-	-	3.3	3.3	-	3.3	-	-	3.3	-	-	23.4	23.4	-	3.3	3.3	-	-	3.3	-	-	-	3.3	-	-	-	-
WB10-1 haul	599.8	268.6	-	268.6	64.6	16.8	33.7	-	-	-	-	-	19.6	134.7	2.8	53.3	-	2.8	56.1	-	-	95.4	95.4	5.6	28.1	33.7	5.6	-	-	2.8	-	-	8.4	-	-	-	-
WB12-1 haul	282.9	127.6	-	127.6	11.1	-	2.8	-	-	25.0	-	-	-	38.8	-	2.8	-	-	2.8	-	2.8	94.3	97.1	-	5.5	5.5	-	-	-	8.3	-	-	8.3	-	2.8	-	2.8
WB13-2 hauls	974.3	328.9	-	328.9	30.6	89.7	4.5	-	-	109.1	-	-	42.4	276.3	3.5	8.0	-	-	8.0	-	-	171.4	171.4	5.2	43.1	48.3	95.2	-	-	13.2	29.5	-	137.9	-	-	-	-
WB14-2 hauls	356.3	68.4	-	68.4	15.8	46.3	20.9	1.2	-	25.2	-	-	12.5	121.8	1.9	8.9	-	-	8.9	-	-	64.2	64.2	11.5	41.5	53.0	6.2	-	-	31.9	-	-	38.1	-	-	-	-
WB15-1 haul	71.0	12.4	-	12.4	3.1	-	6.2	-	-	-	-	-	9.3	18.5	-	9.3	-	-	9.3	-	-	21.6	21.6	6.2	3.1	9.3	-	-	-	-	-	-	-	-	-	-	-
WB16-1 haul	118.9	18.3	-	18.3	-	15.2	3.0	-	-	6.1	-	-	3.0	27.4	-	18.3	-	-	18.3	-	-	21.3	21.3	-	27.4	27.4	6.1	-	-	-	-	-	6.1	-	-	-	-
WB17-2 hauls	205.2	108.8	-	108.8	0.8	50.5	-	-	-	2.3	-	-	2.3	55.9	0.8	2.3	-	-	2.3	-	-	18.4	18.4	-	1.5	1.5	-	-	-	17.6	-	-	17.6	-	-	-	-
WB18-2 hauls	214.0	24.5	-	24.5	42.5	3.8	14.0	-	-	23.7	-	-	8.7	92.6	-	11.7	-	-	11.7	-	-	49.7	49.7	10.9	7.5	18.4	3.8	-	-	13.2	-	-	17.0	-	-	-	-
WB19-1 haul	192.8	107.4	-	107.4	-	30.3	11.0	-	-	-	-	-	-	41.3	-	13.8	-	-	13.8	5.5	-	24.8	24.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WB20-1 haul	102.7	44.0	-	44.0	-	-	-	-	-	-	-	-	-	-	-	44.0	-	-	44.0	-	14.7	-	14.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WB21-2 hauls	1236.2	297.0	2.9	299.9	16.9	219.2	9.9	-	-	51.3	2.9	-	32.7	332.9	2.8	87.7	-	-	87.7	-	-	151.7	151.7	9.8	37.3	47.1	8.6	-	-	298.5	-	7.1	314.2	-	-	-	-
WB22-1 haul	1668.0	1403.8	3.3	1407.1	46.2	39.6	16.5	-	-	3.3	-	-	6.6	112.3	3.3	29.7	-	-	29.7	-	-	95.8	95.8	-	9.9	9.9	3.3	-	-	6.6	-	-	9.9	-	-	-	-
WB23-1 haul	107.5	9.6	-	9.6	64.5	-	11.9	-	-	-	-	-	-	76.4	-	4.8	-	-	4.8	2.4	-	9.6	9.6	2.4	2.4	4.8	-	-	-	-	-	-	-	-	-	-	-
WB24-1 haul	136.8	23.8	-	23.8	8.9	3.0	3.0	-	-	3.0	-	-	8.9	26.8	3.0	3.0	-	-	3.0	-	-	53.5	53.5	-	11.9	11.9	3.0	-	-	5.9	-	-	8.9	-	5.9	-	5.9
WB25-1 haul	876.5	139.4	-	139.4	47.2	268.7	-	-	-	87.1	-	-	21.8	424.8	7.3	3.6	-	-	3.6	-	-	145.2	145.2	7.3	43.6	50.8	3.6	-	-	101.7	-	-	105.3	-	-	-	-
WB26-1 haul	270.0	62.5	-	62.5	6.6	16.5	3.3	-	-	62.6	-	-	9.9	98.8	3.3	6.6	-	3.3	9.9	-	-	72.5	72.5	-	-	-	13.2	-	-	-	-	-	13.2	-	6.6	3.3	9.9
WB28-1 haul	43.1	12.3	-	12.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.3	12.3	-	12.3	12.3	-	-	-	-	-	-	-	6.2	-	-	-
WB30-1 haul	1529.2	497.8	4.7	502.5	9.5	544.1	-	-	-	61.5	4.7	-	4.7	624.6	-	-	-	-	-	-	-	373.8	373.8	-	9.5	9.5	-	-	-	18.9	-	-	18.9	-	-	-	-
WB31-2 hauls	41.5	14.7	-	14.7	-	-	-	-	-	-	-	-	3.5	3.5	-	1.8	-	-	1.8	-	-	3.2	3.2	-	5.3	5.3	11.4	1.6	-	-	-	-	12.9	-	-	-	-
WB32-3 hauls	138.4	15.4	-	15.4	1.0	-	12.8	-	-	-	-	-	5.0	18.8	-	22.2	-	-	22.2	-	-	36.0	36.0	1.9	42.2	44.1	1.9	-	-	-	-	-	1.9	-	-	-	-
WB34-1 haul	250.4	65.2	-	65.2	37.7	89.2	-	-	-	24.0	-	-	-	150.9	-	-	-	-	-	-	-	17.1	17.1	10.3	3.4	13.7	-	-	-	3.4	-	-	3.4	-	-	-	-
WB35-1 haul	783.1	210.1	-	210.1	13.1	189.4	-	-	-	29.5	-	-	13.1	245.1	-	3.3	-	-	3.3	-	-	213.1	213.1	-	13.1	13.1	-	-	-	95.1	-	3.3	98.4	-	-	-	-
WB36-1 haul	40.1	20.0	15.0	35.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.0	5.0	-	-	-	-	-	-	-	-	-	-	-

Table C2.3- 2 Abundance of fishes caught by beam trawl (continued).

Station - *n* hauls	All fishes	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus jaok*	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Trichocottus brashnikovi*	*Triglops nybelini*	*Triglops pingelii*	**Cottidae** (9 spp.)	*Nautichthys pribilovius* = **Hemitripteridae**	Aspidophoroides olrikii	Leptagonus decagonus	Podothecus veternus	**Agonidae** (3 spp.)	Eumicrotremus derjugini = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Leptoclinus maculatus*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (6 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus*	*Limanda* sp. (not *proboscidea*)	**Pleuronectidae** (2 species)
Central Beaufish																																					
CB01-1 haul	125.4	11.9	-	11.9	23.9	11.9	17.9	-	-	-	-	-	11.9	65.7	-	-	-	-	-	-	-	-	-	-	-	-	17.9	-	-	29.9	-	-	47.8	-	-	-	-
CB02-1 haul	50.8	16.2	-	16.2	4.6	11.6	-	-	-	-	-	-	4.6	20.8	-	2.3	-	-	2.3	-	-	4.6	4.6	-	6.9	6.9	-	-	-	-	-	-	-	-	-	-	-
CB03-1 haul	88.5	22.1	-	22.1	2.2	22.1	2.2	-	-	17.7	-	-	11.1	55.3	-	-	-	-	-	-	-	8.9	8.9	2.2	-	2.2	-	-	-	-	-	-	-	-	-	-	-
CB05-1 haul	148.0	24.7	-	24.7	6.2	83.2	-	-	-	12.3	-	-	-	101.7	-	-	-	-	-	-	-	21.6	21.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB06-2 hauls	181.6	43.8	-	43.8	-	89.9	3.3	-	-	1.0	-	-	3.3	97.5	-	-	-	-	-	-	-	35.0	35.0	-	2.0	2.0	1.0	-	-	2.3	-	-	3.3	-	-	-	-
CB07-1 haul	106.6	43.2	-	43.2	2.9	46.1	-	-	-	-	-	-	5.8	54.7	-	-	-	-	-	-	-	2.9	2.9	-	-	-	-	-	-	5.8	-	-	5.8	-	-	-	-
CB08-2 hauls	84.1	11.6	-	11.6	21.3	25.8	1.5	-	-	-	-	-	1.0	49.7	-	-	-	-	-	-	-	21.9	21.9	-	-	-	1.0	-	-	-	-	-	1.0	-	-	-	-
CB09-1 haul	95.7	27.8	-	27.8	3.1	24.7	-	-	-	-	-	-	-	27.8	-	-	-	-	-	-	-	37.0	37.0	-	3.1	3.1	-	-	-	-	-	-	-	-	-	-	-
CB10-1 haul	90.2	8.7	-	8.7	-	17.5	-	-	-	-	-	-	-	17.5	-	-	-	-	-	-	-	64.0	64.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB11-1 haul	55.5	1.4	-	1.4	12.2	-	25.7	-	-	-	-	-	1.4	39.2	-	4.1	-	-	4.1	-	-	2.7	2.7	4.1	2.7	6.8	-	-	-	1.4	-	-	1.4	-	-	-	-
CB12-2 hauls	77.0	1.3	-	1.3	5.4	12.9	35.7	-	-	-	-	-	7.7	61.7	-	6.3	-	-	6.3	-	-	2.6	2.6	5.2	-	5.2	-	-	-	-	-	-	-	-	-	-	-
CB13-1 haul	33.6	-	-	-	-	2.2	8.9	-	-	-	-	-	-	11.2	-	4.5	-	-	4.5	-	-	-	-	-	2.2	2.2	15.7	-	-	-	-	-	15.7	-	-	-	-
CB14-1 haul	53.7	15.3	-	15.3	10.2	2.6	5.1	-	-	-	-	-	2.6	20.5	-	2.6	-	-	2.6	-	-	7.7	7.7	-	5.1	5.1	-	-	-	2.6	-	-	2.6	-	-	-	-
CB15-1 haul	64.6	20.1	-	20.1	2.2	2.2	15.6	-	-	2.2	-	-	4.5	26.7	-	-	-	-	-	-	-	4.5	4.5	2.2	6.7	8.9	-	-	-	4.5	-	-	4.5	-	-	-	-
CB16-1 haul	40.0	14.7	-	14.7	-	-	8.4	-	-	4.2	-	-	2.1	14.7	-	-	-	-	-	-	-	-	-	4.2	6.3	10.5	-	-	-	-	-	-	-	-	-	-	-
CB17-1 haul	112.6	30.7	-	30.7	-	15.4	10.2	-	-	15.4	-	-	5.1	46.1	-	-	-	-	-	-	-	15.4	15.4	5.1	5.1	10.2	5.1	-	-	5.1	-	-	10.2	-	-	-	-
CB20-1 haul	167.2	17.4	-	17.4	-	69.7	-	-	-	7.0	-	-	-	76.6	-	-	-	-	-	-	-	48.8	48.8	-	-	-	-	-	-	24.4	-	-	24.4	-	-	-	-
CB22-1 haul	5.4	2.7	-	2.7	-	-	-	-	-	-	-	-	-	-	-	1.3	-	-	1.3	-	-	-	-	-	1.3	1.3	-	-	-	-	-	-	-	-	-	-	-
CB23-1 haul	81.4	37.2	-	37.2	-	-	2.3	-	-	-	-	-	7.0	9.3	-	25.6	-	-	25.6	-	-	7.0	7.0	-	-	-	-	-	-	2.3	-	-	2.3	-	-	-	-
CB25-1 haul	48.7	38.3	-	38.3	-	-	-	-	-	-	-	-	3.5	3.5	-	3.5	-	-	3.5	-	-	3.5	3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB30-1 haul	62.9	-	-	-	-	-	-	-	-	-	-	-	15.7	15.7	-	31.4	-	-	31.4	15.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB31-1 haul	154.6	30.3	-	30.3	-	51.5	-	-	-	3.0	-	-	6.1	60.6	-	-	-	-	-	-	-	63.6	63.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB32-2 hauls	128.7	86.5	-	86.5	7.4	4.6	-	-	2.0	5.0	-	-	-	18.9	-	-	-	-	-	-	-	17.0	17.0	-	-	-	-	-	-	6.3	-	-	6.3	-	-	-	-
CB33-3 hauls	471.0	99.0	-	99.0	13.6	201.2	-	-	-	13.8	-	-	34.9	263.4	-	-	-	-	-	-	-	68.5	68.5	-	7.1	7.1	-	-	-	33.1	-	-	33.1	-	-	-	-
CB34-1 haul	136.1	25.9	-	25.9	-	-	6.5	-	-	-	-	-	-	6.5	-	64.8	-	-	64.8	6.5	-	13.0	13.0	-	-	-	13.0	-	-	-	-	-	13.0	-	6.5	-	6.5
CB35-2 hauls	115.2	50.5	-	50.5	-	-	2.9	-	-	-	-	7.1	-	9.9	-	2.9	3.5	-	6.4	-	2.9	6.4	9.3	-	29.1	29.1	3.5	-	-	-	-	-	3.5	-	6.4	-	6.4

Table C2.3- 2 Abundance of fishes caught by beam trawl (continued).

Station - *n* hauls	All fishes	*Boreogadus saida*	*Eleginus gracilis*	**Gadidae (2 spp.)**	*Artediellus scaber*	*Gymnocanthus tricuspis*	*Icelus* spp.	*Myoxocephalus jaok*	*Myoxocephalus quadricornis*	*Myoxocephalus scorpius*	*Trichocottus brashnikovi*	*Triglops nybelini*	*Triglops pingelii*	**Cottidae** (9 spp.)	*Nautichthys pribilovius* = **Hemiptipteridae**	Aspidophoroides olrikii	Leptagonus decagonus	Podothecus veternus	**Agonidae** (3 spp.)	Eumicrotremus derjugini = **Cyclopteridae**	*Careproctus* spp.	*Liparis* spp.	**Liparidae** (2 taxa)	*Gymnelus* spp.	*Lycodes* spp.	**Zoarcidae** (n=2 taxa)	*Anisarchus medius*	*Eumesogrammus praecisus*	*Leptoclinus maculatus*	*Lumpenus fabricii*	Stichaeidae larvae unid.	*Stichaeus punctatus*	**Stichaeidae** (6 taxa)	*Ammodytes hexapterus* = **Ammodytidae**	*Hippoglossoides robustus*	*Limanda* sp. (not *proboscidea*)	**Pleuronectidae** (2 species)
Eastern Beaufish																																					
EB02-1 haul	35.9	4.0	-	4.0	1.3	-	13.3	-	-	-	-	-	2.7	17.3	-	9.3	-	-	9.3	-	-	1.3	1.3	4.0	-	4.0	-	-	-	-	-	-	-	-	-	-	-
EB04-1 haul	25.1	2.1	-	2.1	1.0	2.1	9.4	-	-	-	-	-	2.1	14.7	-	-	-	-	-	-	-	-	-	-	2.1	2.1	6.3	-	-	-	-	-	6.3	-	-	-	-
EB06-1 haul	89.8	9.0	-	9.0	13.5	-	49.4	-	-	-	-	-	2.2	65.1	-	11.2	-	-	11.2	-	-	2.2	2.2	-	2.2	2.2	-	-	-	-	-	-	-	-	-	-	-
EB08-1 haul	32.1	9.2	-	9.2	-	9.2	-	-	-	-	-	-	4.6	13.8	-	-	-	-	-	-	-	-	-	-	4.6	4.6	4.6	-	-	-	-	-	4.6	-	-	-	-
EB12-2 hauls	47.7	7.7	-	7.7	3.1	1.5	21.5	-	-	-	-	-	3.1	29.3	-	2.9	-	-	2.9	1.5	-	1.5	1.5	4.6	-	4.6	-	-	-	-	-	-	-	-	-	-	-
EB14-1 haul	78.6	4.6	-	4.6	-	2.3	17.3	-	-	-	-	-	10.4	30.0	-	3.5	-	-	3.5	-	-	10.4	10.4	4.6	1.2	5.8	24.3	-	-	-	-	-	24.3	-	-	-	-
EB16-1 haul	100.8	4.9	-	4.9	2.5	2.5	54.1	-	-	-	-	-	12.3	71.3	-	19.7	-	-	19.7	-	-	2.5	2.5	2.5	-	2.5	-	-	-	-	-	-	-	-	-	-	-
EB19-1 haul	36.7	16.7	-	16.7	3.3	10.0	-	-	-	-	-	-	6.7	20.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EB21-1 haul	251.8	14.2	-	14.2	10.6	-	78.0	-	-	-	-	-	-	88.7	-	85.1	-	-	85.1	3.5	-	3.5	3.5	42.6	10.6	53.2	3.5	-	-	-	-	-	3.5	-	-	-	-
EB23-1 haul	114.0	11.0	-	11.0	-	-	22.1	-	-	3.7	-	-	3.7	29.4	-	22.1	-	-	22.1	-	-	11.0	11.0	3.7	33.1	36.8	-	-	-	3.7	-	-	3.7	-	-	-	-

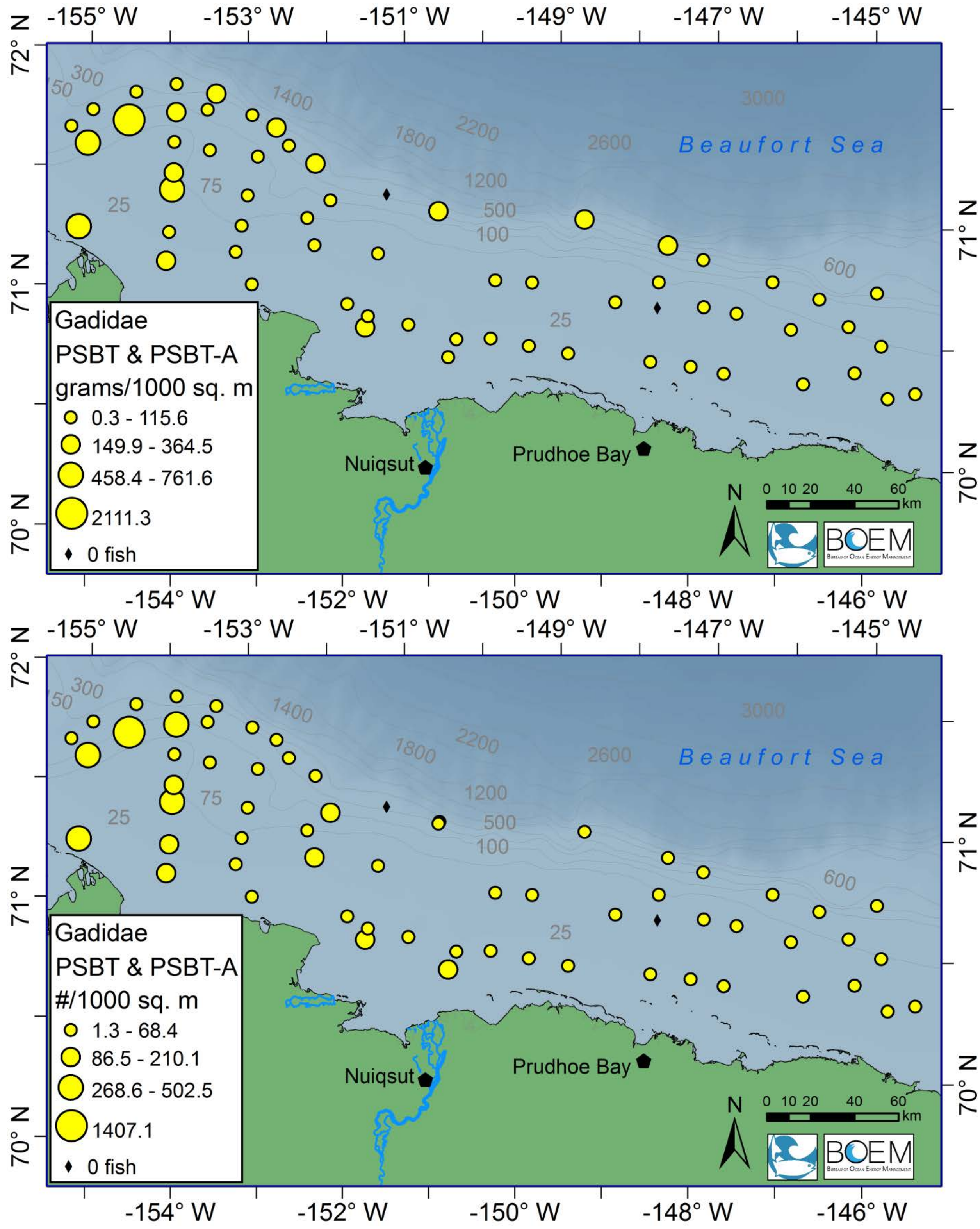


Figure C2.3- 1 Gadidae – biomass and density in catches by beam trawl during BOEM-2011.

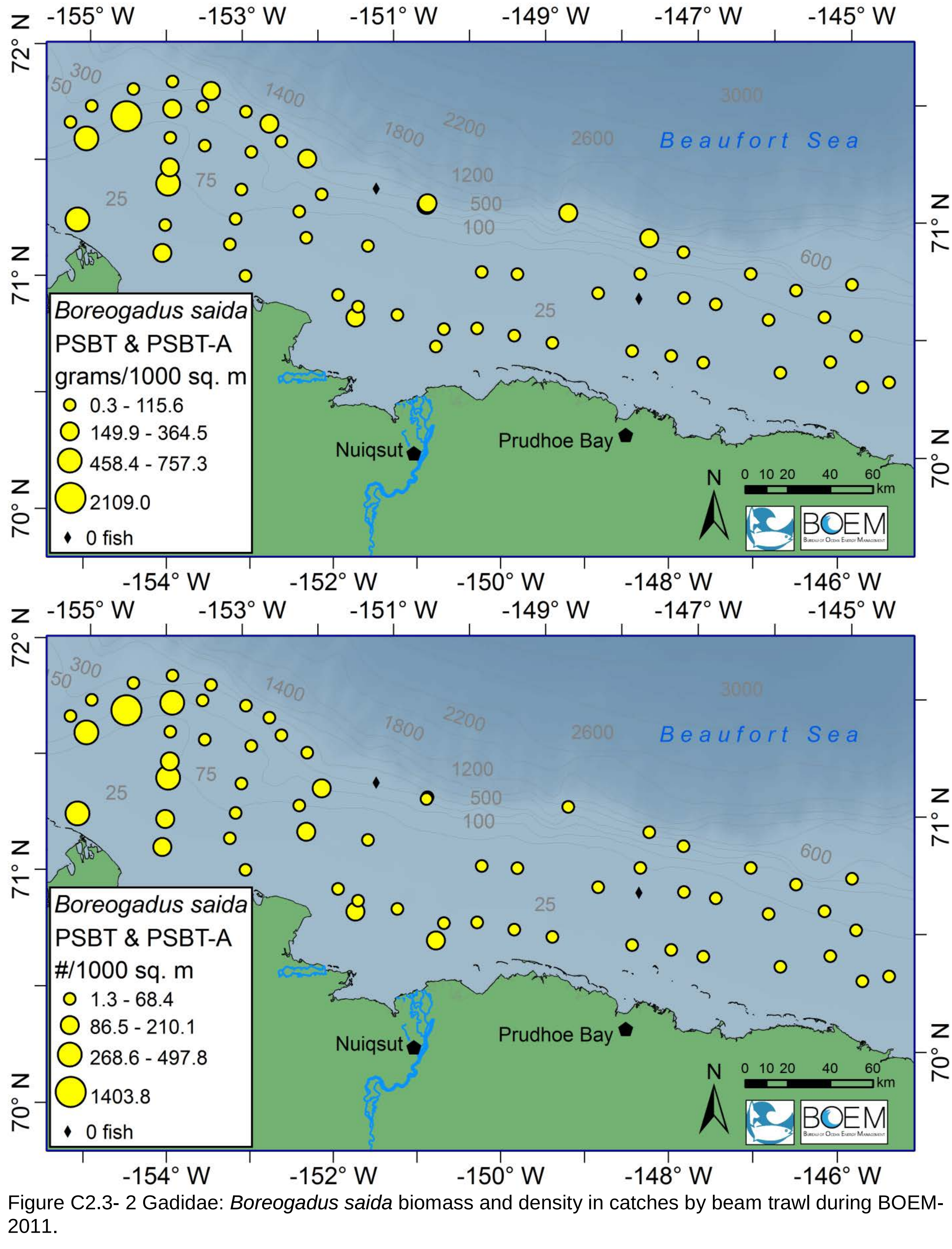


Figure C2.3- 2 Gadidae: *Boreogadus saida* biomass and density in catches by beam trawl during BOEM-2011.

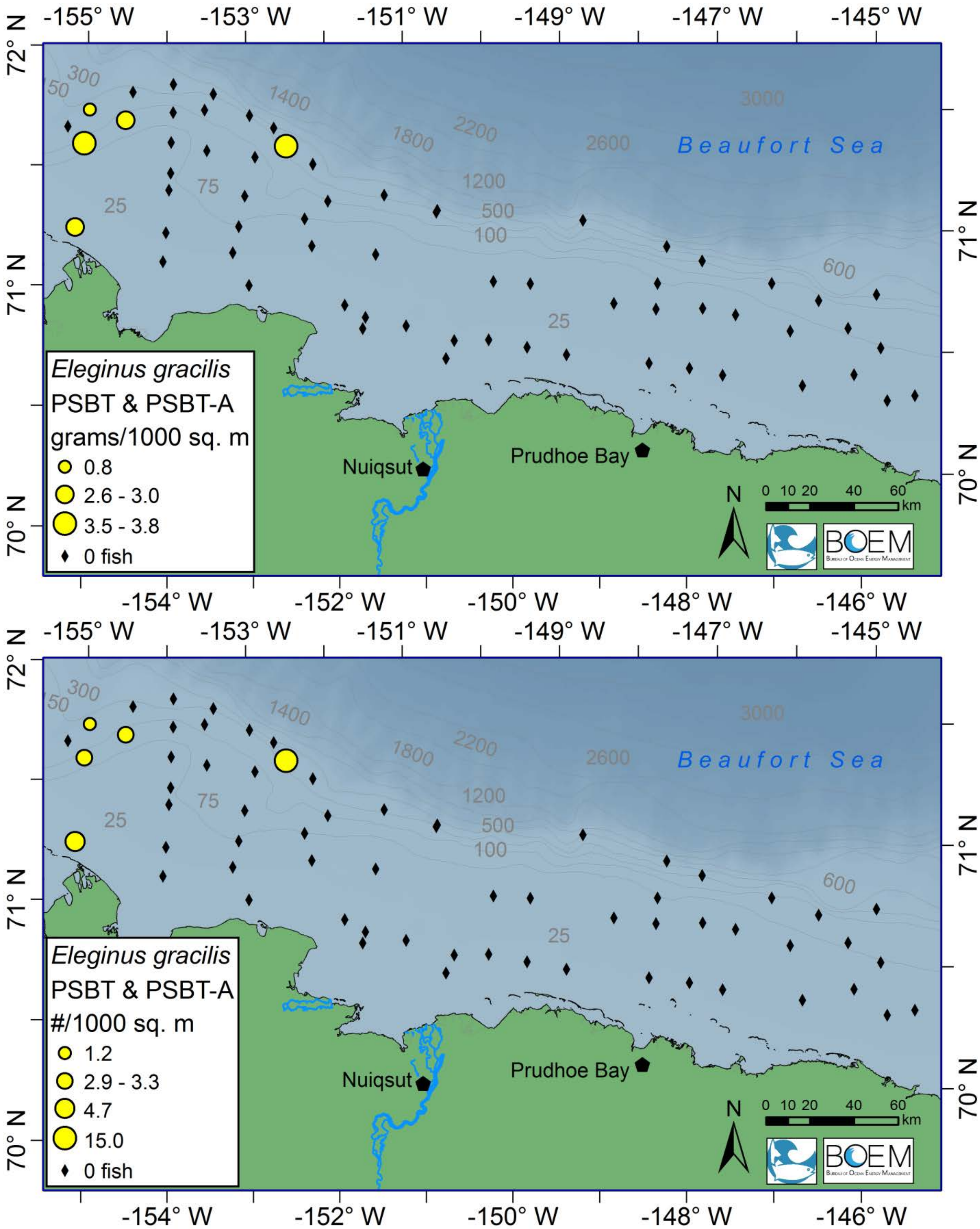


Figure C2.3- 3 Gadidae: *Eleginus gracilis* biomass and density in catches by beam trawl during BOEM-2011.

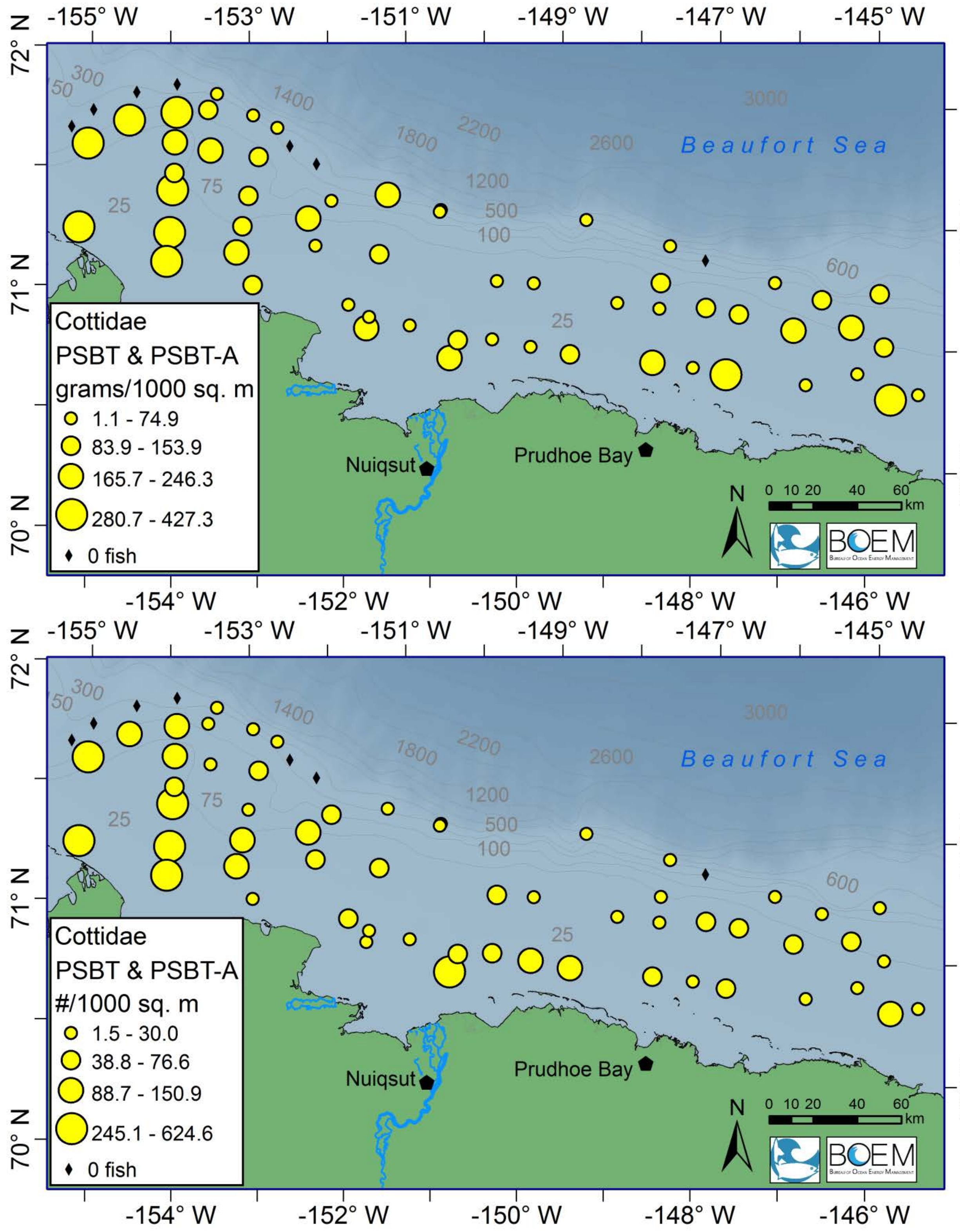


Figure C2.3- 4 Cottidae – biomass and density in catches by beam trawl during BOEM-2011.

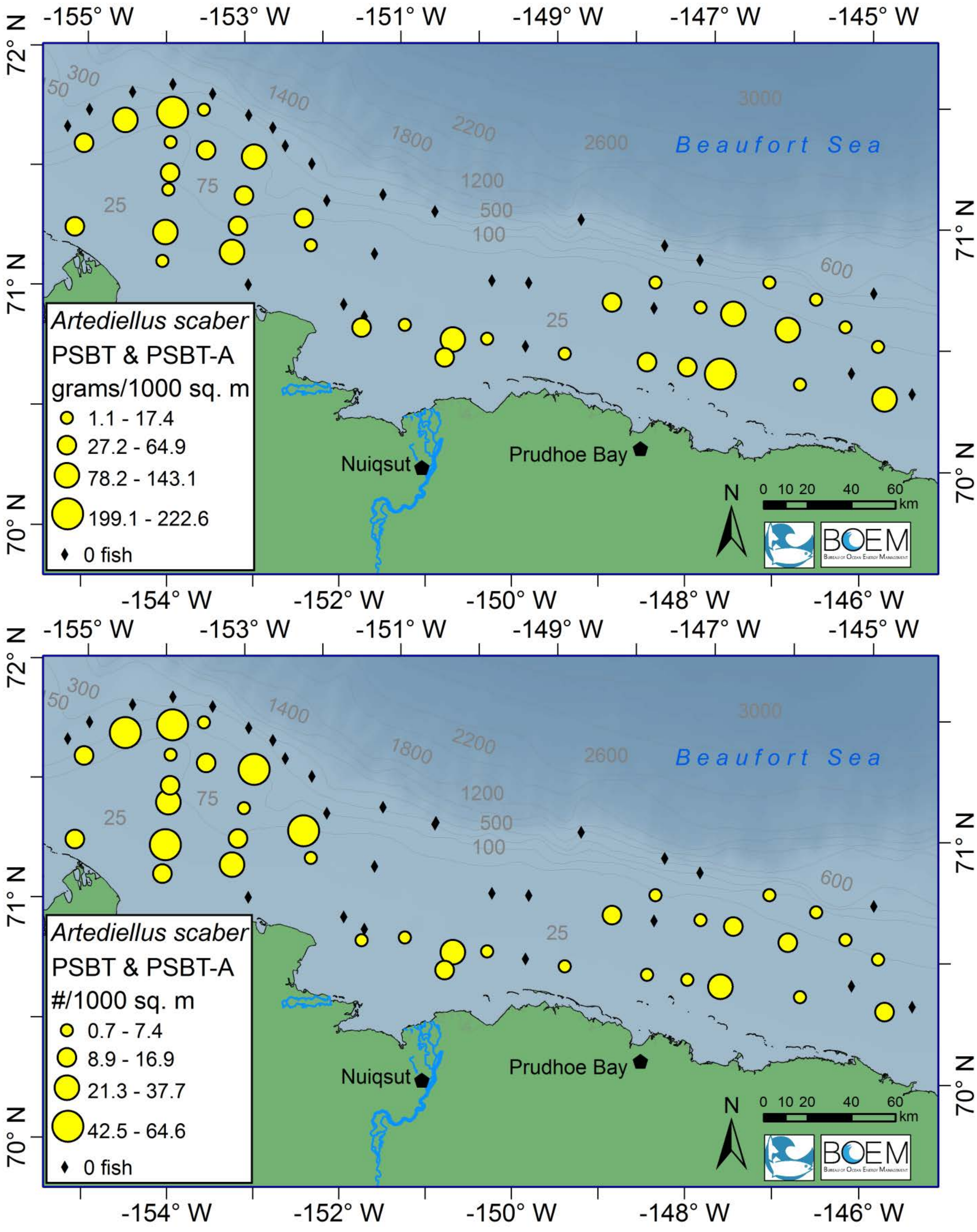


Figure C2.3- 5 Cottidae: *Artediellus scaber* biomass and density in catches by beam trawl during BOEM-2011.

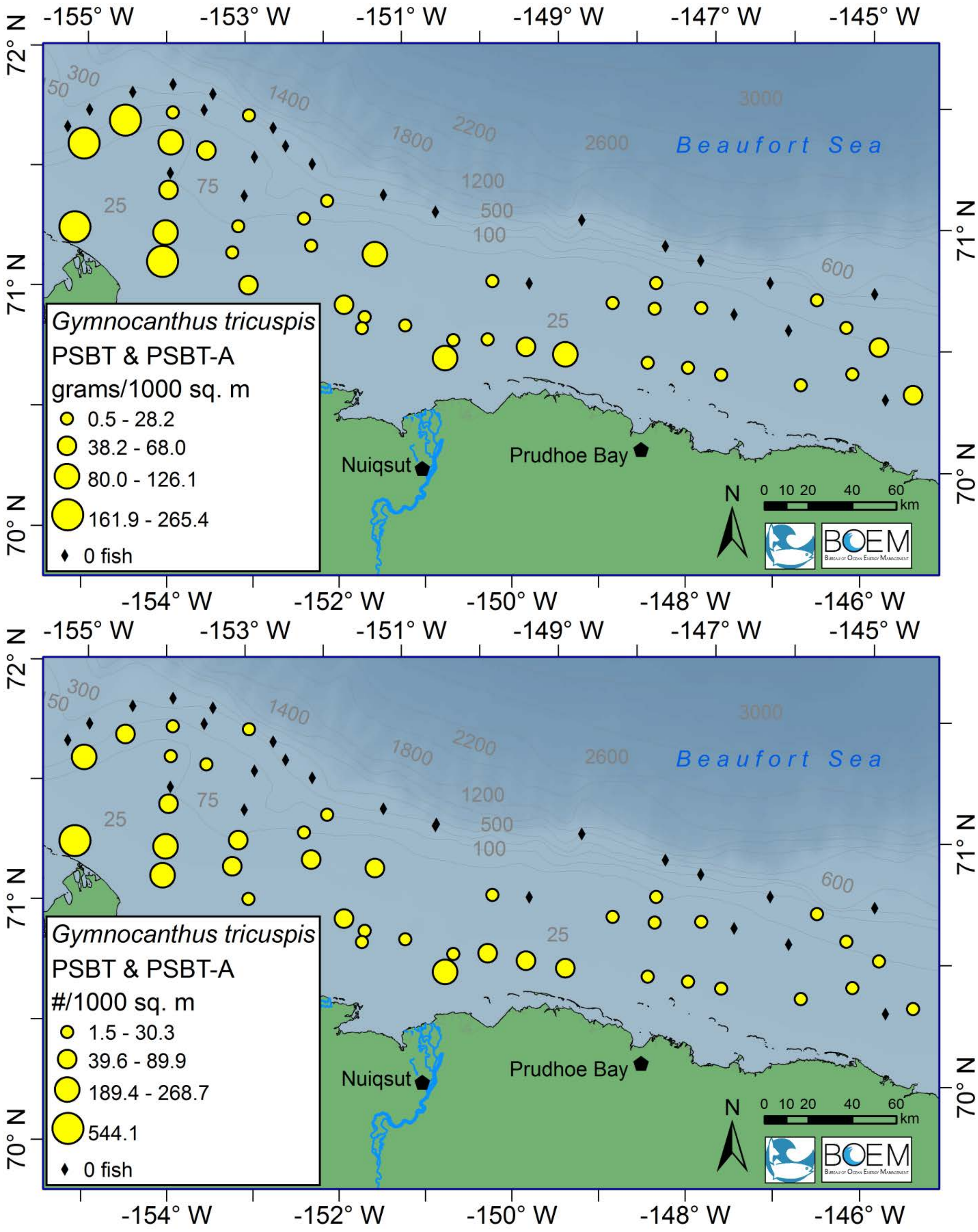


Figure C2.3- 6 Cottidae: *Gymnocanthus tricuspis* biomass and density in catches by beam trawl during BOEM-2011.

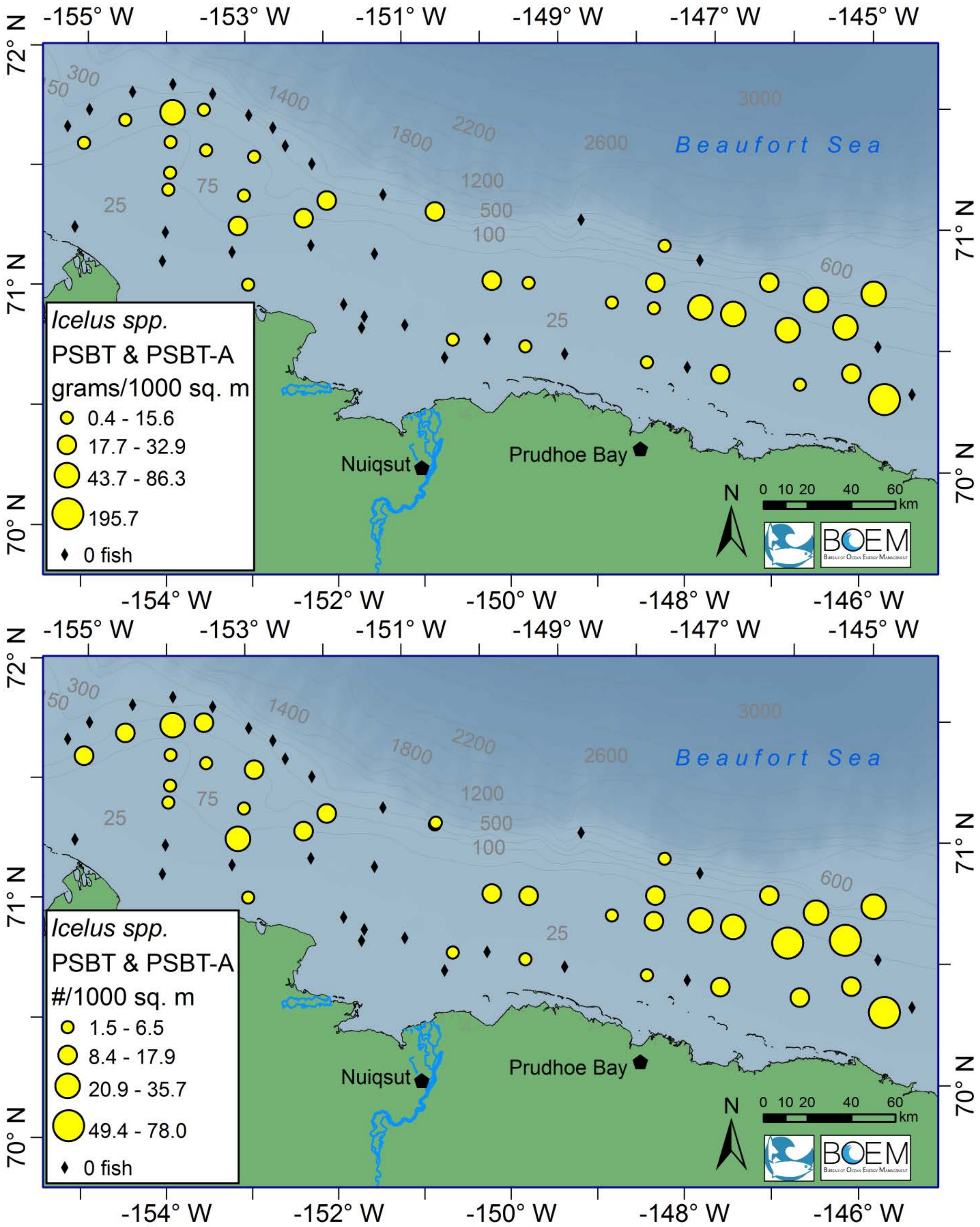


Figure C2.3- 7 Cottidae: *Icelus* spp. biomass and density in catches by beam trawl during BOEM-2011.

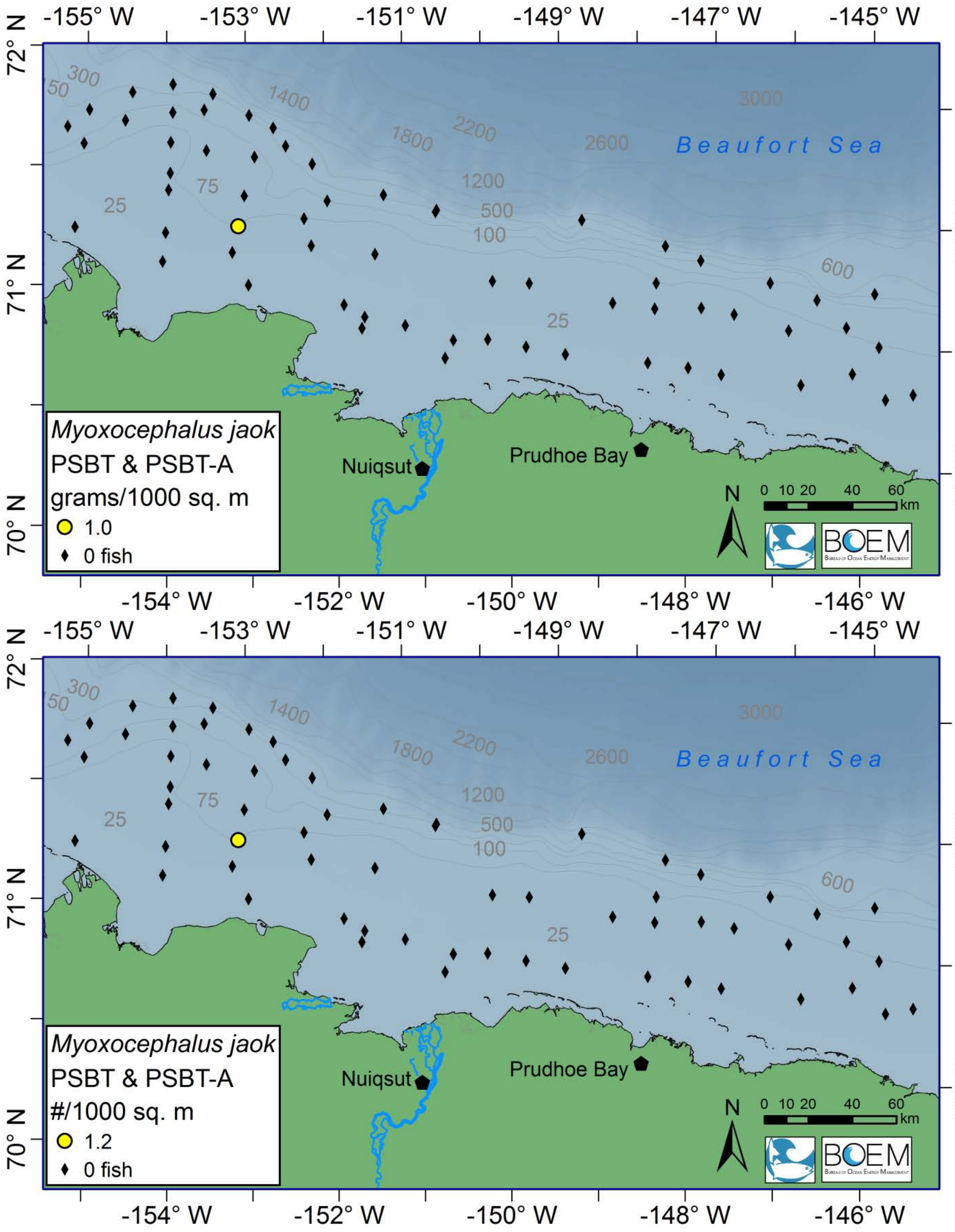


Figure C2.3- 8 Cottidae: *Myoxocephalus jaok* biomass and density in catches by beam trawl during BOEM-2011.

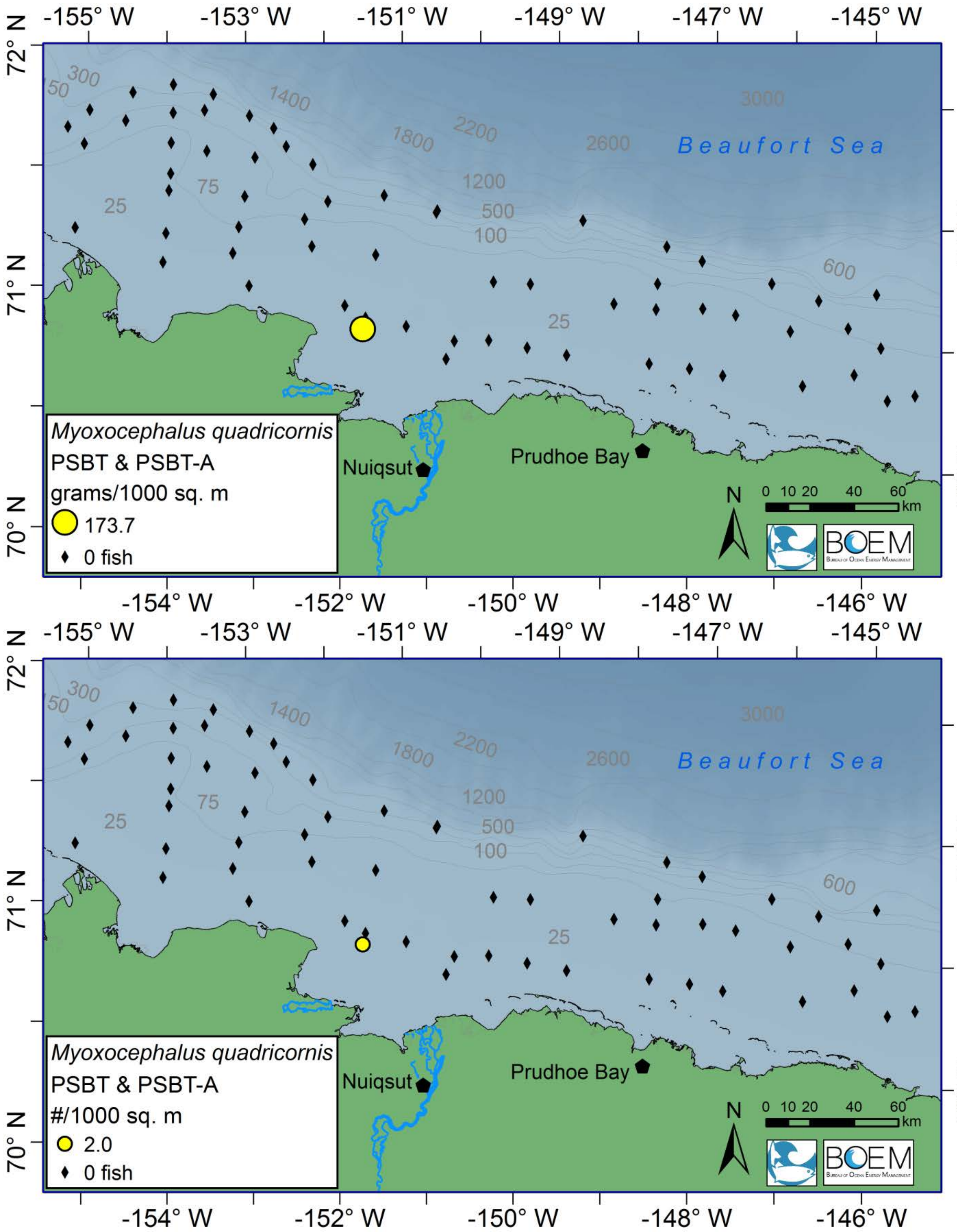


Figure C2.3- 9 Cottidae: *Myoxocephalus quadricornis* biomass and density in catches by beam trawl during BOEM-2011.

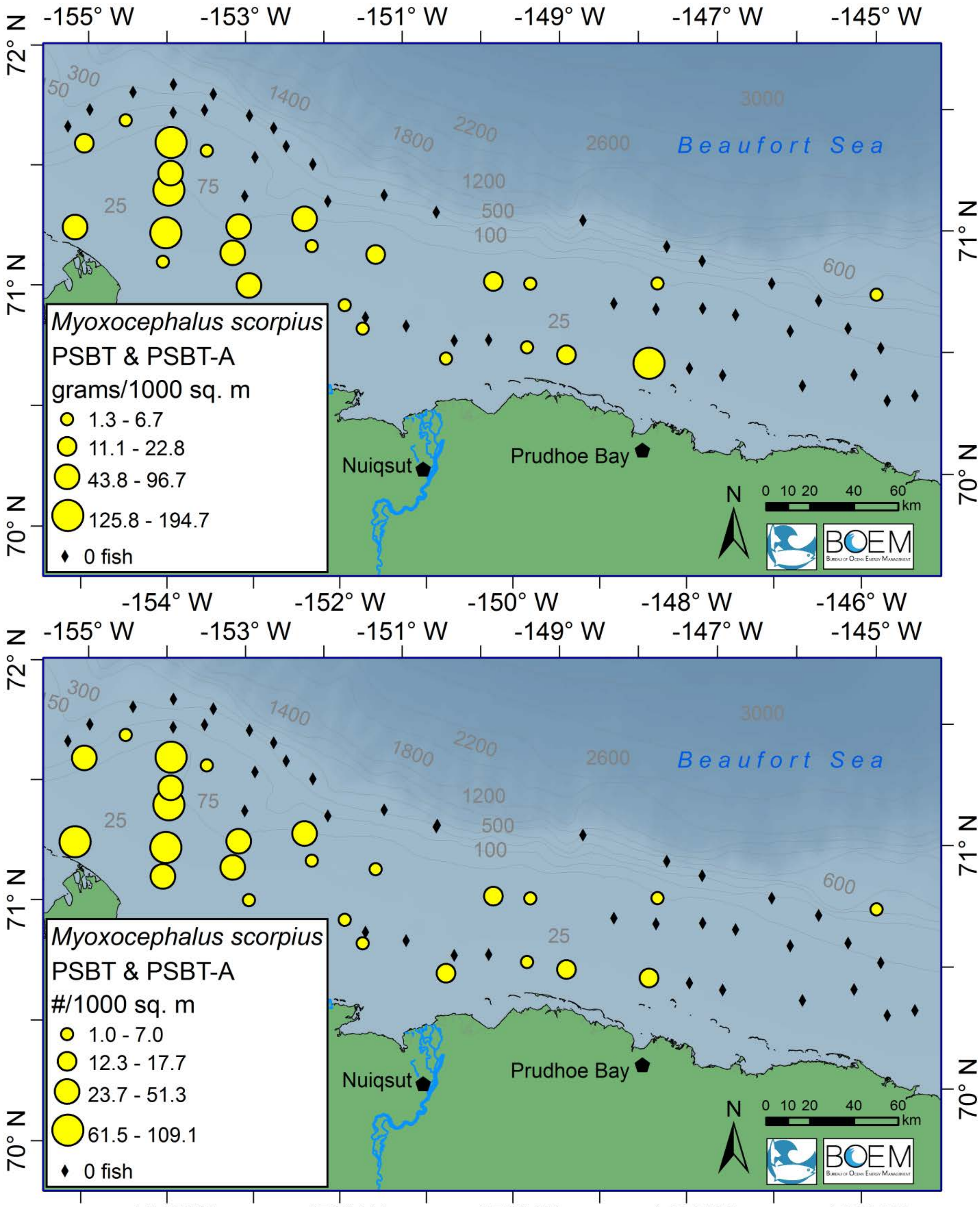


Figure C2.3- 10 Cottidae: *Myoxocephalus scorpius* biomass and density in catches by beam trawl during BOEM-2011.

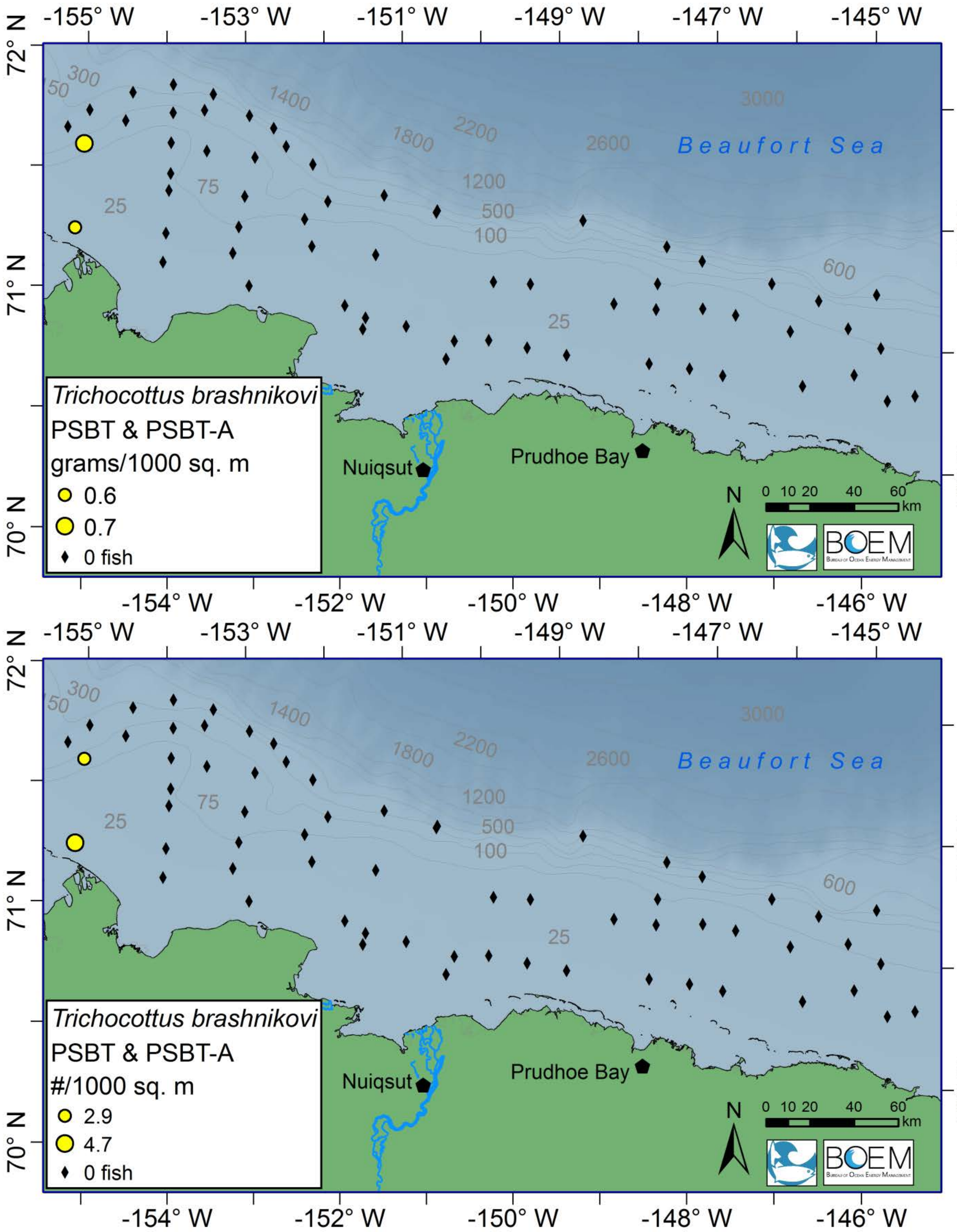


Figure C2.3- 11 Cottidae: *Trichocottus brashnikovi* biomass and density in catches by beam trawl during BOEM-2011.

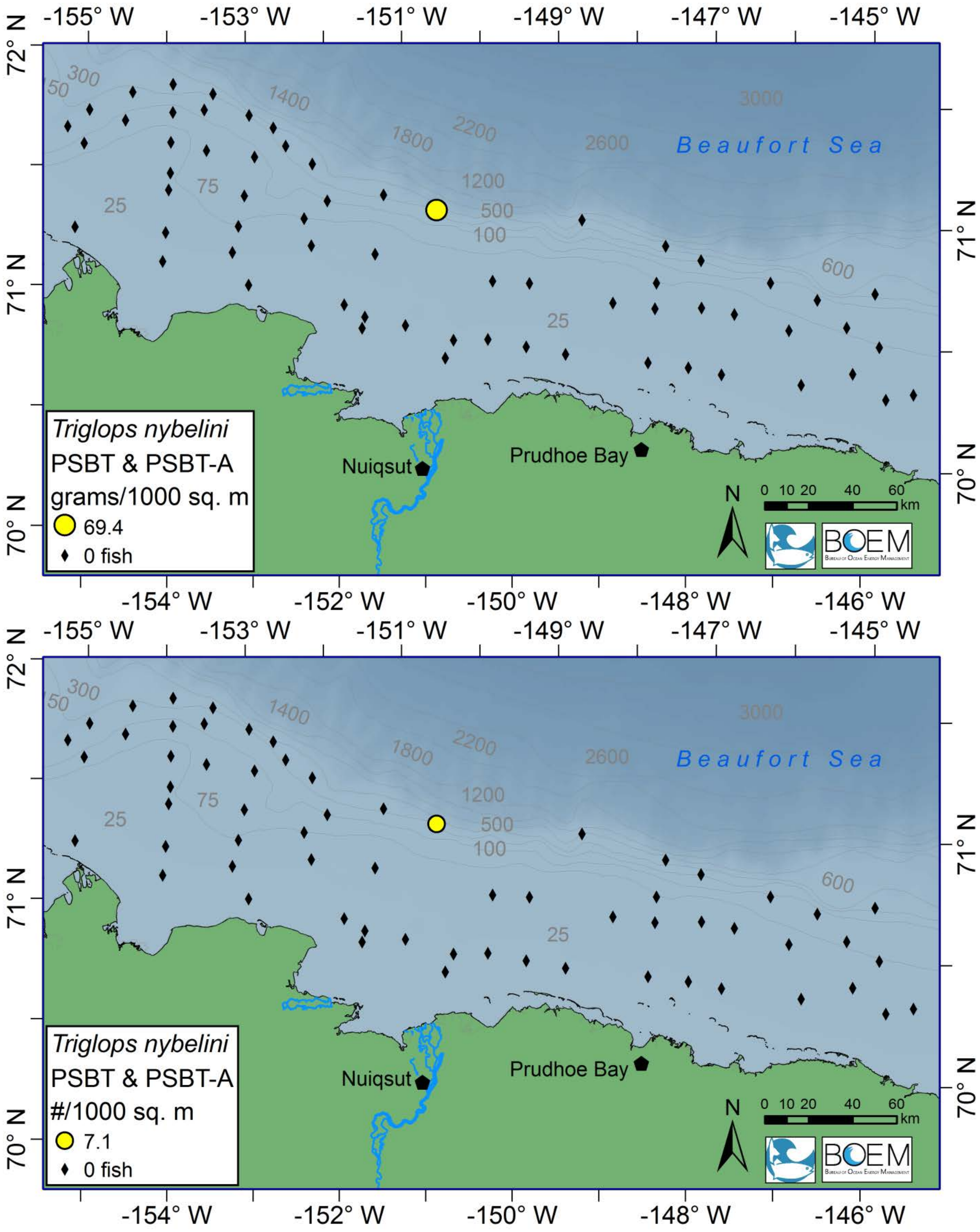


Figure C2.3- 12 Cottidae: *Triglops nybelini* biomass and density in catches by beam trawl during BOEM-2011.

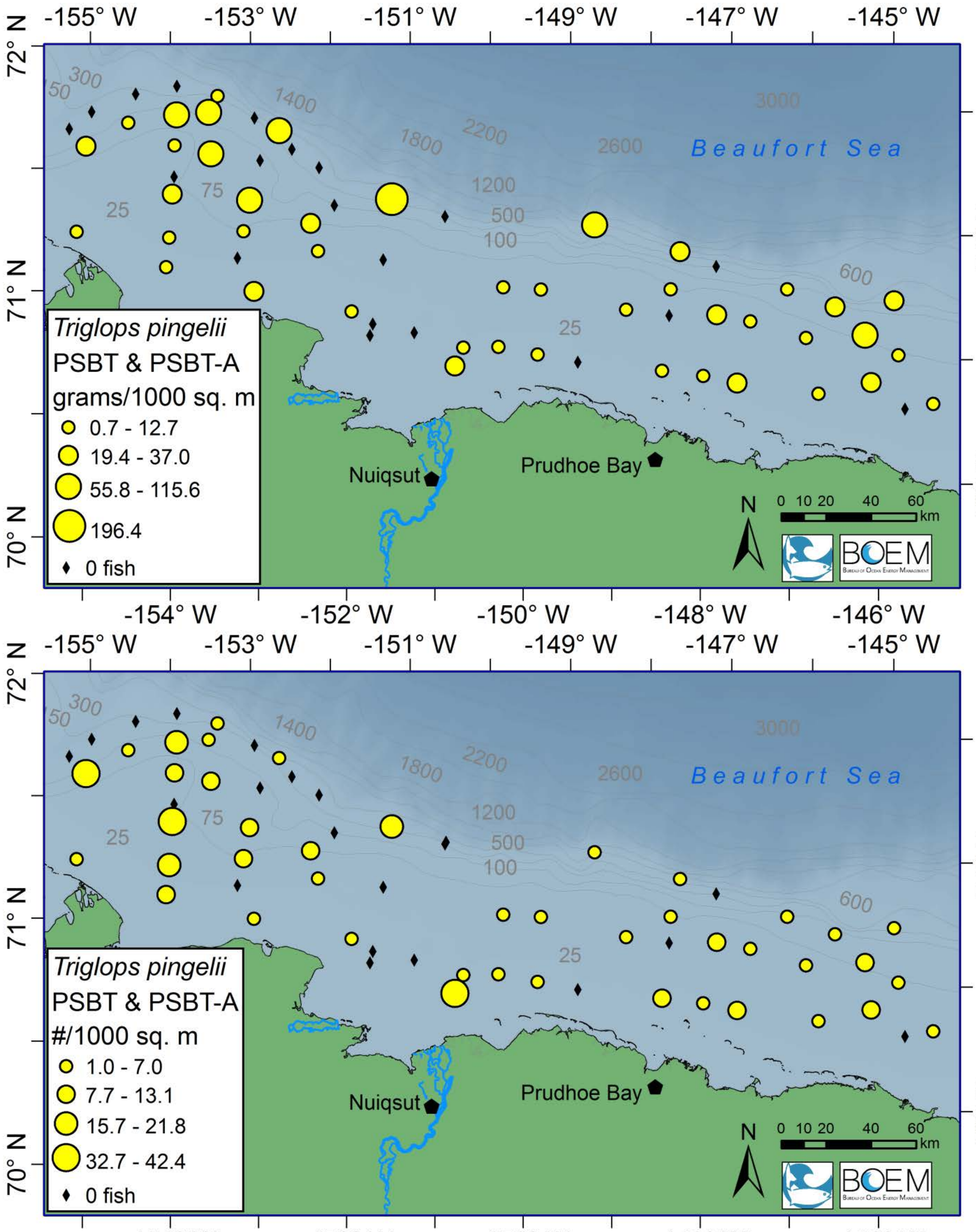
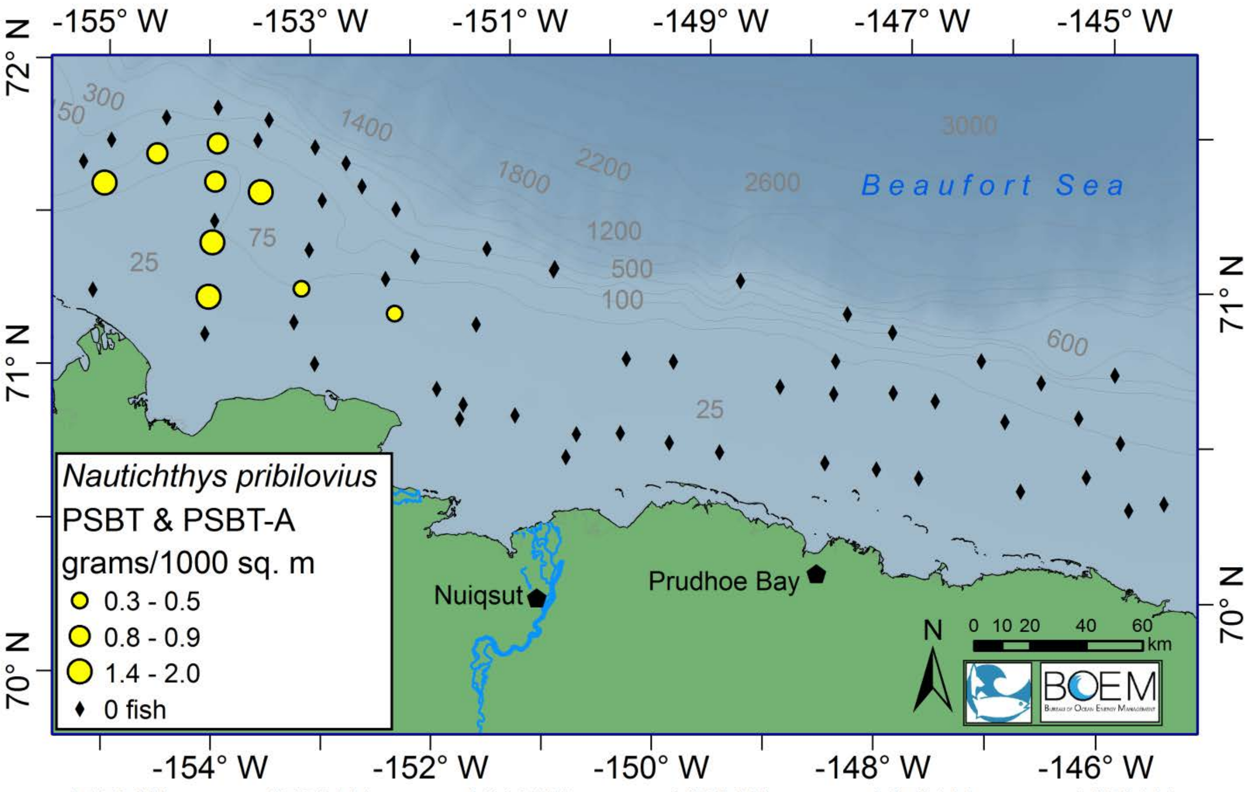


Figure C2.3- 13 Cottidae: *Triglops pingelii* biomass and density in catches by beam trawl during BOEM-2011.



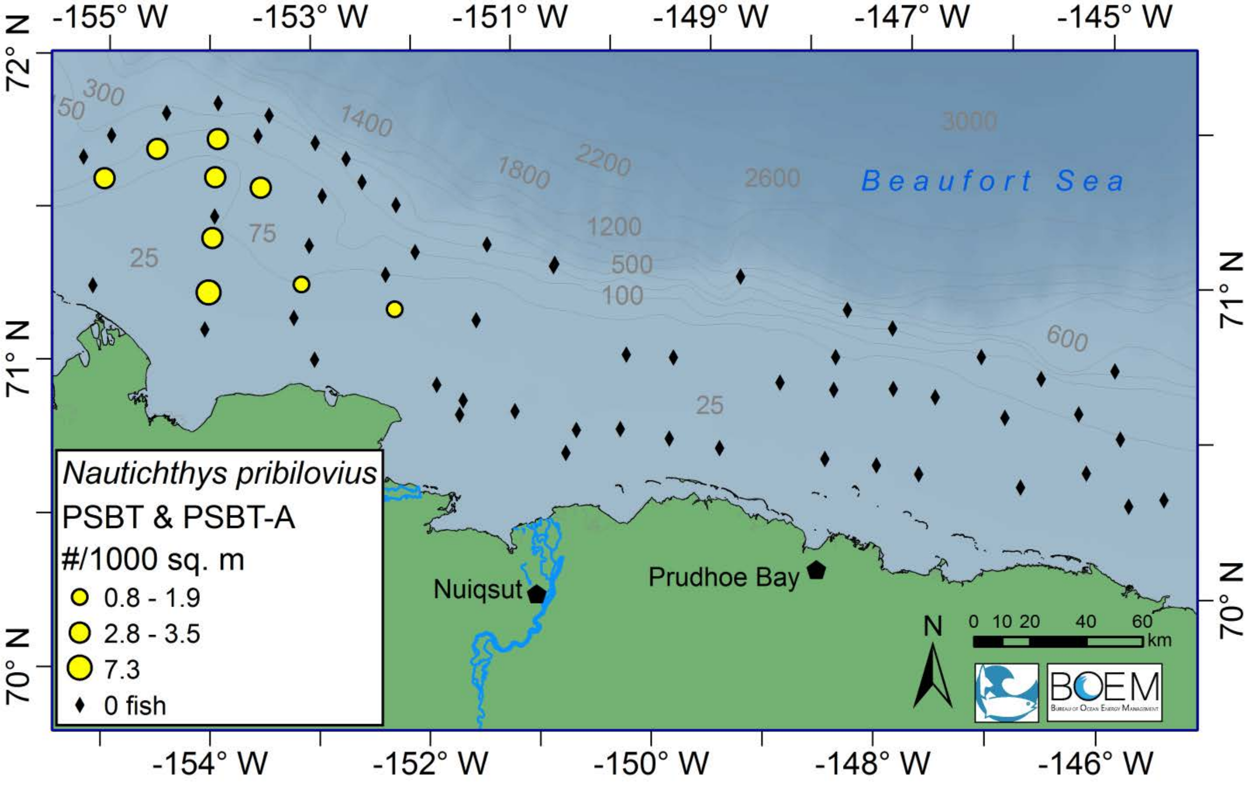


Figure C2.3- 14. Hemitripteridae: All were *Nautichthys pribilovius* – biomass and density in catches by beam trawl during BOEM-2011.

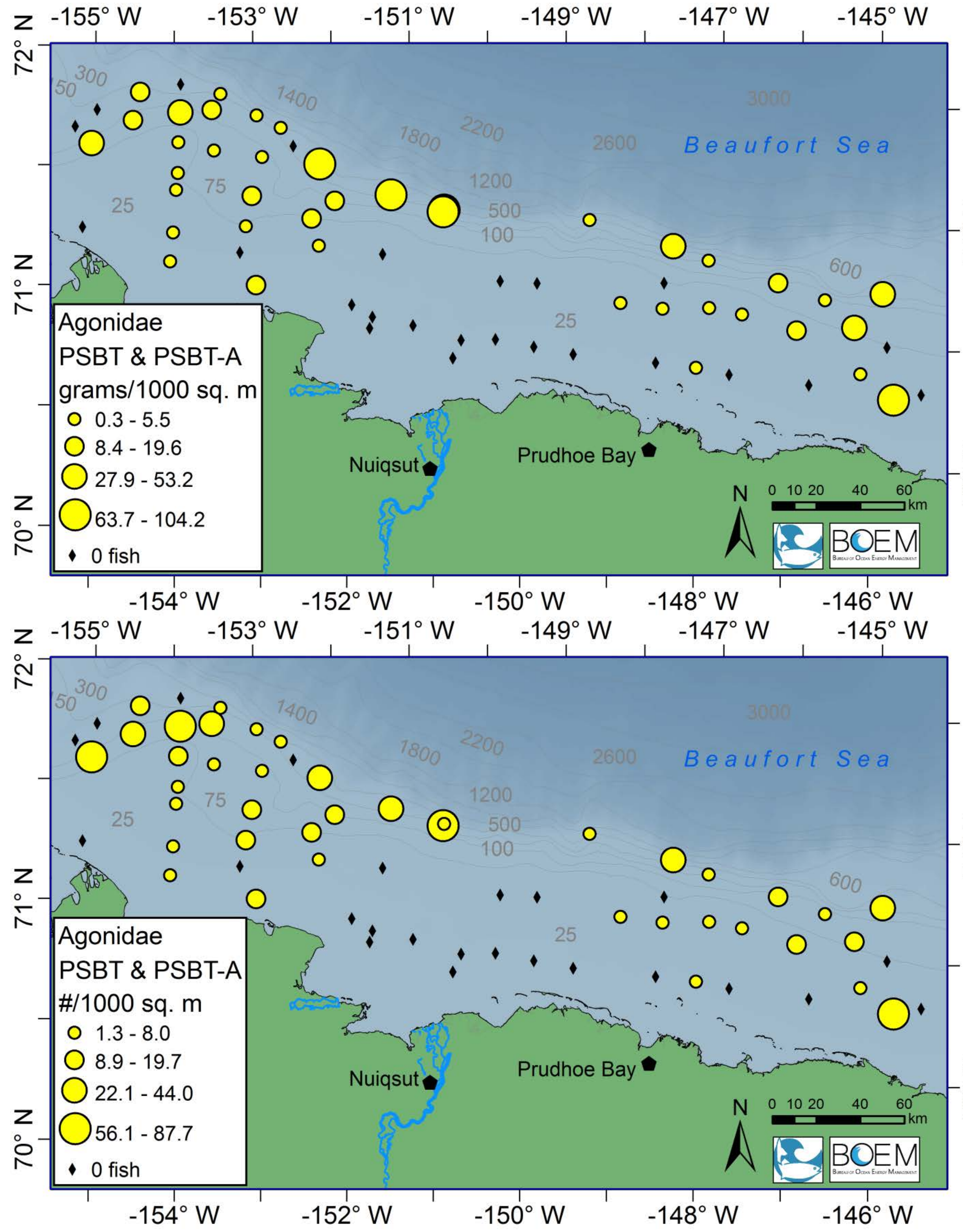


Figure C2.3- 15 Agonidae – biomass and density in catches by beam trawl during BOEM-2011.

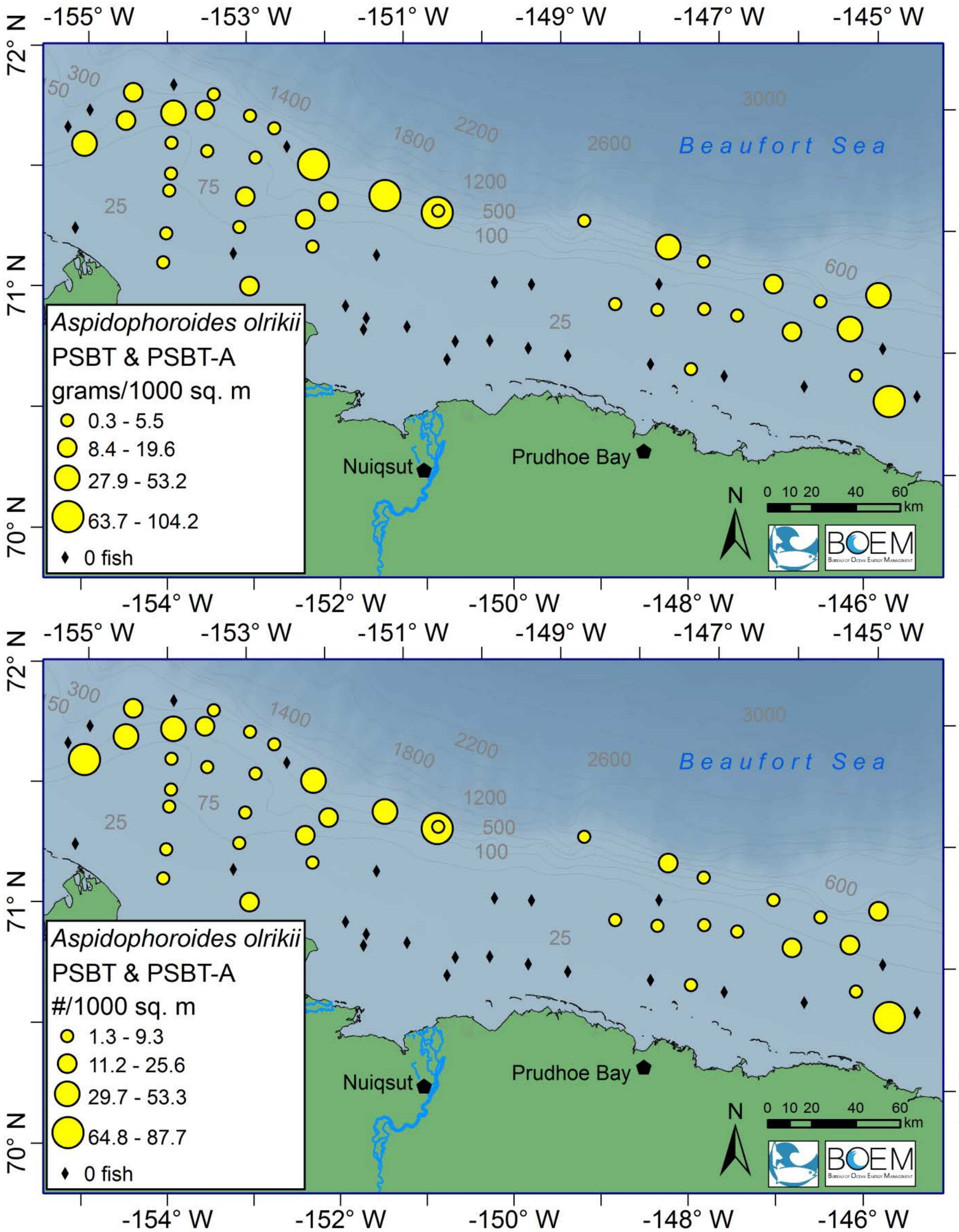


Figure C2.3- 16 Agonidae: *Aspidophoroides olrikii* biomass and density in catches by beam trawl during BOEM-2011.

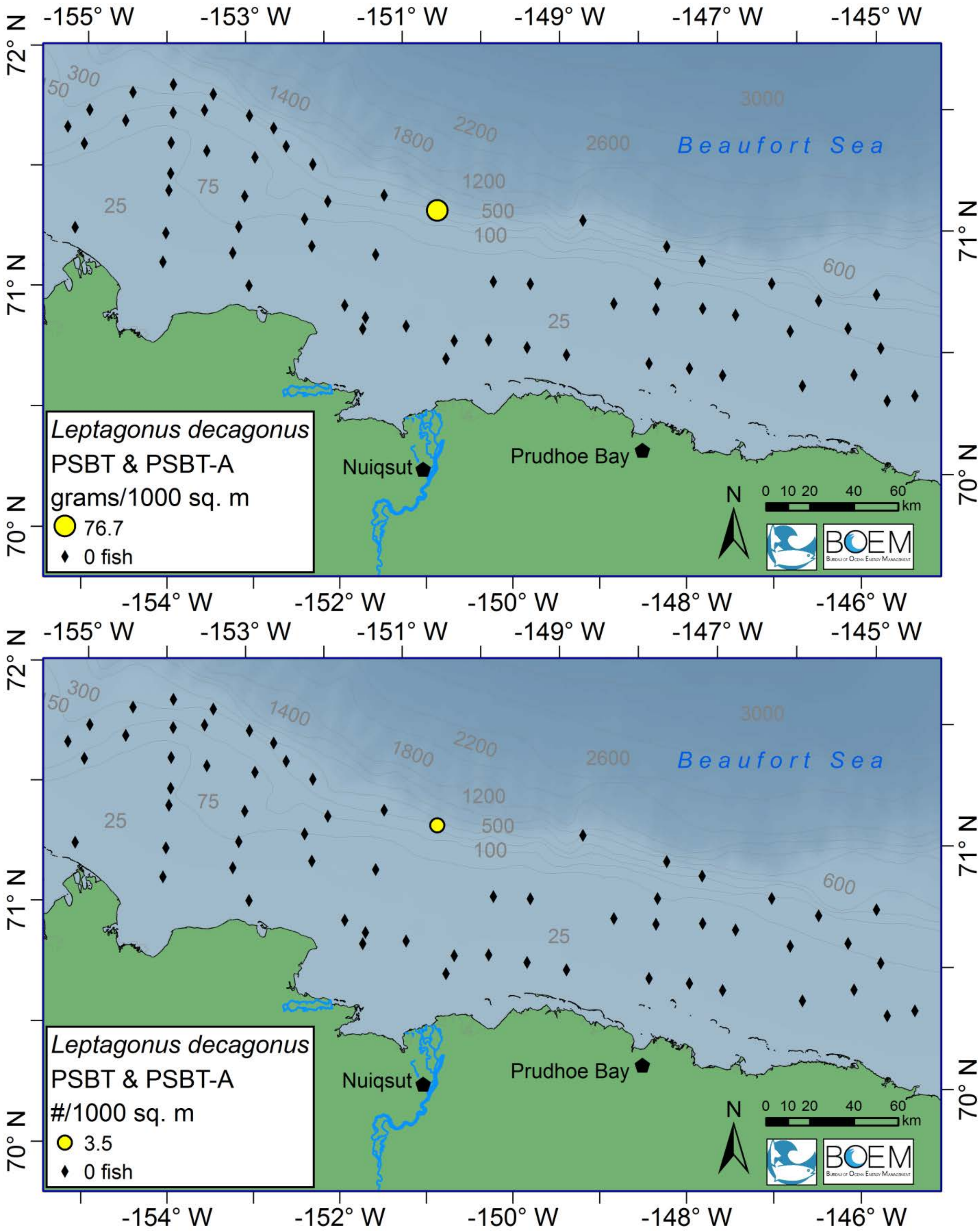
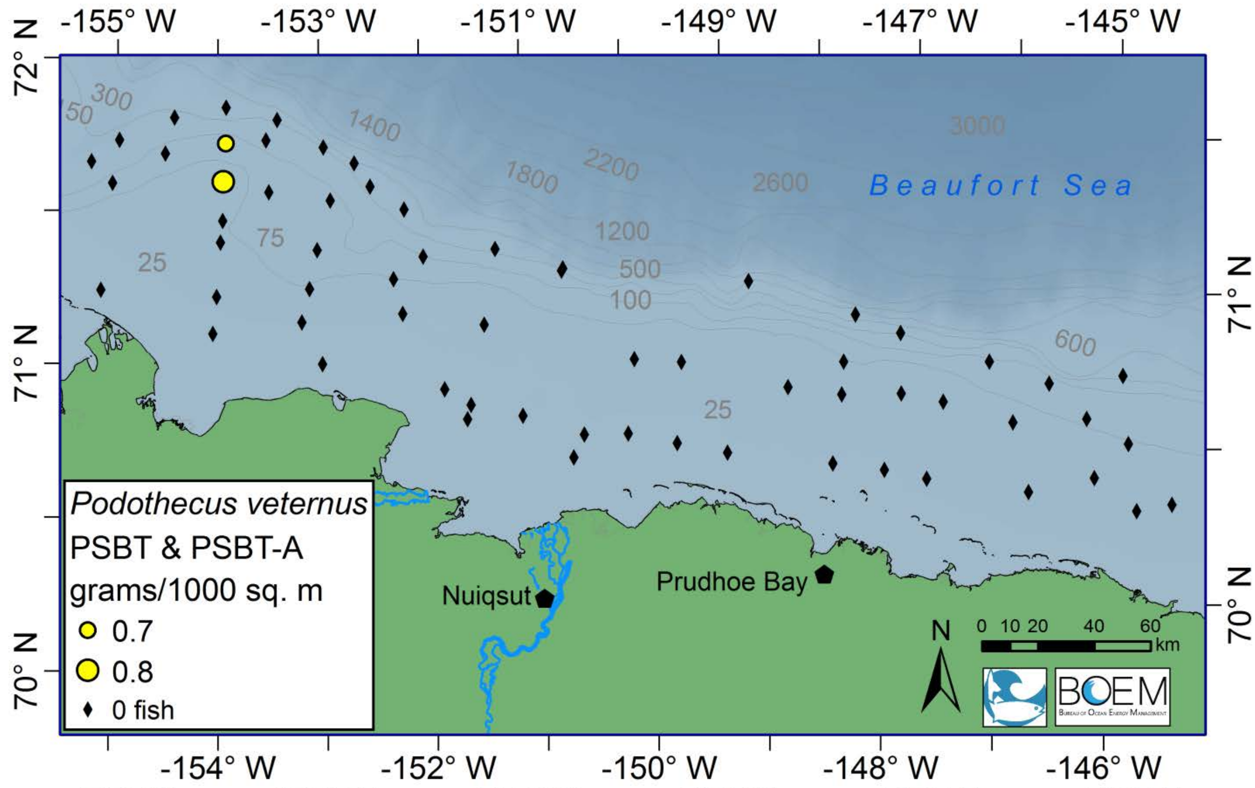


Figure C2.3- 17 Agonidae: *Leptagonus decagonus* biomass and density in catches by beam trawl during BOEM-2011.



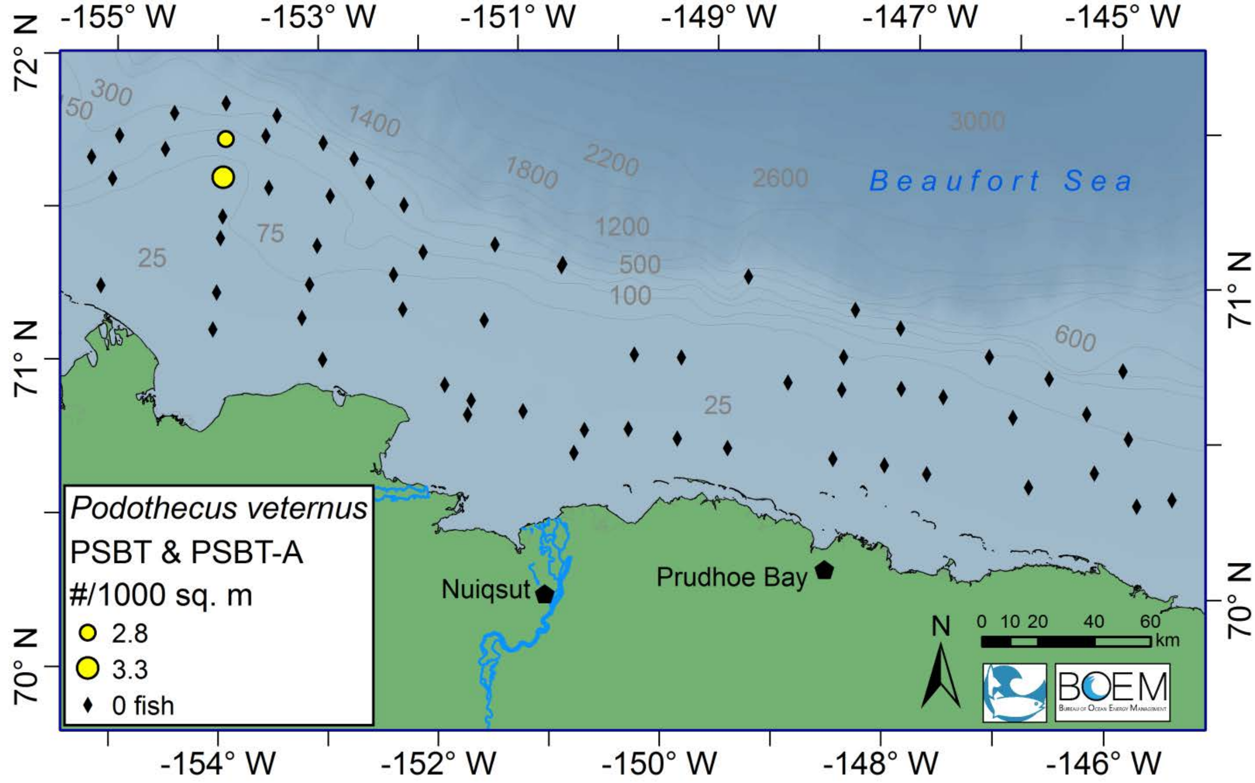


Figure C2.3- 18 Agonidae: *Podothecus veternus* biomass and density in catches by beam trawl during BOEM-2011.

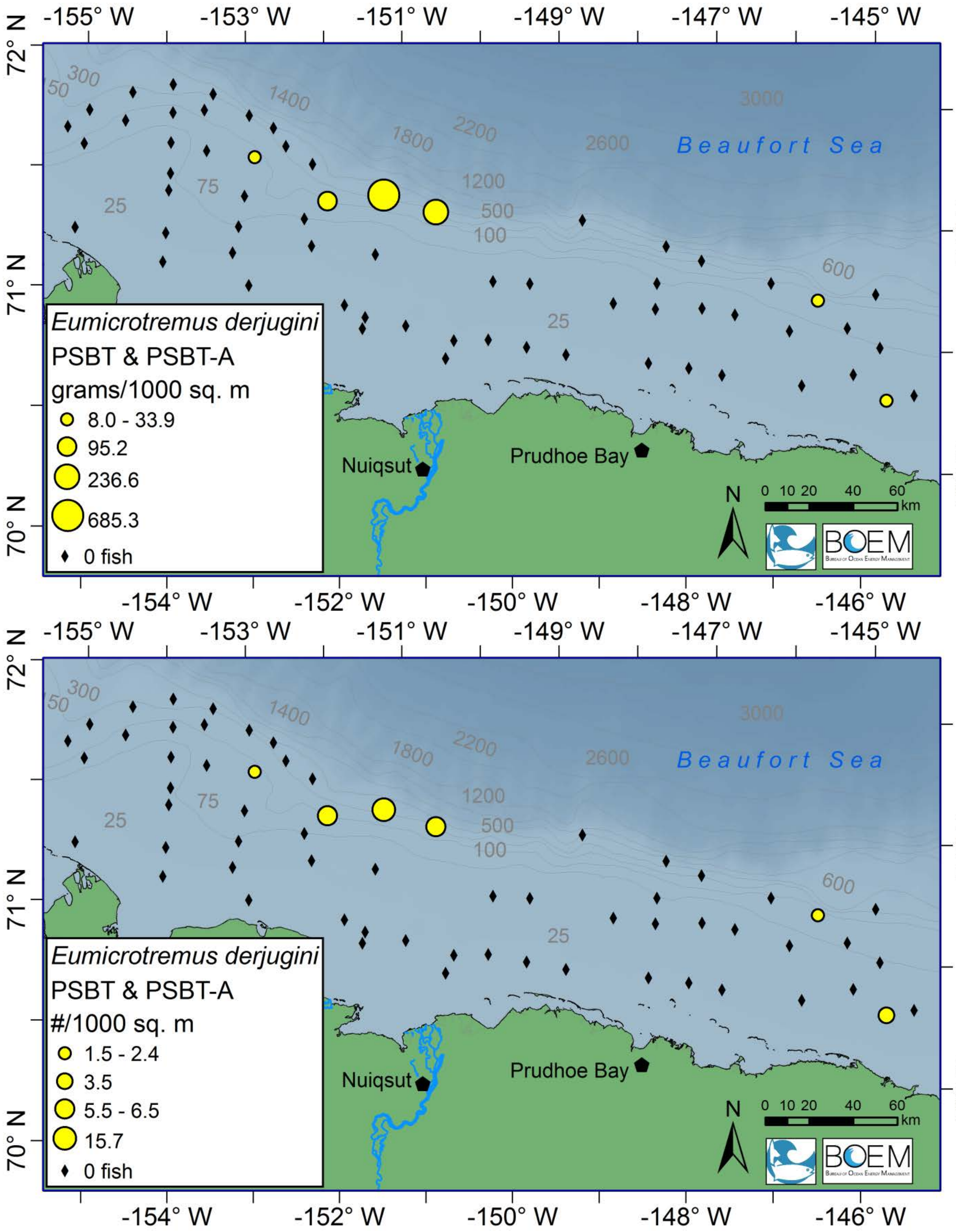


Figure C2.3- 19. Cyclopteridae: All were *Eumicrotremus derjugini* – biomass and density in catches by beam trawl during BOEM-2011.

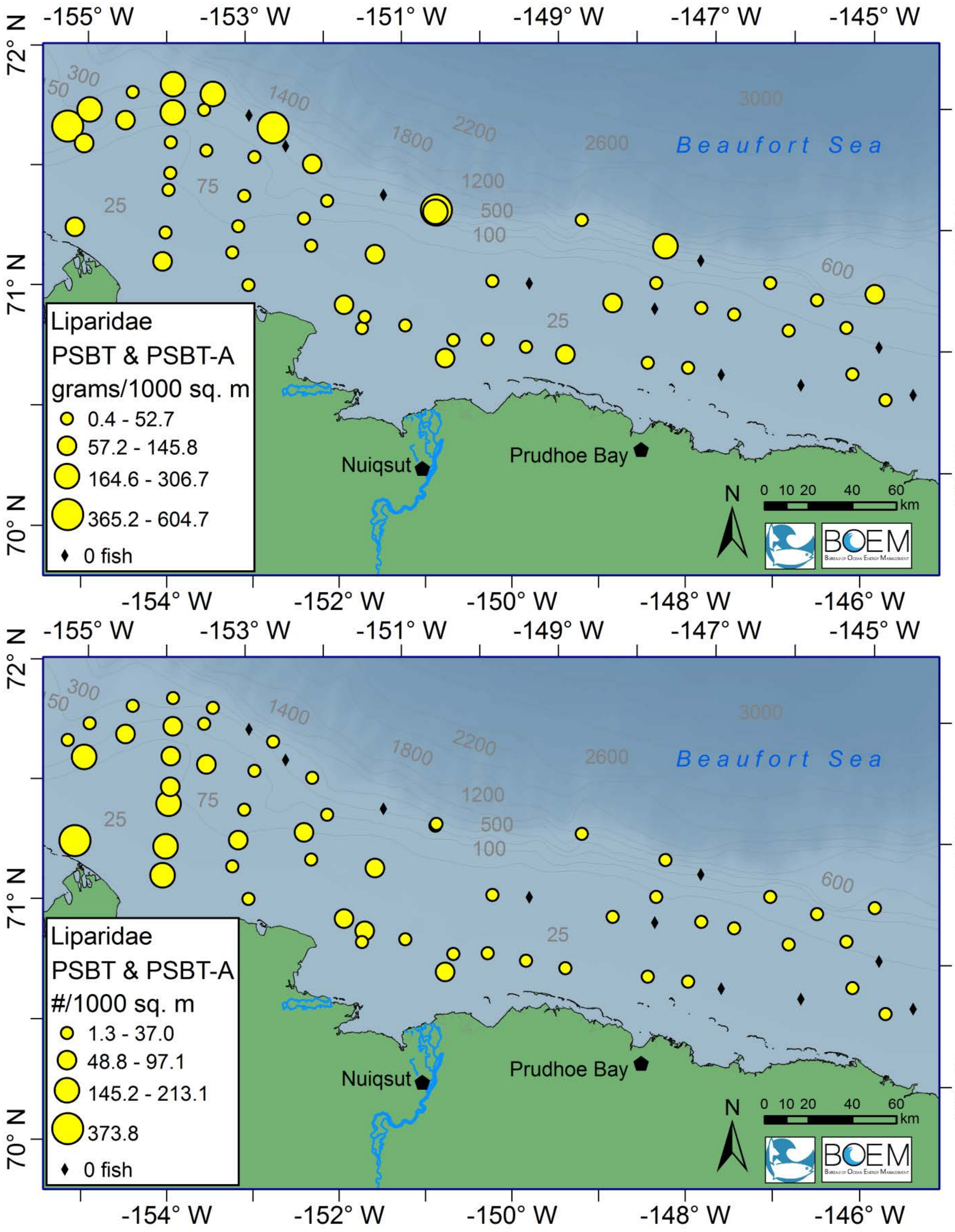


Figure C2.3- 20 Liparidae – biomass and density in catches by beam trawl during BOEM-2011.

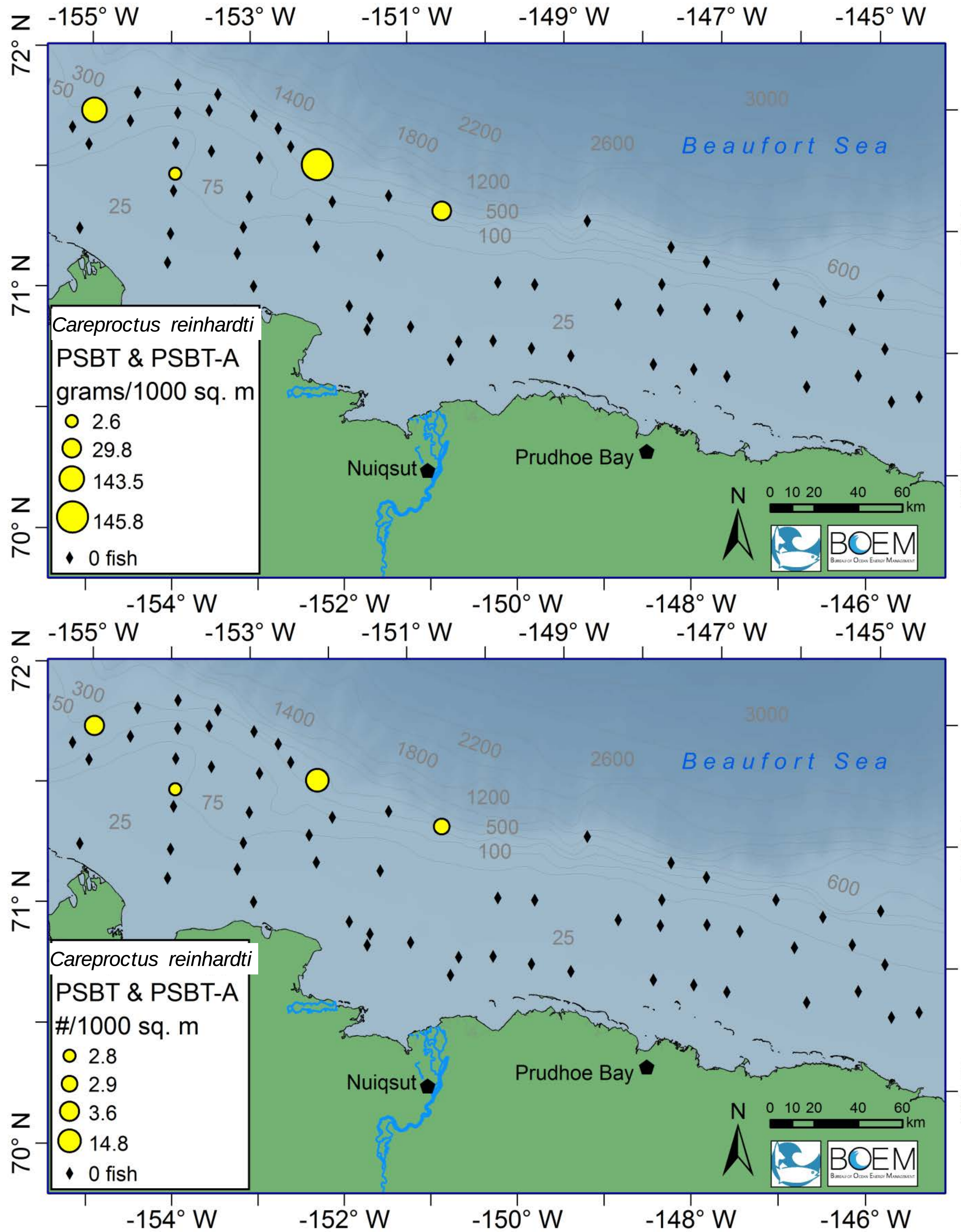


Figure C2.3- 21 Liparidae: *Careproctus reinhardti* biomass and density in catches by beam trawl during BOEM-2011.

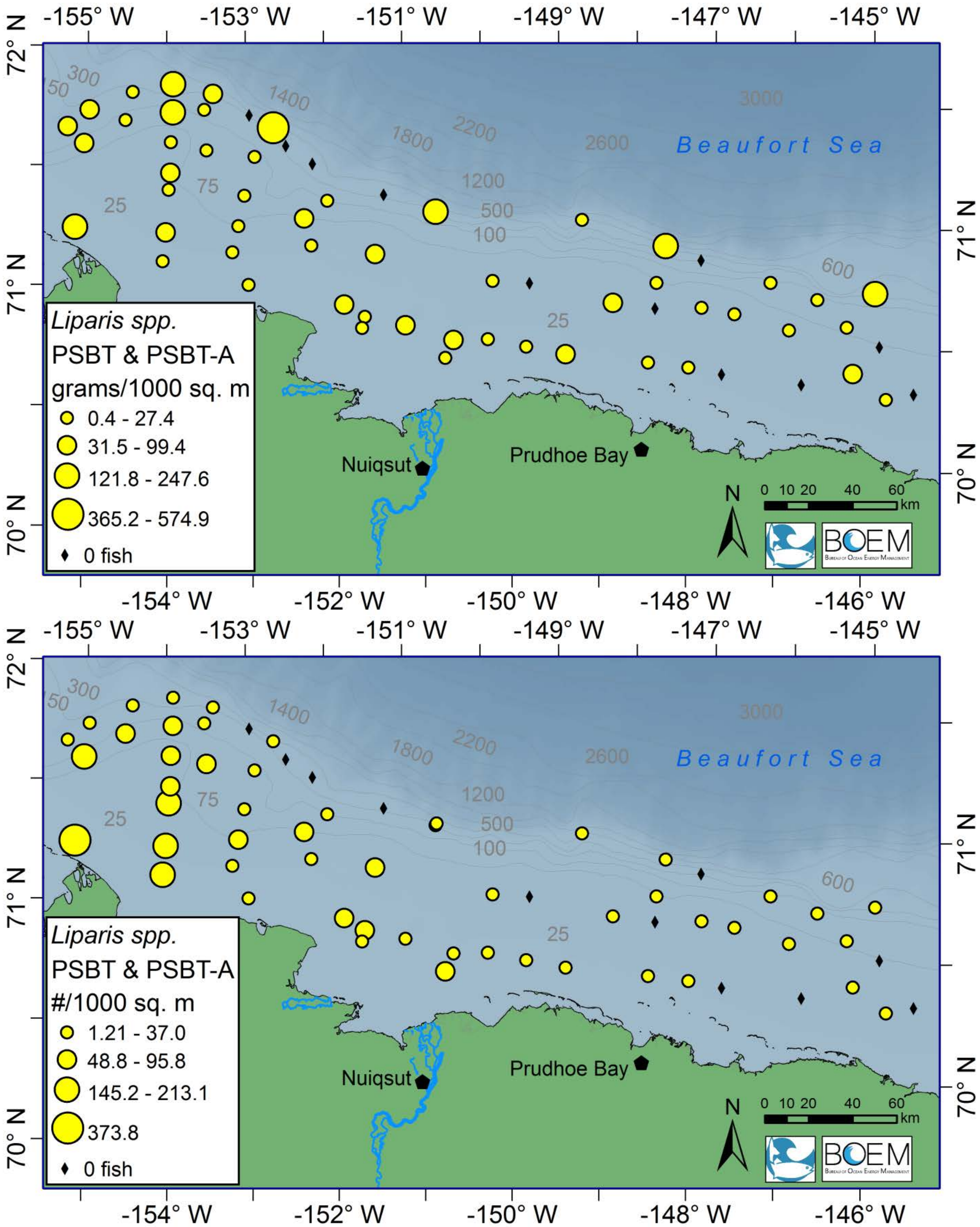


Figure C2.3- 22 Liparidae: *Liparis* spp. biomass and density in catches by beam trawl during BOEM-2011.

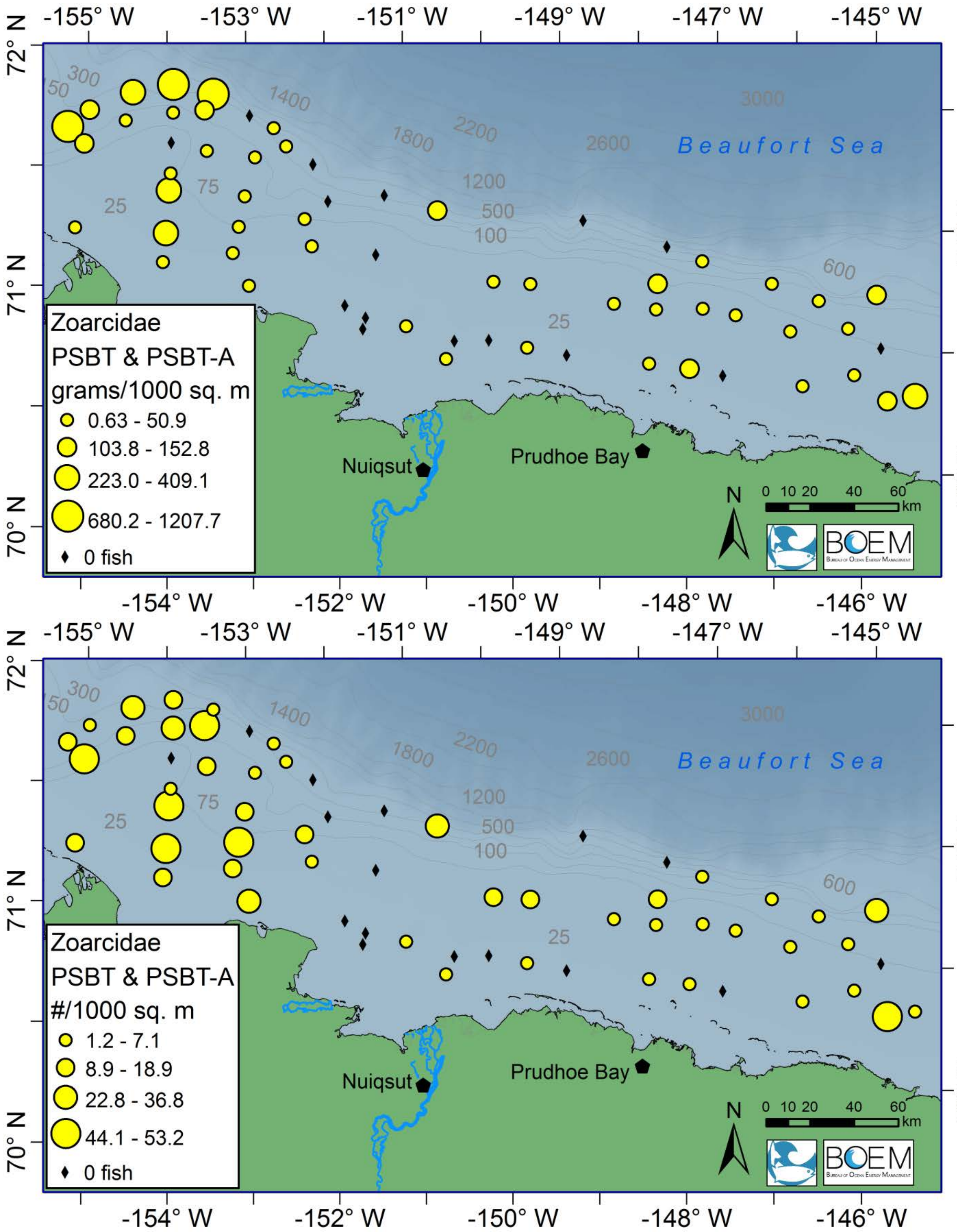


Figure C2.3- 23 Zoarcidae – biomass and density in catches by beam trawl during BOEM-2011.

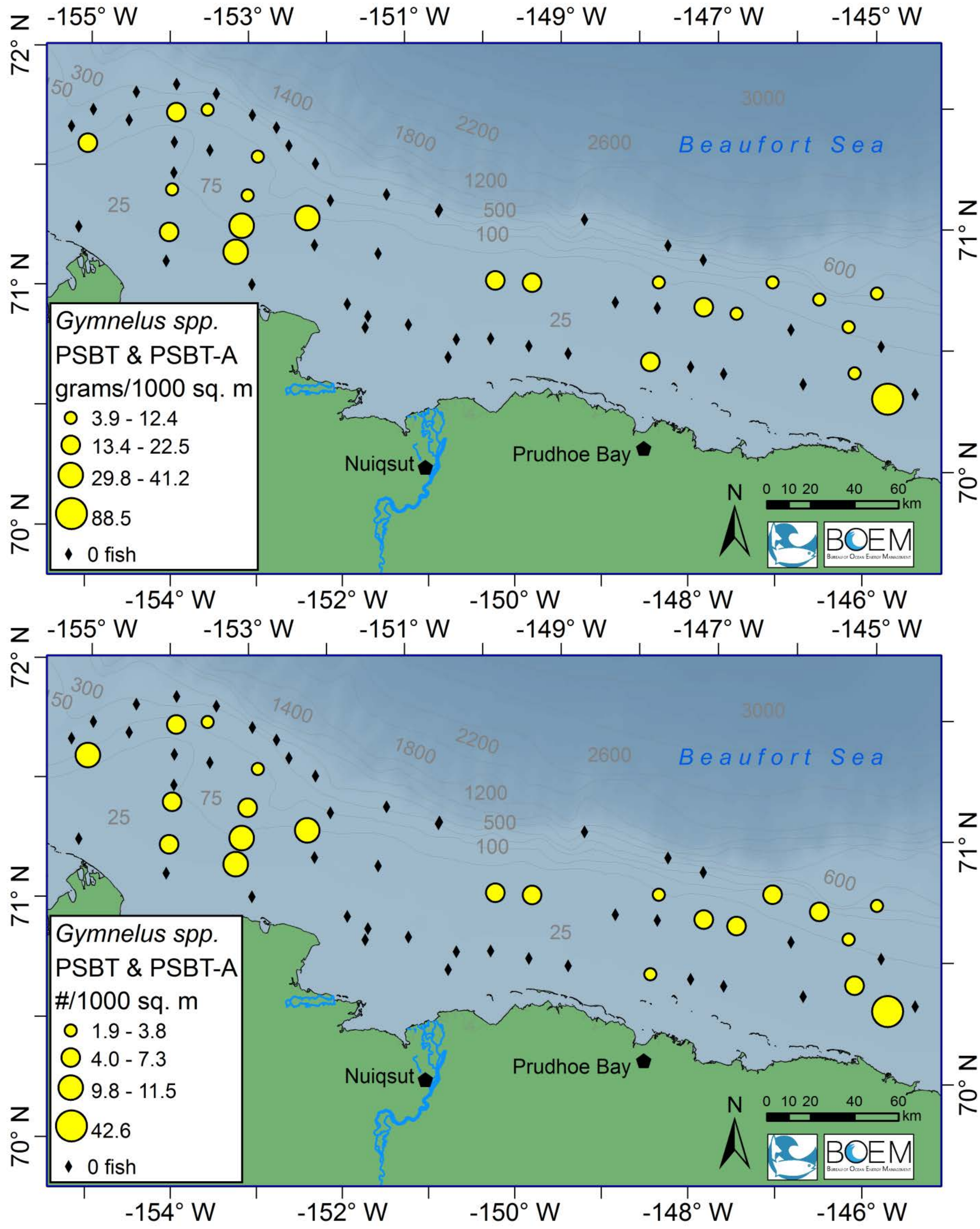


Figure C2.3- 24 Zoarcidae: *Gymnelus* spp. biomass and density in catches by beam trawl during BOEM-2011.

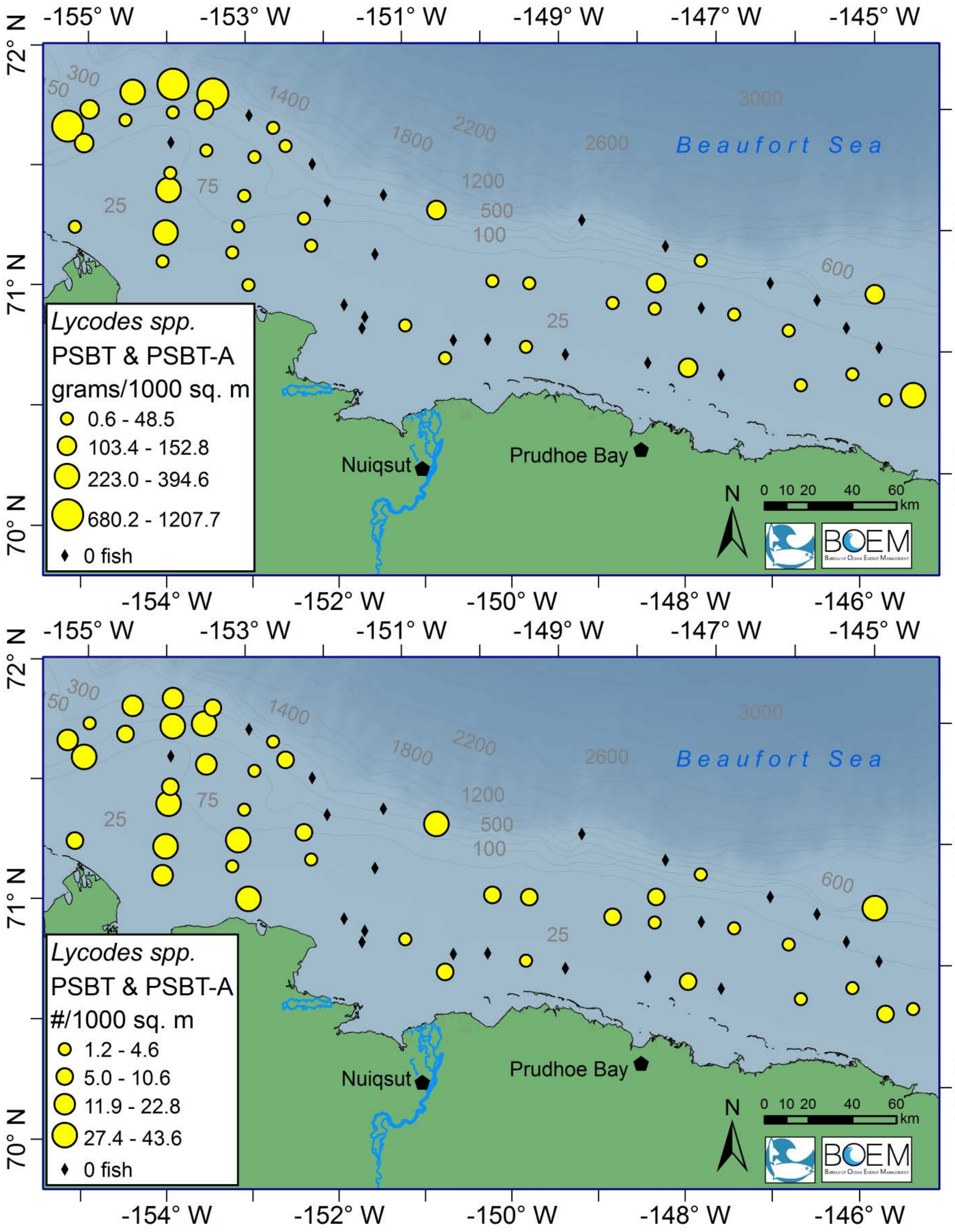


Figure C2.3- 25. Zoarcidae: *Lycodes* spp. biomass and density in catches by beam trawl during BOEM-2011.

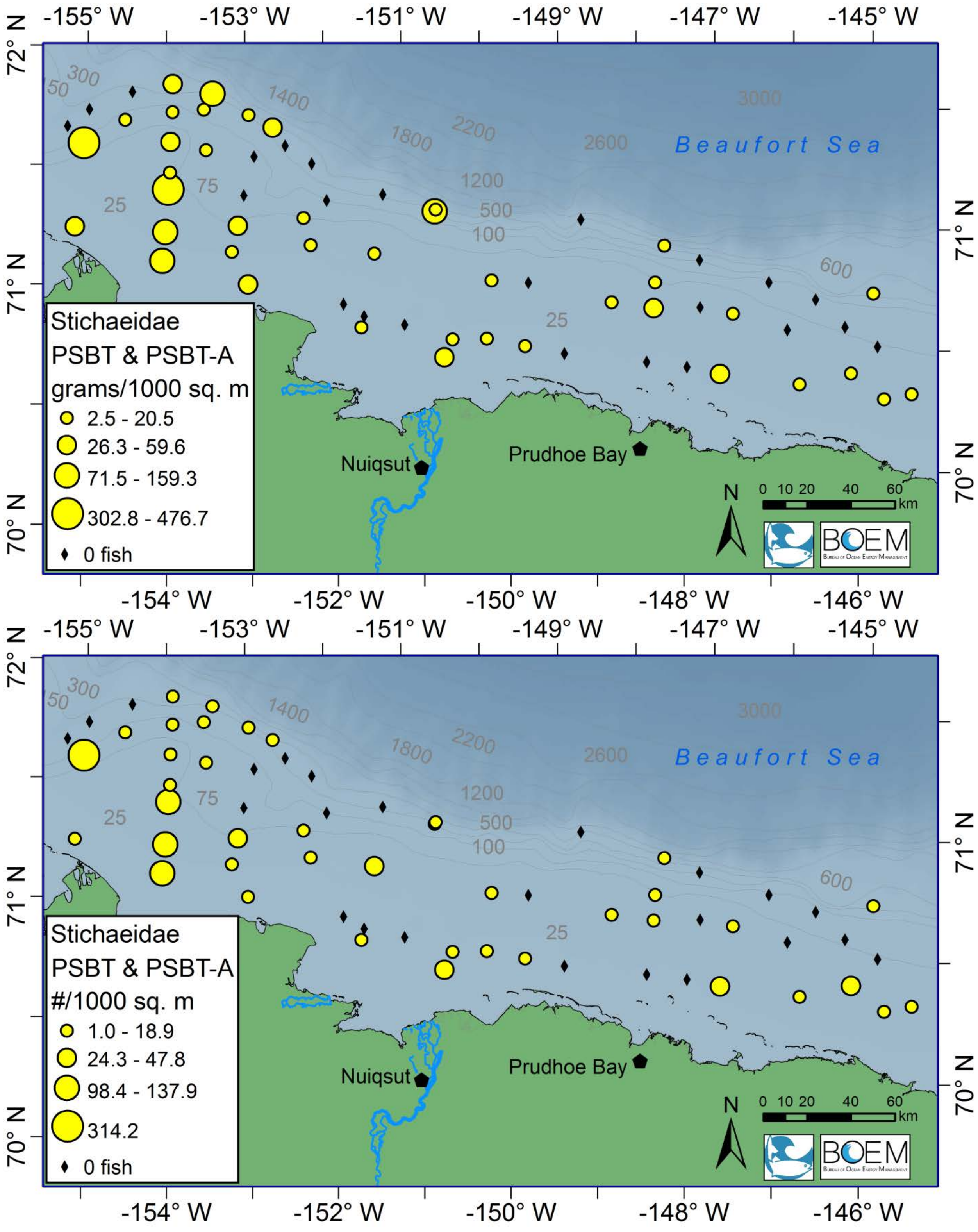


Figure C2.3- 26 Stichaeidae – biomass and density in catches by beam trawl during BOEM-2011.

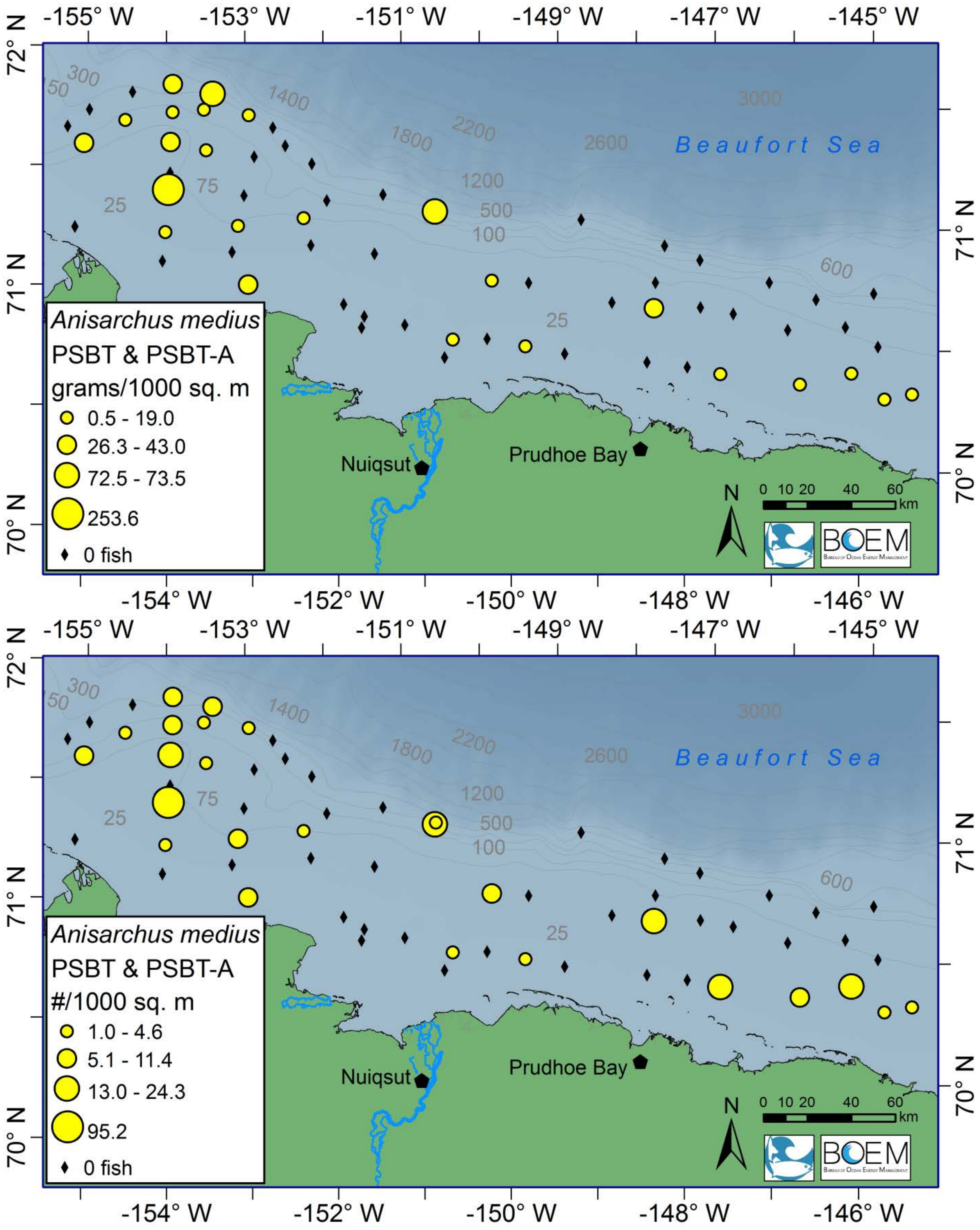


Figure C2.3- 27. Stichaeidae: *Anisarchus medius* biomass and density in catches by beam trawl during BOEM-2011.

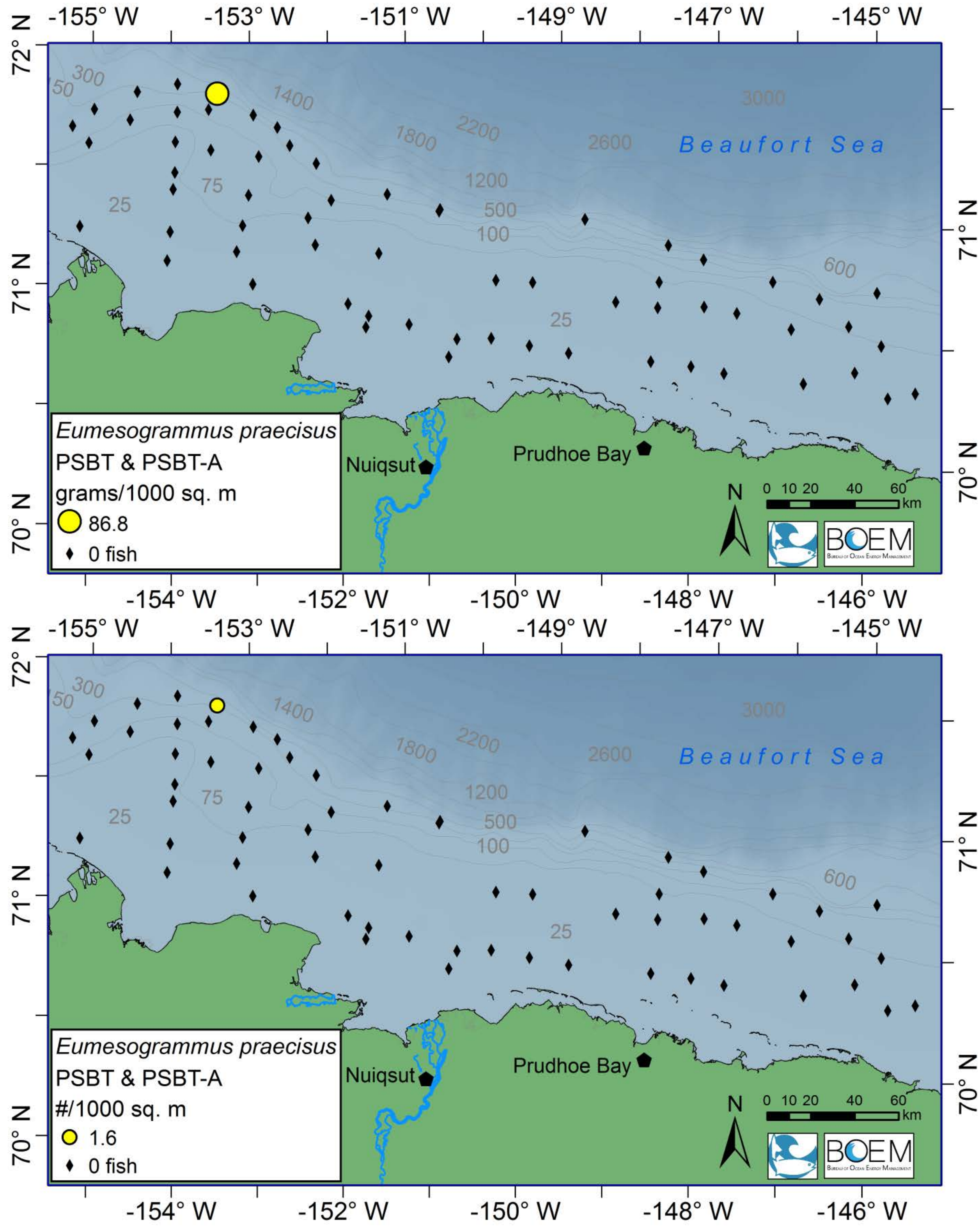


Figure C2.3- 28. Stichaeidae: *Eumesogrammus praecisus* biomass and density in catches by beam trawl during BOEM-2011.

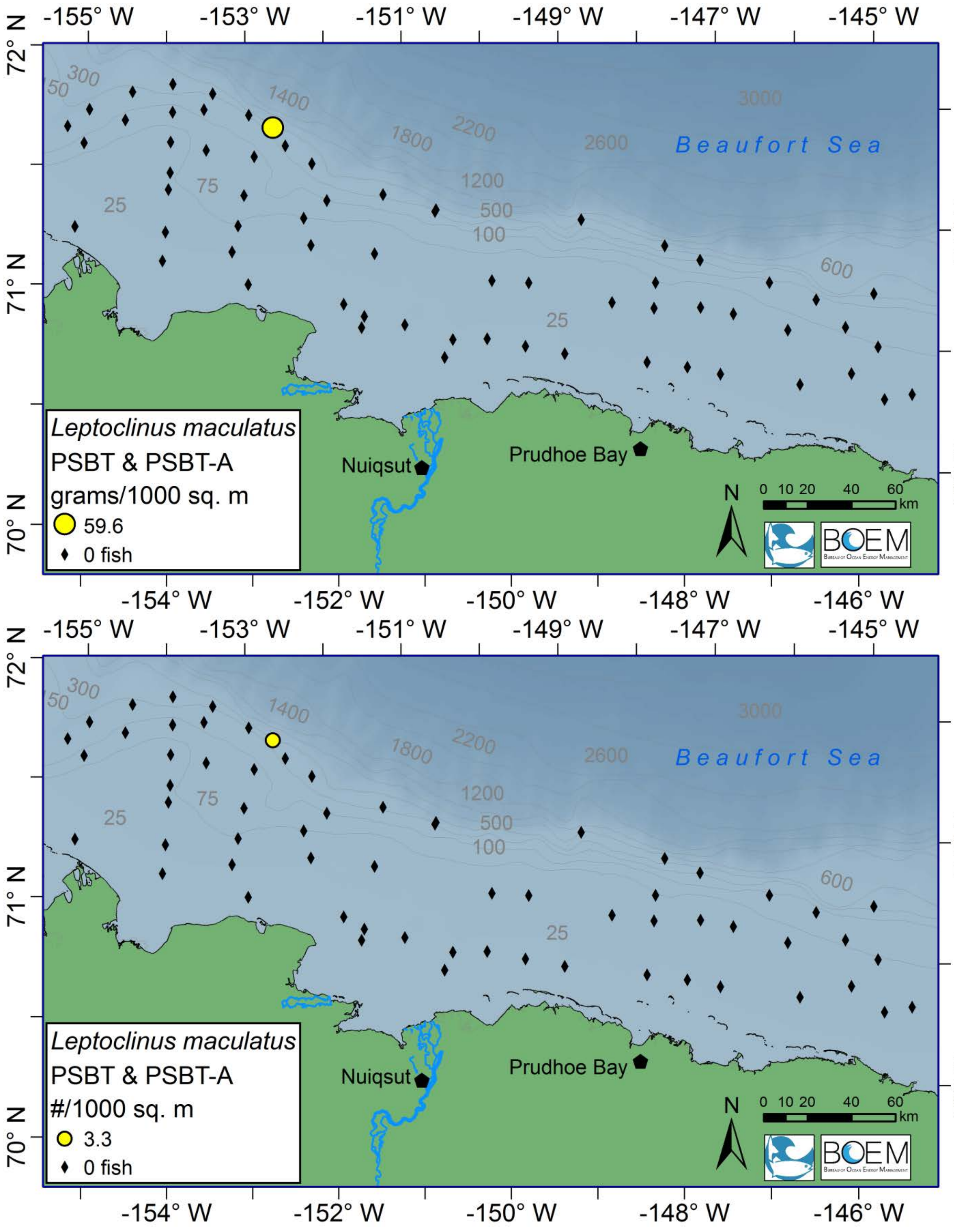


Figure C2.3- 29 Stichaeidae: *Leptoclinus maculatus* biomass and density in catches by beam trawl during BOEM-2011.

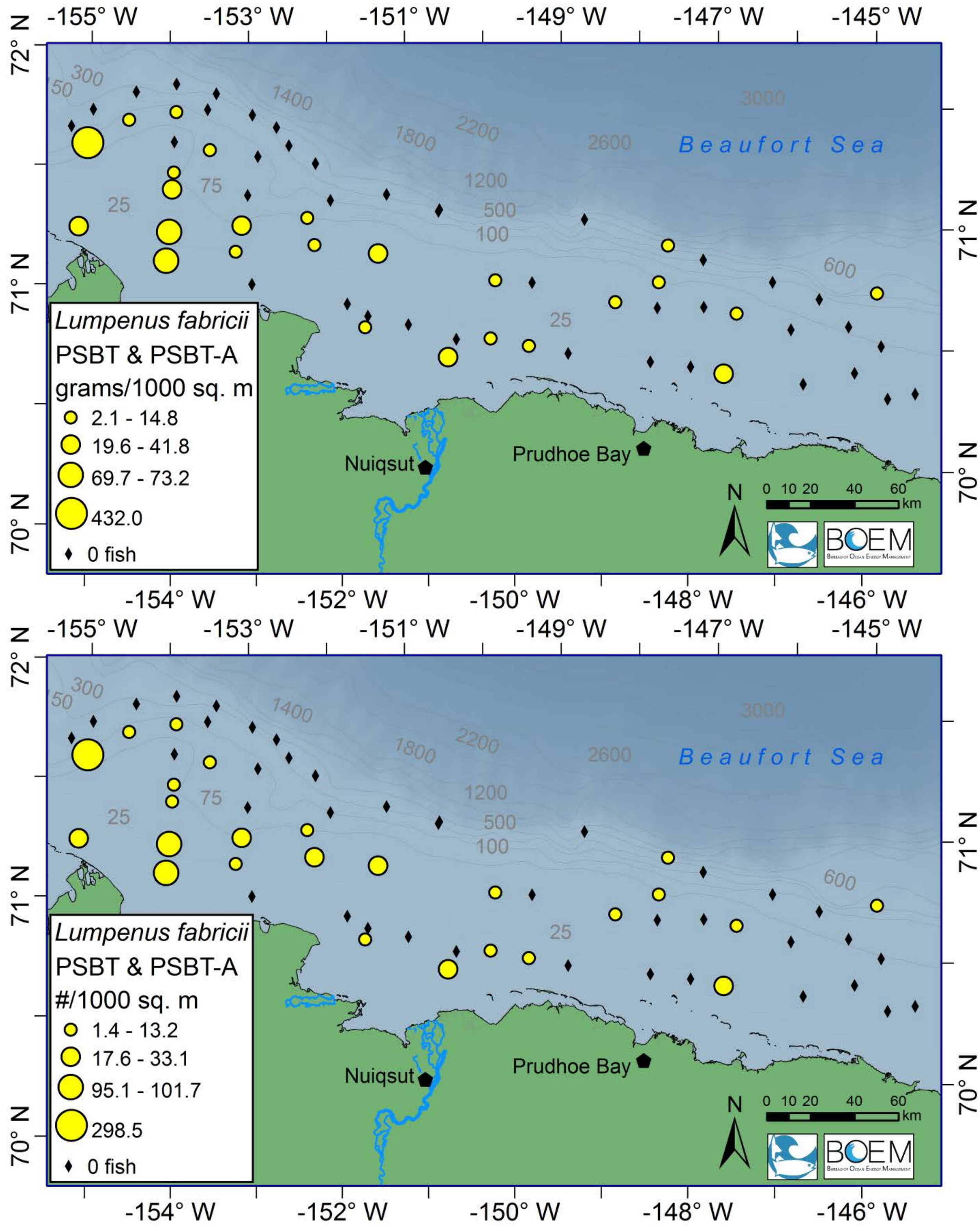


Figure C2.3- 30 Stichaeidae: *Lumpenus fabricii* biomass and density in catches by beam trawl during BOEM-2011.

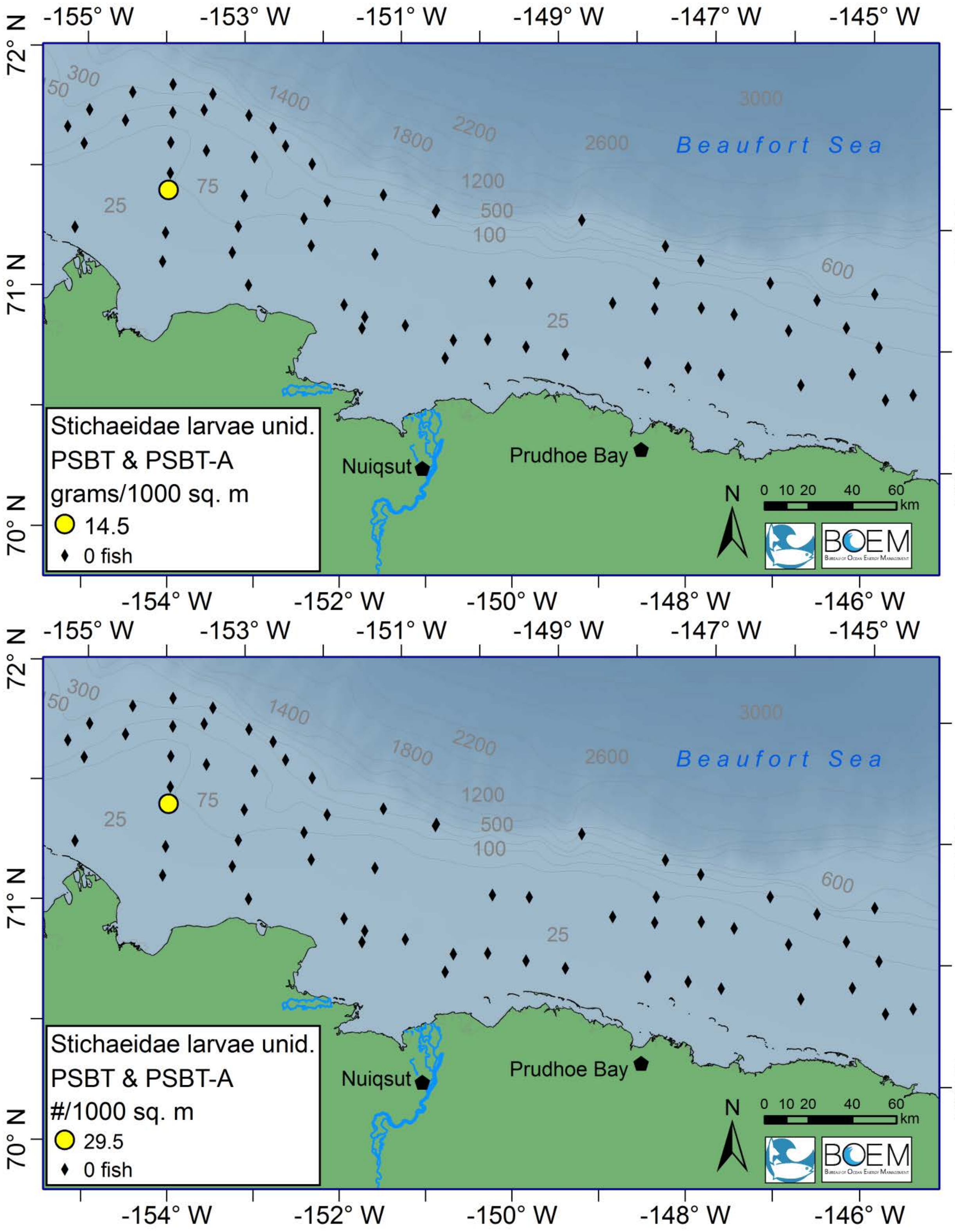


Figure C2.3- 31 Stichaeidae: Unidentified larvae biomass and density in catches by beam trawl during BOEM-2011.

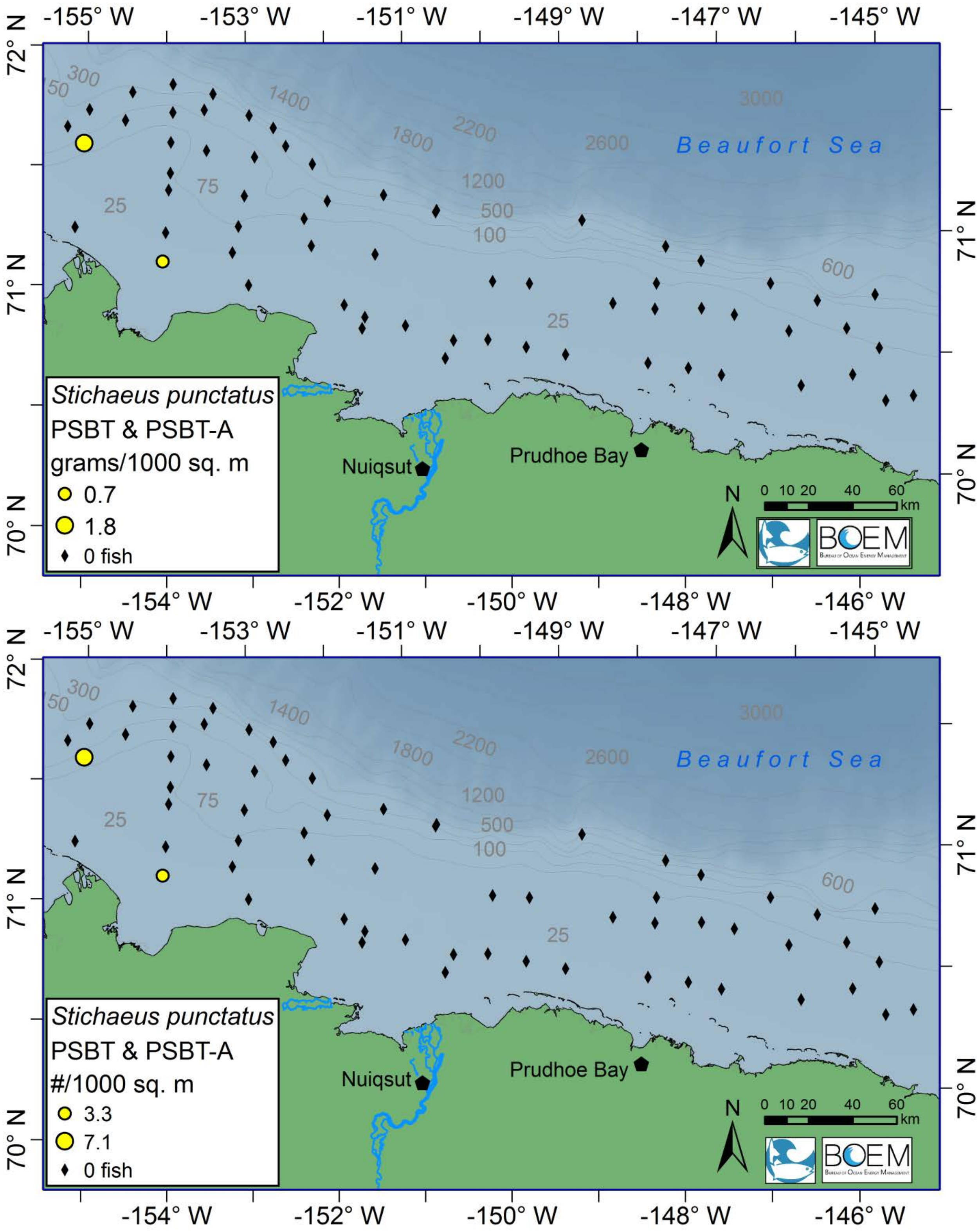


Figure C2.3- 32 Stichaeidae: *Stichaeus punctatu*s biomass and density in catches by beam trawl during BOEM-2011.

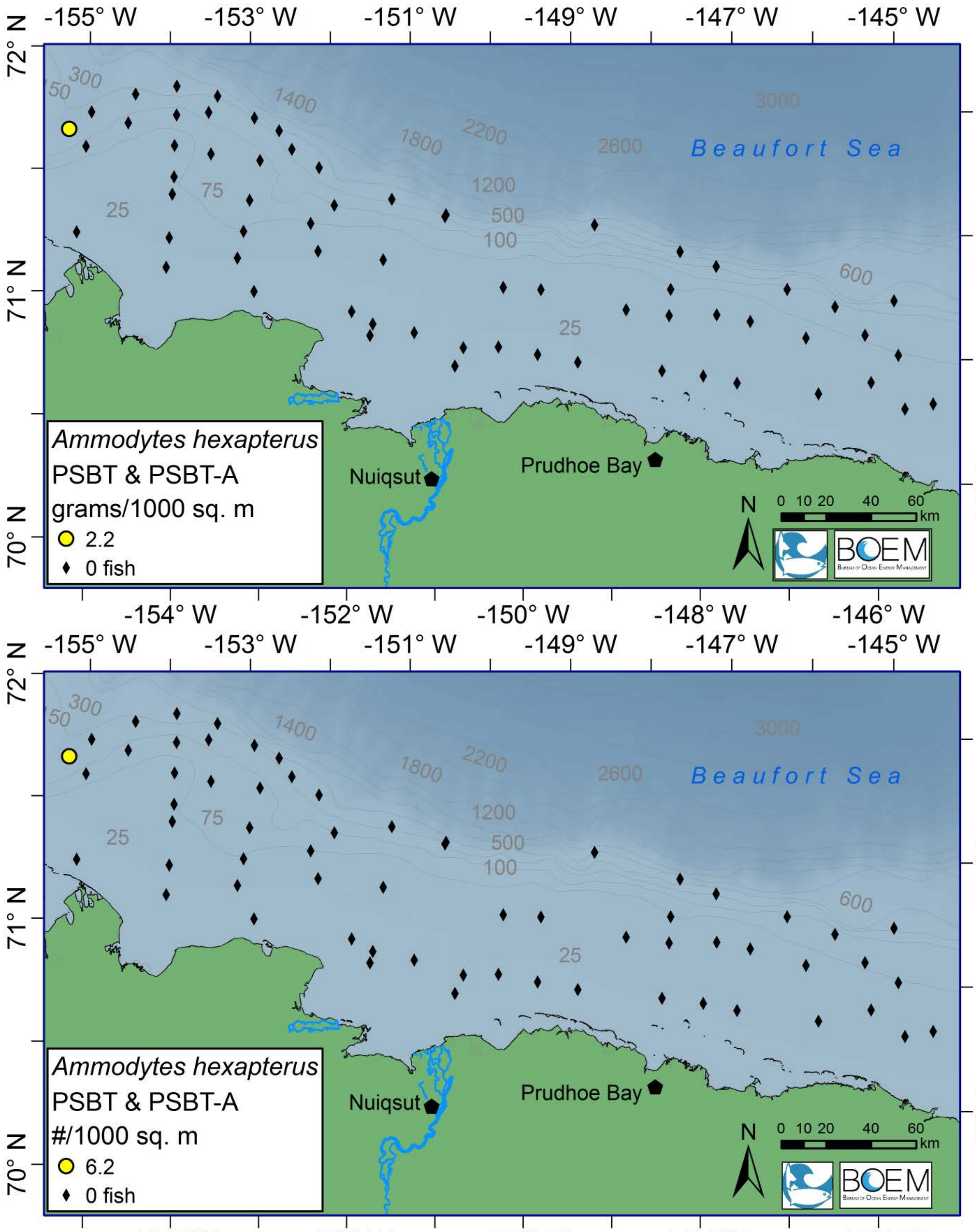


Figure C2.3- 33. Ammodytidae: All were *Ammodytes hexapterus* – biomass and density in catches by beam trawl during BOEM-2011.

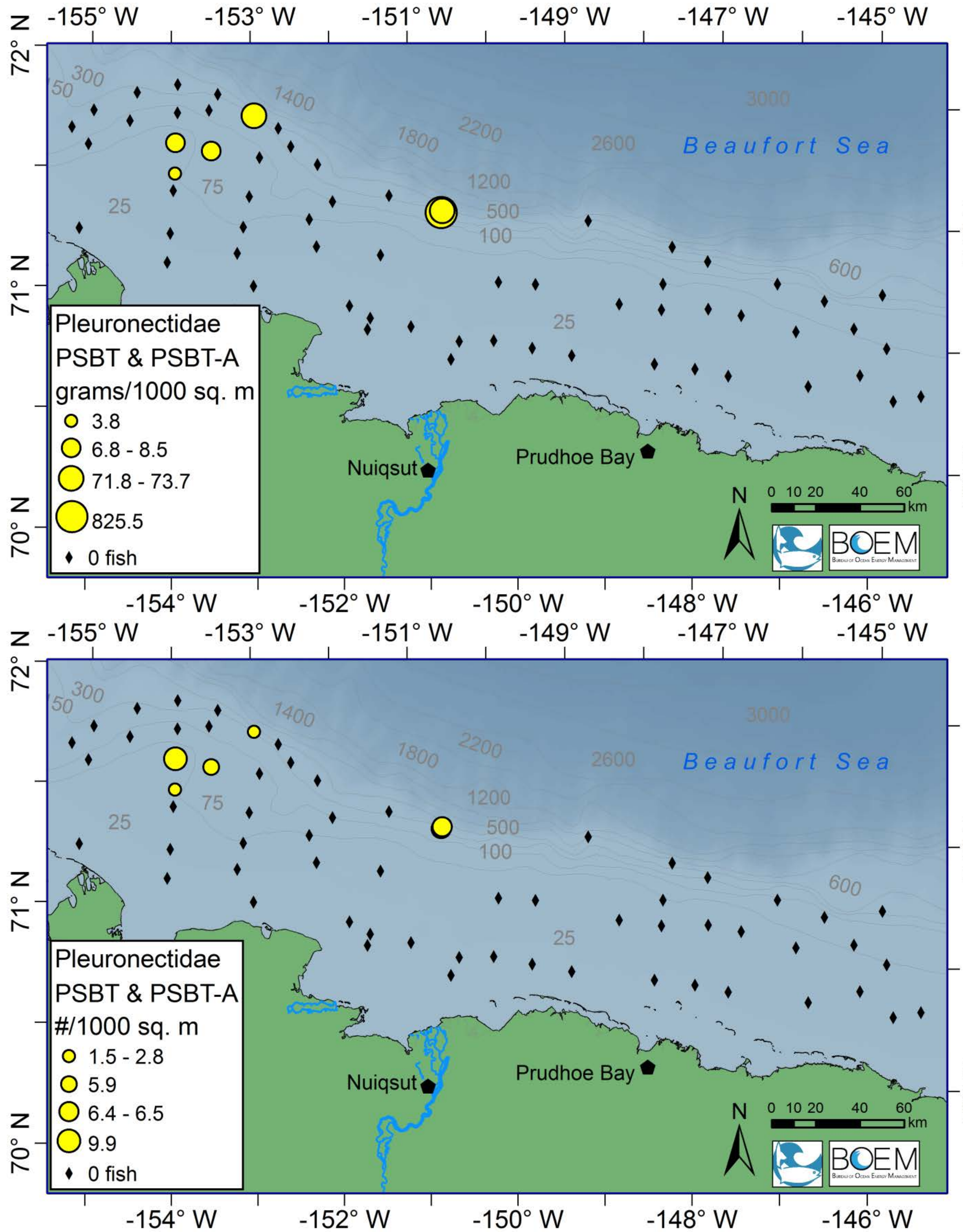


Figure C2.3- 34 Pleuronectidae – biomass and density in catches by beam trawl during BOEM-2011.

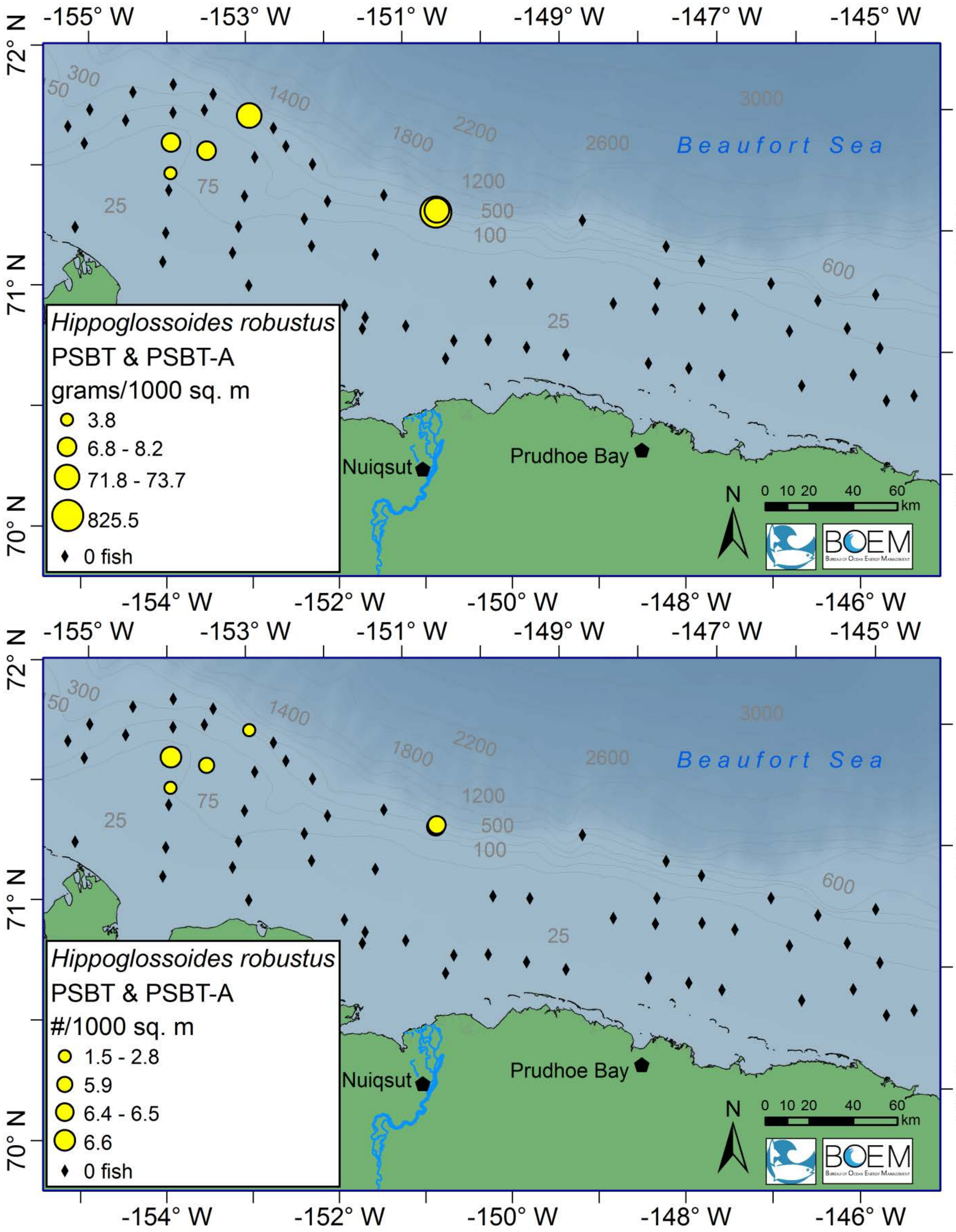


Figure C2.3- 35 Pleuronectidae: *Hippoglossus robustus* biomass and density in catches by beam trawl during BOEM-2011.

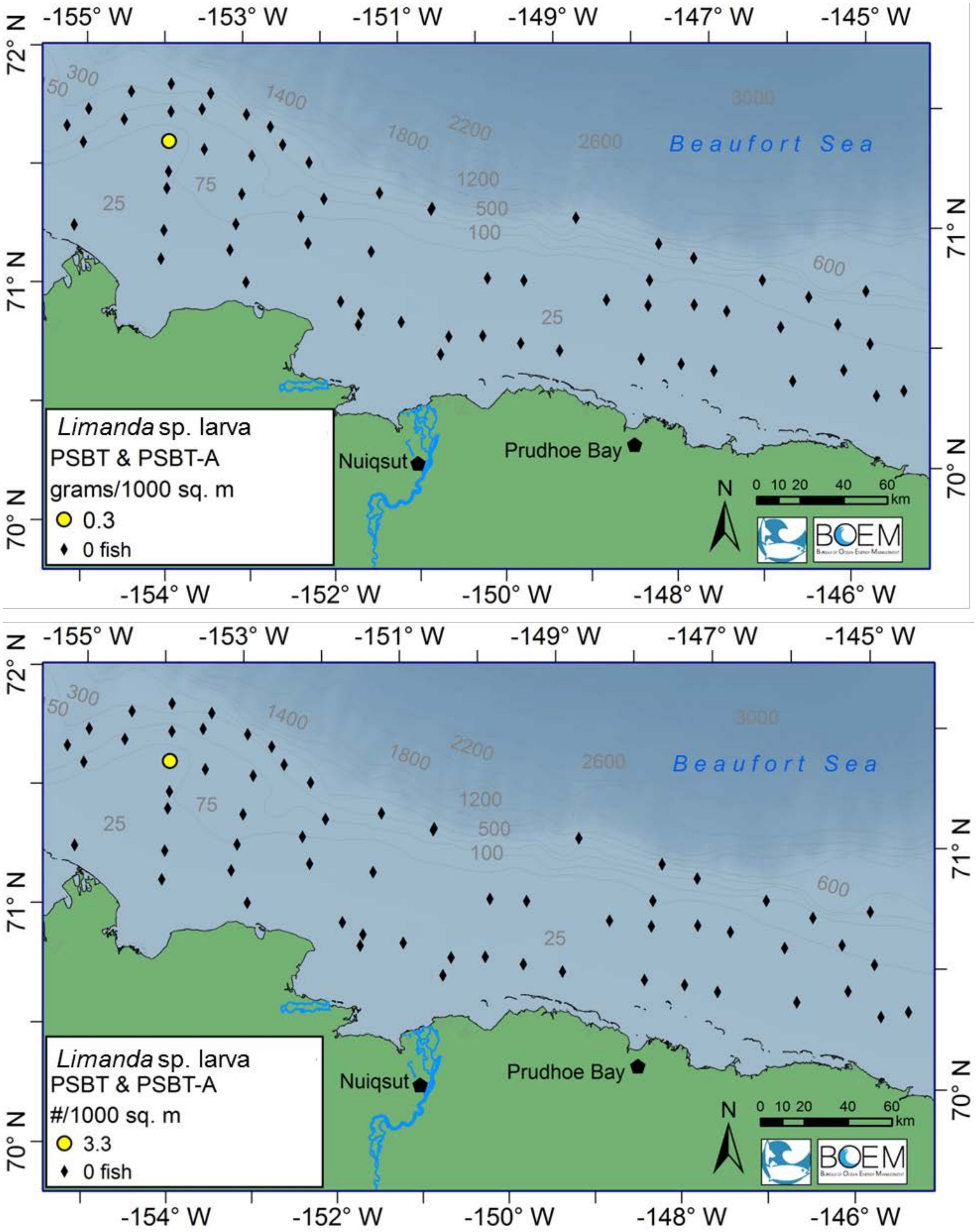


Figure C2.3- 36. Pleuronectidae: *Limanda* sp. biomass and density in catches by beam trawl during BOEM-2011.

APPENDIX C3. DATA FIGURES SUPPLEMENTAL TO "CHAPTER 4.1. LENGTH-WEIGHT-AGE RELATIONSHIPS OF DEMERSAL FISHES IN THE BEAUFORT SEA"

Appendix C3 is information additional to that presented in **Chapter 4.1** of this report. Images of weight-at-length and age-at-length regressions are presented in this Appendix for each of the ten species for which length, weight, and age were analyzed (**Figures C3-1 through C3-10**). Species include Gadidae: *Boreogadus saida*, *Eleginus gracilis*; Cottidae: *Gymnocanthus tricuspis, Myoxocephalus scorpius*; Agonidae: *Aspidophoroides olrikii;* Liparidae: *Liparis fabricii*; Zoarcidae: *Lycodes polaris;* Stichaeidae: *Anisarchus medius, Lumpenus fabricii*; and Pleuronectidae: *Hippoglossoides robustus*.

Statistical and graphic analyses were performed using SigmaPlot 12.5 (Systat Software 2013). To exert control over the quality of the data, for each species an initial length-weight relationship was estimated by polynomial linear regression using the standard fisheries allometric equation (Ricker 1975) as $W = a\ L^{b}$, where W = total weight (g), L = total length (mm), a = the y-intercept and b = the slope. After removing points >3 standard deviations from the mean of the initial data, one scatter-plot of weight versus length and another of age versus length were graphed with revised equations and are presented in this appendix (**Figures C3-1 through C3-10**).

REFERENCE

Ricker WE (1975) Computation and interpretation of biological statistics of fish populations. Bulletin Fisheries Research Board Canada 191:1–382

Systat Software, Inc. (2013) SigmaPlot for Windows, version 12.5

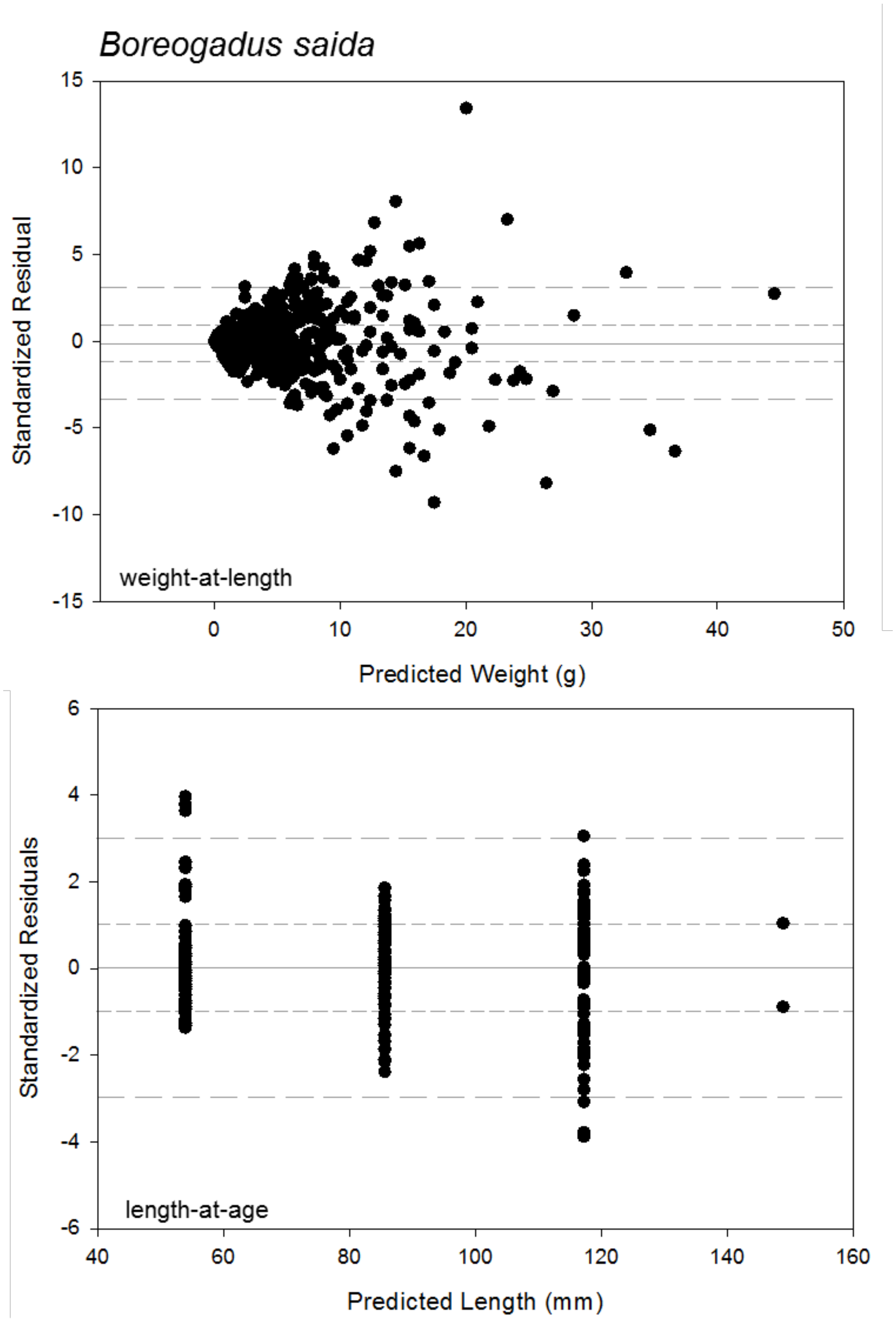


Figure C3-1. Gadidae, *Boreogadus saida*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

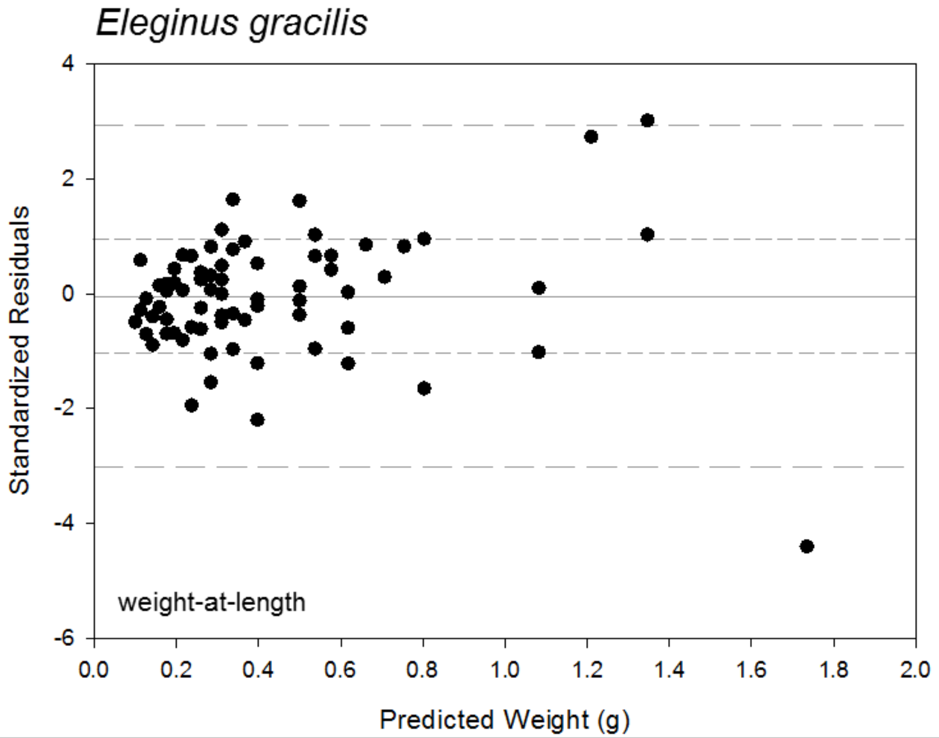


Figure C3-2. Gadidae, *Eleginus gracilis*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

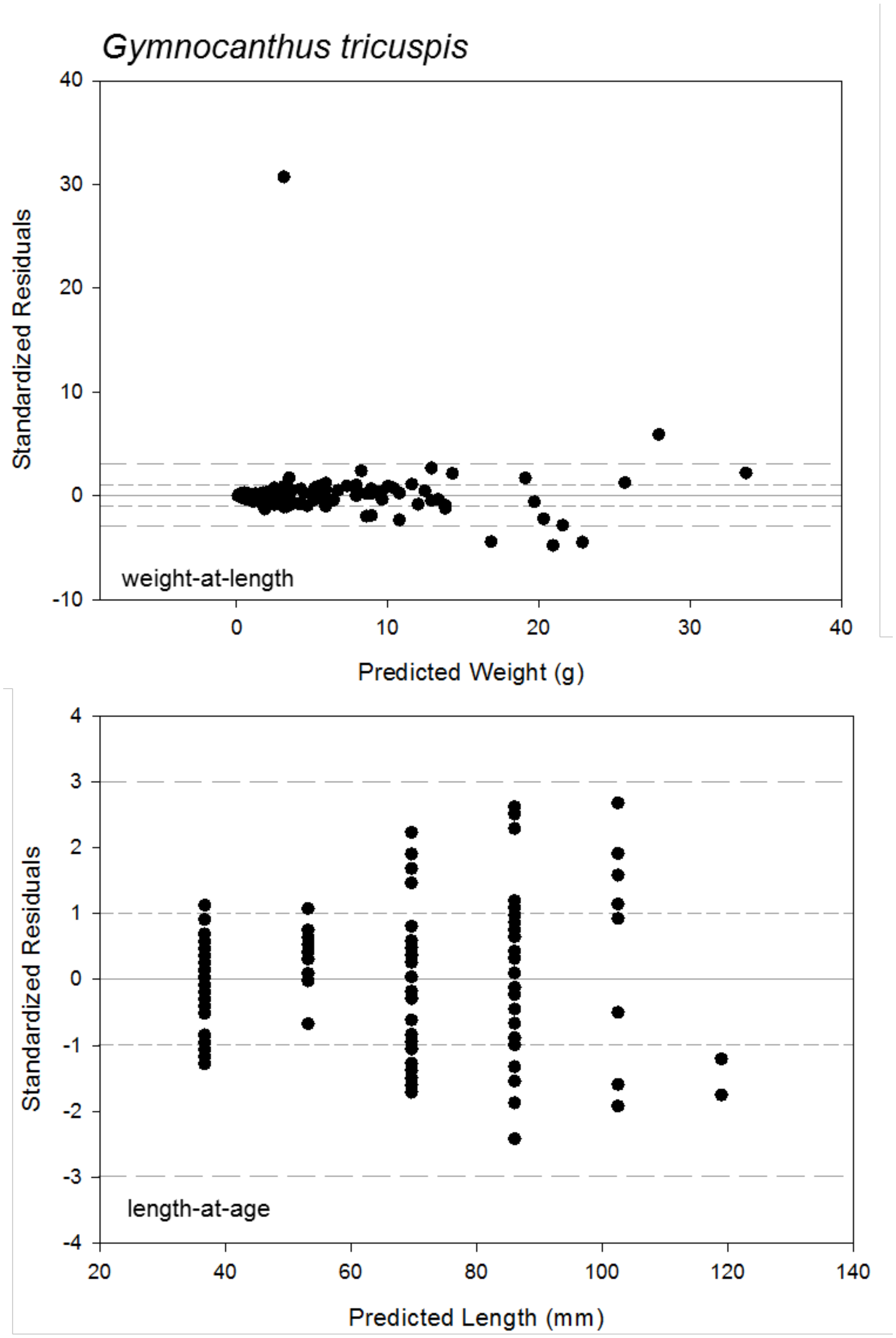


Figure C3-3. Cottidae, *Gymnocanthus tricuspis*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

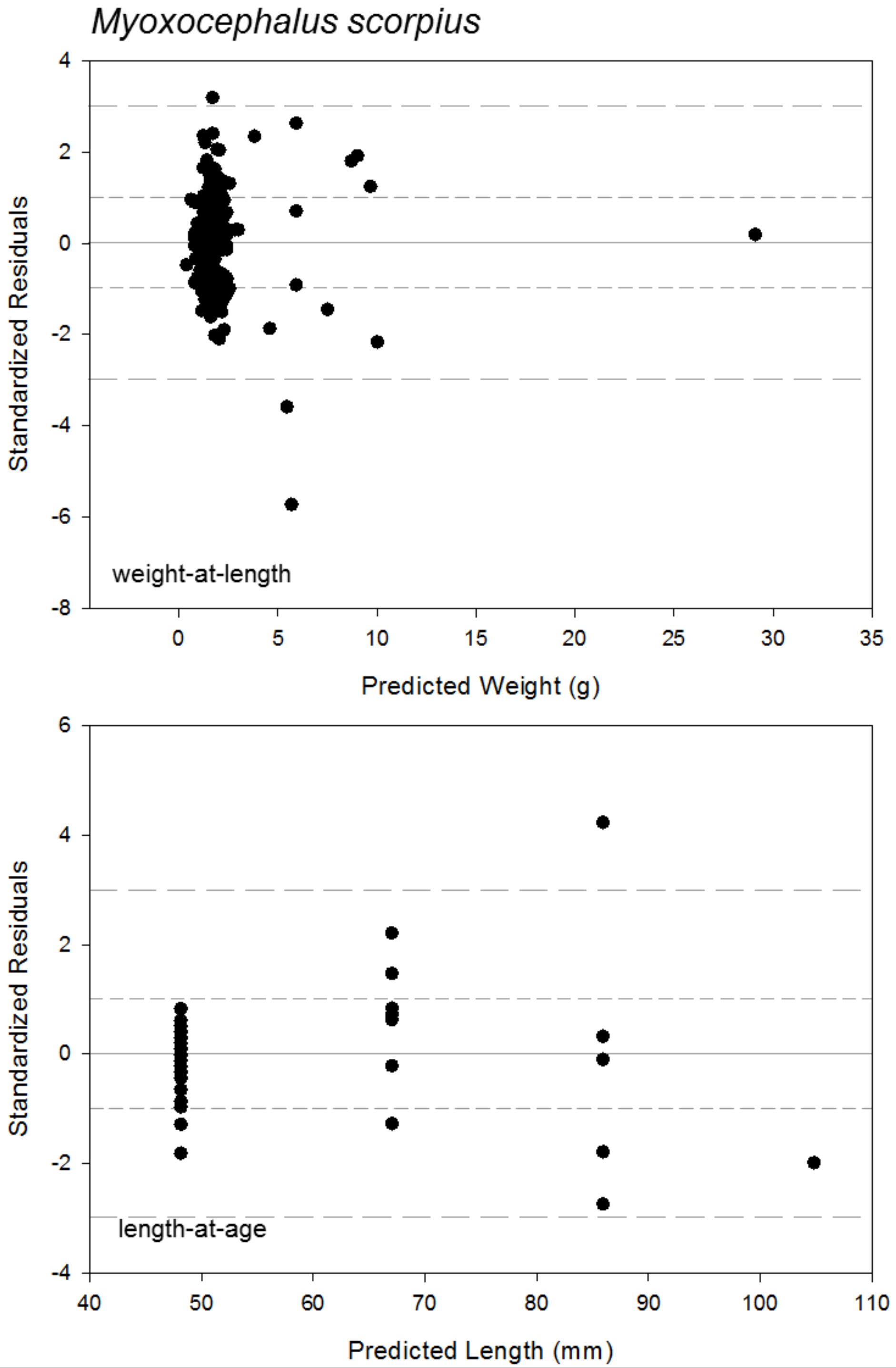


Figure C3-4. Cottidae, *Myoxocephalus scorpius*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

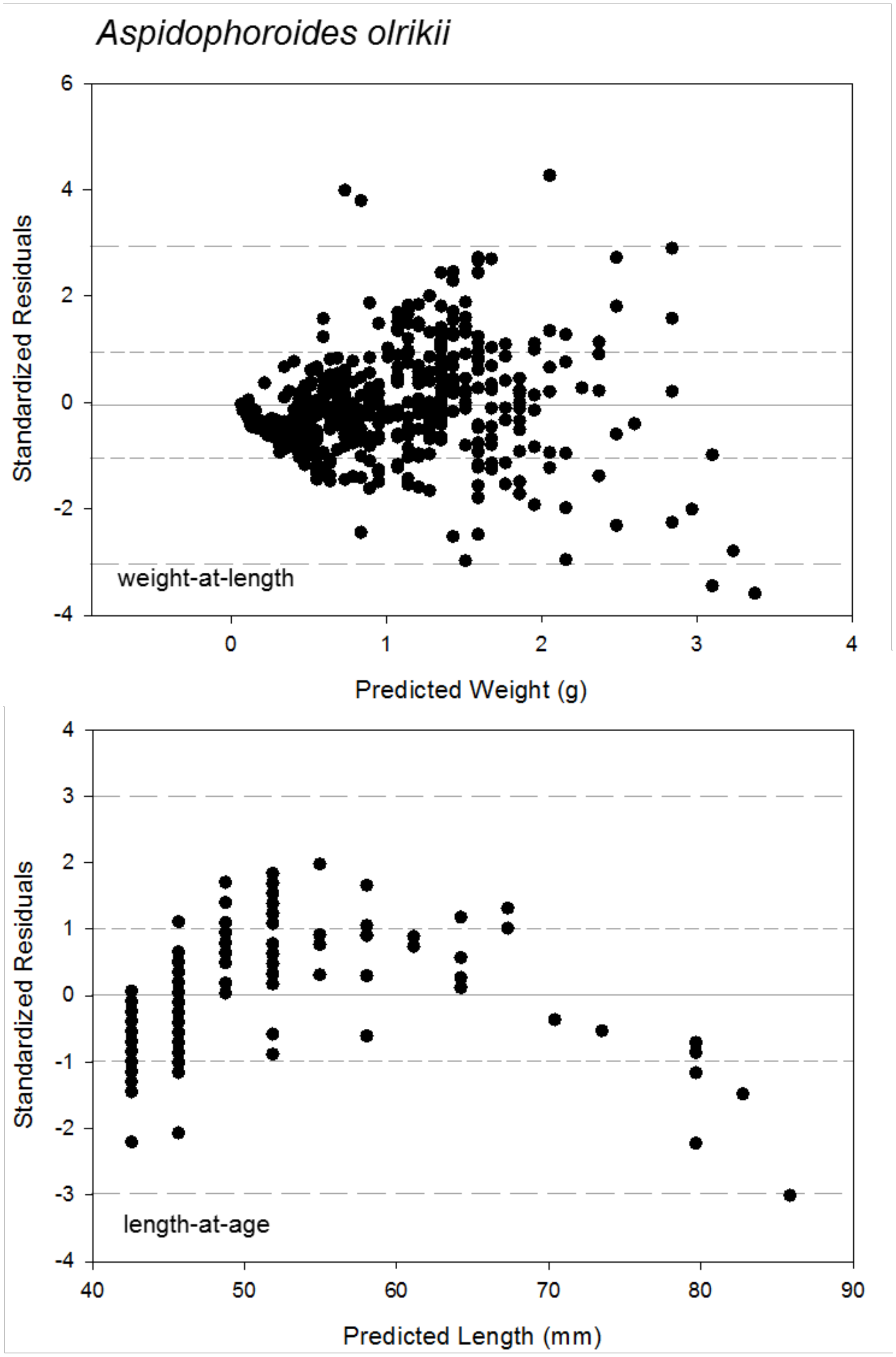


Figure C3-5. Agonidae, *Aspidophoroides olrikii*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

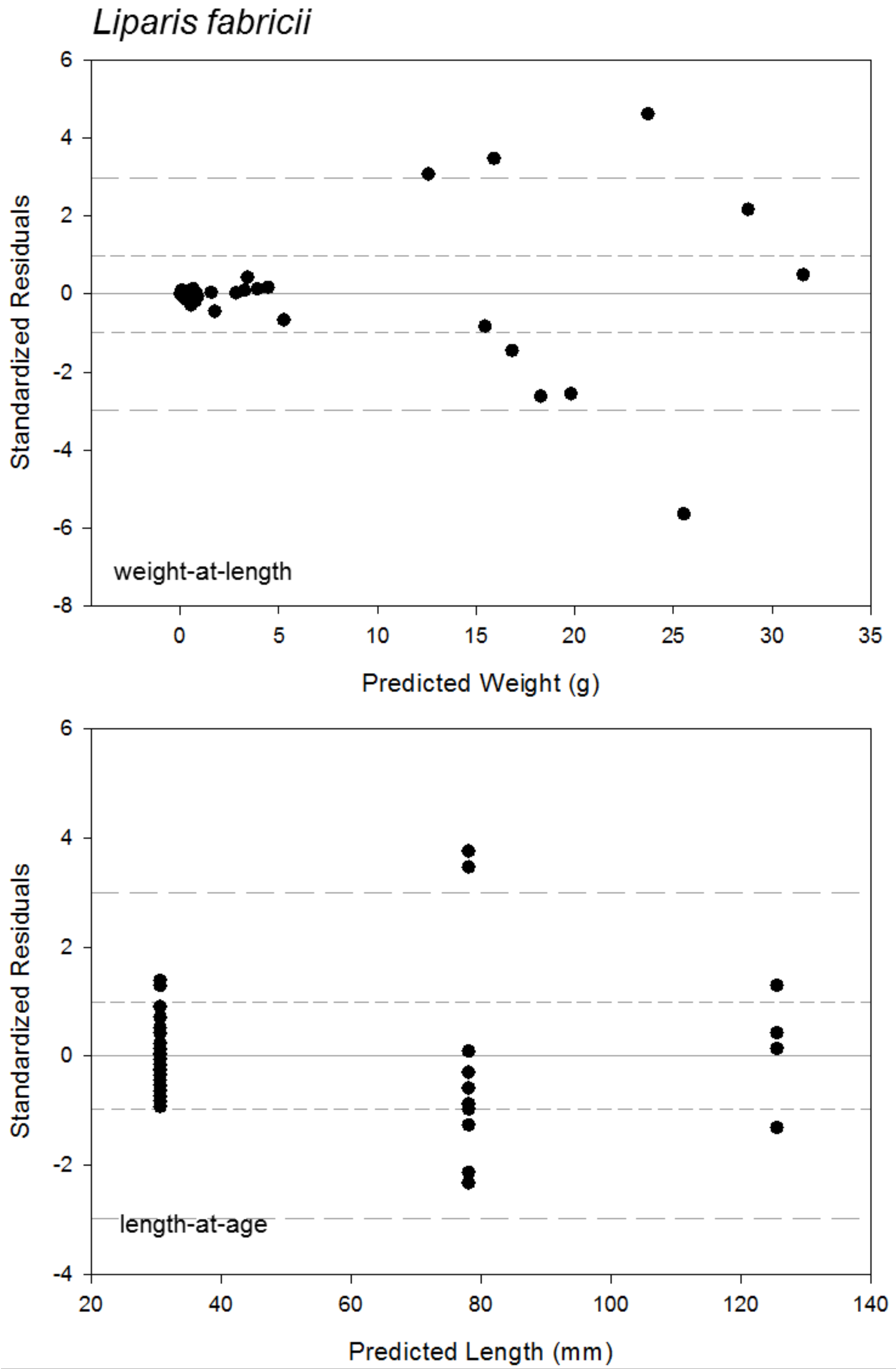


Figure C3-6. Liparidae, *Liparis fabricii*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

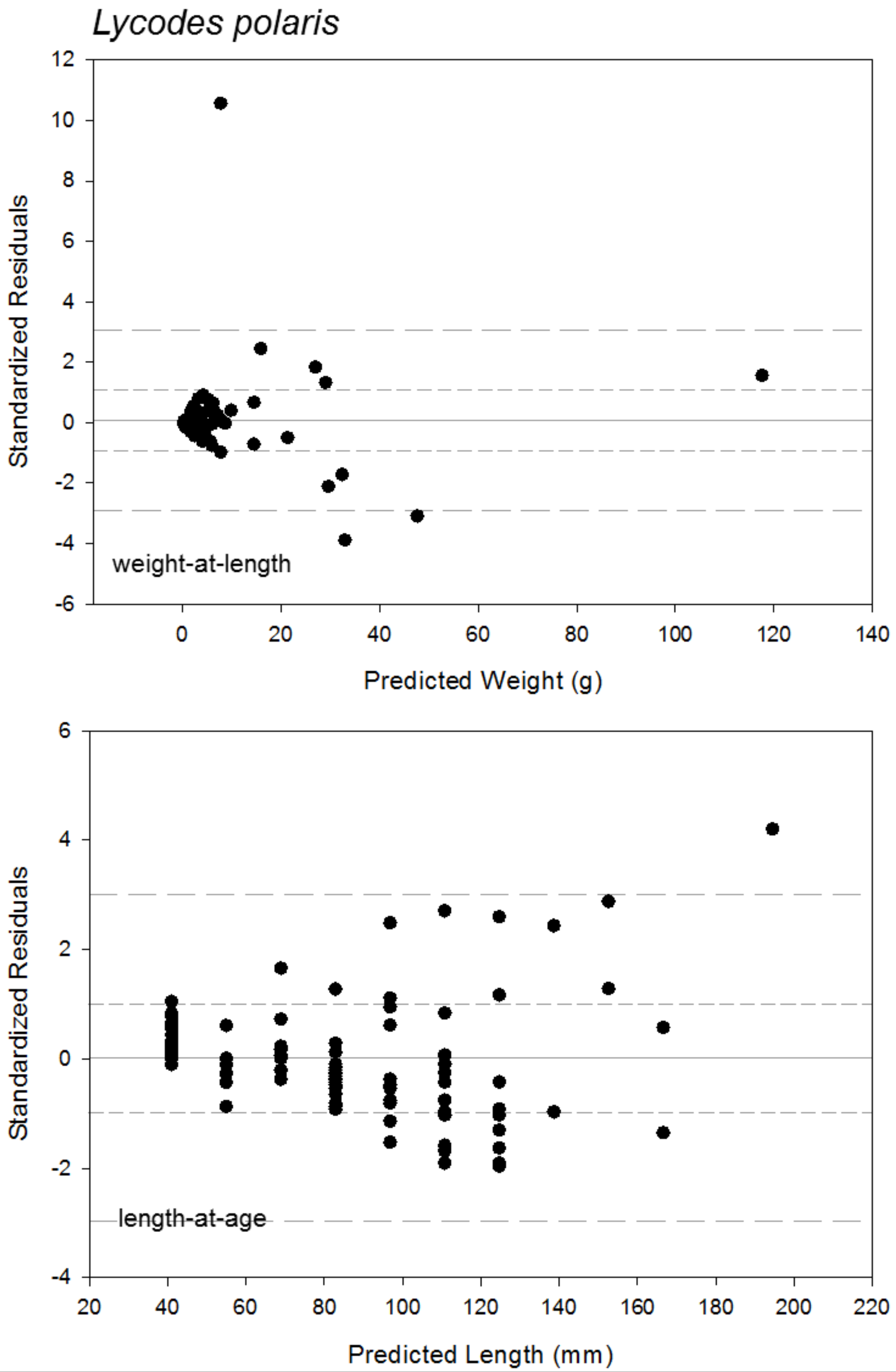


Figure C3-7. Zoarcidae, *Lycodes polaris*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

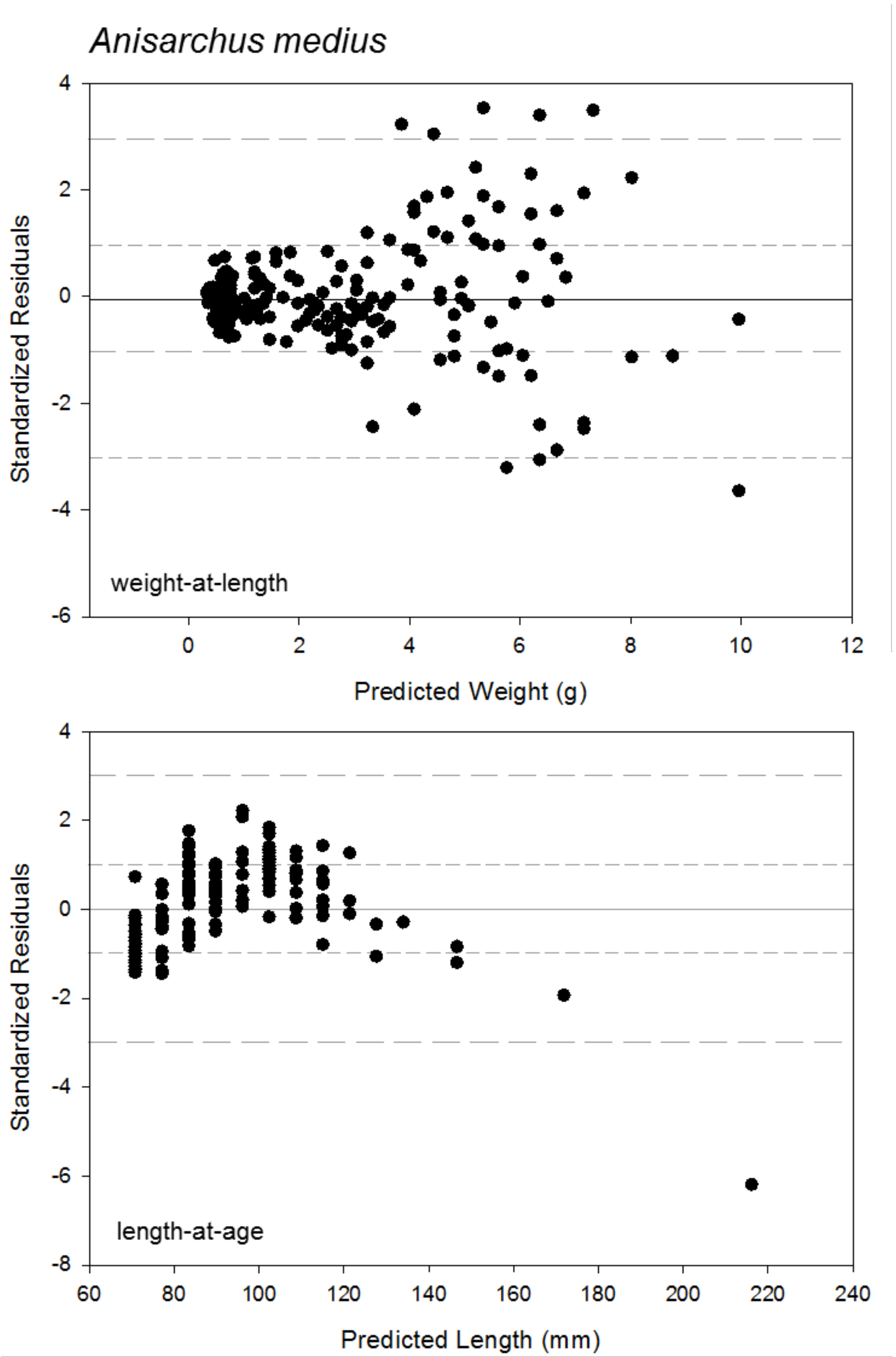


Figure C3-8. Stichaeidae, *Anisarchus medius*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

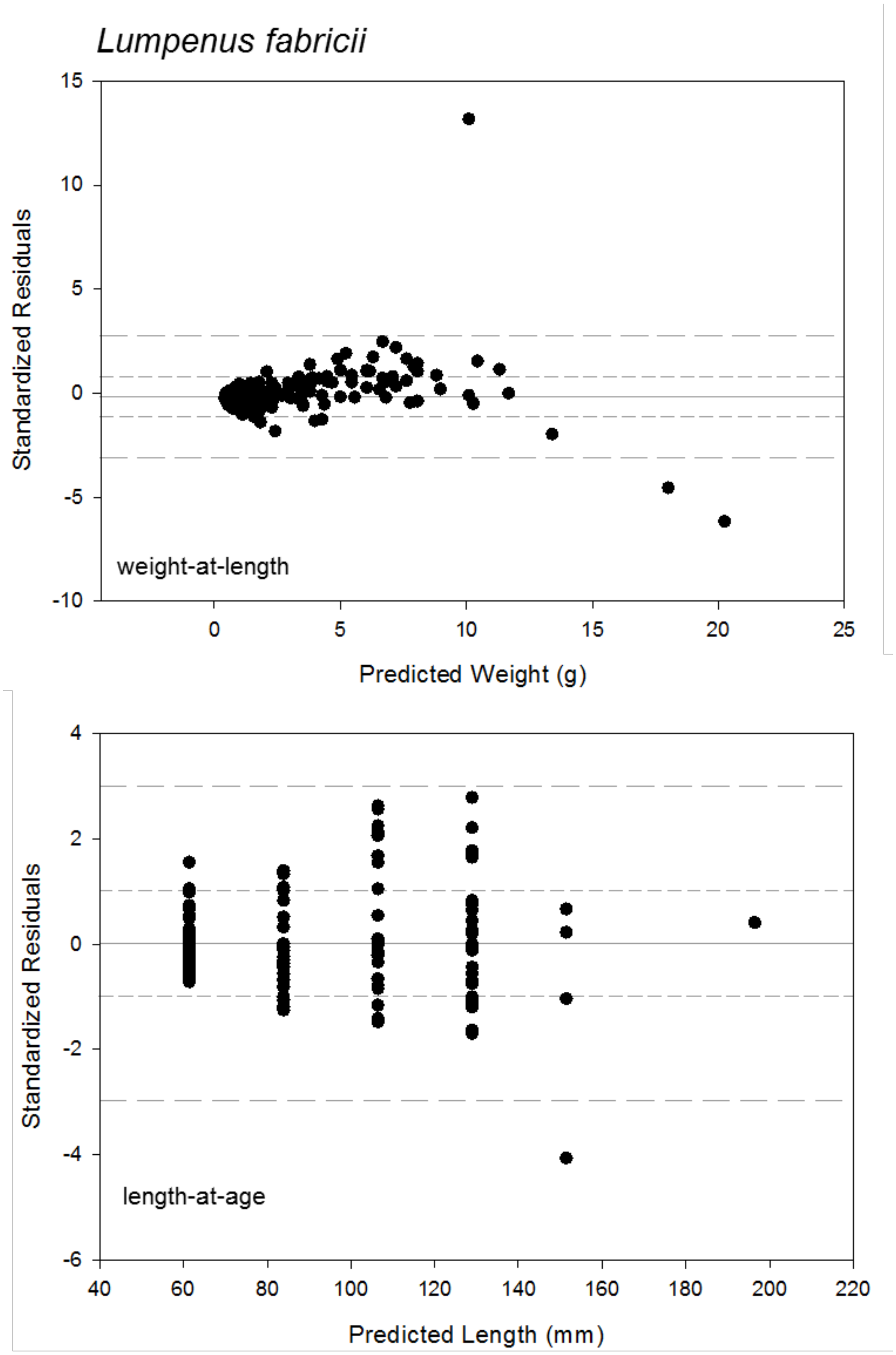


Figure C3-9. Stichaeidae, *Lumpenus fabricii*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

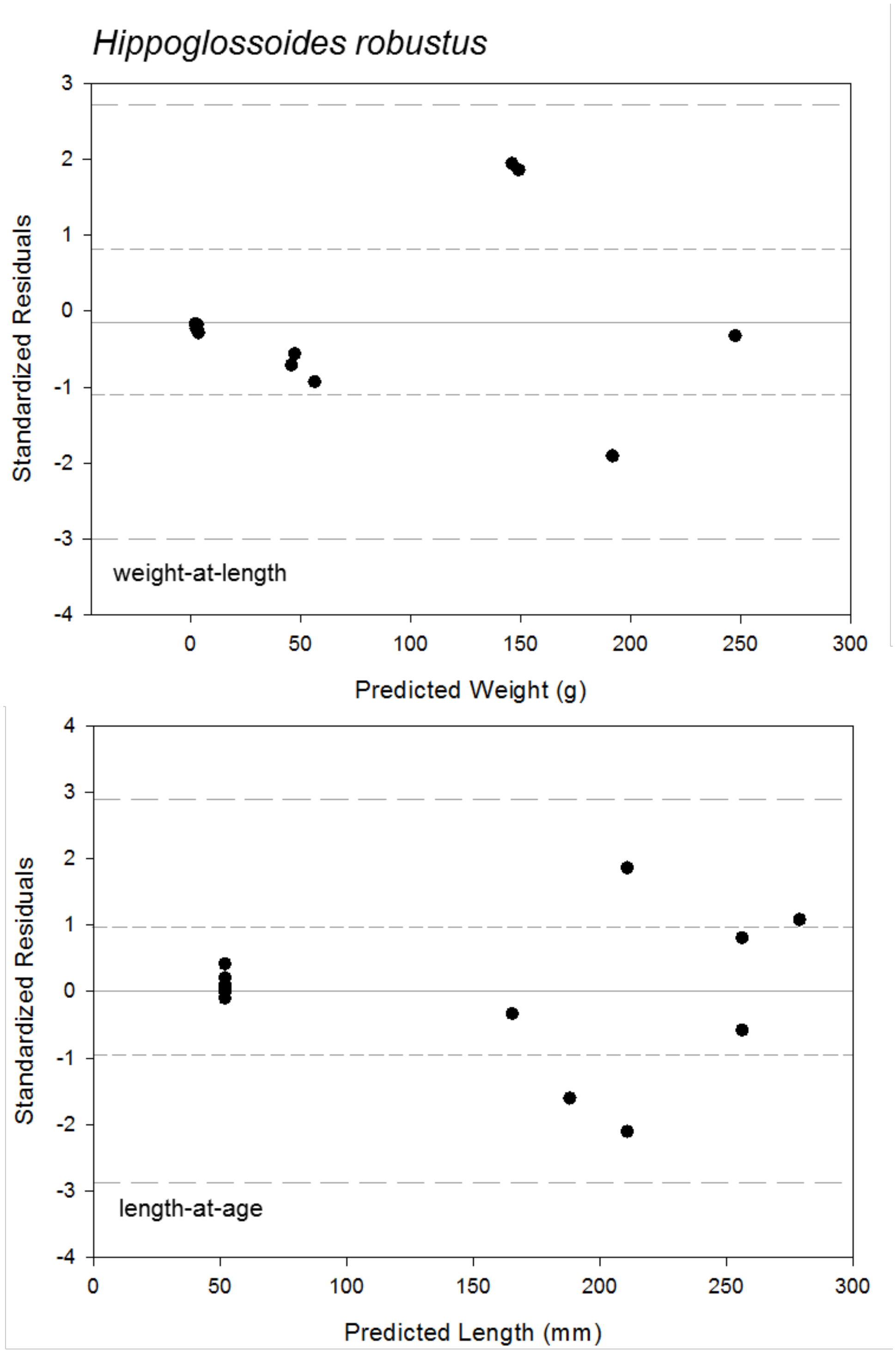


Figure C3-10. Pleuronectidae, *Hippoglossoides robustus*: Standardized residuals of weight-at-length and length-at-age regressions from fish collected during BOEM-2011.

APPENDIX C4. DATA TABLES SUPPLEMENTARY TO “CHAPTER 3.2 FISH DIETS ACROSS THE CHUKCHI AND BEAUFORT SEAS”

Table C4- 1 List of identified prey taxa, by predator species and region.

	Arctic Cod				**Arctic Staghorn Sculpin**				**Shorthorn Sculpin**			
Prey taxonomy list	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**
Benthic amphipods	x	x	x	x	x	x	x	x	x	x	x	x
Ampeliscidae		x		x	x	x	x	x	x	x		
Ampelisca spp.		x		x	x				x	x		
Ampelisca eschrichti						x						
Ampelisca macrocephala		x			x	x				x		
Byblis spp.		x				x						
Byblis frigidus						x						
Haploops spp.								x				
Ampithoidae						x			x			
Ampithoe spp.						x			x			
Atylidae		x				x				x		
Atylus collingi		x				x				x		
Corophiidae		x			x	x	x	x	x	x		
Corophium spp.					x							
Pontoporeia spp.						x						
Protomedeia spp.		x			x	x	x	x	x	x		
Epimeriidae										x		
Paramphithoe spp.										x		
Eusiridae						x			x	x		
Rhachotropis spp.						x			x	x		
Isaeidae								x				x
Ischyroceridae				x	x	x	x		x	x		
Ericthonius spp.				x	x	x			x	x		
Ischyrocerus spp.						x	x		x	x		
Lysianassidae	x				x	x				x		
Orchomene spp.	x				x	x				x		
Maeridae	x					x			x	x		
Maera spp.	x					x			x	x		
Melitidae	x	x			x	x	x	x	x	x	x	x
Melita spp.	x	x			x	x	x	x	x	x	x	x
Oedicerotidae	x	x		x	x	x	x	x	x	x	x	x
Acanthostepheia spp.						x	x	x	x		x	x

Table C4- 1 List of identified prey taxa (continued).

	Arctic Cod				**Arctic Staghorn Sculpin**				**Shorthorn Sculpin**			
Prey taxonomy list	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**
Acanthostepheia behringiensis						x						
Acanthostepheia malmgreni						x						
Aceroides spp.	x	x			x	x	x		x	x		
Bathymedon spp.		x										
Monoculoides spp.	x	x		x	x			x		x		x
Oediceros spp.		x			x				x			
Paroediceros spp.						x	x					x
Westwoodilla spp.									x			
Photidae					x	x				x		
Photis spp.					x	x				x		
Phoxocephalidae					x	x				x		
Grandifoxus spp.						x				x		
Harpina spp.					x	x						
Paraphoxus spp.						x				x		
Pleustidae										x		
Pleustes spp.										x		
Pontogeneiidae						x	x					
Pontogeneia spp.						x	x					
Stenothoidae	x				x				x			
Metopa spp.	x				x				x			
Synopiidae						x				x		
Syrrhoe spp.						x				x		
Uristidae				x	x	x	x	x	x	x		
Anonyx spp.				x	x	x	x	x	x	x		
Onisimus spp.					x							
Caprellid amphipod					x	x			x	x		
Calanoid copepods	x	x	x	x	x			x	x	x		x
Acartiidae	x											
Acartia longiremis	x											
Aetideidae			x	x								
Centropagidae	x				x							
Centropages abdominalis	x				x							
Metridinidae	x	x	x	x	x							
Metridia longa	x	x	x	x	x							
Metridia pacifica	x		x									
Euchaetidae		x	x	x								x
Euchaeta spp.		x	x	x								x
Paraeuchaeta norvegica			x	x								
Heterohabdidae		x		x								

Table C4- 1 List of identified prey taxa (continued).

	Arctic Cod				**Arctic Staghorn Sculpin**				**Shorthorn Sculpin**			
Prey taxonomy list	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**
Calanidae	x	x	x	x	x	x			x	x	x	x
Calanus glacialis	x	x	x	x	x	x			x	x	x	x
Calanus hyperboreus		x	x	x				x				x
Neocalanus spp.	x	x								x		
Clausocalanidae	x	x	x	x	x							
Pseudocalanus minutus	x	x	x	x								
Pseudocalanus spp.	x	x	x	x	x							
Spinocalanidae				x								
Spinocalanus spp.				x								
Crabs	x	x	x	x	x	x	x	x	x	x	x	x
Decapoda (crab) zoea	x		x				x		x	x	x	x
Decapoda (crab) megalops	x	x				x			x	x	x	
Cheiragonidae					x	x			x	x		
Telmessus cheiragonus (meg)					x				x			
Telmessus cheiragonus (juv)					x	x			x	x		
Oregoniidae		x				x			x	x	x	
Chionoecetes opilio zoea									x	x	x	
Chionoecetes opilio megalops									x	x		
Chionoecetes opilio juvenile									x	x	x	
Hyas coarctatus megalops						x			x	x		
Hyas coarctatus juvenile		x				x			x	x		
Lithodidae									x			
Paralithodes spp.									x			
Crabs	x	x	x	x	x	x	x	x	x	x	x	x
Paguridae	x	x	x	x	x	x	x		x	x	x	x
Paguridae zoea	x		x				x		x	x	x	x
Paguridae juvenile	x	x	x	x	x	x	x		x	x	x	x
Pagurus spp. juvenile						x						
Labidochirus splendescens										x		
Cumaceans	x	x	x	x	x	x	x	x	x	x	x	
Diastylidae	x	x			x	x	x	x	x	x		
Diastylis spp.	x	x			x	x	x	x	x	x		
Diastylopsis spp.								x				
Leptostylis spp.								x				
Leuconidae	x	x	x	x	x		x		x			
Eudorella spp.	x	x	x	x	x				x			
Eudorellopsis spp.	x	x			x							
Leucon nasica	x	x	x				x					

Table C4- 1 List of identified prey taxa (continued).

	Arctic Cod				**Arctic Staghorn Sculpin**				**Shorthorn Sculpin**			
Prey taxonomy list	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**
Nannastacidae	x	x			x		x		x	x		
Cumella spp.	x	x			x		x		x	x		
Euphausiids	x	x	x	x				x	x	x	x	
Euphausiidae	x	x	x	x				x	x	x	x	
Thysanoessa raschii	x	x	x	x				x	x	x	x	
Fish prey	x	x			x	x			x	x		
Agonidae									x			
Aspidophoroides olrikii									x			
Ammodytidae										x		
Ammodytes hexapterus										x		
Cottidae					x				x	x		
Gymnocanthus tricuspis									x	x		
Gadidae		x								x		
Boreogadus saida		x								x		
Liparidae										x		
Liparis spp.										x		
Plueronectidae									x			
Stichaeidae	x				x				x	x		
Lumpenus fabricii									x			
Zoarcidae										x		
Gymnelus hemifasciatus										x		
Hyperiid amphipods	x	x	x	x	x		x	x	x	x	x	x
Hyperia spp.	x						x	x	x		x	x
Hyperia galba	x						x					
Hyperoche spp.		x									x	
Hyperoche medusarum		x										
Themisto spp.	x	x	x	x	x		x	x	x	x	x	x
Themisto abyssorum	x	x	x	x				x			x	x
Themisto libellula	x	x	x	x	x		x		x	x	x	x
Isopods						x	x		x	x	x	
Chaetiliidae							x					
Saduria spp.							x					
Idoteidae						x	x		x	x		
Synidotea spp.						x	x		x	x		
Mollusks	x		x	x	x	x	x	x	x	x		x
Bivalve	x			x	x	x	x	x	x	x		
Bivalve siphons			x		x							x
Gastropoda					x		x		x			
Carditidae						x						

Table C4- 1 List of identified prey taxa (continued).

Prey taxonomy list	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**
Naticidae					x				x			
Lunatia pallida					x							
Nuculana spp.									x			
Pteropoda									x			
Trochidae									x			
Yoldiidae							x					
Mysids		x	x	x								
Mysidae		x	x	x								
Mysis oculata		x	x	x								
Polychaetes	x	x			x	x	x	x	x	x	x	
Ampharetidae						x						
Flabelligeridae							x					
Glyceridae							x	x	x			
Glycera spp.							x	x				
Goniadidae					x							
Glycinde spp.					x							
Lumbrineridae					x	x						
Lumbrineris spp.					x							
Maldanidae						x						
Nephtyidae					x	x						
Nephtys spp.					x	x						
Nuculidae					x							
Ennucula tenuis					x							
Oweniidae					x							
Phyllodocidae						x	x					
Phyllodoce groenlandica							x					
Polynoidae	x	x			x	x		x	x	x	x	
Arcteobia anticostiensis						x			x			
Eunoe spp.		x										
Gattyana spp.					x	x						
Harmothoe spp.						x			x	x		
Hesperonoe adventor											x	
Terebellidae							x					
Shrimps	x	x	x	x	x	x		x	x	x	x	x
Crangonidae					x	x		x	x	x	x	
Argis spp.					x	x		x	x	x		
Crangon spp.										x		
Sclerocrangon boreas									x			
Hippolytidae	x	x							x	x		
Eualus spp.		x							x	x		

Table C4- 1 List of identified prey taxa (continued).

	Arctic Cod				**Arctic Staghorn Sculpin**				**Shorthorn Sculpin**			
Prey taxonomy list	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**	**S Chukchi**	**N Chukchi**	**W Beaufort**	**E Beaufort**
Pandalidae					x				x	x		
Pandalopsis spp.					x							
Pandalus spp.					x				x			
Other prey	x	x	x	x	x	x	x	x	x	x	x	x
Calliopiidae	x	x										
Apherusa spp.	x	x										
Amphipoda frags	x	x	x	x	x	x	x	x	x	x	x	x
Bryozoa						x						
Copepod nauplii	x	x	x		x	x						
Cyclopoid copepod	x		x		x							
Cyprid	x	x	x		x	x	x	x	x		x	
Gastropod egg casing					x				x			
Harpacticoid copepod	x		x		x	x	x	x	x		x	x
Hydrozoa					x					x		
Ophiurodea	x					x				x		
Ostracoda					x	x	x	x	x	x		x
Tanaidacea						x			x			
Unid. animal tissue	x	x	x	x	x	x	x	x	x	x	x	x
Unid. crustacean fragments	x	x	x	x	x	x	x	x	x	x	x	x
Total # of unique prey	**69**	**73**	**45**	**48**	**91**	**90**	**56**	**44**	**103**	**100**	**38**	**33**

APPENDIX C5 SUBSTRATE MAPS THAT SUPPLEMENT CHAPTER 3 "FISH COMMUNITIES"

During BOEM-2011, substrate was collected at 75 stations using a Van Veen grab. A sample of the surface layer was frozen and retained for subsequent onshore grain size analysis. Only one sample of substrate for grain size was collected at any station; due to weather unconducive to deploying the grab, not every fishing station had a substrate sample. It should be noted that the sediment sample is not fully representative of the sea floor fished by a bottom trawl, since it is a single sample amounting to <0.01% of a haul track.

In the laboratory, sediment samples were thawed, wet-sieved and dried, and then proportional dry weight was calculated for gravel, sand, and mud; particle sizes in mm are: 64 < gravel <2; 2 < sand < 0.062; mud <0.0625 (**Table C5-1**). From those stations where sufficient mud was retained, the dry weight fractions of silt (4–63 microns) and clay <4 microns) were analyzed using a Sedigraph III V1.06 (Micromeretics Instrument Corporation). GRADISTAT software (Blott 2001, version 8 Blott 2010) was run in Microsoft Excel version 14.0 (Microsoft Corporation 2010) to calculate particle size statistics and describe sediment. The three stations that had gravel, sand and mud, but not silt or clay, were processed separately from the 72 stations that had gravel, sand, silt and clay data. Data generated by GRADISTAT that are included in the summary sediment data file are: sediment description (GRADISTAT calls this TEXTURAL GROUP), mean phi size, and description of mean phi size.

Maps (**Figures C5-1 through C5-11**) were generated that indicated sediment descriptions and proportional grain size, using ArcMap 10.2.1 (ESRI Inc. 2013).

Fish catches were analyzed using proportional gravel, sand and mud data (**Chapter 3**). Of the 75 stations at which sediment was collected, 61 stations were sampled by quantitative hauls of plumb staff beam trawl or modified plumb staff beam trawl (total of 78 hauls). Only three of the quantitative beam trawl hauls were not represented by grain size data (3 stations, 3 hauls).

REFERENCES

Blott SJ (2010) GRADISTAT Version 8.0: A grain size distribution and statistics package for the analysis of unconsolidated sediments by sieving or laser granulometer, *http://www.kpal.co.uk/GRADISTATv8xlsm.zip*

Blott SJ, Pye K (2001) GRADISTAT: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms 26: 1237–1248

Microsoft Corporation (2010) Mocrosoft Excel version 14.0.7128.5000, part of Microsoft Office Professional Plus 2010

Table C5- 1. Sediment description and proportional grain size at stations of BOEM-2011 cruise. A Van Veen grab was deployed at each station except those where the weather was too poor to deploy and at stations where no fish trawl. Sediment was sampled from the surface layer of substrate collected by Van Veen grab; grain size was assessed from one sample per station. See **Table C5-2** for substrate classification and description of grain sizes.

Station	Latitude	Longitude	Gravel %	Sand %	Mud %	Silt %	Clay %	Substrate	Substrate Abbreviation	Mean Phi	Mean Phi Description	Mean Phi Abbreviaion	Comment
CB01	70.5145	-147.3533	4.0	27.3	68.5	32.7	35.8	Slightly Gravelly Sandy Mud	sgsM	5.1	Coarse Silt	CSi	
CB02	70.5570	-147.7415	4.3	24.9	70.6	33.2	37.4	Slightly Gravelly Sandy Mud	sgsM	5.3	Coarse Silt	CSi	
CB03	70.5928	-148.2158	16.4	70.2	13.3	6.5	6.9	Gravelly Muddy Sand	gmS	1.4	Medium Sand	MS	
CB04	70.6262	-148.6868	1.6	28.1	70.2	37.5	32.7	Slightly Gravelly Sandy Mud	sgsM	5.2	Coarse Silt	CSi	
CB05	70.6548	-149.1974	0.0	85.9	13.9	6.2	7.7	Muddy Sand	mS	1.9	Medium Sand	MS	
CB06	70.6970	-149.6623	0.0	9.2	90.5	42.5	48.1	Mud	M	6.8	Medium Silt	MSi	
CB07	70.7384	-150.1203	0.0	9.7	90.1	40.8	49.3	Mud	M	6.8	Medium Silt	MSi	
CB08	70.7432	-150.5349	0.0	23.4	76.4	36.2	40.2	Sandy Mud	sM	5.8	Coarse Silt	CSi	
CB09	70.8136	-151.1057	0.0	83.3	16.6	6.7	9.9	Muddy Sand	mS	2.1	Fine Sand	FS	
CB10	70.8556	-151.5946	0.0	16.6	83.1	40.5	42.6	Sandy Mud	sM	6.3	Medium Silt	MSi	
CB11	70.7583	-147.1254	5.9	52.4	41.5	19.3	22.2	Gravelly Muddy Sand	gmS	3.7	Very Fine Sand	VFS	
CB12	70.7989	-147.5143	58.5	30.2	11.2	4.5	6.7	Muddy Sandy Gravel	msG	0.7	Very Coarse Sand	VCS	
CB13	70.8133	-148.0767	0.0	37.1	62.7	26.8	35.9	Sandy Mud	sM	5.0	Coarse Silt	CSi	
CB14	70.8528	-148.5788	4.3	26.7	68.7	27.6	41.2	Slightly Gravelly Sandy Mud	sgsM	5.3	Coarse Silt	CSi	
CB15	70.9201	-148.0300	4.1	28.8	66.9	27.0	39.9	Slightly Gravelly Sandy Mud	sgsM	5.2	Coarse Silt	CSi	
CB16	70.9602	-149.5722	3.0	17.2	79.6	29.9	49.8	Slightly Gravelly Sandy Mud	sgsM	6.2	Medium Silt	MSi	
CB17	70.9791	-150.0197	0.6	21.9	77.3	33.3	44.0	Slightly Gravelly Sandy Mud	sgsM	5.9	Coarse Silt	CSi	
CB18	71.0344	-150.5549	0.0	35.2	64.6	--	--	Slightly Gravelly Sandy Mud	sgsM	4.4	Very Coarse Silt	VCSi	
CB19	71.0585	-150.9187	0.0	33.8	66.0	32.4	33.7	Sandy Mud	sM	5.1	Coarse Silt	CSi	
CB20	71.1149	-151.4424	0.6	29.3	69.9	29.9	40.0	Slightly Gravelly Sandy Mud	sgsM	5.4	Coarse Silt	CSi	
CB22	70.9950	-147.4627	3.5	32.9	63.4	25.5	37.9	Slightly Gravelly Sandy Mud	sgsM	5.0	Very Coarse Silt	VCSi	
CB23	71.0686	-147.8788	4.3	32.3	63.2	31.4	31.8	Slightly Gravelly Sandy Mud	sgsM	4.8	Very Coarse Silt	VCSi	
CB24	71.1592	-148.3365	11.4	31.6	56.7	21.0	35.7	Gravelly Mud	gM	4.3	Very Coarse Silt	VCSi	
CB25	71.2073	-148.8749	15.0	25.8	59.0	23.5	35.4	Gravelly Mud	gM	4.2	Very Coarse Silt	VCSi	
CB26	71.2111	-149.3684	33.8	20.8	45.2	18.5	26.7	Muddy Gravel	mG	3.5	Fine Sand	FS	
CB27	71.2184	-149.9031	24.7	15.3	59.7	25.1	34.6	Gravelly Mud	gM	4.3	Very Fine Sand	VFS	
CB28	71.2520	-150.4104	9.5	28.5	61.8	--	--	Gravelly Mud	gM	4.0	Very Fine Sand	VFS	
CB29	71.3151	-150.9197	6.7	32.9	60.1	27.6	32.5	Gravelly Mud	gM	4.6	Very Coarse Silt	VCSi	
CB30	71.3610	-151.3092	0.4	14.4	84.9	49.0	35.9	Slightly Gravelly Sandy Mud	sgsM	6.3	Medium Silt	MSi	
CB31	70.9089	-151.8422	0.0	66.3	33.5	20.6	12.8	Muddy Sand	mS	3.4	Very Fine Sand	VFS	
CB32	70.8096	-151.6320	0.0	96.0	3.8	1.4	2.4	Sand	S	1.6	Medium Sand	MS	
CB33	70.6700	-150.6458	0.0	58.2	41.6	20.0	21.7	Muddy Sand	mS	3.9	Very Fine Sand	VFS	
CB34	71.2805	-150.6733	--	--	--	--	--						No sediment sample
CB35	71.2883	-150.6699	0.0	23.4	76.3	30.1	46.2	Sandy Mud	sM	6.0	Coarse Silt	CSi	
EB02	70.8725	-146.6500	0.0	39.0	60.7	22.5	38.3	Sandy Mud	sM	5.0	Very Coarse Silt	VCSi	
EB04	70.4360	-146.4200	13.5	32.8	53.5	20.2	33.3	Gravelly Mud	gM	4.0	Very Coarse Silt	VCSi	
EB06	70.6667	-146.4938	33.6	30.8	35.4	12.4	23.0	Muddy Gravel	mG	3.0	Fine Sand	FS	
EB08	70.3367	-146.1104	0.7	35.7	63.3	28.9	34.5	Slightly Gravelly Sandy Mud	sgsM	5.0	Very Coarse Silt	VCSi	
EB10	70.5619	-146.1066	52.7	29.9	17.2	6.5	10.8	Muddy Sandy Gravel	msG	1.2	Very Coarse Sand	VCS	
EB12	70.7782	-146.1099	0.0	48.4	51.3	17.2	34.1	Sandy Mud	sM	4.3	Very Coarse Silt	VCSi	
EB14	70.4561	-145.7967	4.9	61.0	33.9	14.2	19.7	Slightly Gravelly Muddy Sand	sgmS	3.5	Very Fine Sand	VFS	
EB16	70.6503	-145.7977	3.8	51.4	44.7	16.2	28.4	Slightly Gravelly Muddy Sand	sgmS	3.9	Very Fine Sand	VFS	

Table C5- 1. Sediment properties (continued)

Station	Latitude	Longitude	Gravel %	Sand %	Mud %	Silt %	Clay %	Substrate	Substrate Abbreviation	Mean Phi	Mean Phi Description	Mean Phi Abbreviaion	Comment
EB18	70.2165	-145.4433	--	--	--	--	--	--	--	--	--	--	Zooplankton station - no Van Veen
EB19	70.5520	-145.4381	29.4	23.0	47.4	19.7	27.7	Gravelly Mud	gM	3.6	Fine Sand	FS	
EB21	70.3315	-145.4430	4.9	39.5	55.4	21.8	33.6	Slightly Gravelly Sandy Mud	sgsM	4.5	Very Coarse Silt	VCSi	
EB23	70.7739	-145.4070	2.3	19.2	78.2	32.6	45.6	Slightly Gravelly Sandy Mud	sgsM	6.0	Coarse Silt	CSi	
EB25	70.2163	-145.1065	13.9	24.1	61.8	26.7	35.1	Gravelly Mud	gM	4.4	Very Coarse Silt	VCSi	
EB26	70.3304	-145.1053	--	--	--	--	--	--	--	--	--	--	Zooplankton station - no Van Veen
EB27	70.4521	-145.0877	54.1	30.5	15.2	6.1	9.1	Muddy Sandy Gravel	msG	0.9	Very Coarse Sand	VCS	
EB29	70.6698	-145.1038	49.2	18.7	32.0	11.0	21.0	Muddy Gravel	mG	2.3	Medium Sand	MS	
EB32	70.9101	-146.4159	63.3	9.4	27.1	13.5	13.6	Muddy Gravel	mG	2.1	Coarse Sand	CS	
WB02	71.7344	-154.9747	--	--	--	--	--	--	--	--	--	--	High seas - no Van Veen
WB04	71.8418	-153.9206	0.0	18.2	81.5	39.4	42.0	Sandy Mud	sM	6.2	Medium Silt	MSi	
WB05	71.8086	-154.4321	--	--	--	--	--	--	--	--	--	--	High seas - no Van Veen
WB07	71.7085	-152.9630	0.0	8.6	91.1	43.4	47.7	Mud	M	6.8	Medium Silt	MSi	
WB08	71.6546	-152.6614	0.0	13.4	86.2	--	--	Slightly Gravelly Sandy Mud	sgsM	5.7	Coarse Silt	CSi	
WB10	71.7238	-153.9227	0.0	58.3	41.6	21.1	20.4	Muddy Sand	mS	3.9	Very Fine Sand	VFS	
WB12	71.4710	-153.9570	0.0	11.6	88.1	38.4	49.7	Sandy Mud	sM	6.8	Medium Silt	MSi	
WB13	71.4000	-153.9770	0.0	7.8	91.9	39.2	52.8	Mud	M	6.9	Medium Silt	MSi	
WB14	71.2457	-153.1169	0.0	16.1	83.6	36.3	47.3	Sandy Mud	sM	6.5	Medium Silt	MSi	
WB15	71.3723	-153.0386	5.9	29.4	64.4	30.3	34.1	Gravelly Mud	gM	4.9	Very Coarse Silt	VCSi	
WB16	71.0000	-153.0000	0.0	26.7	73.1	36.5	36.6	Sandy Mud	sM	5.5	Coarse Silt	CSi	
WB17	71.1594	-152.2214	0.0	14.8	85.0	41.5	43.5	Sandy Mud	sM	6.5	Medium Silt	MSi	
WB18	71.2730	-152.3036	14.1	29.3	56.5	24.1	32.4	Gravelly Mud	gM	4.1	Very Coarse Silt	VCSi	
WB19	71.3442	-152.0087	20.7	22.7	56.4	24.7	31.8	Gravelly Mud	gM	4.1	Very Fine Sand	VFS	
WB20	71.5000	-152.1833	0.0	10.4	89.3	40.6	48.7	Sandy Mud	sM	6.8	Medium Silt	MSi	
WB21	71.5933	-155.0366	0.0	9.3	90.4	42.1	48.4	Mud	M	6.8	Medium Silt	MSi	
WB22	71.6912	-154.5217	49.7	19.1	31.0	15.5	15.5	Muddy Gravel	mG	2.2	Medium Sand	MS	
WB23	71.5343	-152.9027	0.0	33.7	66.0	32.6	33.4	Sandy Mud	sM	5.1	Coarse Silt	CSi	
WB24	71.5634	-153.5034	0.0	15.3	84.5	49.5	35.0	Sandy Mud	sM	6.3	Medium Silt	MSi	
WB25	71.2221	-154.0137	0.0	12.8	87.0	41.5	45.5	Sandy Mud	sM	6.6	Medium Silt	MSi	
WB26	71.5988	-153.9508	0.0	22.7	77.0	41.8	35.3	Sandy Mud	sM	5.7	Coarse Silt	CSi	
WB27	71.8512	-154.4951	--	--	--	--	--	--	--	--	--	--	High seas - no Van Veen
WB28	71.6624	-155.2461	61.4	23.8	14.6	8.0	6.6	Muddy Sandy Gravel	msG	0.9	Very Coarse Sand	VCS	
WB29	71.4726	-155.0913	0.0	5.5	94.3	50.0	44.3	Mud	M	6.8	Medium Silt	MSi	
WB30	71.2433	-155.1354	0.0	12.2	87.6	49.3	38.3	Sandy Mud	sM	6.4	Medium Silt	MSi	
WB31	71.8005	-153.4167	0.0	11.4	88.3	51.5	36.8	Sandy Mud	sM	6.4	Medium Silt	MSi	
WB32	71.7340	-153.5261	0.0	29.2	70.5	35.4	35.1	Slightly Gravelly Sandy Mud	sgsM	5.3	Coarse Silt	CSi	
WB34	71.1379	-153.1948	0.0	8.6	91.1	50.2	40.9	Mud	M	6.6	Medium Silt	MSi	
WB35	71.1017	-154.0514	5.6	15.0	79.1	36.9	42.3	Gravelly Mud	gM	5.9	Coarse Silt	CSi	
WB36	71.5773	-152.5094	0.0	9.9	89.8	45.4	44.3	Sandy Mud	sM	6.7	Medium Silt	MSi	

Table C5- 2. Sediment classification by proportional grain size (after Sheppard 1973 and Folk 1980).

Classification	Substrate Abbreviation	% Boulder	% Cobble	% Gravel	% Sand + Mud	% Sand	% Mud
	Grain size (mm)	B > 256	256> C >64	64> G >2		2 > S > 0.07	0.07 > M
	Grain size (Phi)	-8 > B	-8 < C < -6	-6 < G < -1		-1 < S < 4	M > 4
Boulder	B	80< B <100	C <20	G <20			
Cobbly boulder	cB	B > C	20< C <50	G < C			
Gravelly boulder	gB	B > G	C < G	20< G <50			
Cobble	C	B = 0	80< C <100	G < C			
Bouldery cobble	bC	0< B <20	80< C <100	G < B			
Gravelly cobble	gC	B = 0	C > G	G < C			
Bouldery gravel	bG	0< B <20	C < B	G > B			
Cobbly gravel	cG	B = 0	0< C <50	G > C			
Gravel	G	B = 0	C = 0	80< G <100	20> S+M		
Muddy gravel	mG	B = 0	C = 0	30< G <80	70> S+M >20	S < M	M > S
Muddy sandy gravel	msG	B = 0	C = 0	30< G <80	70> S+M >20	S > M	M < S
Sandy gravel	sG	B = 0	C = 0	30< G <80	70> S+M >20	S > 9(M)	9(M) < S
Sand	S	B = 0	C = 0	0< G <5	100> S+M >95	S > 9(M)	9(M) < S
Gravelly sand	gS	B = 0	C = 0	5< G <30	95> S+M >70	S > 9(M)	9(M) < S
Gravelly muddy sand	gmS	B = 0	C = 0	5< G <30	95> S+M >70	S > M	M < S
Muddy sand	mS	B = 0	C = 0	0< G <5	100> S+M >95	S > M	M < S
Mud	M	B = 0	C = 0	0< G <5	100> S+M >95	9(S) < M	M > 9(S)
Gravelly mud	gM	B = 0	C = 0	5< G <30	95> S+M >70	S < M	M > S
Sandy mud	sM	B = 0	C = 0	0< G <5	100> S+M >95	S < M	M > S

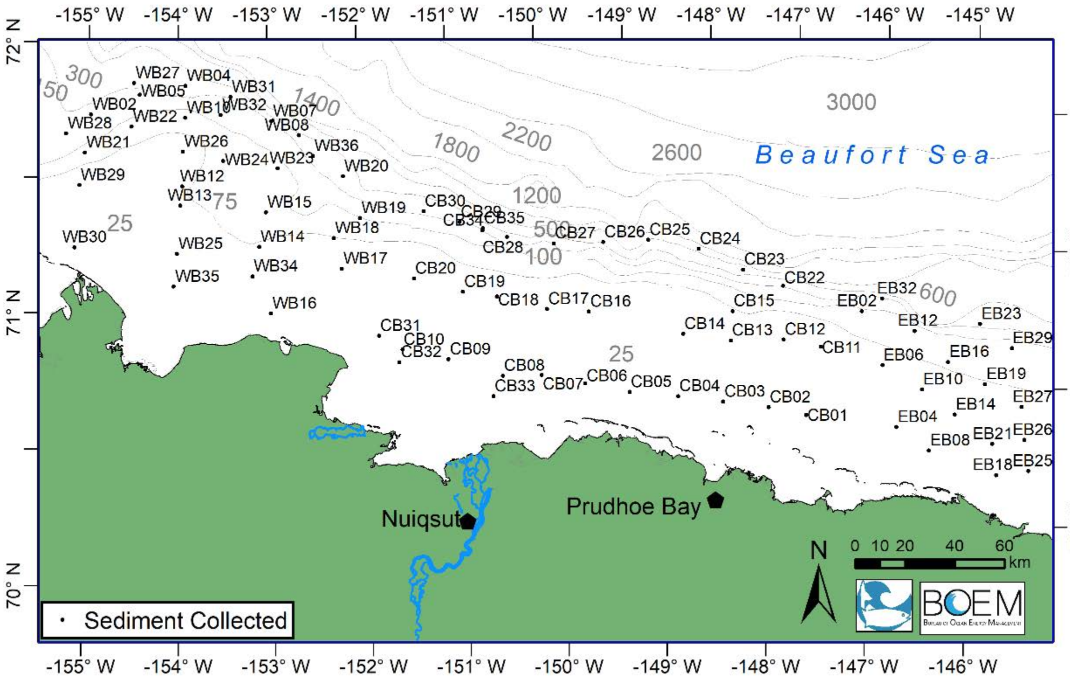


Figure C5- 1. Map of BOEM-2011 stations where substrate was collected by Van Veen grab and analyzed for percents gravel, sand and mud. Mud was further analyzed for percents silt and clay from a subset of stations.

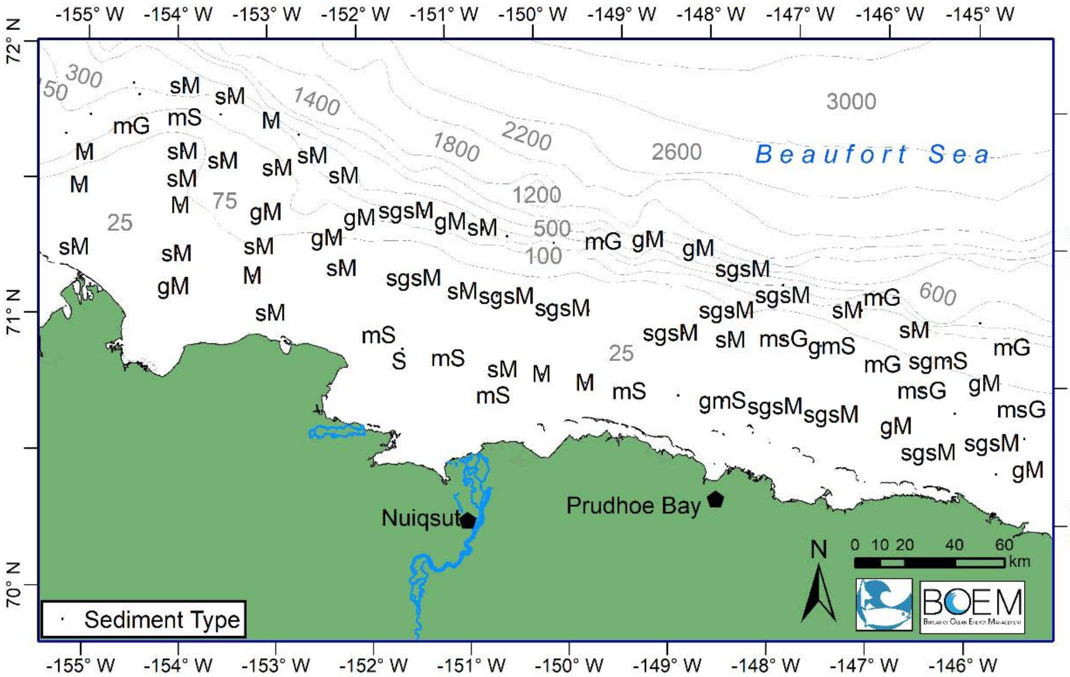


Figure C5- 2. Map labeled with description of substrate type.

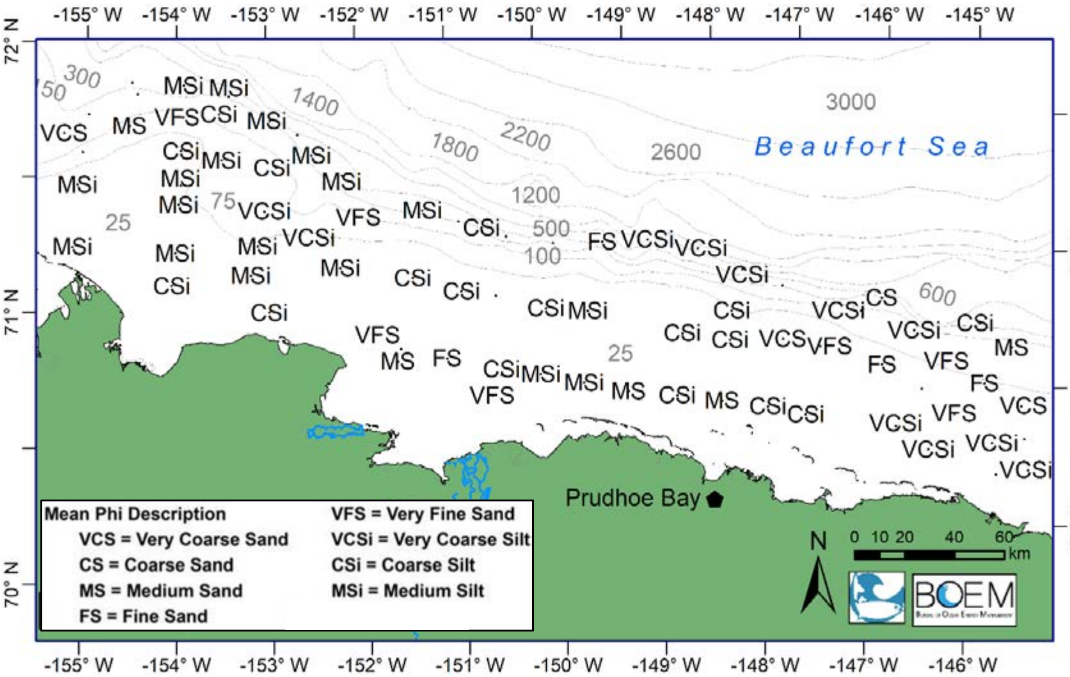


Figure C5- 3. Map labeled with description of mean phi size.

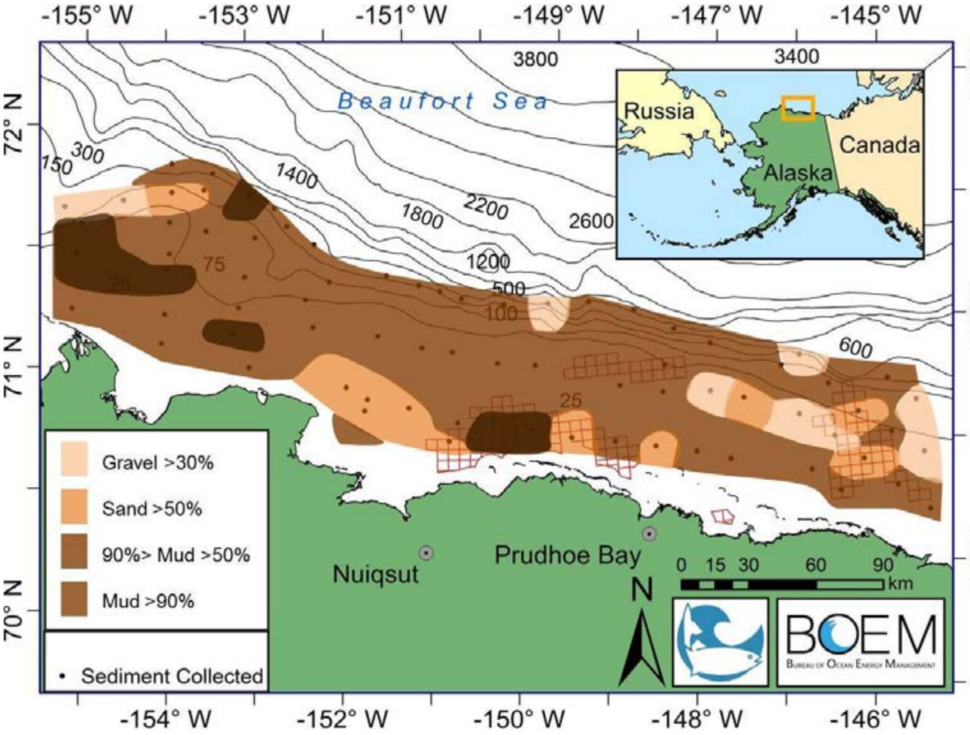


Figure C5- 4. Map with shading that indicates the primary sediment grain size.

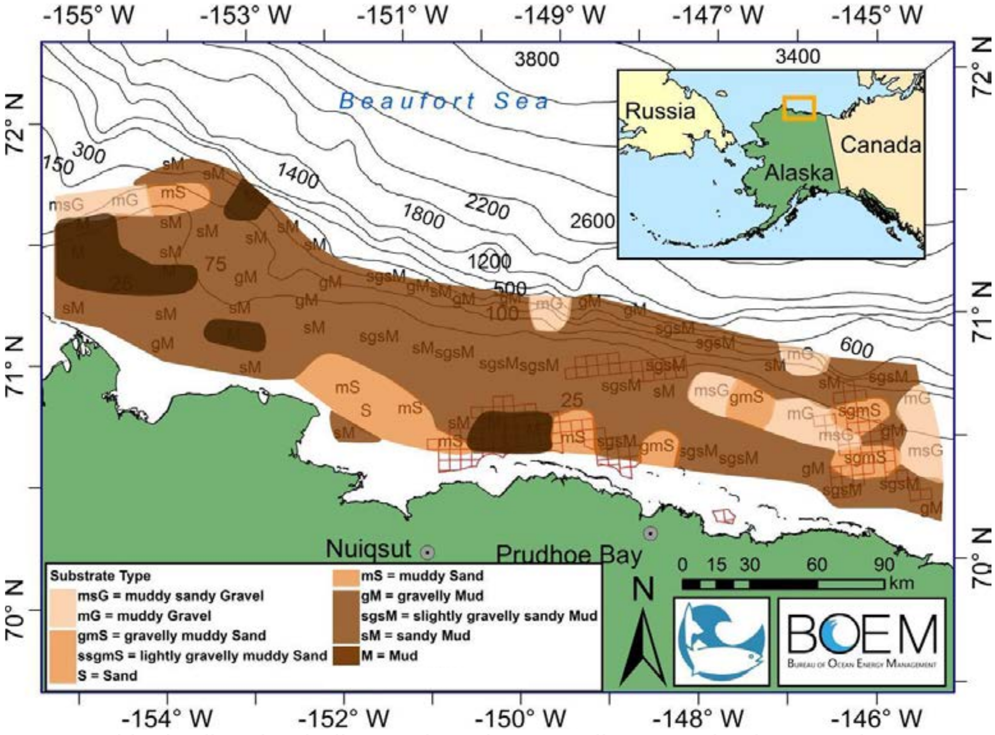


Figure C5- 5. Map with shading that indicates the primary sediment grain size. G substrates are >30% gravel, S substrates are >50% sand, M substrates are >50% mud, and sites labeled as “M” are >90% mud.

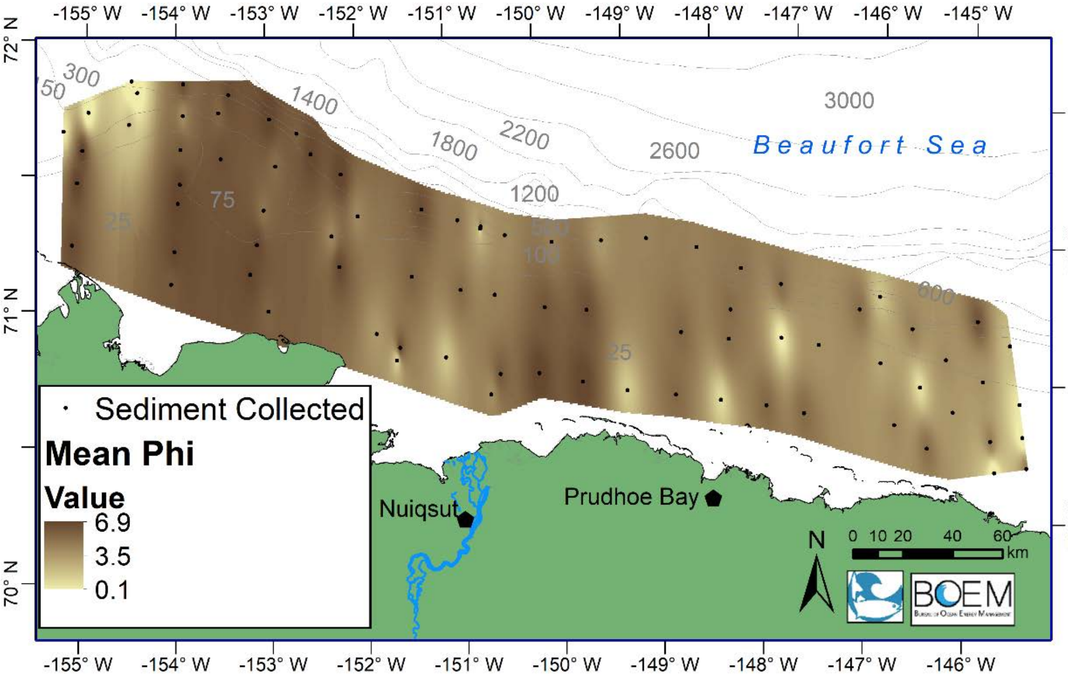


Figure C5- 6. Map: Mean phi size.

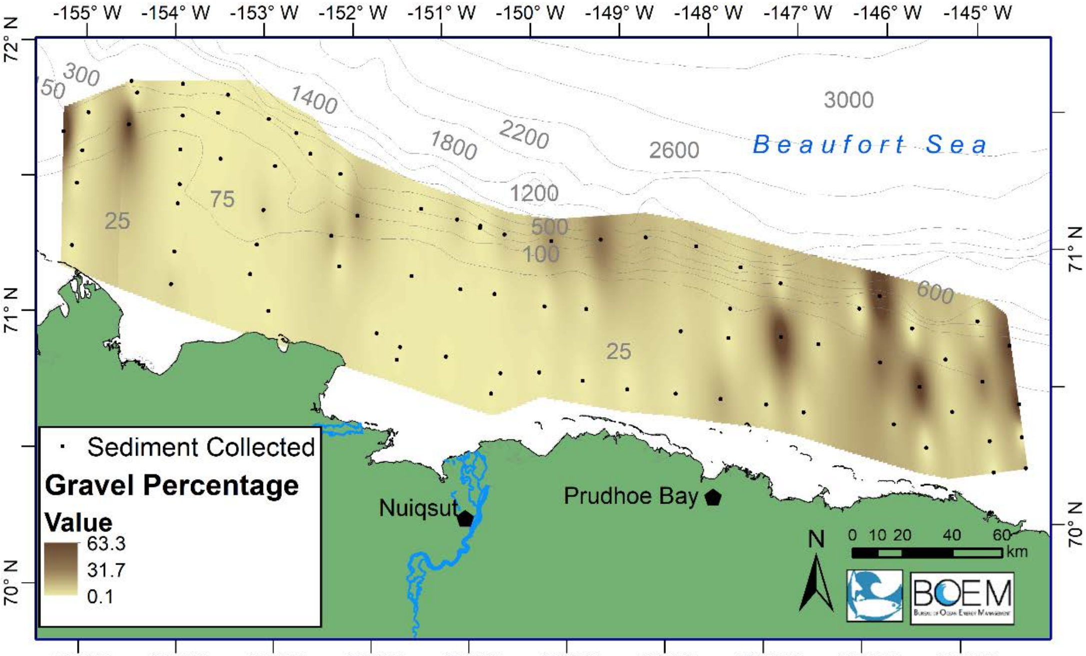


Figure C5- 7. Map: Gravel percentage.

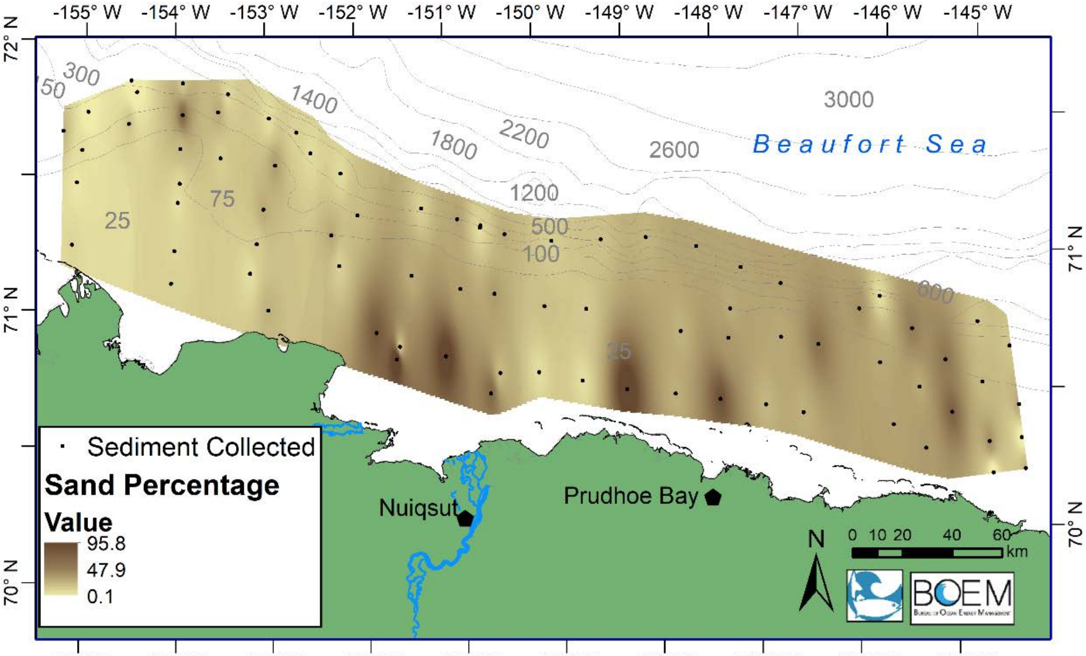


Figure C5- 8. Map: Sand percentage.

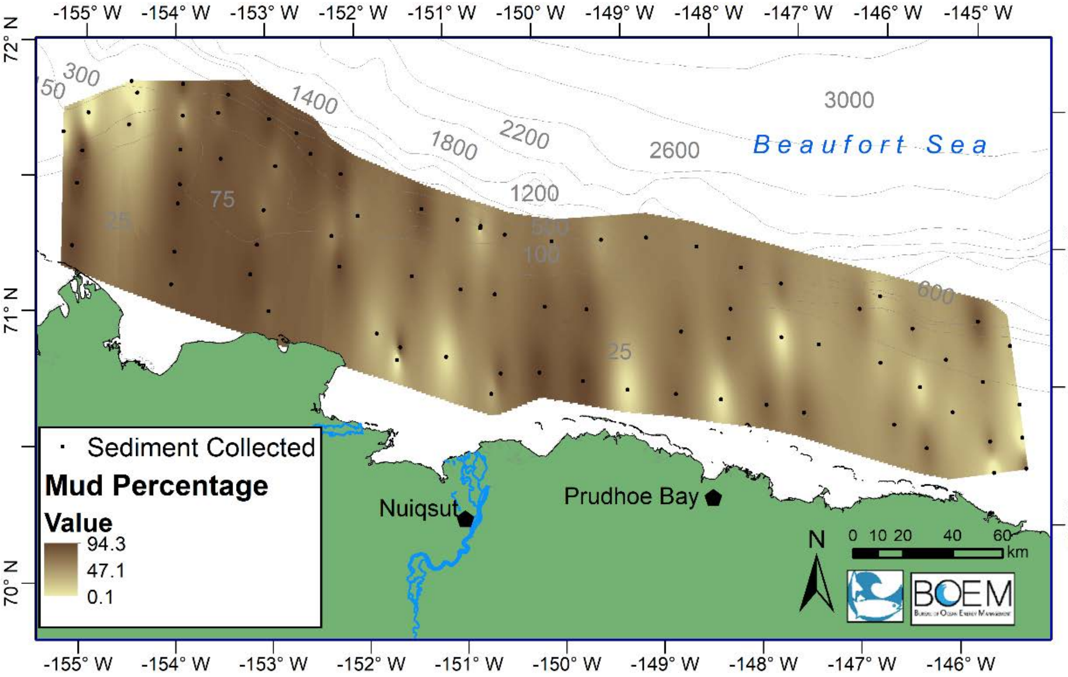


Figure C5- 9. Map: Mud percentage.

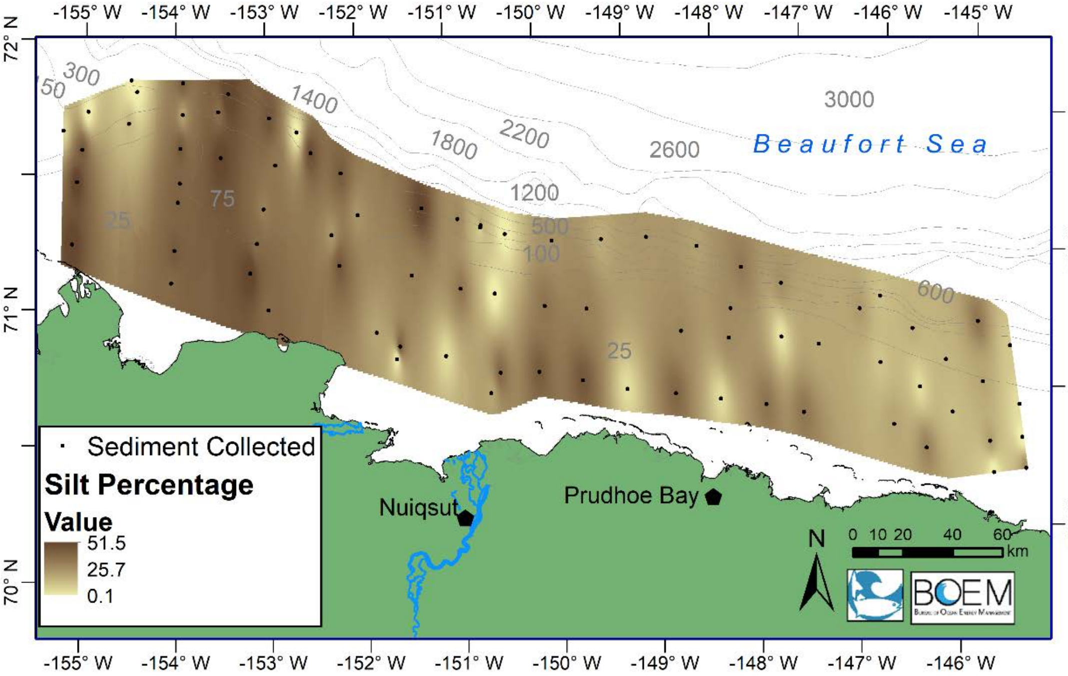


Figure C5- 10. Map: Silt percentage.

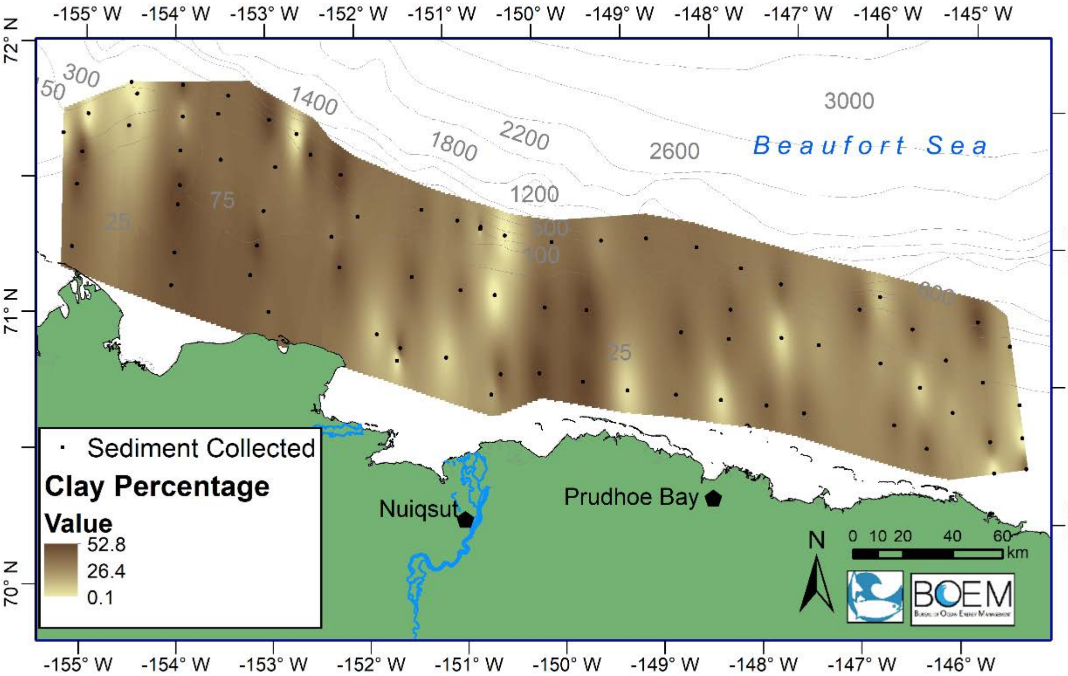


Figure C5- 11. Map: Clay percentage.

APPENDIX C6. TAXONOMIC COMPOSITION OF ICHTHYOPLANKTON AND THE OTOLITH MICROSTRUCTURE OF ARCTIC COD (BOREOGADUS SAIDA) LARVAE IN THE BEAUFISH-2011 (BOEM-2011) SURVEY AREA

Edited by Dominique Robert and submitted to LGL Environmental Research Associates Inc., February 3rd, 2012

Sections of text and results were revised by Brenda Holladay, University of Alaska Fairbanks, December 1, 2014; those revised sections are in italics font to differentiate from the Robert (2012) report.

Laboratory analyses of BOEM-2011 ichthyoplankton samples

Laboratory analyses consisted of taxonomical identification and otolith microstructure analysis and were under the responsibility of one Principal Investigator (PI):

Prof. Louis Fortier (collaborators: Dominique Robert, Caroline Bouchard, Louis Létourneau and Hélen Cloutier)

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APPENDIX C6. INTRODUCTION

This report was commissioned by LGL Environmental Research Associates Inc. to summarize ichthyoplankton data collected in the western Beaufort Sea in August–September 2011 by Brenda Norcross' team (Institute of Marine Science, University of Alaska Fairbanks). Main objectives consisted of:

1) Identifying larval and juvenile fish to the highest taxonomical level possible;
2) Determining age and hatch date frequency distribution of young Arctic Cod through otolith microstructure analysis;
3) Estimate mortality rate through the hatch date frequency distribution and catch-at-age curve.

APPENDIX C6. MATERIALS AND METHODS

FIELD SAMPLING

A survey comprising 81 stations was conducted in the western Beaufort Sea onboard the R/V *Norseman II* from 16 August to 3 September 2011 (Fig. 1; Tables 1–3).

Ichthyoplankton was collected using bongo nets of 505µm mesh in the codends. Bongo net deployments were effected from the stern at a speed of approximately 40–45m/min. The net was towed in a single oblique haul at 2 kt, and fished from the surface to a maximum depth of 5–10 m above the bottom.

Additional early juvenile fish (0+) were captured using various samplers designed for targeting late juvenile and adult pelagic fish (1+). This included an Isaacs-Kidd Midwater Trawl (IKMT), which fished from the surface to 10 m above the bottom. The IKMT had 3 mm mesh throughout body and codend with mouth dimensions of 1.5 m wide by 1.8 m high, totalizing an effective fishing area of 2.137 m^2 when fished at the angle of 45º. A rigid diving vane kept the mouth of the net open during towing and exerted a depressing force to stabilize the net vertically. The IKMT was deployed from the stern and towed with the current at approximately 4 kt speed in a double oblique tow. During the haul, the towing cable was continuously released or retrieved at the rate of approximately 30 m/min, and rate was periodically adjusted to maintain the targeted wire angle of 45º.

Additional gear used to sample demersal fish consisted in otter trawls (OT), plumb staff beam trawls (PSBT), and modified plumb staff beam trawls (PSBT-A). The 9.1 m OT had 38 mm stretch mesh on the codend and 19 mm stretch mesh on the codend liner. It was deployed from the stern and towed at a speed of 2 kt. Both the PSBT and PSBT-A were equipped with a 4.7 m headrope, 4.6 m footrope, 7 mm mesh in body, and 4 mm mesh as codend liner. A rigid 3-m pipe forward of the net held the mouth open for an effective swath of 2.26 m. The PSBT-A was modified according to Abookire and Rose (2005) by adding rollers to the footrope to exclude boulders and rocky substrate and by securing the headrope to the beam in several places in order to prevent fish escapement. The modified plumb staff was used at stations where a regular PSBT would have been impractical (i.e., dense mud or boulders). Both the PSBT and

PSBT-A were deployed from the stern at 30 m/min with a ratio of 2.5–5 m of towing cable to 1 m of water depth. These nets were towed with the current at approximately 1–1.5 kt speed.

Larval and juvenile fish were preserved in ethanol 95%, and shipped to Louis Fortier's laboratory (Université Laval, Quebec City, Canada) for taxonomical identification and otolith analyses (Arctic Cod only).

LABORATORY ANALYSIS

In the laboratory, larval and juvenile fish were attributed an identification number and individually transferred to a 20 ml scintillation vial. Each individual was then measured for its standard length (SL) and body width (BW), and identified to the species or highest taxonomical level possible. *In Appendix C6, the specimens are reported at the family level because identity of a subset of specimens has been redetermined at the UAF Fisheries Oceanography Laboratory with use of taxonomic guides developed for the northeastern Pacific Ocean (Matarese et al. 1989, 2012, 2013); larvae are held at UAF pending additional morphometric and genetic examination.*

Upon identification, otoliths of all Arctic Cod individuals were taken for further aging. Lapilli were extracted and mounted separately on a microscopic slide with Crystalbond® thermoplastic cement (Fortier et al., 2006). Each otolith was ground on its medial side on a 3-µm aluminum grit paper. Daily increments of the left lapillus were enumerated and measured under a light microscope coupled to a camera and image analyzer system (Image-Pro Plus®) (Fig. 2). In some individuals, the left lapillus was damaged and the right lapillus was analyzed instead. The hatch date of an individual fish was determined by subtracting its age (in days) from its date of capture. The hatch-date frequency distribution (HFD) of the young fish captured was built by tallying the number of fish hatched in the same 7-d period.

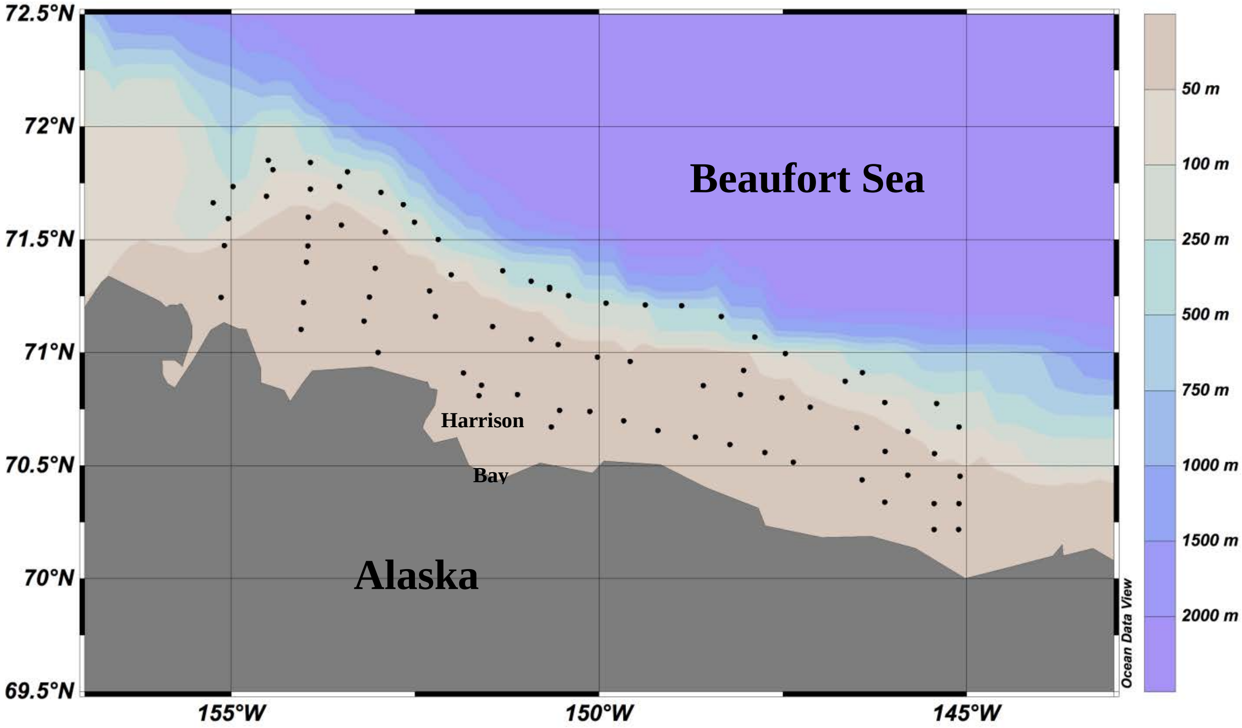

Figure C6- 1 Map of the BOEM-2011 sampling grid in the western Beaufort Sea. Color scale indicates bathymetry.

Table C6- 1 Location of the easternmost stations of the BOEM-2011 sampling area.

Station	Station Depth (m)	Date	Latitude	Longitude	Notes
EB02	64	08/20/11	70.8725	-146.6500	
EB04	35	08/19/11	70.4360	-146.4200	
EB06	45	08/19/11	70.6667	-146.4938	
EB08	30	08/19/11	70.3367	-146.1104	
EB10	41	08/19/11	70.5619	-146.1066	
EB12	68	08/18/11	70.7782	-146.1099	
EB14	39	08/18/11	70.4561	-145.7967	
EB16	56	08/18/11	70.6503	-145.7977	
EB18	20	08/16/11	70.2165	-145.4433	Zooplankton Only
EB19	33	08/18/11	70.5520	-145.4381	
EB21	52	08/18/11	70.3315	-145.4430	
EB23	127	08/17/11	70.7739	-145.4070	
EB25	27	08/16/11	70.2163	-145.1065	
EB26	30	08/17/11	70.3304	-145.1053	Zooplankton Only
EB27	43	08/17/11	70.4521	-145.0877	
EB29	58	08/17/11	70.6698	-145.1038	
EB32	126	08/20/11	70.9101	-146.4159	

Table C6- 2 Location of the central stations of the BOEM-2011 sampling area.

Station	Station Depth (m)	Date Sampled	Latitude	Longitude	Notes
CB01	23	08/21/11	70.5145	-147.3533	
CB02	28	08/21/11	70.5570	-147.7415	
CB03	23	08/22/11	70.5928	-148.2158	
CB04	13	08/22/11	70.6262	-148.6868	
CB05	19	08/23/11	70.6548	-149.1974	
CB06	19	08/23/11	70.6970	-149.6623	
CB07	19	08/23/11	70.7384	-150.1203	
CB08	19	08/25/11	70.7432	-150.5349	
CB09	18	08/26/11	70.8136	-151.1057	
CB10	17	08/26/11	70.8556	-151.5946	
CB11	48	08/20/11	70.7583	-147.1254	
CB12	41	08/21/11	70.7989	-147.5143	
CB13	43	08/22/11	70.8133	-148.0767	
CB14	36	08/22/11	70.8528	-148.5788	
CB15	33	08/23/11	70.9201	-148.0300	
CB16	33	08/23/11	70.9602	-149.5722	
CB17	30	08/23/11	70.9791	-150.0197	
CB18	13	08/25/11	71.0344	-150.5549	
CB19	13	08/25/11	71.0585	-150.9187	
CB20	20	08/25/11	71.1149	-151.4424	
CB22	184	08/21/11	70.9950	-147.4627	
CB23	183	08/21/11	71.0686	-147.8788	
CB24	180	08/22/11	71.1592	-148.3365	
CB25	179	08/22/11	71.2073	-148.8749	
CB26	183	08/23/11	71.2111	-149.3684	
CB27	163	08/24/11	71.2184	-149.9031	
CB28	103	09/03/11	71.2520	-150.4104	
CB29	103	08/24/11	71.3151	-150.9197	
CB30	183	08/25/11	71.3610	-151.3092	
CB31	17	08/26/11	70.9089	-151.8422	
CB32	16	09/02/11	70.8096	-151.6320	
CB33	16	09/03/11	70.6700	-150.6458	
CB34	183	09/03/11	71.2805	-150.6733	
CB35	223	09/03/11	71.2883	-150.6699	

Table C6- 3 Location of the westernmost stations of the BOEM-2011 sampling area.

Station	Station Depth (m)	Date	Latitude	Longitude	Notes
WB02	183	08/30/11	71.7344	-154.9747	
WB04	184	08/29/11	71.8418	-153.9206	
WB05	155	08/30/11	71.8086	-154.4321	
WB07	183	08/27/11	71.7085	-152.9630	
WB08	183	08/27/11	71.6546	-152.6614	
WB10	53	08/29/11	71.7238	-153.9227	
WB12	52	08/29/11	71.4710	-153.9570	
WB13	43	08/31/11	71.4000	-153.9770	
WB14	41	09/01/11	71.2457	-153.1169	
WB15	79	08/29/11	71.3723	-153.0386	
WB16	65	08/28/11	71.0000	-153.0000	
WB17	24	08/26/11	71.1594	-152.2214	
WB18	51	09/02/11	71.2730	-152.3036	
WB19	90	08/26/11	71.3442	-152.0087	
WB20	184	08/27/11	71.5000	-152.1833	
WB21	48	08/31/11	71.5933	-155.0366	
WB22	51	08/30/11	71.6912	-154.5217	
WB23	60	08/28/11	71.5343	-152.9027	
WB24	53	08/28/11	71.5634	-153.5034	
WB25	23	09/01/11	71.2221	-154.0137	
WB26	49	08/29/11	71.5988	-153.9508	
WB27	178	08/30/11	71.8512	-154.4951	
WB28	183	08/30/11	71.6624	-155.2461	
WB29	15	08/31/11	71.4726	-155.0913	
WB30	13	08/31/11	71.2433	-155.1354	
WB31	183	08/28/11	71.8005	-153.4167	
WB32	83	08/28/11	71.7340	-153.5261	
WB34	25	09/01/11	71.1379	-153.1948	
WB35	18	09/01/11	71.1017	-154.0514	
WB36	154	09/02/11	71.5773	-152.5094	

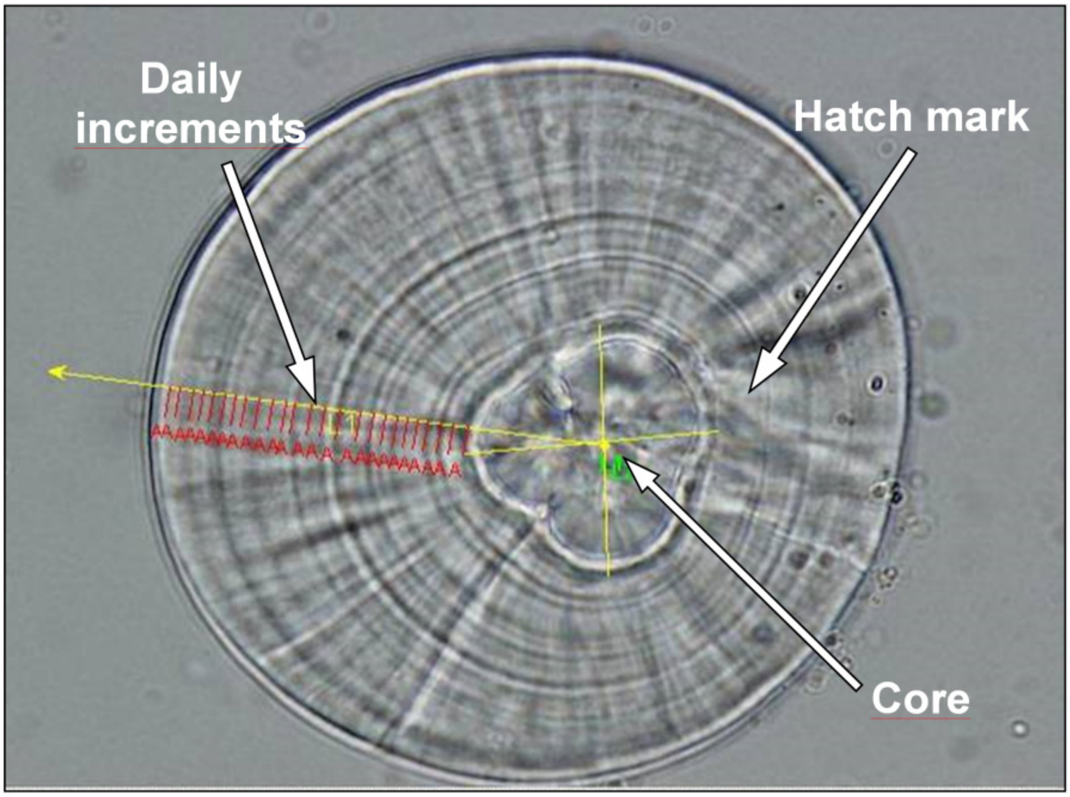

Figure C6- 2 Larval Arctic Cod lapillus with core, hatch mark, and daily growth increments.

APPENDIX C6. RESULTS

TAXONOMICAL COMPOSITION OF ICHTHYOPLANKTON

Detailed data on the taxonomy of larval and juvenile fish are provided in database table tbl_IchthyoplanktonID.

*A total of 545 larval and juvenile fish was identified of which 531 specimens were captured by bongo net (***Table C6-4***). The most abundant fishes in the bongo catch were snailfishes (Liparidae, 32%), pricklebacks (Stichaeidae, 27%), cods (Gadidae, 21%; primarily Boreogadus saida), and sculpins (Cottidae, 16%) (***Figure C6-3***). A few specimens were also collected of poachers (Agonidae), sand lances (Ammodytidae, >1%), and flatfishes (Pleuronectidae (1%).*

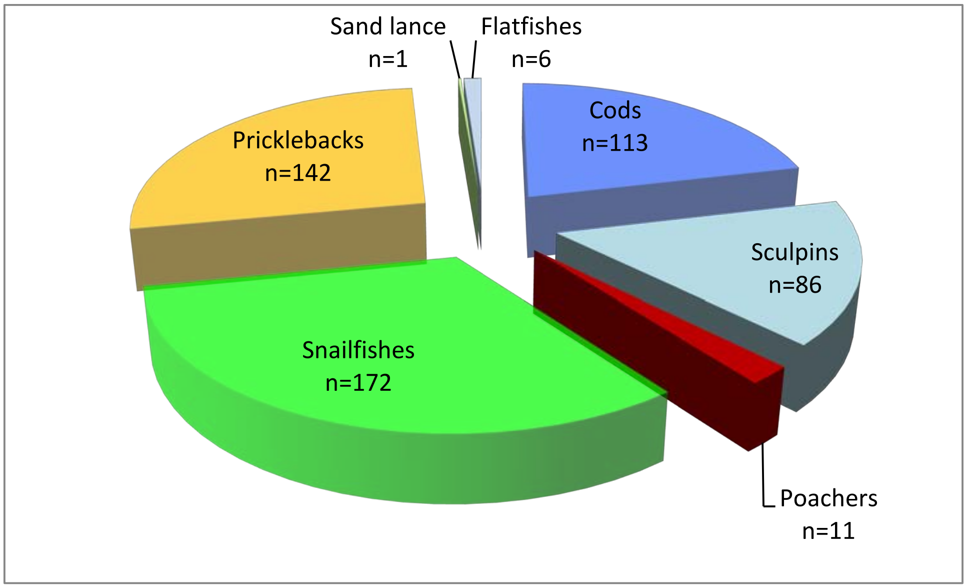

Figure C6- 3. Taxonomical composition of ichthyoplankton captured by bongo plankton net of 505 micron mesh during the BOEM-2011 survey in the western Beaufort Sea.

Table C6- 4. Count of fishes collected by bongo plankton net (all) and the subset of fishes caught by Isaacs-Kidd midwater trawl that were identified by Fortier lab. Fishes were caught during BOEM-2011 survey in the western Beaufort Sea.

Station	Gear	Haul	Cods	Sculpins	Snailfishes	Poachers	Pricklebacks	Sand Lance	Flatfishes	Total
CB01	IKMT	23	-	5	-	-	-	-	-	5
	OB505A	19	-	-	-	-	1	-	-	1
CB03	OB505A	25	-	1	-	-	-	-	-	1
	PSBT-A	15	-	1	-	-	-	-	-	1
CB04	OB505A	26	2	-	1	-	-	-	-	3
CB05	OB505A	31	-	1	-	-	-	-	-	1
CB06	OB505A	32	-	1	-	-	-	-	-	1
CB07	OT	17	-	1	-	-	1	-	-	2
CB08	IKMT	48	-	1	-	-	-	-	-	1
CB11	OB505A	18	1	-	-	-	-	-	-	1
CB12	OB505A	11	3	-	-	-	-	-	-	3
		21	5	-	-	-	-	-	-	5
CB13	IKMT	28	-	4	1	-	-	-	-	5
	OB505A	24	1	-	-	-	-	-	-	1
CB14	OB505A	27	1	-	-	-	-	-	-	1
CB15	IKMT	35	-	2	2	-	-	-	-	4
CB16	oblique	35	3	-	-	-	-	-	-	3
CB22	OB505A	22	3	-	-	-	-	-	-	3
CB23	OB505A	54	1	-	-	-	-	-	-	1
CB24	OB505A	28	-	-	1	-	-	-	-	1
CB26	IKMT	41	-	6	3	-	-	-	-	9
	OB505A	36	2	-	-	-	-	-	-	2
	OT	18	-	1	-	-	-	-	-	1
CB28	OB505A	38	1	-	-	-	-	-	-	1
CB29	OB505A	39	2	-	-	-	-	-	-	2
CB30	OB505A	40	1	-	-	-	-	-	-	1
CB31	IKMT	51	-	-	10	-	2	-	-	12
	OB505A	53	4	-	-	1	-	-	-	5
CB32	IKMT	83	-	1	5	-	7	-	-	13
	OB505A	76	1	-	1	-	17	-	-	19
CB33	IKMT	84	-	19	127	-	22	-	-	168
	OB505A	77	-	-	2	-	1	-	-	3
EB02	OB505A	17	1	-	1	-	-	-	-	2
EB04	IKMT	15	-	-	1	1	-	-	-	2
	OB505A	14	3	1	-	-	-	-	-	4
EB06	OB505A	15	4	-	-	-	-	-	-	4
EB08	IKMT	14	-	3	2	1	-	-	-	6
	OB505A	13	1	-	-	-	-	-	-	1
EB10	IKMT	13	-	12	-	-	-	-	-	12
EB14	OB505A	9	6	1	-	-	-	-	-	7
	OT	6	-	1	-	-	-	-	-	1
EB16	IKMT	11	-	-	1	-	-	-	-	1
	OB505A	10	1	-	-	-	-	-	-	1
EB19	IKMT	9	-	5	-	-	-	-	-	5
	OB505A	8	-	-	-	-	2	-	-	2
EB21	OB505A	7	1	-	1	-	-	-	-	2
EB23	OB505A	6	1	-	-	-	-	-	-	1

Table C6-4. Count of fishes collected by bongo net (all) and IKMT (subset) (continued).

Station	Gear	Haul	Cods	Sculpins	Snailfishes	Poachers	Pricklebacks	Sand Lance	Flatfishes	Total
EB25	IKMT	1	-	2	1	1	-	-	-	4
		3	3	5	-	-	-	-	-	8
		4	3	7	1	-	3	-	-	14
EB26	OB505A	3	1	-	-	-	-	-	-	1
EB27	OB505A	4	3	-	-	-	-	-	-	3
EB29	OB505A	5	3	-	-	-	-	-	-	3
EB32	IKMT	18	-	1	-	-	-	-	-	1
WB02	oblique	65	-	-	-	-	2	-	-	2
WB04	IKMT	67	-	-	-	-	3	-	1	4
	OB505A	62	1	-	-	-	-	-	-	1
WB05	IKMT	69	-	1	1	-	7	-	2	11
	OB505A	64	9	1	-	1	1	-	-	12
WB07	IKMT	57	-	-	-	1	-	-	-	1
	OB505A	52	3	-	1	-	-	-	-	4
WB08	OB505A	51	16	-	-	-	-	-	-	16
WB10	IKMT	66	-	-	-	-	1	-	-	1
	OB505A	61	1	-	-	-	1	-	-	2
WB12	OB505A	59	1	-	-	-	-	-	-	1
	OT	34	-	-	-	-	1	-	-	1
WB14	IKMT	80	1	-	-	-	-	-	-	1
WB15	IKMT	63	4	-	-	-	23	-	-	27
	OB505A	58	1	-	1	1	1	-	-	4
WB16	IKMT	62	-	-	-	-	5	-	-	5
	OB505A	57	-	-	1	-	-	-	-	1
WB17	IKMT	52	-	-	2	-	-	-	-	2
	OB505A	48	1	-	-	-	-	-	-	1
WB18	OB505A	75	2	-	-	1	1	-	-	4
WB19	OB505A	49	4	-	-	-	-	-	-	4
	OT	24	-	-	-	-	4	-	-	4
WB20	IKMT	55	1	-	-	-	-	-	-	1
	OB505A	50	1	-	-	-	-	-	-	1
WB21	IKMT	73	-	-	-	-	6	-	-	6
	OB505A	67	2	-	-	-	-	-	-	2
	PSBT	17	-	4	-	-	-	-	-	4
WB22	OB505A	64	-	-	-	-	2	-	-	2
WB25	IKMT	77	-	-	-	-	6	-	-	6
	OB505A	70	-	-	-	-	1	-	-	1
WB27	IKMT	68	-	-	-	-	8	-	1	9
	OB505A	63	1	-	-	-	2	-	-	3
WB28	IKMT	72	-	2	-	-	6	-	1	9
	OB505A	66	-	-	-	-	-	1	-	1
WB30	IKMT	75	-	-	-	-	6	-	-	6
WB31	IKMT	58	1	1	-	-	1	-	1	4
WB32	IKMT	59	-	-	5	2	3	-	-	10
	OB505A	16	1	1	-	-	1	-	-	3
WB35	IKMT	78	-	1	-	-	-	-	-	1
WB36	OB505A	74	-	-	-	1	-	-	-	1
	OB505B	74	-	1	-	-	-	-	-	1
Total			113	94	172	11	148	1	6	545

Age and mortality rate of juvenile Arctic Cod

Detailed otolith microstructure analysis data are provided in Database Table tbl_ArcticCod_Otolith_Microstructure.xlsx.

Hatch date frequency distribution of Arctic Cod juveniles

Lapillar otoliths of the 99 Arctic Cod larvae and juvenile were taken for analysis of the otolith microstructure. Both left and right lapilli of 3 individuals were damaged and were thus excluded from the analysis.

Hatch date of Arctic Cod sampled during the BOEM-2011 survey ranged from early January to mid-June with a peak at the end of April (Fig. 4).

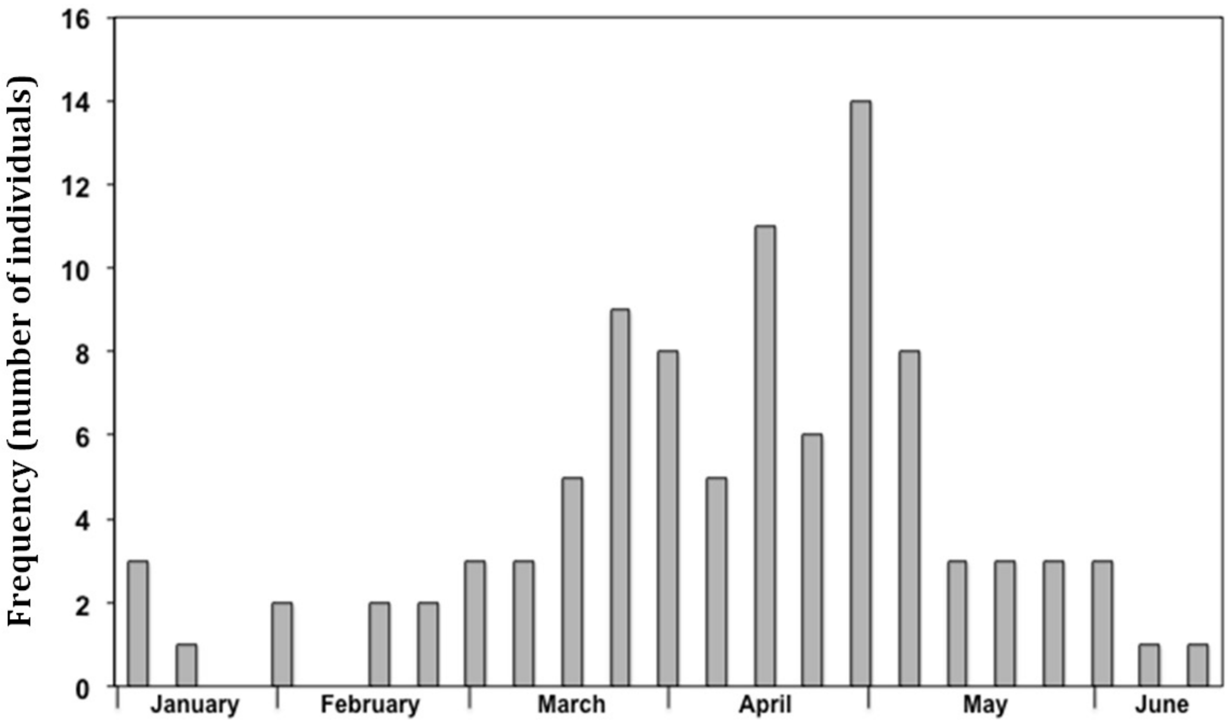

Figure C6- 4 Hatch date frequency distribution (HFDs; 7-d intervals) of Arctic Cod juveniles captured during the BOEM-2011 survey in the western Beaufort Sea. The HFDs are not corrected for differential mortality and dispersion caused by age differences among the bins.

Catch-at-age curve and estimation of mortality rate

The rate of mortality-dispersion was assessed from the catch-at-age curve (**Figure C6-5**). The catch-at-age curve was discontinuous prior to the age of 110 d, likely reflecting the late timing of sampling relative to that of the early growth season. Nevertheless, a distinct mortality-dispersion phase was obvious past the age of 110 d, with a dispersion-mortality rate of 2.2% d^{-1}.

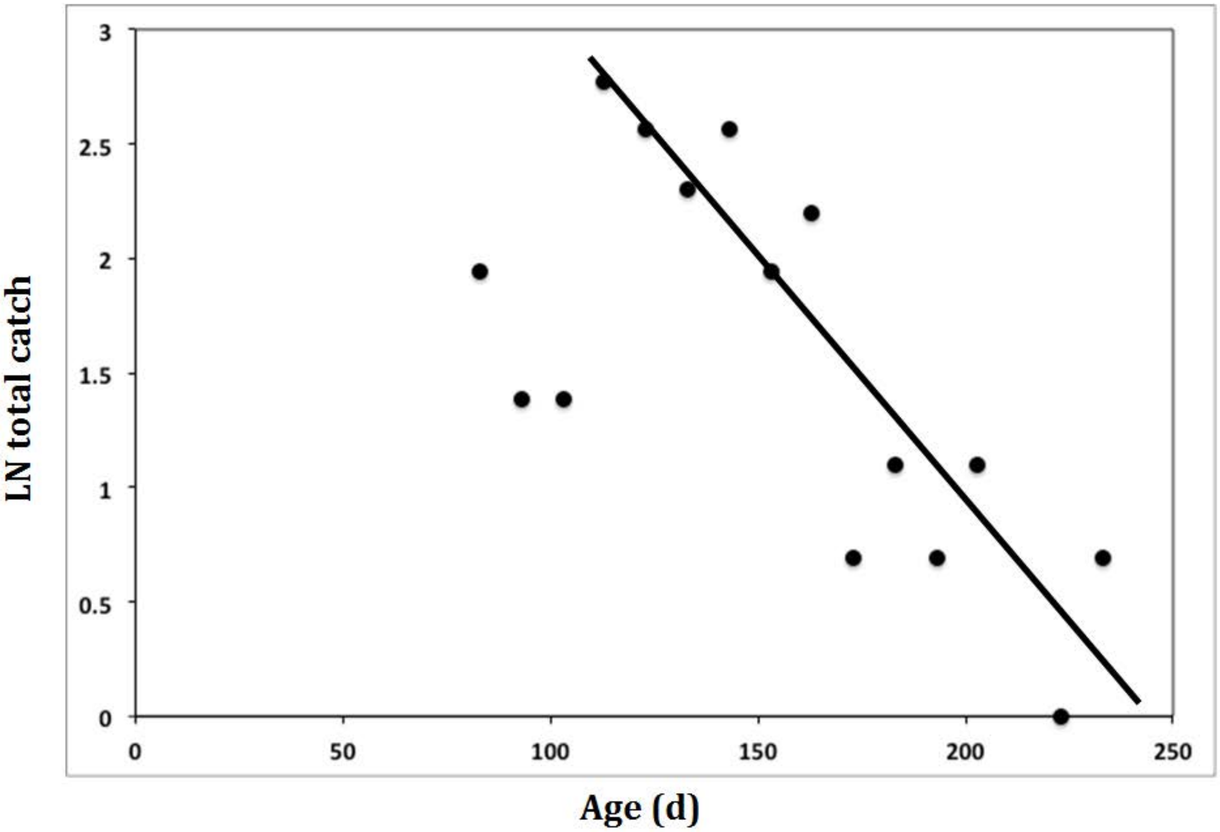

Figure C6- 5 Juvenile Arctic Cod catch during the BOEM-2011 survey in the western Beaufort Sea. The slope of the regression fitted to the 110–235 d age interval (ln catch = -0.022 + 5.293 age, $r^2 = 0.824$, $p < 0.0001$) was used to estimate the rate of loss of juveniles due to mortality and dispersion out of the sampling area.

APPENDIX C6. DISCUSSION

TAXONOMICAL COMPOSITION OF THE FISH ASSEMBLAGE

The Arctic Cod, *Boreogadus saida,* strongly dominates the pelagic fish assemblage of Arctic seas (e.g. Craig et al. 1982, Jarvela and Thorsteinson 1999, Sekerak 1982). Without surprise, Arctic Cod juveniles contributed 61.5% of the total catch from the bongo nets and were virtually absent from the catch of other samplers (with the exception of 8 individuals distributed within 4 IKMT hauls). On the other hand, snailfishes (Liparidae) and pricklebacks (Stichaeidae) were captured in high numbers by the different types of trawls targeting demersal and benthic fishes in coastal waters. These results appear consistent with the biology of the different species occurring in the coastal Beaufort Sea.

HATCHING PERIOD AND MORTALITY OF ARCTIC COD IN THE WESTERN BEAUFORT SEA

Hatching of Arctic Cod in the western Beaufort Sea in 2011 ranged from January to June (**Figure C6-4**), consistent with the findings of Lafrance (2009) in the southeastern Beaufort Sea in 2004. Hatch date frequency distribution (HFD) suggested that peak hatching occurred during late April in the present study, while it was reached slightly earlier (March–April) in the southeastern Beaufort Sea in 2004.

In the present study, HFD must be interpreted with caution as its pattern may partly reflect a sampling artifact. The BOEM-2011 survey was conducted over a short period of ~2 weeks in late August, which did not overlap with the hatching season of Arctic Cod. Because late hatchers emerged at least 2 months prior to the cruise, individuals sampled in the present study were necessarily >60 d old. The first three data points (ages <100 d) on Figure 5 represented these late hatchers only, and could not be used in the calculation of mortality-dispersion rate. The impossibility of determining mortality-dispersion rate for individuals <100 d prevented the estimation of the usually extreme mortality prevailing during the larval stage of the species (Fortier et al., 2006; Lafrance, 2009; Thanassekos and Fortier, 2012), and from correcting HFDs for differential mortality and dispersion caused by age differences among sub-cohorts (Fortier and Quiñonez-Velazquez, 1998).

In the present study, a weak but highly significant mortality-dispersion rate of 2.2% d-1 was observed in juveniles aged >100 d. In this study, mortality thus appeared higher during the early juvenile stage relative to the values reported by Lafrance (2009) in the southeastern Beaufort Sea in 2004, where mortality rate was so low that it could not be quantified for individuals aged >120 d.

As previously mentioned, mortality-dispersion rate is known to culminate during the larval stage, when individuals are highly vulnerable to starvation and predation (Anderson, 1988; Cushing, 1990; Houde, 2002). To date, larval mortality rate of Arctic Cod was estimated in the Northeast Water polynya, in the North Water polynya and in the southeastern Beaufort Sea (Fortier et al., 2006; Lafrance, 2009; Thanassekos and Fortier, 2012). In the Northeast Water, the spring cohort suffered an extremely high mortality rate of 63.3% d-1, while the summer cohort was characterized by a milder mortality rate of 13.9% d-1 (Fortier et al., 2006). In the North Water, mortality rate was estimated at 14.5% d-1 (Thanassekos and Fortier, 2012), while in the southeastern Beaufort Sea, it reached 12.0% d-1 and 7.8% d-1 for larvae aged 0–35 d and 48–120 d, respectively (Lafrance, 2009). On average, larval mortality rate is thus at least one order of magnitude superior compared to the juvenile mortality rate measured in the present study. While the BOEM-2011 dataset yielded important information on the hatching period and mortality rate of the early juvenile stage of Arctic Cod in the western Beaufort Sea, further sampling at higher spatiotemporal resolution is needed to refine estimates of HFD and early life mortality rate for this keystone species. An additional survey would also allow quantifying interannual variability in juvenile mortality for the species. While interannual variability in mortality processes would constitute crucial information for the development of sound mortality models, it remains largely unknown.

APPENDIX C6. ACKNOWLEDGEMENTS

I would like to express my gratitude to B. Gallaway (LGL Environmental Research Associates Inc.) and B. Norcross (University of Alaska Fairbanks) for initiating this project. B. Holladay and L. Edenfield kindly provided detailed methodology and metadata of ichthyoplankton sampling. Laboratory analyses were realized by L. Létourneau, H. Cloutier and C. Bouchard.

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APPENDIX C7. ARCHIVED SAMPLE LIST

Appendix C7 lists fishes archived from the BOEM-2011 cruise.

Table C7-1 indicates species and samples held at the University of Alaska (UAF) Museum of the North (UAM), of which the DNA was analyzed of some specimens and is included in the standardized reference sequence library Fish Barcode of Life (*http://www.fishbol.org/).* UAM identifying numbers for each sample of one or more individuals, and the identifying codes for those specimens with data in FishBOL are listed. Catherine W. Mecklenburg, Point Stephens Research, Auke Bay, Alaska, identified and prepared the voucher specimens for storage, prepared tissue samples for DNA analysis, and interpreted FishBOL results.

Table C7-2 indicates the quantity of larval and small juvenile specimens archived at the UAF Fisheries Oceanography Laboratory for potential additional identification via examination of morphometrics and genetics. The count of specimens is reported by station, gear and haul in **Appendix C6** (see **Table C6-4**).

Table C7- 1 Archived fish specimens held at the Museum of the North, University of Alaska Fairbanks (UAM) or with data in the standardized reference sequence library Fish Barcode of Life *www.fishbol.org/*. All specimens were identified by C.W. Mecklenburg of Point Stephens, Auke Bay, Alaska. Data downloaded 19-Nov-2014 from Arctos online database *http://arctos.database.museum/*.

Scientific Name	UAM Fish#	FishBOL Barcode#
Ammodytes hexapterus	6360, 6362, 6368, 6370, 6372	BEAU2011-06, -101 (60 mm), -106, -12, -15
Anisarchus medius	2967, 6294, 6303, 6307, 6349, 6435	BEAU2011-45 (110 mm)
Artediellus scaber	6326, 6332, 6338, 6355, 6387, 6414	BEAU2011-35 (70 mm)
Aspidophoroides olrikii	2965, 6269, 6283, 6301, 6304, 6316, 6324, 6327, 6343, 6354, 6373, 6374, 6397, 6406, 6407, 6411, 6416, 6419, 6422, 6423, 6430, 6431, 6432, 6433, 6436, 6445	BEAU2011-116, -117, -133, -136, -24 (61 mm), -83, -84 (33 mm), -85, -86 (34 mm), -87 (49 mm)
Boreogadus saida	6274, 6280, 6290, 6328, 6341, 6350, 6369, 6378, 6380, 6381, 6388, 6396, 6401, 6405, 6408, 6412, 6426, 6437, 6446, 6447	BEAU2011-109 (39 mm), -114 (104 mm), -132, -53 (105 mm), -66 (120 mm)
Careproctus	6356	BEAU2011-151
Careproctus reinhardti	6317, 6448	BEAU2011-05, -103 (103 mm), -104 (73 mm)
Careproctus reinhardti cf.	2973	
Eleginus gracilis	2966, 6361, 6376, 6398, 6413	BEAU2011-125
Eumesogrammus praecisus	6300, 6351	BEAU2011-82, -95
Eumicrotremus derjugini	6270, 6313, 6353	BEAU2011-152, -153, -23
Gymnelus hemifasciatus	6271, 6296, 6297, 6345, 6363, 6389	BEAU2011-112 (102 mm), -113 (97 mm), -119, -120, -122, -20 (94 mm), -21 (89 mm), -99 (62 mm), -100 (110 mm)
Gymnelus viridis	6272, 6275, 6417	BEAU2011-19, -22, -96 (91 mm), -97 (110 mm)
Gymnocanthus tricuspis	6279, 6288, 6298, 6325, 6329, 6333, 6382, 6390, 6400, 6402, 6409, 6420, 6425	BEAU2011-07 (101 mm), -08 (126 mm), -118, -25, -27, -33, -34, -36 (100 mm)
Hippoglossoides robustus	6286, 6337	

Table C7-1. Archived fish at UAM or FishBOL (continued).

Scientific Name	UAM Fish#	FishBOL Barcode#
Icelus bicornis	6449	BEAU2011-46
Icelus spatula	6273, 6299, 6334, 6357, 6415, 6418, 6424, 6438	BEAU2011-121, -137, -138, -139, -140, -141, -142, -143, -144, -145, -16 (39 mm), -17 (77 mm), -30, -32, -37 (62mm), -38 (82 mm), -39 (72 mm), -49
Leptagonus decagonus	6450	BEAU2011-68
Leptoclinus maculatus	6318, 6439	BEAU2011-67
Liparis bathyarcticus	6278, 6319, 6440	BEAU2011-102, -55, -64,BEAU2011-65 (107 mm)
Liparis fabricii	6305, 6320, 6399, 6451	BEAU2011-108, -115, -40, -70
Liparis tunicatus	6277, 6291, 6309, 6310, 6315, 6391, 6427	BEAU2011-09 (97 mm), -10 (95 mm), -51 (33 mm),BEAU2011-54 (30 mm), -76 (34 mm), -77 (31 mm), -78,BEAU2011-80 (30 mm, -79
Lumpenus fabricii	6284, 6293, 6392	BEAU2011-50, -94 (172 mm)
Lycodes mucosus	2963, 2964, 6281, 6314, 6336, 6344, 6365, 6371, 6393, 6529	BEAU2011-04 (50 mm), -74, -75
Lycodes polaris	6276, 6308, 6321, 6323, 6346, 6366, 6375, 6377, 6442	BEAU011-149, -105, -43, -69, -73, -81, -88 (148 mm), -89 (155 mm), -90 (239 mm), -91 (251 mm), -98
Lycodes raridens	6347, 6367, 6443	BEAU2011-110 (77 mm), -42
Lycodes rossi	6452	BEAU2011-47 (96 m), -48 (57 mm)
Mallotus villosus	6394	BEAU2011-107
Myoxocephalus jaok	6421	BEAU2011-93
Myoxocephalus quadricornis	6428	BEAU2011-146, -147, -148
Myoxocephalus scorpius	6285, 6289, 6330, 6339, 6358, 6385, 6403, 6410, 6429	BEAU2011-135, -26 (53 mm), -31
Nautichthys pribilovius	6312, 6340, 6530	BEAU2011-02 (46 mm)
Podothecus veternus	6359, 6364	BEAU2011-13, -14
Trichocottus brashnikovi	6379, 6531, 6532	BEAU2011-01, -03, -92
Triglops nybelini	6302, 6306, 6434, 6444, 6453	BEAU2011-123, -124, -131, -41, -44, -63 (108 mm)
Triglops pingelii	6282, 6287, 6322, 6335, 6348, 6352, 6386, 6395, 6404	BEAU2011-11 (112 mm), -111 (120 mm), -28 (53 mm)

Table C7- 2. Ichthyoplankton specimens archived at UAF Fisheries Oceanography Laboratory for potential additional identification via examination of morphometrics and genetics. Count of specimens is reported by station, gear and haul in Appendix C6 (see Table C6-4) for potential species verification followed by archival in a museum.

Scientific Name	Common Name	Count of specimens
Gadidae	Cods	113
Cottidae	Sculpins	94
Liparidae	Snailfishes	172
Agonidae	Poachers	11
Stichaeidae	Pricklebacks	148
Ammodytidae	Sand Lance	1
Pleuronectidae	Flatfishes	6
Total Count		545

UNDER-ICE PILOT PROJECT:

APPENDIX D
TO THE FINAL REPORT FOR CENTRAL BEAUFORT SEA MARINE FISH MONITORING, BOEM 2014-***

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University of Alaska Fairbanks

August 2018

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APPENDIX D1. UNIAQ PROJECT-SPECIFIC SAFETY PLAN

UNIAQ Project-Specific Safety Plan
UNIAQ Science, Ukpeaġvik Iñupiat Corporation, Barrow Alaska
UAF Marine Fish Monitoring Under-Ice Pilot Study
Brenda Norcross, Principal Investigator
Lorena Edenfield, Chief Scientist Investigator
21 February 2013

Introduction
UNIAQ is a business unit of the Ukpeaġvik Iñupiat Corporation (UIC), the village corporation for Barrow, Alaska. UNIAQ's Science Logistics group provides support to visiting research groups in the vicinity of Barrow to include project planning; health, safety, and environmental compliance; cargo receipt and handling; laboratories; and in-the-field support such as Ice Guides and Bear Guards. Each visiting project is managed as a separate entity depending on the specific requirements of each, including the creation of Project-Specific Safety Plans such as this document.

Purpose of Project Specific Safety Plan
UIC and UNIAQ are committed to proactive planning to address the Health, Safety, and Environmental (HSE) needs for each of our client projects. The UAF Marine Fish Monitoring Under-Ice Pilot Study led by Brenda Norcross involves activities which present a unique set of hazards including SCUBA diving under the wintertime Chukchi sea ice which warrant the creation of a Safety Plan specific to this project. By definition not all emergency situations can be foreseen ahead of time. However, with this and referenced documents we attempt to provide a reasonable framework to guide safe, productive, and environmentally sound fieldwork as well as respond appropriately to any unplanned circumstances.

Project Fieldwork Summary
A research team of 8 persons, funded via the US Department of Interior's Bureau of Ocean Energy Management, will visit Barrow, Alaska from 27 February through 4 March 2013. The field team includes Brenda Konar (UAF Diving Control Board Administrative Officer) and Rob Robbins (US Antarctic Program Senior Dive Supervisor) representing a significant level of experience in under-ice diving.

UNIAQ will provide airport pickup service; lodging; vehicle(s); general orientation; snow machine training; and field support to include tents, radios, generators, and other minor equipment; camp setup and movement; Ice Guide, Bear Guard, and general on-ice assistance.

The researchers will conduct a series of on- and under-ice activities to survey for the presence and abundance of different marine fish species during wintertime conditions. Up to four sites separated by ~100 meters will be sampled. The exact location of sites will depend on sea ice conditions and surveyed water depths. UNIAQ staff will scout and monitor potential sites during the weeks prior to the researchers' arrival; the target water depth for this project is 10-15 meters. Planned activities include the following:

- Holes will be cut through the ice to allow access to the water
- Tents will be set up as shelter for the researchers
- SCUBA divers will conduct a visual survey of the under-ice environment
- Water properties and ocean bottom sediments will be measured/sampled with standard oceanographic instruments
- Vertical plankton net casts (25 cm diameter ring net with 200 μm mesh) will be conducted
- A Video Ray Pro-3 GTO remotely operated vehicle (ROV) will be deployed into the water to collect still and video imagery
- A DIDSON active sonar system mounted on a pole will be deployed into the water to monitor fishes and the environment
- A gill net (20 meters long x 2.4 meters tall, 13 mm monofilament mesh) will be deployed under the ice overnight

The tents will be heated with propane stoves, as UNIAQ has successfully done for past projects. Lighting and power for the scientific instruments, including the tethered ROV and sonar systems, will be provided by small (<5kW) portable generators with appropriate spill containment.

The sonar system operates at acoustic frequencies of 0.7–1.8 MHz, similar to that of medical ultrasound devices and well above the known hearing range of bowhead whales, by transmitting a sound pulse every 0.1 seconds and receiving a signal reflected back by fishes, the underside of the ice, and the ocean bottom sediments. This work is occurring early enough in the season that no interference with subsistence whaling activities is expected. However, the project activities will be presented to the Barrow Whaling Captains' Association for their concurrence.

Anesthetics will be used in the field on fishes caught in the gill net according to approved protocols. Samples will be processed in laboratories at the Barrow Arctic Research Center on the NARL campus prior to being shipped for further analysis at UAF.

General Diving Protocols

Dive operations will follow standards established by the University of Alaska and described in the *Scientific Diving Safety Manual* including medical qualification, diver experience, depth limitations, equipment, dive logging, and surface tending. Specific protocols for this project include:

- Divers will work at depths no greater than 30 feet and will not exceed no-decompression bottom times for these depths. Most dives will be considerably shallower, occurring primarily directly under the ice. Therefore, emergency hyperbaric treatment is highly unlikely to be required.
- Approximately 6 dives are planned, and each will be conducted as a buddy pair with a backup diver on standby and acting as the surface tender. Some dives will be on SCUBA (open circuit) gear and the rest will use rebreather equipment. Divers are certified on this gear, and all equipment has been field tested under similar conditions in the Antarctic.
- A down line with strobes will be placed in the dive hole to help divers relocate their access point.
- Divers will be tethered.
- All dives will be done during daylight conditions.
- Water currents will be monitored before dives are conducted.

Safety Responsibilities

Each of the parties involved in these field activities is assigned specific responsibilities to ensure safe operations or to respond appropriately to emergencies as described below. In general, UNIAQ is responsible for field safety, while the research team is responsible for dive safety.

UNIAQ Operations Staff

- Scout sea ice during late February to locate suitable site(s) which satisfy:
  - ~200 m x 200 m relatively undeformed ice cover
  - Accessible by snow machine
  - 10-15 meters water depth
  - Low tidal current (if possible)
- Review and sign JHAs for snow machine use, on-ice travel, and Bear Guard activities.
- Recommend a location for the researcher-provided air compressor being used to refill scuba tanks. Such location must provide appropriate air intake free of chemical or petroleum fumes, vehicle exhaust, or excessive moisture and be protected from the weather.
- Provide snow machine training to researchers prior to beginning of fieldwork.
- Monitor trail and study site for ice stability throughout period of fieldwork.
- Verify radio compatibility with NSB SAR and Barrow Volunteer SAR teams.

- Provide proper spill containment for generators, stoves, and other on-ice equipment.
- Conduct daily safety meetings each morning prior to going on to the ice to review planned activities and verify preparedness.
- Ensure propane stoves and fittings are secure and not leaking.
- Maintain positive radio communication with base station (likely staff at Building 42) at all times including periodic check-in calls to convey operational status. Frequency of check-ins to be determined during pre-fieldwork orientation.
- Provide Bear Guard support.
- Advise research party immediately about any observed changes in weather or ice conditions which may affect operations.
- In case of any on-ice emergency, notify base station.
- In case of injury or medical emergency, ensure patient is stabilized then evacuate to hospital via most efficient means.

UNIAQ Administrative Staff

- Review this Project-Specific Safety Plan with all project participants prior to fieldwork beginning. Document participation with signed meeting log.
- Establish and document safe weather, air temperature, and water current limitations for field operations in consultation with the research team.
- With researchers, designate lead "Medical Officer" to be in charge of the immediate response to any emergency medical issues on the ice.
- Notify local Search and Rescue units of planned activities and study site location prior to beginning of fieldwork.
- Monitor radio traffic during field operations and ensure timely check-in calls are made and logged.
- In case of emergency, notify appropriate agency (SAR, hospital, police).
- In case of injury of medical emergency, stage truck as near to study site as possible to receive patient and transport to hospital.

Researchers

- Participate in snow machine training and sign attendance log.
- Provide DAN oxygen kit to be available on the ice.
- Provide emergency contact information for all team members working on the sea ice including non-divers to the UNIAQ Administrative Staff.
- Ensure that no equipment including active sonar systems will be placed into the water during dive operations without the specific approval of divers.

Divers

- Obtain appropriate medical clearance and certification including familiarization with equipment to be used in dry suit under-ice conditions.

- Ensure that all dive equipment is appropriate for its intended use and in good working condition.
- Establish communication protocols between surface tender and divers, including a signal to immediately terminate operations due to ice movement, polar bear presence, or other external condition of which the divers may be unaware.
- Create a written dive plan, to be shared among all divers and other support personnel as appropriate, prior to each day's diving operations.
- Ensure all divers adhere to accepted dive tables for determination of decompression status and surface intervals.
- Suspend diving operations if Lead Diver determines conditions are not safe.
- Conduct pre-dive equipment safety checks.
- Complete post-dive log entries.

UNIAQ Project-Specific Safety Plan
UAF Marine Fish Monitoring Under-Ice Pilot Study
Addendum
27 February 2013

Per our phone conversation, I would like to update you on the status of the project. Currently 3 holes have been cut, I've attached pictures for you and your group to review.

The Barrow Logistics staff have brought up some concerns that we believe your project staff should be aware of including recommendations for 2/28/13 and field plans.

1. A 3 lb. ball was placed and a swift current is noted in all three locations, we will continue to monitor, however it is suggested that the dive plans are modified on the first day, which will include a site visit after orientation, review of the Project Specific Safety plan, and snow machine operation training. This will give your project staff a sense of ice/hole conditions, temperature, currents and general awareness to be prepared the following day with diving.
2. Sled organization, should be organized as project gear that you need first when setting up gear and instruments you need first belong in the front, so unloading isn't tedious and limits cold weather exposure.
3. The camp is being set up today, with tents and propane stoves. I will forward pictures when I receive them.
4. A communication plan should be developed with your project staff and UNIAQ staff after review of the Project Specific Safety plan, all should be aware of who will communicate with the appropriate people while in the field and staff at the field office. Who will respond, what type of communication the divers have to notify us or each other to respond. Each day a safety meeting will be conducted and if there are issues that anyone noticed that could be improved please note and correct the following day to stay safe.
5. 2 – Bear Guards will go out with the group. With 2- Laborers to assist with unloading the sled, loading the sled, keeping the hole free from ice, etc.
6. All project staff will be housed at 5011 Boxer Street, Apartment #4. Charlie and Kate are unable to attend, there will be a total of 6 people in the project group.
7. The Roster will need to be signed by Project Personnel to acknowledge that the Project Specific Safety plan has been read and understood.

UNIAQ Safety Plan. Appendix A: Emergency Contact Information

North Slope Borough Police monitor VHF Channel 68
UNIAQ uses UHF Channel A1 for operations

Agency	Phone	Notes
Barrow Search and Rescue	907-852-2808	Volunteer organization
Divers Alert Network	919-684-9111	
Emily Roseberry	907-360-2685	UNIAQ Science Logistics Manager
Michael Donovan	907-229-6037	UNIAQ Acting Operations Manager
North Slope Borough Police	907-852-0311	
North Slope Borough Search and Rescue	907-852-2822	
Providence Hospital, Anchorage (emergency number)	907-261-3111	Closest decompression chamber
Samuel Symmonds Hospital	907-852-4611	
UNIAQ On-Call	907-367-6020	

UNIAQ Safety Plan. Appendix D: References

Antarctic Scientific Diving Manual, US Antarctic Program, October 1998.

NOAA Diving Manual, Diving for Science and Technology, National Oceanic and Atmospheric Administration, Office of Undersea Research, US Department of Commerce, 2001.

Norcross Under-Ice Cruise Plan 7 Feb 2013

North Slope Borough Land Management Regulation permit #13-316, North Slope Borough Planning and Community Services Department

Scientific Diving Safety Manual, University of Alaska, May 2004 (http://www.sfos.uaf.edu/dive/manual/divemanual-entire-04.pdf)

Standards for the Conduct of Scientific Diving, US National Science Foundation Office of Polar Programs, June 2011 (http://www.sfos.uaf.edu/dive/NSF-OPP_diving_standards.pdf)

University of Alaska Dive Plan form, University of Alaska (http://www.sfos.uaf.edu/dive/forms/UA_dive_plan_form.doc)

APPENDIX D2. BEAUFORT SEA UNDER-ICE-2013 PILOT STUDY PLAN

Authors: Edenfield LE, Norcross BL
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A. PLANNED FIELD DATES

28 February 2013: Personnel arrive in Barrow, AK
28 February 2013: UNIAQ orientation, prep for field work
28 February – 4 March 2013: Field work under ice
4 March 2013: Pack up gear, return to Fairbanks

B. RESEARCH PARTICIPANTS

Science Personnel (name, affiliation, role, e-mail)

1. Brenda Konar, UAF- chief scientist, diver, bhkonar@alaska.edu
2. Mark Barton, Florida International University- DIDSON operator, mbart034@fiu.edu
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5. Sarah Traiger, UAF- diver, sbtraiger@gmail.com
6. Dan Anderson, Global Diving and Salvage, Inc.- ROV operator

Field Logistics Personnel, UNIAQ, LLC (name, affiliation, role, e-mail, phone)

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C. CORE PROJECT SUMMARY

Divers and scientists from the University of Alaska Fairbanks (UAF) will conduct the work specified in the BOEM Agreement Number M10AC2004, "Central Beaufort Sea Marine Fish Monitoring." The Beaufort Sea under-ice survey will compare SCUBA diver and ROV observations with gill net captures and DIDSON. It will also include CTD and zooplankton collection. The data collected, coupled with information gathered during the open water season 2011, will provide a baseline data set that encompasses summer and winter seasons in the Beaufort Sea.

D. RESEARCH OBJECTIVE

Our research objective is to collect quantitative gill net, SCUBA, DIDSON, and ROV data to assess presence and abundance of marine fishes that occupy the nearshore habitat around Barrow, AK area during the ice-covered season. We plan to sample four sites at 10-15 m depth with a minimum distance of 100 m between holes. Sites will be located within the proposed sampling area (Figure D2-1) but actual site location will be determined by UNIAQ personnel based on ice condition near the time of sampling.

We anticipate collecting the following samples:

- Fishes from overnight gill net sets
- Zooplankton tows (ice associated fauna)
- SCUBA observations
- ROV video footage
- DIDSON imaging
- CTD data
- ADCP data

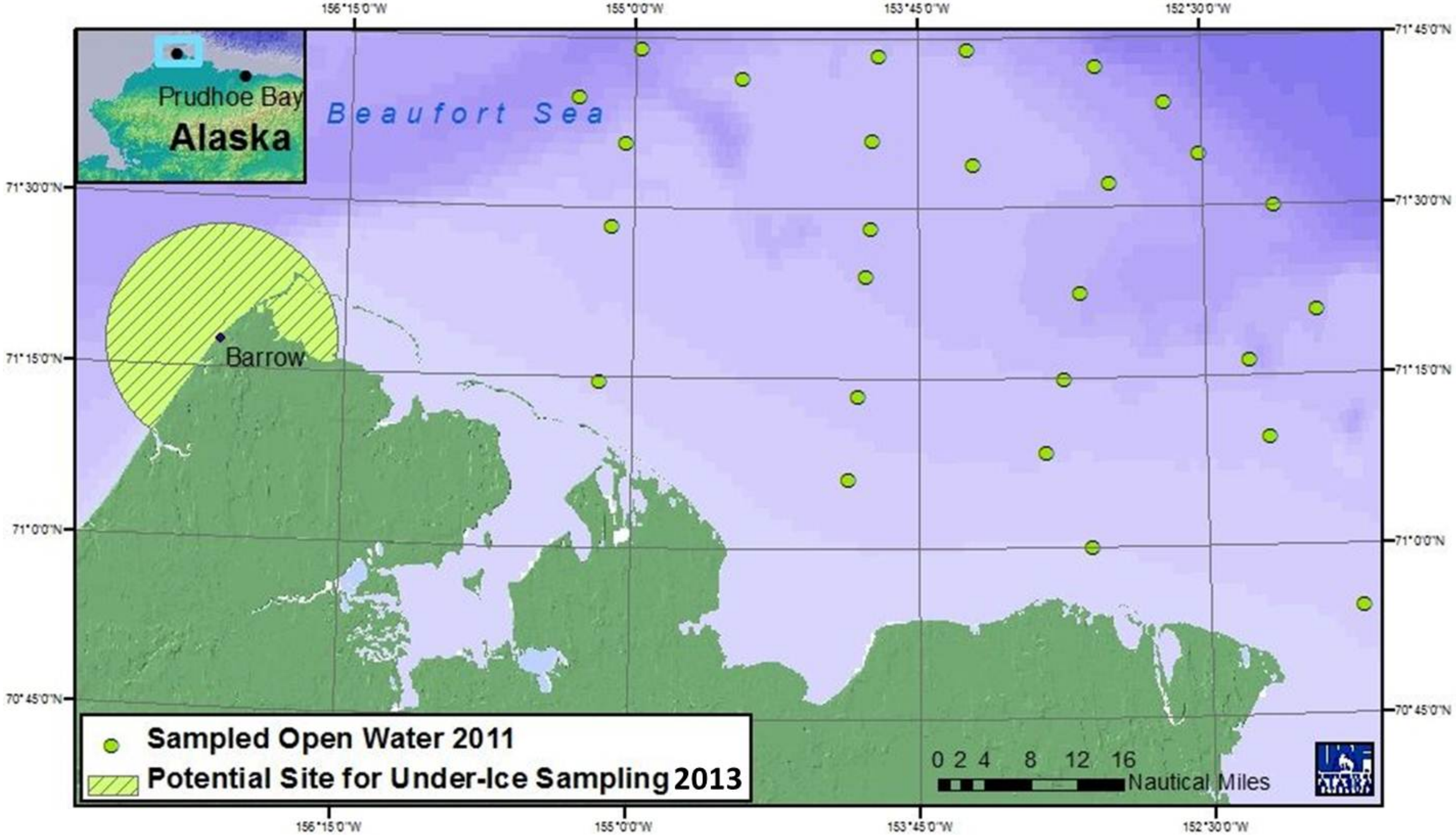

Figure D2-1. Potential sites for under-ice sampling in spring 2013. Actual location to be determined on site, based on ice conditions.

E. FIELD EQUIPMENT

Specifications, operating procedures, and samples

E.1. CTD

- YSI EXO sonde with DO, TSS, temperature, conductivity and depth (from Kevin Boswell)

At each site, at least one CTD will be cast by hand through the water column vertically.

E.2. Vertical Net

N= 1 nets, N=1 frame, N=1 codend

- Frame: aluminum 25 cm ring net frame (sturdy)
- Net: 25 cm x 1 m 200 µm mesh style nets
- Codend: 200 µm, 6 cm (diameter) x 21 cm (length), PVC

One sample of zooplankton will be collected daily by towing the zooplankton net by hand through the water column vertically. Upon retrieval, nets will be rinsed with saltwater to wash the sample into the codend.

E.3. Gill Nets

N= 2 nets, weights/floats to be provided by UNIAQ

- Monofilament floating gill net 20 m (L) x 2.4 m (H) with 13 mm mesh

Monofilament gill net dimensions are: 20 ft L x 8 ft D, with 1/2" mesh. Prior to leaving the ice each day, with the assistance of divers, a gill net will be set under the ice. We anticipate 4 distinct gill net sets for this study. The depth of the net set will be based on the sampling location (to be determined at time of ice drilling, based on ice conditions), but the net will be set at or near the bottom. Gill nets will be set beneath the ice in the evening and pulled immediately upon returning to the site in the morning (approximately a 12 hr soak time). Fish encountering the gill net will become entrained in the nets. All marine fish species are targeted. Any non-target bycatch will be released on site.

All fish will be removed as gently as possible from the gill net. Fishes will be euthanized according to approved UAF International Care and Use Committee protocol 307495-3 (Under-Ice Beaufort Sea Survey) by placing the fish in a 130 mg/liter solution of tricaine methanesulfonate (MS-222) in freshwater until gill movement ceases or by a sharp blow to the head followed by cutting the gills. Euthanized fish will be placed on the ice or in ice water during processing. Fish identification keys and descriptive information (e.g., Matarese et al. 1989 and Mecklenburg et al. 2002) will be used for identification. All fish captured will be identified, counted, and measured. If necessary, verification of field identification to species will be done in the UAF Fisheries Oceanography Lab in Fairbanks under a dissection microscope. All fishes will be retained returned to the Fisheries Oceanography Lab for precise measurement of length and weight; some fishes will be archived for potential additional analyses (e.g., otoliths, stomach contents, and stable isotope analysis).

All fishes will be retained and transported to the UAF Fisheries Oceanography Laboratory in Fairbanks, AK for further processing. After on-site length processing, fishes will be packaged by species into groups of 5–10 individuals in a Ziploc bag with a label containing collection information (date, location, species) and kept on ice until the nightly return to Barrow, at which point they will be frozen or preserved for transport back to the UAF Fisheries Oceanography lab in Fairbanks, AK. Specimens needing further identification will be preserved in genetics grade ethanol. Muscle tissue or fin clips may be collected from some species for genetic analysis.

E.4. Dive Plan

Project or Mission:

The goal of this portion of the under-ice study is to determine the feasibility of using rebreathers to quantify the density and distribution of under-ice arctic fishes and their ice habitat. This study will also determine the ease of using divers to facilitate gill net deployment in under-ice conditions. These goals will be achieved by 1) conducting both scuba and rebreather surveys for fish and under-ice habitat and 2) using both scuba and rebreathers to deploy gillnets outside Barrow Alaska.

Sample Methods:

In Barrow, one hole will be placed in the ice by the UNIAQ. This ice hole will be covered with a heated tent or weatherport. There will always be two divers (one on scuba and one on a rebreather) in the water with one diver on the surface for support.

Fish density will be determined using a visual survey. For this, the divers will count and identify all fishes along three randomly placed 10 m (long) x 1 m (wide) transects under the ice and radiating at random directions from the ice hole. On every dive, one diver will be using scuba, while the other is using a rebreather. Divers will work simultaneously on opposite sides of the transect so that each can watch her dive partner without disturbing the partner's transect. Diver fish surveys will consist of two search patterns, (1) the initial search will target mobile fish within 2 m (vertical distance) of the ice interface (2) the second search will target cryptic species associated with the ice crystals. When the fish transect is done, under-ice rugosity will be measured using a modified bar and chain method (probably in a second dive). In this modified version, the chain is replaced by a positively buoyant and flexible material. This modified version was tested in the Antarctic in October 2012. On a third dive, divers will attempt to use slurp guns to collect a representative sample of the fish being seen on the transects for positive identification. Fish collected with the slurp gun will be immediately given to the fish personal on the surface for processing. It is hoped that with these data, fish abundance and diversity can be correlated to ice rugosity.

Dates:

Dive between Feb 28-March 3, 2013

Diver Qualifications:

-Brenda Konar: Current UA scientific diver, depth certification 130 ft, PADI Instructor, rebreather proficiency
-Rob Robbins: Current USAP scientific diver, depth certification 190 ft, NAUI Instructor, rebreather proficiency
-Sarah Traiger: Current UA Scientific diver, depth certification 30 ft, Open Water Diver

Emergency Plan:

Personal emergency contact for each diver

- Brenda Konar: Doug Schneider, Husband, 907-388-4726
- Rob Robbins: Robbie Score, Wife, H: 303-770-3696, C: 303-906-0093
- Sarah Traiger: Father, 907-345-1045

Recompression Chamber/Hospital/Transportation

Anchorage

Chamber Operator: American Marine	907-565-4600
Chamber Supervisor: Robert Thompson, MD	907-565-4600
Providence Hospital Outside Anchorage	800-478-5433
Providence Hospital	907-261-3120
Providence Hospital Emergency	907-261-3111
Providence Hospital Air Ambulance	907-261-3070
Alaska Regional Hospital: Air Ambulance	907-276-1131 800-478-9111
Anchorage USCG	907-271-6700 907-229-8203
Barrow Hospital	907-852-4611
Barrow Fire	907-852-3473/3476
Barrow Rescue Coordination	1800-830-2822
DIVERS ALERT NETWORK	919-684-4326

Approximate Number of Proposed Dives:

Konar and Robbins will do approximately 6 dives each (half on scuba, half on rebreather). Traiger is a back-up diver.

Location of Proposed Dives*:*

Dives will be conducted through a dive hole on the sea ice outside Barrow. Exact location will be determined after consulting with UNIAQ (logistics company). All dives will be under-ice.

Estimated depth(s) and bottom time(s) anticipated:

Divers will dive to depths no greater than 30 feet and will not exceed no-decompression bottom times for these depths. Most dives will be considerably shallower since we will primarily be directly under the ice.

Decompression status and repetitive dive plans:

All divers will follow and not exceed the no-decompression limits for bottom time and repetitive dive plans.

Notify chamber if decompression diving is anticipated:

No diver will conduct decompression diving during this trip.

Proposed work, equipment, and boats to be employed:

We will be conducting approximately six rebreather dives for proficiency of the equipment and to survey under-ice fish and fish habitat. Rebreathers that will be used are Poseidon. Training and certification for Robbins and Konar on this unit was done in summer 2011. On each dive, one rebreather diver and one scuba diver will go underwater; the third diver will surface tend. Traiger will only dive scuba.

Any hazardous conditions anticipated:

To help prevent freeze-up of gear, a fish hut or similar shelter will be placed above the dive hole. A down line with strobes will be placed in the dive hole to help relocate the hole. Divers will be tethered. Divers will be done during daylight conditions. Tidal currents will be monitored before dives are conducted. Dr. Konar will make the initial decision on when these conditions are not favorable. Cold water temperatures and below freezing air temperatures are expected conditions as well. Dry gloves and cold water hoods will be provided for divers to help them function efficiently and safely in the cold conditions.

A hole/diver tender (with emergency dive gear and DAN O2 kit at the ready) will be present at all times divers are in the water.

E.5. ROV

- Video Ray Pro 3 GTO
    - Owned and operated by Global Diving and Salvage, Inc.
    - Specifications appended. This particular ROV will have mounted and calibrated lasers attached for accurate underwater measuring capabilities

The ROV will be manipulated in real time by an operator on the surface of the ice. ROV observation transects will follow the transects completed by divers, matching compass heading and minimum distance. Footage will be recorded and brought back to the UAF Fisheries Oceanography Laboratory in Fairbanks, AK, where it will be analyzed. Fishes will be visually counted and identified to the lowest possible taxonomic level (most likely family). When possible, fish length will be recorded from the calibrated laser display. The ROV video footage will be compared with the fish counts and identification from the SCUBA dives.

E.6. DIDSON

Fish and invertebrate movement around ice edges will be sampled using an ARIS acoustic imaging sonar (http://www.soundmetrics.com). The ARIS operates as an acoustic video camera (4–30 frames/s) and is not dependent on light or water clarity for imaging. In high-frequency mode (3.0 MHz), the ARIS will use 128 beams (0.24° horizontal [H] x 14° vertical [V]) for a total field of view of 31° H x 14° V. Given the very high-frequency (3MHz) and low power (30W), this device is well outside the hearing range of all fishes and mammals (Webb et al. 2008).

Building upon previous acoustic imaging sampling efforts (Handegard et al. 2012; Kimball et al. 2010; Boswell et al. 2008), a vertically oriented ARIS will be deployed through a hole in the ice to collect under-ice imagery of fish and invertebrates in the water column and associated with the bottom. The sonar will be mounted to a rotating motor to allow for panning and tilting with real-time viewing of collected data via the connected computer. Power supply and data acquisition will be controlled from the channel bank, where the two ARIS units will interface with a laptop computer for real-time viewing and data storage.

E.7. ADCP

An acoustic Doppler current profiler (ADCP) is a quasi-remote sensing tool that can measure velocity profiles away from a set of transducers. The main objective of the data collection for this study using an ADCP is to quantify the vertical profiles of the velocity vector field under the ice and determine the variation during time of observations. The ADCP will also provide surface temperature as well as backscatter of the water column at different depths, giving information of distribution of small particles in the water.

As indicated in Figure D4-2, the ADCP is screwed through a foam disk sandwiched by two thin disks of wood board for buoyancy. The diameter of the ADCP is ~ 9 inches and the diameter of the foam is 11.5 inches. The height of the entire structure including both ADCP and the foam disk is ~ 1.5 ft. The ADCP will be weighted and anchored to the ice in such a way that the instrument will be at mid-depth. The instrument is set to start logging on 02/28/2013 at 2300 UTC and run for 30 days.

GPS location and deployment time will be recorded at each deployment and retrieval of the ADCP. The data collection is automated such that data are directly saved in the computer every second. ADCP deployments will last as long as possible, but are dependent on other gears and sampling methods. If other operations are been done at the same time, the ADCP measurements can be done in alternation with other activities so that we have a maximum data collection. This should be whenever possible during the sampling period so we can eventually piece the data together to extract tidal and non-tidal signals through various post sampling analyses.

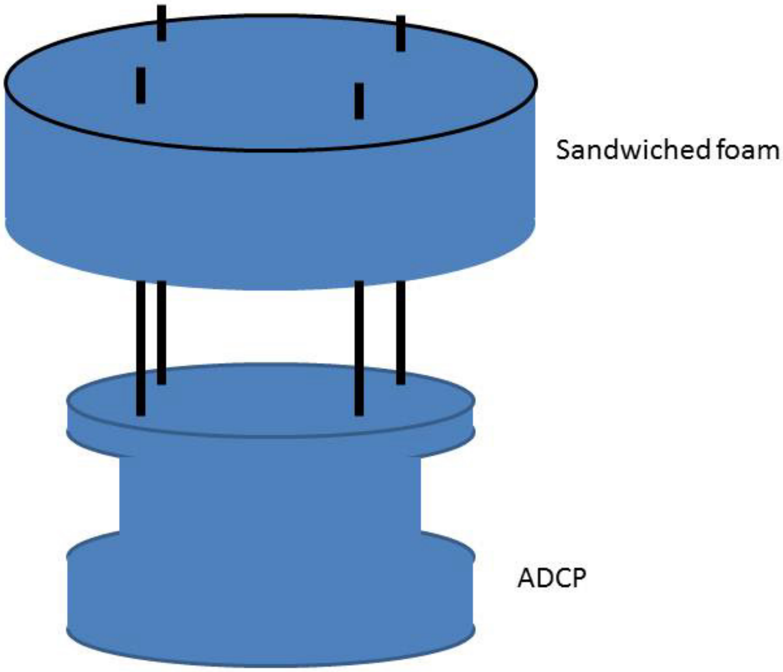

Figure D2-2. Diagram shows the ADCP with sandwiched foam disk for buoyancy. The diameter of the ADCP is ~ 9 in and the diameter of the foam is 11.5 in. The height is ~ 1.5 ft.

F. TENTATIVE SCHEDULE

Table D2-1 indicates a tentative schedule of sampling. This schedule assume dives and ROV each take approximately 1.5 hours each, and that plankton/CTD/gill nets takes another 1.5 hours for a total daily time on ice approximately 9-10 hours. ADCP and DIDSON will be running as often as possible during and between other sampling events. All sampling events can be shuffled around based on current conditions.

G. PERMITS AND NOTIFICATION

1. Outreach information was presented to the Alaska Eskimo Whaling Commission in February, 2012 by Dr. Brenda Norcross
2. ADF&G Fish Collection Permit– submitted
3. North Slope Borough Land Use Permit– approved 12 Feb 2013
4. IACUC / UAF: Protocol 307495-3– approved by the Institutional Animal Care and Use Committee, Office of Research Integrity, UAF

Table D2-1. Tentative schedule for under ice sampling.

	28-Feb-13				1-Mar-13			2-Mar-13			3-Mar-13			4-Mar-13			
	Barrow	Site #1	Site #2	Site #3	Site #1	Site #2	Site #3	Site #1	Site #2	Site #3	Site #1	Site #2	Site #3	Site #1	Site #2	Site #3	Barrow
Diving- habitat assessment					X				X				X				
Diving- capture and count fish					X				X				X				
Diving- set gill net evening (can be combined with another dive)					X				X				X				
Pull gill net								X				X				X	
DIDSON		X			X	X			X	X			X			X	
ROV, following dive transects					X				X				X				
CTD- morning					X				X				X				
CTD- evening		X				X				X							
Plankton Cast- evening		X				X				X							
ADCP		X			X	X			X	X			X			X	
Prep gear for sampling or transport	X																X

APPENDIX D3. REPORT ON CRUISE UNDER-ICE-2013

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A. FIELD DATES

28 February 2013: Personnel arrive in Barrow, AK
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B. RESEARCH PARTICIPANTS

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1. Brenda Konar, UAF- chief scientist, diver, bhkonar@alaska.edu
2. Mark Barton, Florida International University- DIDSON operator, mbart034@fiu.edu
3. Lorena Edenfield, UAF- fish collection/identification leedenfield@alaska.edu
4. Rob Robbins, UAF- diver, robbinro@gmail.com
5. Sarah Traiger, UAF- diver, sbtraiger@gmail.com
6. Dan Anderson, Global Diving and Salvage, Inc.- ROV operator

Field Logistics Personnel, UNIAQ, LLC (name, affiliation, role, e-mail, phone)

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8. Dominique Fox- Project Coordinator, dominique.fox@uicUNIAQ.com
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9. Brower Frantz- Barrow Operations Manager, brower.frantz@uicUNIAQ.com
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    907-360-2007 or 907-852-7457
11. Karl Newyear- Chief Scientist, karl.newyear@uicUNIAQ.com
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12. Emily Roseberry- Science Logistics Manager, emily.roseberry@uicUNIAQ.com
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C. CORE PROJECT SUMMARY

Divers and scientists from the University of Alaska Fairbanks (UAF) conducted the work specified in the BOEM Agreement Number M10AC2004, “Central Beaufort Sea Marine Fish Monitoring.” The Beaufort Sea under-ice survey included SCUBA diver and ROV observations, gill net sets, DIDSON, CTD casts, and zooplankton collection.

D. RESEARCH OBJECTIVE

Our research objective was to collect quantitative gill net, SCUBA, DIDSON, and ROV data to assess presence and abundance of marine fishes that occupy the nearshore habitat around Barrow, AK area during the ice-covered season. We sampled three sites at 10-15 m depth with a minimum distance of 100 m between holes.

E. PILOT STUDY RESULTS

Researchers arrived in Barrow, AK on 28 February 2013. Three sampling sites had been prepared by UNIAQ personnel prior to our arrival. After a safety orientation at UNIAQ offices, we went to Hole #3 to inspect the site and do a CTD cast. Following that, we returned to Barrow to prepare gear for the next day of full sampling.

On 1 March 2013, we arrived at Hole #3 and noted that a fish was observed in the hole near the surface. Species identification was not possible. After a successful CTD cast, the divers conducted a habitat dive. The undersurface of the ice was characterized as very flat, while the substrate was muddy. No fish were observed. The ROV was then deployed, but no fish were observed. The ROV operator noted that the compass of the ROV was having some issues, possibly due to the location of the site. Unfortunately, the video feed did not record properly at this site. After the ROV was retrieved, the DIDSON was deployed for approximately 90 minutes. Again, no fish were observed. A vertical plankton tow was conducted, and preserved for transport to Fairbanks, AK. The final deployment on this date was the gill net, which was set by the divers. The initial deployment procedure proved to be very difficult for the divers to control the weights and stretch the net across the hole without becoming tangled with the tether line. It was decided that future gill net deployments would be modified so that one diver would bring the entire net out from the hole, with the other diver swimming alongside the ice holding the transect tape. The diver holding the net would then drop the net and use the transect tape as a tether to the hole. Then, at the hole, both divers would take the end of gill net, which is tethered to surface with the dive tether and try to stretch net out more then follow tether line back up.

The following day, we started sampling by pulling the gill net set at Hole #3. No fish were captured, although two 50 mm isopods were retrieved along with the net. From there, we traveled to Hole #2. The CTD was successfully deployed. The divers conducted a habitat assessment dive and the under-ice habitat was again classified as flat with muddy substrate. One jellyfish was observed. The ROV was deployed and we were able to observe what appeared to be an under-ice ridge with organisms moving around it. We were unable to get close enough to identify them, however. Due to the issues with the heading readings, we can only say that this ice ridge was within 25 m linear distance from the hole. The video feed from this site recorded successfully and isopods and shrimps can be observed in the footage. The ADCP and the DIDSON were then deployed. Again, nothing was observed on the DIDSON, although scientists observed a jellyfish at the surface of the hole. A vertical plankton tow was conducted, followed by a gill net set. The modified setting plan from the previous day worked well. We returned to Barrow for the night.

On 3 March 2013, we arrived at Hole #2 in the morning to pull the gill net. No fish were captured, but the net was full of jellyfish. There were approximately 20 jellyfish ranging in size from 50-400 mm. A few 50 mm isopods were also present in the gill net. After the gill net was retrieved, we traveled to Hole #1 to continue sampling. At this hole, it was noted that a crack had developed overnight, which made sampling unsafe. In addition, the weather had come up significantly since the morning travel and was at the limit of what UNIAQ personnel were comfortable being on the ice. As a result, sampling at Hole #1 was canceled, and we packed our gear and returned to Barrow. Upon returning to Barrow, gear was packed up and prepared for transport to Fairbanks.

This project was very important in answering questions about gear deployment and feasibility for sampling under the ice in the Arctic. In future studies, we recommend having a scientist on site during site selection to ensure that an area with adequate under-ice habitat is selected. We believe that holes located closer to jumble ice would have had better fish and invertebrate habitat for scientific observations.

Table D3- 1. Sampling effort during Under-Ice-2013.

Hole #	**Latitude (°N)**	**Longitude (°W)**	**Depth (m)**	**CTD**	**Dive**	**ROV**	**ARIS**	**ADCP**	**Plankton tow**	**Gill net**
1	71.3800	156.5883	8.5	X						
2	71.3818	156.5792	9.1	X	X	X	X	X	X	X
3	71.3770	156.5810	9.7	X	X	X	X		X	X

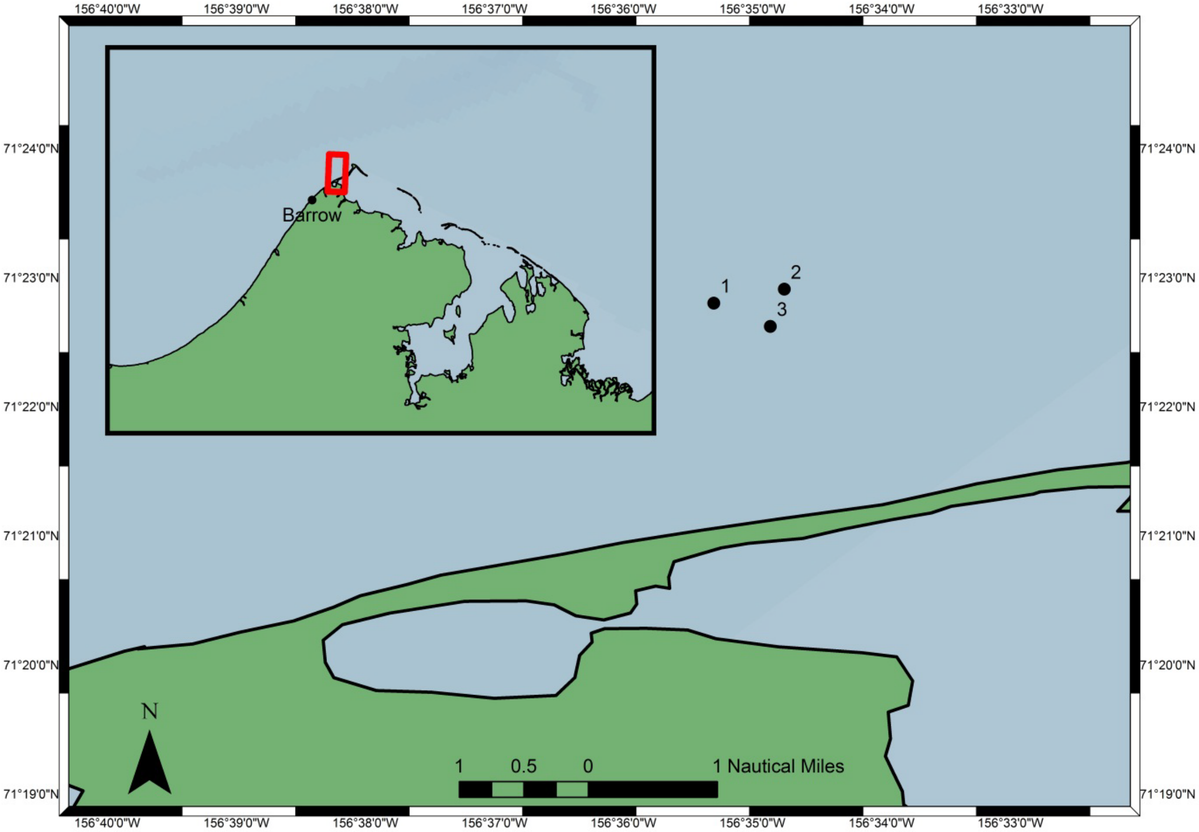


Figure D3-1. Sample locations (Holes 1–3) examined March 2013 during Under-Ice-2013.

APPENDIX D4. DIVE REPORT FOR CRUISE UNDER-ICE-2013

Author and Co-Principal Investigator: Konar B

FEBRUARY 28 2013, DAY 1: DIVERS

After leaving Fairbanks at 7 am, we arrived in Barrow around 10:30 am. Once we arrived, we went through an extensive safety and general project briefing with UNIAQ, including talking about diving concerns. This discussion went well and everyone seemed to agree on all points that were brought up (concerns regarding ice break-out, polar bear sighting, strong currents, etc…). After the briefing and lunch, we went to examine our first site (Hole #3). It seems to be in a good location, i.e. away from leads, in about 10 m of water, and has a nice sized opening (about 4 ft x 4 ft). We lowered a transect tape with a 5 lb weight on the end into the hole to see if we could detect any currents. Since none were felt, we put in a transect tape with no line. At this point, a slight current was noted but not bad enough that the divers thought it would be a concern. We could also see that water visibility was about 2 m vertical, which is okay. If conditions hold until tomorrow, we will dive tomorrow. After accessing the hole, we went back to our storage area and put the rebreathers together, filled our scuba and rebreather tanks, and checked and staged on our other dive gear. This took a bit longer than anticipated so we had a short dinner break and then continued. We finished up at around 11 pm.

MARCH 1 2013, DAY 2: DIVERS

At the morning safety meeting with UNIAQ at 8:00 am, we went over the day's plan. After the meeting, we went back to the warehouse to finish prepping the gear and packing it all on the sleds. One of the rebreathers would not start because of unknown reasons (it had a slight free-flow that we could not fix that may have been causing the error) but the second one was fine. We got to the dive site (Hole #3) around 11:30 am and checked the current and visibility. There was a small current (a bit more than the previous day) but it was hard to gauge its strength. Vertical visibility was approximately 3 m. We put in one tethered diver (Konar) to check the current directly below the ice. The current was not that bad so the second diver (Robbins) went in on the rebreather. The purpose of this dive was to determine habitat rugosity and under-ice fish density. Three 10 m transects were surveyed in three random directions radiating from the hole. All the ice was completely flat (rugosity = 1) with no brash ice and no fish were seen. At the end of the dive, the divers descended to the bottom (10 m) to determine substrate, visibility, and potential for fish. The bottom was mud with some ice scouring apparent. Visibility was down to about 0.5 m on the bottom. After checking out the bottom, the divers surfaced, stored their gear and had lunch. After all other tasks were complete, the divers assisted in putting in the gill net. One interesting thing that was noted with the ROV was the diver bubbles under the ice surface. It was very obvious where the scuba diver had gone under the ice because of the air pockets. When the net was placed under water, the net was centered below the hole, with 10 m of the net stretched out from opposite sides of the hole. The net was fairly close to the bottom because the line from the net to the 25 lb weights was short (about .25 m). When this was done, the gear was all repacked on the sleds or stored in the tent and we went back to the warehouse. At the warehouse, we hung up our gear to dry, filled tanks, cleaned the rebreather and went back to the apartment for dinner at about 6:30 pm.

MARCH 2 2013, DAY 3: DIVERS

Prior to the safety meeting, we went to the warehouse to start packing the gear. At 7:30 am, we went to the college for breakfast and the morning safety meeting with UNIAQ. The meeting went well. We were happy with the support we had the previous day. There was a discussion regarding the possibility of taking the divers back to town after the habitat assessment was done. They could get some gear dried off, including the gill net. The divers would then return to the hole in the late afternoon with the dried gill net that they would then deploy. UNIAQ did not think that this would be a problem. After the morning meeting, we went to the warehouse to finish packing and loading the gear onto the sleds. The same rebreather that would not start yesterday would not start again today so we started a 6 hr re-initialization (as suggested in the manual). We then packed the same rebreather that we used yesterday. Once the sleds were packed we returned to the first day's hole (Hole #3), where we pulled the gill net. We had two isopods in the net and no fish. We packed up the net and went to a new hole (Hole #2, second site). At this hole, we checked for current with the transect tape. We had only a slight current and similar visibility to yesterday so we decided to go with the same plan as yesterday. We put in one tethered diver (Konar) to check the current directly below the ice. The current was not that bad so the second diver (Robbins) went in on the rebreather. The purpose of this dive was to determine habitat rugosity and under-ice fish density. Three 10 m transects were surveyed in three random directions radiating from the hole. All the ice was completely flat (rugosity = 1) with no brash ice and no fish were seen. At the end of the dive, the divers descended to the bottom (10 m) to determine substrate, visibility, and potential for fish. The bottom was mud with a few mud covered rocks, and some ice scouring. Visibility was approximately 4 m on the bottom but vertically, we could see the hole. This site had better visibility than yesterday's site. After checking out the bottom, the divers surfaced, stored their gear and returned to the warehouse with the drysuits, regulators, rebreather, and gill net. We disassembled everything and hung everything to dry for an hour, after which we packed the dive gear and net and headed back out to the hole. Konar took the graduate student for a short check-out dive so that she could get some under-ice experience. They went along the ice for a while and then descended to the bottom. They looked at some isopods on the mud, swam around a bit and then came up to explore the under-ice some more. A few ctenophores were seen. After 11 minutes, Traiger went out of the hole and Robbins came in to help deploy the gill net. This time, the net was extended with one end at the hole and the other 20 m away. The set went well and overall seemed a safer and more efficient way to deploy the net. After this, we went back to the warehouse to clean and hang gear to dry. It should be noted that the dive that Traiger did was an excellent opportunity for this student to experience something new, diving under the ice in Barrow.

MARCH 3 2013, DAY 4: DIVERS

Similar to yesterday, prior to the safety meeting, we went to the warehouse to start packing the gear. At 7:30 am, we went to the college for breakfast and the morning safety meeting with UNIAQ. The meeting went well. Again, we were happy with the support we had the previous day. There was some discussion about the weather getting worse with colder temperatures and higher winds. After the meeting, we went back to the warehouse and packed the sleds and headed out for the new hole. When we got to Hole #1 (third site), we checked the current, which was significant. As we were discussing safety concerns regarding the current, UNIAQ's operation manager came into the tent and pointed out a new crack that went diagonally through the hole (that was not there the day before). Because of the wind and current directions and the position of the crack, the operations manager called the day. There was some discussion about going to a different hole but the weather was continuing to get worse.

Table D4-1. Dive activity.

Date	Hole #	Activity	Under-ice Observations
February 28	Hole 3, first site	Observed site, no dive	
March 1	Hole 3	Habitat dive: 30 ft 16 min Net dive: 30 ft 12 min	Rugosity = 1 (completely flat) No brash ice Bottom was mud with some ice scouring
March 2	Hole 3	Pulled gill net	2 isopods
	Hole 2, second site	Check out dive: 30 ft 11 min Habitat dive: 30 ft 13 min Net dive: 30 ft 14 min	Rugosity = 1 (completely flat) No brash ice Bottom was mud with a few mud covered rocks, and some ice scouring; Observed isopods on bottom Observed ctenophores (comb jellies) under ice
March 3	Hole 1, third site	No dive: unsafe conditions	

APPENDIX D5. CTD PROFILES

Prepared by: Mark Barton, Florida International University

Data collected by the YSI EXO sonde with sensors measuring DO, TSS, temperature, conductivity and depth.

HOLE 1

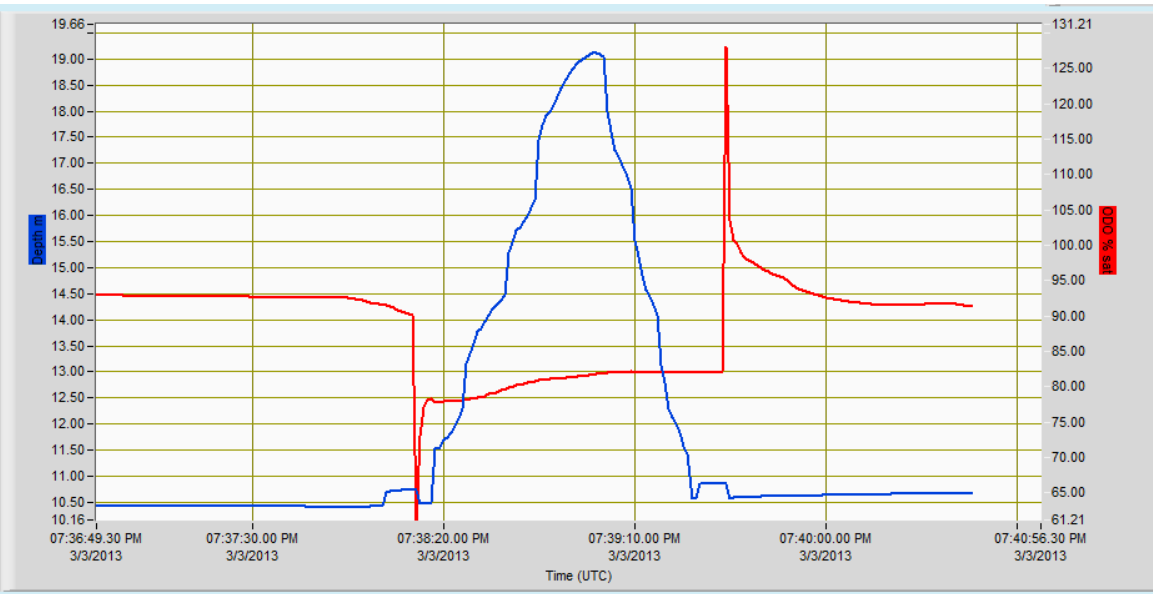


Figure D5-1a. Hole 1: Dissolved oxygen (ODO) % saturation

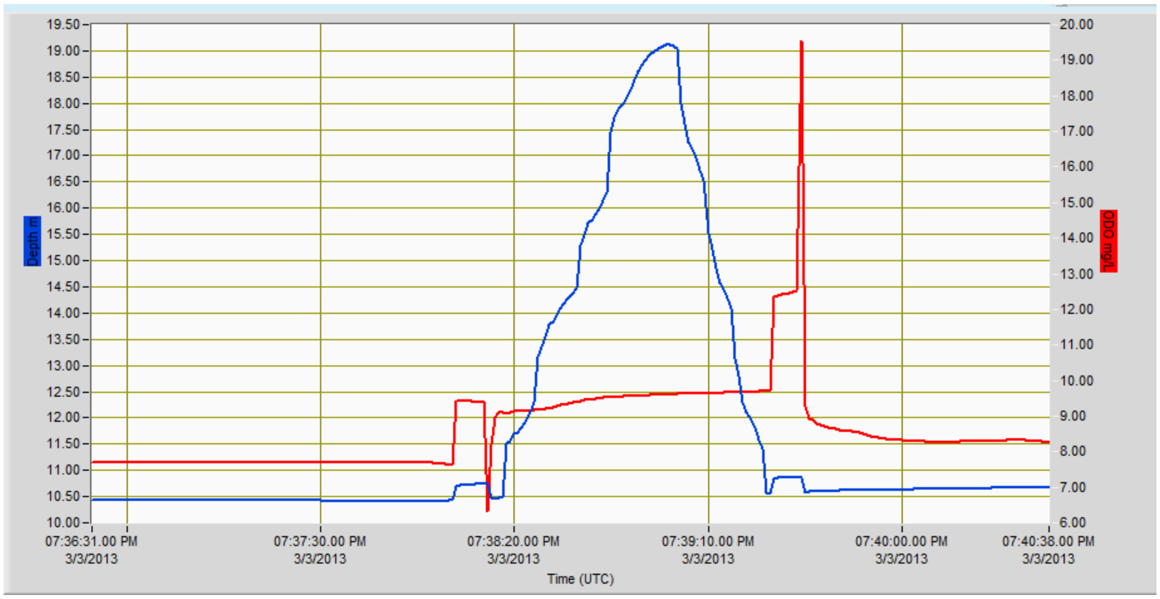


Figure D5-1b. Hole 1: Dissolved oxygen (ODO) in mg/L

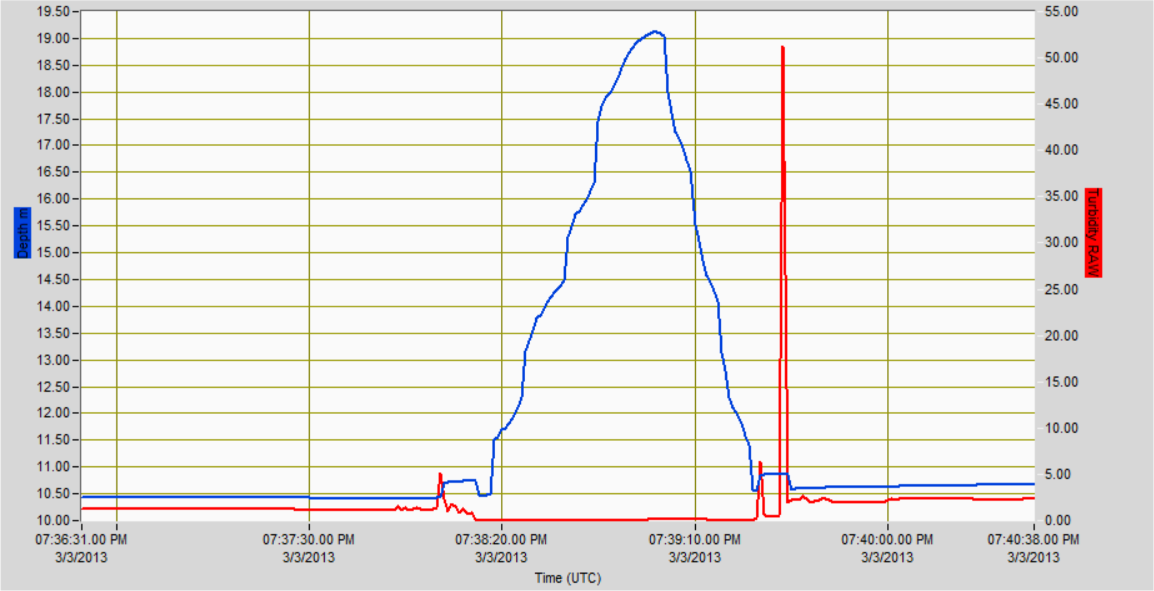


Figure D5-1c. Hole 1: Turbidity RAW (NTU = Nephelometric Turbidity Units)

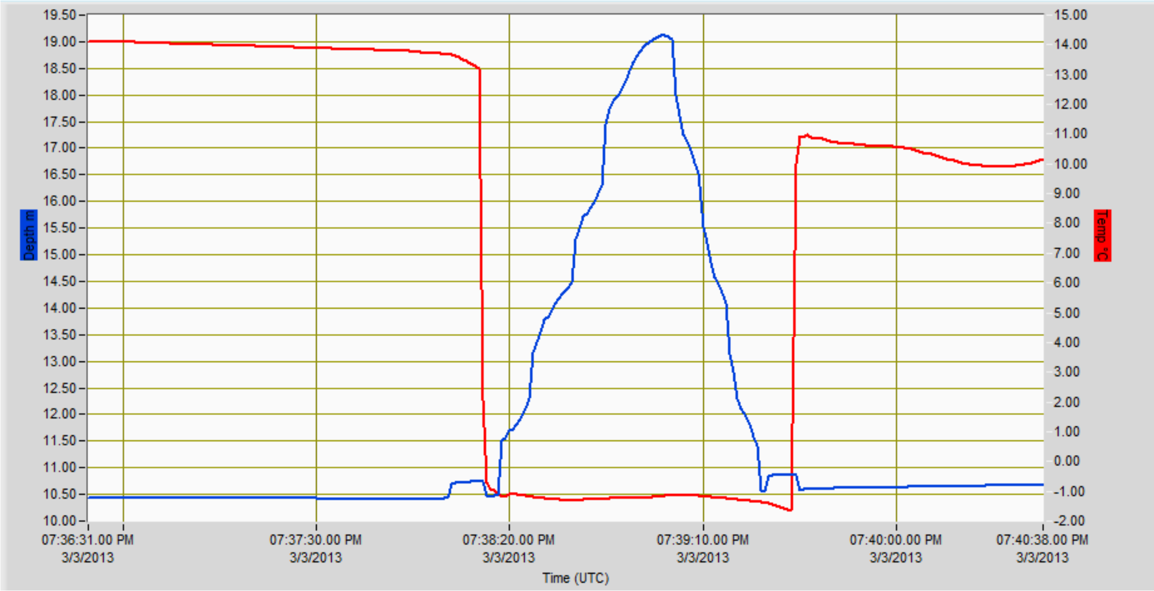


Figure D5-1d. Hole 1: Temperature (°C)

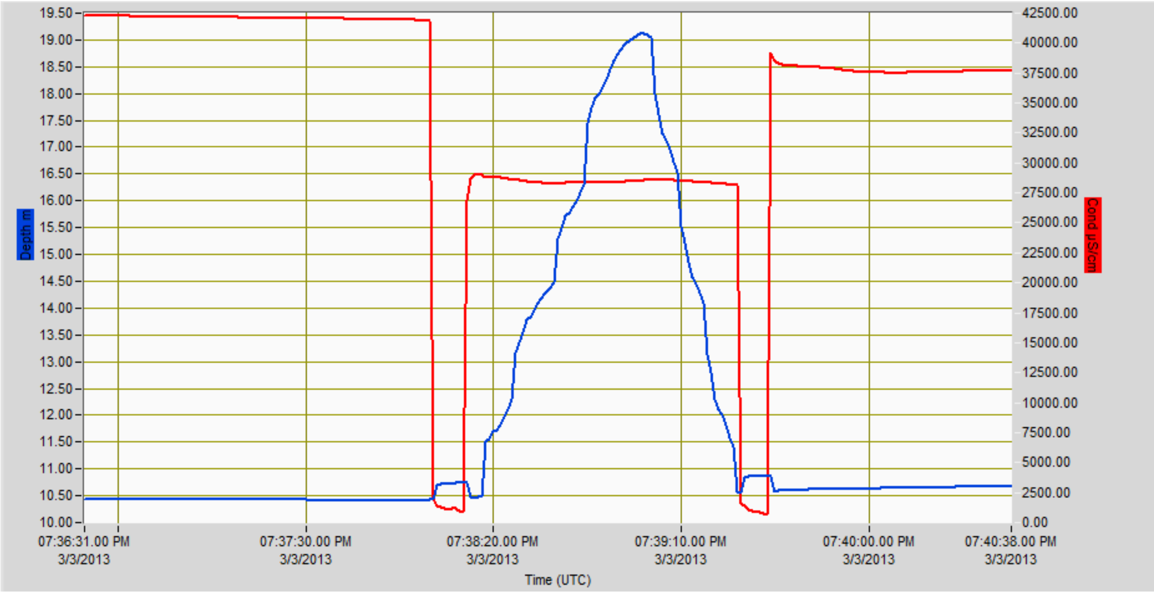


Figure D5-1e. Hole 1: Conductivity µS/cm (microsiemens per centimeter)

HOLE 2.

Oscillations before submersion were from trying to defrost the sensor cup which had frozen onto the CTD.

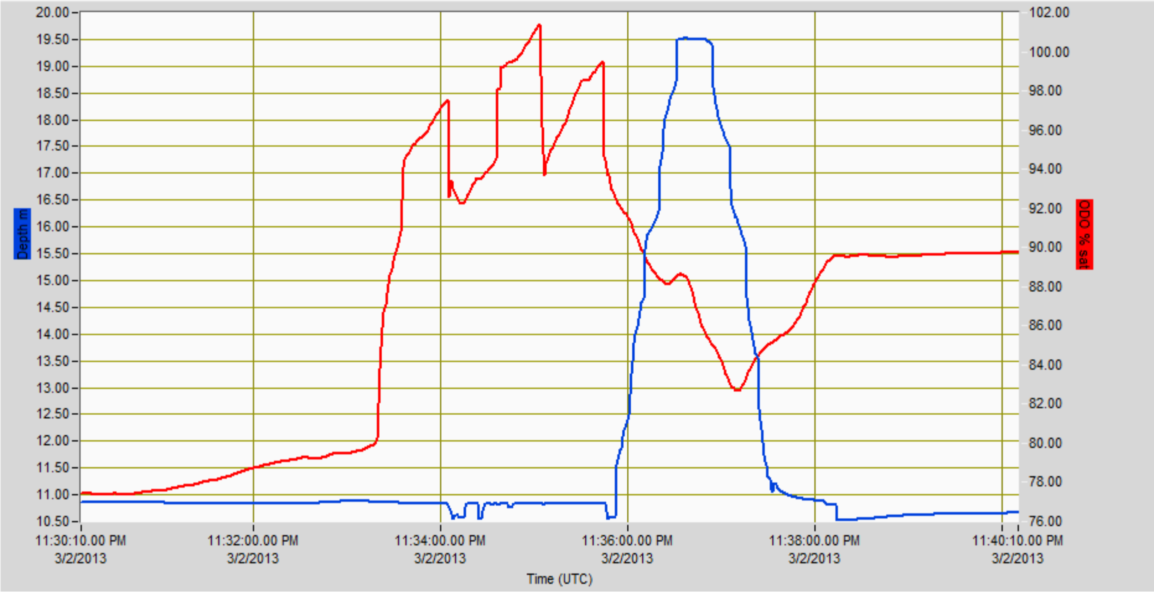


Figure D5-2a. Hole 2: Dissolved oxygen (ODO) % saturation

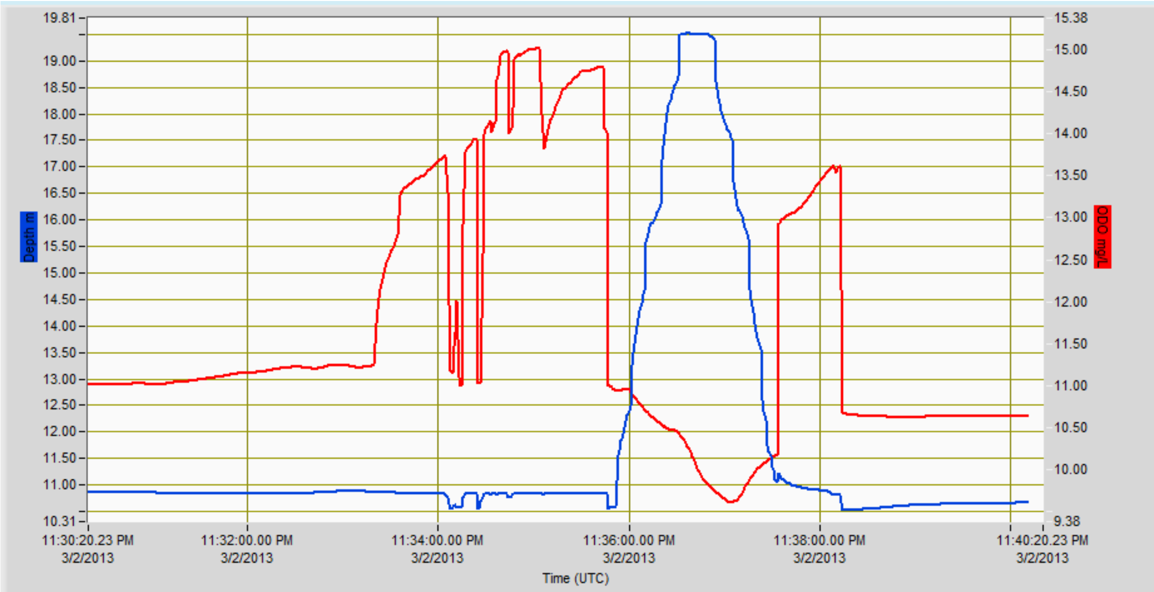


Figure D5-2b. Hole 2: Dissolved oxygen (ODO) in mg/L

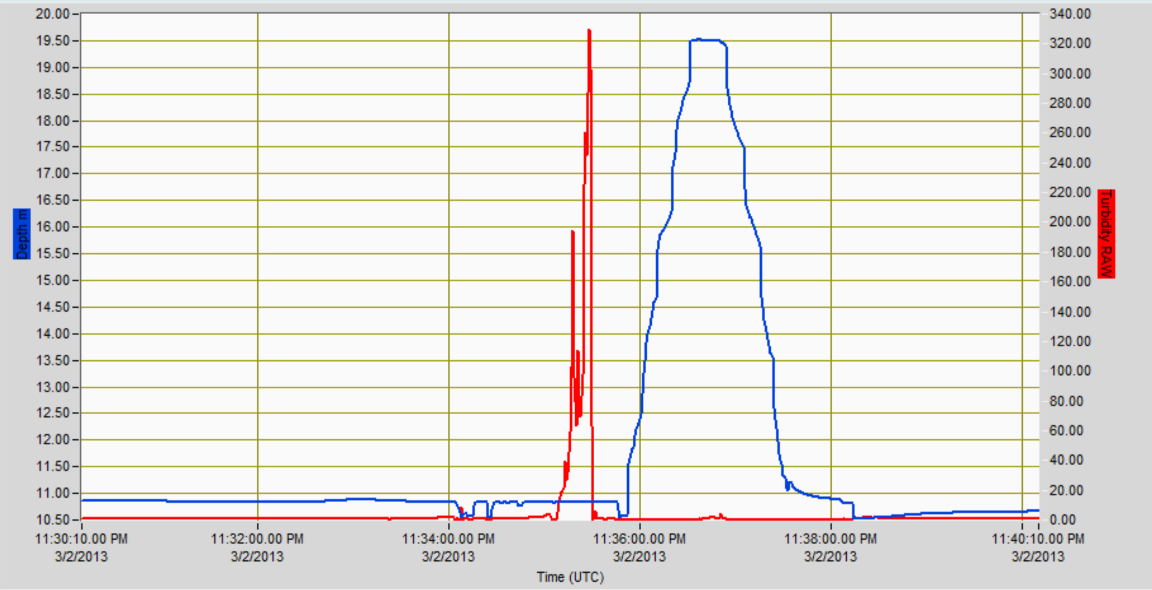


Figure D5-2c. Hole 2: Turbidity RAW (NTU = Nephelometric Turbidity Units

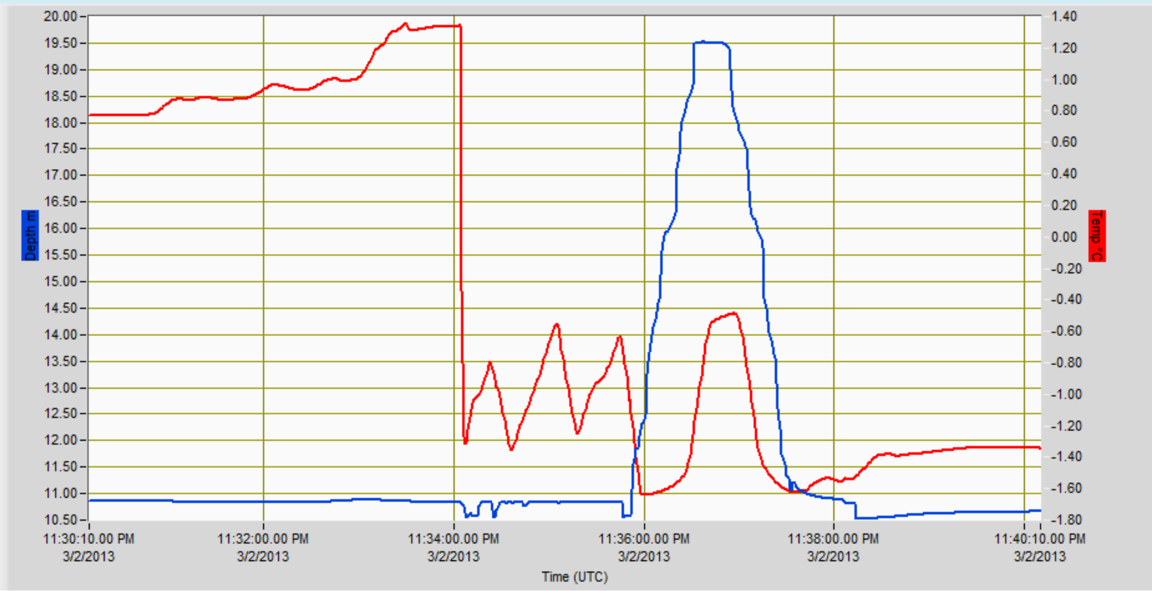


Figure D5-2d. Hole 2: Temperature (°C)

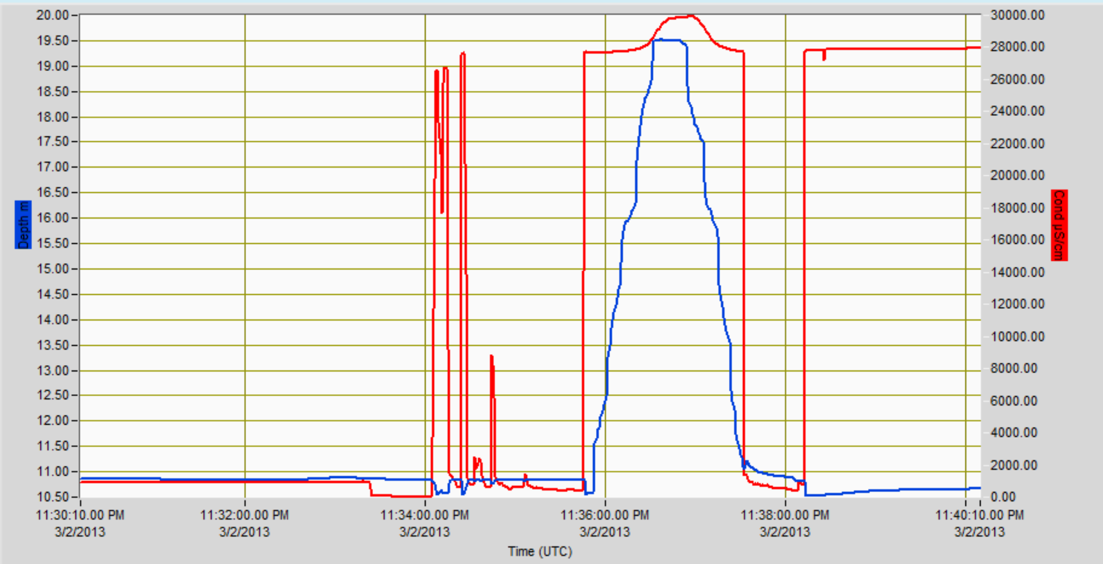


Figure D5-2e. Hole 2: Conductivity µS/cm (microsiemens per centimeter)

Hole 3 First Cast (Unofficial)

The first cast at Hole 3 was done during site inspection with no other gears sampled)

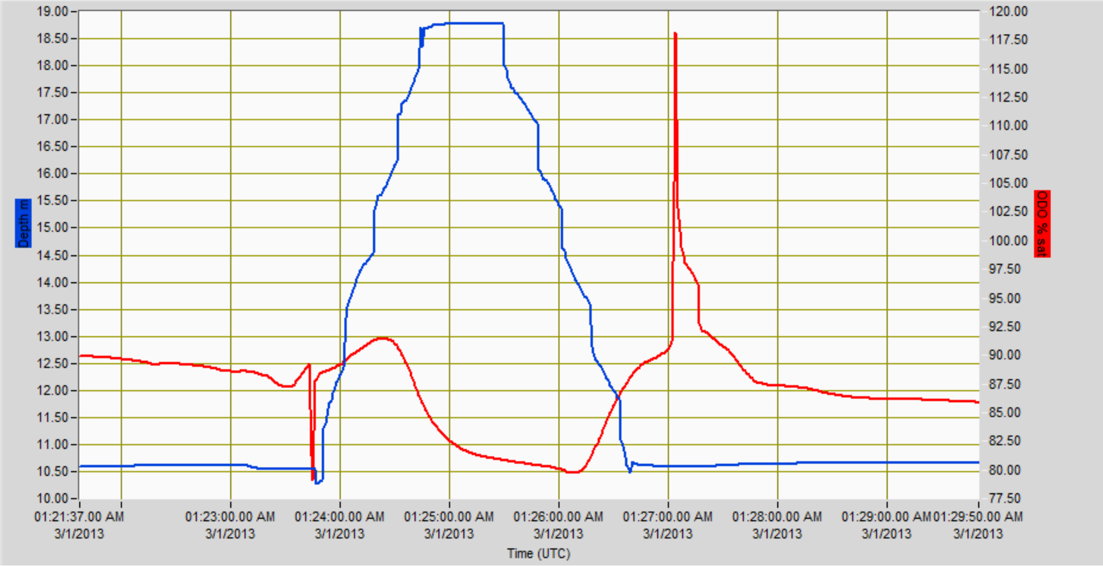


Figure D5-3a. Hole 3 first cast: Dissolved oxygen (ODO) % saturation

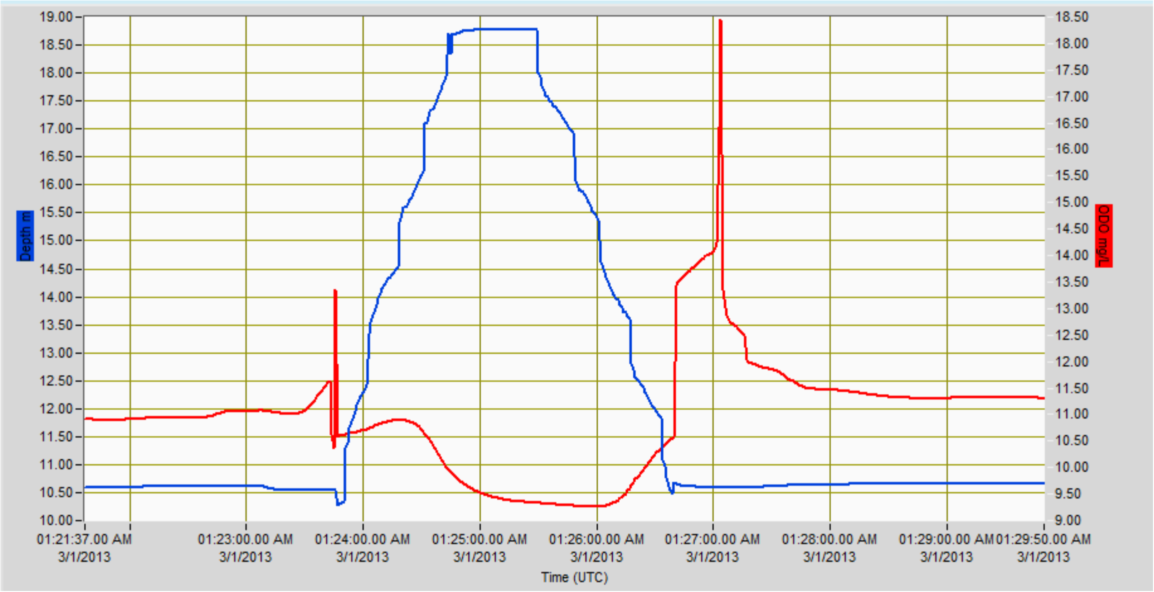


Figure D5-3b. Hole 3 first cast: Dissolved oxygen (ODO) in mg/L

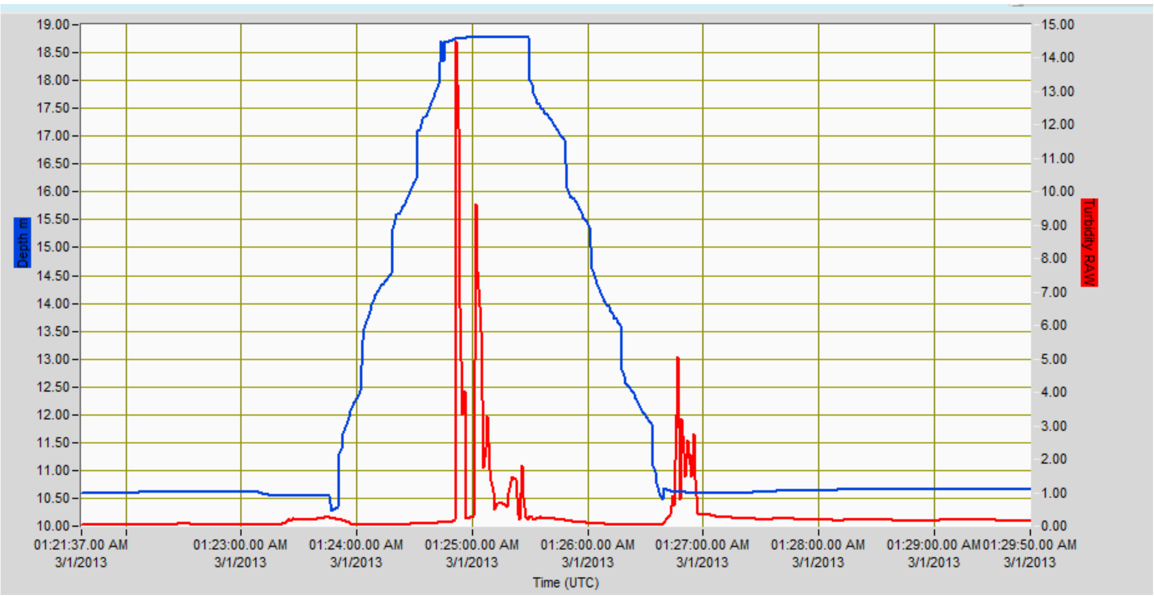


Figure D5-3c. Hole 3 first cast: Turbidity RAW-peaks in turbidity were caused by the sediment plume when retrieving the CTD

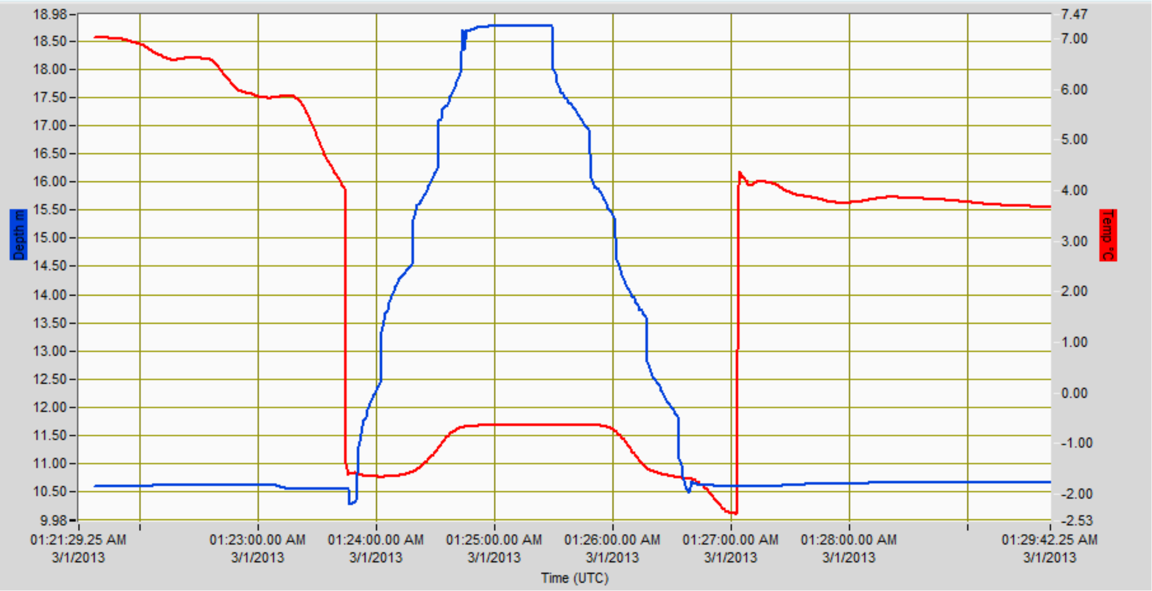


Figure D5-3d. Hole 3 first cast: Temperature (°C)

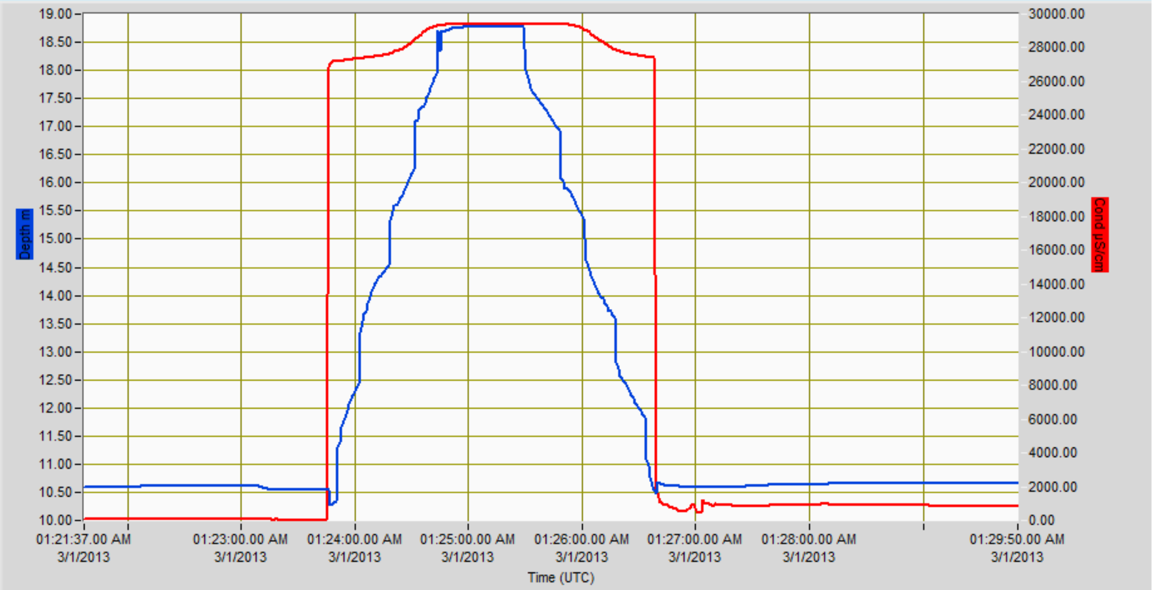


Figure D5-3e. Hole 3 first cast: Conductivity µS/cm (microsiemens per centimeter)

HOLE 3 SECOND CAST (OFFICIAL CAST AT SITE)

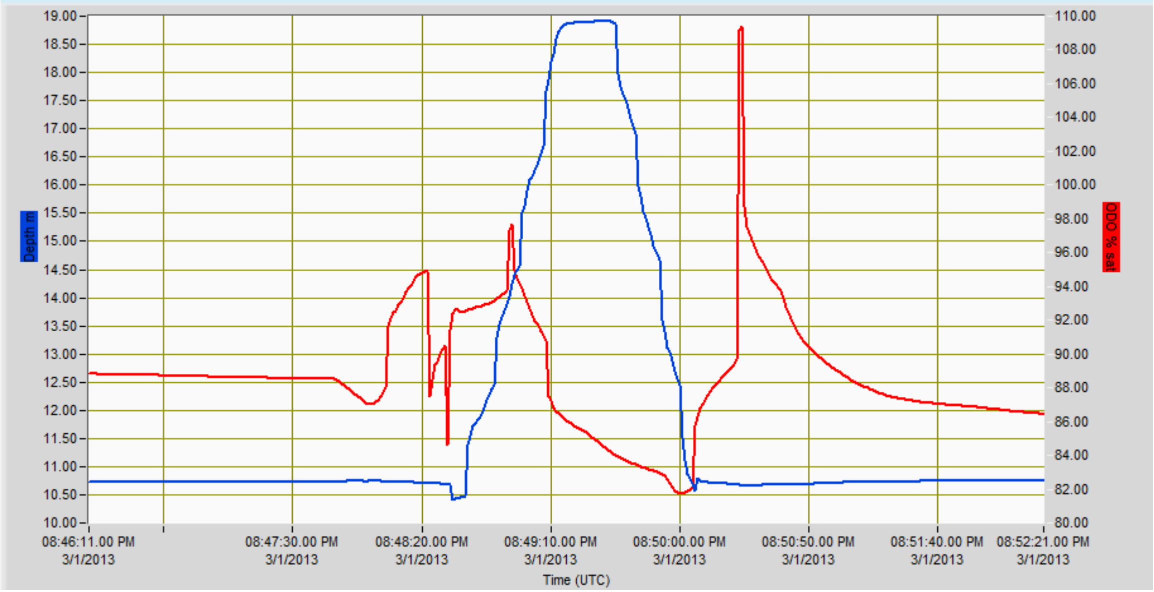


Figure D5-4a. Hole 3 second cast: Dissolved oxygen (ODO) % saturation

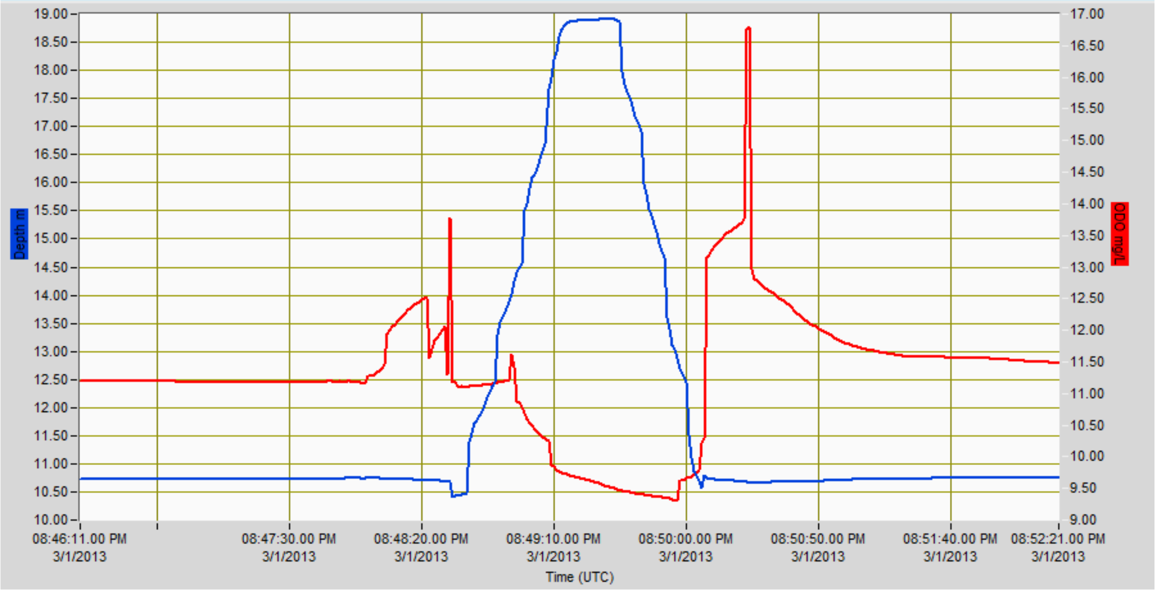


Figure D5-4b. Hole 3 second cast: Dissolved oxygen (ODO) in mg/L

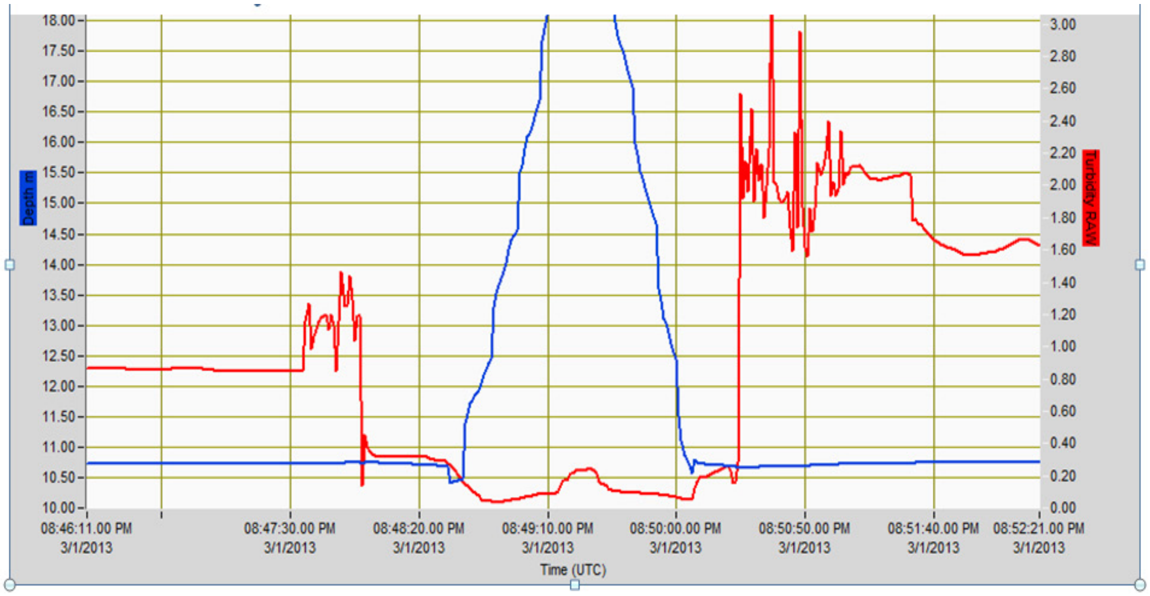


Figure D5-4c. Hole 3 second cast: Turbidity RAW (NTU = Nephelometric Turbidity Units)

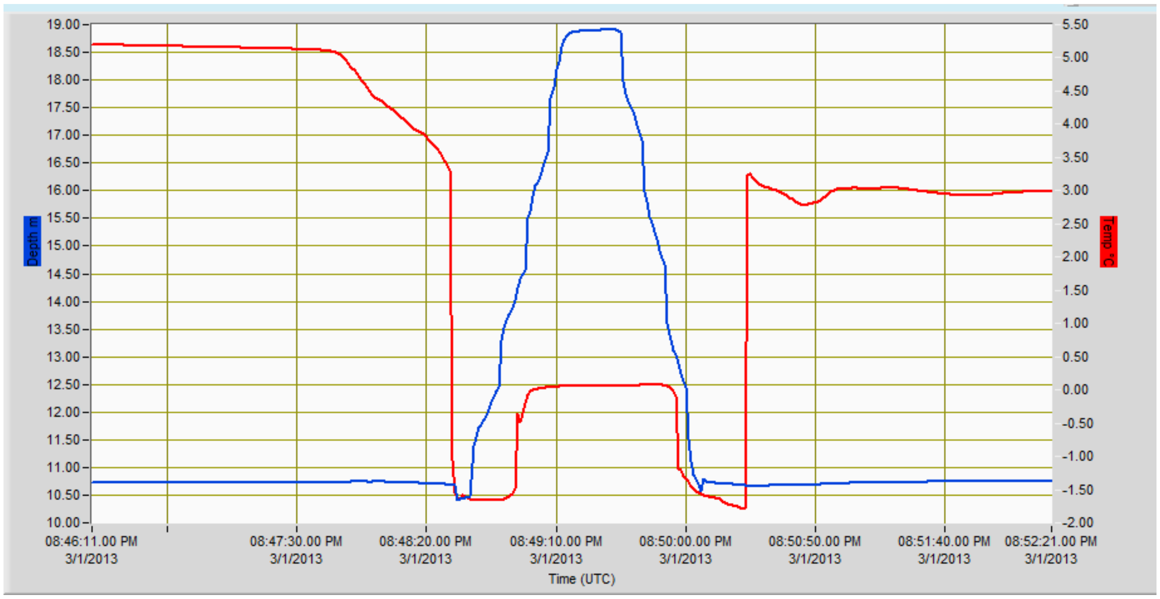


Figure D5-4d. Hole 3 second cast: Temperature (°C)

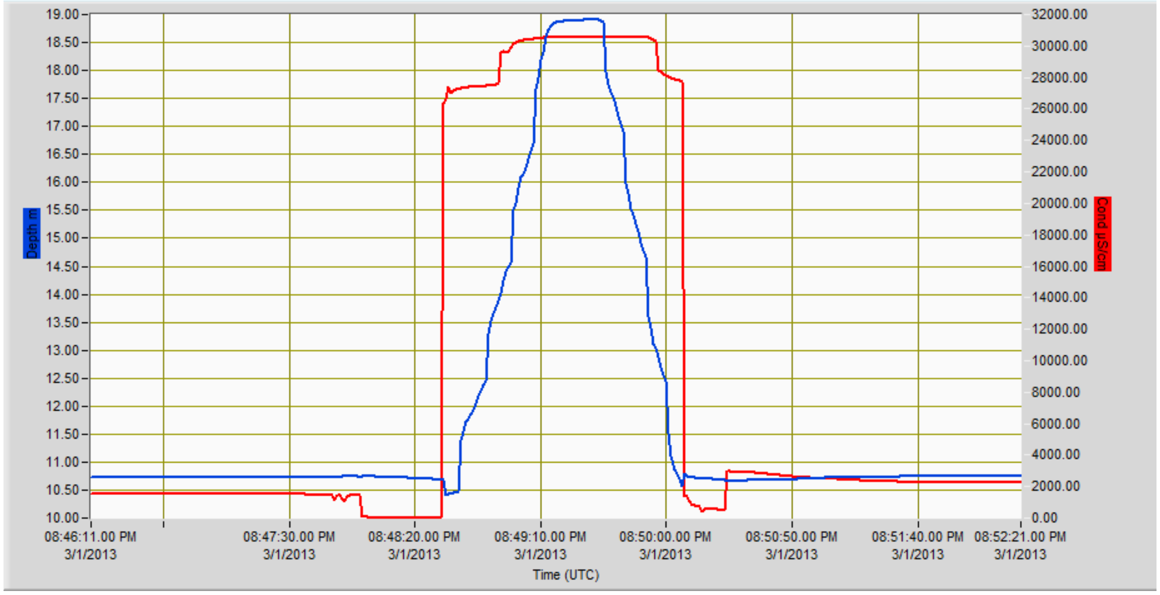


Figure D5-4e. Hole 3 second cast: Conductivity µS/cm (microsiemens per centimeter)

APPENDIX D6. PUBLIC RELATIONS ARTICLE

Author: Sharice Walker, UAF/SFOS Public Information Officer

SFOS SCIENTISTS TEST UNDER ICE RESEARCH TOOLS IN BEAUFORT SEA

Posted on March 14, 2013. *https://web.sfos.uaf.edu/wordpress/news/?p=244*

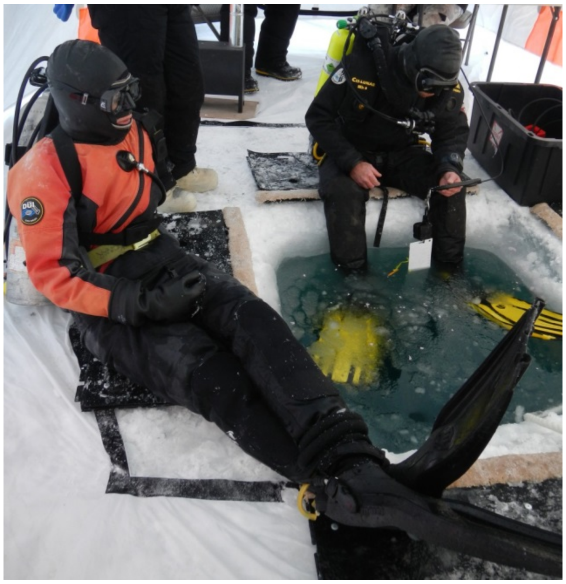
Ice on the Beaufort Sea. Photo by Lorena Edenfield.
Sharice Walker
907-474-7208

What do you bring on a trip to the Beaufort Sea in February to conduct under ice fish and habitat surveys? Three divers, two bear guards and a remotely operated vehicle (ROV) are all useful.

A research team from the University of Alaska Fairbanks School of Fisheries and Ocean Sciences spent four days camped on the ice near Barrow testing several ways of collecting data about the fishes and habitat below them.

The team, led by project manager Lorena Edenfield, used two four-foot by four-foot holes cut in the ice to experiment with data collection techniques including gill nets, DIDSON sonar, and an ROV. Divers, under the direction of chief scientist Brenda Konar, also tested standard SCUBA gear and a rebreather unit, which is a breathing apparatus that eliminates escaping air bubbles.

“We didn’t catch any fish, which is disappointing, but with that aside, everything that we put down worked and we didn’t have any problems,” said Edenfield, “It was a really successful way to test if the stuff is feasible on the ice in this extreme environment – and it was.”



Brenda Konar (in orange) and Rob Robbins prepare for an under ice dive March 1 near Barrow. Photo by Lorena Edenfield.

The pilot study is a component of the larger, “Central Beaufort Sea Marine Fish Monitoring” research project funded by the Bureau of Ocean Energy Management (BOEM) and managed by principal investigator Brenda Norcross.

The research team included Konar, Edenfield, and graduate student Sarah Traiger from UAF, Mark Barton from Florida State University, and diver Rob Robbins, as well as an ROV operator from Global Diving & Salvage in Anchorage. Local bear guards and laborers were hired through UNIAQ, who provided logistical support for the project.

The field work, originally scheduled for Feb. 28 through March 4, wrapped up on March 3, a day early due to inclement weather and unsafe conditions at a third research site.

“We had three different holes drilled in the ice, but we were only able to sample in two of them. We got to the third site and there was a crack through the ice, so we came back to town,” said Edenfield, “But that’s okay, because that was the day it was white-out conditions with a wind chill of minus 55.”

The next steps for the project will be compiling a report for BOEM, which will eventually be publicly available, and to use the results of the pilot study to plan for future under ice projects. Norcross has another BOEM-funded project that includes more under ice survey work for 2014 near Kaktovik.

A remotely operated vehicle (ROV) deployed under ice can provide live video feed. Photo by Lorena Edenfield.

OCS Study
BOEM 2017-33

Appendix E

TRANSFORMATIONS

US Department of the Interior

Bureau of Ocean Energy Management

Alaska Region

List of Tables

List of Figures

Acronyms

2RT	square root
4RT	fourth root
BPUE	biomass per unit effort
BT	beam trawl
CPUE	catch per unit effort
IKMT	Isaacs-Kidd midwater trawl
nMDS	non-metric multidimensional scaling
NT	no transformation
PA	presence/absence

1 Transformations

To analyze fish assemblages for bottom trawl (BT) catch per unit effort (CPUE), we examined several transformations to determine which best represented our objectives (**Table 1**). Shade plots were used to visualize geographic concentrations and absences of species. To do this, we used SHADE plots in PRIMER v.7; this program standardizes and transforms data to visually display it, but it is not a statistical analysis (Clarke and Gorley 2014). [VSL1]All transformations were examined for CPUE of BTs. No transformation (NT) puts the most weight on abundant species. Square root (2RT) lessens the weight on the most abundant species. Fourth root (4RT) further lessens effect of individual high catches and increases the effect of zero catches. Log+1 puts even more emphasis on zero catches by adding 1 to each catch. Presence/absence (PA) gives equal weight for all species, i.e., more emphasis on rare species. The transformed values were used to construct Bray-Curtis dissimilarity coefficients that were used in cluster and similarity analyses. Cluster analysis was used because it resolves inter-species associations, allowing an examination of community structure (as adapted from Doyle et al. 2002). A hierarchical cluster analysis for 999 permutations identified fish assemblages that grouped stations according to their taxa composition. The resulting dendrogram displayed stations progressively aggregated into smaller numbers of groups containing more stations.

For each gear type, SHADE plot matrices produced by transformation of CPUE or biomass per unit effort (BPUE) clustered by station on the x-axis, and clusters of standardized CPUE or BPUE, by species, on the y-axis. The y-axis (species clusters) is the same for all transformations as it is not influenced by geographic density patterns. The color intensity in a shade plot visually portrays which species and locations are influential and can be used to help determine which transformation to use (Clarke et al. 2014). Shade plots show which transformations capture the “depth of view” of the community, from solely dominant (no transformation) to the equal representation of all species (presence/absence). Only the 4RT transformation was used for BT biomass (BPUE), otter trawl CPUE and BPUE, and IKMT, as justified in the proposal and here in the analysis of multiple transformations of BT CPUE data. Hierarchical cluster analyses (CLUSTER, PRIMER v.7) for CPUE or BPUE of species at stations used the Bray-Curtis dissimilarity coefficient. Clusters are indicated in plots by colors; significance level was chosen to portray a meaningful number of clusters.

When employing cluster analysis, the biological or environmental conditions being examined must be considered. Cluster analysis may find groups even if they are not relevant in nature, i.e., it is possible for random data to produce groups. We used SIMPROF (PRIMER v.7) to introduce some rigor as an *a posteriori* test of significance of dissimilarities among cluster groups ($p<0.05$, $p<0.01$, or $p<0.005$). The significance level used was chosen to represent fish groups but not to create so many clusters as to render the results meaningless. A Similarity Profile test (SIMPROF, PRIMER v.7) is a permutation test of the null hypothesis (Clarke and Gorley 2006), i.e., it tests whether distributions of fishes are equal. SIMPROF was used to test the significance of each grouping of fish taxon density that resulted from the cluster analysis. When the statistical test of clusters (SIMPROF) is not significant, further differentiation should not be considered (Clarke et al. 2008). Alternatively, it may be appropriate to group supersets of statistically different clusters when cluster analysis results in only one or two stations, as those might not be valid groups (Clarke et al. 2008). RELATE (PRIMER v.7) compares resemblance matrices of each combination of two transformations.

Species that were good discriminators within designated fish community groups were identified using Similarity Percentage (SIMPER, PRIMER v.7). SIMPER provides a statistical mechanism to show similarities within cluster groups. This test is a breakdown, by taxa, of Bray-Curtis similarities within groups. SIMPER can characterize groups and be used to compare between groups. The objective was to find typicality, i.e., what species typify group A and not group B, and vice versa. The result was a list, in decreasing order, of each species' contribution to a fish community group.

Non-metric multidimensional scaling plots (nMDS; Kruskal 1964[VSL2]) were used to examine patterns among sample groups. nMDS ordination plots have no numerical interpretable axes, are based on simple matching coefficients calculated between pairs of species, and describe the precise biotic relationships among samples (Clarke et al. 2008; Somerfield et al. 2008). A stress of <0.1 is considered to be a good fit, while a stress of <0.2 is potentially useful (Clarke and Warwick 2001). nMDS ordinations were presented of fish density assemblages for each transformation (nMDS, PRIMER v. 7). Bubble plots of *B. saida* were plotted on the same nMDS representations of fish assemblages.

Analysis of Similarity (ANOSIM, PRIMER v.7) was used to estimate differences in species abundance and composition relative to bottom depth, bottom temperature, bottom salinity, longitude, latitude, sediment (category), and water mass (category). ANOSIM is a nonparametric, multivariate permutation test, somewhat analogous to the parametric, univariate ANOVA (Clarke et al. 2014). ANOSIM treatment groups were defined *a priori,* i.e., they were the environmental factors examined. Multiple 1-way ANOSIMs were run because the habitat parameters were not symmetrical; the Bonferroni adjustment was not applied to ANOSIM.

Bray-Curtis dissimilarity matrices of transformed CPUE values for each taxon at each station were used for ANOSIM calculations. To provide the best reasonable result, 999 permutations were run for each ANOSIM. An R statistic, defined as a comparison of the average between-group rank similarity to the average within-group rank similarity, was calculated using the following formula:

$$R = \frac{(\bar{r}_B - \bar{r}_W)}{n(n-1)}$$

where $\bar{r}_B$ and $\bar{r}_W$ are the average rank similarities for each pair of intervals between and within groups, respectively, and n is the sample size. The R value is between -1 and 1, and the closer R is to 1, the more distinct the groups are (Clarke et al. 2014).

With no transformation (NT), there were five station groups at $p<0.05$ (**Figure 1**). The most abundant taxa, *B. saida, G. tricuspis, Liparis* spp., and *Lumpenus fabricii* dominated one 8-station cluster ("b", red inverted triangles), of which seven stations were in the western Beaufort Sea and one station was off Nuiqsut. All fish abundances in the other five communities were barely noticeable by comparison. The majority of the stations clustered into one large ill-defined group ("c", green squares) with stations spread across the entire sample area. *B. saida* was the dominant species in three of the communities, in which it made up 38–69% of all individuals (**Table 2**). For communities "b" and "c", ~70% of the abundance was *B. saida, G. tricuspis,* and *Liparis* spp., though the percentages of each differed among communities. The stations' clusters were evident in the nMDS (**Figure 2**). *B. saida* was clearly most abundant in cluster "b". NT was not very informative except to highlight the extremely abundant taxa, *B. saida, G. tricuspis,* and *Liparis* spp., which grouped together in cluster "b".

In a square root transformation (2RT), there were six station groups at $p<0.01$. Similar to the NT transformation, *B. saida, G. tricuspis, Liparis* spp., and *L. fabricii* dominated and grouped together, but this time in a 13-station cluster ("e", red inverted triangles), again in western Beaufort Sea. Cluster "d" was similar, but the abundances were much lower (**Figure 3**). The taxa in Spp group "l" were present across most other stations also. There was more of a spatial pattern to station groups than observed with no transformation, though one cluster ("f", green squares) was still spread over much of the shelf. *B. saida* was the dominant species in five of the communities, where it made up 21–60% of all individuals

(**Table 3**). For communities “b” and “c”, ~60% of the abundance was *B. saida,* with only one other taxa in each (“b” *Lycodes* spp.; “c” *Aspidophoroides olrikii*) contributing an additional 26–40%. The dominance of *B. saida* was evident in the most defined clusters (“d” and “e”) (**Figure 4**).

A fourth root transformation (4RT) further emphasized the presence of more taxa. The six station groups (at p<0.01) were similar, though not identical, to those clusters from the 2RT transformation (**Figure 5**). As less abundant taxa were given more weight by 4RT than square root transformation (2RT), more patterns became evident because the station clusters were based on more information. The original station group (“c”, red inverted triangles) with *B. saida, G. tricuspis, Liparis* spp., and *Lumpenus fabricii,* was maintained, but included one more station in the western Beaufort Sea. With increased transformation applying more weight to less abundant species, groups became more geographically distinct across the sample area (e.g., cluster “f’ (blue triangles) at the shelf break in the western Beaufort Sea). However, the stress of the nMDS increased slightly to 0.22 as groups were not as distinct and the dominance of *B. saida* was evened out across all groups (**Figure 6**). The six fish communities formed by 4RT transformation (**Figure 5**) could be characterized by combinations of 2–7 taxa (**Table 4**). These communities had distinct profiles of abundant taxa. Four of the six communities had *B. saida* as a substantial component. Community “a” was composed of only one station. Of three species collected there, *Aspidophoroides olrikii* made up 50% of the small CPUE. In the three stations of community “b”, 75% of the catch consisted of prickleback (*Anisarchus medius)*, sculpin (*Gymnocanthus tricuspis),* or eelpouts (*Lycodes* spp.). Community “c” was made up of 14 stations, the majority of which were on the wider shelf of the western Beaufort Sea nearest to Barrow. Community “c” was the most diverse, seven taxa contributed 77% of the similarity, and it was characterized by four taxa *B. saida*, *Liparis* spp., *G. tricuspis*, and *Artediellus scaber.* Although the number of stations was similar to “c”, only three taxa made up 72% of the catch in community “d”: *B. saida*, *G. tricuspis* and *Liparis* spp. Locations were spread across nearshore and shallow waters. The 24 stations of community “e”, which were mainly in the eastern part of the study area (**Figure 5**), were dominated by four taxa: *B. saida*, *A. olrikii, Liparis* spp., and *Icelus* spp. Community “f”, found in the outer, deeper shelf-break stations of the western-most part of sampling area, was described by *B. saida* and *Lycodes* spp.

Similar results were seen with the log-plus-one (Log+1) transformation, which gave even more weight to less abundant species, i.e., *Myoxocephalus scorpius*, *Aspidophoroides olrikii*, *Icelus* spp., and *Anisarchus medius,* than the 4RT transformation and resulted in eight station clusters at p<0.01 (**Figure 7**). There were two more groups than with 4RT transformation; the additional groups blurred rather than clarified geographical distinctions. For example, the shelf-break group was separated into two groups (“g” and “h”) with no clear geographical pattern. The dominant species in five of the communities was *B. saida,* which made up 17–68% of all individuals (**Table 5**). For community “h”, 68% of the abundance was *B. saida,* with only one other taxon present, *Aspidophoroides olrikii*, which contributed an additional 16%. Again, the dominance of *B. saida* was evened out across all groups (**Figure 8**).

Finally, the most extreme transformation, presence/absence (PA) gives equal weight to all abundance levels of taxa. This transformation produced seven station clusters at p<0.05 (**Figure 9**), including one extremely large station (cluster “f’) similar to that found with no transformation, though the station composition was not exactly the same. The other six clusters were composed of only 2–7 stations. Geographical distinctions were minimized; however, as in the 4RT transformation, a shelf-break community “g” appeared in the western Beaufort Sea. *B. saida* made up 14–46% of all individuals in six of the seven communities, but it was only dominant in clusters “f” and “g” (**Table 6**). The nMDS plot for *B. saida* was non-informative because it only indicated the presence of that species at all stations (**Figure 10**).

After being standardized to CPUE, fish catch data were standardly transformed to emphasize or deemphasize rare species. Any number of analyses (example of which are cited here) can be found using a variety of transformations from mild to extreme. No transformation (NT) puts the most weight on more abundant species and is not generally used for fisheries analysis. 2RT is a mild transformation that down weights the most abundant species and has been used in the western Beaufort Sea (Bluhm et al. 2014) and the Philippines (Russ et al. 2015). 4RT is a moderate transformation that further lessens effect of individual high catches as well as increases the effect of zero catches. For the North Sea (Rutterford et al. 2015) and Kodiak, Alaska (Mueter and Norcross 2000a), CPUE data were 4RT to reduce skewness (Field et al. 1982). The purpose of $\log_{10}$ transformation is to achieve a normal distribution. Only data that contain no zero catches, such as fish surveys in the Northeast Atlantic (Hinz et al. 2003), can be directly log transformed. As that is rare, one is added to CPUE values prior to log transformation; therefore, Log+1 puts even more emphasis on zero catches by adding one to each catch. The most extreme transformation is PA which equally weights all species, i.e., more emphasis on rare species. PA is appropriate when CPUE values are not equitable, e.g., among gear types.

The five transformations analyzed for beam trawl CPUE were statistically compared. All matrices of abundance transformations, and subsequent Bray-Curtis resemblances, were significantly different from each other (**Table 1**, RELATE, PRIMER v.7). Although all levels of transformation are valid, they were not equivalent; therefore, it was necessary to determine which of the transformations provided the information most useful for interpreting fish catches in the Beaufort Sea. Less abundant species are important to include in community analysis because they are the ones that may be indicators of climate change or anthropogenic effects. Prior to the onset of computerized methods, $\log_{10}+1$ was the commonly used transformation for fisheries catches as it was easy to calculate (discounting no transformation and presence/absence). The advent of computing power made 4RT a desirable method (Field et al. 1982) as it is very similar to, but does not weight zero catches as heavily as, $\log_{10}+1$. We chose to use 4RT for all additional analyses because it gives information of both less abundant and most abundant species, and most importantly, in this analysis it was shown most clearly to spatially define fish communities (**Figure 5**).

Analysis of multiple transformation for demersal fish communities showed that fourth root transformation (4RT) most clearly spatially defined the communities because it provides more equitable information on very abundant and very sparse fishes as found for these collections. When the density differences are less than the three orders of magnitude found in this study, potentially a square root transformation (2RT) could be used though some expert statisticians such as Dr. Franz Mueter (University of Alaska Fairbanks) still prefer a fourth root transformation.

Table 1: Comparisons of Beam Trawl CPUE transformations (RELATE PRIMER v.7)

	NT	2RT	4RT	Log+1	PA
Nt		0.898	0.696	0.771	0.430
2RT	0.001		0.934	0.963	0.748
4RT	0.001	0.001		0.974	0.930
Log+1	0.001	0.001	0.001		0.845
PA	0.001	0.001	0.001	0.001	

Transformations: NT – no transformation, 2RT - square root transformation, 4RT - fourth root transformation, Log+1 – log+1, PA – presence/absence. Upper values are Spearman rho. Lower values are significance; all pair combinations are significantly different.

Table 2: Beam Trawl CPUE, No Transformation

		Fish Communities				
		a	b	c	d	e
	# Stations	2	8	40	11	3
Taxa	# Taxa Observed	3	15	17	10	13
Gadidae	*Boreogadus saida*	68.9	37.8	49.2	8.4	
Cottidae	*Gymnocanthus tricuspis*		20.6	10.1		
	Artediellus scaber				7.7	
	Icelus spp.				50.0	
	Myoxocephalus scorpius					
	Triglops pingelii					
Agonidae	*Aspidophoroides olrikii*				9.9	77.3
	Eumicrotremus derjugini					
Liparidae	*Careproctus reinhardti*					
	Liparis spp.		21.6	19.4		
Zoarcidae	*Gymnelus* spp.					
	Lycodes spp.	31.1				
Stichaeidae	*Anisarchus medius*					
	Lumpenus fabricii					
Total % Contributed		100.0	80.0	78.7	76.1	77.3
# Taxa Contributing >70% Density		2	3	3	4	1
Within-Community Similarity		47.9	52.4	38.6	44.7	36.6

Percent contribution of taxa density to each of five fish communities ($p<0.05$) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 1** shade dendrogram.

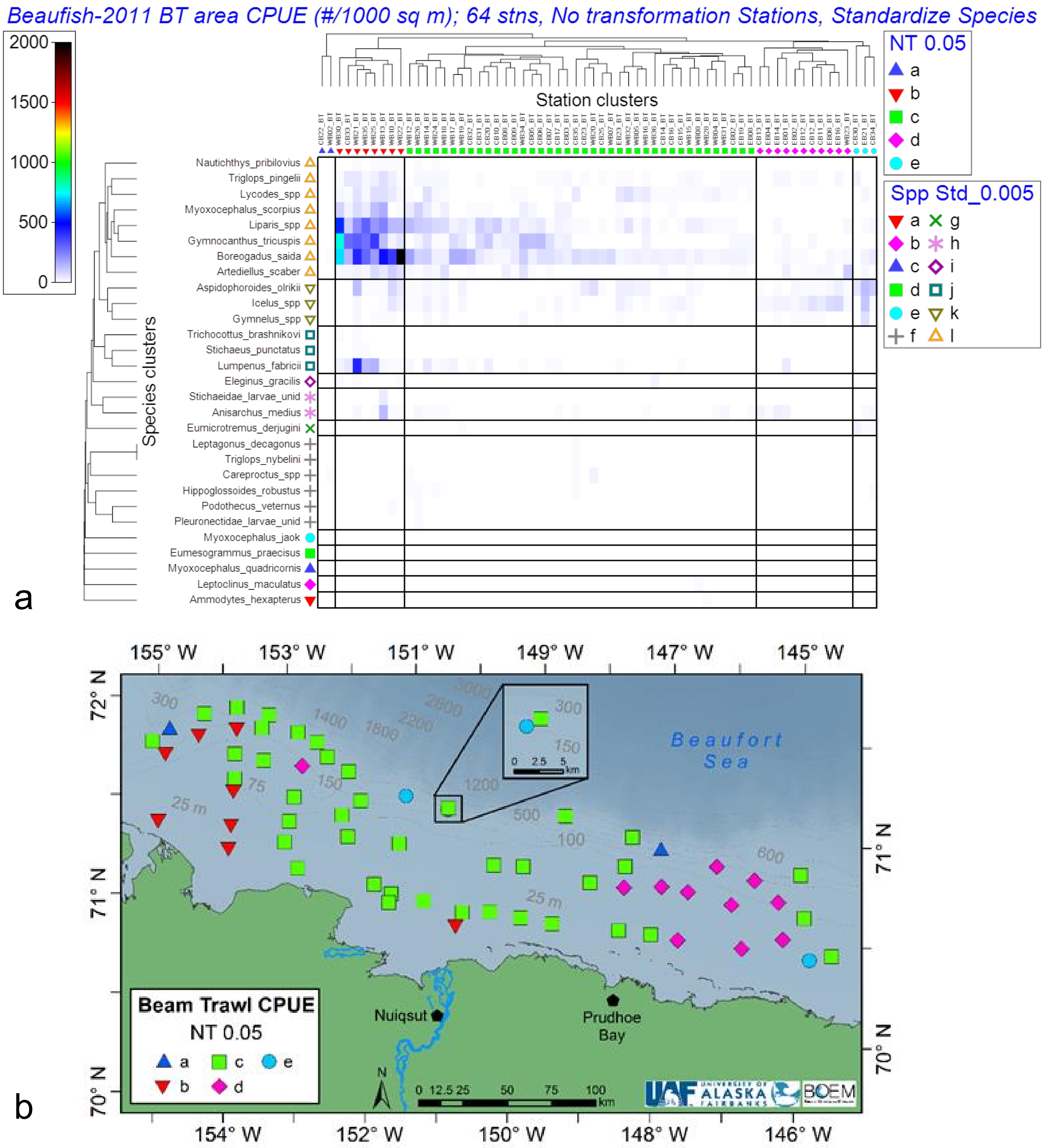
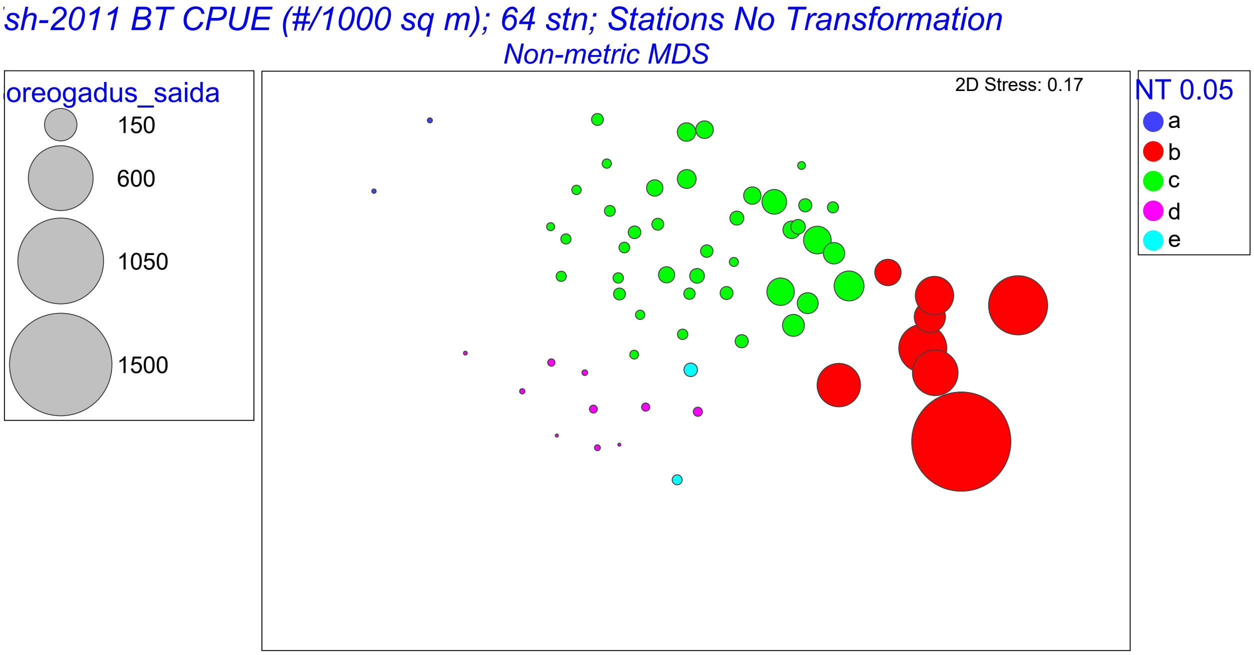


Figure 1: **Beam Trawl CPUE Five Fish Communities Formed by No Transformation (NT) at $p<0.05$: a) shade plot, b) distribution map**



Untransformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble. Largest bubble is station WB22.

Figure 2: **Non-Metric Multidimensional Scaling of Beam Trawl CPUE (catch) Fish Communities (colors) Formed by No Transformation (NT)**

Table 3: Beam Trawl CPUE, Square Root Transformation (2RT)

		Fish Communities					
		a	b	c	d	e	f
	# Stations	1	2	4	11	13	33
Taxa	# Taxa Observed	3	6	8	14	21	15
Gadidae	*Boreogadus saida*		59.8	57.9	28.3	21.4	29.1
Cottidae	*Gymnocanthus tricuspis*				32.0	10.3	
	Artediellus scaber	50.0				8.6	
	Icelus spp.						12.5
	Myoxocephalus scorpius					8.3	
	Triglops pingelii	25.0					10.7
Agonidae	*Aspidophoroides olrikii*			26.3			
	Eumicrotremus derjugini	25.0					
Liparidae	*Careproctus reinhardti*						
	Liparis spp.				26.4	20.7	12.3
Zoarcidae	*Gymnelus* spp.						
	Lycodes spp.		40.2				11.0
Stichaeidae	*Anisarchus medius*						
	Lumpenus fabricii					6.6	
Total % Contributed		100.0	100.0	84.1	86.6	75.9	75.9
# Taxa Contributing >70% Density		3	2	2	3	6	5
Within-Community Similarity		100.0	50.0	49.7	64.6	62.7	47.9

Percent contribution of taxa density to each of six fish communities ($p<0.01$) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 3** shade dendrogram.

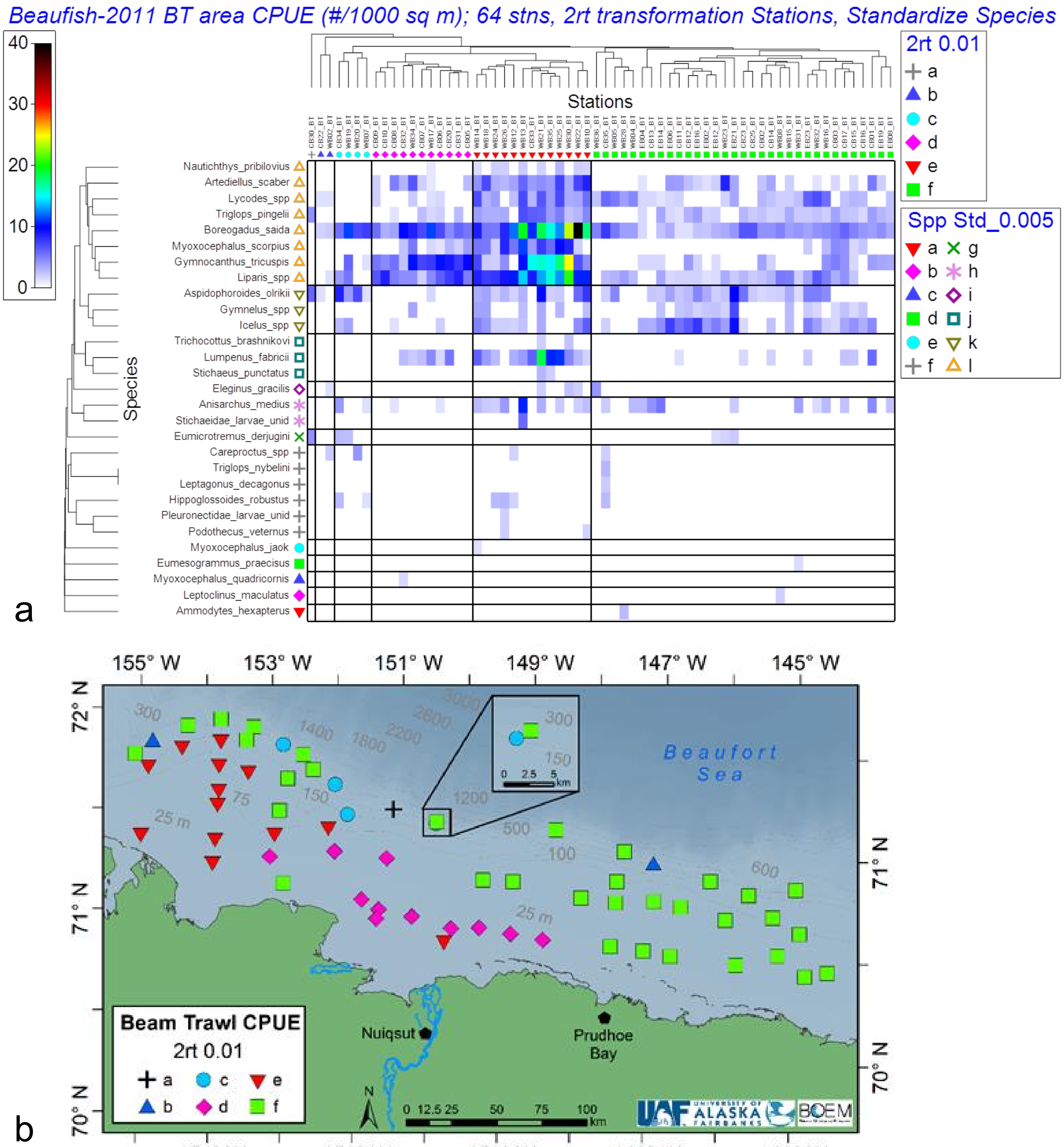
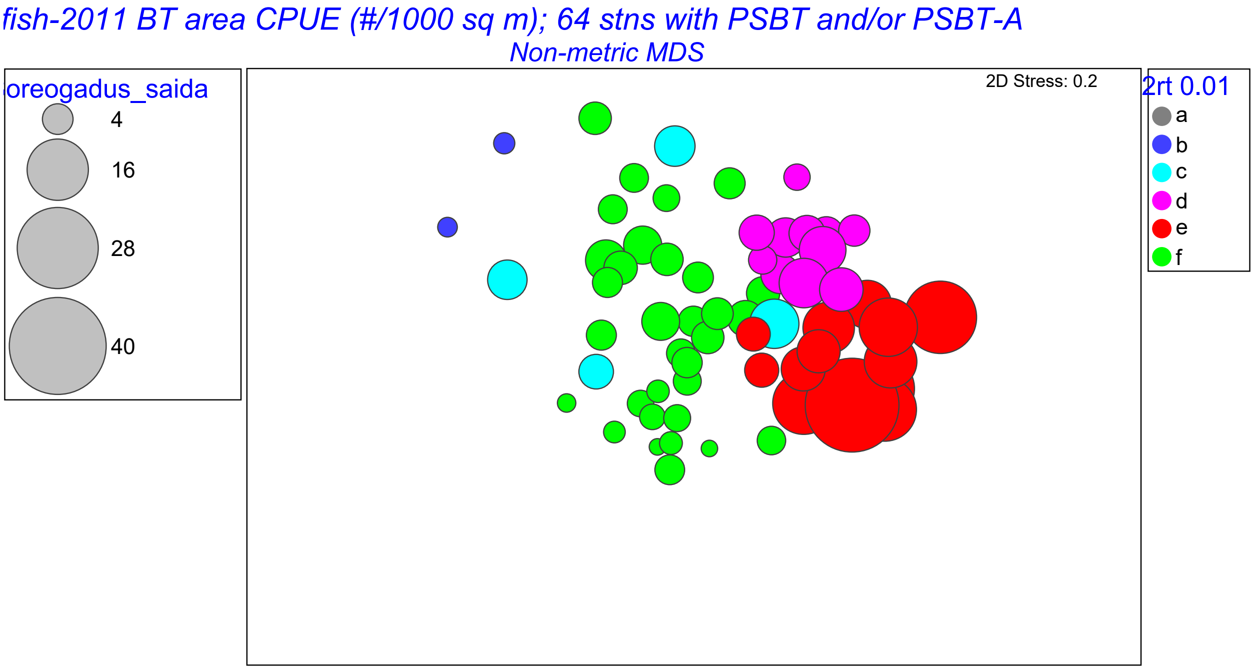


Figure 3: Beam Trawl CPUE (catch) Six Fish Communities Formed by Square Root Transformation (2RT) at p<0.01: a) shade plot, b) distribution map



Square root transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 4: **Non-Metric Multidimensional Scaling of Beam Trawl CPUE (catch) Fish Communities (colors) Formed by Square Root Transformation (2RT)**

Table 4: Beam Trawl CPUE, Fourth Root Transformation (4RT)

		Fish Communities					
		a	b	c	d	e	f
	# Stations	1	3	14	15	24	7
Taxa	# Taxa Observed	3	7	22	12	19	7
Gadidae	*Boreogadus saida*			16.4	27.2	22.6	59.6
Cottidae	*Gymnocanthus tricuspis*		23.0	10.3	26.0		
	Artediellus scaber	50.0		9.5			
	Icelus spp.					12.7	
	Myoxocephalus scorpius			8.7			
	Triglops pingelii	25.0					
Agonidae	*Aspidophoroides olrikii*					17.9	
	Eumicrotremus derjugini	25.0					
Liparidae	*Careproctus reinhardti*						
	Liparis spp.			15.4	18.3	17.0	
Zoarcidae	*Gymnelus* spp.						
	Lycodes spp.		23.0	7.8			22.6
Stichaeidae	*Anisarchus medius*		28.6				
	Lumpenus fabricii			8.5			
Total % Contributed		100.0	74.6	76.5	71.5	70.2	82.2
# Taxa Contributing >70% Density		3	3	7	3	4	2
Within-Community Similarity		100.0	64.1	70.9	63.2	60.6	44.4

Percent contribution of taxa density to each of six fish communities ($p<0.01$) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 5** shade dendrogram.

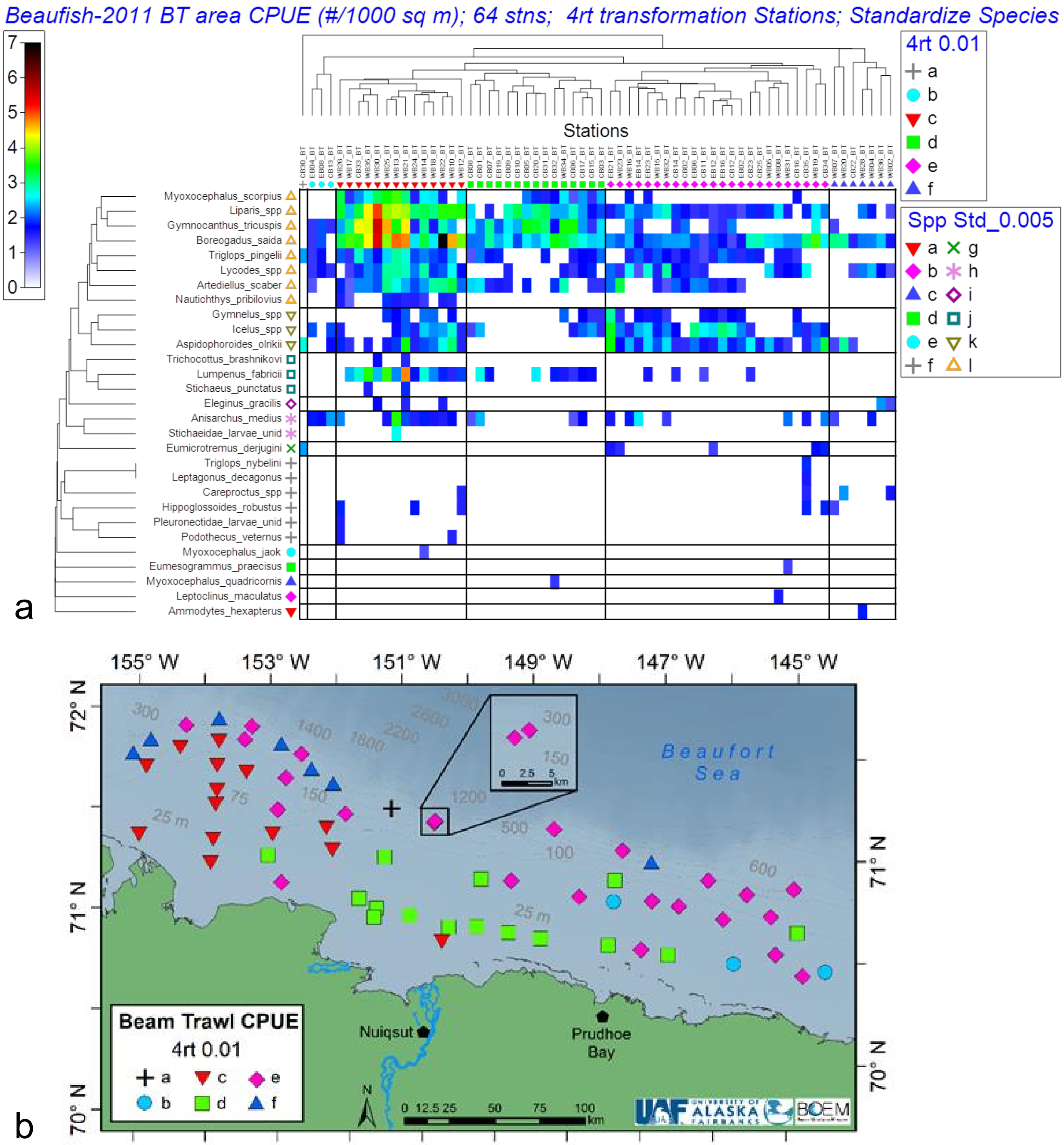
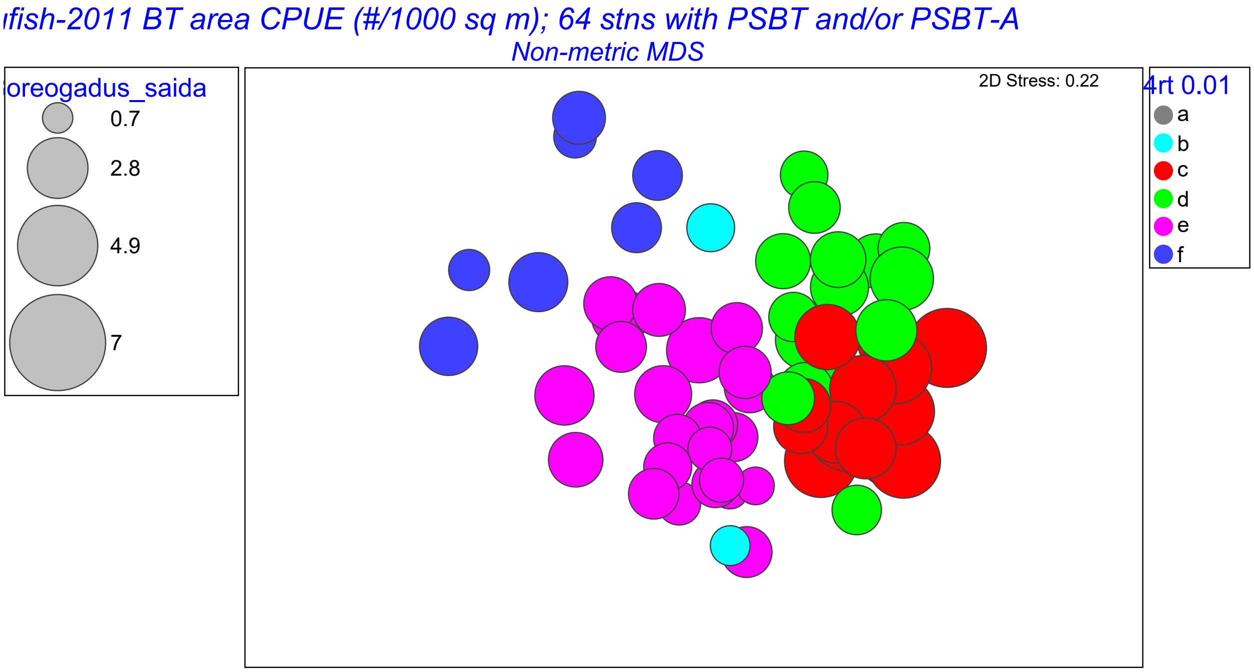


Figure 5: **Beam Trawl CPUE (catch) Six Fish Communities Formed by 4RT at p<0.01: a) shade plot, b) distribution map**



Fourth root transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 6: **Non-Metric Multidimensional Scaling of Beam Trawl CPUE (catch) Fish Communities (colors) Formed by 4RT**

Table 5: Beam Trawl CPUE, Log+1 Transformation

		Fish Communities							
		a	b	c	d	e	f	g	h
	# Stations	1	2	14	1	12	23	7	4
Taxa	# Taxa Observed	3	8	14	7	23	15	15	10
Gadidae	*Boreogadus saida*			30.2		16.8	22.4	43.1	67.5
Cottidae	*Gymnocanthus tricuspis*		17.3	28.1		9.7			
	Artediellus scaber	50.0			19.1	10.1			
	Icelus spp.		35.0		14.3		18.2		
	Myoxocephalus scorpius					9.0			
	Triglops pingelii	25.0					10.4		
Agonidae	*Aspidophoroides olrikii*						13.8		16.4
	Eumicrotremus derjugini	25.0							
Liparidae	*Careproctus reinhardti*								
	Liparis spp.			21.8		17.0	15.1		
Zoarcidae	*Gymnelus* spp.								
	Lycodes spp.					*7.9*		33.8	
Stichaeidae	*Anisarchus medius*		*30.4*		14.3				
	Lumpenus fabricii				23.9				
Total % Contributed		100.0	82.7	78.7	75.2	70.4	80.0	76.9	83.9
# Taxa Contributing >70% Density		3	3	3	4	6	5	2	2
Within-Community Similarity		100.0	69.9	38.6	100.0	70.9	57.7	54.5	39.6

Percent contribution of taxa density to each of five fish communities (p<0.01) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 7** shade dendrogram.

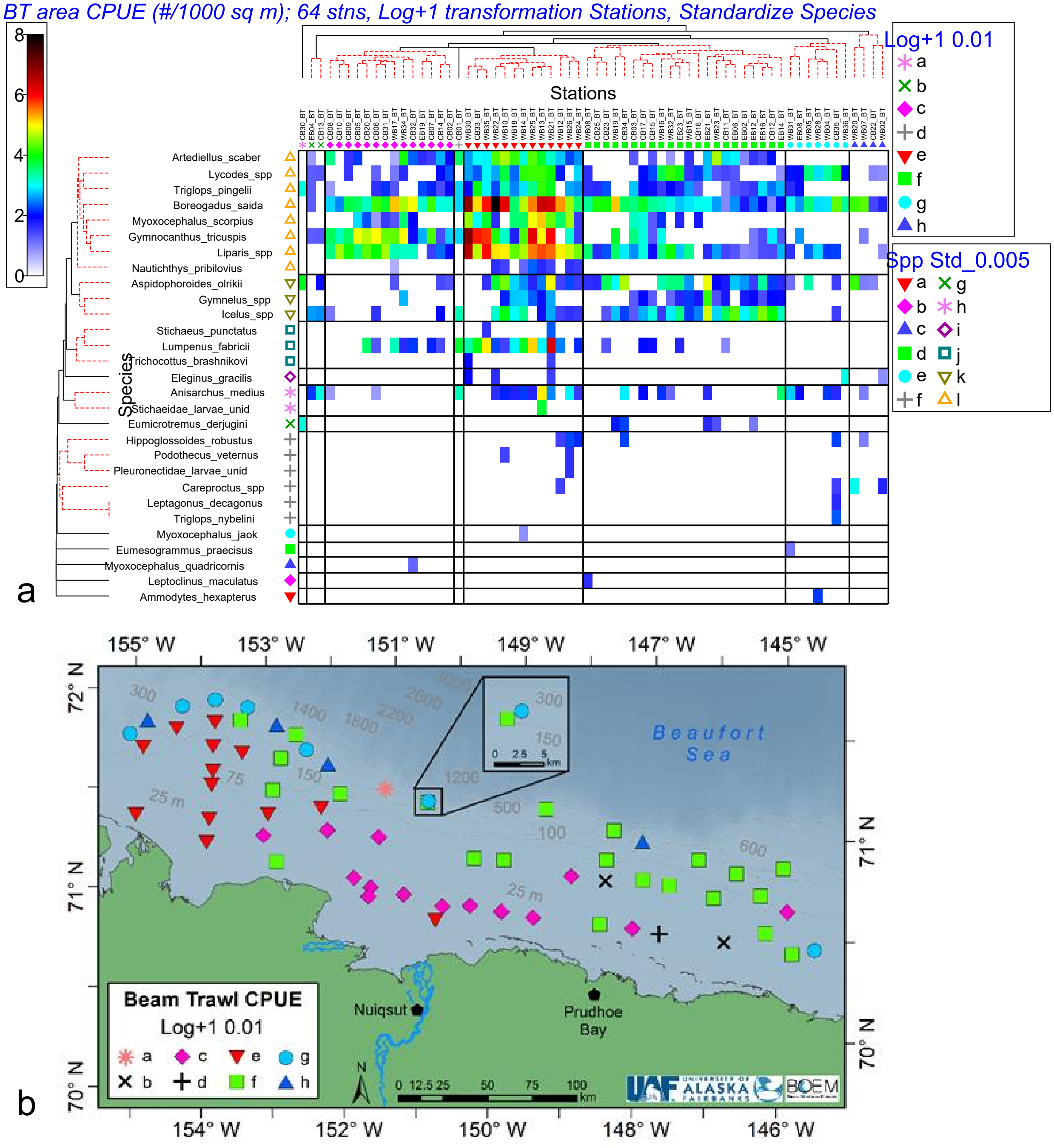
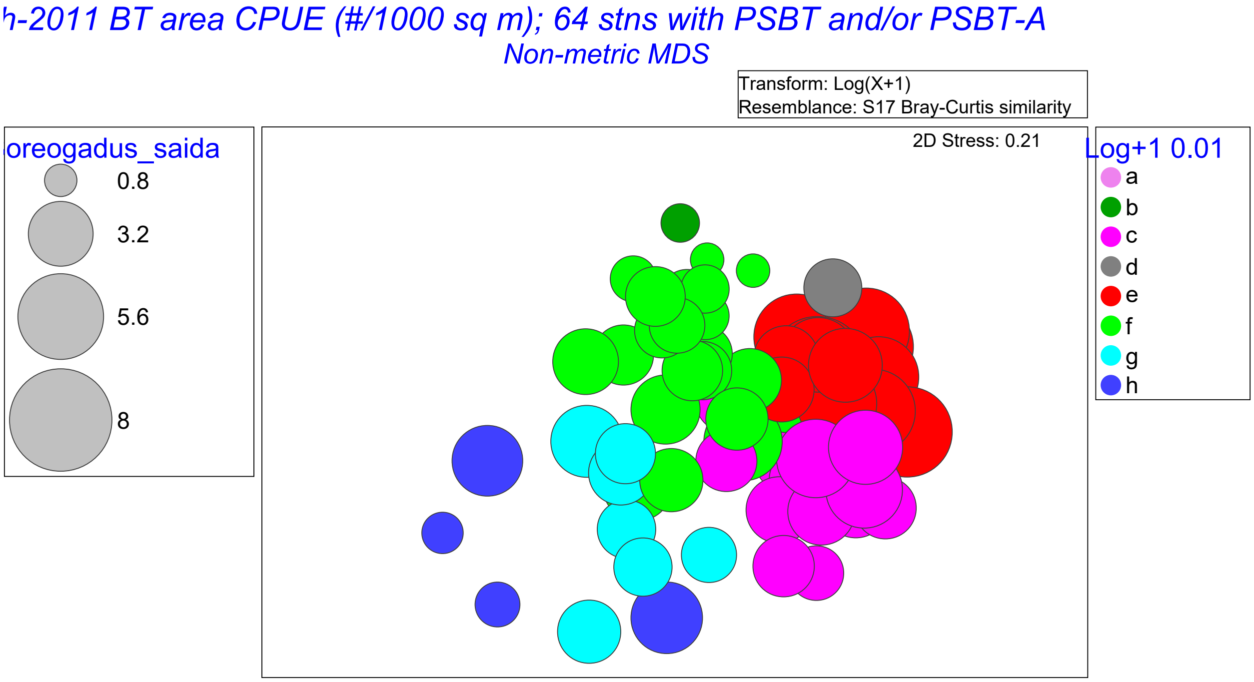


Figure 7: **Beam Trawl CPUE (catch) Eight Fish Communities Formed by Log+1 Transformation at p<0.01: a) shade plot, b) distribution map**



Log+1 transformed numerical contribution of *Boreogadus saida* in each community indicated by size of bubble.

Figure 8: **Non-Metric Multidimensional Scaling of Beam Trawl CPUE (catch) Fish Communities (colors) Formed by Log+1 (Log+1) Transformation**

Table 6: Beam Trawl CPUE, Presence/Absence (PA) Transformation

		Fish Communities						
		a	b	c	d	e	f	g
	# Stations	1	4	6	2	4	40	7
Taxa	# Taxa Observed	3	8	9	10	8	22	8
Gadidae	*Boreogadus saida*		13.9	27.9	14.3	24.1	16.2	45.8
Cottidae	*Gymnocanthus tricuspis*		15.6	27.9			9.3	
	Artediellus scaber	50.0					10.7	
	Icelus spp.						8.6	
	Myoxocephalus scorpius							
	Triglops pingelii	25.0					13.7	
Agonidae	*Aspidophoroides olrikii*		29.0		14.3	24.1		
	Eumicrotremus dejugini	25.0						
Liparidae	*Careproctus reinhardti*				14.3			
	Liparis spp.			27.9	14.3	24.1	11.6	
Zoarcidae	*Gymnelus* spp.							
	Lycodes spp.							31.7
Stichaeidae	*Anisarchus medius*		14.7					
	Lumpenus fabricii							
Pleuronectidae	*Hippoglossoides robustus*				14.3			
Total % Contributed		100.0	73.1	83.6	71.4	72.4	70.1	77.5
# Taxa Contributing >70% Density		3	4	3	5	3	6	2
Within-Community Similarity		100.0	60.5	73.3	70.0	73.0	69.5	59.6

Percent contribution of taxa density to each of five fish communities ($p<0.05$) and mean similarity of taxon density within community. Only taxa selected by SIMPER as descriptive of 70% of the community are included here. The proportional within-community similarity is presented visually in the **Figure 9** shade dendrogram.

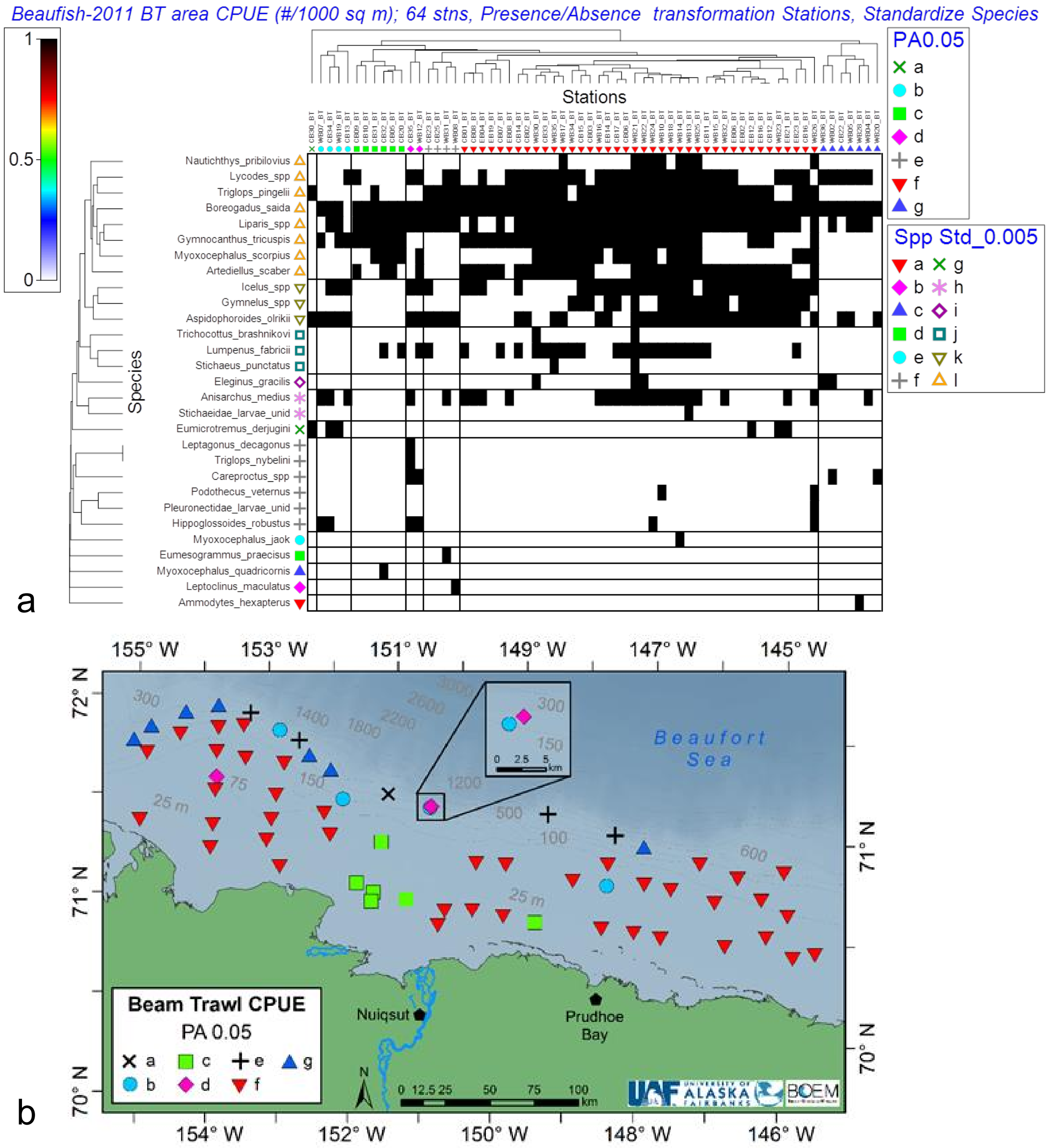
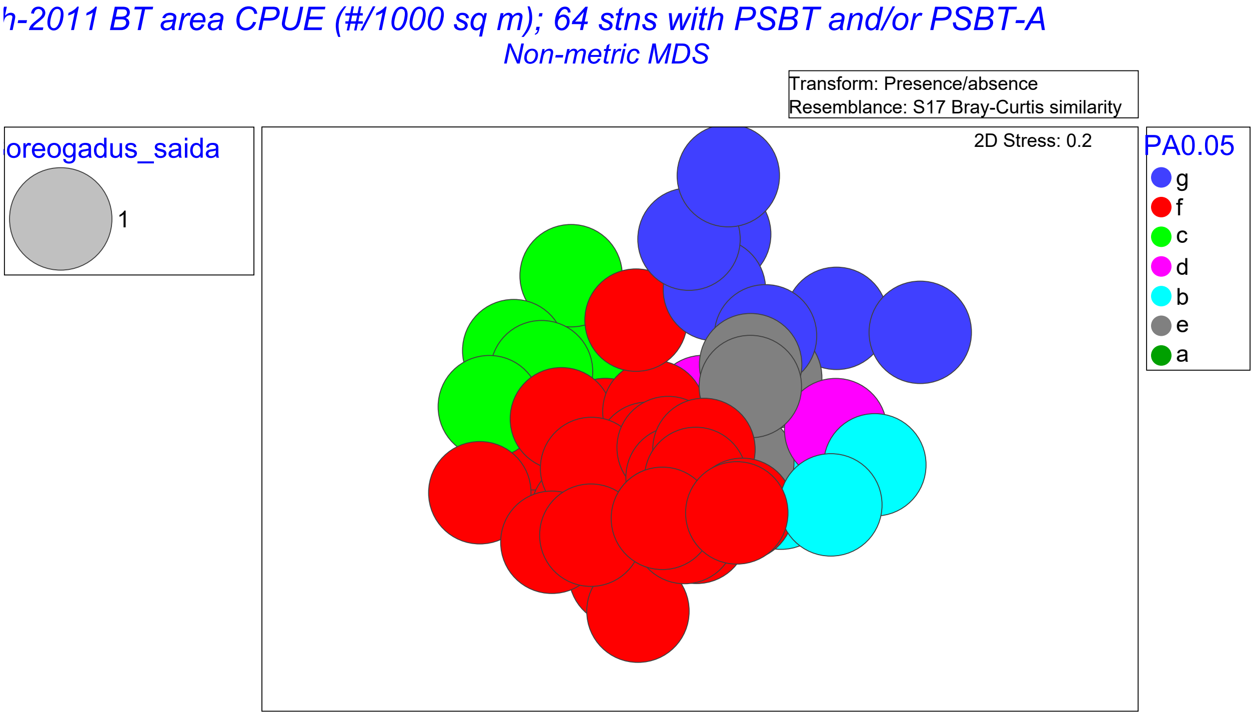


Figure 9: Beam Trawl CPUE (catch) Seven Fish Communities Formed by Presence/Absence (PA) Transformation at $p<0.05$: a) shade plot, b) distribution map



Presence/absence transformed contribution of *Boreogadus saida* in each community indicated by bubble.

Figure 10: Non-Metric Multidimensional Scaling of Beam Trawl CPUE (catch) Fish Communities (colors) Formed by Presence/Absence (PA) Transformation

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OCS Study
BOEM 2017-33

Appendix F

LENGTH FREQUENCY PLOTS

US Department of the Interior

Bureau of Ocean Energy Management

Alaska Region

OCS Study
BOEM 2017-33

1 Length Frequency Plots

Proportional catch of all fish species were examined for the three bottom trawls (**Figure 2.3.9)**. At least 98% of the catch (**Table X**) of each trawl was of fish smaller than 135 mm; the maximum lengths of captured fishes were 325 mm for OT, 205 mm for PSBT, and 335 mm for PSBT-A. It was expected that the otter trawl – with a codend liner mesh five times as large as that of the beam trawls – would capture larger fish, but this was not always the case. The most notable difference was that larger numbers of 35 mm fishes were caught by the beam trawls, whereas higher catches of 65 mm fishes were caught by otter trawl. There were some differences among sizes and abundances of fish species captured by bottom trawls (**Appendix F**).

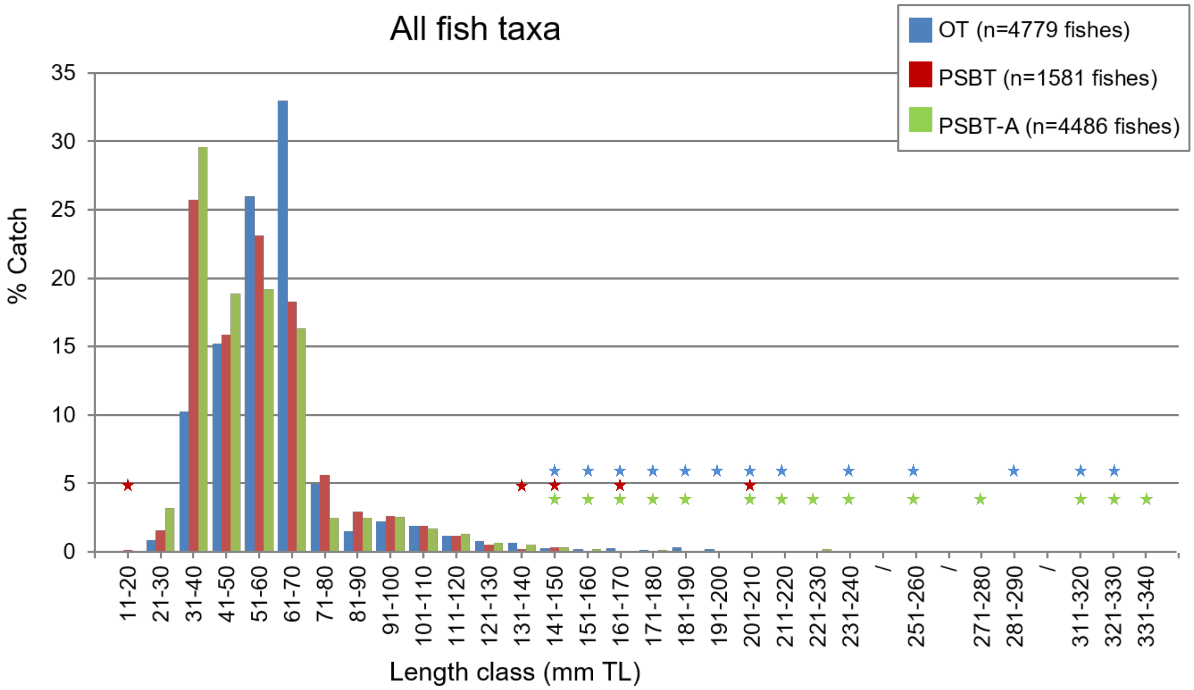

Figure 2.3.9. Frequency of lengths of fishes captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A), all taxa combined. Catch is standardized to count per 1000 m towed. * indicates catch ≤0.05%.

Table 2-1 Length Ranges of Most Abundant Species by Gear (# of Tows)

	Otter trawl (32)				PSBT (13)				PSBT-A (68)			
Taxa	**N**	**Range (mm)**	**Mode (mm)**	**%**	**N**	**Range (mm)**	**Mode (mm)**	**%**	**N**	**Range (mm)**	**Mode**	**%**
All species	4,779	25-325	65	30	1,581	15-205	35	25	4,486	25-335	35	25
Gadidae												
Boreogadus saida	3,593	225-325	65	40	278	25-205	65	45	1,678	25-335	65	30
Cottidae												
Gymnocanthus tricuspis	151	25-115	35	60	223	35-85	35	85	781	25-125	35	75
Icelus spp.	139	35-85	45	45	102	25-85	45	40	180	25-95	45	40
Myoxocephalus scorpius	71	25-165	55	70	100	15-95	55	60	157	25-125	55	55
Agonidae												
Aspidophoroides olrikii	102	35-105	45	35	106	35-65	45	50	157	25-75	45	55
Liparidae												
Liparis spp.	384	25-185	35	65	207	25-105	35	70	733	22-225	35	60
Liparis fabricii	8	35-145	35	55	1	65	65	100	19	25-155	75	20
Liparis gibbus	29	25-155	25	25	13	35-105	35	50	88	25-215	35	55
Liparis tunicatus	14	45-135	55	25	13	35-105	95	30	95	25-125	35	45
Zoarcidae												
Gymnelus hemifasciatus	10	85-145	95	40	31	35-115	75	25	33	45-125	105	20
Gynmelus viridis	9	95-145	115	40	7	75-115	85,95,115	86	1	115	115	100
Lycodes spp.	62	45-325	185	20	56	35-205	45	35	194	35-335	45	15
Lycodes mucosus	7	75-115	95	50	3	45	45	100	7	45-315	85	30
Lycodes polaris	34	45-325	185	35	44	35-165	45	35	122	35-335	45	15
Lycodes raridens	17	45-315	85	40	8	45-85	75	60	53	45-225	75	15
Lycodes reticulatus	0				0				6	45-115	65	50
Lycodes seminudus	4	155-255	255	50	0				3	65-145	65,95	65
Stichaeidae												
Anisarchus medius	44	55-145	125	35	84	55-125	95	25	51	55-155	115	20
Lumpenus fabricii	54	55-195	75	15	238	55-145	65	35	150	55-155	55	40
Pleuronectidae												
Hippoglossoides robustus	7	55-205	55	55	0				9	55-255	55	25

N = Number of Fish Range = min/max lengths Mode = most frequent length class captured % = percentage in modal size class

Twenty-two species or genera that were abundant and representative of fish families of the Beaufort Sea were chosen for length comparisons by bottom gear type. All three trawls caught the gadid *B. saida* mainly in the 55 and 65 mm length classes (**Figure 2.3.10**); fish of this species were small regardless of the type of trawl or size of net mesh used. Three cottid taxa were examined. *G. tricuspis* were predominantly 35 mm (**Figure 2.3.11**), whereas *Icelus* spp. were slightly larger with mode at 45 mm (**Figure 2.3.12**) and *M. scorpius* were larger with mode at 55 mm (**Figure 2.3.13**). Specimens of the agonid *Aspidophoroides olrikii* were nearly all 35–65 mm, with 45–55 mm being the largest component (**Figure 2.3.14**). All three trawls captured the liparid genus *Liparis* spp. almost exclusively at the 35 mm length class, though specimens of 25 and 45 mm were also common in all bottom trawls and *Liparis* spp. as large as 225 mm were captured with the PSBT-A (**Figure 2.3.15**). Most specimens of *Liparis* spp. smaller than 70 mm were identified only to genus, whereas larger specimens were typically identified to species. A single *L. bathyarcticus* specimen of 115 mm was caught by PSBT-A (**Figure 2.3.16**). *L. fabricii* were caught in length classes from 25 to 155 mm and by all three trawls, though only one was caught by PSBT (**Figure 2.3.17**). *Liparis gibbus* was caught in length classes from 25 to 215 mm and by all three trawls, with the majority of individuals being in 25 and 35 mm length classes (**Figure 2.3.18**). Liparis gibbus larger than 105 mm length class were caught only by OT and PSBT-A. The majority of *L. tunicatus* were in the 25 and 35 mm length classes and captured by PSBT-A, with individuals as large as the 125 mm length class. *L. tunicatus* caught by OT were 45–135 mm length classes (**Figure 2.3.19**). Two genera and seven species of zoarcids were selected for length comparisons by bottom trawl. *Gymnelus* spp. and *G. hemifasciatus* were caught in length classes from 35 to 145 mm; OT captured them only ≥85 mm (**Figures 2.3.20 and 2.3.21**). *G. viridis* were caught at 75–145 mm length classes, but only one was caught by PSBT-A (**Figure 2.3.22**). Of all taxa, *Lycodes* spp. were caught in the largest range of lengths, 35 to 335 mm (**Figure 2.3.23**). Catches of *Lycodes* spp. were dominated by 45–85 mm specimens, though there also were substantial catches of larger fishes. The largest length class of *Lycodes* spp. caught by the PBST was 205 mm, whereas individuals as large as the 335 mm length class were caught by the PSBT-A and 325 mm by OT. *Lycodes mucosus* were caught at 45–315 mm; this species was caught by all three trawls, with individuals 175–315 mm caught only by PSBT-A (**Figure 2.3.24**). *L. polaris* were caught at 35–335 mm length classes, with fish smaller than 165 mm caught by all gears and larger fish caught only by OT and PSBT-A (**Figure 2.3.25**). Fish caught by PSBT exhibited a strong mode at 45 mm, whereas most fish caught by PSBT-A were smaller than 125 mm and fish caught by OT exhibited a mode of 185 mm. *L. raridens* were caught at 45–315 mm length classes (**Figure 2.3.26**). As with *L. polaris*, the PSBT caught smaller *L. raridens* than the other gears; the mode of PSBT catches was 75 mm and the maximum size was 85 mm. The mode of OT catches of *L. raridens* was 85 mm, and the OT caught specimens 45–315 mm; specimens caught by PSBT-A did not have a mode, but were distributed throughout 45–225 mm. *L. reticulatus* were caught at 45–105 mm and only by PSBT-A (**Figure 2.3.27**). *L. seminudus* smaller than 145 mm were caught only by PSBT-A and larger than 155 were caught only by OT (**Figure 2.3.28**). Two species of stichaeid were selected for length comparisons (**Figures 2.3.29 and 2.3.30**). *Anisarchus medius* were captured at 55–155 mm (**Figure 2.3.29**), and the length distribution of this species was different from that of the other species. Two or possibly three cohorts were indicated. A cohort <81 mm was captured by both the PSBT and PSBT-A, whereas the PSBT did not capture *A. medius* at lengths >130 mm; a second cohort of 85–105 mm was caught mainly by PSBT and OT, and possibly a third cohort of 115–125 mm was caught mainly by OT and PSBT-A. PSBT and PSBT-A predominantly caught *Lumpenus fabricii* 51–70 mm, while OT caught fish throughout the 55–195 mm length classes (**Figure 2.3.30**). There were very few *H. robustus* captured over a very wide size range (55–255 mm); none were caught by PSBT (**Figure 2.3.31**).

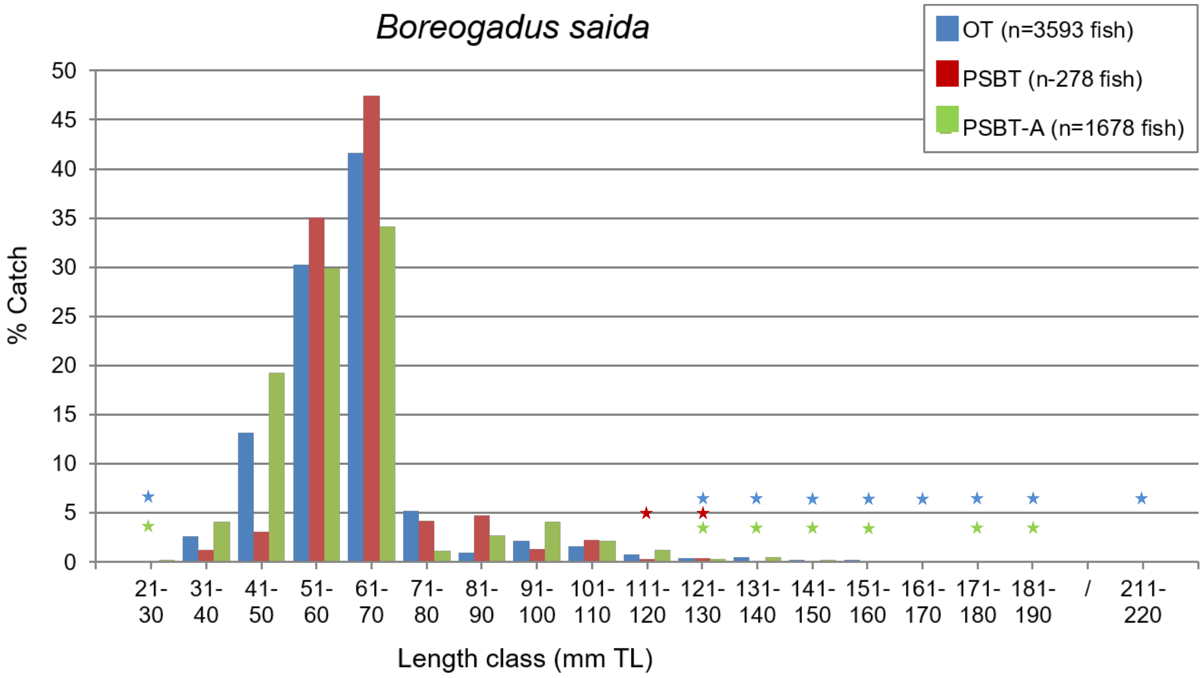

Figure 2.3.10. Frequency of *Boreogadus saida* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤0.05%.

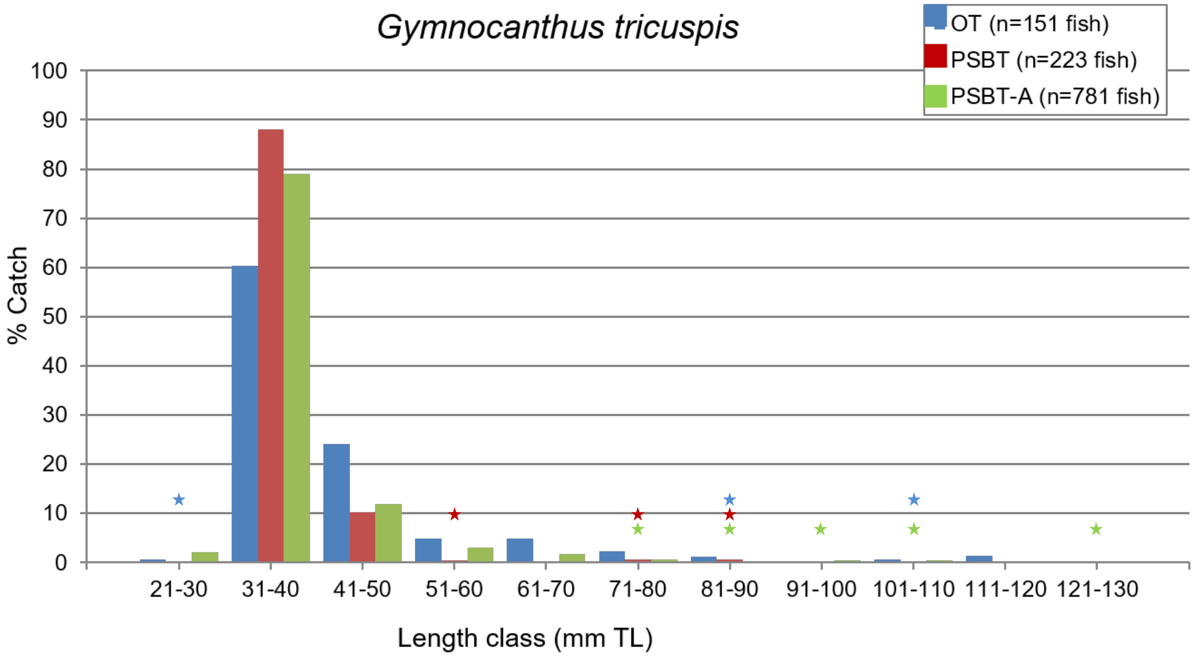

Figure 2.3.11. Frequency of *Gymnocanthus tricuspis* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤1%.

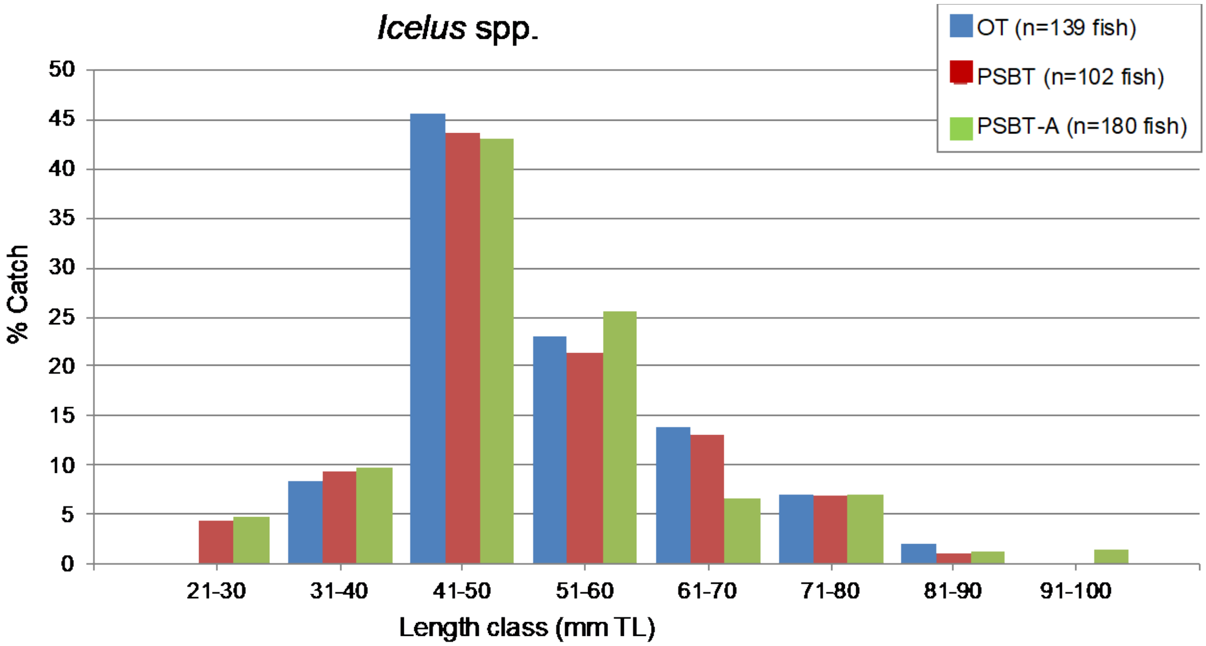

Figure 2.3.12. Frequency of *Icelus* spp. lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

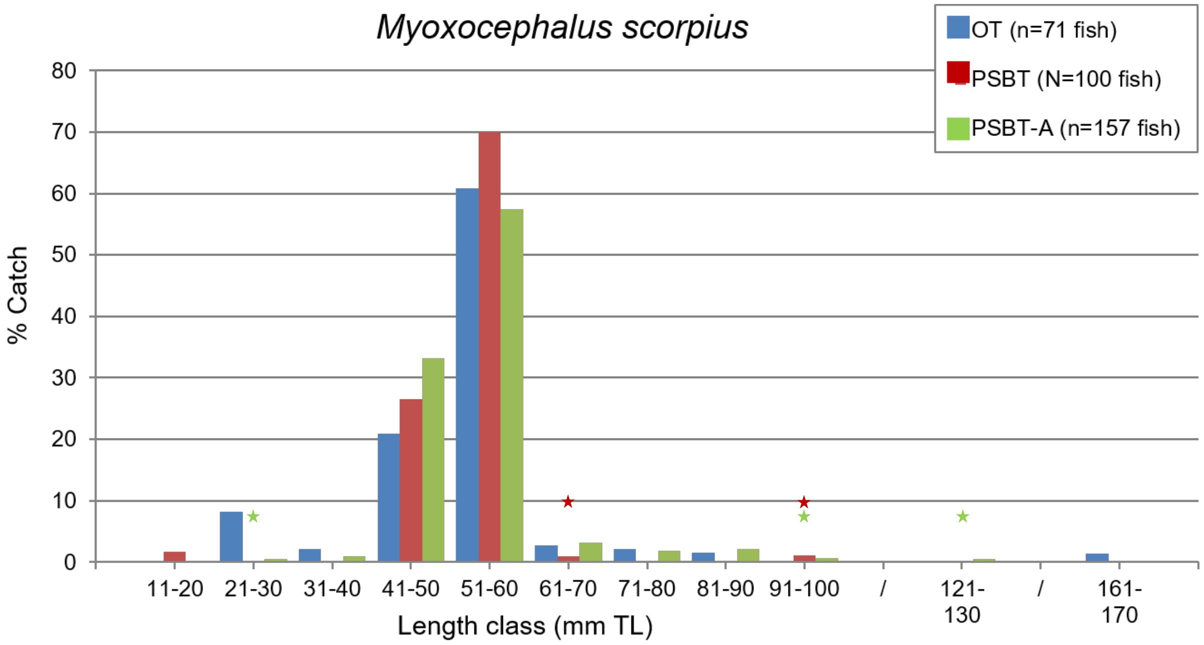

Figure 2.3.13. Frequency of *Myoxocephalus scorpius* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤1%.

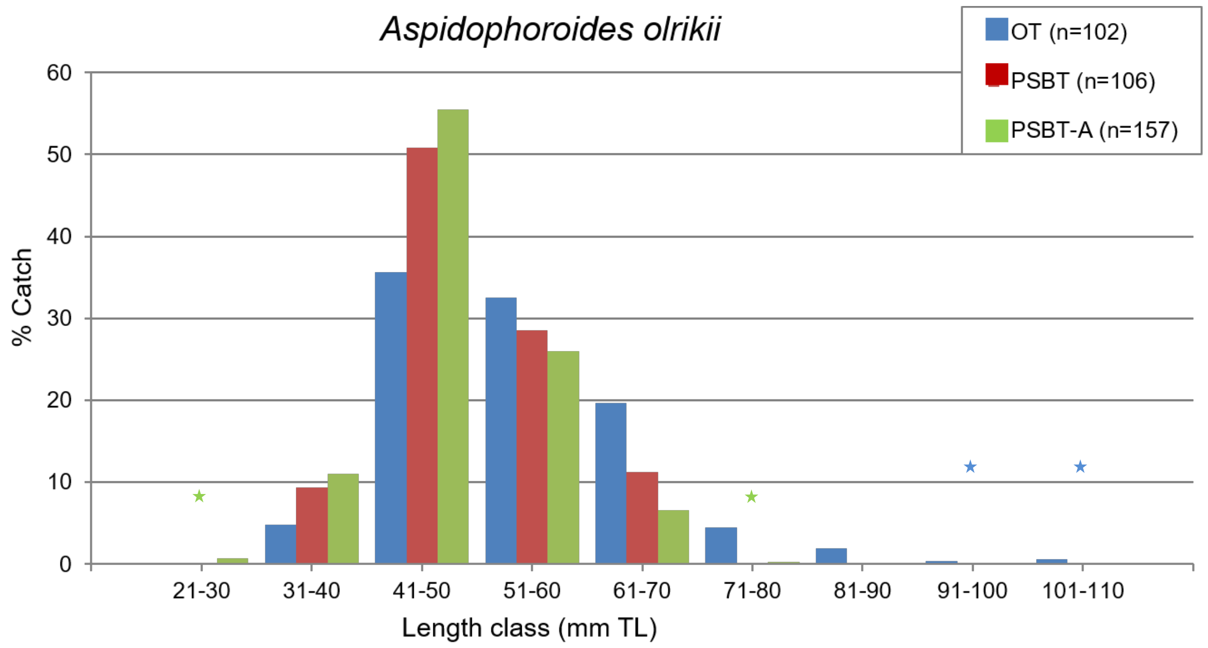

Figure 2.3.14. Frequency of *Aspidophoroides olrikii* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤1%.

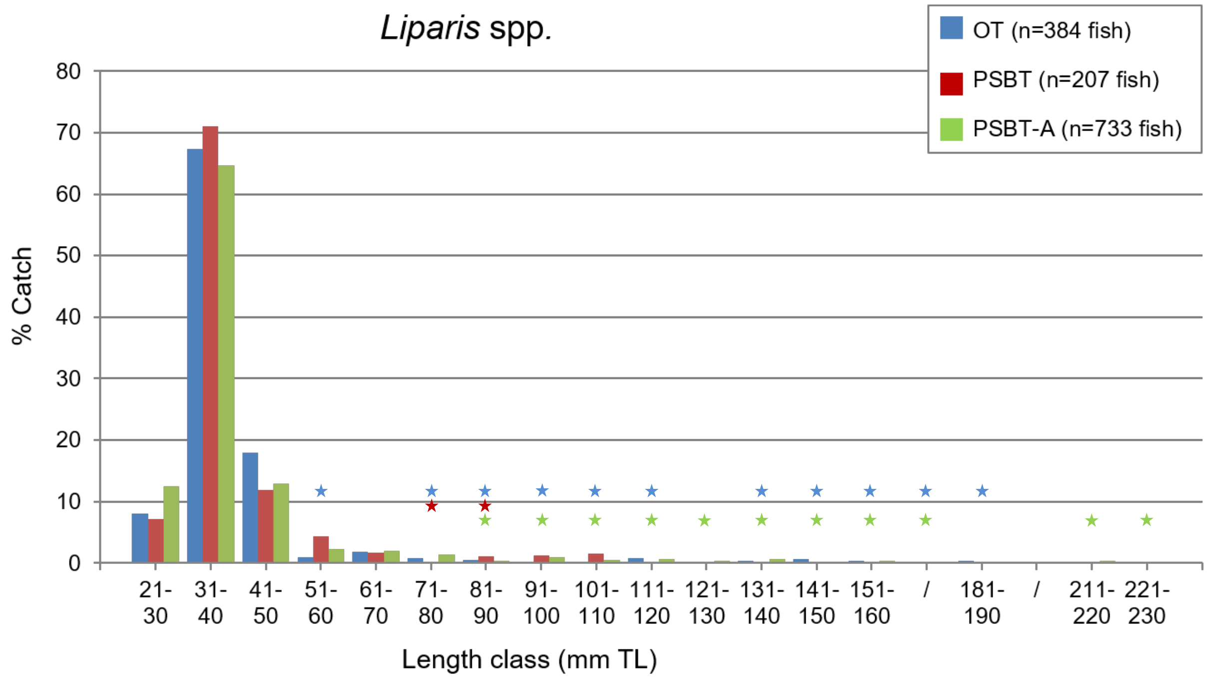

Figure 2.3.15. Frequency of *Liparis* spp. lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤1%.

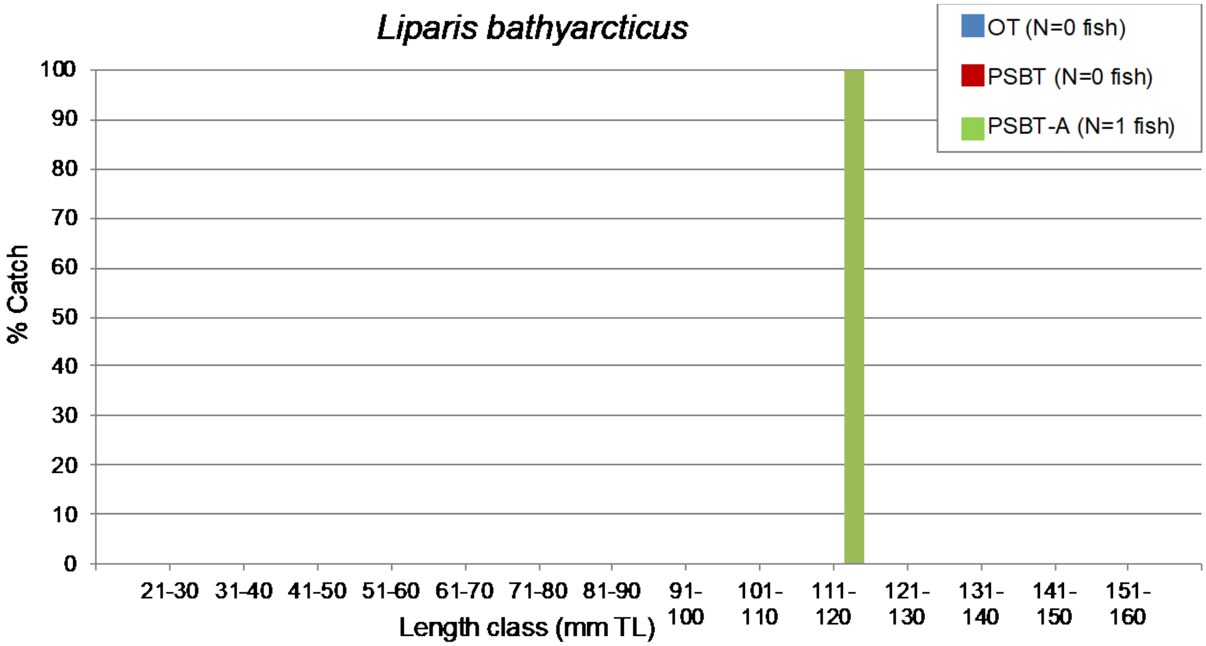

Figure 2.3.16. Frequency of *Liparis bathyarcticus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

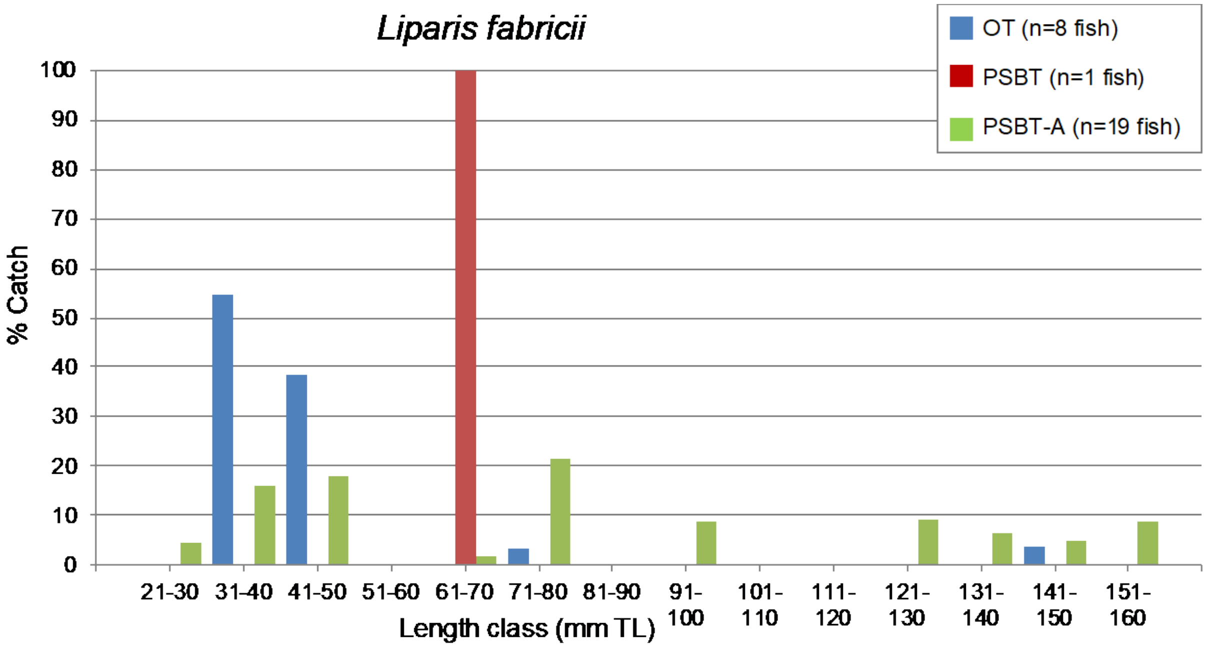

Figure 2.3.17. Frequency of *Liparis fabricii* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

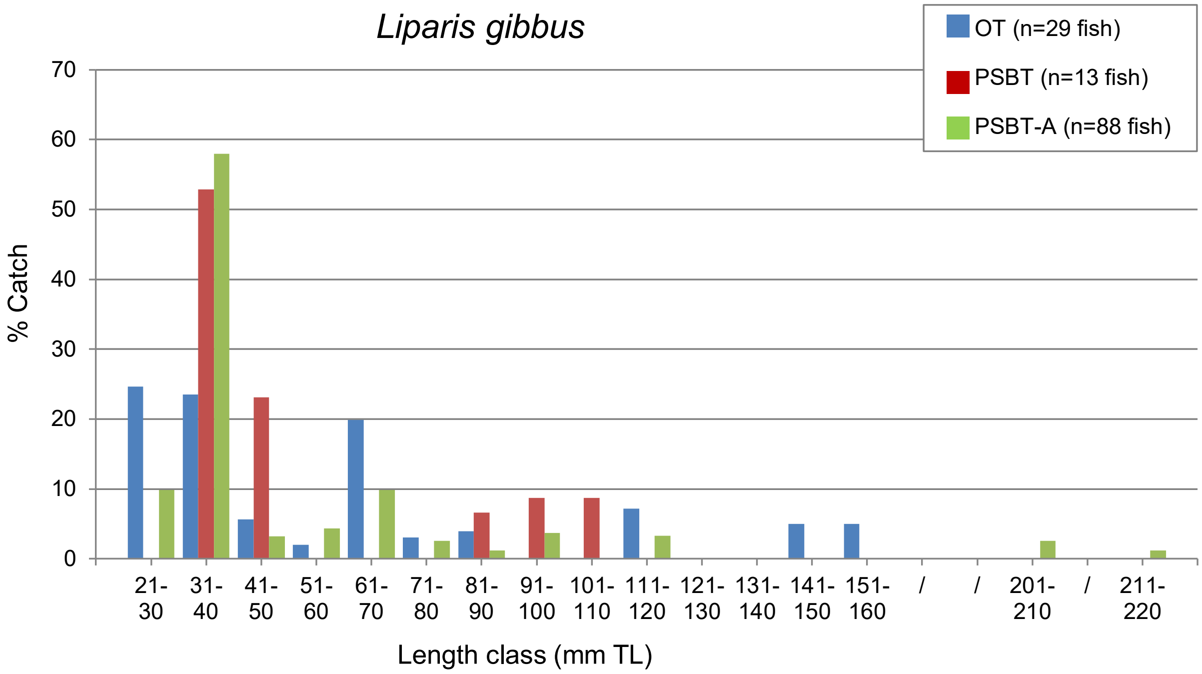

Figure 2.3.18. Frequency of *Liparis gibbus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

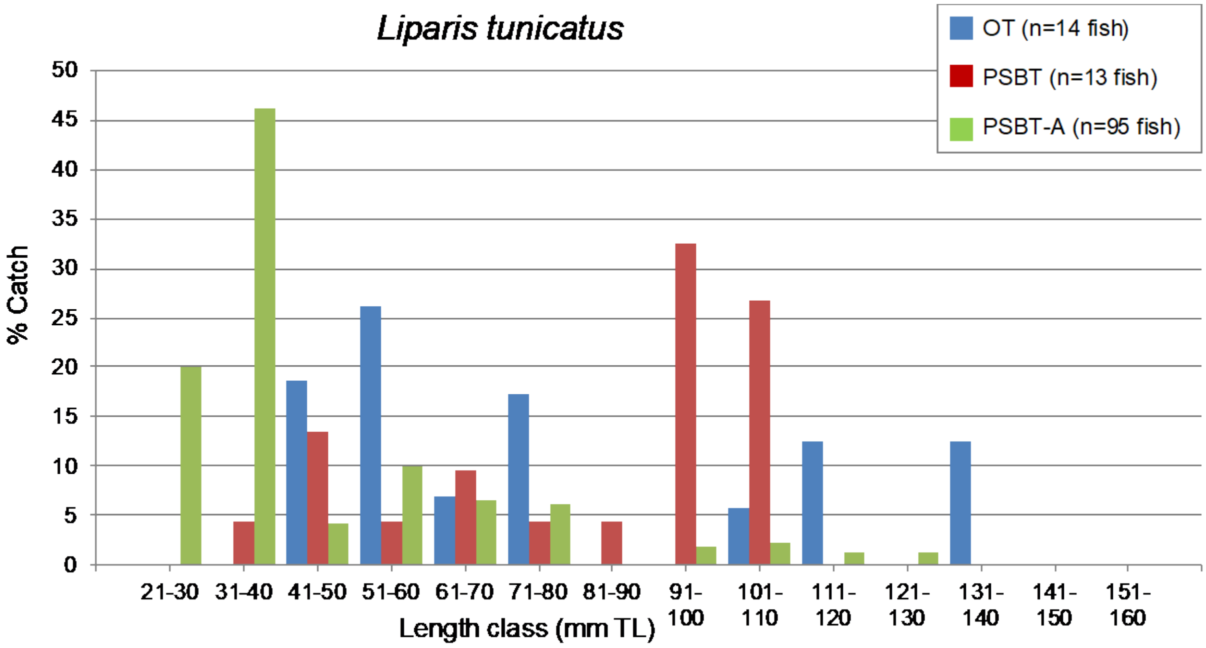

Figure 2.3.19. Frequency of *Liparis tunicatus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

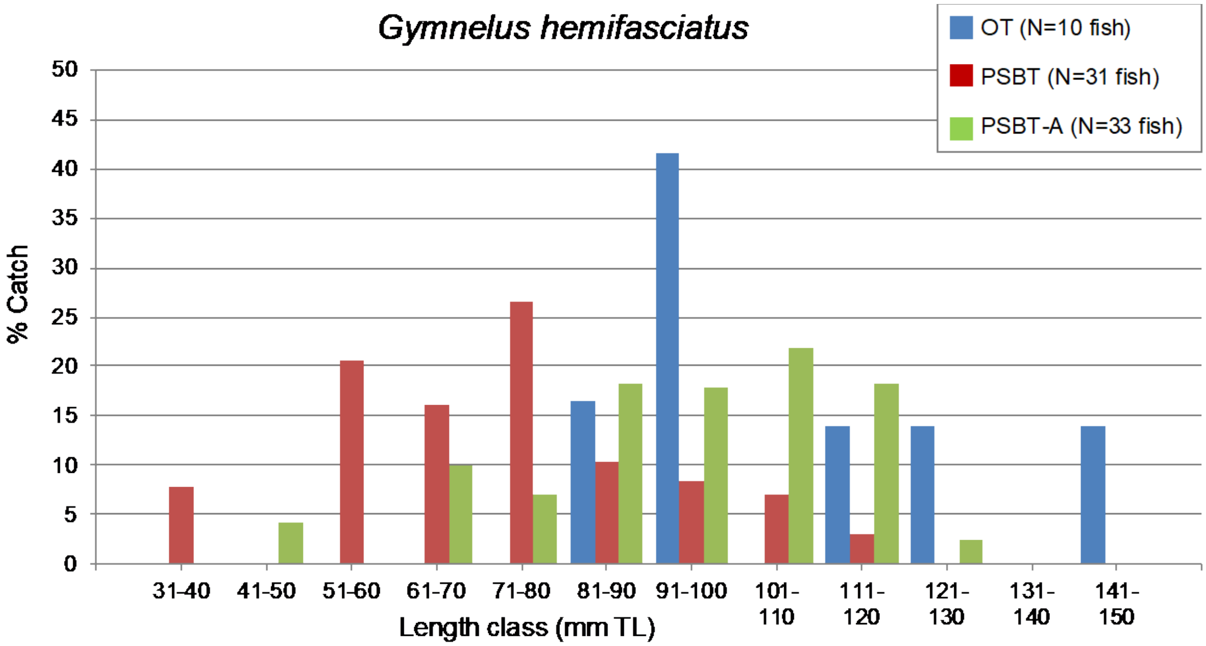

Figure 2.3.21. Frequency of *Gymnelus hemifasciatus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

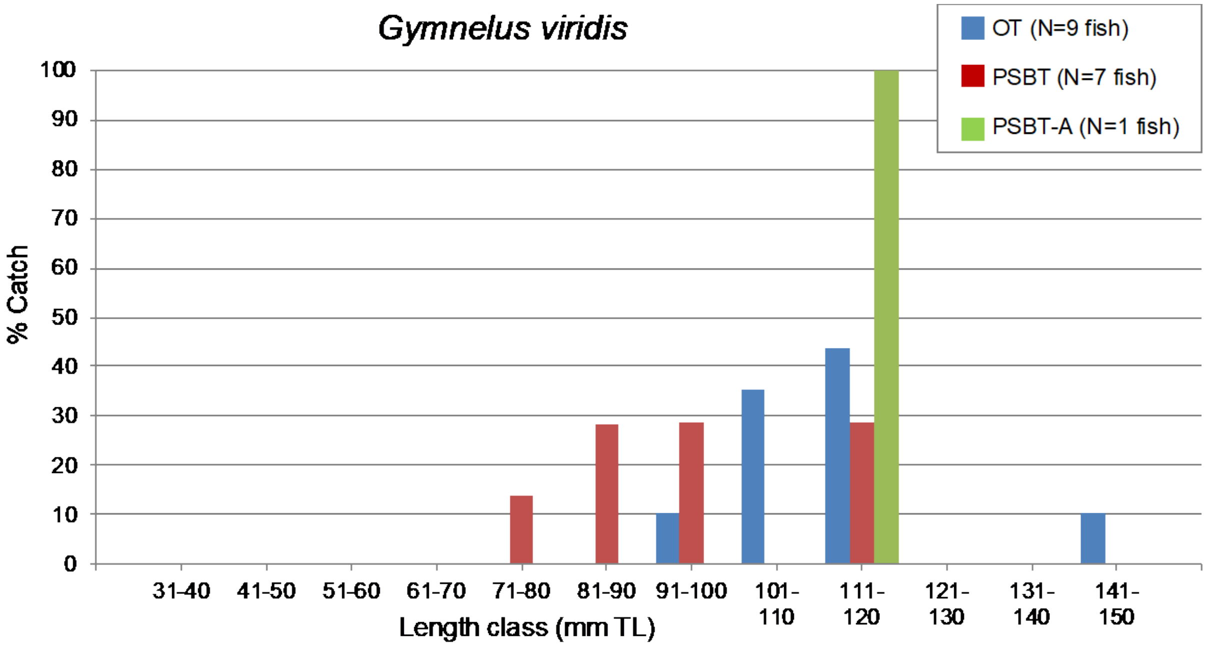

Figure 2.3.22. Frequency of *Gymnelus viridis* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

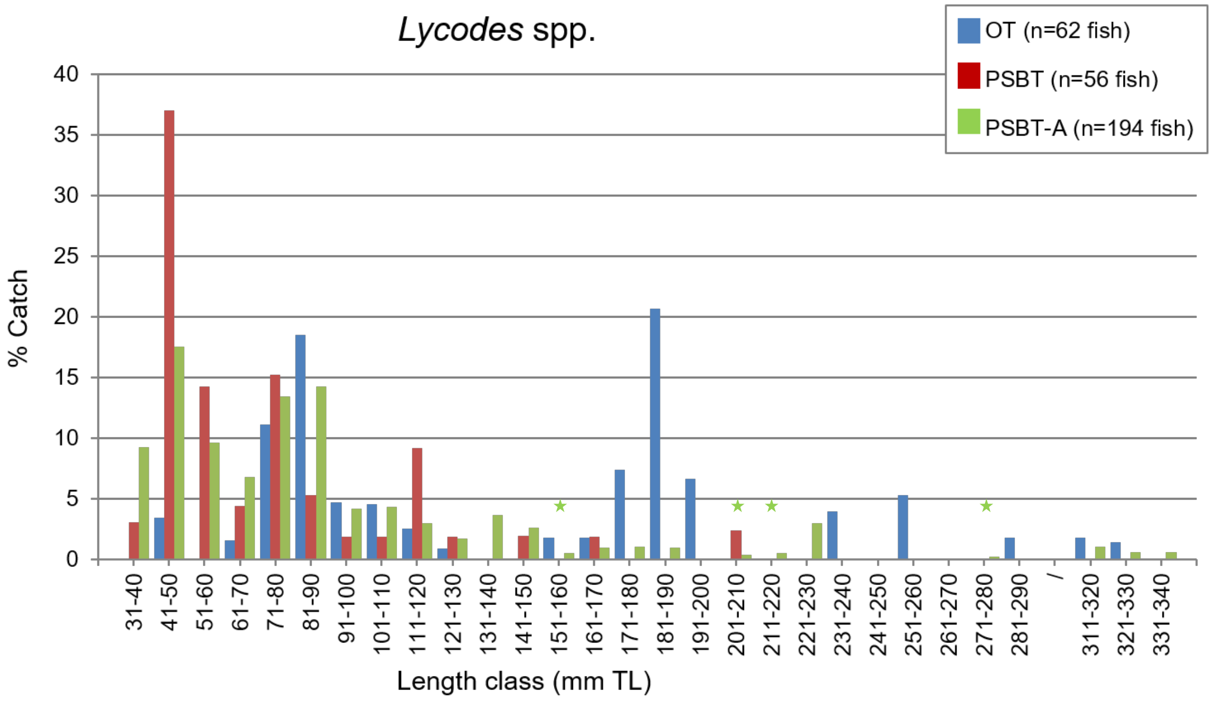

Figure 2.3.23. Frequency of *Lycodes* spp. lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤0.5%.

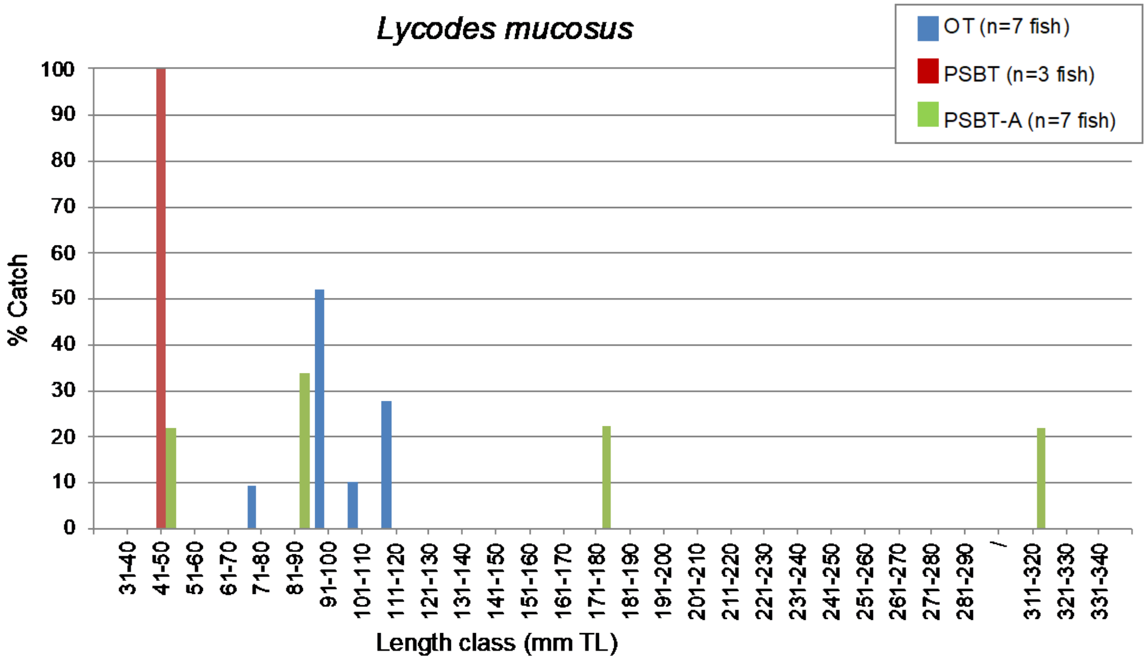

Figure 2.3.24. Frequency of *Lycodes mucosus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

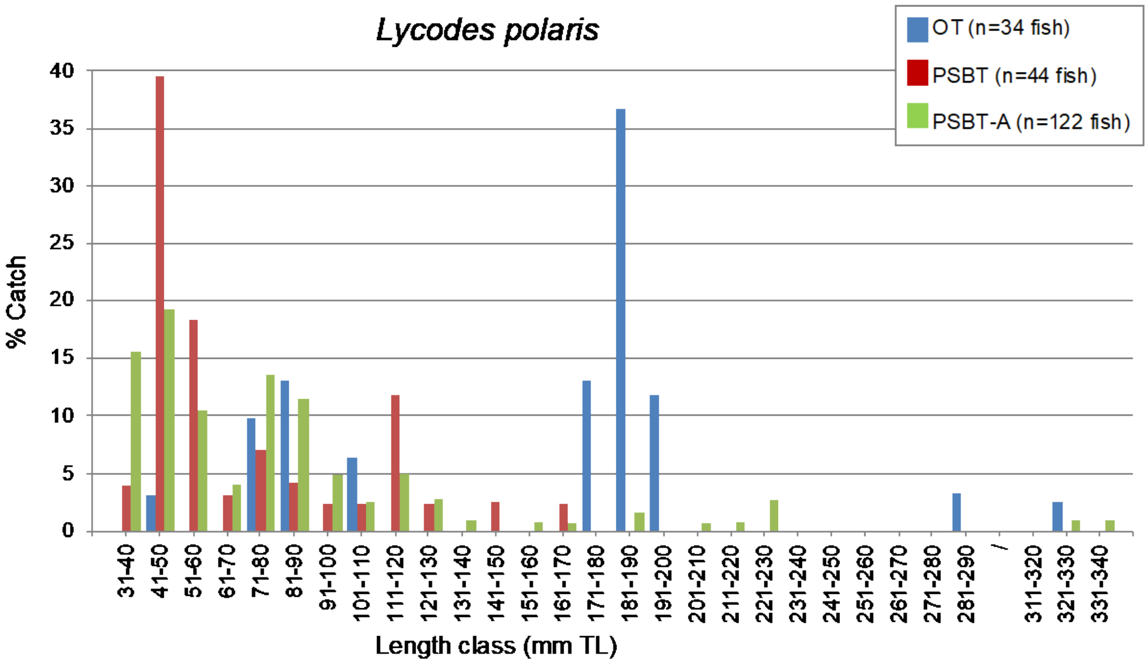

Figure 2.3.25. **Frequency of *Lycodes polaris* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.**

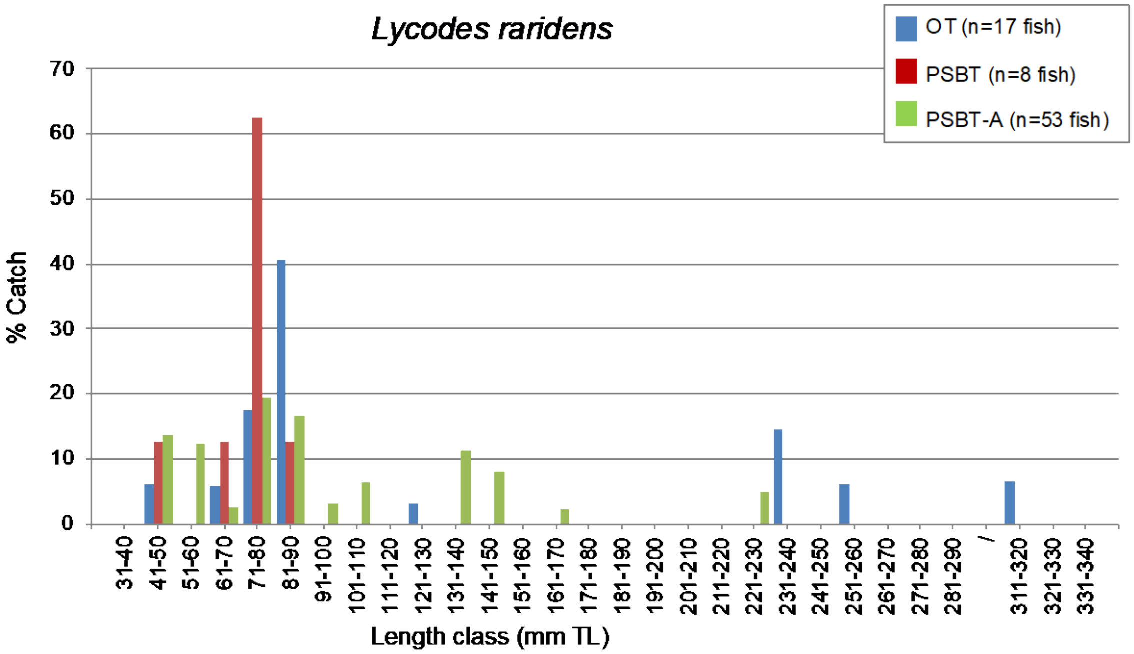

Figure 2.3.26. **Frequency of *Lycodes raridens* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.**

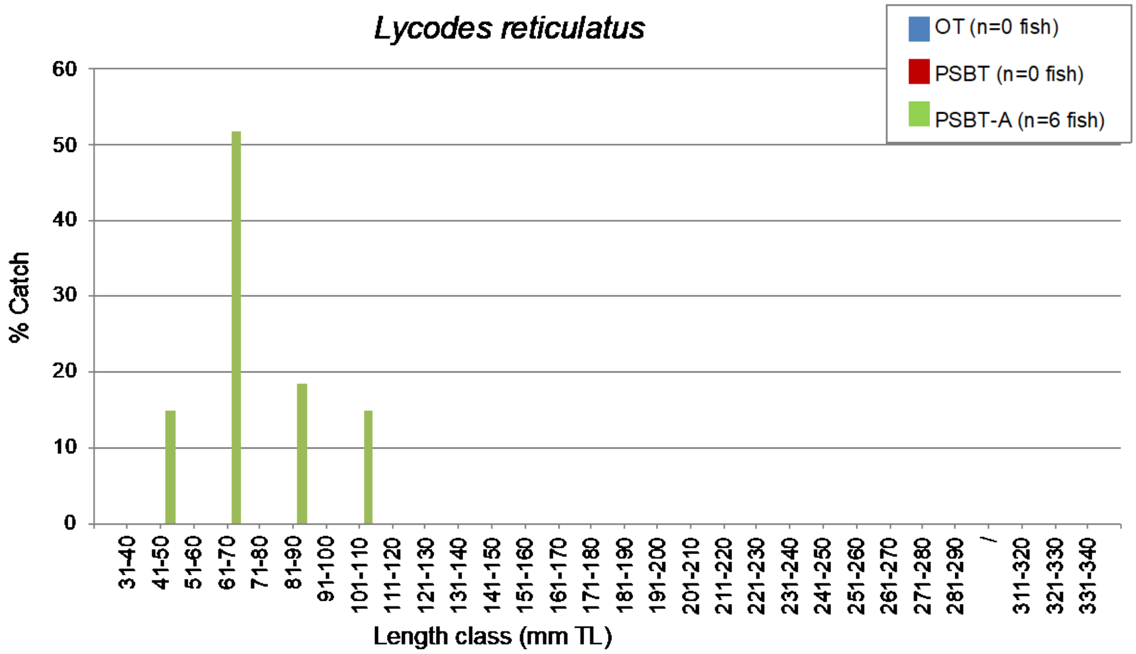

Figure 2.3.27. Frequency of *Lyodes reticulatus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

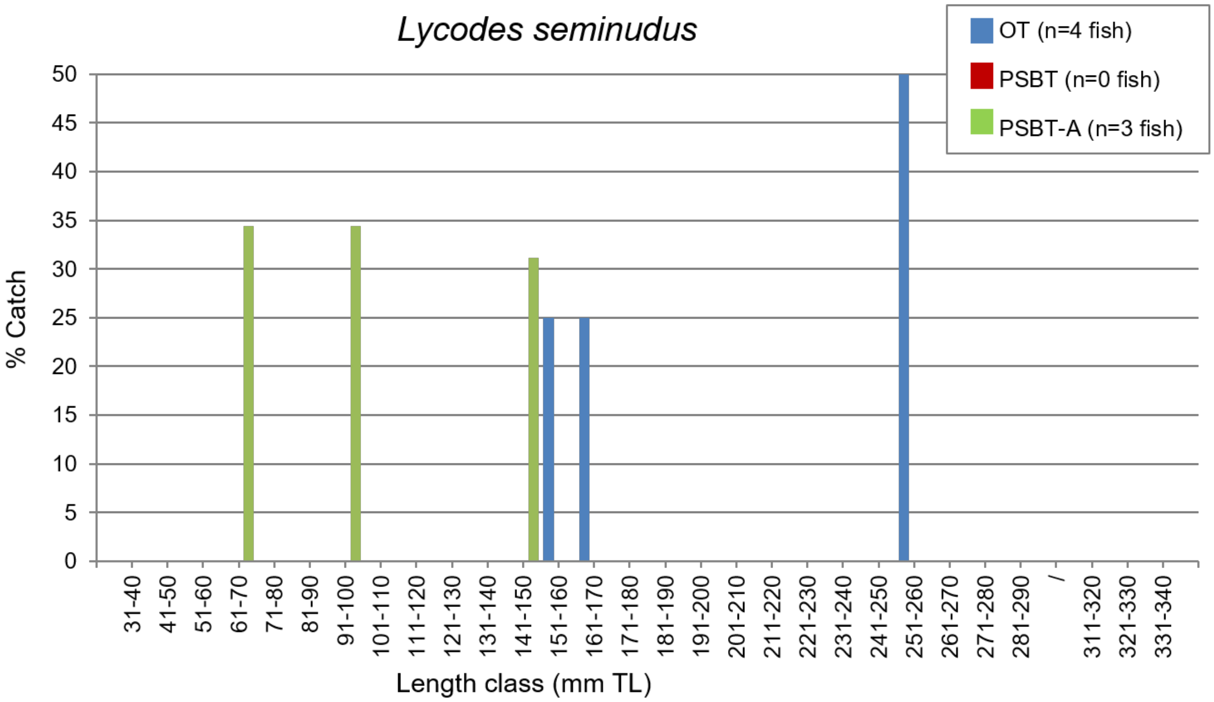

Figure 2.3.28. Frequency of *Lycodes seminudus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

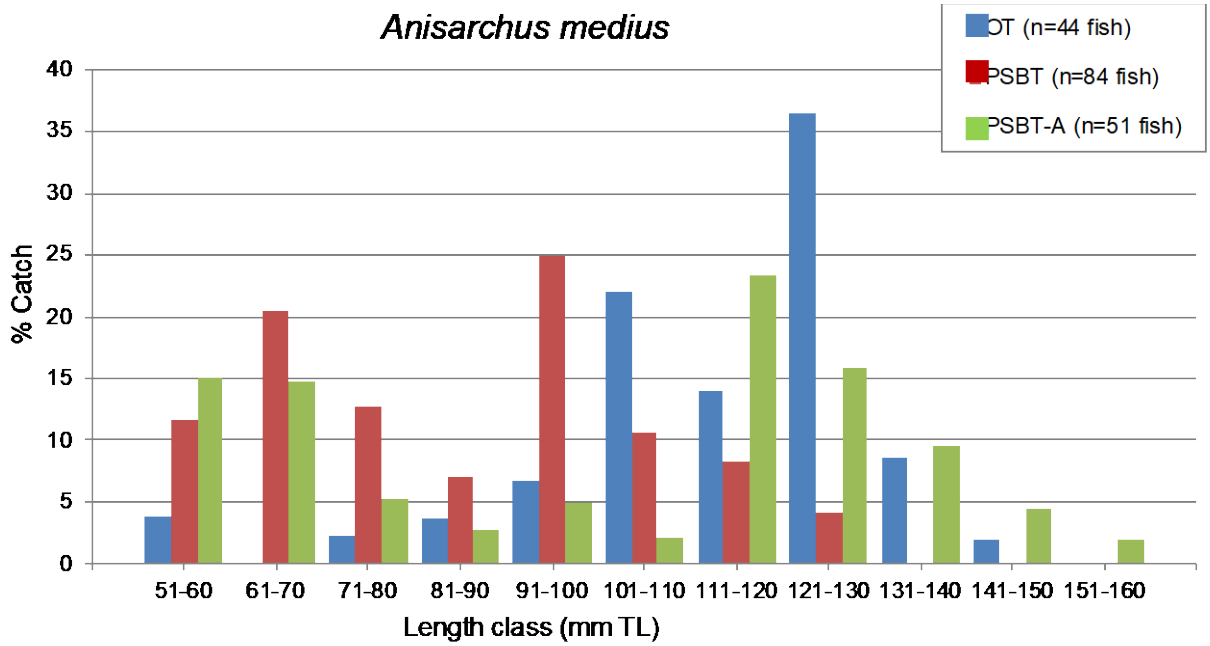

Figure 2.3.29. Frequency of *Anisarchus medius* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.

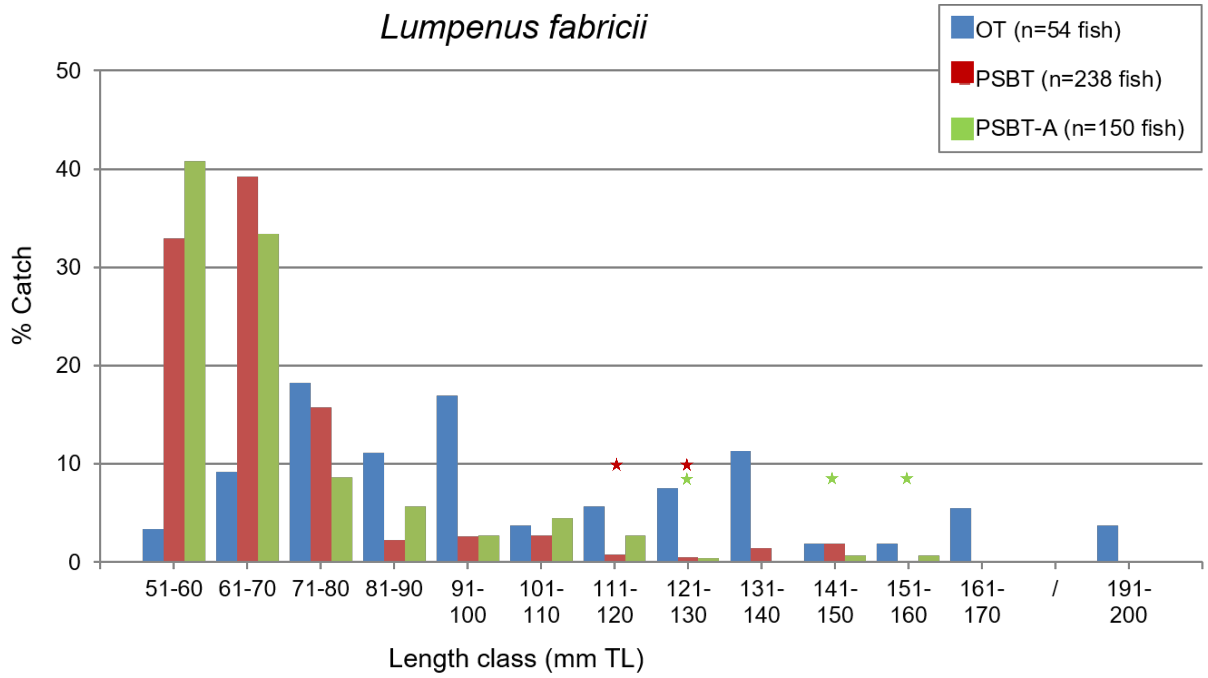

Figure 2.3.30. Frequency of *Lumpenus fabricii* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed. * indicates catch ≤1%.

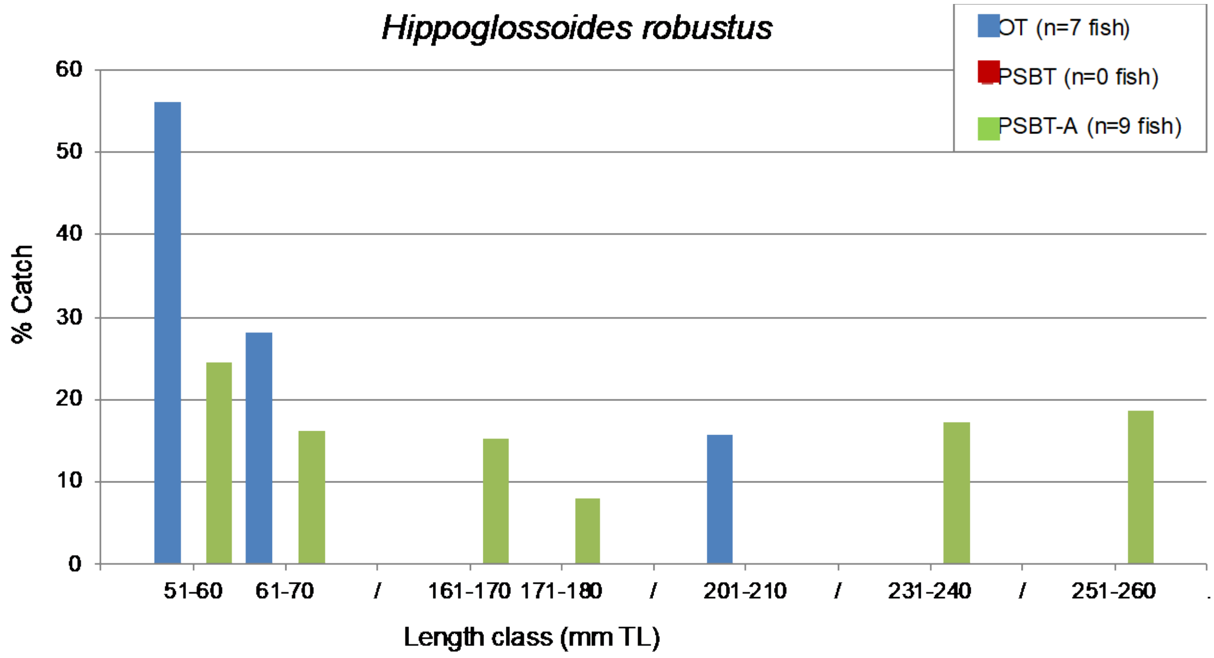

Figure 2.3.31. Frequency of *Hippoglossoides robustus* lengths captured by otter trawl (OT), plumb staff beam trawl (PSBT), and modified plumb staff beam trawl (PSBT-A). Catch is standardized to count per 1000 m towed.